White Paper

Alternative data center power

A quantitative TCO comparison of 400V AC and 600V AC power systems

Abstract

Power efficiency has become a critical focus for IT and facilities managers as they struggle to meet ever-increasing demands for faster, more reliable data processing while also reducing data center cost and minimizing environmental impact.

More efficient power distribution systems, combined with recent advancements in electrical design and uninterruptible power system (UPS) technology, enable data center managers to significantly improve system-wide power efficiency. Studies show that most managers of large data centers are planning to upgrade their existing 480V AC power infrastructure over the next few years, implementing more efficient 400V AC or 600V AC equipment.

This paper provides a quantitative analysis of 400V AC and 600V AC power distribution systems, at power load levels ranging from 300 kVA to 10 MVA, to determine which offers the lowest total cost of ownership (TCO).

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Introduction

The global IT market has seen an exponential increase in data center energy consumption over the last several years due to growing demand for network bandwidth and faster, fault-free data processing—a trend that will undoubtedly continue well into the future.

Industry reports show that data center energy costs as a percent of total revenue is at an all-time high, leaving many companies with large data centers to face reduced profitability due to data center inefficiency. In addition, data center electricity consumption accounts for almost .5 percent of the world's greenhouse gas emissions, with the average data center consuming energy equivalent to 25,000 households.[1] As a result, data center managers are under pressure to maximize data center performance while reducing cost and minimizing environmental impact, making data center energy efficiency critical.

Although there are several methods of improving efficiency, many data center managers are opting to invest in more efficient hardware[2]—a solution that's often less costly and more quickly and easily implemented than data virtualization or additional cooling systems. According to a 2007 Frost & Sullivan survey of 400 IT and facilities managers responsible for large data centers, 78 percent of respondents indicated that they were likely to adopt more energy efficient power equipment in next five years.[3]

While major advancements in electrical design and UPS technology have provided incremental efficiency improvements, the key to improving system-wide power efficiency within the data center is power distribution.[4] However, today's 480V AC power distribution systems—standard in most U.S. data centers and IT facilities—are not optimized for efficiency.[5]

Of the several alternative power distribution systems currently found in the U.S. and Canada, 400V AC and 600V AC systems are generally accepted as the most viable. While both have been proven reliable in the field, conform to current National Electrical Code (NEC) guidelines, and can be easily deployed into existing 480V AC infrastructure, there are important differences in efficiency and cost that must be carefully weighed.[6]

This paper offers a quantitative comparison of 400V AC and 600V AC power distribution configurations at load levels ranging from 300 kVA to 10 MVA using readily available equipment, taking into account the technology advancements and installation and operating costs that drive TCO.

The traditional US data center power system

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.

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 a reliable and consistent level of power and provides seamless backup power protection. Isolation transformers then step down the incoming voltage to the utilization voltage, and power distribution units (PDUs) feed the power to multiple branch circuits. The isolation transformer and PDU are normally combined in a single PDU component, many of which are required throughout the facility. Finally, the power supply converts the utilization voltage to the specific voltage needed for each server. It is important to note that most IT equipment can operate at multiple voltages, including 208/120V AC and 230V AC.

In evaluating data center efficiency, the emphasis is often placed on the efficiency ratings of the server and IT equipment alone. Recent advances in energy management and server technology—such as high-density blade servers—can help to improve data center efficiency; however, maximum efficiency can be achieved only by taking a holistic view of the complete power distribution system. Each component carries a cost and impacts the end-to-end efficiency of the system. Therefore, the entire system must be optimized in order for the data center to fully realize the efficiency gains offered by these new server technologies.

As shown in Figure 1, losses through the UPS, the isolation transformer/PDU and the server equipment produce an overall end-to-end efficiency of approximately 76 percent.

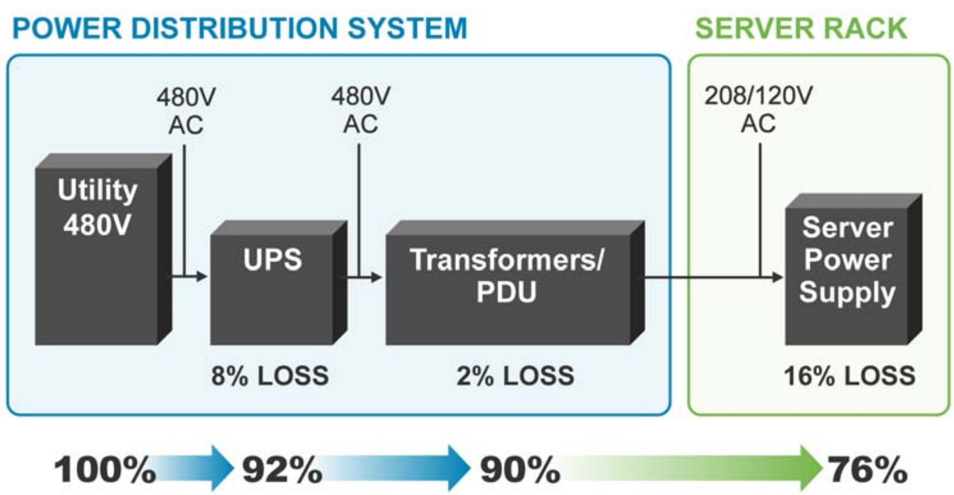

Figure 1: End-to-end efficiency in the 480V AC power distribution system

The 400V AC power system

The 400V AC power distribution model, commonly used across Europe, Asia and South America[7], offers a number of advantages in terms of efficiency, reliability and cost, as 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 80 percent.

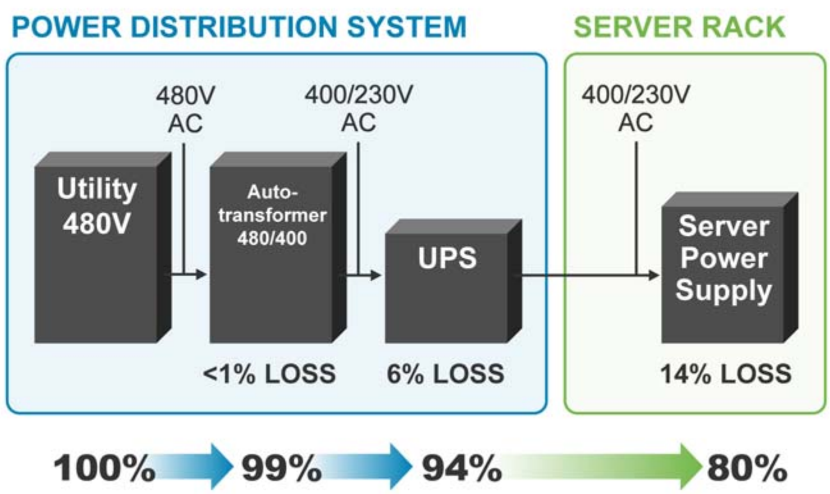

Figure 2: End-to-end efficiency in the 400V AC power distribution system

The 600V AC power system

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

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

Additional savings can be achieved using 600V AC power equipment in unique circumstances where larger data centers deploy multi-module parallel redundant UPS systems. In practice, 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. This allows the data center manager to add a small amount of extra capacity at a nominal cost and with no increase in the footprint of the switchgear.

The primary drawback to 600V AC power as 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, adding significant cost and reducing overall efficiency. Some UPS vendors create a 600V AC UPS using isolation transformers in conjunction with a 480V AC UPS, reducing efficiency even further.[6]

As shown in Figure 3, losses through the UPS, the isolation transformer/PDU, and the server equipment produce an overall end-to-end efficiency of approximately 76 percent—comparable to the efficiency of today's traditional 480V AC power distribution system.

