Electric Power-grid Friendly Characteristic Data Center  
Energy Consumption Optimization Method

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Abstract. With the acceleration of the digitization process, the load of the data center on the power grid continues to increase. During the operation of the data center, the load demand on the power grid is relatively large, and the load demand on the power grid fluctuates greatly. In the Power industry, the average PUE (power usage effectiveness) of data center is above 2, which is extremely unfriendly to the power grid. This paper proposes and summarizes the optimization parameters at various levels, the energy efficiency of software and hardware, and provides a method for optimization through global variables for high-efficiency and energy-consuming data centers, which can minimize cooling energy consumption and IT energy consumption. To build an electric power grid-friendly characteristic data center with high efficiency and low energy consumption.

Keywords: Electric; Power; Data center; Power usage effectiveness; Software and hardware integration optimization.

1. Introduction

With the continuous development of cloud computing, many companies have established their own cloud computing platforms, such as Google's "AWS" cloud computing platform, IBM's "Blue Cloud" computing platform, and Microsoft's "Azure", but cloud computing data centers some outstanding problems that need to be solved are gradually exposed in use: (1) The energy consumption is huge, and the resource utilization rate is extremely low. In 2015, the total power consumption of data centers in my country was as high as 100 billion kWh. In 2020, the power consumption of data centers in the United States is close to 135 billion kWh [1]. Most of the data centers have a PUE (power usage effectiveness) greater than 2.2 [3], which is extremely low. Conducive to the realization of my country's dual-carbon goals; at the same time, the resource utilization rate of the data center is extremely low, and there is huge room for energy efficiency optimization. (2) The power distribution capacity of the power grid is difficult for my country's cloud computing strategic demand. The demand for cloud data center construction is concentrated in economically developed cities, further exacerbating the imbalance of regional power supply and demand; in addition, existing power distribution stations are difficult to support the construction of new data centers. According to statistics from Beijing Electric Power, since 2014, about 30% of data center construction applications have not been approved. Therefore, the need to improve energy efficiency is imminent. This paper proposes and summarizes the optimization methods of energy efficiency for the three levels of the data center, including the infrastructure layer, IT facility layer, and application software layer. It is hoped that the energy utilization rate of the cloud computing platform can be improved to a certain extent.
2. Power Usage Efficiency (PUE)
As the energy consumption and efficiency of the data center are extremely difficult to predict and control, this has led to a lot of electrical energy being consumed and wasted for no reason. Today, it is feasible and practical to design to measure and improve the electrical efficiency of data centers. In normal operation, the actual efficiency of the equipment is often far lower than the efficiency during optimal operation. For some users, the cost of electricity will far exceed the cost of purchasing and installing IT equipment. At present, there is a need for a method that not only quantitatively evaluates the energy consumption of the data center, but also conducts a complete quantitative evaluation and comparison of the energy efficiency of the data center through the recorded data and the parameters of the equipment operation [2]. At present, the most common method for analyzing data center energy efficiency is to use power usage efficiency (PUE). PUE is defined as the ratio of the total power consumed by the data center to the power consumed by the IT load [3].

\[
PUE = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}}
\]

The higher the PUE value, the lower the efficiency of the data center, because powering electrical loads consumes more energy. The ideal situation is that the value of PUE is 1, which means that there is no data center all the energy is used for IT equipment. The PUE value of most data centers in China is above 2, and the ideal PUE range is below 1.4. However, due to the removal of IT loads, UPS, fans, pumps, transformers, power distribution lines, humidifiers, and other auxiliary equipment will inevitably consume power, it is impossible for PUE to achieve the most ideal situation. The following are the factors that affect the efficiency of data center energy utilization.

