Power Grid Resource Integration of Enterprise Middle Station based on Analytic Hierarchy Process

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***Abstract*—With the transformation from smart grid to power Internet of Things, new power businesses such as power grid automation and power quality monitoring are constantly emerging. The load environment of power grid is changeable. In order to meet the needs of multi-service, the integrated access scheme for power grid resources in power enterprises is gradually diversified, which brings challenges to the unified management and control of power grid communication network. In this paper, SDN technology is used to improve the operation and maintenance management and control of power communication network, which aims at the integration scheme of power grid resources in power enterprises. Based on the controller cluster technology, combined with the new power business requirements, this paper designs a software-defined network centralized control architecture of the new business of power communication network. The architecture realizes the operation and maintenance management of network resources under the centralized control architecture of typical enterprise scenarios, such as power grid enterprises. The convergence speed is improved by 27%. The minimum value of iterative convergence is 31% better than that of other methods. The system requirement is reduced by 13.5%, which is helpful to improve the efficiency of node dynamic allocation and ensure the need of large-capacity data transmission of smart grid. The research in this paper can realize the two-way interaction, real-time expansion and unified deployment of power business in the future, and promote the intensive and lean development of power communication network.**

Keywords*—Power grid enterprises; SDN; power grid resources; centralized control architecture; power communication network

I. Introduction

Under the environment of orderly release of new policies, such as power generation, consumption plan and incremental business of power grid, all kinds of users will actively participate in the related industries of power distribution and consumption side. At the same time, with the development of sensing, edge computing, big data processing and other technologies, the transformation from smart grid to power Internet of Things is accelerating. The information exchanges with things and things, people and things is more frequent [1]. The power grid resource business center cooperates with the customer service center. The data center and the IOT management center to jointly support the power grid business applications, such as power outage analysis, accurate fault research and judgment, and line loss analysis in the same period [2]. It can arrange enterprise-level business services to solve the problems of non-standard business services, difficult precipitation and insufficient sharing.

Resource aggregation in China and abroad has also been widely concerned and discussed by experts and scholars. The author in [3] uses the panoramic theory to integrate a variety of micro grid resources, which takes into account the complementarity of various distributed generations. micro grid aggregation not only minimizes the damage to the power grid caused by the output fluctuation of the micro grid, but also improves the security of the system and ensures the optimization of its own economic benefits. The author in [4] considers the uncertainty of EV behavior characteristics of Load Aggregator (LA), and uses this method to integrate discrete EV energy storage. The author in [5] puts forward the resource evaluation system and resource quality distinction criteria for demand response, and builds a demand response resource integration model for multiple user load groups. In [6], Virtual Power Plant (VPP) is introduced into the wind power and EV, with power balance as the constraint. Taking the highest comprehensive economic benefit of its discharge as the goal, the mathematical model of the power generation plan is constructed.

The research proposes a scheme for fast recovery of the power communication network after a fault occurs. To make the time delay of the power business meet the provisions of the standard IEC 61850, a new network calculus method is proposed. Author proposes an SDN platform, which is suitable for the large-scale intelligent meter reading system, and can balance the load of power communication network through flow monitoring, load assessment, active control and path selection. However, with the gradual expansion of the distribution communication network, there are some problems such as low efficiency of network management and control, lack of rationality of the architecture, and lack of reliability. The research proposes an algorithm, which can realize the load scheduling of the QoS. Meanwhile, in order to reduce the delay of service transmission, the algorithm adopts the scheme that the multiple SDN controllers cooperate to manage the traffic of power communication network, but there is still the problem of complex protocol conversion between different communication media. The research innovatively introduces the SDN centralized control architecture into the power wide area communication network, and proposes a new fair resource allocation algorithm for power services, which is used to ensure that high-priority services are allocated to the shortest path for transmission and maximize throughput. Considering the burden of communication network, it affects the operation and maintenance management and control of power communication network.

The main innovations of this paper are:

1) This paper proposes to use the NFV technology to complete the software of various terminal hardware functions of general hardware.

2) Improve all kinds of power distribution and consumption monitoring and control equipment, centralize the proprietary hardware into a general hardware, and use software to realize its functions.

3) Based on the analytic hierarchy process (AHP), a multi-objective decision-making algorithm is proposed to the multi-domain communication network of power business, which takes the performance of the enterprise middle station network as the judgment index.

