

Highly Power-Efficient Rack-Level DC Power Architecture Combined with Node-Level DC UPS

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This letter presents a highly efficient rack-level DC power architecture combined with a node-level DC uninterruptible power supply (UPS). The proposed system can provide almost the equivalent power efficiency of a high-voltage DC data center without any change in the existing power infrastructure. The node-level DC UPS combined with a power distribution board provides high power efficiency as well as lower UPS installation costs. Implemented on a rack, the entire power system can be monitored through a network.

Keywords: Rack-level DC power supply, power monitoring, node-level DC UPS, power distribution.

I. Introduction

The study of high-voltage DC (HVDC) as an energy efficient distribution for data centers has been actively pursued in recent years. Lawrence Berkeley National Laboratory and various computer companies have experimented with transmitting power at 380 V DC within data centers, and a 10% to 15% reduction in power loss has been reported [1]. Other DC data centers have also reported on a reduction of power efficiency when changing the DC power distribution. However, a company, American Power Conversion, determined that the power efficiency of an HVDC data center improved a mere 1% compared with the high efficiency of an AC data center [2]. Moreover, there are no mandatory standards for solving the DC power distribution in HVDC.

Low-cost servers occupy 88% of server shipments and consume 68% of electricity in data centers worldwide. Google

uses cheap x86 platform-based servers for search and cluster fields. Google no longer uses ATX standard power supplies and has changed over to 12 V single DC power to improve its energy efficiency [3]. Moreover, they changed their centralized uninterruptible power supply (UPS) to built-in 12 V UPS in the server power supply units (PSUs) and obtained UPS efficiency of 99.9% [4].

This letter aims to find solutions for improving the power and monitoring efficiency in AC data centers at low-cost volume server farms without any change in power infrastructure.

This letter proposes an improved efficiency architecture consisting of a 12 V rack-level DC power supply, called a rack PSU (RPSU), combined with a DC UPS in the power distribution board (PDB), or uPDB, of each server. To improve power efficiency, the RPSU supports DC distribution using dynamic load-sharing and a rack voltage of 12 V. The uPDB reduces conversion loss by including a DC UPS and increases efficiency using 12 V bypass architecture. The power state of the racks and nodes proposed in the system can be monitored through a network. Without any change in data center power infrastructure, the power efficiency of the proposed system is nearly the same as in an HVDC.

II. New Power Delivery Architecture

Existing power delivery is divided into three broad categories: AC, rack-level DC, and facility-level DC. In conventional AC power delivery architecture, the UPS, power distribution unit (PDU), and PSU power make up the delivery path. In the delivery path, double conversion, AC/DC or DC/DC, occurs at the UPS and PSU, causing power loss. On the other hand, facility-level DC power distribution provides

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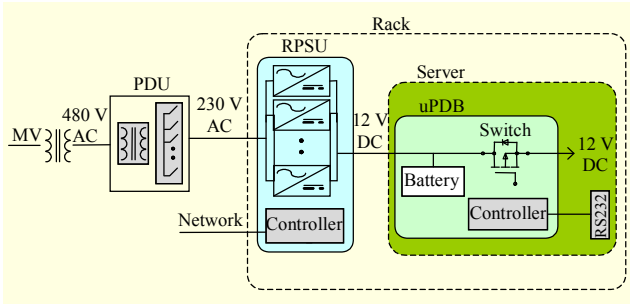


Fig. 1. Rack-level DC power distribution architecture combined with node-level DC UPS.

48 V DC or 400 V DC prior to the UPS, reducing AC/DC power conversion loss at the UPS and PSU and improving the overall efficiency. A rack-level DC delivery architecture using a highly efficient rectifier provides 48 V DC or 400 V DC power in the rack, and the PDB changes to 12 V DC power at the server. Since the number of conversion stages is the same as in AC architectures, a simply reorganized rack-level DC cannot improve efficiency and simply provides rack-level power redundancy [1], [5].

In this letter, we propose a highly-efficient rack-level DC power architecture combined with a node-level DC UPS, as shown in Fig. 1. First, we remove the facility-level UPS located in front of the PDU and make a node-level DC UPS, which improves the efficiency of the UPS by reducing energy conversion instantly and distributing the UPS at the node level. Second, we used a 12 V rack-level RPSU with DC power supply consisting of multipower modules and supporting a dynamic load-sharing method that automatically turns on/off the multipower modules optimally based on the load amount [6]. Therefore, the RPSU supports more efficient power at low loads providing $N+1$ power redundancy. Third, we reduce DC/DC conversion loss by making a 12 V bypass PDB, which provides 12 V directly to the motherboard without any DC/DC conversion in previous research [7].

When using a 12 V DC in the rack, the PDB can be designed for maximum efficiency, but the current is limited to 25 A considering the cable loss between the RPSU and PDB. Fortunately, these days, low-cost volume servers do not exceed 300 W in maximum load. We can easily implement a uPDB, including a battery and controller, in a small form factor. There are no problems in installing the uPDB to replace the local PSU. Embedded controllers in the uPDB and RPSU enable us to control and monitor the power state through a network.