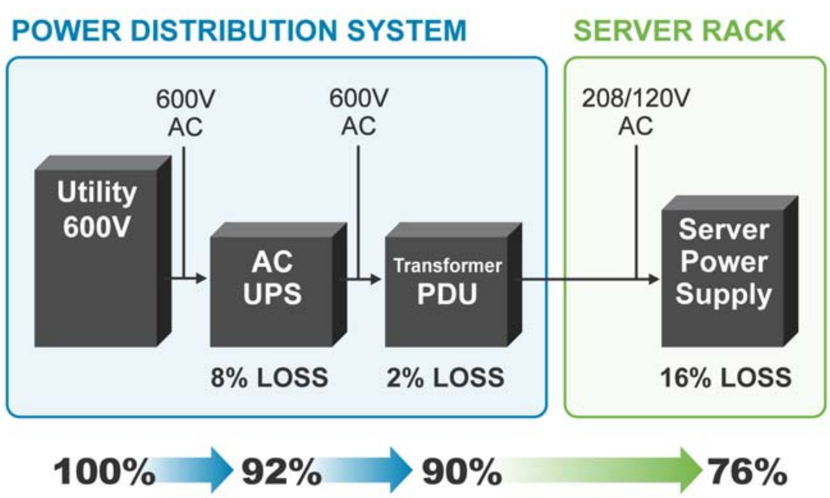

Figure 3: End-to-end efficiency in the 600V AC power distribution system

Comparing total cost of ownership

Understanding how greater efficiency helps lower TCO

TCO for the power distribution system is determined by adding capital expenditures (CAPEX) such as equipment purchase, installation and commissioning costs, and operational expenditures (OPEX), which include the cost of electricity to run both the UPS and the cooling equipment required to remove heat resulting from the normal operation of the UPS.

As previously illustrated in Figures 2 and 3, the end-to-end efficiency of the 400V AC power distribution system is 80 percent versus 76 percent efficiency in the 600V AC system, with both systems running in conventional double conversion mode. The 400V AC system's higher efficiency drives significant OPEX savings over the 600V AC system, substantially lowering the data center's TCO both in the first year of service and over the 15-year typical service life of the power equipment.

The effect of Energy Saver System on the power distribution system

To further reduce OPEX, many UPS manufacturers offer high-efficiency systems that use various hardware- and software-based technologies to deliver efficiency ratings between 96 and 99 percent. Energy Saver System from Eaton® increases UPS efficiency from 94 percent, when running in double conversion mode, to 99 percent by analyzing the quality of incoming power and selectively and automatically controlling the power conversion circuitry to optimize power conditioning. It should be noted that Energy Saver System is supported only on transformerless 400V AC and 480V AC UPSs. All 600V AC UPS systems available today feature less efficient, transformer-based designs.

As shown in Figure 4, losses through the auto-transformer, the UPS running in Energy Saver System and the server equipment produce an overall end-to-end efficiency of approximately 84 percent.

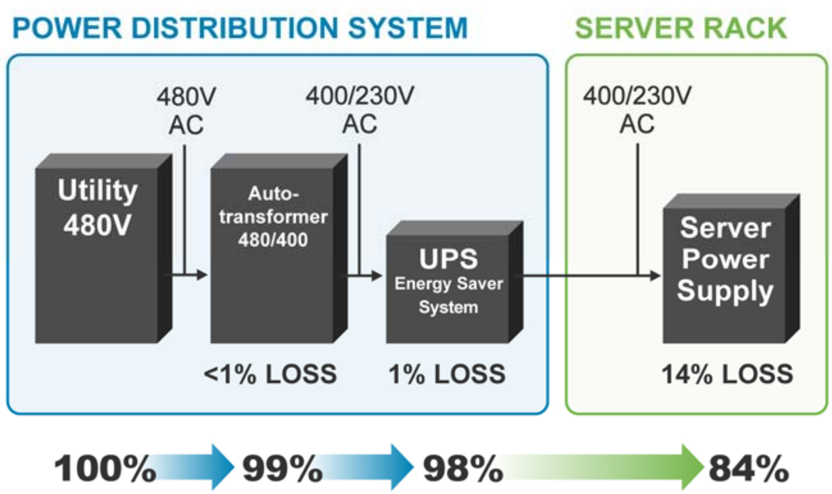

Figure 4: End-to-end efficiency in the 400V AC power distribution system with the UPS running in Energy Saver System

Illustrating TCO savings with the 400V AC power distribution system

Figure 5 compares the equipment purchase and installation costs for 400V AC and 600V AC power distribution configurations designed to support a 1 MVA power load, with complete CAPEX, OPEX, and TCO savings highlighted below. Savings comparisons at the 300 kVA, 2 MVA, 5 MVA, 6 MVA, 8 MVA and 10 MVA load levels are available in Appendices 1-6.

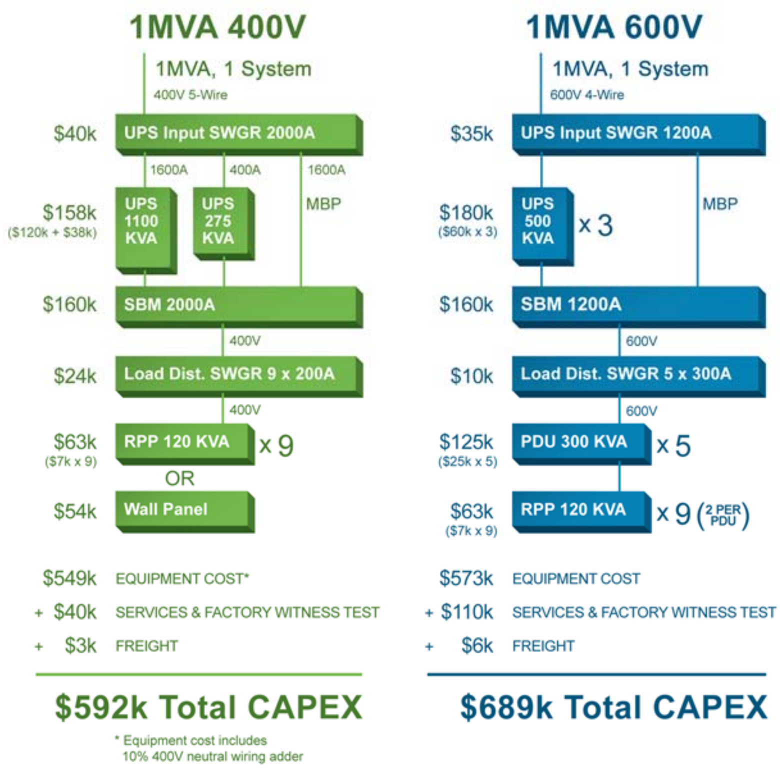

Figure 5: 1 MVA 400V AC and 600V AC CAPEX savings comparison*

		400V AC	600V AC	SAVINGS 400v vs. 600V	
CAPEX		$592k	$689k	$97k	
15 Years: Double Conversion Mode	OPEX	$7,027k	$7,284k	$257k	
	TCO	$7,619k	$7,973k	$354k	4% SAVINGS
15 Years: Energy Saver System	OPEX	$6,072k	$7,284k	$1,212k	
	TCO	$6,664k	$7,973k	$1,309k	16% SAVINGS

* The 400V AC and 600V AC power distribution configurations in Figure 5 each consist of multiple UPSs, input switchgear to feed the UPSs, and a paralleling cabinet known as a system bypass module, or SBM. Note that the 600V AC configuration adds the multiple isolation transformer-based PDUs needed to step down the incoming voltage to the 208/120V AC utilization voltage. These are not required in the 400V AC configuration, in which the UPS delivers 230V power directly to the IT equipment. As previously discussed, most IT equipment can operate at multiple voltages, including 208/120V and 230V AC.

Charts 1 and 2 illustrate the 15-year TCO for 400V AC versus 600V AC power distribution configurations at the 300 kVA, 1 MVA, 2 MVA, 5 MVA, 6 MVA, 8 MVA and 10 MVA load levels. Complete first-year and 15-year CAPEX, OPEX and TCO breakdowns are shown in Appendix 8.

