277 Volts to your Server?

Improving Data Center Energy Efficiency and Reducing Construction Costs

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Introduction

Improving electrical energy performance is an important consideration in the design, construction and operation of any data center. This paper proposes a holistic methodology in achieving energy performance and capital expenditure (Cap X) savings. While achieving these savings, the challenge is to maintain or increase reliability, in other words, decreasing risk. Most data center energy projects usually focus on a single goal, not considering the holistic effect of increased risk or decreased reliability. When these non-tangible omissions become apparent, the energy performance aspect frequently becomes marginalized or canceled.

Key Factors:

The key factors in achieving electrical energy performance and Cap X savings using the holistic approach include:

- IT and IT Facilities collaboration
- IT Information Communication Technology (ICT) architecture
- The IT Facilities power distribution with system voltage selection.

Using the key factors as the data center's building blocks, many white papers have been written on the advantages of IT and IT Facilities collaboration. From the onset of a retrofit to a legacy project, the collaboration must also take into consideration the IT and IT Facilities vendors. A best practice is to have a round table dialog that supports the selection of the ICT and IT Facilities power architecture.

Some may argue that selection of the ICT equipment should take place just before or independent of the IT and IT Facilities collaboration process. Simply stated, IT Facilities should only provide for the output of IT's ICT requirements. Under the holistic approach this is not the best solution. Without collaboration, this design juncture is a crucial point where the ICT's electrical power requirements and the IT Facilities equipment selection process diverge. Neither group fully achieves a holistic solution. Yet, the ICT equipment selection group is usually not aware of just how important to the IT Facilities equipment selection process that a unified agreement is, regarding the equipment and voltage. This agreement is fundamental in all future equipment selection decisions for both IT and IT Facilities.

On the IT Facilities side, proper selection of the electrical distribution and voltage architecture integrates the IT equipment into the IT Facilities selection process. This integration is fundamental in delivering superior energy performance and reducing Cap X.

Of prime consideration, yet rarely discussed or debated, is selecting the integrated equipment voltage. Voltage is fundamental in efficiency and reliability. When ICT equipment voltage is selected in concert with the IT Facilities systems voltage a unified operating system is achieved. Secondly, a more streamlined facility equipment power supply chain can be installed. This uniformity in voltage and equipment streamlining can greatly contribute to increasing reliability and reducing data center risk.

As will be explained throughout this paper, the actual ICT equipment (and more specifically the server power supply) input voltage has a significant impact on the overall energy performance in the data center. To achieve this uniformity and server performance in North American data centers, servers must incorporate 277 Volt into their power supply architecture.

History of Power Supply Voltages

All digital electronic equipment operates on DC (direct current) voltage. However, most power consumed in data centers is AC (alternating current) voltage. Most data centers operate on the principle of accepting the AC voltage provided to the servers and allowing the server power supply to convert the power to DC.

Various AC operating voltages are used around the world. The most common AC operating voltages in North America are:

- 208Y120 Volts (V), 3 phase, 4 wire, 60 Hz,
- 480Y277 Volts (V), 3 phase, 4 wire 60 Hz, and
- 575Y332 Volts (V), 3 phase, 4 wire, 60 Hz.

The most common operating voltage outside of North America is 400Y230V, 3 phase, 4 wire, 50 Hz.

Early server power supplies were designed to operate on common “house” voltage (120V, 60 Hz in North America and 230V, 50 Hz in most of the rest of the world) before the upsurge of data center power consumption which necessitated the use of higher voltages to deliver more power to the racks. To facilitate worldwide sales, power supply manufacturers have since developed universal power supplies that would operate from 100 to 230V with input frequencies of either 50 or 60 Hz.

Why is the standard voltage in the United States 120V and most of the rest of the world 230V?
The original use of electricity was to power lighting. Early electric lamps were carbon filament lamps that operated more efficiently and lasted longer at 90-100V. The development of metal filament lamps in the late 1890s allowed higher voltages to be used thus reducing losses. In Europe where development was after the US, the higher voltage was adopted.

Comparative Analysis

Presently, most server power supplies in North America operate at 208V. Several strategies have been developed to increase the efficiency of the data center such as operating data centers at 400Y230V. However, many “legacy” North American computers / servers are not designed to operate at voltages higher than 208V and therefore cannot use the power at 400Y230V. This means that so-called “legacy” equipment cannot take advantage of the more efficient power delivery at this voltage level. Likewise, the most common output voltage for high-efficiency UPS modules in the USA is 480V (3 phase, 3 wire). Therefore, with very few modifications and the simple addition of an output neutral the UPS can deliver 277V.

