Study on Control Strategy of Microbus Power System Based on Branch-and-Bound Algorithm

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Abstract. With the development of information technology, the scale of data center infrastructure has become larger and larger, which has always brought many challenges, such as unbalanced power load, high energy consumption, small scalable space and so on. In recent years, a distributed power supply structure, namely microbus power supply, has emerged, which is different from the traditional power distribution mode in computer room. It can adjust the power load distribution online in real time. This paper analyses the advantages of this microbus structure power supply mode, and optimizes the cabinet power collection strategy based on branch and bound algorithm. By modeling and simulating the power consumption of the computer room in a real data center, the experimental results show that the proposed algorithm can greatly reduce the unbalance rate of the three-phase power supply equipment in the upper end of the computer room. Compared with the traditional power supply mode, it can reduce the maximum power imbalance by 49.88%.

1. Introduction
With the continuous development of communication services and Internet applications, the construction of IDC (Internet Data Center) has become one of the key business of communication enterprises to meet the business needs of accelerated development in the next few years. With the continuous expansion of business and scale, the input and output of data center or computer room infrastructure plays an important role in the business development of communication enterprises. However, the high energy consumption of communication industry has become a hot topic. The harmonious development of data center and environment, society and economy will face a severe test. On June 28, 2016, the State Administration of Organizational Affairs and the Development and Reform Commission compiled the 13th Five-Year Plan for Energy and Resources Conservation in Public Institutions [1]. In the plan, we need to strengthen the management of energy saving in the computer room. We must build a computerized monitoring and control system for the energy consumption and environment of the computer room, improve the energy saving management level of the data center, carry out the pilot project of the green data center, implement the energy saving transformation of the data center, and require that the average energy consumption of the data center be reduced by 8% after the transformation.

This paper focuses on the analysis and research of the rational distribution and utilization of power resources in computer room. Energy saving can be achieved by improving the utilization rate of electric energy. The main contributions are as follows: the analysis of the new power distribution mode of microbus [2] which someone else call it the track busway in computer room, and the optimization
of power distribution based on branch and bound method, aiming at improving the utilization efficiency of power in computer room to the greatest extent on the basis of ensuring the balance of three-phase power supply.

The rest of this paper is organized as follows: Section 2 introduce the backgrounds which analyze the disadvantages of the traditional power system. In Section 3, we introduce the new type of power supply mode that is microbus in computer room. In Section 4, we model the microbus power distribution problem as an integer programing problem, and propose a branch-and-bound based algorithm to optimize the power supply within microbus. In Section 5, we present the experimental results. Finally, conclusions are provided in Section 6.

2. Backgrounds
At present, China's data centers are becoming larger and larger, more and more equipment, more and more complex systems, so the demand for power supporting facilities, especially power system, is also increasing. The traditional power supply mode of cabinet in data center is mainly composed of Uninterruptible Power Supply, header cabinet, PDM (Power Distribution Module), PDU (Power Distribution Unit), etc. Through UPS power supply to the header cabinet, and then from the header cabinet to the rack. It can hardly be modified after the construction, and the rated capacity and potential of the cabinet must be confirmed before construction, resulting in inconvenience for later use. The above-mentioned traditional power supply mode not only easily leads to the three-phase imbalance of power supply, but also restricts the flexible use of racks. Moreover, when the room is expanded and transformed, the traditional power supply system has almost no possibility to benefit the old. The traditional power supply mode will face enormous challenges. The following main problems exist in the traditional power supply mode.

2.1 Electricity consumption of cabinet cannot be reasonably allocated
Because there are many kinds of information system equipment, and the power consumption and volume cannot be unified, some equipment is small but the power consumption is large, some equipment is large and the power consumption is small. After installation, the power consumption of cabinet will vary greatly. There will often be a phenomenon that rack space is full but the power consumption is low, and the power consumption is full but the rack interior space is rich, which leads to the power and space waste.