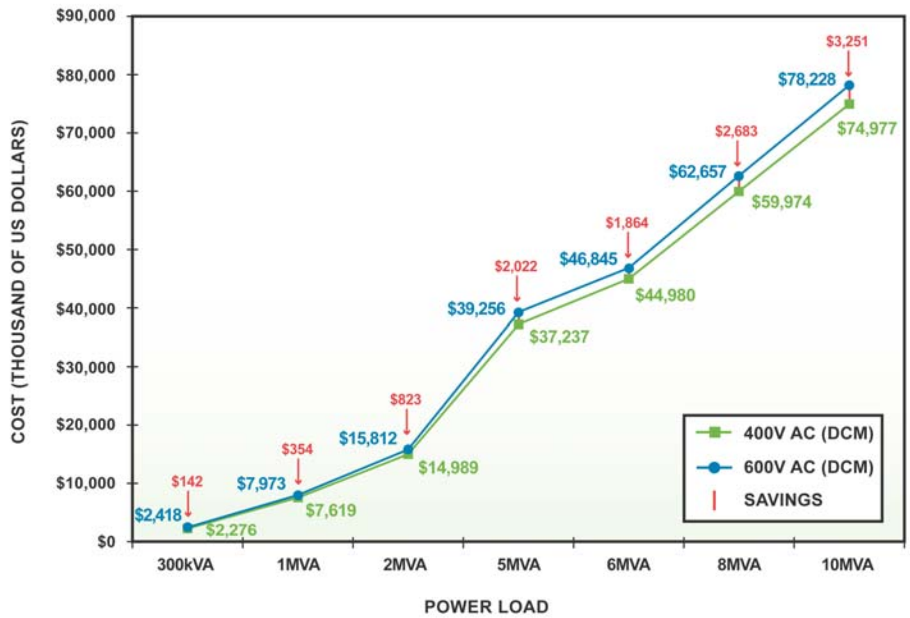

Chart 1: 15-year TCO (400V AC vs. 600V AC, both in double conversion mode)

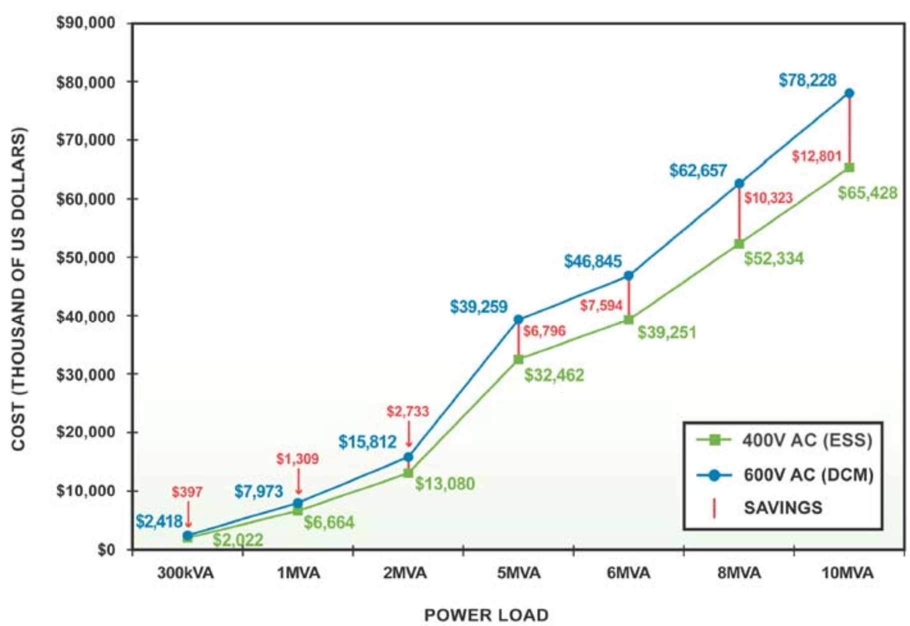

Chart 2: 15-year TCO (400V AC Energy Saver System vs. 600V AC double conversion mode)

Methodology

- CAPEX is calculated using the following UPS equipment:
  - 400V AC: Eaton 9395 transformerless UPSs
  - 600V AC: Eaton 9315 transformer-based UPSs
- All 400V configurations require 4-pole automatic transfer switches.
- OPEX calculations are based on actual UPS and cooling, refrigeration and air conditioning (CRAC) efficiency values measured at 50 percent load. This is the typical operating point for the dual-bus systems common in data centers today.
- 400V OPEX calculations include 2 percent server efficiency improvement at 230V AC
- Floor space cost is calculated at $800 per square foot and 12 square feet per PDU.
- Utility power costs are calculated using $0.10 per kWh, and utility demand charges assume $12 per kW. (These power and demand costs will vary slightly depending on data center location.)
- Startup service cost (including engineering and factory witness test) is calculated based on the following configurations:
  - 400V AC configuration: 2x UPS + system bypass module (SBM)
  - 600V AC configuration: 3x UPS + system bypass module (SBM)

Summary

The 400V AC power distribution system's lower equipment cost and higher end-to-end efficiency deliver significant CAPEX, OPEX and TCO savings as compared to the 600V AC system. The following table summarizes CAPEX, OPEX and TCO savings across all power loads analyzed. Refer to Appendix 7 for detailed cost and savings comparisons at the 300 kVA, 1 MVA, 2 MVA, 5 MVA, 6 MVA, 8 MVA and 10 MVA power load levels.

	Savings with 400V AC in Double Conversion Mode	Savings with 400V in Energy Saver System
CAPEX	**2 - 26%**	
First-year OPEX	**4 - 6%**	**17 - 18%**
First-year TCO	**4 - 16%**	**9 - 22%**
15-year OPEX	**4 - 6%**	**17 - 18%**
15-year TCO	**4 - 6%**	**16 - 17%**

- The 400V AC system running in conventional double conversion mode offers an average 10 percent first-year TCO savings as compared to the 600V AC system. When running the 400V AC UPS in Energy Saver System, the TCO savings increase to 16 percent, minimizing data center cost in terms of both CAPEX and OPEX.

- Over the 15-year service life of the UPS, the 400V AC system running in double conversion mode delivers an average 5 percent TCO savings as compared to the 600V AC system. When running the 400V AC UPS in Energy Saver System, the 15-year TCO savings increase to 17 percent.

- In CAPEX investment alone, the 400V AC configuration offers an average 15 percent savings over the 600V AC configuration for all system sizes analyzed. The 400V AC system's lower CAPEX gives data center managers a more cost-effective solution for expanding data center capacity.

- The systems analyzed produced an average annual OPEX savings of 4 percent with the 400V AC system running in double conversion mode and 17 percent when running in Energy Saver System. OPEX savings rates are linear across all system sizes, indicating that savings will continue to increase in direct proportion to the size of the system.

Conclusion

As demonstrated in this analysis, the 400V AC power distribution system offers the highest degree of electrical efficiency for modern data centers, significantly reducing capital and operational expenditures and total cost of ownership as compared to 600V AC power systems. Recent developments in UPS technology—including the introduction of transformerless UPSs and new energy management features—further enhance the 400V AC power distribution system for maximum efficiency.

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.

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.

Sources

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2. Aperture Research Institute, "Data Centers are Adopting Green Initiatives but are Wary of Vendors' Marketing Messages," research note (March 11, 2008), pp. 4-5.

