THE GREEN GRID PEER REVIEW OF "DC POWER FOR IMPROVED DATA CENTER EFFICIENCY" BY LAWRENCE BERKELEY NATIONAL LABORATORY

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ABSTRACT

As the demands on data centers increase, creating higher costs and power usage, the industry is looking for ways to increase efficiency and decrease operating costs in the data center. One potential area of increased efficiency lies in the power distribution configuration within the data center and its IT equipment. In early 2007, Lawrence Berkeley National Laboratory (LBNL) posted results of a direct current (DC) demonstration project, which operated from June to August of 2006. Here, a peer review of that study is provided, including a critical review of the results as well as a discussion of next steps in the evaluation of this and other power distribution topologies.

Overall, the LBNL study was successful in demonstrating the potential for energy savings using a 380Vdc system when compared with current North American AC practice. The Green Grid would like to clarify that the 5-7% energy savings gain posted by LBNL should be the relevant discussion, not the 28% compared to typical, as other AC and DC distribution configurations can also be more efficient than current North American AC practice. The Green Grid concurs that additional work must precede wide scale deployment of 380Vdc.

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INTRODUCTION

Data center costs continue to escalate as the demand for higher computational power increases. Fortunately the rate of IT performance is far outstripping the rise in energy costs, but the cost is at a significant level and is getting well deserved attention. The cost increases are both in the capital equipment in the data center and the operational costs related to the energy consumption. Reducing the costs in both of these categories is a worthwhile endeavor. The Green Grid supports any efforts to address these needs and advance the practice of lower cost and more efficient data centers. In early 2007, Lawrence Berkeley National Laboratory (LBNL), with many other companies (including Green Grid members), posted results[1] of a 380V direct current (DC)[*] demonstration project which operated from June to August 2006. This paper provides a peer review of that study, as well as discussing next steps in the evaluation of this and other AC and DC power distribution topologies. For the purpose of this paper, the unit “Vdc” stands for volts of direct current and “Vac” stands for volts of alternating current.

BACKGROUND

Data center costs are a significant portion of any IT budget, with operational and capital costs continuing to grow. Over the life of a server, the sum of the electrical costs to power and cool the server may exceed the purchase cost of the server[2]. Capital equipment and construction costs for data centers can range from $6,000 per delivered kW to over $25,000 per kW[3]. The electrical portion of new projects typically ranges from 33% to 40% of all construction and infrastructure fit out. Anything that can be done to reduce the capital cost is worth exploring. For the purposes of this paper, the AC system used for comparison is the typical North American system of 480Vac enters the UPS and the servers are powered at 208Vac (hereinafter, 480-208Vac). The DC system used for comparison will be 480Vac entering the UPS with the servers powered at 380Vdc (hereinafter, 380Vdc).

With the level of interest in reducing energy consumption and costs, the work done by LBNL and their demonstration team received significant attention. Unfortunately several portions of the study have been taken out of context by some in the industry, overstating the benefits of 380Vdc power. Specifically, LBNL discusses a 28% energy consumption improvement with 380Vdc power over “typical” AC power distribution. The authors are the first to point out that such a “typical” system does not represent state of the art technology, however many consumers still ignore efficiency and buy equipment based solely on initial cost.

While the 380Vdc technology has merit and the highest theoretical efficiency[4,5], the LBNL study also shows that an optimized deployment of today’s pervasive 480-208Vac topology would yield a 23% savings over the “typical” alternating current (AC) system. From this, it can be inferred that a 5% decrease in energy consumption would be expected of a 380Vdc distribution system over a modern 480-208Vac topology. This was confirmed by the data taken as part of this study, which measured a decrease of about 5-7% between their 480-208Vac and 380Vdc configurations.

It is also likely that other configurations (not tested by this study) can achieve an additional efficiency benefit over an optimized 480-208Vac system. For example, a system similar to a European set up of 400V-230Vac eliminates a conversion step and could be shown to have a higher overall efficiency than an optimized 480V-208Vac system.

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* There is often confusion in data center related publications about power whether DC stands for Data Center or Direct Current. In this work we will use DC for Direct Current and not abbreviate Data Center.

It is the desire of The Green Grid (and the Task Force created to perform this review) to provide a review of the posted report of the 380Vdc demonstration. Our goal is to provide the industry with relevant facts and references such that each data center owner can do an analysis to determine if 380Vdc power may be appropriate for them in a future data center. Also, The Green Grid wants to dispel the notion that 380Vdc power is a universally appropriate solution and can get everyone a savings in excess of 20% today.

Regardless of the power distribution configuration chosen, good engineering, simple optimization of design, and selection of the highest efficiency components will yield a significant benefit using either AC or DC power.

