AC vs. DC Power Distribution for Data Centers

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White Paper #63

Revision 5

Executive Summary

DC power distribution has been proposed as an alternative to AC power distribution in data centers, but misinformation and conflicting claims have confused the discussion. A detailed analysis and model show that many of the benefits commonly stated for DC distribution are unfounded or exaggerated. This paper explains why high efficiency AC will likely emerge as the dominant choice for data center power distribution.

Related white paper with detailed analysis of the two "best" distribution methods
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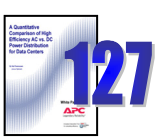

A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution for Data Centers

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Introduction

Power distribution to IT equipment in a data center or network room can be accomplished using AC or DC power. AC power is typically distributed at the local mains voltage of 120 V, 208 V, or 230 V. DC power is typically distributed at the telecommunications standard voltage of 48 V.

Most installations use AC distribution. However, from time to time beginning in the early 1990's various manufacturers and engineers have suggested that a change to DC distribution was advantageous, and predicted a widespread adoption of a DC standard for data center power. In fact, the opposite has occurred, and the usage of DC relative to AC has declined.

Recently, new conceptual proposals have been made based on DC distribution at voltages above 48 V DC, in order to overcome some of the earlier problems with DC power. DC distribution voltages of 300, 380, 400, and 575 V have been proposed in various forums.

In this paper, the characteristics, features, and limitations of AC and DC distribution are explained. In addition, a mathematical model of the efficiency of two different AC distribution systems and three different DC distribution systems is used to establish the expected electrical efficiency performance of the different distribution systems for different operating conditions.

Many data center and network room operators appreciate and respect the high availability demonstrated by telephone system central offices, which have historically exhibited much higher availability than network rooms and data centers. Naturally there is a desire to duplicate this level of availability in commercial networks. This has led to the assumption that practices such as the use of DC have contributed to telephone system availability and should be copied. This assumption is examined in this paper.

The Various AC and DC Distribution Options

When comparing AC and DC distribution, there is an assumption that we are comparing two alternative approaches. However, there are actually at least five power distribution designs that are commonly discussed during these comparisons, each with different efficiencies, costs, and limitations. Therefore it is essential to identify these and carefully assess each method independently. The five basic power distribution approaches are shown in **Figures 1a-1e**.

For each of the five basic types in the figures, the utility AC power enters from the left and the end point on the right represents the internal distribution voltage within the IT device. Note that different internal distribution voltages may be used within IT devices, but this does not preclude the use of any of the five basic power distribution approaches. For this paper we will assume an internal distribution voltage of 12 V DC.

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Figure 1a-1e: *Alternative data power distribution methods illustrating two AC types and three DC types*

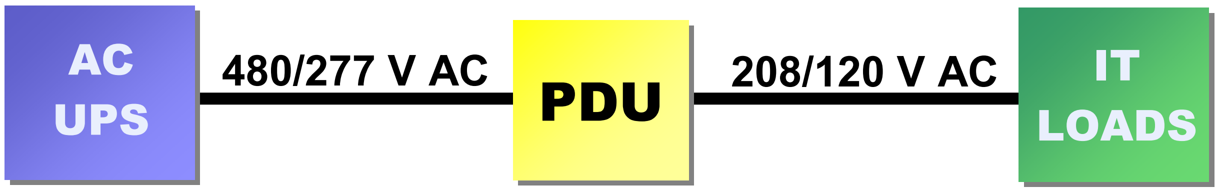

Figure 1a *– Common AC distribution in North America*

Figure 1a represents the common AC distribution system in North America. The power goes through a UPS and a transformer-based power distribution unit (PDU) before entering the IT device power supply. There are five principal losses generated in this system: the UPS losses, the primary distribution wiring, the PDU losses, the branch circuit distribution wiring, and the IT power supply.

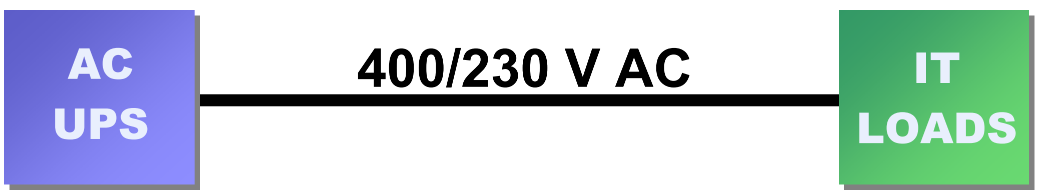

Figure 1b *– Common AC distribution outside North America*

Figure 1b represents the common AC distribution system used outside of North America. Note in this case the PDU transformer and the associated losses are eliminated. This is because the output voltage of the UPS is directly compatible input voltage range of nearly all IT Loads.