The benefits of using 277V power supplies are:

- Reduced energy losses.
- Increased capacity.
- Reduced equipment expenses.
- Reduced space requirements.
- Increased reliability.
- More Watts for the ICT equipment designer.

Reduced Energy Losses

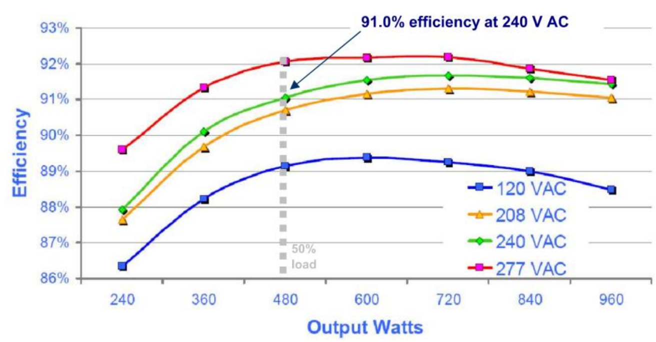


Figure 1:

Hewlett-Packard server power supply efficiency as a function of load.[1]

Power supplies operate more efficiently at higher voltages. The example in Figure 1 shows a Hewlett-Packard server with a 960 watt power supply. Most servers do not operate at full load, but typically operate in the 20-60% load range. At part load (50%) there is a slight improvement from operating at 240V compared to 208V (approximately .25%). When operating at 277V there is about a 1% improvement in efficiency versus operating at 230V and over 1.25% improvement in efficiency versus operating at 208V and almost 3% improvement versus 120V.

At an average Power Usage Effectiveness (PUE) of 1.6, this improves overall efficiency at 277V by 2% over 208V. By eliminating PDUs (assuming 2% losses) the 277V efficiency is 1.6 x (2%+2%) = 6.4% better than 208V.

In North America, most Uninterruptible Power Supply (UPS) systems operate at 480V. To operate servers at 208V or 230V, Power Distribution Units (PDUs) or transformers are required to step the voltage down. Figure 2 shows the typical Uptime Tier III configuration utilizing PDUs to step the voltage down to 208V. By changing the upper range of the power supply voltage from 230V to 277V, the PDUs are no longer required as shown in Figure 3. The PDUs or transformers increase the system losses due to the inherent losses of the transformers. Newer energy efficient transformers are 98-99% efficient; however, it is important to note that transformer efficiencies are listed for linear loads. Non-linear loads such as switch mode power supplies increase the transformer losses. At 50% load (which is typical of transformer loading in a data center) the losses for non-linear loads is approximately 3.3% versus 1.5% losses for a linear load as indicated in Figure 4.

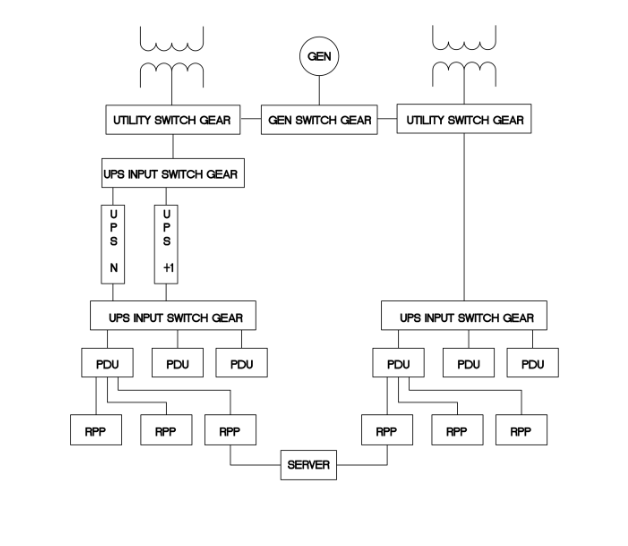


Figure 2: Typical 208/120V Configuration.