LBNL PROJECT GOALS

The stated goals of the LBNL project are listed below:

"The following goals were identified for this demonstration project:

1. Show that [380V] DC-powered server(s) exists in the same form factor or can be built.
2. Show that [380V] DC-powered server(s) provides the same level of functionality.
3. Measure and document any efficiency gains from the elimination of multiple conversion steps in the delivery of [380V] DC power to the server hardware.
4. Identify areas requiring further development or follow up investigations."

The LBNL study did not constitute an effort to find the best power distribution architecture but instead to review a promising one currently in development.

In this assessment, The Green Grid will consider how successful the demonstration project was in each of those four goals.

GOAL #1 FORM FACTOR

The project reviewed the question of whether there would be an impact to the form factor of existing servers to run at 380Vdc. The project demonstrated that the only change to the individual server is the power supply unit (PSU), as the output from the PSU to the server internals is identical in both the AC and 380Vdc cases. The next issue discussed was PSU form factor. As pointed out in the LBNL report, -48Vdc power supplies are currently available in the same form factor as 100-240Vac PSUs commonly in use today. Discussions were held with PSU manufacturers and the conclusion was that the 380Vdc PSU does fit readily in the same space. For the study, power supplies were modified to physically demonstrate that PSUs can be run within the same form factor. It is also important to note that the 380Vdc internal components will actually use somewhat less space inside the PSU than the AC components, but no expectation exists that this space would be used advantageously as the base server platform would still need to accommodate AC supplies for the foreseeable future.

GOAL #2 FUNCTIONALITY

In the compute functionality area, the various servers in the LBNL demonstration ran server workloads and, as expected, there were no difference in that capability.

The one area that remains to be accomplished to ensure like-functionality is the 380Vdc bus and PSU specifications. Currently AC power supplies are designed to carry the server thru a range of power variations and power quality issues. That same level of functionality remains to be specified into the 380Vdc power supply. Unfortunately this is not straightforward, as there is no data on the “inlet variability” that needs to be corrected to give the same “output quality”. Until enough 380Vdc systems are built and operational, the range of issues the PSU needs to deal with must be based on design and engineering judgment. These issues will need to be identified and input specifications will need to be developed for the PSU. The Green Grid believes this is one of the key engineering tasks needing to be accomplished before the 380Vdc architecture can move forward.

GOAL #3 EFFICIENCY GAINS

LBNL's goal was to measure whether a 380Vdc power distribution system could have an efficiency gain and this was proven to be the case. However, the following issues were noted in the LBNL study and we believe they may have affected the overall efficiency results.

While not having a quantitative effect on the efficiency, the terminology that represents the AC system can be misleading. At multiple instances, the phrase “best in class” is used for the AC system that was tested. However, The Green Grid would not consider it to be a best in class system; it did not utilize the highest efficiency components that were available at the time.

Also, The Green Grid believes these specific areas affected the overall efficiency of the AC system:

1. Neither of the UPSs used in the study were considered “best in class” or were the most efficient units available; hence these units could have affected the overall efficiency difference between the two systems. The AC UPS was 89% efficient and the 380Vdc UPSs were 92% and 94% efficient. A previously published report on UPS efficiencies by LBNL listed the highest efficiency for a double conversion AC UPS as 94%[6]. 380Vdc UPSs were not available at the time of the study, so a solar inverter and flywheel were used in place of a 380Vdc UPS. Today, some double conversion AC UPS are about 96% efficient and some 380Vdc UPSs can be demonstrated to be 97% efficient.
2. The AC UPS was 208V; the 380Vdc UPS was a 480V system. It is widely known that a 480V UPS is more efficient than a 208V UPS by approximately 1-3% at heavy load. Also, the placement of the transformer (ahead of the UPS) was detrimental to the efficiency of the AC system.

For this demonstration, the actual overall efficiency of the power system considered all components in the chain, including the first conversion in the server. There are also a number of analytical studies where this has been done, comparing a 380Vdc system to the pervasive 408-208Vac system present in North American data centers. The Green Grid believes the issues noted above affected the documented efficiency improvement as well as the absolute efficiency in the LBNL study and are partly responsible for the differences between the referenced studies noted in the fourth column of Table 1, on Page 7.

TABLE 1. PUBLISHED EFFICIENCIES OF 480VAC AND 380VDC SYSTEMS.

Author	408-208Vac Best Practice	380Vdc	Efficiency Improvement	References
LBNL DC system A vs. AC system B @ ~30% load	79%	87%	8%	1
LBNL DC system B vs. AC system B @ ~30% load	79%	85%	6%	1
Pratt @ 50% load	68%	74%	6%	4
Rasmussen @ 50% load	84%	88%	4%	5
The start and end points of the power path vary between each study, which is the major reason for the variation in efficiencies.				