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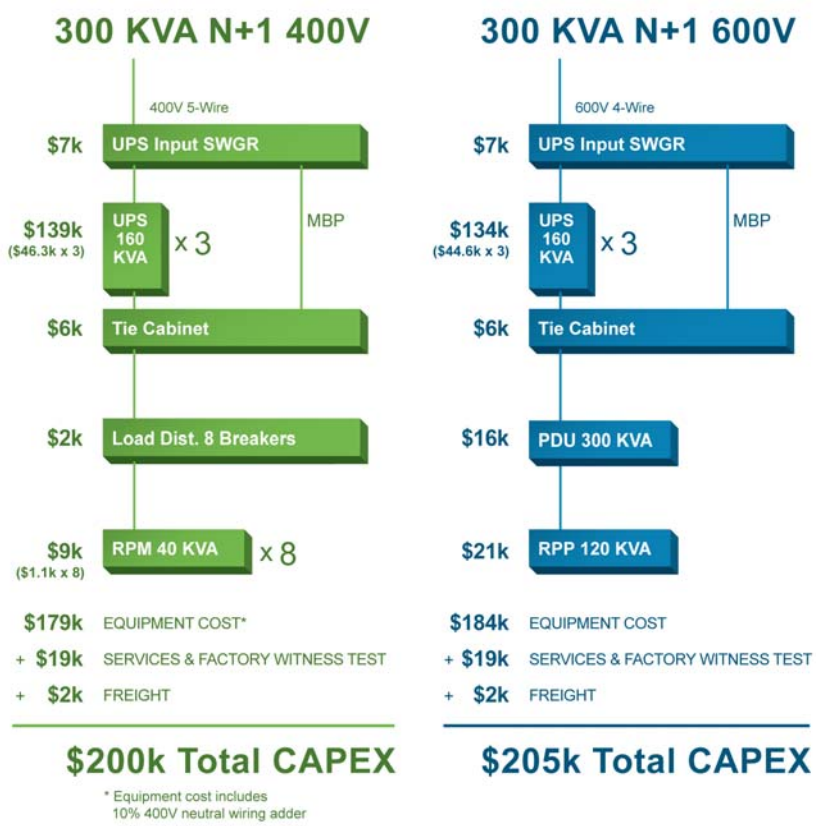
6. Spears, "Future Trends in Power Conversion: High Efficiency, High Availability Data Center Strategy," pp. 13-23.

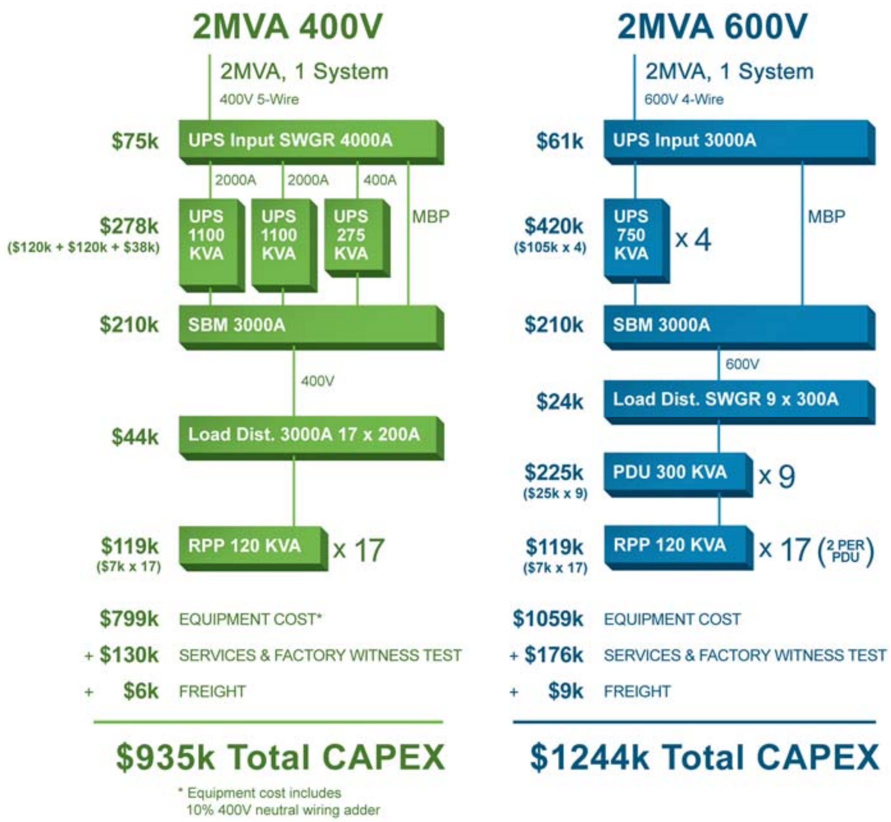
7. Carr, J., and McCall, L.V., "Divergent Evolution and Resulting Characteristics among the World's Distribution Systems," *Power Delivery, IEEE Transactions on*, vol. 7, issue 3 (July 1992), pp.2.

Appendix 1: 300 KVA N+1 cost and savings comparisons



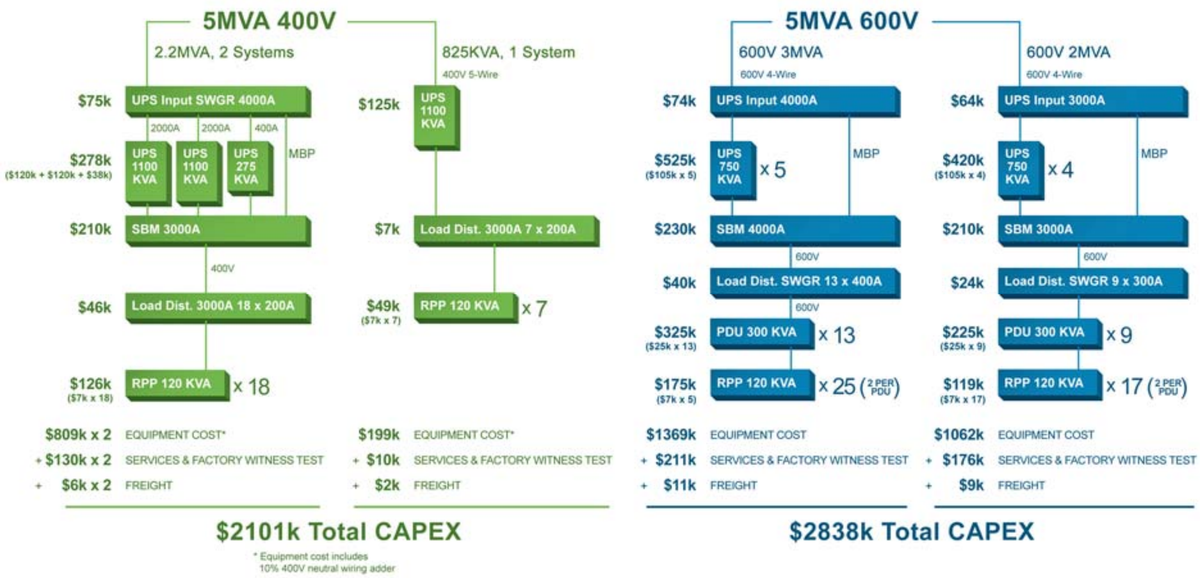
		400V AC	600V AC	SAVINGS 400v vs. 600V	
CAPEX		$200k	$205k	$5k	
15 Years: Double Conversion Mode	OPEX	$2,076k	$2,213k	$137k	
	TCO	$2,276k	$2,418k	$142k	6% SAVINGS
15 Years: Energy Saver System	OPEX	$1,822k	$2,213k	$392k	
	TCO	$2,022k	$2,418k	$397k	16% SAVINGS