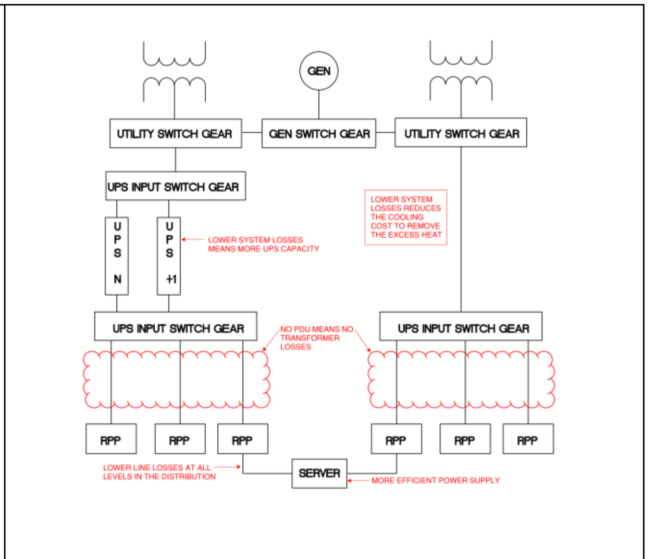
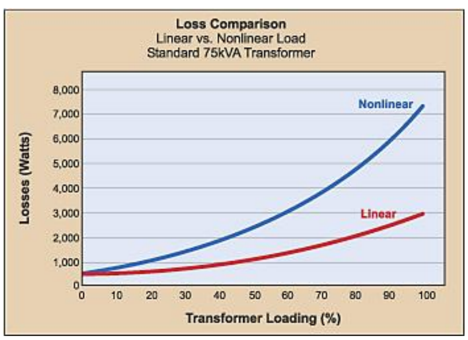


Figure 3: Typical 277V Configuration.



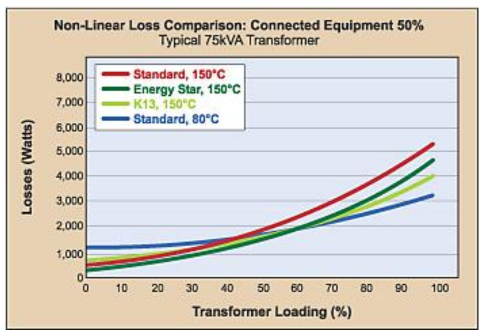


Figure 4:

Loss comparison standard 75 kVA transformer of linear and non-linear loads.

When operating at higher voltage, less current is required to provide the same amount of real power to the server (1.5%), resulting in a reduction of the losses in the circuits feeding the equipment. These losses are often referred to as I^2R losses. For example, a rack has a 2000 watt load and is located 100 feet from the Remote Power Panel (RPP). At 208V the I^2R loss is approximately 30 watts. At 277V the I^2R loss is approximately 17 watts (0.85%) which is a reduction of 43% in I^2R losses in the branch circuit feeding the equipment using the same size conductors.

In addition, the UPS has to be provided with a larger capacity in order to accommodate the system losses. Also, the additional load on the UPS itself creates additional system losses due to the efficiency of the UPS.

All of the additional losses create additional heat in the data center which will increase the energy and costs required to cool the space.

Providing 277V for power supply usage is not restricted to servers - SAN, robotic tape storage, and networking could benefit from the lowered losses and increased efficiency of 277V power supply voltage. By powering these devices using 277V power the cooling load is lowered even further and additional white space is made available for servers or other revenue-generating equipment.

Increased Capacity

Delivering power at higher voltages increases the capacity of the same size circuit. This allows more power to be delivered to the rack with the same size circuit. In a 2N distribution, a typical rack would have two 208V, 30A circuits feeding in-rack PDUs to serve server equipment. By Code, the circuit is limited to 80% of rated capacity so the available capacity to the rack at 208V is 4992 watts. At 277V, the same circuit has a rated capacity of 6648 watts which is a 33% increase in capacity for the same circuit. Another way to look at this is for the same 30A circuit a rack with 120V servers would have 3 servers, at 208V would have 5 servers and at 277V would have 6 servers as shown in Figure 5.

