

Is an energy-wasting data center draining your bottom line?

New technology options and power distribution strategies can dramatically reduce the cost and carbon footprint of your data center.

Abstract

An unforgiving economic climate has left many organizations struggling to sustain (or restore) profitability. Many of them reacted to the downturn by restructuring, trimming back R&D and marketing, and laying off employees. All of these moves leave a company in a vulnerable position when the market rebounds, which it inevitably will.

Meanwhile, *huge* potential savings are sitting, untapped, right in the company's data center.

Data center energy costs as a percent of total revenue are at an all-time high. In fact, energy costs are emerging as the second highest operating cost in the IT organization, behind labor. A typical one-megawatt data center consumes 16 million kilowatt-hours of electricity a year—roughly equivalent to the energy consumed by 1400 average U.S. households.

The IT and electrical industries have responded with new energy-saving technologies and approaches that could have a notable, positive impact on a company's profitability.

This white paper looks at two key ways that data center managers can improve end-to-end energy efficiency: by changing the voltage of power distribution and by taking advantage of new, high-efficiency, multi-mode uninterruptible power systems (UPSs).

This analysis shows that 400V AC power distribution offers a high degree of energy efficiency for modern data centers, significantly reducing capital and operational expenditures and total cost of ownership, compared to 600V AC and traditional 480V AC power systems. Recent developments in UPS technology—including the introduction of transformer-less UPSs with new energy management features—further enhance a 400V AC power distribution system to maximize energy efficiency.

Contents

Beyond energy-efficient servers and virtualization	2
Traditional powering in U.S. data centers—480V AC	3
A compelling alternative—400V AC power.....	4
The prevailing Canadian power system—600V AC	4
Capital expense is also lower with 400V power distribution.....	5
What about DC power distribution for the data center?	7
Gain even more from a 400V AC power system with new, high-efficiency UPSs.....	7
Key findings—Comparing 400V and 600V AC power, with and without Energy Saver System	9
Conclusion.....	9
About Eaton.....	10

Is an energy-wasting data center draining your bottom line?

New technology options and power distribution strategies can dramatically reduce the cost and carbon footprint of your data center.

Globally, data centers are consuming exponentially more energy than they did only a few years ago, due to growing demand for network bandwidth and faster, fault-free data processing—trends that will undoubtedly continue well into the future.

As demand and utility rates continue to rise, energy costs are emerging as the second highest operating cost (behind labor) in 70 percent of data centers worldwide, according to Gartner Research. During a 10-year service life, a typical one-megawatt data center consumes 160 million kilowatt-hours of electricity—roughly equivalent to the energy consumed by 1400 average U.S. households in that time period. Data centers already account for almost .5 percent of the world's greenhouse gas emissions. And only about 40 percent of incoming utility power actually fuels data processing; the rest is consumed by power and cooling systems.

The pressure is on to maximize data center performance while reducing cost and environmental impact. Energy efficiency is becoming a critical focus. However, few data centers are taking full advantage of available technologies and strategies that can significantly reduce energy consumption and costs.

Beyond energy-efficient servers and virtualization

In evaluating efficiency, data center managers and facilities engineers tend to focus on the efficiency ratings of servers and other IT equipment. Recent advances in energy management and server technology—such as high-density blade servers—can certainly improve data center efficiency. Virtualization is reducing server count to deliver dramatic savings in power consumption and cooling requirements. Manufacturers such as Eaton are putting a lot of effort into creating more energy-efficient power and cooling systems.

However, maximum efficiency can be achieved only by taking a *holistic view* of the complete power distribution system.

Today's 480V AC power distribution systems—the standard in most U.S. data centers—are inexpensive and ubiquitous, but not optimized for efficiency. In a typical, legacy 480V data center, the UPS might be about 94 percent efficient. The power distribution units are about 98 percent efficient, and the servers about 84 percent. So you have a little bit of power being skimmed off at each step along the way. Power gets converted between alternating current (AC) and direct current (DC) *five* times along the way. End-to-end efficiency ends up being about 77 percent.