In review of the LBNL study, as well as the other references, The Green Grid concludes that an end user could obtain an improvement of 4-6% efficiency points over well designed efficient 408-208Vac systems available today.

GOAL #4 DEVELOPMENT REQUIRED FOR DC POWER

The LBNL report goes into significant detail about the challenges associated with bringing a new technology to market. The Green Grid encourages anyone considering a 380Vdc power architecture for their new data center to spend the time to fully read chapter 4 of the study and understand the path to bring the technology to a commercially viable state. We recognize and agree with LBNL's concerns about the availability of 380Vdc equipment for a future implementation. Beyond the issues stated in that work, The Green Grid believes other additional challenges lie ahead.

Before a commercially available data center 380Vdc system is implemented, the availability of UL489 circuit breakers needs to be addressed, as well as the determination of other equipment needs, such as interlocks on connectors, breaker coordination and over current protection.

Also, LBNL noted concern with untrained personnel access within racks, but The Green Grid believes that this is not required as equipment within the rack can be designed with untrained personnel access in mind. Therefore the argument for training should apply to facility level work only. The facility level of work will need some best practices defined, as well as the proper protective equipment, which may still need to be developed or adapted for data centers.

380VDC USE CASES

While LBNL did not look at specific use cases for 380Vdc, The Green Grid considers it to be an important portion of the discussion. The efficiencies inherent in the 380Vdc power architecture are attractive but are not appropriate for all data centers. The Green Grid is concerned that the 28% power savings over a legacy 408-208Vac data center, as shown in the LBNL study, is often misinterpreted to be achievable in all situations. This gives way to inadequate consideration of the applicability of this power configuration for specific situations.

Replacing an existing operational 480Vac system will rarely, if ever, have a positive ROI. The efficiencies gained would not pay for the capital expenditures. The electrical portion of a new data center is roughly 30-40% of the new building total cost in new construction. In a retrofit into an existing space the new DC power system would likely require another 40-50% of the total cost of the building. This assumes a phased approach to the switch over with servers being replaced at their end of life, stretching out obtaining the efficiency gains over several years. A full data center approach would have to include shutting down each server and replacing it with a either a new 380Vdc server or replacing the server's power supply unit with a 380Vdc PSU. The assumption that a new 380Vdc PSU would be available for all existing operational servers is risky at best. The operational impact of this server shutdown and replacement would also need to be considered. The ROI for this type of conversion would be measured in decades, not years. (If the 480Vac system were at end-of-life and needed to be replaced then the economics would change, but this scenario represents a major retrofit or expansion and not a replacement.)

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Retrofitting rack level 380Vdc into an existing UPS-served 480Vac facilitated data center is not an attractive choice and would likely save no power. The elimination of power conversion steps that make 380Vdc attractive would not happen as they exist in the base system. Essentially a 380Vdc rack level system simply moves one AC/DC conversion step from the server-level PSU to a rack-level power distribution unit. Where a rack level implementation may make sense is in a data center with only rack level UPSs (no centralized UPS). There, if fed with 480Vac, a 380Vdc rack/server configuration would show an efficiency gain.

The 380Vdc powered data center would need to be an all new or extensive retrofit with a new UPS for the whole facility, to allow for the best ROI. Any new data center without a UPS will not benefit from a 380Vdc power architecture. For applications where a UPS is not needed, the overall efficiency of a 480Vac configuration will be essentially the same as a 380Vdc configuration, as the number of conversions (with associated losses) is roughly the same.

A data center with two types of power (AC and DC UPSs) fully available would also have a capital cost which would prevent the owner from obtaining an improvement in TCO. As mentioned previously, the electrical power portion of a new data center is 30-40% of the total building, duplicating electrical distribution would have a major impact on capital cost for a limited gain on efficiency. In fact the parallel systems would likely be more lightly loaded due to the split distribution scheme, potentially giving up any efficiency gains that could be had from the 380Vdc design.

The data center where 380Vdc power will be the most successful is likely a large homogenous data center where procuring a smaller number of different models of DC servers could best be accomplished. Also, the larger data centers' challenge with the absolute magnitude of the power costs will be a driver for implementation of this architecture. (4-6% savings on a $10,000 operating expense may not warrant acceptance of the risks of an early adopter as readily as 4-6% savings on a $1,000,000 power bill.)