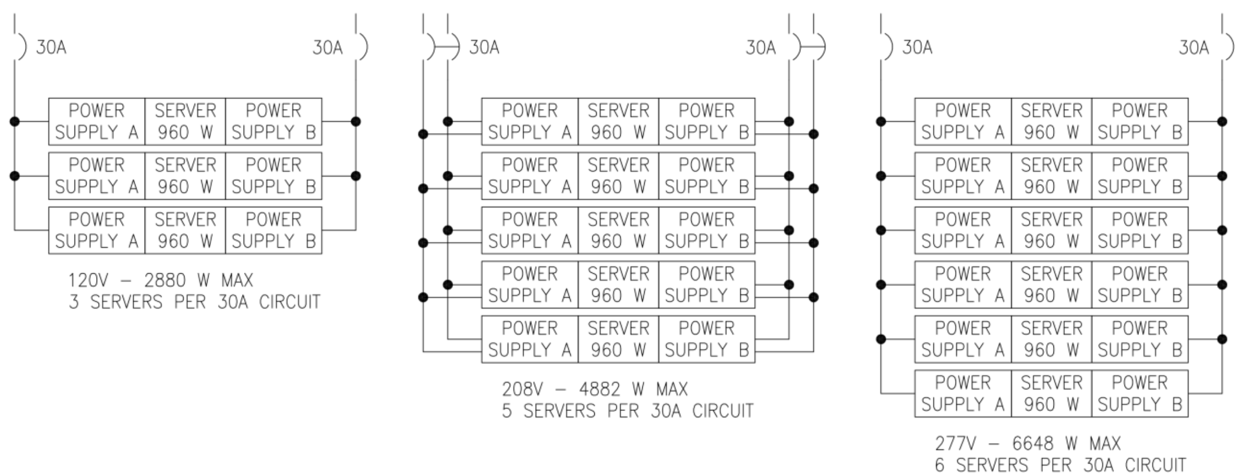


Figure 5: Circuit capacity comparison of 30A circuits at various voltages.

Also, as noted above, because the losses from the UPS to the server are reduced by approximately 5%, that UPS capacity is gained back which allows additional load to be added without increasing the size of the UPS.

Reduced Equipment Expenses

Because distribution voltage is the same as the UPS output, PDUs or transformers are no longer necessary. The UPS output distribution would feed into remote power panels (RPPs) that would feed the load directly.

Because 208V is line to line voltage, each circuit requires a 2 pole circuit breaker. 277V is line to neutral voltage and would only require a single pole circuit breaker. This would cut the number of required Remote Power Panels (RPPs) in half, providing savings in construction costs.

Because each circuit can supply 33% more capacity, fewer circuits are required to feed the same load. This is more applicable to high density loads where multiple circuits would be required to feed a single rack. In most cases, a circuit must be run to each rack. Depending upon the load some single circuits may be smaller. For a 4000W load, a 208V circuit would be a 30A circuit. The same load at 277V would require a 20A circuit.

Likewise, the number of 277V RPPs needed for a particular load is less than half (actually 44%) of the number needed at 208V. For a given white space, this permits more computer equipment cabinets to be installed at 277V than at 208V. This is especially important because computer equipment cabinets generate revenue while RPPs do not.

Reduced Space Requirements

As noted above, PDUs would not be required and only half of the RPPs would be required thus eliminating the requirements for additional “white” space which would reduce the initial facility construction cost or free up the “white” space to install additional racks. A typical 150-225 kVA PDU and required Code working clearances takes up approximately 30 SF of white space for each PDU. A typical 4-panel RPP and required Code working clearances takes up approximately 16-30 SF of white space for each RPP.

Increased Reliability

By eliminating the PDUs and transformers and their associated circuit breakers from the circuit you remove components that can fail from the power chain, increasing the overall reliability of the distribution system.

Example

Table 1 shows the summary of the system losses for a 1 MW data center with 200 racks at approximately 4 kW per rack and the annual cost for the losses with an electric rate of $.06/kWH and $.10/kWH. The annual savings would be between $40,779 and $67,965.

Table 1. Summary of System Losses and Costs

System	Power Supply Losses (W)	Branch Circuit I^2R Losses (W)	PDU Losses (W)	Additional Cooling Power (W)	Total Annual kWH for Losses	Total Annual Cost at $.06/kWH	Total Annual Cost at $.10/kWH
208V	74000	12000	26400	68640	1,603,430	$96,206	$160,343
277V	64000	7000	0	42600	995,136	$59,708	$99,514

Reducing the downstream losses frees up an additional 20 kW of capacity in the UPS or the equivalence of 5 additional racks.

For a 2N distribution system, this would eliminate 10 PDUs (5-225 kVA PDUs per side) and about 8 RPPs which would save approximately 400 SF of white space which is the equivalent space of 20 additional racks.

The disadvantage of using 277V power supplies are:

- Availability of power supplies.
- Increased cost of power supplies.
- Distributed neutral through the 480V portion of distribution.
- Potential for increased fault current and arc flash hazard.
- Unfamiliarity of distribution.
- Dealing with legacy equipment.
- Added cost of four-pole circuit breakers at output of UPS.