Figure 2 shows the power monitoring system for the proposed system configuration. There are many racks in the data center. Each rack has one RPSU. The rack power monitoring software (RPMS) monitors RPSU information, such as the state of the power module, power consumption,

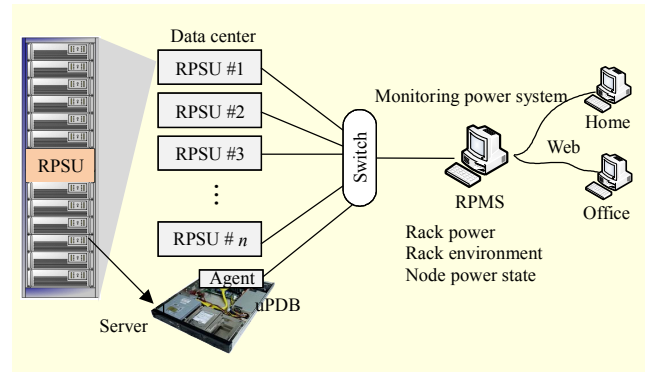


Fig. 2. Power monitoring architecture of proposed system.

temperature and humidity around the rack, and the node on/off state through the network. The RPMS also monitors each node's power state using a power agent located in each server that communicates with the uPDB sensor. Using an Apache web server, the RPMS can be accessed anywhere via the Internet. The RPMS can analyze the power consumption of RPSUs and shows any hot zones occurring in the data center. If problems occur, such as a power module failure, high temperature, or battery failure in the uPDB, the RPMS immediately informs the data center manager. Moreover, RPMS helps the data center manager to more easily create a power and cooling policy.

III. Power Efficiency Analysis

A power efficiency model of the RPSU system can be divided into three main parts: RPSU, cable, and uPDB. The efficiency can be expressed as the product of multi-PSU efficiency in the RPSU, cable efficiency, and uPDB efficiency:

$$Eff_{RPSU\text{System}} = Eff_{RPSU} \times Eff_{Cable} \times Eff_{uPDB}, \quad (1)$$

where the efficiency of the RPSU and uPDB can be measured and the efficiency of the cable is calculated using the equation. The RPSU was designed using eight high-capacity and efficient power modules, and it utilizes dynamic load-sharing according to the load amount by supporting $N+1$ redundant power. This method has an efficiency advantage at low loads by turning off unnecessary power modules. The power efficiency of the RPSU was 86.5% at a 10% load and 87.76% at loads over 30% as shown in Fig. 3.

To provide compatibility for all racks, the RPSU and servers are connected by a cable. Due to its resistance, the cable used between the RPSU and uPDB causes a voltage drop. Assume that the wire thickness is 6 mm^2 and the length is 1 m where the input voltage V_1 is 12 V. The cable efficiency is then calculated as in (2) and plotted as in Fig. 3.

$$Eff_{Cable} = \frac{V_O \times I}{V_I \times I} \times 100 = \frac{100 \times (V_I - V_{drop})}{V_I} = 100 - 0.049I, \quad (2)$$

$$V_{drop} = \frac{35.6 \times I \times L}{1,000 \times S}, \quad (3)$$

where 35.6 is the coefficient in a two-wire DC, I is the current (A), L is the cable length (m), V_{drop} is the voltage drop (V), and S is the conductor area (mm²).

Since the uPDB is designed using a 12 V bypass architecture, the loss occurring at the 12 V bypass switch is a constant value regardless of the load. Therefore, as the computer load increases, the uPDB efficiency increases linearly up to 98% as shown in Fig. 3.

Finally, the power efficiency of the RPSU system is a product of the RPSU, cable, and uPDB, as in (1). Figure 3 shows a maximum efficiency of up to 86% and over 80% even at a 20% load.

To compare the proposed system with other power delivery

systems, we used the efficiency modeling data from AC, rack-level DC, and facility-level DC, provided in [1], [8]. The AC system is divided into a general 480 V AC and highly efficient 480 V AC. The facility-level DC is divided into 48 V DC and 400 V DC. In the rack-level DC, a conventional 48 V DC and 400 V DC are used. Finally, in the proposed systems, 12 V DC and 12 V DC with node-level UPS are utilized. To compare the overall efficiency of a data center, we included the power loss of the PDU and voltage regulator (VR) in the system efficiency. The overall system efficiency, defined as the ratio of load power to UPS input power, is shown in Fig. 4. Table 1 shows the efficiency of each unit throughout the power delivery path in detail. The server PSUs shown in the table are a 12 V single output PSU or PDB. The efficiency of the VR stage in the motherboard is 87.69%, which is the same value throughout the system.