That's why managers of many large data centers are planning to upgrade their existing 480V AC power infrastructure to more efficient 400V AC or 600V AC equipment in the next few years. Servers could run more efficiently, you can eliminate the need for a transformer-based power distribution unit, and there are only three points of AC/DC conversion. End-to-end efficiency can improve to around 79 percent.

That doesn't sound like much of an increase, but the dollars really add up, especially when you consider that the typical data center has duplicate power systems for redundancy. That means two of everything either saving money or wasting it. Savings can be increased even more by using new, high-efficiency UPSs.

This paper summarizes the results of a 2008 study conducted at Eaton's Innovation Center in Cleveland, Ohio, to compare the energy efficiency, capital expense and operating expense of power distribution at 400V and 600V as alternatives to traditional 480V. The study confirmed that by modifying the voltage at which power is distributed in the data center, data center managers can dramatically reduce energy consumption and the cost of power equipment.

Traditional powering in U.S. data centers—480V AC

Figure 1 illustrates the chain of electrical elements used to deliver 208/120V AC power to servers and other IT equipment in most U.S. data centers today. In this distribution scheme:

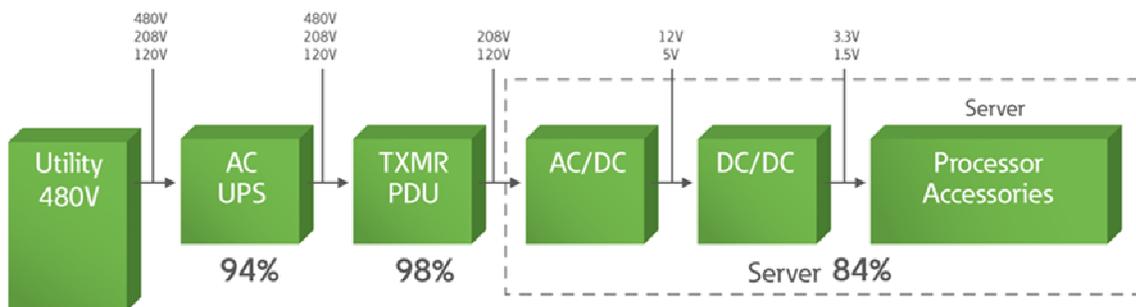
- Utility distribution gear transfers incoming power from the electrical grid to the facility.
- Input switchgear provides electrical protection and distributes the power within the facility.
- The UPS ensures reliable and consistent power and provides seamless backup power protection.
- Isolation transformers then step down the incoming voltage to the utilization voltage.
- Power distribution units (PDUs) feed the power to multiple branch circuits. (The isolation transformer and PDU are normally combined in a single PDU component; a facility usually has many PDUs.)
- The power supply inside the IT equipment converts the utilization voltage to the specific voltage it requires. (It is important to note that most IT equipment can operate at multiple voltages, including 208/120V AC and 230V AC.)

Each component along the way uses a little bit of incoming power to do its job, and each component wastes a little bit of power as well. Overall, end-to-end efficiency is about 77 percent.

End-to-end efficiency = 77%

Number of converter stages = 5

Number of isolation transformers = 2



Advantages

- Inexpensive to procure
- Installation and safety procedures are well documented
- Easy to scale for growth

Disadvantages

- Relatively large footprint
- Paralleling adds complexity
- 480V must be "stepped down" to 208/120V for use with IT loads

Figure 1. End-to-end efficiency in the traditional, 480V AC power distribution system

A compelling alternative—400V AC power

The 400V AC power distribution model, commonly used across Europe, Asia and South America, offers several advantages in terms of efficiency, reliability and cost, when compared to the 480V AC and 600V AC models.

