RESEARCH ON POWER INTERNET OF THINGS MODEL AND RESOURCE ALLOCATION BASED ON EDGE COMPUTING

Jing LI[1], Xutao LU[2*], Feng LIU[3], Xiangquan HUANG[4], He LIN[5], Yifeng REN[6]

In order to improve the efficiency of resource allocation in the power Internet of Things, a micro-service model for power Internet of Things was proposed by edge computing Business data was divided into 4 different types, and resource matching calculation for aggregated services was completed by edge computing. Computing resource allocation model was used to obtain the computing resource allocation and resource supply of the edge computing terminals. In the test experiment, the CPU resource occupancy curve was obtained in the condition of different resource scaling ratios. It verified the feasibility of the algorithm. The resource utilization ratio of simultaneous trigger service and non-simultaneous trigger service was compared and analyzed. The results show that it verifies the optimization effect of this algorithm, which can reduce the total cost.

Keywords: power Internet of things; edge computing; resource allocation; optimization algorithm

1. Introduction

In the power Internet of things (IoT) [1, 2], the effective allocation of resources can greatly improve the work efficiency of the system. During efficient resource allocation processes, it is very important to reduce the processing delay of edge data. As a result, edge computing technology is widely used in the power Internet of Things, such as "edge-edge interaction" , "edge-end interaction", and so on [3-5]. Edge computing terminals (ECT) [6] can improve network

---

[1] Associate Prof., School of Electrical and Control Engineering, North University of China, China, e-mail: lj@nuc.edu.cn

[2] Associate Prof., College of Mechatronics Engineering, North University of China, China, e-mail: luxutao@nuc.edu.cn **(Corresponding Author)**

[3] Senior Engineer, Chongqing Optoelectronics Technology Institute, China, e-mail: lfcoeri@sohu.com

[4] Senior Technician, Sichuan Institute of Piezoelectric & Acoustooptic Technology, China, e-mail: a3019640832@126.com

[5] Technician, Chongqing Optoelectronics Technology Institute, China, e-mail: 447291377@qq.com

[6] Prof., School of Electrical and Control Engineering, North University of China, China, e-mail: renyifeng126@126.com

performance by optimizing resource allocation algorithms. ECT network design is great significance based on edge algorithm.

In the cloud-edge fusion system, the edge computing terminal can support the depth perception of network information and +b 7realize the diversification and ecologicalization of IoT devices for power supply system [7-9]. The edge computing terminal model of IoT devices for power supply system is great significance, which can avoid waste of resources.

For the division of nodes in complex networks, Liu et al [10] proposed a method to determine subgraphs by the node connection relationship, but it did not consider the influence of node location differences. Zhou et al [11] proposed a power terminal control algorithm in the cloud-edge collaboration mode, which combined the density and distance parameters, but it still did not consider the influence of mutual communication between terminals.

Wang et al [12] proposed a task configuration decision algorithm, which could effectively balance equipment energy consumption and calculate task processing time by calculating the equipment quota. However, it did not fully consider the impact of the relationship between services on the terminal network. Feng et al. [13] built a fog computing model based on the quality of user experience. It realizes task allocation and optimizes the quality of user experience.

Feng et al [13] built a fog computing model based on the quality of user experience. It realizes task allocation and optimizes the quality of user experience. Xin et al [14] analyzed the key technologies of edge computing nodes, and proposed the implementation scheme of edge computing nodes. Its distribution network application scenarios was designed. Si et al [15] established a cloud-edge collaboration structure model, the business was completed by the edge computing platform, and the data comprehensive processing business was completed by the cloud-edge collaboration.

This paper focuses on fully creating a power IoT model based on edge cloud computing, so that it can reasonably allocate network resources. Its application scenario is the power distribution website area. Microservice model and computing resource allocation method were proposed. According to the characteristics of the power Internet of Things, the microservice structure was optimized to reduce resource consumption.