Figure 1c *– Typical telecom DC distribution*

Figure 1c represents typical telecom DC power distribution. A DC UPS provides 48 V DC for distribution to the DC powered IT loads.

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Figure 1d – *Hypothetical approach for distributing 380 V DC*

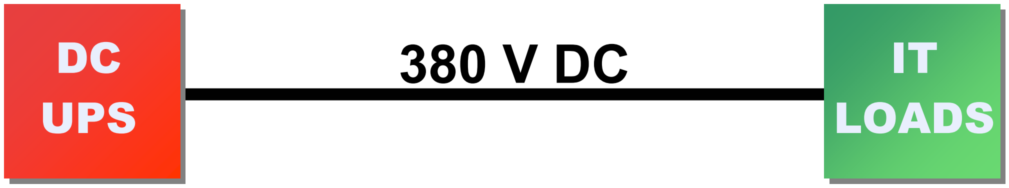

Figure 1d represents a hypothetical approach distributing 380 V DC. IT devices designed to operate from 380 V DC would need to exist in order for this approach to work.

Figure 1e – *Hypothetical hybrid 575 V DC system*

Figure 1e represents a hypothetical hybrid 575 V DC system. This system utilizes IT devices designed to operate from 48 V DC, but uses a 575 V DC UPS and an intermediate 575 V DC to 48 V DC step-down converter. It combines some of the attributes of **Figure 1c** and **Figure 1d**.

A comparison of the five distribution systems of **Figure 1** must include the following considerations:

- Efficiency
- Cost
- Compatibility
- Reliability
- Safety

These factors are each discussed in the following sections. The discussion begins with a detailed analysis of efficiency, since this is commonly stated as the key reason why DC distribution should be considered.

Efficiency Comparison

A principal argument put forth for the use of DC power in data centers is that it improves electrical efficiency. This is based on the logic that some steps of power conversion are eliminated, resulting in reduced losses. The losses in a power system occur in the following places: generation of uninterruptible power, distribution

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of power, and utilization of power by IT equipment. Typical discussions in the literature comparing AC to DC distribution efficiencies make various assumptions that this paper will demonstrate are flawed, and have caused many false conclusions to be published regarding the merits of the different distribution systems. Accurate assessment of electrical efficiency in real-world situations requires a mathematical model that (1) takes into account the variation of device efficiencies with load and (2) properly comprehends sizing issues. Such a model is described in the next section, along with the quantitative efficiency results.

In this paper, we compare the efficiencies of the five different distribution systems at 50% load. From this comparison, two approaches clearly emerge as the efficiency leaders: one DC system and one AC system. To compare these two leading high-efficiency approaches with additional precision, a detailed analysis backed up with extensive data is provided in a companion paper, APC White Paper #127, "A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution for Data Centers".

Efficiency model for power distribution systems

APC has developed a robust efficiency model for data centers, as described in detail in APC Paper #113, "Energy Efficiency Modeling for Data Centers". A complete derivation of the model and its principles of operation will not be repeated here. Key attributes of the model include:

- Effectively models the efficiency variations of devices with load
- Effectively models the fractional loading across device types
- Effectively models redundancy configurations
- Provides efficiency data for any system load

Analysis demonstrates that all of the above characteristics are critical to achieve meaningful efficiency comparisons.

Using this APC modeling methodology, mathematical models were developed for the five different power distribution methods described in the previous section. For each type of device modeled, actual data from best-in-class examples was used to construct the model. For the devices that are hypothetical, estimates were made of realistically achievable performance.

It is important to reiterate that best-in-class device data was used in the model. There is considerable variation in performance among real devices such as UPS and IT power supplies. One of the findings of this analysis is that some crude published models compare AC designs using inefficient equipment to hypothetical DC designs using theoretically achievable high-efficiency equipment. The results in these cases are significantly skewed. This analysis attempts to correct this defect.