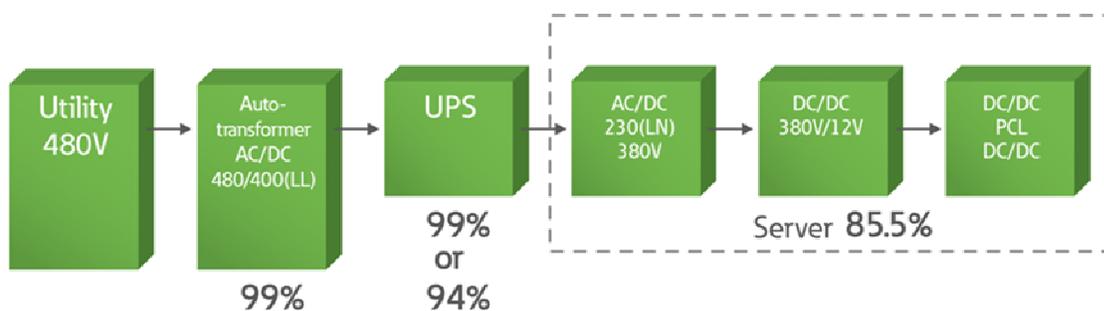
In the 400V AC system, the neutral is distributed throughout the building, eliminating the need for PDU isolation transformers and delivering 230V phase-neutral power directly to the load. This not only enables the system to perform more efficiently and reliably, but significantly lowers the overall cost of the system by omitting the multiple isolation transformers and branch circuit conductors required in 480V AC and 600V AC power systems.

As shown in Figure 2, losses through the auto-transformer, the UPS and the server equipment produce an overall end-to-end efficiency of approximately 79 percent—higher with high-efficiency UPSs.

End-to-end efficiency = 79% (84% with high-efficiency UPSs)

Number of converter stages = 3

Number of isolation transformers = 1



Advantages

- IT Gear runs 1.5 -2% more efficiently
- No changes needed for UPS (UL listed)
- No changes to IT equipment needed
- Transformer PDU eliminated-saves footprint

Disadvantages

- Autotransformer often needed
- Neutral is required in the distribution wiring
- Minor changes to UPS documentation
- UL Listing at 400V required

Figure 2. End-to-end efficiency in the 400V AC power distribution system

The prevailing Canadian power system—600V AC

The 600V AC power system used in many Canadian data centers offers certain advantages over both the 480V AC and 400V AC systems, but inherent inefficiencies make 600V AC an impractical option for most U.S. data centers.

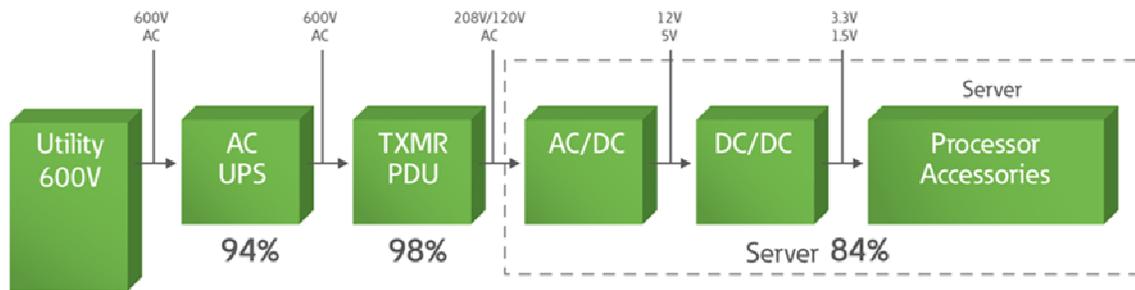
The 600V AC system offers a modest equipment cost savings, compared 480V AC and 400V AC systems, requiring less copper wiring feeding into the UPS and from the UPS to the PDU. Lower currents also enable less heating of the wires, reducing energy cost.

In larger data centers that use multi-module, parallel redundant UPS systems, 600V AC power provides further savings. For this unique circumstance, a single 4000A switchboard can support up to five 750 kVA or 825 kVA UPS modules in a 600V AC system but only four modules in a 400V AC system. The data center manager can therefore gain some extra capacity at nominal cost and with no increase in switchgear footprint.

