Operation optimization of data center based on multi-station integration

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Abstract. With the rapid development and extensive application of Internet technology, the data information grows exponentially. The proposal of the multi-station integration mode not only provides effective assistance for the development of the big data industry, but also put forward a new direction for the energy-saving operation of data centers. This paper presents a cooperative operation architecture of the fusion station covering substation, data center and energy storage power station, and establishes a mixed integer nonlinear programming model which aims at minimizing the annual total cost. The analysis of the role of data migration and energy storage scheduling are carried out by case study. The calculation results showed that, the typical daily operation cost was reduced by 10.52% and the annual total cost was reduced by 5.96% after the implementation of the data migration and the energy storage scheduling. Results demonstrate that on the premise of satisfying the delay constraint, the complementary scheduling of each fusion station can be realized through a certain data migration strategy, hence reducing the cost. Furthermore, the energy storage scheduling can transfer the peak load to the valley load, thus significantly decreasing operation costs.

1 Introduction

With the rapid development of the mobile Internet, the world has fully entered the era of digital information interconnection. As an important network infrastructure, data center undertakes the transmission, integration, analysis and processing of massive data information, and is an important support platform to promote digital transformation. Especially since 2020, the state has focused on promoting the "new infrastructure" strategy, which has provided a booster for the rapid development of data centers.

As the scale of data center deployment continues to grow, data centers have become a considerable power load. In the face of huge power costs and massive data processing tasks, data center energy saving and data migration strategy research have been widely concerned. "Multi-station integration" advocates the use of existing substation resources to build data centers, energy storage power stations, charging stations, 5G base stations and other functional stations, so as to fully carry the grid business data, meet the increasing demand for data storage, integration and value-added operations, and realize the integration of the three

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streams of "energy flow, business flow, and data flow"[1]. The application of the multi-station integration mode can improve the resource utilization rate and energy efficiency of substation stations, while developing emerging businesses such as big data industry and 5G industry in the area.

The proposal of the multi-station integration mode not only provides effective assistance for the development of emerging services such as the big data industry and 5G industry, but also proposes a new direction for the location planning and energy-saving operation of data centers. The energy consumption of the data center mainly includes the energy consumption for processing data loads and daily operation of devices. Existing research also optimizes the operation of the data center from these two aspects.

Several studies have considered how to design data task migration strategies to minimize energy consumption and cost of the data center. Cuervo et al.[2] proposed the MAUI task migration platform, which supports task migration by identifying application code. Chae et al.[3] proposed CMcloud, a task migration platform, to migrate as many mobile applications as possible to a single server to minimize server costs. Lagerspetz[4] proposed that energy consumption was the most basic evaluation standard for migration, but time requirement was not taken into account. Zhang et al. [5] considered energy consumption and time as the evaluation criteria for task transfer. Jia et al. [6] decomposed the task into multiple chained sub-tasks, constructed the problem of minimizing energy consumption into the shortest path problem, and obtained the approximate optimal solution by using the Lagrange relaxation algorithm. Li et al. [7] put forward an optimization scheme for task migration in mobile edge computing environment by comprehensively considering three factors: energy consumption, time delay and server execution cost.

In terms of energy saving in daily operation, several research has been done. Srikantaiah et al. [8] improved the resource utilization of data center servers through server consolidation, and reduced data center energy consumption by reducing the number of servers running. Andreolini et al. [9] realized dynamic management of servers by virtualization and consolidation technologies considering the heterogeneity of servers in data centers. Le et al. [10] aimed at minimizing energy consumption and cost, considering the data center service level agreement, and optimized the application integration strategy in the cloud computing scenario. Alqawasmeh et al.[11] established a data center energy consumption model considering server performance status, allowing the server to make trade-offs between different processing rates and energy consumption, and realizing collaborative optimization of service quality and energy consumption level of data center.

Although there are many literatures on data center operation optimization, there are still some problems that have not been well solved. At present, there are few studies considering the task migration strategy among multiple edge data centers. And the operation method of multi-station integration also needs to be further expanded.

In this work, we construct the load model of data center(DC) and the mathematical model of energy storage power station(ESPS), present a mixed integer nonlinear programming (MINLP) model for tackling the scheduling problem which aims at minimizing the total annual cost of a fusion station covering data center, energy storage power station and substation. Finally, we propose the optimal data migration scheduling strategy for multi-destination and the optimal operation scheme of the fusion station.

The rest of this paper is organized as follows. In Section 2, the problem is described briefly. In Section 3, the mathematical model is provided. Subsequently, a case study based on the developed approach is presented in Section 4. Finally, conclusions are given in Section 5.