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Efficiency model results

For each distribution system, the losses at 50% load for each segment of the power path are estimated from the best available data. The resulting data for the non-redundant scenarios are compiled in **Table 1**.

Table 1 *– Overall power distribution efficiency calculation at 50% load comparing the five AC and DC distribution methods*

	UPS		Distribution Wiring + PDU Wiring + step-down converter		IT Power Supply		Overall Efficiency
480 to 208 V AC	96.20 %[1]	X	96.52 %[1]	X	90.00 %[1]	=	83.56 %
400/230 V AC	96.20 %[1]	X	99.50 %[1]	X	90.25 %[1]	=	86.39 %
48 V DC	92.86 %[2]	X	99.50 %[1]	X	91.54 %[2]	=	84.58 %
380 V DC	96.00 %[1]	X	99.50 %[1]	X	91.75 %[1]	=	87.64 %
Hybrid 575 V DC	95.32 %[2]	X	92.54 %[1]	X	91.54 %[2]	=	80.74 %

[1] APC White Paper #127, "A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution for Data Centers"

[2] *Evaluation of 400 V DC Distribution in Telco and Data Centers to Improve Energy Efficiency*. A. Pratt, P. Kumar, and T. Aldridge, Corporate Technology Group, Intel Corporation.

The data shows significant variation among the different distribution approaches. The 380 V DC system provides the highest efficiency of the systems modeled, and the hybrid 575 V DC system provides the lowest efficiency. The most interesting data is that of the 400/230 V AC system, which has almost the same efficiency as the 380 V DC system.

The efficiencies of the various methods can also be calculated for a redundant dual path power system, in which case, all efficiencies will be lower. However, the *relative* performance of the each method is unchanged, with 400/230 V AC and 380 V DC distribution providing superior efficiency.

Interpretation of the efficiency results

The findings generally support the common hypothesis that eliminating power conversion stages increases electrical efficiency. The two superior approaches, 380 V DC and 400/230 V AC, both eliminate an intermediate conversion stage that some of the alternative approaches use, as illustrated in **Figure 1** earlier. These two approaches also operate the maximum fraction of the power path at the highest voltage.

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A detailed study of the model reveals that wiring conduction losses are insignificant in real data centers. This is because on average, due to load diversity, the actual wiring circuits are loaded well below their rated capacity, even when the data center is operated at full rated load. This does not suggest that wires could be reduced in size, because wire sizing must still be designed for worst-case operation due to safety reasons.

The data shows that of the five systems examined, two clearly emerge as the efficiency leaders and are the best candidates for next-generation data centers. **If efficiency is a key objective, the other three distribution approaches should be eliminated from consideration.** 380 V DC gives very high efficiency but requires massive changes to the industry over a long period of time. 400/230 V AC also provides very high efficiency and is already a standard in most of the world, and could be implemented in North America. Therefore, these two leading candidates should be compared in much more detail to gain a clear quantitative understanding of their efficiency differences and theoretical and practical possibilities. This detailed analysis is undertaken in a companion paper, APC White Paper #127,"A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution for Data Centers".

Reconciliation of the efficiency results with other published claims

The findings in this paper are clearly in conflict with many published articles, many of which suggest higher efficiency gains for DC power systems. A variety of published work on this subject was examined and compared with the findings of this paper. It was found, in general, that other published work in this area uses crude models and assumptions that give rise to the discrepant conclusions. The primary reasons why other studies obtain different results from this study are articulated below.

Other DC vs. AC studies utilize historic values for AC device efficiencies that are not representative of what is currently available, yet these are compared with hypothetical best-case DC products. For example, a recent article assumes an AC UPS efficiency value of 74-96% and a hypothetical DC UPS efficiency value of 97%. In contradiction to this assumption, at least three different product lines manufactured by APC-MGE have independently certified efficiencies of over 96% sustained over a range of 56-100% load. This understatement of the efficiency of new UPS systems is a massive error which completely accounts for the discrepancy in the results obtained by papers making this assumption.