2.2 Three-phase imbalance
Three-phase imbalance refers to the large deviation of current or voltage amplitude of three-phase electricity (phase A, phase B and phase C) in power system. If the amplitude of current or voltage of three-phase current is the same and the difference of phase angle is $2\pi/3$, it is called three-phase equilibrium or three-phase symmetry. In the three-phase imbalanced state of power supply system, there are a large number of zero-sequence [3] or negative-sequence [4] components in the system, which not only cause energy damage, but also bring a lot of adverse effects on equipment in the whole power system, which may endanger the security of the whole power system, and have some specific hazards including but not limited to increasing line loss, reducing the service life of transformers as well as the uninterruptible power supply (UPS) [5] equipment, and Influencing the operation safety of IT equipment (such as large servers, storage servers, etc.) in computer room.

3. Analysis of Power Supply Mode of New Type Microbus in Computer Room
In order to solve the above problems, in recent years, a microbus power supply mode which someone else call it the track busway has emerged in the computer room, which provides a feasibility for ensuring three-phase balance of power supply, improving the efficiency of cabinet utilization and reducing investment costs. This kind of power supply adopts the principle of distributed system design, which can distribute the equipment in the head cabinet. As shown in figure 1:
Figure 1. Schematic diagram of distributed microbus power supply system for racks.

From figure 1, it can be seen that all parts of the header cabinet are distributed installed, including overhead distribution cabinet (incoming cabinet), distribution bus, plug-in box (or terminal), branch switches and power supply detection system.

By using busbar to supply power to the racks, it is equivalent to draining water from a water tank, so it can control the reasonable output of power well. The main advantages are as follows:

1. When the power load of one rack is lower than the rated power, the other racks under the same-phase power supply in this column can use the power beyond the rated power, as long as the total current of this phase does not exceed the rated current of the power bus.

2. The racks supplied by different phases can also be flexibly adjusted and distributed. Because of the use of buses for power supply, the connection mode of branch cables is more flexible, and can be connected by plug-in boxes or industrial connectors. Therefore, when the power supply of one phase deviates from other phases, the balance of three-phase power supply can be guaranteed by commutating the rack.

3. For the rack powered by single machine and double bus, the above-mentioned method can also be used to ensure load balance between two or more UPS.

4. Microbus modeling and Power Distribution Strategy Based on Branch and Bound Algorithm
In the data center, a set of UPSs will supply power for multiple racks. In the UPS output cabinet, a three-phase output switch is usually used for only one column of racks. The racks only use single-phase electricity, the number of racks per column is generally three times the number of integers, such as 9, 12, etc., so as to ensure that each column of racks can achieve the optimization goal. Bus-bar power supply system is as figure 2.
4.1 Modeling of The Power Distribution in Microbus

The optimization objective of this paper is to ensure load balance between two UPS with single machine and double bus, and load balance among different phases of UPS. The equation is as follows:

\[ s = \min(w_1|Q_1 - Q_2| + w_2(D_1 + D_2)) \]  \hspace{1cm} (1)

\[ Q_i = \sum_{j=1}^{3} \sum_{r=1}^{n_{row}} \sum_{k=1}^{n_r} x_{ijk\text{r}} \times \text{load}_{r\text{kp}}, i = 1,2; \]  \hspace{1cm} (2)

\[ Q_{ij} = \sum_{r=1}^{n_{row}} \sum_{k=1}^{n_r} x_{ijkrp} \times \text{load}_{r\text{kp}}, i = 1,2, j = 1,2,3; \]  \hspace{1cm} (3)

\[ D_i = \frac{1}{3} \sum_{j=1}^{3} (Q_{ij} - \frac{1}{3} \sum_{j=1}^{3} Q_{i(j)})^2, i = 1,2; \]  \hspace{1cm} (4)

s.t.