2. System Model Construction

2.1 Architecture

The architectural form adopted is a total of 5 layers, namely the access layer, the facility layer, the platform layer, the support layer and the business layer. The access layer imports business requirements. The facility layer provides resource facilities for the platform layer. The platform layer provides management instructions for edge computing. The support layer provides background services for the business layer. The business layer is divided into two types: aggregate business and basic business. The aggregation service aggregates a set of basic services, and it is shown in Fig. 1.

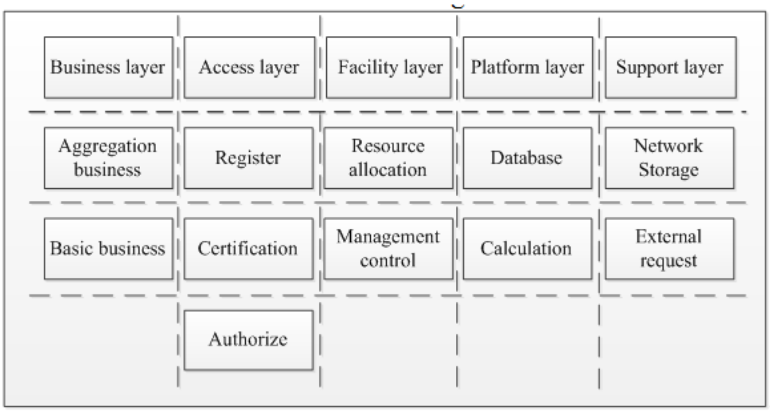


Fig.1. Architecture design of the system

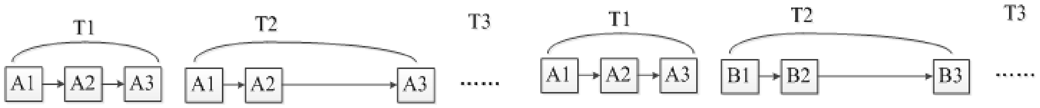
It has good compatibility with edge computing terminals and microservice technology. It has the characteristics of lightweight independent deployment for microservice, and it can effectively improve to development. The edge computing terminal adopts container technology, which can build multiple containers at the same time, and this structure can meet the needs of multiple basic services.

2.2 Timing Model

Serial and parallel are used to express the temporal logical relationship of basic services, and aggregation degree is used to express the relevance and periodicity of aggregated services. Serial and parallel are the communication attributes of data, which determine the data communication format. There are 4 characteristic forms: associative periodic aggregation (AP), associated aperiodic aggregation (AA), non-associated periodic aggregation (NP) and non-associated aperiodic aggregation (NA) [16-18]. Its timing expression is shown in Fig. 2.

(a) Associative Periodic Aggregation

(c) Non-Associative Periodic Aggregation



(b) Associative Aperiodic Aggregation

(d) Non-Associative Aperiodic Aggregation

Fig. 2. Sequence logic expression of four aggregated services

Matrix Q and matrix W are used to characterize the correlation and periodicity of aggregation services, respectively. Q represents the degree of data correlation, and A1A2A3 and A1A2A3, A1A2A3 and B1B2B3 are correlation functions. W represents the periodic correlation degree, and its correlation functions are between the first T1T2T3 and the second T1T2T3.

Each column of matrix Q represents an aggregation service, and the elements in the first row of the matrix represent the aggregation service. The aggregation services with the group number constitute an associated aggregated business, and the aggregated services of a separate group are non-associated aggregated services. T is the execution time. Similarly, each column of the matrix W represents an aggregation service, and the element in the first row of the matrix is the periodicity of the aggregation service. When it is 1, it means the data is periodic. When it is 0, it means the data is aperiodic.

3. Resource Allocation Algorithm

3.1 Edge Computing

Let the resource model matrix S [19] has:

$$S = \begin{bmatrix} s_{i,j} & s_{q,g} \end{bmatrix}^T \tag{1}$$

Among the parameters above, *s* is the service resource, *i* and *j* are *j*-th basic service in *i*-th aggregated service under relevant conditions. Respectively, *p* and *g* are respectively *g*-th basic service in *p*-th aggregated service under non-correlated conditions.