Availability

Mainframes are available with 480V 3 phase input but currently very few servers, switches, data center equipment, etc. are available with 277V power supplies. IBM and HP are evaluating or developing equipment with 277V power supplies for limited use but don't have specific plans to develop new equipment for general use. One well known vendor plans to offer the next generation equipment in the Enterprise space with 277V input. We understand that a major manufacturer of servers plans to ship a significant quantity of 277V PS servers in Q4 2010. As more manufacturers offer equipment with 277V power supplies and more end users express interest and a desire to switch to more efficient solutions, additional equipment will be made available with 277V power supplies.

Increased Cost for Power Supplies

The initial cost of 277V power supplies will be higher than the current universal power supplies because the product is new and initial demand will be low. Preliminary forecasts indicate that the initial cost of a 277V power supply will be about 10-15% greater than a current power supply. However, as with any new product, as demand increases the cost will go down.

Distributed neutral through the 480V portion of distribution

In a traditional critical facility design the neutral is not run through the 480V portion of the distribution. Typical UPS design uses a 3-wire output at the UPS feeding into a PDU which transforms the power to 208Y120 4-wire for distribution. "Ditching the neutral" reduces cost in the feeders and switchgear and also simplifies the switching. In a system with 277V critical loads, this issue can be managed through the use of 4-pole breakers and proper sizing of the neutral.

Another limitation with 277V loads is that the neutral must be solidly grounded. This precludes the use of an impedance-grounded neutral in the 480V distribution system.

Potential for Increased Fault Current and Arc Flash Hazard

In some situations, when the voltage is increased and the transformers are removed, the available fault current may increase, which in turn may increase the arc flash hazard. In data center environments, panels cannot be shut down to add or change circuits. In areas where the arc flash hazard category is higher, electricians may be required to wear higher levels of personal protective equipment (PPE) to work on energized equipment. This increases the risk to personal injury and increased equipment damage in the event of an incident during energized work. However, with careful planning (proper selection of upstream transformers to minimize available fault current; proper placement of downstream equipment to allow the length of feeders to lower available fault current) and proper circuit breaker selection (using similar brand of breaker manufacturer to provide tighter coordination) it is still possible to maintain the arc flash hazard to a category 0 (lowest level).

Unfamiliarity of Distribution

There is a higher risk involved with installing equipment at higher voltages. Many IT personnel are not trained or familiar with the risks. Additional training would be required to allow IT personnel to plug in equipment at the higher voltage. In some cases, IT Facilities electricians may be needed to plug in the IT equipment. However, it bears noting that 277V is a common voltage level in North America, so licensed electricians will not experience the same unfamiliarity as would IT personnel.

Dealing with Legacy Equipment

What do you do with the legacy equipment? Owners will have to provide temporary PDUs or even permanent PDUs to accommodate legacy equipment. However, just as 120V equipment has been replaced with 208V equipment and single corded equipment has been replaced with dual corded equipment, so too shall 277V equipment replace 208V equipment.

Added Cost of Four Pole Breakers at UPS Output

There is an additional cost factor associated with the increase in space and size required for switchgear that incorporates a four pole breaker at the output of the UPS. Also, at this time there are a limited number of manufacturers who provide the capability of installing four pole breakers on the UPS output.

What about 230V or DC?

With 400/230V systems, you gain some efficiency over 208V systems but you still require a transformer to convert the standard 480/277V to 400/230V and the efficiency gain is 1-2% lower than the gain at 277V.

Questions to ask internally:

- ❑ Making any change to the data center has some amount of risk. This risk is often balanced against some sort of business gain. Therefore, how do you demonstrate the business correlation between Cap X, Op X, availability for IT growth and new power demands and systems performance?
- ❑ How do you quantify data center RISK when presenting efficiency improvements?

Questions to ask your server, storage or network equipment vendors:

- ❑ Do you have equipment with input voltage of 277 Volt?
- ❑ Do you plan on providing equipment with an input voltage of 277 Volts?
- ❑ What are the cost implications of using power supplies of this type?

To date, DC data centers have not lived up to the efficiency expectations. It has been shown that high efficient AC data centers operate as efficient as or better than DC data centers. Also, there are no DC design standards and there aren't very many qualified DC technicians.

Conclusion

Increasing the range of the voltage rating of existing universal power supplies to 277V will provide the opportunity to reduce energy consumption in the data center by about 5% and reduce the initial capital cost of building a new data center.

References:

[1] Hewlett-Packard Presentation by Paul Perez, Uptime Institute Symposium, March 5, 2007.