The primary drawback to 600V AC power, compared to 400V AC, is that the distribution system requires multiple isolation transformer-based PDUs to step down the incoming voltage to the 208/120V AC utilization voltage. These extra PDUs add significant cost and reduce overall efficiency. Some UPS vendors create a 600V AC UPS using isolation transformers in conjunction with a 480V AC UPS, reducing efficiency even further.

Overall end-to-end efficiency is approximately 77 percent—the same as traditional 480V AC power distribution.

End-to-end efficiency = 77%
Number of converter stages = 5
Number of isolation transformers = 3



Advantages

- More kVA available through 4000A switchgear, saves floor space in the largest UPS installation
- No changes to IT equipment needed
- Some savings in copper wiring costs

Disadvantages

- UPS requires input and output transformer, size, weight, and efficiency are a challenge.
- Minor changes to National Electrical Code for 600V in the data center

Figure 3. End-to-end efficiency in the 600V AC power distribution system

Because the 400V AC system is more energy-efficient, operating expense and total cost of ownership are substantially lower than for 600V AC systems—both in the first year of service and over the 15-year typical service life of the power equipment.

Capital expense is also lower with 400V power distribution.

Figure 4 compares equipment purchase and installation costs for 400V AC and 600V AC power distribution configurations to support a 1 MVA power load. For both strategies, the calculations of CAPEX, OPEX and TCO included:

- Purchase and installation costs of input switchgear to feed the UPS, multiple UPS modules and a paralleling cabinet known as a system bypass module (SBM)
- Floor space priced at \$800 per square foot, 12 square feet per PDU
- Utility power at \$0.10 per kWh, and utility demand charges at \$12 per kW (Utility rates and demand charges will vary slightly depending on data center location.)
- UPS and cooling, refrigeration and air conditioning (CRAC) efficiency values at 50 percent load, the typical operating point for the dual-bus systems common in data centers today

What is different between the 400V and 600V configurations? For one, the 600V AC configuration in our example would need three Eaton 9315 transformer-based UPS modules, versus two Eaton 9395 transformer-less UPS modules for the 400V option. The 600V AC configuration requires multiple isolation transformer-based PDUs to step down the incoming voltage to the 208/120V AC utilization voltage. These are not required in the 400V AC configuration, because the UPS delivers 230V power directly to the IT equipment—which can comfortably operate at multiple voltages, including 208/120V and 230V AC. In addition, the servers are two percent more efficient running on the 230V power delivered by the 400V option.

For this sample configuration, total cost of ownership is \$156,000 lower for 400V AC power than for 600V AC. Eaton research showed that data centers of every size evaluated—from 300 kVA to 10 MVA—stood to gain by choosing 400V AC power, saving approximately four to six percent across a 15-year service life, with additional savings seen in reduced service costs.

