On Energy-Saving Strategies for Data Center Power Systems (Postprint)

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Abstract

In data center infrastructure, the power system constitutes a critical component and an indispensable foundational safeguard for secure communication system operation. With the evolution of communication technologies and the continuous proliferation of data centers, the demand for energy conservation and consumption reduction in power systems has become increasingly urgent and imperative. This paper primarily investigates energy-saving aspects of data center power systems and proposes a series of targeted recommendations.

Full Text

Preamble

A Preliminary Study on Energy-Saving Strategies for Data Center Power Systems

Abstract: The power system constitutes a critical component of data center infrastructure, providing essential foundational support for the safe operation of communication systems. With the advancement of communication technologies and the continuous proliferation of data centers, the demand for energy conservation and consumption reduction in power systems has become increasingly urgent and necessary. This paper investigates energy-saving aspects of data center power systems and proposes a series of targeted recommendations.

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With the development of communication technology and the increasing number of data centers, energy-saving issues in power systems have gradually attracted widespread attention. This concern reflects both the requirements of sustainable social development and the direct economic interests of enterprises. However, numerous problems persist in power energy conservation, requiring technical personnel to begin with theoretical analysis and continuously summarize practical experience to enhance the energy-saving effectiveness of power systems and achieve favorable economic and social benefits.

1. Current Development Status of Data Center Power Systems

Power systems represent key infrastructure for data centers, encompassing a broad range of components including switching power supplies, phase-controlled power supplies, AC/DC uninterruptible power supplies, and power transformation and distribution facilities. Development trends for power supply units include improving efficiency, enhancing reliability, and reducing footprint—particularly crucial given the shortage of computer room space and the urgent need to improve space and energy utilization efficiency. The advancement of various semiconductor device-based technologies has laid a solid foundation for the development of data center power technology. Early thyristors were limited by switching frequency, and current sharing in multi-unit parallel configurations posed an obstacle to their development. With the transition from thyristor technology to IGBT (Insulated Gate Bipolar Transistor), the switching frequency of power transistors has increased, making current sharing control among power units easier and enabling multi-module parallel operation for computer room power supplies. Currently, the manufacturing process for new SiC semiconductor power devices is maturing, and the application of new power transistors has significantly increased the chopping frequency of power supplies. This has led to the miniaturization of filtering inductors and capacitors in power units, creating new possibilities for modular power supply design. Through power factor correction technology, improving the input power factor of power supplies reduces losses in the power grid and further enhances equipment efficiency. Additionally, the increasing intelligence of power systems allows for dynamic adjustment of equipment load rates through changes in operating modes, further improving efficiency metrics and enhancing the efficiency of technical maintenance and inspection work [**?**].

2.1 Installing Power Supplies in Equipment Rooms

The 48V DC power supply is commonly used for carrier access equipment. Before installation, power capacity should be selected based on computer room area or cabinet count, and the spatial layout should be reasonably planned to position power supplies as close as possible to the load center. When conditions permit, DC power supplies can be installed directly within communication equipment rooms. Because lower supply voltage levels require larger cable cross-sections for equivalent power, this approach yields more pronounced energy-saving effects. Reducing cable length between communication equipment and distribution panels not only decreases line losses but also reduces investment costs. Although this increases cable length between the power supply unit and batteries, batteries remain in float-charge state for extended periods with minimal current, making the resulting line loss increase negligible and the heating loss from battery cables completely ignorable [?]. Typically, comparing the cable heating losses between electrical equipment and power supply units under both schemes suffices. Through these measures, heating losses in conductors between communication equipment and DC panels can be effectively reduced, ultimately achieving energy savings.

The heating loss formula is as follows:

$$Q = I^{2Rt}$$

where Q represents heating loss, I denotes current, R represents cable resistance, and t is the duration of current flow through the cable. One year corresponds to $t = 3.15 \times 10^7$ seconds. Since cable resistance is proportional to length, comprehensive evaluation of both design schemes demonstrates that installing power supplies within communication equipment rooms not only reduces electrical energy losses but also significantly decreases cable investment costs, ultimately achieving excellent results in both energy conservation and cost reduction.