3. Factors Affecting PUE
3.1. Changes in Business Needs
Changes in data center business requirements and the load of IT equipment and the power consumed are the most unpredictable and one of the most important factors affecting the efficiency of data center power consumption. The new energy management function in the constantly evolving IT equipment makes the IT load height change according to the real-time changes of business requirements. There are two specific types of demand fluctuations as follows, tidal demand and periodic demand. A tidal business demand with obvious load peaks and valleys with a daily active cycle as a cycle, and a cyclical demand with regular short-period fluctuations similar to a sine curve or square wave, as shown in the figure below. In fact, in addition to these two most typical requirements, the superposition of these two types of requirements can be seen in other scenarios. Therefore, complex load change scenarios result in daily IT load and weekly IT load, and PUE is difficult to predict.

![Figure 1. Schematic diagram of tidal business requirements.](image-url)
3.2. The Influence of Outdoor Temperature
The most important factor for data center energy efficiency is outdoor air temperature. As the temperature increases, the efficiency of the data center decreases. Because as the outdoor temperature rises, the heat rejection system consumes more energy when processing heat in the data center.

3.3. User Configuration
Due to the numerous actions of users, PUE has undergone tremendous changes. The following are the actions of the user. These actions will affect the efficiency and vary greatly, and depend on the precise design of the power supply and cooling system:-changes in temperature set points, changes in humidity set points, changes in vent floor tiles, Changes in overall pressure and failure of clean air filters. When performing any of the above operations, the design of the data center will change, so a new efficiency measurement must be carried out to determine the user configuration.

3.4. The Combined Effects of Other Conditions
As any of the conditions described in this section will have a comprehensive impact on the efficiency of electric energy utilization. Changes in daily climate conditions, fluctuations in IT load caused by business needs, different business needs on weekends and work, and improper maintenance of equipment during data center operations will all lead to a decline in power utilization efficiency and unpredictability.

4. Cold Plate Liquid-cooled Server
The data center studied in this paper is a data center based on cold-plate liquid-cooled servers. The main deployment method of cold-plate liquid cooling is to configure a water divider on the liquid-cooled cabinet to provide the liquid-cooled computing node with water inlet and outlet branch pipelines, and the branch pipelines enter and exit. The water pipes are respectively connected with the water inlet and outlet of the liquid-cooled computing node through joints, and are connected with the inner cold plate pipeline of the liquid-cooled computing node to realize the liquid cooling cycle in the liquid-cooled computing node. The liquid of the liquid-cooled computing node converges at the cabinet level. The cabinet level has one inlet and one outlet, two joints connected with external pipelines. The joints are connected with an external or built-in switched cabinet distribution units(CDU) to realize the liquid cooling cycle of the liquid-cooled whole machine and take away the liquid. The heat of the cold compute node. In the liquid cooling node in the cold plate liquid cooling system, the CPU and other high power consumption components use liquid cooling cold plates to dissipate heat, while other small heating devices (such as hard disks, interface cards, etc.) still use air-cooled heat dissipation systems.

Compared with traditional air cooling, this heat dissipation method has higher density, more energy saving, and better noise prevention effect. Since the cold-plate liquid cooling technology does not require expensive water-cooled units, after deployment, while reducing the total cost of ownership, the power utilization efficiency of the data center is significantly increased. At present, under the air-cooling technology, the power consumption of each cabinet can only reach 20-30kW at most. The cold plate liquid cooling can achieve a total power consumption of 45kW-80KW per cabinet at a flow rate of 60 liters per minute, which can realize a higher density data center. The cold source of the cold
plate system is the cooling water produced by the cooling tower. The liquid-cooled water pump sends the primary cooling water to the plate heat exchanger. The primary water exchanges heat with the secondary water in the plate heat exchanger, and the secondary water after cooling passes through the circulation pump in the LMU realizes the secondary water closed circulation. The schematic diagram of cold plate liquid cooling is as follows:

![Schematic diagram of cold plate liquid cooling principle.](image)