Other DC vs. AC studies assume that if a 48 V DC distribution bus is available, the IT devices can utilize this directly and eliminate various power conversion stages in their power supplies. This is flawed logically for the following two reasons:

1. All IT equipment using a DC input is designed to provide complete electrical isolation between the load and the DC UPS; which is accomplished using isolated power converters in the same way as is done in an AC power supply. This isolating power supply is required in order to ensure that the high power DC supply is not electrically connected to the IT equipment chassis. **Without this isolation stage, DC currents would circulate between rack cabinets and wiring shields, creating a safety hazard.** For example, the manufacturer of a

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converter included in a recently published design states the following application guidelines[1]: "The DC-DC power module should be installed in end-use equipment in compliance with the requirements of the application and is intended to be supplied by an isolated secondary circuit." While some converters do provide limited isolation, this limited isolation does not meet the safety requirements associated with high power distribution.

2. The majority of servers utilize an internal 12 V DC distribution bus. Clearly a converter is required to produce 12 V DC from any of the distribution voltages considered in this study.

Measuring the power draw of the same piece of IT equipment configured for AC and then for DC, such as a router or server, demonstrates this fact.

The comparisons done in most other studies do not include the 400/230 V AC power distribution option. This paper clearly demonstrates that if high efficiency is a goal, then the 400/230 V AC configuration is superior to conventional methods and nearly as good as the highest efficiency 380 V DC system.

Examination of a specific energy savings analysis

While most papers claiming efficiency benefits for DC systems do not present a detailed model with underlying calculations and numbers, the Lawrence Berkeley National Laboratory does publish a model for AC vs. DC distribution which is available at the LBL.gov web site. In the reference model published 4/10/2004, a 48 V DC system is compared with an AC system and a benefit of $86 per year of electrical savings per server (approximately a 30% reduction in power consumption) is computed for the DC system.

In the model, however, an efficiency of 85% was assumed for the UPS system, and 72% efficiency was assumed for the server AC/DC power supply. **This is much lower efficiency than is readily obtainable today for these devices**. For example, when 96% efficiency is used for the UPS and 90% efficiency is used for the power supply, the benefit of the DC option computed by this published model is zero. As stated earlier, the documented efficiency of a modern UPS such as the APC Symmetra MW is over 96% for most of its operating range. While 90% for a power supply does represent current best-in-class performance, it is common for new servers and we expect 94% efficient power supplies to be shipping within a year. **This published model, commonly cited in claims of the superiority of DC, shows no benefit for DC when current realistic values for AC performance are used as input to the model.**

The 400/230 V AC distribution option

The efficiency findings in this paper clearly show the efficiency advantage of 400/230 V AC distribution, yet this method is not commonly described in the literature. Note that this method is not novel or new because it is the standard data center design architecture outside of North America.

The analysis of this paper shows that the PDU used in the standard North American data center is clearly a significant source of inefficiency, as well as a consumer of floor space and an additional floor load. In the

[1] http://www.digchip.com/datasheets/parts/datasheet/154/PKJB1.php (accessed April 20, 2006).

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case of a redundant dual path system the problem is further compounded by 2X. PDUs typically do not operate at their rated power and end up operating at reduced efficiency. Furthermore, they are typically oversized compared to the rated system load. Therefore in North America, a system that can eliminate PDU transformers has a significant advantage. **It is important to understand that, in a modern data center, PDU transformers are not necessary and can be eliminated.** The data clearly shows that any attempt to create a high efficiency data center should use 400/230 V AC distribution if possible. For a complete discussion on how PDU transformers and their associated weight and losses can be eliminated in North America, see APC White Paper #128, "Increasing Data Center Efficiency by Using Improved High Density Power Distribution".

The 380 V DC distribution option

The efficiency findings in this paper clearly show that 380 V DC distribution provides the highest efficiency DC option, particularly when compared with the 48 V DC system or the hybrid 575 V DC system. The efficiency performance is the key reason why this approach has been proposed. It is realistic to assume that for a fully loaded system a 380 V DC approach may offer approximately a 1% advantage over the best AC system. For most installations, this is a minor gain in efficiency when compared with other avoidable losses such as those associated with air conditioning; however for very large data centers this can represent a sizable electrical savings.

In addition, the 380 V DC distribution approach may save copper in comparison with any other system. Depending on the precise voltage specified, 10% of the copper costs could be avoided. In a 400/230 V AC system, using 50-amp wiring, four-wire distribution delivers 150A or 34.5kW, corresponding to 8.625 kW per wire. In a 380 V DC system using a 380 V bus and 50-amp wiring, two-wire distribution delivers 50 A or 19 kW, corresponding to 9.5 kW per wire. This calculation can be extended to any wire size, giving approximately a 10% reduction in copper for 380 V DC.