II. Related Work

A. The Overall Structure of the Enterprise

In the environment of power Internet of Things, the information transmission between power users and power grid becomes more frequent. The demand for power consumption quality, real-time and reliability of information is higher and higher. The safe and efficient power communication network is the key link to cope with this demand. The comprehensive control function of the power communication network is the most important one [7]. This paper is based on the architecture of the resource control system of enterprise middle station as shown in Fig. 1.

The architecture covers three parts: power business data forwarding layer, SDN cluster control system and software-based power business layer. The first layer mainly includes passive optical network, wireless private network, industrial Ethernet and other hardware devices. The NFV technology is used to transform the switches and other equipment of the multi-domain accesses network. The OpenFlow general protocol is used to realize the integrated management and control of the cluster control system over the underlying equipment routing, bandwidth allocation, inter-domain switching and other functions. The underlying switch only needs to complete simple information forwarding and flow table matching tasks [8]. The southbound interface, which is responsible for the communication with the terminal, is responsible for providing a channel for information interaction with the control system. At the same time, distribution transformer videos surveillance, power consumption information acquisition and other services are connected to the data forwarding layer through the underlying hardware devices so that the control system can flexibly monitor and control them.

B. Power Communication Network SDN Operation and Maintenance Control

Realize the centralized operation, maintenance, management and control of power communication network, optimize the allocation of resources, and increase the flexibility and compatibility of the network. The idea of applying the SDN to the current power communication networks operation and maintenance management is shown in Fig. 2.

This paper uses the method of operation and maintenance management and control for reference to improve various power distribution monitoring and management and control devices. It concentrates the proprietary hardware on a general hardware, uses software to realize its function, and makes it support programmable network interface.

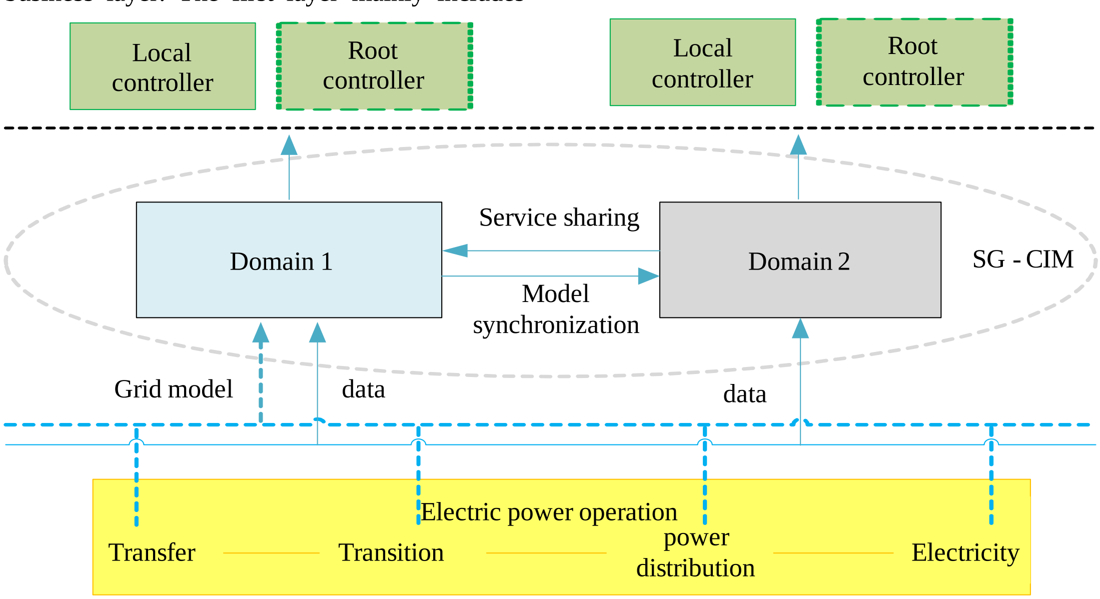

Fig. 1. Enterprise Mid-stage Control Architecture.