Edge computing is performed for the above four aggregation services respectively. Edge computing terminal containers have a corresponding relationship with basic services, and each aggregated service includes multiple basic services. There is a functional relationship between aggregation services and containers. Edge computing terminals use a set of containers to supply resources for aggregation services. Its supply computing resource model is as follows:

$$AP(t) = \sum_{k=0}^{U} \left\{ \left[\sum_{i=1, j=1}^{n} s_{i,j} \left(\varepsilon \left(t - t_{i,j} \right) \right) \right] \left(t - kT - k\Delta t \right) \right\} \tag{2}$$

Which *s* is the business resource; ε is the function of step; *t* is times; *k* is the correction parameter; *U* is the extreme value of the correction parameter; *T* is the cycle time; *i* and *j* are the *i*-th cycle and the *j*-th association. respectively type, *n* is the sub-targets included, and *AP* (*t*) is the timing curve of the aggregated service supplying CPU resources.

For *AA* aggregation, its supply computing resource model is

$$AA(t)=\sum_{k=0}^{U}\left\{\left[\sum_{i=1,j=1}^{n}s_{i,j}\left(\varepsilon\left(t-t_{i,j}\right)\right)\right]\left(t-\sum_{x=1}^{X}T_x\right)\right\} \tag{3}$$

Which *x* is the time delay, and *X* is the upper limit of the time delay. Other parameters are the same as (2). *AA* (*t*) is the timing curve of supplying CPU resources for aggregated services. The same curve applies to the memory timing curve. For *NP* aggregation, its supply computing resource model is

$$NP(t)=\sum_{h=0}^{Q}\left\{\left[\sum_{q=1,g=1}^{Q}s_{q,g}\left(\varepsilon\left(t-t_{q,g}\right)\right)\right]\left(t-hT-h\Delta t_q\right)\right\} \tag{4}$$

Which *s* is the service resource; *ε* is the function of step; *t* is the time; *h* is the compensation parameter; *Q* is the extreme value of the compensation parameter; *T* is the cycle time; *q* and g are the *q*-th cycle and the *j*-th non-period; *n* is the number of sub-targets included; *NP* (*t*) is the timing curve of the aggregated service supplying CPU resources. The same curve applies to the memory timing curve. For *NA* aggregation, its supply computing resource model is

$$AA(t)=\sum_{q=1,g=1}^{Q}s_{q,g}\left(\varepsilon\left(t-t_{q,g}\right)-\varepsilon\left(t\right)\right) \tag{5}$$

Which *s* is the business resource; *t* is the time; *k* is the correction parameter; *U* is the extreme value of the correction parameter; T is the cycle time; *i* and *j* are the *i*-th cycle and the *j*-th correlation type, respectively. *NA* (*t*) is the timing curve of supplying CPU resources for aggregated services. The same curve applies to the memory timing curve. Finally, the expression of the total supply computing resource model of edge computing terminals is

$$P(t)=\sum_{i=0,j=0}^{U}\left[AA(t)+AP(t)\right]+\sum_{p=0,g=0}^{Q}\left[NP(t)+NA(t)\right] \tag{6}$$

P (*t*) is the CPU resource timing curve of the edge computing terminal, and it is also applicable to memory timing curve. *i* and *j* are the cycles and association numbers corresponding to the associated business resources, while *p* and *g* are the cycles and association numbers corresponding to the non-associated business resources.

2.2 Resource Configuration Optimization

Resource configuration model should consider computing resource input cost, operation cost and aggregate service delay penalty cost. The resource input cost should consider the grid asset distribution and available space of edge computing terminals. It will affect the comprehensive index of investment and will also affect the computing resource allocation of the edge computing terminals. The operating cost should consider comprehensive indicators, such as heat loss, energy consumption of computing resources. The aggregated service delay penalty cost should be analyzed according to the service quality, and it can be given an evaluation index.