\[ x_{ijkrp} \in (0,1); \]  \hspace{1cm} (5)

\[ \sum_{j=1}^{3} \sum_{p=1}^{n_{ps}} x_{ijkrp} = 1, i = 1,2, r = 1,\ldots,n_{row}, k = 1,\ldots,n_r; \]  \hspace{1cm} (6)

\[ \sum_{i=1}^{2} \sum_{j=1}^{3} x_{ijkrp} = 1, r = 1,\ldots,n_{row}, k = 1,\ldots,n_r, p = 1,2; \]  \hspace{1cm} (7)

\[ \sum_{r=1}^{n_r} x_{ijkrp} \times \text{load}_{r\text{kp}} \leq C_{ijr}, i = 1,2, j = 1,\ldots,n_{ps}, r = 1,\ldots,n_{row}; \]  \hspace{1cm} (8)

Equation (1) is the optimization objective of this paper, and \( w_1 \) and \( w_2 \) are the weights. \( \text{load}_{r\text{kp}} \) in equation (2) denotes the load of the \( p \)th route of the \( k \)th rack in \( r \)th column, which can be collected in real time during the operation of the computer room. \( Q_i \) in equation (2) denotes the total load of the \( i \)th UPS. \( Q_{ij} \) in equation (3) denotes the phase \( j \) load of the \( i \)th UPS. \( D_i \) in equation (4) represents the variance of load between phases of the \( i \)th UPS. Equation (5) denotes the connection between each circuit of each cabinet and the bus bar above the cabinet. When the value of \( x_{ijkrp} \) is 1, the circuit of the \( p \)th route of the \( k \)th rack in \( r \)th column is taken from the phase \( j \) of the \( i \)th UPS, and when the value of \( x_{ijkrp} \) is 0, it represents that the circuit of the \( p \)th route of the \( k \)th rack in \( r \)th column is not taken from the phase \( j \) of the \( i \)th UPS. Equation (6) indicates that each circuit of each cabinet can only be taken from one phase of an UPS, and that two circuits are taken from different UPS. Equation (7) indicates that the power of each rack from one UPS phase cannot exceed the capacity \( C_{ijr} \) of the bus above the cabinet. Equation (8) denotes that the power of all phases taken from an UPS in a computer room cannot exceed the capacity \( C_{ij} \) of the phase of the UPS.
From the power supply structure of microbus and the optimization formulas, it can be seen that each rack can get power from phase A, B and C of this column separately, and only from one phase. As from which phase to get power can make UPS output more balanced, this kind of problem is a kind of integer programming problem [6], which is NP-hard problem [7]. The most effective solution to this kind of problem is branch and bound algorithm [8].

4.2 Branch and Bound Based Algorithm to Optimize The Power Distribution in Microbus

Branch and bound algorithm is a method of searching the solution of the problem by using the solution space tree of the problem. The specific method is to decompose the given problem into several relatively small sub-problems (called branches), and each sub-problem can continue to decompose downward until the decomposed sub-problems can no longer continue to decompose downward or the sub-problems cannot produce optimal solutions. In the process of branching the problem to be solved, it is called bounding to estimate the corresponding bounds or target ranges for each subproblem decomposed. The purpose of delimitation is to predict the trend of approaching the target value according to the characteristics of the problem, and to retain the branch whose trend is correct or cannot be judged yet. Deleting branches that deviate significantly from the target and tend to or are sure to be the optimal solution is called pruning. Through this method, the number of operations can be simplified and the convergence can be accelerated.

There are many constraints in power distribution system, which can be divided into three parts:

(1) The first part is that the total cabinet load of each distribution bus does not exceed the carrying capacity of the bus.

(2) The second part is load balancing among three-phase UPS.

(3) The third part is load balancing between two parallel dual bus UPS.

Therefore, according to the above constraints, a solution space tree can be established to solve the problem. Firstly, the solution space tree is established for the first and second constraints.