Appendix 2: 2 MVA cost and savings comparisons



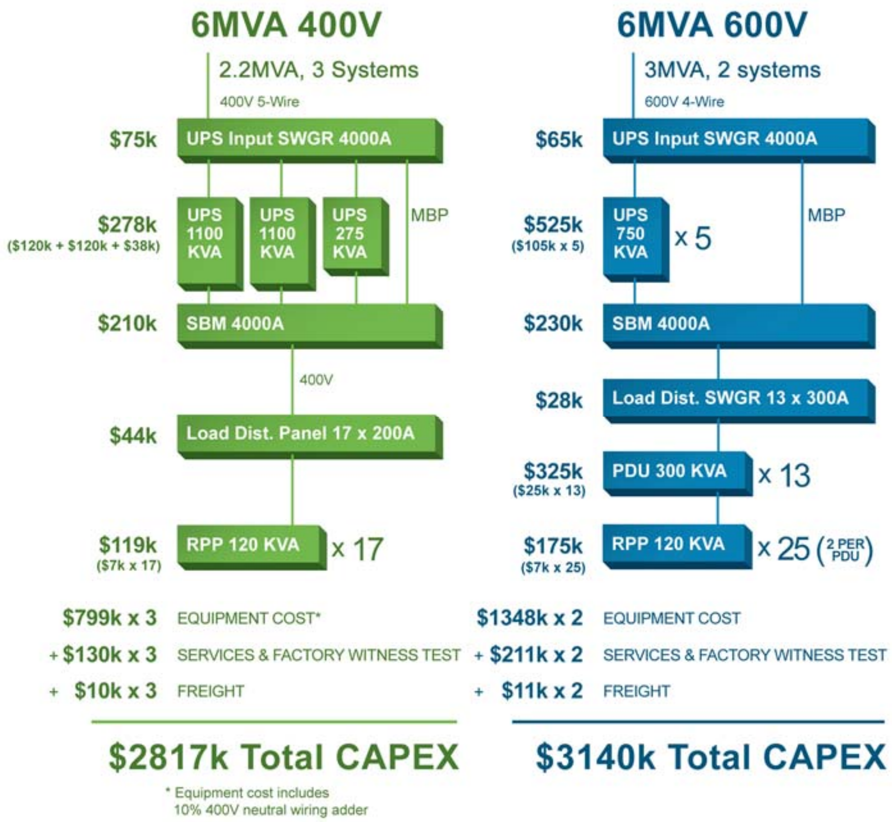
		400V AC	600V AC	SAVINGS 400v vs. 600V	
CAPEX		$935k	$1,244k	$309k	
15 Years: Double Conversion Mode	OPEX	$14,054k	$14,568k	$514k	
	TCO	$14,989k	$15,812k	$823k	5% SAVINGS
15 Years: Energy Saver System	OPEX	$12,145k	$14,568k	$2,424k	
	TCO	$13,080k	$15,812k	$2,733k	17% SAVINGS

Appendix 3: 5 MVA cost and savings comparisons



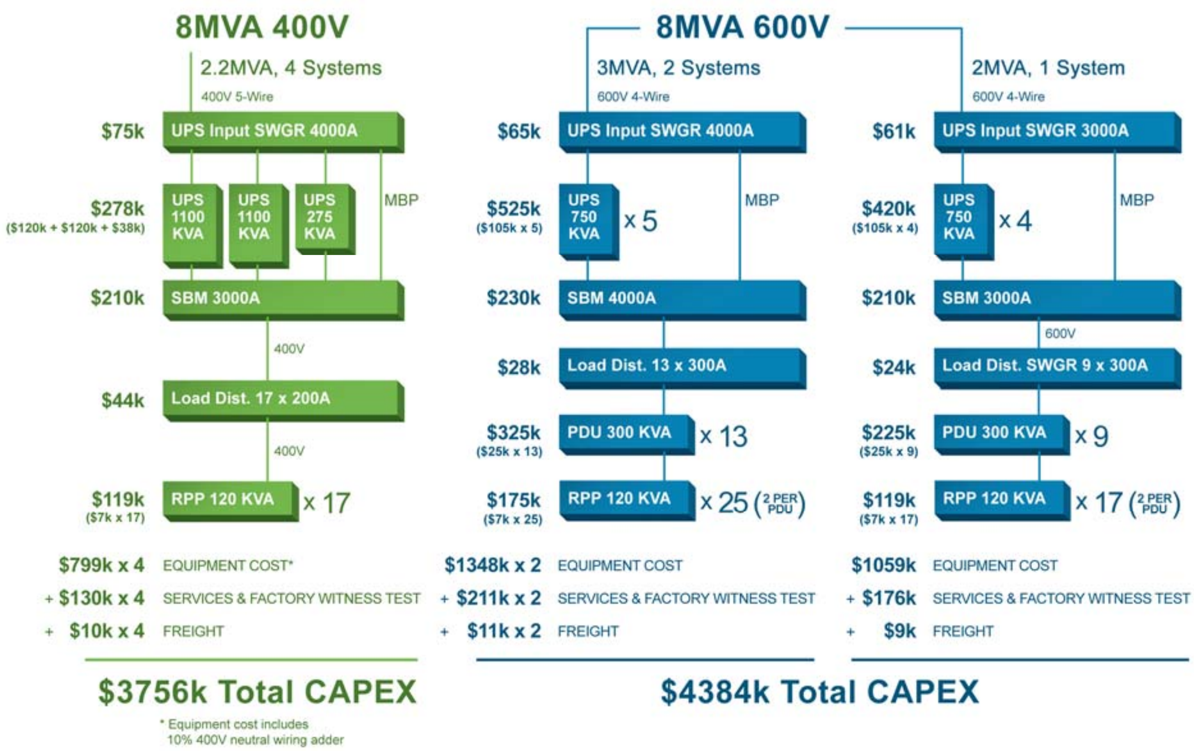
		400V AC	600V AC	SAVINGS 400v vs. 600V	
CAPEX		$2,101k	$2,838k	$737k	
15 Years: Double Conversion Mode	OPEX	$35,136k	$36,421k	$1,285k	
	TCO	$37,237k	$39,259k	$2,022k	5% SAVINGS
15 Years: Energy Saver System	OPEX	$30,361k	$36,421k	$6,059k	
	TCO	$32,462k	$39,259k	$6,796	17% SAVINGS

Appendix 4: 6 MVA cost and savings comparisons



		400V AC	600V AC	SAVINGS 400v vs. 600V	
CAPEX		$2,817	$3,140k	$323	
15 Years: Double Conversion Mode	OPEX	$42,163k	$43,705k	$1,541	
	TCO	$44,980	$46,845k	$1,864	4% SAVINGS
15 Years: Energy Saver System	OPEX	$36,434k	$43,705k	$7,271k	
	TCO	$39,251	$46,845k	$7,594	16% SAVINGS