The constraints of the resource configuration model mainly include the computing resource capacity constraints and resource utilization of edge computing terminals [20], so the main constraint parameters can be quantitatively expressed by the following functions,

$$P(t) \leq E, \frac{1}{\sigma E}\sum_{\lambda=0}^{\sigma} P(\lambda\Delta t) \geq \theta \tag{7}$$

Among the parameters above, E is the configuration amount of the CPU resources; θ is the expected utilization of the CPU resources of the edge computing terminal; Δt is the simulation step size; σ is the total number of Δt.

2.3 Algorithm Implementation

According to the calculation for $P(t)$, the program implementation of the algorithm is shown in Fig. 3.

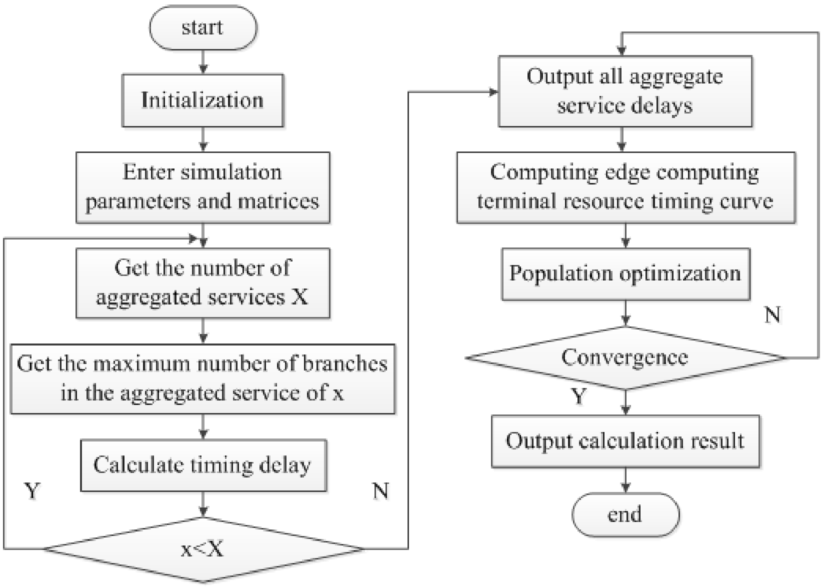


Fig. 3. Flowchart of the algorithm program

The time variables of the basic business and the aggregated business need to satisfy the temporal logic relationship. The delay was solved in the right half of the algorithm flow by the function. The solvers, toolboxes, etc. were used to the differential evolution algorithm. It cannot provide an interface for calling functions to get the return value, while the differential evolution algorithm can provide an interface to solve the model. The local information and global information were provided by global search optimization algorithm. So the population gradually was converged to the optimal solution. The optimal population of each generation was retained, and data was optimized. The convergence condition was set to reach some iterations and the change value could satisfy the convergence accuracy.

4. Experiments

The automatic control service of the experimental simulation distribution network station was used as an example for verification. The service architecture is shown in Fig. 2. The aggregation service parameters in the distribution network station area were used to solve the edge computing terminals of multi-type aggregation service and calculate the resource allocation results. In the simulation period of 15 s, there were 6 topology identification aggregation services, 2 loop impedance monitoring and positioning aggregation services, 2 line loss aggregation services and 2 automatic charging aggregation services.

4.1 Container Resource Scaling Rate Test

When the container resource scaling ratios of the edge computing terminal were 0%, 5%, 10%, 15%, the resource configuration results were shown in Fig. 4. Resource increments was elastic scaling rate, and the resource supply curve had a decreasing trend in both the horizontal and vertical directions.