Each rack needs and only accesses a bus, that is, the rack is powered by a single-phase bus. The microbus composes three-phase buses, and each phase electricity is a bus, expressed by \( r_x(P), x \in N, P \in (A, B, C) \), for example, phase A of \( r_1 \) column is represented by \( r_1(A) \). Each bus is equivalent to a knapsack, and the cabinet is regarded as the object to be put into the knapsack. It is represented by \( r_x^i, x \in N, y \in N \), for example, \( r_1^1 \) represents the first rack in the \( r_1 \) column. For each parent row of each column, a solution space tree is established. The solution space tree for each phase bus of column 1 is as figure 3:

Figure 3. Solution spatial tree of power supply buses.
The green node in figure 3 represents each computing branch. When the value of the objective function of computing branch \( k \) is larger than that of its parent node, the branch is cut off and its sub-node branches are no longer calculated. \( r^y_x = 1 \) indicates that the cabinet \( cy \) is connected to the corresponding busbar of the \( r_x \) column, and \( r^y_x = 0 \) indicates that the cabinet is not connected. The objective function value of each branch node is calculated sequentially until the smallest branch node, then the algorithm ends and which bus is the preferable power supply for each cabinet.

5. Experiments and discussion

In the computer room, it is usually powered by several UPSs, and each UPS supply power to two or four columns of racks according to its capacity. In this paper, according to the real power distribution system of a data center, modeling and simulation are carried out. There are 2 UPSs supplying power to 3 columns of racks. Each column is composed by 12 racks. Other parameters are set as table 1:

| Serial number of UPS | Total rated capacity(kVA) | Available capacity(kVA) | Phases | Rated capacity of each phase(kVA) | Number of racks | Power supply routes |
|----------------------|---------------------------|-------------------------|--------|----------------------------------|-----------------|--------------------|
| ups1                 | 350                       | 280                     | A/B/C  | 35.2/35.2/35.2                  | 36              | 2                  |
| ups2                 | 350                       | 280                     | A/B/C  | 35.2/35.2/35.2                  | 36              | 2                  |

Three columns of racks with traditional power supply are selected as well as their current loads and power sources are recorded as table 2:

| Power supply and load | c1  | c2  | c3  | c4  | c5  | c6  | c7  | c8  | c9  | c10 | c11 | c12 |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| r1_1 route load(kVA)  | 2.12| 1.34| 4.2 | 2.3 | 2.13| 3.5 | 4.11| 1.4 | 0.8 | 4.43| 1.32| 1.87|
| get power from UPS1   | UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1|
| r1_2 route load(kVA)  | 1.23| 2.34| 0.56| 1.06| 2.1 | 0.67| 1.45| 3.28| 1.21| 0.23| 1.59| 1.45|
| get power from UPS2   | UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2|
| r2_1 route load(kVA)  | 2.13| 1.34| 3.2 | 2.2 | 2.23| 3.5 | 3.51| 1.1 | 1   | 2.43| 4.02| 1.89|
| get power from UPS1   | UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1|
| r2_2 route load(kVA)  | 1.03| 2.34| 0.46| 1.34| 2.12| 0.67| 1.45| 3.25| 2.01| 2.23| 2.79| 1.45|
| get power from UPS2   | UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2|
| r3_1 route load(kVA)  | 2.12| 1.24| 4.2 | 2.3 | 0.13| 2.5 | 3.61| 1.42| 1.8 | 3.43| 2.22| 1.61|
| get power from UPS1   | UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1| UPS1|
| r3_2 route load(kVA)  | 1.23| 2.34| 0.56| 2.56| 1.1 | 1.07| 0.45| 3.28| 1.21| 1.03| 1.19| 1.08|
| get power from UPS2   | UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2| UPS2|

Through table 2, the traditional UPS load can be calculated as table 3:
Table 3. Unoptimized UPS load.