2 Problem description

In this paper, the coupling operation and collaborative optimization of fusion stations are considered. Example of such fusion station is given in Fig. 1. It is assumed that each fusion station integrates a substation, a data center and an energy storage power station. The substation provides power support for the surrounding area, data center and energy storage power station. The data load processed by the data center comes from the surrounding area of the fusion station. A front-end portal is set up to integrate the data load, and redistribute it according to a certain strategy to realize data migration among multiple fusion stations. In addition, traditional data centers are typically equipped with an energy storage system as a backup power supply to provide power for the data center in the event of a power failure. In this work, the optimal configuration of the capacity of the energy storage system is considered. On the premise of reserving the standby power of the data center, the time-of-use electricity price is adopted to cut the peak and fill valleys of the power load through the energy storage system, so as to reduce the operating electricity fee.

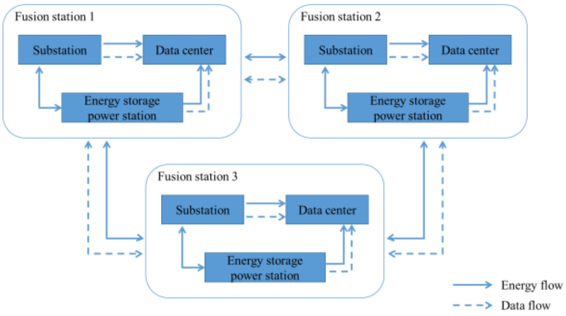


Fig. 1. Example of such fusion stations.

The planning and design of the fusion station also need to consider factors such as the difference in power supply load of each substation, the difference in typical power usage periods, electricity price policy difference and the land resources limitation. The data migration and energy storage scheduling aimed at cost reduction must be carried out under the premise of ensuring the safety of power supply in the substation.

3 Mathematic model

In order to study the data migration method of edge data center and the collaborative optimization of each function station under the mode of "multi-station integration", the DC model and ESPS model are established, and the constraint conditions and objective function involved in the model are designed.

3.1 Data center

The power load of a data center is mainly from IT equipment, air conditioning system, and power distribution system. The power consumption ratio of the three is 5:4:1[12]. Therefore, the DC energy consumption model can be approximately described as follows:

$$P_{\mathrm{DC}} = P_{\mathrm{IT}} + P_{\mathrm{c}} + P_{\mathrm{d}} \tag{1}$$

Where P_{IT}, P_c and P_d denote respectively energy consumption of IT equipment, air conditioning system, and power distribution system.

The energy consumption of IT equipment mainly includes the energy consumption of the server, the energy consumption of the communication equipment and the energy consumption of the storage device. Among them, the energy consumption of the server accounts for about 80%, which is generated in the process of data processing[12]. Therefore, the energy consumption of IT equipment can be calculated by establishing a server energy consumption model and the total energy consumption of DC can be calculated based on the energy consumption of IT equipment.

3.1.1 The energy consumption of server

It is assumed that the server state can be divided into working state and dormant state. It takes a long time for a server to restart, which adversely affects the quality of service (QoS) of DC, and the service life of the server is affected by the frequent startup and shutdown. Therefore, the shutdown status of the server is not considered. The energy consumption of servers can be flexibly regulated by adjusting the number of working servers, which is subsequently evaluated by using the following formula:

$$P_{\mathrm{s},t} = P_{\mathrm{w}} n_t + P_d (M - n_t) \tag{2}$$

Where $P_{\mathrm{s},t}$ is the total energy consumption of the server at time t, P_{w} is the energy consumption of the server in the working state, P_d is the energy consumption of the server in the dormant state, M is the total number of servers, and n_t is the number of working servers.

3.1.2 The delay constraint

The response time of data load is an important indicator of service quality of DC. When the data load is allocated to the data center, it first enters the queue for waiting, and the data center processes it according to the queue order. Based on the knowledge of M/M/1 queuing theory, the average residence time of data load in data center (i.e., data processing delay time) can be calculated, and the delay constraint is expressed as follows:

$$0 \le \frac{1}{\mu - \frac{\lambda_t}{n_t}} \le T_{\mathrm{d}} \tag{3}$$

Where λ_t is the total data load arriving at DC at time t, μ is the average service rate of working servers, which depends on server performance, and T_{d} is the maximum delay time.