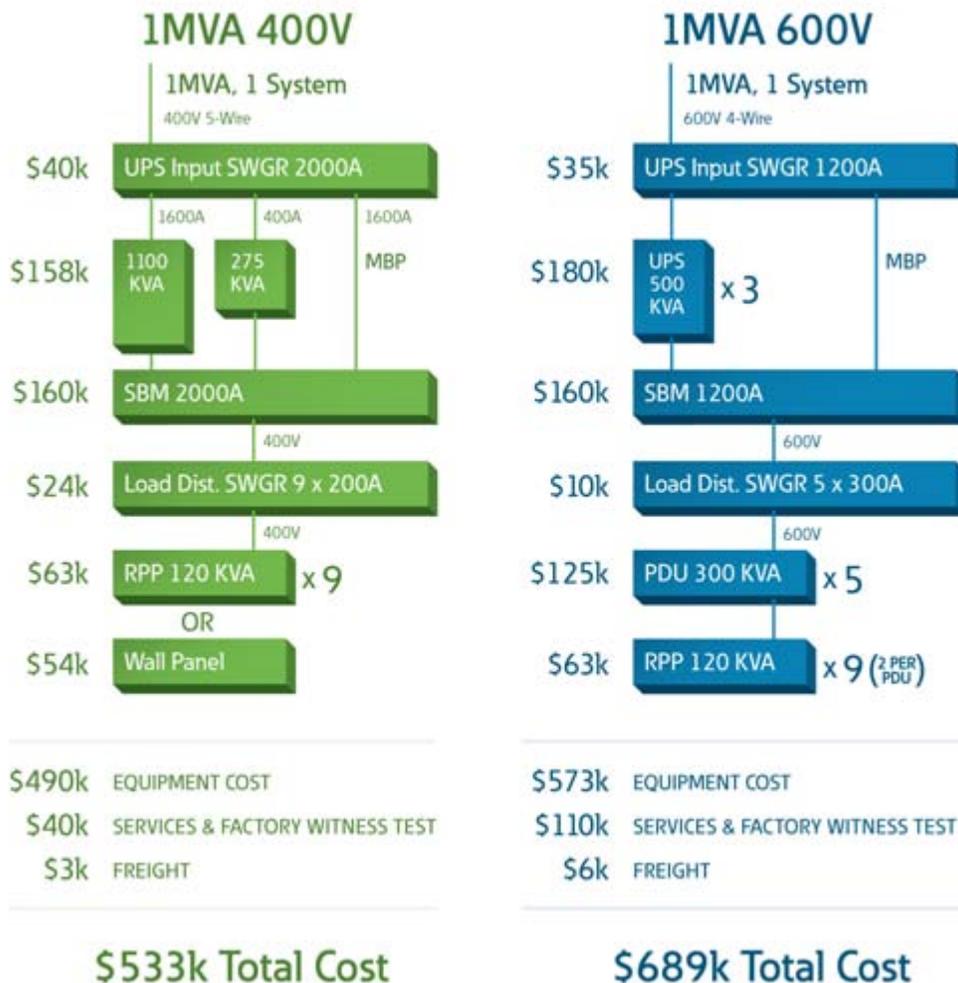


Figure 4. Comparing CAPEX for 400V AC and 600V AC distribution for a 1 MVA data center
 (Equipment cost for the 400V option includes a 10 percent surcharge to cover extra wiring costs.)

What about DC power distribution for the data center?

With all those back-and-forth power conversions between AC and DC robbing efficiency in the power chain, wouldn't it be more efficient to just use DC power distribution for the data center?

That's an important question that has been asked for the last 20 years. Telecommunications equipment, for instance, is powered by -48V DC power. Many decades ago, the Bell Telephone Company took this powering approach because cables were run in corrosive and damp conditions, and low voltage protected the safety of line technicians.

Low-voltage DC power is used in telecom today because that's what has always been done, and because DC equipment is rugged and reliable. For data center applications though, -48 DC requires such large, expensive copper cabling to deliver a relatively small amount of power for any distance.

Higher DC voltage shows a lot of promise though. In 2007 the California Public Energy Commission did a study on 380V DC and found that it was five to seven percent more efficient than best-in-class AC systems. The researchers theorized that as much as 28 percent improvement could be possible, compared to today's average AC systems.

However, there are few standards for high-voltage DC power outside of industrial applications—and no standards for IT systems. There is limited availability of IT equipment that will run this power. And there are some safety issues to be addressed. So 380V DC is promising, but at the moment it remains a future vision.

Gain even more from a 400V AC power system with new, high-efficiency UPSs.

The business case for 400V power is compelling, but it can be improved even more by taking advantage of new, high-efficiency power protection systems.

UPSs vary markedly in their efficiency, depending on vintage and operating mode. As recently as 10 years ago, a state-of-the-art UPS was about 93 or 94 percent efficient. The 2000s have brought some UPSs that operate at 97 percent efficiency or better and are optimized for today's IT equipment power supplies. Still, a typical one-megawatt data center using five- or 10-year-old UPSs could be forfeiting about \$112,000 of its utility power each year to UPS energy losses.

At Eaton, we thought that figure was unacceptably high. So we developed new UPSs that operate at 99 percent efficiency under normal utility conditions. Eaton's Energy Saver System, available on several UPS models, continuously analyzes the quality of incoming power and selectively and automatically controls the power conversion circuitry to optimize power conditioning and efficiency.