380 V DC does offer a small but significant efficiency advantage when compared to 400/230 V AC distribution. However, since virtually all IT equipment is compatible with 400/230 V AC distribution and no available IT equipment is compatible with 380 V DC distribution, there are significant barriers to moving to a 380 V DC system. Moreover, there are serious issues relating to compatibility and safety of 380 V DC.

A critical mass of 380 V DC equipment would need to exist before any user could create a 380 V DC data center. The only realistic way to facilitate this conversion would be for IT vendors to offer equipment that accepts either AC or 380 V DC. However, this change is so revolutionary that it would need to be driven by a compelling economic advantage – an advantage which this paper suggests is relatively small for most users.

Another potential advantage of 380 V DC is the reduction of heat and an increase in available space in the rack. The removal of the AC/DC conversion stage in the power supply, which is the main contributor to the improved efficiency, gives rise to a corresponding reduction in heat generation in the rack of approximately 1.5%. Furthermore, if power supplies were specifically designed without this AC/DC circuit, the size of the

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power supplies could be reduced by approximately 20%, which could free up approximately 3% of the space in a rack. While these reductions are not major, they nevertheless would enable increased computing density.

The most appropriate application of 380 V DC distribution is for very large data centers with a very uniform compliment of IT equipment, where it is potentially practical to obtain specialized IT equipment with 380 V DC inputs. One example of such a data center would be a massive supercomputer installation.

The potential for off-the-shelf computer equipment that can accept either 380 V DC or AC is a realistic possibility. This would entail providing specialized connectors for 380 V DC input that would bypass the internal AC/DC front end stage of the power supply and turn off any unused circuits. In this approach, the size of the power supplies is not reduced. This multi-input architecture is most likely to occur on high end servers and is unlikely to be provided on general purpose IT equipment.

Cost

The cost of a DC UPS system is typically lower than an AC UPS system by 10% to 20%. However, the additional engineering, specialized breakers, and wiring distribution costs associated with DC offset this savings. The DC advantage is greatest in small low-density installations with minimal distribution costs, such as cell tower base stations. In data centers, the need to power some AC-only equipment increases cost of a DC system. The cost premium for DC powered equipment such as servers or storage is also a disadvantage in a DC system. However, the biggest cost problem for a 48 V DC plant is the distribution wiring to the IT equipment. It requires 10X or more weight and cost of copper wiring. Installing and terminating this bulky copper to IT equipment cabinets is extremely expensive and impractical at power levels of greater than 20 kW per cabinet. For 380 V DC distribution, the copper use drops dramatically and is slightly lower than the best AC alternatives.

Overall, there is a slight equipment cost advantage for AC over 48 V DC for data center or network room power. Due to the low volumes associated with 380 V DC equipment there is currently no cost advantage over AC; however if 380 V DC were to become a standard then it has the potential to achieve cost parity when compared with AC.

Compatibility

Circuit-switched telecommunications equipment, such as voice switches for copper loops, has historically been designed for 48 V DC input. Packet-switched telecommunications equipment, such as servers, storage, routers, etc. are almost all designed for AC input. The primary use of a facility will therefore dictate whether AC or DC will provide higher compatibility. The overwhelming use of packet-based equipment in network rooms and data centers suggests that compatibility will be much higher with an AC system.

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Obtaining DC versions of many products, such as monitors, NAS storage appliances, or PCs is virtually impossible. If inverters are used to power these devices, efficiency will suffer.

The use of DC for data center or network room power seriously limits the types of IT equipment that can be used. In most cases operation is not practical without adding a supplementary AC power system. If the potential application is for a standardized harmonized set of IT equipment such as a supercomputer installation, the compatibility problem is reduced.

Furthermore, in a high density installation, ASHRAE and various other organizations have demonstrated the need for uninterruptible operations of air conditioner fans. This means that during a power failure the air conditioner fans cannot wait for a generator to start and must be supplied with uninterrupted power. For an AC system, this is a simple wiring option. However, for a DC system this means that air conditioner fans compatible with external DC power must be used. Such devices are currently not available and are expected to be costly.