As a data center life can be on the order of 15 years, a full scale industry switch to 380Vdc power would be a long term transition and as such, it is more likely that both variants of power architecture configurations could be found in future data centers, with the choice of a particular architecture depending on the specific data center's objectives and priorities.

GREEN GRID FUTURE WORK

The Green Grid is working on a follow-on white paper to The Green Grid white paper #4[7], "Qualitative Analysis of Power Distribution Configurations for Data Centers", with a quantitative analysis of these same system designs. This data will provide the data center owner and designer with information to assist in making an informed choice on what is best for their next data center.

LBNL ADDITIONAL INFORMATION AND STUDY ERRATA

Some additional follow up information was provided to The Green Grid by study participants and LBNL. This information was not directly stated in the report; The Green Grid feels it is important for other readers of the study to be aware of the information as well.

- **MODIFICATION OF POWER SUPPLIES** – All modifications to the power supplies to permit operation from 380Vdc were consistent with what would be required for a commercially available product.
- **EQUIPMENT LOADS** – All AC powered servers were operated at 208Vac.
- **DERIVATION OF THE AC TO DC LOADING RATIO** – Laboratory experiments showed that the power supplies used in the demonstration, when modified to run off 380Vdc, consumed on average between 97% and 98% of the power consumed when running off AC. The total load of the 380Vdc setup was therefore adjusted, via use of load banks, to 97.4% of the total AC load. While the LBNL PSUs ranged from 75% to 92% efficient when running off AC, the input power ratio was measured to be approximately the same despite the range in efficiencies, supporting the 0.974 ratio.
- **INPUT CURRENT DISTORTION** – The input distortion from the AC and DC rectifiers was in line with relevant industry standards.
- **TARE LOSSES OF THE FLYWHEEL** – The flywheel tare losses were included in the DC measurements.
- **NOMINAL CAPACITIES** - The following list contains nominal capacities for the UPSs, rectifiers and transformers:
  - AC System A UPS: 208V, 60 kW/75 kVA
  - AC System B UPS: 208V, 80 kW/80 kVA
  - DC System A Rectifier: 75 kW
  - DC System B Rectifier: 75 kW
  - AC System A 408-208 Isolation Transformer (fed AC System A UPS): 75 kVA
  - AC System B 480:208 Isolation Transformer (fed AC System B UPS): 75 kVA
- **LOAD POINT** – The load point of 23kW was a load level that both AC and DC load banks could accommodate. It constituted approximately 30% load on the UPS.
- **EFFICIENCY CURVES** – Efficiency curves over a wide load range were not produced because of limitations on the load banks.
- **POWER SUPPLY AND TRANSFORMER EFFICIENCIES** – The efficiencies for the power supplies were measured and the transformer efficiencies were determined from vendor published data.

To provide an additional assistance to the reader when working with the LBNL study, The Green Grid has compiled a list of minor errors and typos in the posted report. This is not intended as criticism of the LBNL work, as any technical report of this magnitude will likely have a few of these type of errors.

- Figure 10 on page 29 shows a 480V UPS with an output transformer while this configuration wasn't used in the trial. The transformer was at the input of the UPS (which lowered the efficiency of the AC system) and not at the output of the UPS, which was what was shown in the diagram.
- Figure 14 on page 33 does not show the UPS and the transfer switches.
- Figure 26 on page 56 should show the AC system but it shows the DC system.
- Page 28 contained a typographical error referring to 408V instead of 480Vac.

SUMMARY

Overall the goals established by the LBNL team were met. The Green Grid commends LBNL, their subcontractors and industry partners for the 380Vdc demonstration project and their overview of the implementation issues and next steps for deployment of this technology. The demonstration showed that 380Vdc can make a difference in the right application and it could improve the performance over current AC practice. The Green Grid concludes that the main data to take away from the study should be the measured power savings of the 380Vdc system over their 408-208Vac system, ranging from 5-7%, which was realized by eliminating power conversion stages. The Green Grid also recognizes that there are other alternative high efficiency AC and DC configurations under development[7] and will publish an analysis of the expected efficiencies in an upcoming white paper. The Green Grid wants the reader to be aware of all potential new architectures to allow for the best data center design for any specific situation. Any choice for power distribution configuration must consider not only efficiency but reliability/availability, capital costs, market availability of power and IT equipment, as well as deployment issues. Only when that level of analysis is performed for each data center can the optimum architecture choice be made. There is no "one size fits all" system that The Green Grid is able to recommend.

The Green Grid believes that perhaps the most important measure in the LBNL study is one that was overlooked. Regardless of AC or DC, selecting the right equipment in an engineered and optimized high efficiency power configuration design will likely provide the data center owner with a much lower overall TCO than was typical even a few years ago.

REFERENCES

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