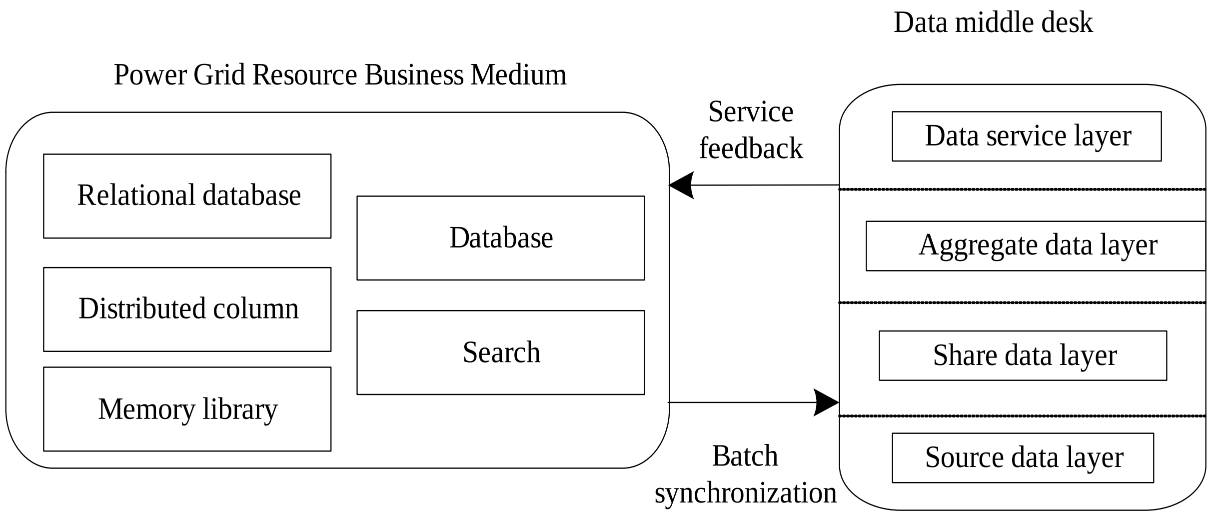

Fig. 2. Network Operation and Maintenance Control based on SDN Technology.

III. SDN High Reliability Control Scheme based on Cluster Technology

In the SDN control architecture, the controller is in the core position and is the basis of realizing the control function. How to deploy the controller and how to achieve the function is the key to realize the centralized management and control of the power communication network. This paper chooses the relatively mature and perfect controller cluster technology in the industry to complete the flexible deployment of various controllers in the architecture control layer, and realizes the operation and maintenance management and control functions of the power communication network through software [9]. The network realizes the data interaction between different functional controllers through a unique cluster communication process. The SDN control architecture based on the controller cluster is shown in Fig. 3.

The architecture is divided into three layers from top to bottom. The first layer is the cluster management layer, which mainly completes the functional task allocation of the root controller and the information synchronization between them. The root controller layer is responsible for ensuring the consistency of the overall state of the network and processing the corresponding business in time. The third layer is the local controller layer, which is responsible for handling complex and diverse local services. At the bottom are some switches, which are used to forward and process the underlying information [10].

The application of cluster technology to the control system can make the centralized control architecture reduce the risk of single point failure of control equipment under the original control mode, which increases the good scalability. It also copes with tens of thousands of switch traffic, significantly shorten the transmission delay of southbound interface protocol packets, and optimize the network transmission quality [11]. For any network G, there are three parts, namely network node devices, communication links, and topology [12]. The reliability R of the network G mainly depends on the reliability L_n of the node equipment. The reliability of the link L_1 and the topology N.' s Functional relationship is as follows:

$$R \in \left(L_n, L_1, N\right) \tag{1}$$

Formula 1 shows that the network reliability is directly proportional to the reliability quality of the three network factors.

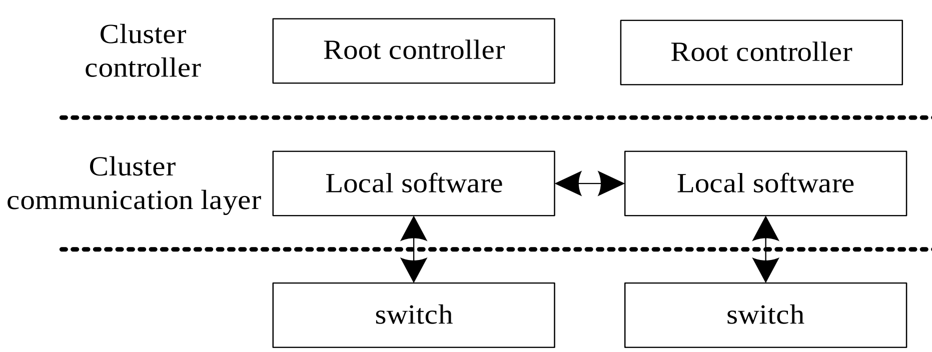

Fig. 3. SDN Control Scheme based on Cluster Technology.

IV. Interdomain Switching Algorithm based on the Analytic Hierarchy Process

When choosing the algorithm, we need to use the appropriate algorithm according to the actual needs. In the evaluation of multi-type resource characteristics of the multiple users participating in the aggregation by the analytic hierarchy process (AHP), the dimension of the clustering vector is low, so this paper analyzes the inter-domain hierarchical switching.