3.2 Energy storage power station

3.2.1 Energy storage process

Electricity stored in the electrical storage at time t is equal to the amount stored at time t-1 plus the electricity charged minus the electricity discharged. Electricity would be lost during the charging and discharging process. The energy storage process is described as follows:

$$\mathrm{SOC}_{i,t} C_{\mathrm{b},i} = \mathrm{SOC}_{i,t-1} C_{\mathrm{b},i} + \eta_{\mathrm{bc}} P_{\mathrm{bc},i,t} - \frac{P_{\mathrm{bd},i,t}}{\eta_{\mathrm{bd}}} \tag{4}$$

Where $\mathrm{SOC}_{i,t}$,$\mathrm{SOC}_{i,t\text{-}1}$ are the state of charge of the battery in the fusion station i at time t and t-1, $C_{\mathrm{b},i}$ is the designed capacity of the battery, $P_{\mathrm{bc},i,t}$ and $P_{\mathrm{bd},i,t}$ are the charging and discharging power of the battery; η_{bc} and η_{bd} are the charging and discharging efficiency.

3.2.2 Energy storage constraints

The energy storage power station should use part of the capacity to achieve peak shaving on the condition that the data center is powered on for half an hour, and the depth of discharge should not be too large in consideration of battery lifetime. The energy storage constraints are given as follows:

$$\mathrm{SOC}_{\min} \le \mathrm{SOC}_{i,t} \le \mathrm{SOC}_{\max} \tag{5}$$

$$\alpha_{\mathrm{bc},i,t} + \alpha_{\mathrm{bd},i,t} \le 1 \tag{6}$$

$$0 \le P_{\mathrm{bc},i,t} \le \alpha_{\mathrm{bc},i,t} P_{\mathrm{bc,max}} \tag{7}$$

$$0 \le P_{\mathrm{bd},i,t} \le \alpha_{\mathrm{bd},i,t} P_{\mathrm{bd,max}} \tag{8}$$

Where SOCmax and SOCmin are the maximum and minimum states of charge of the battery respectively, αbc,i,t and αbd,i,t are the charge and discharge states respectively, which are the binary variables. Pbc,max and Pbd,max are respectively the maximum charge and discharge power.

3.3 Energy balance

The energy required for the daily operation of the fusion station comes from the power grid purchase and the energy stored by the energy storage power station. The energy consumption mainly includes the energy consumption of the data center and the charging of the energy storage power station.

The electricity consumed during each time period is supplied by the grid and electricity received from the electrical storage, minus the energy consumption of DC and electricity sent to the ESPS. The energy constraint is described as follows:

$$P_{\mathrm{g},i,t} + P_{\mathrm{bd},i,t} = P_{\mathrm{DC},i,t} + P_{\mathrm{bc},i,t} \tag{9}$$

$$P_{\mathrm{g},i,t} \le P_{\max} \tag{10}$$

Where $P_{\mathrm{g},i,t}$ is the power exchange between fusion station i and the grid at time t, $P_{\max}$ is the maximum exchange power. When the substation supplies power to the fusion station, it is necessary to ensure the reliability of the surrounding power supply at the same time. Therefore, the surrounding power supply situation of the substation and the limitation of the energy supply network are considered.

3.4 Objective function

The objective function is to minimize the annual total cost of fusion stations, which is calculated as follows:

$$\min F = F_{\mathrm{inv}} + F_{\mathrm{m}} + F_{\mathrm{g}} \tag{11}$$

Where F_{inv} is investment cost, F_{m} is maintenance cost, F_{g} is power purchase cost.

The investment cost, maintenance cost and power purchase cost are calculated as follows:

$$F_{\mathrm{inv}} = f \sum_{u} C_u p_{\mathrm{inv},u} \tag{12}$$

$$F_{\mathrm{m}} = \sum_{t} \sum_{n} P_{n,t} p_{\mathrm{m},n} \tag{13}$$

$$F_{\mathrm{g}} = \sum_{t} P_{\mathrm{g},t} p_t \tag{14}$$

Where f is the capital recovery factor, C_u is the installed capacity of equipment u, $p_{\mathrm{inv},u}$ is the investment cost per unit capacity of equipment u, $P_{u,t}$ is the power of device u at time t, and $p_{\mathrm{m},u}$ is the maintenance cost per unit of equipment u, $P_{\mathrm{g},t}$ is the power that the grid supplies to the fusion station, and p_t is the price of purchasing power from the grid.

4 Case study

4.1 Data and setup

The project life cycle is 10 years and the interest rate is 6%. The time-of-use electricity price is adopted and the electricity price follows different standards according to the surrounding environment and the voltage level of the substation. It is assumed that 110 kV substation supplies power to large industrial parks, 35 kV substation supplies power to small industrial users, and 10 kV substation supplies power to commercial buildings. Time-of-use price trend is shown in Fig.2. The data load arriving at the data center is simulated by Poisson process. The voltage level of substation in each fusion station is different, and the scale of edge data center and energy storage power station is different accordingly. In this work, collaborative optimization of three fusion stations has been considered. The voltage levels of substation of fusion station 1, 2 and 3 are 110 kV, 35 kV and 10 kV respectively.