Appendix 5: 8 MVA cost and savings comparisons

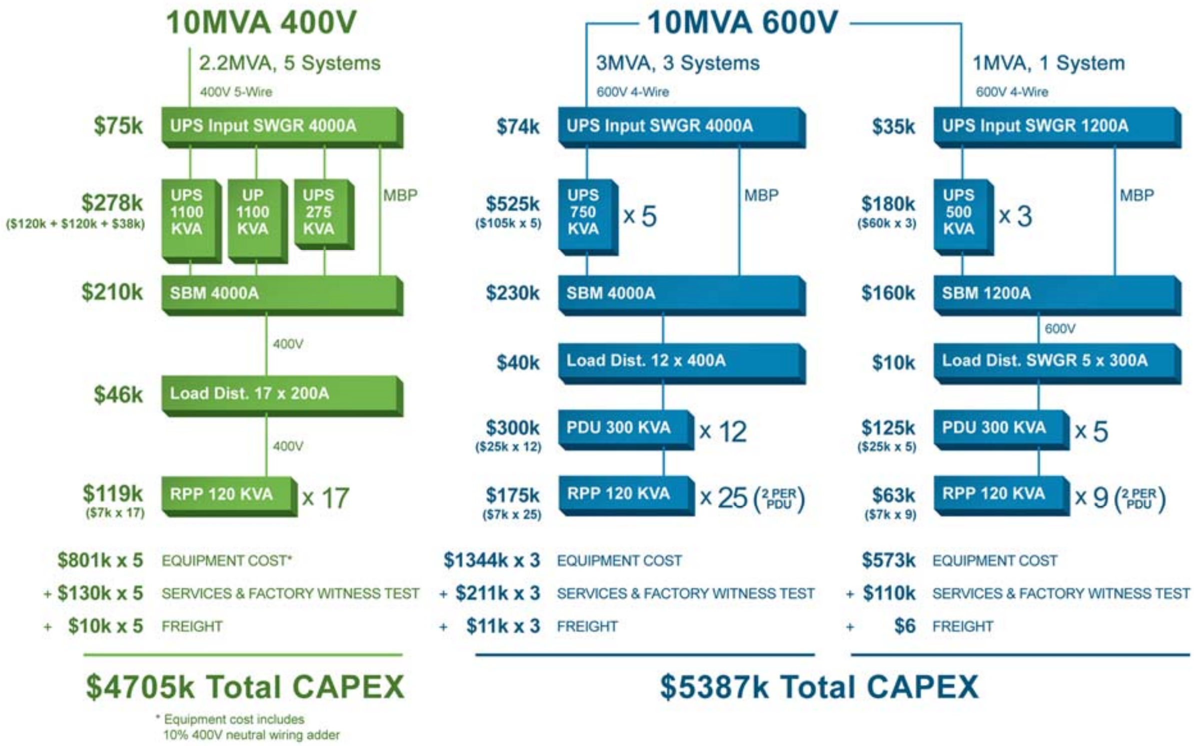


		400V AC	600V AC	SAVINGS 400v vs. 600V
CAPEX		$3,756	$4,384k	$628
15 Years: Double Conversion Mode	OPEX	$56,218k	$58,273k	$2,055k
	TCO	$59,974	$62,657k	$2,683
15 Years: Energy Saver System	OPEX	$48,578k	$58,273k	$9,695k
	TCO	$52,334	$62,657k	$10,323

4% SAVINGS (Double Conversion Mode TCO)

16% SAVINGS (Energy Saver System TCO)

Appendix 6: 10 MVA cost and savings comparisons



		400V AC	600V AC	SAVINGS 400v vs. 600V
CAPEX		$4,705	$5,387	$682
15 Years: Double Conversion Mode	OPEX	$70,272k	$72,841k	$2,569k
	TCO	$74,977	$78,228	$3,251
15 Years: Energy Saver System	OPEX	$60,723k	$72,841k	$12,119
	TCO	$65,428	$78,228	$12,801

4% SAVINGS (TCO, Double Conversion Mode)

16% SAVINGS (TCO, Energy Saver System)

Appendix 7: Detailed savings comparisons

		400V AC	600V AC	SAVINGS 400V vs. 600V	SAVINGS (%)
CAPITAL EXPENDITURES					
TOTAL CAPEX		$200,000	$205,000	$5,000	2%
OPERATIONAL EXPENDITURES AND TCO					
One Year: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$138,389	$147,556	$9,166	6%
	TCO	$338,389	$352,556	$14,166	4%
One Year: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$121,445	$147,556	$26,110	18%
	TCO	$321,445	$352,556	$31,110	9%
15 Years: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$2,075,840	$2,213,336	$137,496	6%
	TCO	$2,275,840	$2,418,336	$142,496	6%
15 Years: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$1,821,682	$2,213,336	$391,654	18%
	TCO	$2,021,682	$2,418,336	$396,654	16%
ADDITIONAL SERVICE COSTS					
STARTUP SERVICES		$6,000	$6,000	$0	0%
SERVICES OVER 15-YEAR LIFE		$182,007	$182,007	$0	0%

Table 1: 300 KVA N+1 400V AC vs. 600V AC savings comparison

		400V AC	600V AC	SAVINGS 400V vs. 600V	SAVINGS (%)
CAPITAL EXPENDITURES					
TOTAL CAPEX		$592,000	$689,000	$97,000	14%
OPERATIONAL EXPENDITURES AND TCO					
One Year: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$468,482	$485,609	$17,127	4%
	TCO	$1,060,482	$1,174,609	$114,127	10%
One Year: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$404,818	$485,609	$80,791	17%
	TCO	$996,818	$1,174,609	$177,791	15%
15 Years: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$7,027,227	$7,284,130	$256,903	4%
	TCO	$7,619,227	$7,973,130	$353,903	4%
15 Years: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$6,072,273	$7,284,130	$1,211,857	17%
	TCO	$6,664,273	$7,973,130	$1,308,857	16%
ADDITIONAL SERVICE COSTS					
STARTUP SERVICES		$93,000	$110,000	$17,000	15%
SERVICES OVER 15-YEAR LIFE		$256,347	$340,200	$84,000	25%

Table 2: 1 MVA 400V AC vs. 600V AC savings comparison

		400V AC	600V AC	SAVINGS 400V vs. 600V	SAVINGS (%)
CAPITAL EXPENDITURES					
TOTAL CAPEX		$935,000	$1,244,000	$309,000	25%
OPERATIONAL EXPENDITURES AND TCO					
One Year: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$936,964	$971,217	$34,254	4%
	TCO	$1,871,964	$2,215,217	$343,254	15%
One Year: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$809,636	$971,217	$161,581	17%
	TCO	$1,744,636	$2,215,217	$470,581	21%
15 Years: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$14,054,454	$14,568,261	$513,807	4%
	TCO	$14,989,454	$15,812,261	$822,807	5%
15 Years: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$12,144,545	$14,568,261	$2,423,715	17%
	TCO	$13,079,545	$15,812,261	$2,732,715	17%
ADDITIONAL SERVICE COSTS					
STARTUP SERVICES		$130,000	$176,000	$46,000	26%
SERVICES OVER 15-YEAR LIFE		$424,796	$517,400	$93,000	18%

Table 3: 2 MVA 400V AC vs. 600V AC savings comparison

		400V AC (2x 2.2MVA + 825kVA)	600V AC (3MVA + 2MVA)	SAVINGS 400V vs. 600V	SAVINGS (%)
CAPITAL EXPENDITURES					
TOTAL CAPEX		$2,101,000	$2,838,000	$737,000	26%
OPERATIONAL EXPENDITURES AND TCO					
One Year: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$2,342,409	$2,428,043	$85,634	4%
	TCO	$4,443,409	$5,266,043	$822,634	16%
One Year: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$2,024,091	$2,428,043	$403,953	17%
	TCO	$4,125,091	$5,266,043	$1,140,953	22%
15 Years: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$35,136,135	$36,420,652	$1,284,517	4%
	TCO	$37,237,135	$39,258,652	$2,021,517	5%
15 Years: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$30,361,364	$36,420,652	$6,059,289	17%
	TCO	$32,462,364	$39,258,652	$6,796,289	17%
ADDITIONAL SERVICE COSTS					
STARTUP SERVICES		$270,000	$387,000	$117,000	30%
SERVICES OVER 15-YEAR LIFE		$1,193,837	$1,247,000	$53,000	4%

Table 4: 5 MVA 400V AC vs. 600V AC savings comparison

		400V AC (3x 2.2MVA)	600V AC (2x 3MVA)	SAVINGS 400V vs. 600V	SAVINGS (%)
CAPITAL EXPENDITURES					
TOTAL CAPEX		$2,817,000	$3,140,000	$323,000	10%
OPERATIONAL EXPENDITURES AND TCO					
One Year: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$2,810,891	$2,913,652	$102,761	4%
	TCO	$5,627,891	$6,053,652	$425,761	7%
One Year: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$2,428,909	$2,913,652	$484,743	17%
	TCO	$5,245,909	$6,053,652	$807,743	13%
15 Years: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$42,163,362	$43,704,783	$1,541,421	4%
	TCO	$44,980,362	$46,844,783	$1,864,421	4%
15 Years: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$36,433,636	$43,704,783	$7,271,146	17%
	TCO	$39,250,636	$46,844,783	$7,594,146	16%
ADDITIONAL SERVICE COSTS					
STARTUP SERVICES		$390,000	$422,000	$32,000	8%
SERVICES OVER 15-YEAR LIFE		$1,365,000	$1,386,000	$21,000	2%