Reliability

Reliability comparisons between AC and DC power systems are highly dependent on the assumptions made. A DC power system is constructed of an array of DC rectifiers supplying one or more parallel battery strings. A number of recent UPS product introductions utilize a similar architecture, with an array of UPS modules connected to a parallel array of battery strings. Due to their similarity, DC and AC systems using these designs can be directly compared. The result of such a comparison clearly indicates that the system reliability is controlled by the battery system. A detailed comparison of various battery system arrangements is presented in APC White Paper #30, "Battery Technology for Data Centers and Network Rooms: Battery Options". For a given life-cycle cost, it is possible to create a battery system for an AC UPS that exhibits the same reliability as a battery system for a DC UPS.

For an equivalent life-cycle cost, there is no clear reliability advantage of AC or DC for data center or network room power.

Harmonics

Many published papers suggest that a key benefit of moving to DC in the data center is the elimination of the "harmonic problem." Early IT equipment generated current harmonics which created various serious problems in data centers, including overheated neutral circuits and overheated transformers. **However, it must be pointed out that international regulations have prohibited the manufacture of IT equipment that generates harmonics since approximately 1993.** The history and details of harmonic problems in data centers are addressed in APC White Paper #26, "Hazards of Harmonics and Neutral Overloads". Only data centers with IT equipment manufactured before 1993 have any significant harmonic currents.

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Obviously, any new data centers would not have IT equipment of this era installed, so claims that DC distribution solves harmonic problems are based on a seriously flawed and outdated understanding of data center power systems. Both the motivation and credentials of authors of such claims should be carefully considered.

Safety

There is a significant body of regulations regarding AC power distribution worldwide, with significant standardization. International regulations exist, and there are regulations at the country level, at the level of zones or states within countries, and even regulations unique to individual cities. These regulations have been developed based on learning from approximately 100 years of commercial and residential AC electrical distribution.

By contrast, there are very few regulations developed around commercial DC distribution. This represents and opportunity to create global standards, but also represents huge potential roadblocks to short-to-intermediate-term deployment of DC. For example, the 380 V DC distribution architecture described in this paper would not be legal in Japan, since the current regulatory limit is 300 V. The installation of DC, other than 48 V DC, in a data center today would challenge engineering firms, local contractors, service people, and local building inspectors. For example, there are no arc-flash regulations for commercial DC in North America, which would lead to widely varying interpretations of clearances, access requirements, etc.

Summary Comparison: DC vs. AC

The above discussion suggests that for most users a move from AC to DC for data centers is not justified when efficiency, cost, compatibility, reliability and safety are considered together. Of all the alternatives considered, 380 V DC offers the best theoretical efficiency, but with significant compatibility issues. 400/230 V AC offers slightly lower efficiency but is universally compatible. For this reason 400/230 V AC is a very practical approach to obtaining high efficiency.

We also find that the conventional 480 V AC distribution system used in North America is a poor choice when efficiency is the goal, and immediate efficiency gains are possible if data centers are designed for 400/230 V AC.

Telephone Central Office Reliability

Telephone central office reliability is generally accepted to be one to two orders of magnitude superior to that achieved by the typical commercial data center. However, this paper suggests that the use of DC in the

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central office is not a key factor in this performance. The demonstrated reliability performance of the central office requires an alternative explanation.

In fact, there is no scientific literature showing a theoretical or basic reliability advantage of DC over AC.

The data regarding downtime for network rooms and data centers shows that the fundamental difference between network rooms and the telephone central office is the stability of the environment. Most data center downtime is caused by human error. The average life of equipment in a data center is only two to three years, and configuration changes happen on a continuous basis. The unforeseen consequences of constant changes to the system, along with mistakes made while making changes, give rise to the vast majority of downtime.

In the telephone central office the limited number of people with access to affect the system, the structured and standardized nature of the system, and the maturity of the operating procedures are all key reliability advantages.

Of the factors related to the actual installation and design, the absence of a raised floor, the low power density, and the common use of convection cooling are fundamental reliability advantages of the telephone central office.

Key imperatives for improvements in data center and network room availability are access control systems, standardization of infrastructure, and monitoring and management systems. The use of AC or DC has minimal bearing on these issues.

Mixed-Use Facilities

Many data centers or network rooms have a small load or group of loads that require 48 V DC. For internet hosting sites with a significant amount of telecommunications equipment, the 48 V DC requirement may be as much as 10% of the AC requirement. This leads to the question of how best to power these loads.