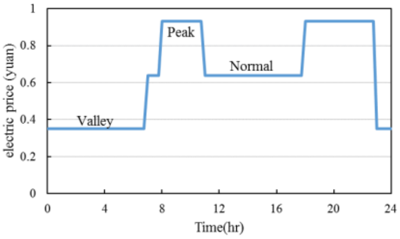


Fig. 2. Time-of-use price trend curve.

4.2 Scenario definition

Scenario A: Data load has no migration strategy, and the energy storage power station is only used as backup power supply.

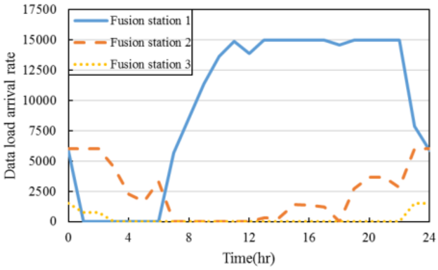
Scenario B: The data load follows the data migration strategy which is oriented to minimize the cost. Migration scheduling is carried out among the three fusion stations, and energy storage power stations are used to participate in the daily power supply.

4.3 Results and discussion

In this subsection, through the comparative analysis of two scenarios presented in the previous subsection, the role of data migration and energy storage scheduling is studied.

Scenario A has no data migration strategy, the data load of each fusion station is distributed proportionally according to its scale. The workload distribution of each fusion station in scenario B is shown in Fig.3. Different from the proportional distribution in scenario A, the data load migrates to fusion station 1 with lower electricity price as far as possible in scenario B. Obviously, operating costs can be reduced in this way.

The typical daily real-time operation of ESPS in scenario B are plotted in Fig.4. As can be seen, the energy storage power station charges and discharges twice a day, charging during normal and valley electricity price periods, and discharges during peak electricity price periods to provide energy for the data center. In this way, peak load can be cut and valley can be filled to reduce the operation cost of data center.



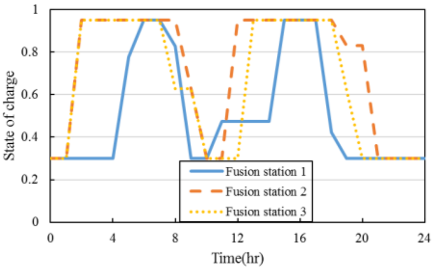


Fig. 3. Workload distribution in scenario B. **Fig. 4.** Real-time operation of ESPS in scenario B.

The comparison of typical daily operating costs of scenarios A and B is shown in Fig.5. As can be seen, the fluctuation of operating cost in scenario A basically corresponds to the change of electricity price. In scenario B, the energy storage power station charges during normal and valley electricity price period and discharges during peak electricity price. Thus the operating cost of scenario B increases in normal electricity price period compared with scenario A, and decreases significantly during peak electricity price period. Compared to scenario A, the typical daily total operating cost of scenario B has been reduced by 10.52% and annual total cost has been reduced by 5.96%.

The results show that the energy storage scheduling and data migration have their advantages in reducing operating costs, and may achieve more significant results when applied to the operation scheduling among multiple fusion stations.

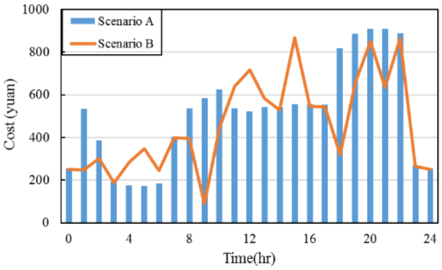


Fig. 5. Comparison of typical daily operating costs.

5 Conclusion

This paper presents a fusion station operation architecture covering substation, data center and energy storage power station, and based on the mixed integer nonlinear programming method, established the collaborative optimization and data migration scheduling model of fusion station with the goal of minimizing the total annual cost. The approach was applied within a case study of different scenarios of two different strategies. The simulation results showed that, the typical daily operation cost was reduced by 10.52% and the annual total cost was reduced by 5.96% after the implementation of the data migration and the energy storage scheduling. The analysis results showed that migrating the data load to the data center with lower electricity price can significantly reduce the data processing cost, on the premise of ensuring the QoS of the data center. In addition, by involving energy storage power stations in daily power dispatching, the peak of power load can be cut and the valley of power load can be filled, thus reducing operation cost.

The work is supported by 'Research on Key Technology of Planning and Construction of Multi-Station Integrated Substation Based on Ubiquitous Electric Internet of Things' (5213402000HF), research project of State Grid Fujian Electric Power Co., LTD.

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