The liquid-cooled cabinet and the LMU form a liquid-cooled micro-module. The liquid-cooled cabinet runs under the pipe, and an elevated floor is set in the machine room for laying liquid-cooled stainless steel pipes and valves. The module adopts a circular pipe design, the circular pipe bridges the branch pipes, and the branch pipes are connected to the cold plate inlet and outlet water pipes of the cabinet through quick connectors to realize the cooling liquid delivery and distribution. For the heat leakage of plate-type liquid cooling, the air-cooled auxiliary cooling system of the liquid-cooled equipment room is required to take away the leaked heat. The air-cooled auxiliary cooling system of the liquid-cooled machine room is the same as the conventional low-density cabinet refrigeration system.

5. Energy Consumption Optimization Method at the Infrastructure Layer

5.1. Hot Aisle and Cold Aisle Layout

The cabinet layout of the data room constructed in the early days did not consider the factors of airflow organization, and generally adopted a unified orientation layout, as shown in the following figure. Under the uniform orientation arrangement, the heat emitted by the front cabinets is mixed with the cold air entering the rear cabinets, which increases the air-cooled inlet temperature of the cabinets and reduces the cooling efficiency of the air-cooled air conditioner. Therefore, the cabinet layout needs to consider the factors of air organization, and adopt a back-to-back, face-to-face arrangement [4], as shown in the figure.

![Schematic diagram of the uniform orientation of the cabinets.](image)

![Schematic diagram of cabinet back-to-back layout.](image)

In this arrangement, a cold aisle and a hot aisle are formed between the cabinets. The cold air flow from the air conditioning system enters the cabinet from the cold aisle, and the hot air formed after cooling the server flows out from the back of the cabinet into the hot aisle and returns to the air conditioning system. The cold and hot aisle separates the cold air from the hot air, which can effectively inhibit the mixing of the cold and hot air, reduce the air inlet temperature of the cabinet,
and improve the cooling efficiency. In addition, in the face-to-face, back-to-back cabinet layout, in order to better isolate the hot and cold airflows, some baffles can be arranged in the cold aisles or hot aisles, or a certain aisle can be completely enclosed to achieve efficient cold airflow utilization. [6].

5.2. Rack and Row-based Cooling
Room-based cooling can be replaced with rack-based cooling or row-based cooling to reduce the energy required to run cooling equipment. In a row-based cooling configuration, CRAH units are only dedicated to servers in a specific row. Compared with room-based cooling, the air flow path in this channel is very short and the effect is clearer. Row coolers are placed directly in the row between the two server racks or near the computer rack above them [5].

5.3. Natural Cooling
The concept of natural cooling is to use a water saver to produce the required chilled water to cool the data center at night under mild outdoor conditions. In areas where the temperature is equal to or lower than 13 degrees Celsius [6], the outdoor low temperature can be easily used to cool the cooling water naturally. Natural cooling reduces the energy consumed by the air conditioner compressor and reduces the temperature of the cooling water according to the system design and outdoor conditions, thereby improving the operating efficiency of the air conditioner. This can reduce energy consumption by 75%. Natural cooling by colleagues will not affect the air quality entering the data center [7] [11].

6. IT Facilities Layer Optimization Method
In terms of IT equipment energy efficiency optimization, server energy consumption accounts for a relatively high proportion of the total energy consumption of IT equipment, and servers will call storage and network resources when processing user applications. Server energy efficiency will have a greater impact on the energy efficiency of storage equipment and network equipment. Therefore, when discussing the energy efficiency optimization of IT equipment, it mainly refers to the energy efficiency optimization of the server. The energy consumption optimization of data center IT equipment can be realized from three aspects: software performance, load scheduling optimization and hardware performance.