Table 5: 6 MVA 400V AC vs. 600V AC savings comparison

		400V AC (4x 2.2MVA)	600V AC (2x 3MVA + 2MVA)	SAVINGS 400V vs. 600V	SAVINGS (%)
CAPITAL EXPENDITURES					
TOTAL CAPEX		$3,756,000	$4,384,000	$628,000	14%
OPERATIONAL EXPENDITURES AND TCO					
One Year: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$3,747,854	$3,884,870	$137,015	4%
	TCO	$7,503,854	$8,268,870	$765,015	9%
One Year: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$3,238,545	$3,884,870	$646,324	17%
	TCO	$6,994,545	$8,268,870	$1,274,324	15%
15 Years: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$56,217,816	$58,273,043	$2,055,228	4%
	TCO	$59,973,816	$62,657,043	$2,683,228	4%
15 Years: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$48,578,182	$58,273,043	$9,694,862	17%
	TCO	$52,334,182	$62,657,043	$10,322,862	16%
ADDITIONAL SERVICE COSTS					
STARTUP SERVICES		$520,000	$598,000	$70,000	12%
SERVICES OVER 15-YEAR LIFE		$1,699,000	$1,811,000	$112,000	6%

Table 6: 8 MVA 400V AC vs. 600V AC savings comparison

		400V AC (5x 2.2MVA)	600V AC (3x 3MVA + 1MVA)	SAVINGS 400V vs. 600V	SAVINGS (%)
CAPITAL EXPENDITURES					
TOTAL CAPEX		$4,705,000	$5,387,000	$682,000	13%
OPERATIONAL EXPENDITURES AND TCO					
One Year: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$4,684,818	$4,856,087	$171,269	4%
	TCO	$9,389,818	$10,243,087	$853,269	8%
One Year: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$4,048,182	$4,856,087	$807,905	17%
	TCO	$8,753,182	$10,243,087	$1,489,905	15%
15 Years: 400V AC Double Conversion Mode vs. 600V AC Double Conversion Mode	OPEX	$70,272,270	$72,841,304	$2,569,035	4%
	TCO	$74,977,270	$78,228,304	$3,251,035	4%
15 Years: 400V AC Energy Saver System vs. 600V AC Double Conversion Mode	OPEX	$60,722,727	$72,841,304	$12,118,577	17%
	TCO	$65,427,727	$78,228,304	$12,800,577	16%
ADDITIONAL SERVICE COSTS					
STARTUP SERVICES		$650,000	$743,000	$93,000	13%
SERVICES OVER 15-YEAR LIFE		$2,124,000	$1,941,000	($183,000)	-9%

Table 7: 10 MVA 400V AC vs. 600V AC savings comparison

Appendix 8: First-year and 15-year CAPEX, OPEX and TCO comparisons

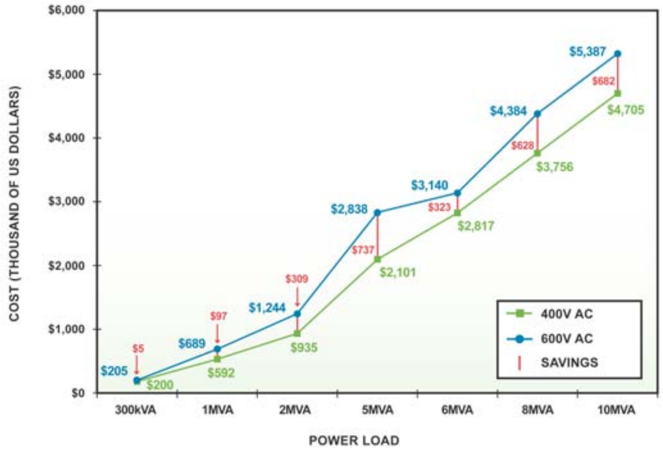


Chart 3: CAPEX (400V AC vs. 600V AC)

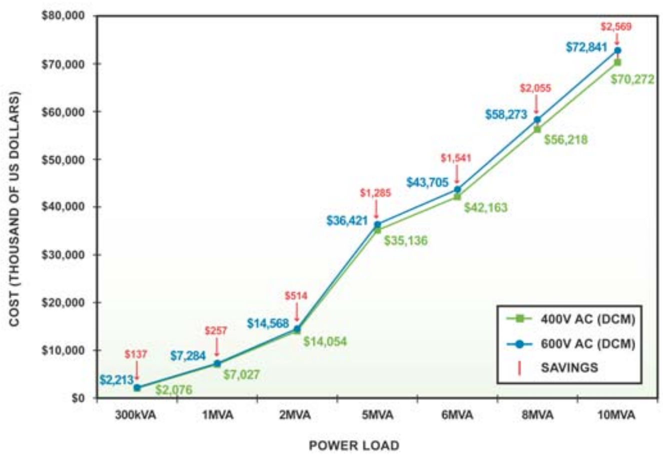


Chart 4: 15-year OPEX (400V AC vs. 600V AC, both in double conversion mode)

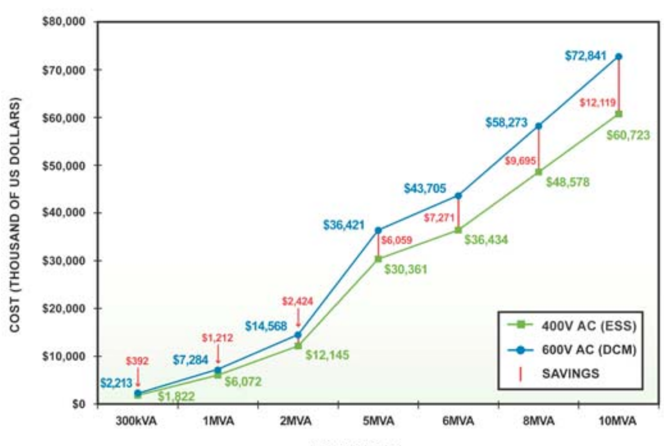


Chart 5: 15-year OPEX (400V AC Energy Saver System vs. 600V AC double conversion mode)

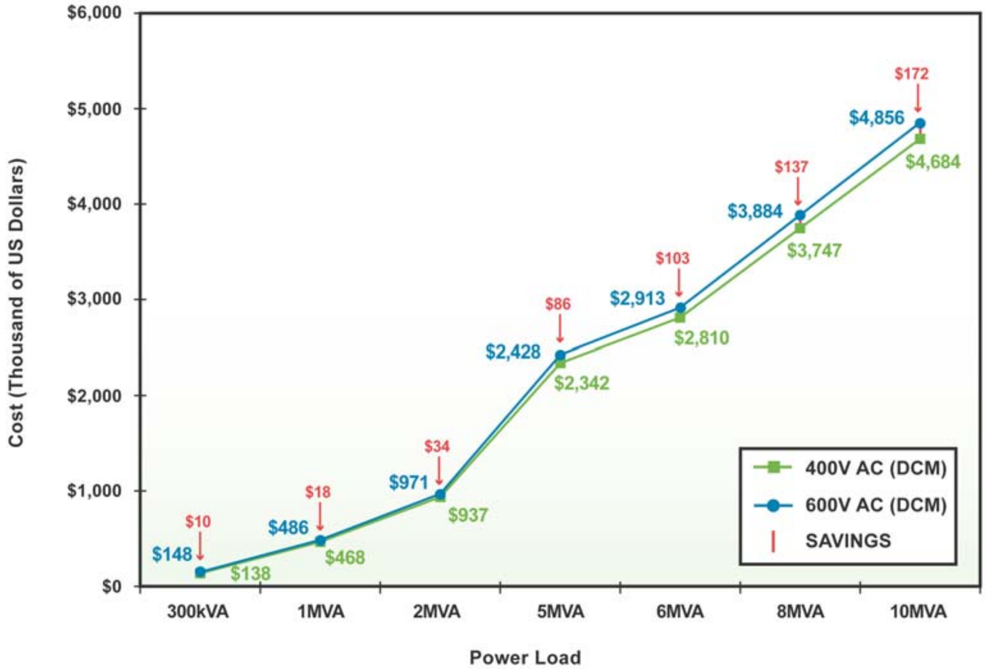


Chart 6: First-year OPEX (400V AC vs. 600V AC, both in double conversion mode)