Energy Saver System is supported only on transformer-less 400V AC and 480V AC UPSs. All 600V AC UPS systems available today feature transformer-based designs that are inherently less efficient.

The advantages of even a few percentage points of UPS efficiency are significant. Suppose you are replacing an older 1 MW UPS that is 93 percent efficient, and you pay 11 cents per kilowatt-hour for energy. A UPS with Energy Saver System would save about \$96,000 per year. That's enough to pay for the UPS in the first few years. The savings continue on for the rest of the unit's service life.

Furthermore, the more energy-efficient UPS eliminates 1,924 metric tons of carbon emissions—the equivalent of taking 116 gas-sucking, carbon-spewing cars off the road.

As shown in Figure 5, a 400V power distribution system using an Energy Saver System UPS produces an overall end-to-end efficiency of approximately 84 percent.

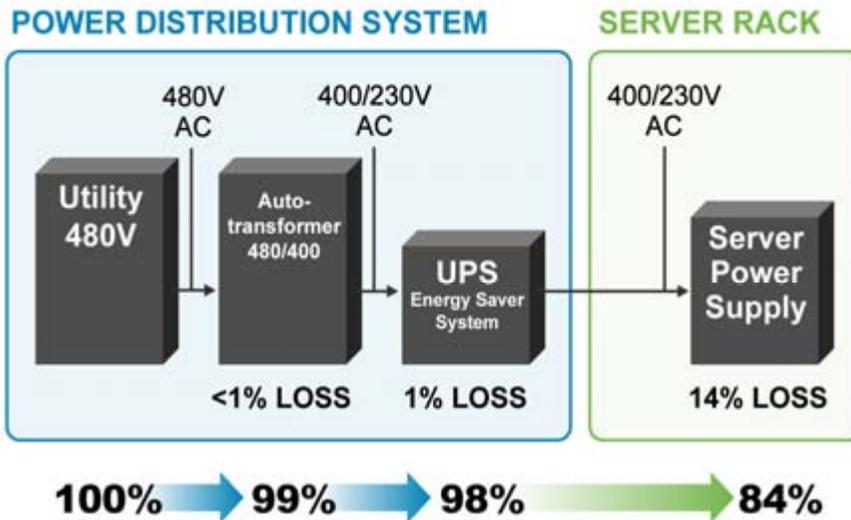


Figure 5. With Energy Saver System, UPS energy loss can be as low as one percent.

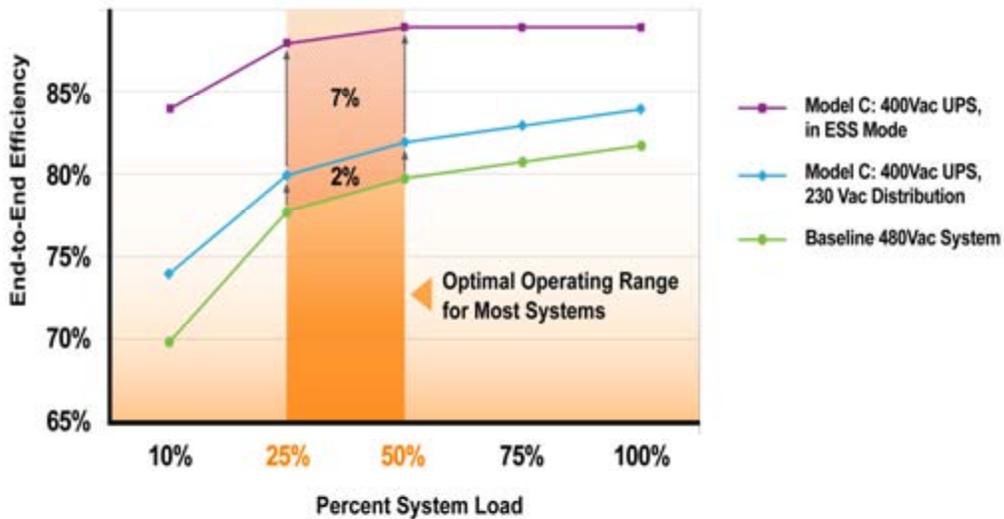


Figure 6. Energy Saver System boosts the end-to-end efficiency of 400V AC systems. The option for 230V distribution enables servers to be more efficient as well.