6.1. Software Performance Optimization
The main goal of data center software performance optimization is to reduce the complexity of application algorithms [8]. Data centers mainly provide external services in the form of IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS (Software as a Service) [11], among which SaaS is one of the more common and widely used service forms. In the SaaS service form, corresponding application service programs are deployed on data center services. These applications receive various data service requests sent by users through the data center network, and pass the calculation returns the request result to the user. From the perspective of applications, in the process of deploying applications, data centers should pay full attention to the complexity of applications, optimize programming algorithms, and adopt applications with lower time complexity and space complexity. With reduced complexity, the resources used by the data center in processing related services will be reduced, and energy consumption will also be reduced. After the application is deployed, it is necessary to strengthen later operation and maintenance to avoid system failures caused by program errors. Some program vulnerabilities may be difficult to detect, which may cause unnecessary energy consumption problems.

6.2. Load Scheduling Optimization
The main goal of load scheduling optimization is to improve the application of data center virtualization technology, and load scheduling is an important server virtualization strategy. Load-based scheduling is actually an energy efficiency optimization method that provides corresponding resources for user application services according to user requests and achieves efficient use of resources. Load scheduling will achieve energy efficiency optimization from two perspectives. One is to allocate user requests to corresponding service nodes according to the corresponding load
scheduling algorithm to achieve server system scheduling balance, which will effectively mobilize
data center computing, storage and network resources, such as Literature, the second is to perform
virtual machine migration scheduling according to business needs, and virtual machine migration can
also achieve load scheduling balance, such as literature.
Energy efficiency optimization solutions based on load scheduling are closely related to the
application of data center virtualization technology. After virtualization technology is applied, data
center IT equipment resource scheduling is more flexible, and virtual machines can also be migrated
between different servers according to business needs. The resource usage status of the flexibly
provides virtual machine resources for software applications, and the migration of virtual machines
needs to ensure that the current business will not be affected. After adopting the load scheduling
scheme, the server can migrate the services to be processed to some servers, so that some servers that
have no business to be processed temporarily are in standby state, which will effectively reduce the
overall energy consumption of the server system. When the data center business volume is relatively
high, When it is large, the load scheduling algorithm can allocate the business reasonably, so that the
server system can achieve load balance. Servers without load will also generate a certain amount of
energy consumption when they are turned on. Some data centers will shut down some servers that
have no tasks temporarily during the load scheduling process, but this may also make it difficult for
the servers to respond to sudden user requests. The University of Michigan Meisner[9] proposed a
server state preservation mechanism. Under the action of this mechanism, the server will be in a low-
power condition similar to shutdown when there is no business. When a task comes, the server can
quickly enter the running state. This solution reduces the energy consumption of the server when it is
idle, and at the same time does not have a major impact on the external service performance of the
server system.
The load balancing scheme is an energy consumption optimization scheme based on the server cluster
level. In the load scheduling scheme, the load balancing scheduling strategy and the virtual machine
migration strategy are two common energy consumption optimization strategies. In fact, this is a two-
layer mapping. From the perspective of considering the allocation of hardware resources and user
application requests, from the above point of view, these two load balancing solutions are to achieve
the balanced distribution of business load on the server, and the load balancing scheduling strategy is
the first time for the business load. Allocation, and the virtual machine migration strategy is to perform
virtual machine scheduling and allocation to the server cluster that is already in the process of running.
This can also be called the secondary allocation of load balancing, but the allocation object becomes a
virtual machine.
The load balancing scheduling strategy mainly considers the mapping between the application and the
virtual machine. After the application reaches the service voucher node, what allocation strategy
should be used to allocate the application to which virtual machine for processing? This is the main
problem that the application scheduling strategy solves. Application scheduling strategies are driven
by performance. In order to achieve performance optimization goals, application scheduling strategies
usually take task response time and throughput per unit time as the criteria for measuring performance
goals.
The virtual machine migration strategy actually solves the problem of the mapping relationship
between the virtual machine and the host. The virtual machine migration can realize the load balancing
of the virtual machine on each physical machine. A schematic diagram of the energy-saving strategy
for the virtual machine migration is shown in the Figure below.
The virtual machine migration strategy is usually associated with the shutdown/open server strategy. Switching the server refers to the strategy of reducing the energy consumption of the server by turning off the idle server. When the server load is low, the idle server is turned off. When the running server cannot be satisfied when the load requires resources, turn on the closed server again. This mechanism can effectively reduce the energy consumption of the server. The virtual resource allocation strategy based on virtualization technology considers how to schedule virtual machines on existing computing and storage resource pools, so that virtual machines can obtain sufficient computing, storage and network resources through migration without affecting the application business. To better meet customer needs. Virtual resource allocation strategies based on virtualization technology usually require the construction of corresponding virtual machine scheduling algorithms, through which the scheduling of virtual machines is realized, and energy efficiency optimization is achieved at the server cluster level.