2.2 Using High-Voltage DC Power to Replace Traditional UPS

In existing data centers, over 90% of servers are powered directly by UPS systems. Since the vast majority of server power modules and computer room equipment are designed for AC power input, UPS systems output AC power compatible with commercial power through AC-DC-AC double conversion, ultimately delivering clean, stable AC power. Comparing Figure 1 [Figure 1: see original paper] and Figure 2 [Figure 2: see original paper] reveals that high-voltage DC UPS equipment eliminates the DC-AC inversion stage and, consequently, one AC-DC rectification stage inside the server. This not only simplifies UPS system complexity but also reduces two power conversion processes, significantly decreasing heating losses in the power supply system and effectively conserving energy [?].

3.1 Achieving Economic Operation of Transformers

During operation, transformers experience no-load losses (iron losses) and load losses (copper losses), resulting in power conversion efficiency always below 100%. In practical applications, transformer losses typically vary with external environmental changes. When grid voltage, frequency, and other parameters remain constant, transformer no-load loss bears no direct relationship to load capacity, while load loss exhibits a non-linear relationship with load rate.

The transformer active power loss formula is:

$$P_T = P_0 + K_T P_K \beta^2$$

$$\beta = S_c / S_r$$

In these formulas, P_0 represents transformer no-load loss, K_T is the load fluctuation loss coefficient, P_K denotes transformer rated load loss, S_c represents the transformer' s calculated load, S_r is the transformer' s rated capacity, and β represents the transformer load rate. Based on losses under different load rates, the theoretical optimal load rate can be determined. When multiple transformers supply a load, actual load conditions can be used to engage or disengage one transformer, enabling operation near the optimal load rate to reduce system energy consumption. Table 1 shows the critical load for economic operation of SCB10 series transformers. When actual load values are smaller than the "maximum load for more economical operation with one fewer unit" values in the table, loads can be reasonably distributed and one transformer can be shut down. This not only minimizes overall losses but also allows for maintenance during scheduled transformer rotation, improving equipment reliability and extending service life.

3.2 Balanced Load Distribution

As demonstrated above, power equipment efficiency varies with load rate. Therefore, daily operation and maintenance should also involve reasonable load distribution based on actual conditions to minimize power losses. For multiple transformers, if the total load remains unchanged and the number of units in operation is already at minimum redundancy, balancing transformer loads can minimize total copper losses [?]. For intelligent UPS parallel systems or communication power modules, since parallel power units can automatically share loads, enabling the system' s energy-saving mode and dynamically adjusting the number of active power units according to load characteristics can effectively improve overall power supply efficiency.

3.3 Harmonic Control in Low-Voltage Power Supply Systems

Communication equipment primarily consists of non-linear loads that inject various harmonics into the power supply circuit. In severe cases, this not only affects normal power system operation but also causes heating in other equipment on the circuit, resulting in energy waste. Therefore, technical personnel should address power system harmonic issues through effective harmonic elimination measures, which also promotes energy conservation. Implementable measures include using twelve-pulse rectifiers with 11th harmonic filters, adding LC filter circuits, installing active filters, and performing reactive power compensation.

4.1 Twelve-Pulse Rectifier with 11th Harmonic Filter

An S6 series 2-group 4$\times$200kVA parallel UPS system in one computer room uses twelve-pulse rectifiers with 11th harmonic filters for harmonic elimination. Field measurements show that at 30% UPS load rate, the three-phase output current averages 88A. Under the same load conditions without the 11th filter, the three-phase input current averages 122A; with the 11th filter in operation, the average input current decreases to 98A, a reduction of 24A per phase.

According to three-phase AC power calculation:

$$P = 1.732UI\cos\varphi$$

where $\cos\varphi$ is the power factor (generally 0.9), P is the actual AC power, U is the actual AC voltage, and I is the actual AC current.

Calculations demonstrate that through 11th filter implementation, this UPS model reduces energy consumption by 14.2kW per unit, saving 124,000 kW·h annually.

4.2 Application of Power-Saving Modes

For carrier access equipment in a computer room, the switching power supply is configured in energy-saving mode. During low-load periods, one redundant power module is retained while remaining modules enter standby sleep mode. Energy-saving effects are tested by comparing input current before and after rectifier module sleep. Equipment DC load is 82A during idle periods and 108A during busy periods, with two identical 400A module DC power supplies and supporting battery banks installed. Each DC power supply has eight 50A DC module slots. When power supply DC load is below 100A, only two rectifier modules need activation; with redundancy consideration, a maximum of three rectifier modules can be activated while other modules stop working and enter standby sleep mode. This approach reduces average input current by approximately

Note: Figure translations are in progress. See original paper for figures.

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