In general 480 V AC delivery, the maximum efficiency is 55.01%. On the other hand, in a highly efficient 480 V AC system, the maximum efficiency is up to 67.87% due to the

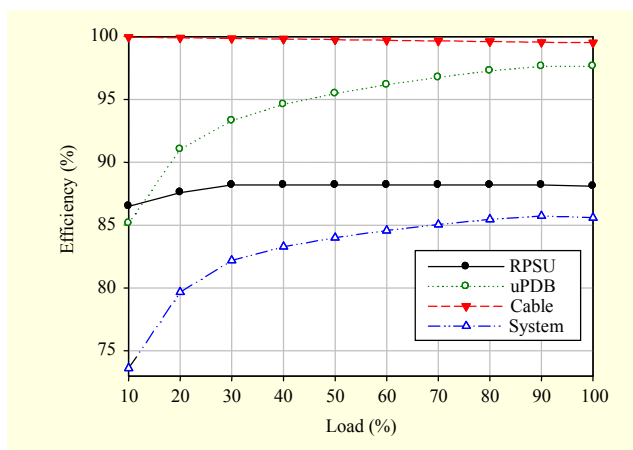


Fig. 3. Power efficiency measurement of RPSU system.

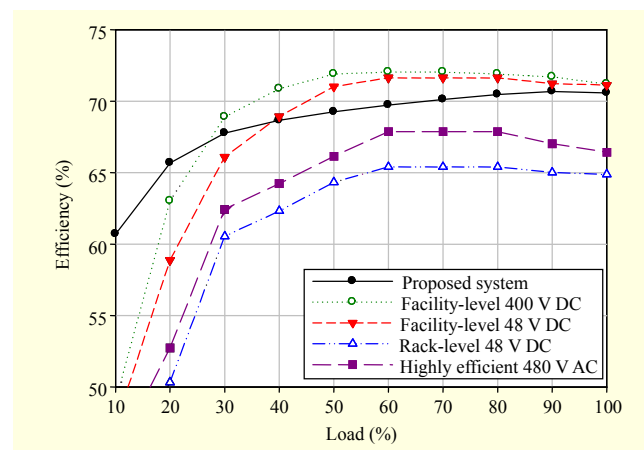


Fig. 4. Comparison of efficiencies as function of load.

Table 1. Calculated power efficiency at full load.

Unit	AC		Facility-level DC		Rack-level DC			
	General 480 V AC	Highly efficient 480 V AC	48 V DC	400 V DC	48 V DC	400 V DC	12 V DC	12 V DC node-level UPS
UPS	89.20	94.00	92.86	95.32	94.00	94.00	94.00	N/A
PDU (including cable loss)	93.20	94.03	96.11	96.78	93.82	93.92	94.03	94.03
Rack-level converter (including cable loss)	N/A	N/A	N/A	N/A	92.38	96.12	87.76	87.76
Server PSU (PDB)	75.46	85.00	91.54	89.05	91.54	89.05	99.00	97.64
VR stage	87.69	87.69	87.69	87.69	87.69	87.69	87.69	87.69
Total	55.01	67.87	71.64	72.04	65.40	66.26	67.34	70.65

improved efficiency of the UPS and PSU. For rack-level DC delivery, conventional 48 V DC or 400 V DC distribution shares the same architecture as AC delivery except for a rack-level converter and PDB. Both of them have similar efficiency, with maximum efficiency of up to around 66%, which is a lower value than the highly efficient 480 V AC delivery. For facility-level DC delivery, 48 V DC and 400 V DC are used for the distribution voltage. The efficiencies of the DC UPSs are 92.86% and 95.32% each, which are higher values than AC UPS. The power loss of the DC PDU is also lower than in the AC PDU. The efficiency of the 48 V PDB or 400 V PDB is up to 90%. The maximum efficiency of the facility-level DC is about 72%, which is 4.17% higher than a highly efficient 480 V AC.

In the proposed 12 V rack-level DC system using a 12 V bypass PDB, the maximum efficiency is up to 67.34%, which is the same efficiency as the highly efficient AC delivery. Moreover, when combined with the proposed uPDB, the maximum efficiency is up to 70.65%. This is 2.78% higher than the highly efficient AC, and the difference with the facility-level DC distribution is from 1% to 1.5%. The proposed system has higher efficiency than the facility-level DC under a 20% load because it uses dynamic load-sharing in the RPSU and a node-level distributed DC UPS. In addition, the proposed system supports rack-level and node-level power monitoring through a network. The proposed node-level DC UPS system is much cheaper than generally used large centralized UPSs and wastes no space for UPS installation.

IV. Conclusion

This letter proposed a 12 V rack-level DC rectifier combined with a node-level DC UPS. The proposed rectifier is fully compatible with the existing AC data center power infrastructure as well as existing racks and servers. The proposed system can solve the power problems in a volume server such as low-power efficiency, no-power redundancy, and no-power monitoring. The measurement results of the proposed system show that its power efficiency improvement of over 2.78% is comparable to a highly efficient AC system and is nearly the same efficiency as a facility-level DC system. Moreover, the power information of a node and rack can be monitored using a network. Removing the necessity for a UPS room will save money and improve capacity. The proposed power delivery architecture provides more efficient power with stability and monitoring ability in a volume server farm.

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