6.3. Hardware Performance Optimization

The main goal of hardware performance optimization is to improve the energy efficiency ratio of IT equipment. Hardware performance optimization strategies mainly include two types. One is to develop and use low-energy electronic components, and the other is to use dynamic voltage and frequency scaling (DVFS) [10]. The DVFS technology mainly reduces the operating frequency of the CPU. Ways to extend the task cycle to reduce energy consumption. Improving hardware performance and improving hardware layout can also reduce the energy consumption of IT equipment to a certain extent. Data center operations managers can consider choosing IT equipment with better performance for business needs within a limited budget. Adjusting the placement of the cabinets or adopting cabinet-level refrigeration equipment can also greatly increase the utilization rate of cold air by the cabinets, thereby reducing the power consumption of air-conditioning equipment. IT equipment with better hardware performance usually has a higher energy efficiency ratio and greater data processing capacity per unit of energy consumption.

Dynamic Voltage and Frequency Scaling (DVFS) refers to adjusting the power consumption of the server by adjusting the voltage evaluation rate of the central processing unit. DVFS technology predicts the subsequent time period based on the current load status of the computing node. Calculate the power that the node may consume, thereby adjusting the clock frequency and voltage of the CPU. The relationship between the energy consumption of a single character and the voltage and frequency of the CPU is as follows:

\[ E = AtCV^2f \]

Among them, \( A \) is the energy consumption coefficient, \( t \) is the execution time, \( C \) is the capacitive load, \( V \) is the CPU voltage, and \( f \) is the CPU clock frequency. When the clock frequency \( f \) decreases, the voltage \( V \) will also decrease, and the CPU energy consumption \( E \) will also decrease. It can be seen from this relationship that reducing the CPU clock frequency and voltage can further reduce the energy consumption of the CPU. For some idle or low-speed servers, this energy optimization strategy can reduce the idle energy consumption of the system.
The server energy consumption optimization from the hardware point of view is actually a single server-level energy consumption optimization scheme. For new data centers in the construction planning stage, you can consider configuring low-energy-consumption servers. For data centers that are already in operation, this solution will cause data center operators to pay larger equipment update costs. DVFS technology reduces the server CPU work efficiency by reducing the CPU voltage or frequency, thereby reducing energy consumption. This dynamic frequency modulation task processing method is more effective than the work method of running the task at the maximum rate first, and then idle the CPU for the remaining time, but this it may also result in slower user service processing speed, and even cause request congestion. Therefore, this solution needs to weigh the relationship between the degree of server performance degradation and the user request processing speed.

7. Application Software Layer Optimization Method
Model the characteristics (variables) that affect the efficiency of data center power usage, and integrate the software and hardware into the power management tool through unified consideration of the infrastructure layer, IT facility layer, and application software layer, and coordinate to achieve this. Reduce the overall power usage efficiency of the data center. This paper proposes the characteristics (variables) of the data center for each level of the data center based on cold plate liquid cooling as follows:

7.1. Data Center Global Characteristics (Variables)
This paper proposes four data center global variables: 1) data center usage area; 2) data center location; 3) data center type; 4) data center construction date.