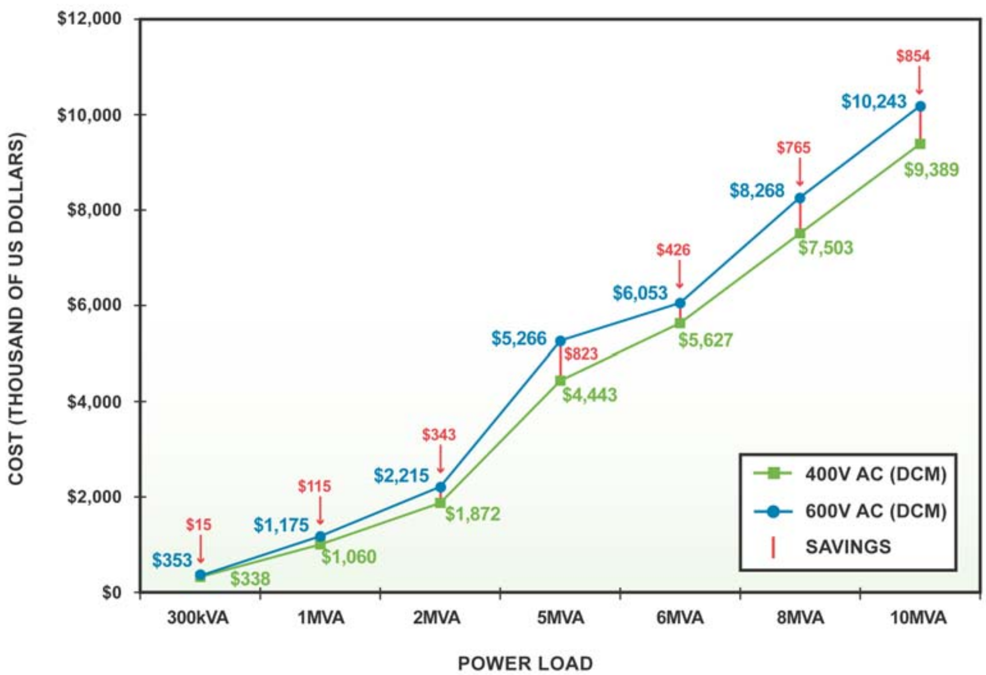


Chart 7: First-year TCO (400V AC vs. 600V AC, both in double conversion mode)

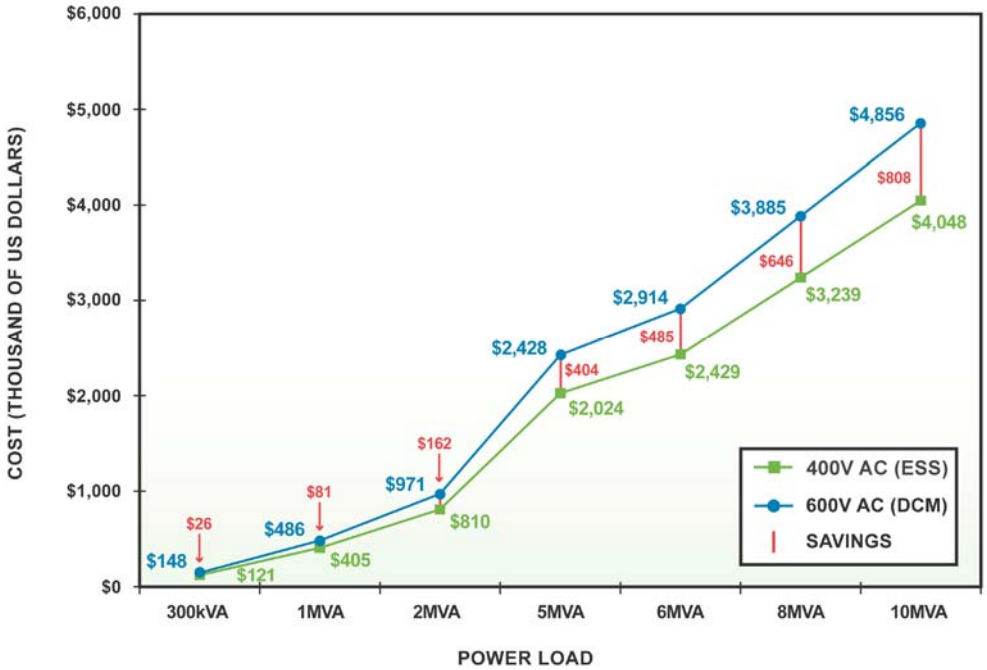


Chart 8: First-year OPEX (400V AC Energy Saver System vs. 600V AC double conversion mode)

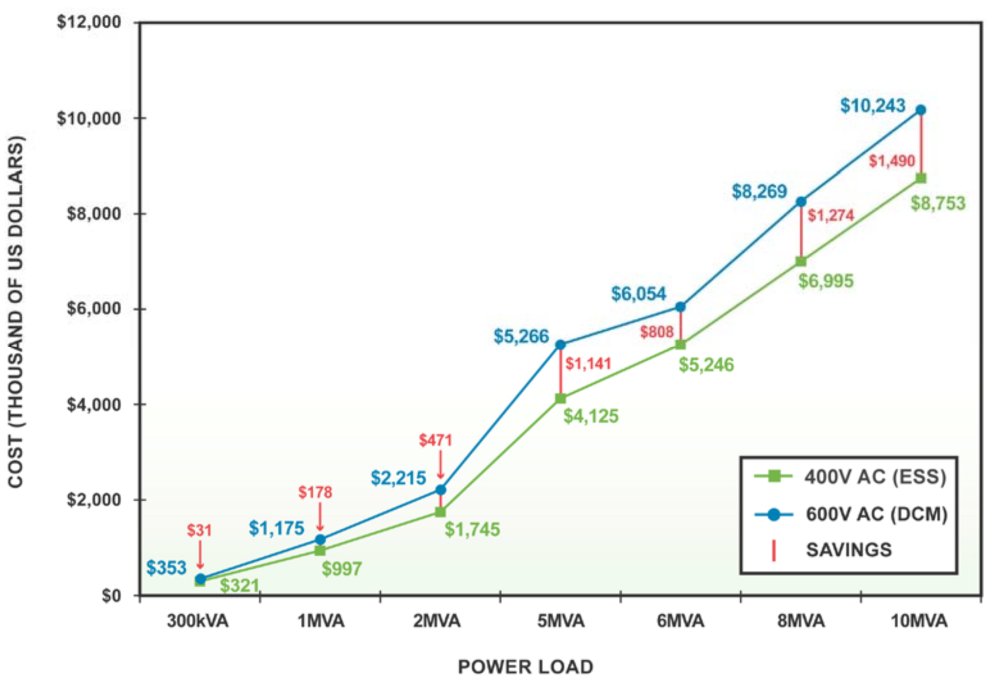


Chart 9: First-year TCO (400V AC Energy Saver System vs. 600V AC double conversion mode)