Key findings—Comparing 400V and 600V AC power, with and without Energy Saver System

A 400V AC power distribution system has a lower equipment cost and higher end-to-end efficiency, compared to 600V AC, delivering significant savings in CAPEX, OPEX and TCO across all power loads analyzed.

- **In the first year alone**, the 400V AC system offers 10 percent lower TCO than the 600V AC alternative. Add Energy Saver System to the equation, and TCO savings increase to 16 percent.
- **Across the 15-year service life** of the UPS, the 400V AC system with traditional, double-conversion UPSs has a four percent lower TCO than the 600V alternative. Add an Energy Saver System UPS, and 15-year TCO savings increase to 16 percent.
- **Looking at CAPEX alone**, the 400V AC configuration saves an average of 15 percent over the 600V AC configuration for all system sizes analyzed (300 kVA, 1 MW, 2 MW, 5 MW, 6 MW, 8 MW and 10 MW)—yielding a more cost-effective solution for expanding data center power capacity.
- **Looking at annual OPEX** across all system sizes evaluated, the 400V AC system saved an average of four percent compared to the 600V AC alternative—with savings increasing in direct proportion to system size. With Energy Saver System, OPEX savings jump to 17 percent.

		400V AC	600V AC	SAVINGS 400v vs. 600V	
CAPEX		\$533k	\$689k	\$156k	
15 Years: Double Conversion Mode	OPEX	\$7,027k	\$7,284k	\$257k	
	TCO	\$7,560k	\$7,973k	\$413k	5% SAVINGS
15 Years: Energy Saver System	OPEX	\$6,072k	\$7,284k	\$1,212k	
	TCO	\$6,605k	\$7,973k	\$1,368k	17% SAVINGS

Figure 7. Comparing 600V, 400V and 400V with Energy Saver System for a 1 MVA data center

Conclusion

Major advancements in UPS and server designs have improved energy efficiency in data centers in recent years. However, the key to improving overall power efficiency is to look at end-to-end power distribution.

Of the alternative power distribution systems currently found in the U.S. and Canada, Eaton recommends 400V power distribution, stepped down to 230V to support IT systems. This approach has proven reliable in the field, conforms to current U.S. regulatory standards, can be easily deployed into existing 480V AC power systems, and doesn't require significant changes to IT systems.

This conclusion is supported by IT industry experts who theorize that 400V AC power distribution will become standard as U.S. data centers transition away from 480V AC to a more efficient and cost-effective solution over the next one to four years.

Organizations that are particularly cost-conscious or have aggressive carbon abatement programs should also consider replacing legacy UPSs. New high-efficiency UPSs with Eaton Energy Saver System pay for themselves within a few years and then continue delivering savings for the rest of their 10- or 15-year service lives.

For more information, visit www.eaton.com/powerquality.

About Eaton

Eaton Corporation is a diversified power management company with 2008 sales of \$15 billion. Eaton is a global technology leader in electrical systems for power quality, distribution and control; hydraulics components, systems and services for industrial and mobile equipment; aerospace fuel, hydraulics and pneumatic systems for commercial and military use; and truck and automotive drivetrain and powertrain systems for performance, fuel economy and safety.

Eaton has approximately 75,000 employees and sells products to customers in more than 150 countries. For more information, visit www.eaton.com.

Tutorials on demand

Download Eaton white papers to learn more about technology topics or explain them to customers and contacts. Maintenance bypass, paralleling, UPS topologies, energy management and more are demystified in free white papers from our online library.

<http://www.eaton.com/pq/whitepapers>

Eaton and Energy Saver System are trademarks of Eaton Corporation.