The analytic hierarchy process (AHP) analyzes various influencing factors of things from different perspectives. Its main steps are shown in Fig. 4.

1) Construct multi-index decision matrix: Firstly, on the basis of analyzing the target of the problem, the scheme set *X* to be selected and the index matrix *S* to make judgment are obtained.

Where $X=\{x_1,x_2,\cdots,x_m\}$ represents that there are *m* alternatives. $S=\{s_1,s_2,\cdots,s_n\}$ indicates that there are *n* evaluation indicators. Then, a multi-index evaluation matrix is constructed:

$$A=(\alpha_{ij})_{mn}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \tag{2}$$

Where a_{ij} represents the result of alternative plan x_i relative to the judgment index s_i.

2) Vector normalization method

The matrix A is normalized.

$$b_n=\frac{a_n}{\sqrt{a^2}a_{ij}^2}\ ,i=1,2,\cdots,m \tag{3}$$

Where, matrix b is the benefit matrix, matrix a is the allocation matrix, i is the set of nodes accessible to ants other than the elements in the tabu list, and a_n represents whether to allocate a frequency band to n users.

3) The characteristics of different parameters are analyzed and compared to establish the corresponding comparison matrix.

Compare each parameter of the candidate scheme. Take the relative importance of the impact factors as the standard. Conduct pairwise comparison. Finally, evaluate different levels according to Table I [13].

4) Perform pairwise comparison on the parameters of different levels, wherein the comparison result forms a judgment matrix $C=\left(c_{ij}\right)$ As shown in the formula (4), the parameter *i* in the matrix $c_{ij}>0$ is more important than the parameter *j*.

$$C=(c_{ij})_{n\times n}=\begin{bmatrix} c_{11} & \cdots & c_{1n} \\ \vdots & \cdots & \vdots \\ c_{n1} & \cdots & c_{nn} \end{bmatrix} \tag{4}$$

For the comparative decision matrix C:

$$CI=\frac{\lambda_{max}(C)-N}{RI} \tag{5}$$

Where CI represents the consistency index, RI represents the average random consistency index, and CR represents the random consistency ratio, and $\lambda_{\max}$ is the increment of the solution converted into pheromone.

$$CR=\frac{CI}{RI} \tag{6}$$

Where *n* denotes the order of the comparison matrix. $\lambda_{\max}\left(c\right)$ represents the largest eigenvalue of the comparison matrix C[14].

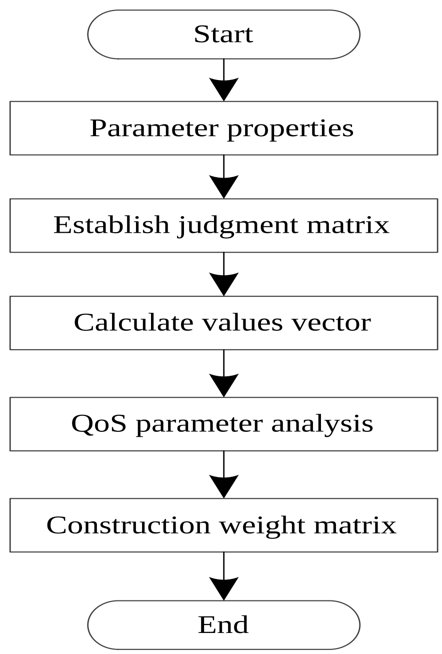

Fig. 4. Power Resource Hierarchical Analysis Process.

TABLE I. A Comparison Table of the Importance of Different Parameters

Comparison of the importance of *i* and *j*	The value of a_{ij}
Equal	1
A little important	3
Important	5
Very important	7
Very strong importance	9

When CR < 0.1, it indicates that the consistency check of the comparison matrix C constructed by AHP is qualified. When CR > 1, it indicates that the consistency check of the comparison matrix C constructed by AHP is unqualified. At this time, the judgment matrix A needs to be reconstructed until the consistency check is qualified [15].

5) The calculation judgment index is the weight of each factor: Assume that the characteristic vector corresponding to the maximum eigenvalue $\lambda_{\max}(C)$ of the comparison matrix C of the decision index is shown in Table II.