The recommended approach is to use small point-of-use DC battery-less rectifiers operating from the AC power system.[2] In this approach, small rack-mount rectifiers can be installed wherever a load requires DC. The need to maintain one or more DC battery plants is eliminated, along with the need to add or move DC wiring on a live system. In fact, no DC distribution planning is needed at all.

[2] For more background on this approach, see “AC, DC or Hybrid Power Solutions For Today’s Telecommunications Facilities” by Gruz + Hall, Intelec 2000 conference proceedings.

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Use of DC within Racks

The discussion in this paper is focused on the distribution of DC power in data centers as an alternative to AC. Another related topic is the use of DC distribution within racks. In this model, AC power is delivered to the rack, but is converted to DC prior to the distribution of power within the rack. The AC/DC power supply is therefore centralized within the rack. This allows the various IT devices within the rack to be smaller and generate slightly less heat. It also allows the centralized in-rack power supply to be optimized for efficiency in ways that might be prohibitive at the IT device level. The power distribution runs within a rack are very short and well-defined, so that the copper penalty is small if 48 V DC is used. This approach has been used in some IT equipment designs such as first generation HP p-Class blade servers (but is not used in second generation HP c-Class blade servers). However, this approach places some undesirable constraints on the deployment options when compared with traditional AC power distribution within the rack, which has prevented its wider adoption.

The long term trends regarding the use of DC within racks remain uncertain. However, in-rack power distribution using DC is a distinct technical approach from powering entire data centers using DC power, with distinct advantages and disadvantages. This paper does not attempt to answer the question of the suitability of DC distribution within racks.

Conclusion

AC is displacing DC and will remain the dominant method for powering network rooms and data centers due to its compatibility. The advantages of using DC vs. AC are small, and some types of DC distribution actually have significant efficiency disadvantages. The DC approach with the best performance is the 380 V DC distribution architecture. However, this approach requires a new generation of IT and power equipment that does not yet exist, and therefore cannot be used today. For customers seeking gains in efficiency today there are much more promising approaches that should be considered first.

To improve data center costs and efficiency, it is clear in the literature that right-sizing the system, use of improved cooling distribution architectures, and economizer air conditioning units all offer huge efficiency improvement opportunities. To improve availability, it is clear from the literature that change control processes are the major opportunity for improvement for virtually all data centers.

Some published articles suggesting significant efficiency advantages for DC were found to be flawed and based on crude models, obsolete product efficiency data, and/or mistaken assumptions.

In North America, the AC power systems in data centers routinely use transformer-based power distribution units that add significant losses, space consumption, and weight. Any systematic effort to improve the power distribution system efficiency should start with eliminating these devices, as described in this paper.

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An important finding of this paper is that the 480 V AC power system used in North America should be viewed as inefficient and obsolete for all new designs.

The most efficient power distribution architectures are the 380 V DC architecture and the 400/230 V AC architecture. Because their efficiencies are so close to one another, a highly detailed and fact-based quantitative comparison is necessary, which is presented in a companion paper, APC White Paper #127, "A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution Alternatives for Data Center". The findings of that research are consistent with the findings in this paper.

New data centers should use 400/230 V AC power systems, combined with high efficiency UPS and server power supplies. This is already the default approach outside of North America so no change is required there. In North America this requires new thinking and new designs. Some vendors have already introduced equipment to support 400/230 V AC power distribution in North America.

Network rooms and data centers will continue to be a heterogeneous mix of equipment. For many devices, AC powering is the only realistic option.

This paper does not address the issue of DC distribution within rack enclosures, using a central rack AC/DC supply instead of separate AC power supplies for IT devices. There are clear trends such as blade servers that suggest that AC/DC supplies powering multiple CPUs within a rack is an approach that will exist in future data centers. The conclusions of this paper are not affected by the trend toward more centralized power supplies and/or DC distribution ***within*** the rack.

DC power remains the system of choice for circuit-based networks, such as legacy-style wired voice telephone networks. The flexibility and compatibility of AC power, combined with fact that there are AC distribution options that offer very high efficiency, suggests that it will continue to be the standard for power distribution for network rooms and data centers.

About the Author:

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Prior to founding APC in 1981, Neil received his Bachelors and Masters degrees from MIT in electrical engineering where he did his thesis on the analysis of a 200MW power supply for a tokamak fusion reactor. From 1979 to 1981, he worked at MIT Lincoln Laboratories on flywheel energy storage systems and solar electric power systems.

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