| Serial number of UPS | Phase | Load(kVA) | Imbalance ratio(%) |
|----------------------|-------|-----------|--------------------|
| UPS1                 | A     | 34.69     | 22.94              |
|                      | B     | 19.89     | 29.51              |
|                      | C     | 30.07     | 6.57               |
| UPS2                 | A     | 15.29     | 17.22              |
|                      | B     | 27.72     | 50.08              |
|                      | C     | 12.4      | 32.86              |

The load of UPSs optimized by the proposed algorithm in this paper is as table 4:

Table 4. Optimized UPS load.

| Serial number of UPS | Phase | Load(kVA) | Imbalance ratio(%) |
|----------------------|-------|-----------|--------------------|
| UPS1                 | A     | 23.29     | 0.23               |
|                      | B     | 23.29     | 0.23               |
|                      | C     | 23.45     | 0.46               |
| UPS2                 | A     | 23.28     | 0.27               |
|                      | B     | 23.39     | 0.20               |
|                      | C     | 23.36     | 0.07               |

Figure 4. Comparison of UPS load before and after optimization
As can be seen from Table 4, Figure 4, and Figure 5, the load of each UPS that is optimized is equal, which is 70.03 kVA, and the load of each phase of UPSs is balanced. It shows that the microbus power supply mode is superior to the traditional power supply mode in UPS load balancing and power distribution.

6. Conclusion
In this paper, the characteristics of traditional distribution system in data center are analyzed. It is pointed out that the microbus power supply mode can promote the three-phase balance of power supply, improve the efficiency of cabinet utilization and reduce the investment cost, which is of great help to the economic and safe operation of power distribution system. At the same time, a control strategy of rack power supply based on branch and bound algorithm is presented. By modeling and simulating the actual power consumption of a data center computer room, it can be seen that the algorithm in this paper can greatly balance the balance of three-phase power supply, thus reducing the potential safety hazards of distribution system.

Although the power distribution of bus-type power supply system is deeply studied in this paper, there are many problems involved in the computer room, so further research is needed to give full play to the advantages of bus-type power supply system.

(1) Busbar power supply system can be adjusted online according to the actual power consumption of the cabinet. The reading of the electrical parameters and the release of the control strategy need an advanced power environment monitoring system to assist in the completion.

(2) When the size of the computer room is large, the cabinet is required to adjust the bus automatically according to the downward control strategy. Therefore, the cabinet side needs to cooperate with the automatic conversion device.

References
[1] 13th Five-Year Plan for energy and resources conservation in public institutions by national government offices administration of China. http://ecpi.ggj.gov.cn/news/56166 [accessed 8 October 2019].
[2] Microbus model of power distribution by STARLINE company. https://www.starlinepower.com/busway. [accessed 8 October 2019].
[3] Elmer Sorrentino, Juan Carlos Burgos. Rules to estimate the expected values of zero-sequence impedances in 3-phase core-type transformers. 2018 Electric Power Systems Research. 165 94-101
[4] Sunghyok Kim, Songchol Hyon, Chonung Kim. Distributed virtual negative-sequence impedance control for accurate imbalance power sharing in islanded microgrids. 2018 Sustainable Energy, Grids and Networks. 16 28-36
[5] Fang Cao, Yajing Wang, Feng Zhu, Yujie Cao, Zhaohao Ding. UPS node based workload management for data centers considering flexible service requirements. In: 2019 IEEE/IAS 55th Industrial and Commercial Power Systems Technical Conference. (Calgary, Canada) p 1-9.

[6] Reed Harder, Vikrant Vaze. An integer programming approach to fisheries observer deployment. 2019 Transportation Research Part E 127 132-149

[7] Xiaodong Wang, Jun Tian. Dynamic programming for NP-Hard problems. 2011 Procedia Engineering 15 3396-3400

[8] Jeffrey Schaller, Jorge Valente. Branch-and-bound algorithms for minimizing total earliness and tardiness in a two-machine permutation flow shop with unforced idle allowed. 2019 Computers & Operations Research 109 1-11