7.2. Data Center Pressure Characteristics (Variables)
This paper proposes five data center energy consumption variables, 1) total electricity consumed by data centers; 2) total electricity consumed by IT facilities; 3) total electricity consumed by air conditioning systems (HVAC); 4) total fuel consumed by generators; 5) The total energy consumed by the cooling water of the data center. All of the electricity and energy measurements can be read by electric energy meters and natural gas meters.

7.3. Data Center Heat Distribution Characteristics (Variables)
1) Air conditioning supply air temperature (°C); 2) Air conditioning return air temperature (°C); 3) Cabinet inlet air supply temperature (°C); 4) Cabinet outlet return air temperature (°C); 5) Cabinet liquid cooling inlet cooling water Temperature (°C); 6) The temperature of the liquid-cooled cooling water at the cabinet outlet (°C); 7) The relative humidity of the supply air (%); 8) The relative humidity of the return air (%); 9) The air volume of the fan (m³/s).

7.4. Data Center Power Guarantee Characteristics (Variables)
1) UPS peak load; 2) UPS load capacity; 3) UPS input power; 4) UPS output power; 5) IT facility average power; 6) lighting facility average power; all variables are in kilowatts.

7.5. Data Center Cooling Characteristics (Variables)
1) Air conditioning power (kW); 2) Average cooling load (tons); 3) Installed cooling load (tons); 4) Peak cooling load (tons); 5) Average water consumption of water savers;

7.6. Power Management Tools
Through the above characteristics (variables) as input, the overall model of the data center, through resource pooling [11], software and hardware integration, systematically consider the above variables as features, and incorporate them into the machine learning model. The adjustment of variables, including air-conditioning air outlet, return air temperature, CPU operating frequency, etc., improves the resource utilization rate of the data center and improves the power usage efficiency of the data center. Use data center characteristics (variables) to optimize computing resource scheduling, use
device pressure characteristics to achieve single device power consumption control optimization, and use data center heat distribution to achieve cooling optimization and scheduling optimization. The algorithm is suitable for data centers based on plate liquid cooling, and has typical Computing-intensive applications with time-varying characteristics, and application platforms with scalability. Data center energy efficiency improvement software under the premise of realizing basic energy efficiency improvement, the most important point is to ensure the availability of the software so that it has real practical value. Therefore, before realizing the above functions, it is necessary to fully consider the actual prerequisites for the availability of the functions. In terms of usability, the following issues need to be addressed,

7.6.1 Stock data center compatibility. How to apply software to existing data centers and existing applications, and to optimize energy efficiency as much as possible without changing the hardware, is an important manifestation of the actual value of software.

7.6.2 Lossless computing resource scheduling application. Since the most suitable resource is used to carry the application, when the new application traffic arrives, the current resource may not meet the application traffic pressure. How to ensure that the resource can quickly respond to application needs when the new traffic or burst traffic arrives.

7.6.3 The power consumption control status of the equipment is consistent. Due to the diversity of control methods, how to select appropriate control methods and set appropriate parameters to ensure that the control state of the device is consistent and effective, that is, to effectively reduce power consumption without affecting the service instances on the device.

7.6.4 Effectiveness of long-term control. For equipment or systems in the data center with a long control effective period (such as refrigeration, the effect may not be reflected until 15 minutes after adjusting the parameters), how to effectively predict the rationality of the current control. For example, if the refrigeration temperature is increased because the current load is low, it may happen that the load pressure becomes higher when it takes effect after 15 minutes, directly causing business losses.

8. Conclusion

In this paper, we aims at the high-efficiency data center based on cold plate liquid cooling, summarizes the energy consumption optimization methods for each level of the data center, proposes the optimization parameters of energy utilization that affect the data center, and provides a global variable to optimize energy consumption Methods. It is hoped that this paper can promote the energy efficiency of the data center to the greatest extent and help achieve the goal of carbon peak and carbon neutrality.

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