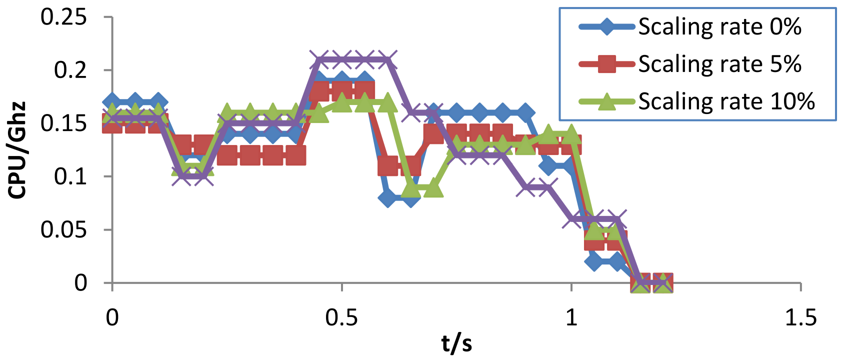


Fig.4. CPU resource supply curve

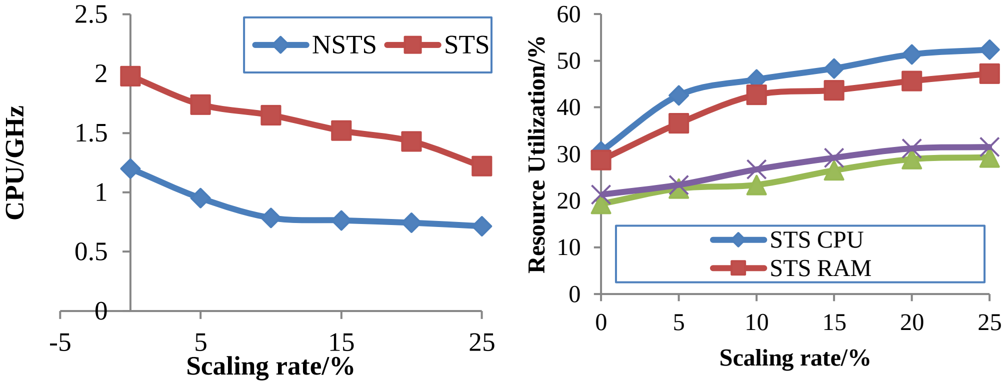
Horizontally, the aggregation service latency was reduced from 0.8 s to 0.7 s. CPU resources were reduced from 0.24 GHz to 0.21 GHz. The elastic scaling rate increase of container resources can be used to the supply resources, and each container can be flexibly adjusted in a wider range. It can help to save resources and reduce the delay of aggregation services, thereby improving resource utilization.

4.2 Resource Allocation Optimization Test

Different simulation conditions of aggregated services were constructed, which were simultaneous triggering services and non-simultaneous triggering services. The result of computing resource configuration of edge computing terminal was used to solve these two scenarios in Fig. 6. In the non-simultaneous trigger business scenario, during the simulation period, the random number was used as the start time of the aperiodic aggregation service, and 100 samples were constructed to obtain the expected value. During the simulation period, all aggregated services were executed at the same time, and the peak values were taken away by the system.

When the crossover probability of the differential evolution algorithm varied from 0.1 to 0.3, it had little effect on the average objective function value. The maximum solution fluctuation was less than 1%, and the convergence limit reached 0.5 × 10^{-6}. When the population dimension increased from 20 to 50, the time to solve a single aggregation service increased about 2.5 times, and the time to solve multiple aggregation service flows increased about 2 times. The computing resource allocation method belonged to the resource planning level, so the test results can reflect the optimization effect of the system algorithm.

In the non-simultaneous trigger business scenario, the container resource scaling rate was 15.0% in Fig. 5.



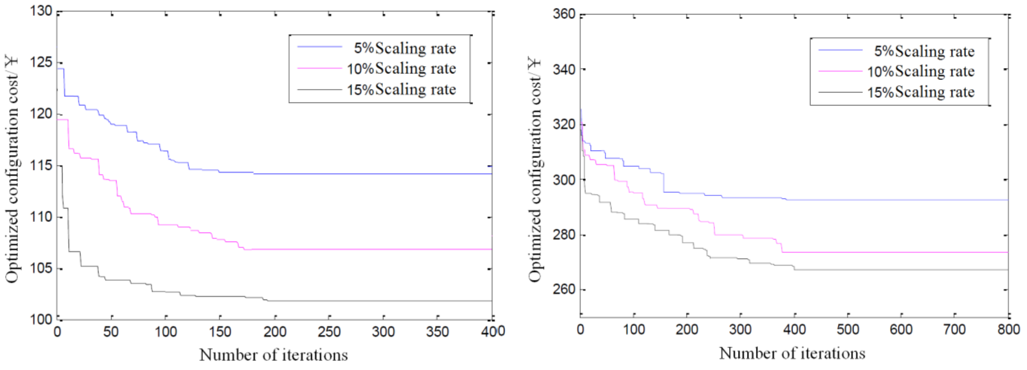
(a) CPU operating frequency (b) Average utilization of CPU and RAM

Fig.5. Resource allocation optimization test results

When the configuration was 0%, it saved about 40.2% of the CPU resource. Resource utilization was increased by about 14.5%. In the simultaneous trigger business scenario, the CPU resource was saved by about 18.3%, and the CPU resource utilization rate was increased by about 12.1%. Therefore, the improvement of the scaling rate can save computing resources and resource utilization.

4.3 Cost Analysis

The cost of the proposed algorithm was tested experimentally. When the crossover probability of the differential evolution algorithm changed from 0.15 to 0.25, it had little effect on the average objective function value. The maximum solution fluctuation was less than 2.0%, and the convergence limit reached 1.1×10^{-6}. For the stability of the algorithm, the convergence time of optimal resources was compared and analyzed under different resource allocation rates. The stability of the algorithm was verified. The data was shown in Fig. 6.



(a) Non-simultaneous trigger service (b) Simultaneous trigger service

Fig.6. Cost optimization curve

As shown in Fig. 6(a), for non-simultaneous triggered services, when the scaling ratio was increased, the total cost of system optimization configuration decreased significantly, from 113.5￥ to 107.2￥. When it's 15%, it reached the lowest value, which was 102.3￥. As shown in Fig. 6(b), for the simultaneous trigger service, when the scaling ratio was increased, the total cost of system optimization configuration decreased, from 291.3￥ to 274.3￥. When it's 15%, it reached the lowest value, which was 270.1￥. The overall level of decline was slightly lower than the non-simultaneous trigger business, but it still served as a cost-cutting effect. This algorithm can reduce the number of iterations, so it can reduce the cost, and it verifies the feasibility of this design.

5. Conclusions

The sequential logic model of basic business and aggregate business was established. A computing resource allocation method by edge computing terminals was proposed based on microservices. The model and algorithm can provide analysis means and reference for the engineering design. According to the particularity of power application, the stability of node is high in IoT devices for power supply systems. Therefore, traditional IoT resource optimization methods are not applicable. We analyzed the structure of power IoT and used the edge algorithm to achieve the purpose of resource optimization. It was targeted for the resource optimization of the power IoT. The experimental results verified the feasibility of this design.

A computing terminal was studied for the distribution network station area. It can be applied to gateways, concentrators, station area master meters, etc. And it can also be deployed and implemented independently. Due to the limitations of the research work, this paper still has some shortcomings. In the distribution network station area, the business in the power system has diversified characteristics. How to build suitable edge computing terminals for the real-time and reliability requirements of different business types will become the focus of future research. The paper belongs to the level of resource planning, and the microservices timing logic and resource utilization are considered in the optimization model. For real-time computing and different types of business scenarios, edge computing terminals focus on different indicators and models. It needs to be analyzed and designed separately under different circumstances. How to analyze the future development trend of power IoT through uncertainty modeling of microservices will be an important follow-up research direction.

Acknowledgements

This paper was supported by Shanxi Provincial Applied Basic Research Project No.201701D221124, Shanxi Provincial Key R&D Project No.201903D221025.

REFERENCES

[1] Bedi G, Venayagamoorthy G, Singh R, et al. Review of Internet of Things in electric power and energy systems, IEEE Internet of Things Journal, 2018, volume 5(02): 847-870.

[2] Nian LIU, Xinghuo YU, Jianhui WANG, et al. Optimal operation of power distribution and consumption system based on ubiquitous Internet of Things: a cyber-physical-social system perspective, Automation of Electric Power Systems, 2020, volume 44(01): 1-12.

[3] GUO Qinglai, WANG Bohong, TIAN Nianfeng, et al. Data transactions in energy internet: architecture and key technologies, Transactions of China Electrotechnical Society, 2020, volume 35(11): 2285-2295.

[4] LI Qiuyan, WANG Lili, ZHANG Yihan, et al. A review of coupling models and dynamic optimization methods for energyinternet multi-energy flow, Power System Protection and Control, 2020, 48(19): 179-186.

[5] YANG Ting, ZHAI Feng, ZHAO Yingjie, et al. Explanation and prospect of ubiquitous electric power Internet of Things, Automation of Electric Power Systems, 2019, volume 43(13):9-20.

[6] LI Jianlin, NIU Meng, ZHOU Xichao, et al. Energy storagecapacity planning and investment benefit analysis of micro-energysystem in energy interconnection, Transactions of China Electrotechnical Society, 2020, volume 35(4): 874-884.

[7] ZHAO Ziming, LIU Fang, CAI Zhiping, et al. Edge computing: platforms, applications and challenges, Journal of Computer Research and Development, 2018, volume 55(2): 327-337.

[8] CAI Zexiang, SUN Yuyan, GUO Caishan. Construction of supporting platform and industry ecosystem towards electric Internet of Things, Mechanical & Electrical Engineering Technology, 2019, volume 48(6): 1-4.

[9] LI Qinhao, ZHANG Yongjun, CHEN Jiaqi, et al. Development patterns and challenges of ubiquitous power Internet of Things, Automation of Electric Power Systems, 2020, volume 44(1): 13-22.

[10] LIU Qi, ZHOU Haiquan, HE Hao, et al. Coordinated optimal operation strategy of a regional energy internet based on the nonequilibrium cobweb model, Power System Protection and Control, 2020, volume 48(17): 93-107 .

[11] ZHOU Feng, ZHOU Hui, DIAO Yinglong. Development of intelligent perception key technology in the ubiquitous Internet of Things in electricity, Proceedings of the CSEE, volume 2020, 40 (1): 70-82.

[12] WANG Xuechun, CHEN Hongkun, CHEN Lei. Multi-player interactive decision-making model for operational flexibility improvement of regional integrated energy system, Transactions of China Electrotechnical Society, 2021, volume 36(11): 2207-2219.

[13] FENG Zhiyong, XU Yanwei, XUE Xiao, et al. Review on the development of microservice architecture, Journal of Computer Research and Development, 2020, volume 57(5): 1103-1122.

[14] XIN Yuanyuan, NIU Jun, XIE Zhijun, et al. Survey of implementation framework for microservices architecture, Computer Engineering and Applications, 2018, volume 54(19): 10-17.

[15] SI Yufei, TAN Yanghong, WANG Feng, et al. Cloud-edge collaborative structure model for power Internet of Things, Proceedings of the CSEE, 2020, volume 40(24): 7973-7979.

[16] LI Yang, CAI Zhiyuan, LIU Haitao, et al. Research on "cloudclient" Autonomous distribution system-oriented energy internet, Proceedings of the CSEE, 2017, volume 37(17): 4950-4955.

[17] NIE Zheng, ZHANG Jianmin, FU Huawei. Key technologies and application scenario design for making distribution transformer terminal unit being a containerized edge node, Automation of Electric Power Systems, 2020, volume 44(3): 154-161.

[18] Jiangyu Yan. Security Protection Design for Edge Computing of Power Internet of Things, International Core Journal of Engineering, 2021, volume 7(9): 62-66.

[19] Ai Xin, Zhao Lu. Comprehensive Evaluation of Power Grid Planning in Coastal Regions of China in the Context of Power Internet of Things (PIoT), Journal of Coastal Research, 2021, volume 37(4): 761-770.

[20] Zhao Jingcheng, Chao Xu, Hong Tao, et al. Efficient Directional Antenna Design Suitable for Ubiquitous Power Internet of Things, Electronics, 2021, volume 10(13): 1521-1521.