According to the comparison matrix of different candidate schemes under each index, the respective weight matrix is calculated as follows:

$$W'' = \{w_1', w_2'' \cdots w_n'\} \tag{7}$$

$$W^P = \{w_1^p, w_2^p \cdots w_n^p\} \tag{8}$$

Finally, the distribution coefficients of the different alternatives can be obtained by multiplying W^P and W'. For weight sorting, the scheme corresponding to the maximum weight is the best scheme at the total level. The decision function is expressed as:

$$f_{AHP} = \max\left(W^p \times W'\right) \tag{9}$$

The flow chart of the decision algorithm is shown in Fig. 5.

TABLE II. THE RI VALUE OF THE ORDER COMPARISON MATRIX

m	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

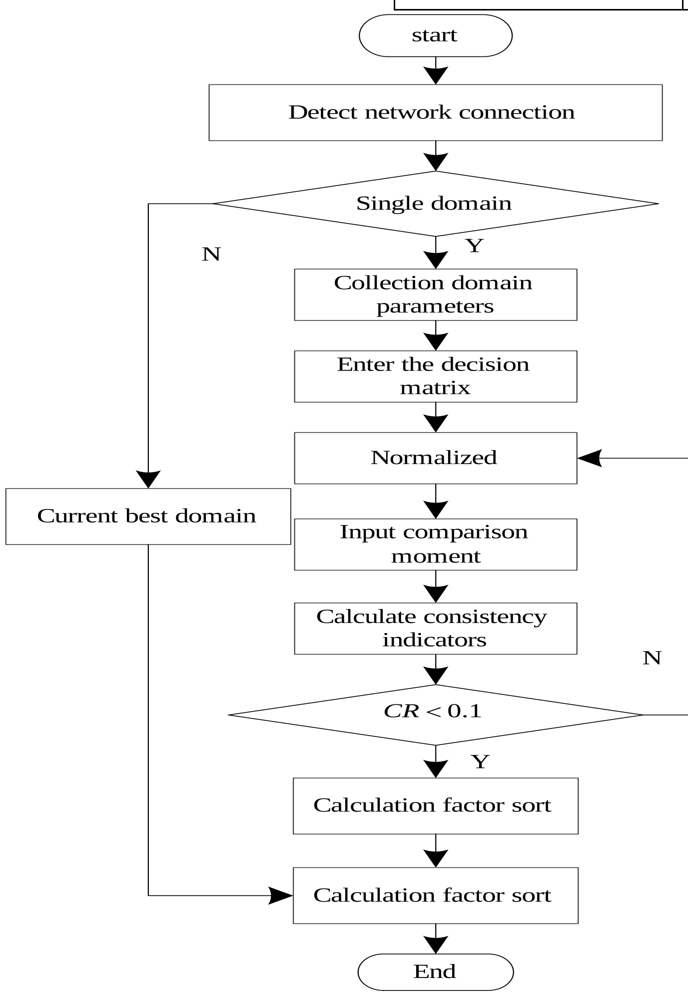

Fig. 5. AHP Algorithm Flow Chart.

V. Simulation Experiment Analysis

A. Contrast Solution

In order to verify the performance of the algorithm in this paper, the following algorithm is used as a comparison scheme.

1) RAR _ RS _ BiG: according to the algorithm idea, first perform augmentation operation on each SFC (Service Function Chain), that is, add backup VNF (Virtualised Network Function） in each SFC chain to meet the availability of the whole chain. Where: RAR is the file attribute.

2) JDBS _ s: all VNF instances in the JDBS _ s algorithm are implemented based on the single-tenancy technology.

3) GREP: The core idea of GREP to improve the availability of AHP is to provide backup for the VNF with the lowest availability in its corresponding SFC. Then, gradually provide backup for the less reliable VNF until the availability requirements of SFC are met.

B. Parameter Settings

For AHP, the number of VNFRs contained in each AHP is an integer randomly selected from the list [3, 4, 5, 6]. The CPUDRC, memory DRC and bandwidth resource requirements of each VNFR follow the uniform distribution of (10, 50) units. There are 10 kinds of VNFs in the simulation. The initial availability of each original VNF and the availability of each backup VNF are subject to the uniform distribution of (0.99, 0.999). The number of AHP to be mapped, the availability requirements of AHP, and the CPU BRC and memory BRC required to instantiate a VNF will be used as variables in different simulation scenarios

C. Simulation Results and Performance Analysis

1) Comparative analysis of processing ability: In order to reduce the impact on errors, each set of results is based on the statistical values obtained from 10 experiments. The error bar to the figure represents the 95% confidence interval. In the simulation, enough resources are set for the data center so that all AHPs can be mapped to the network. Therefore, in each set of experimental results, the final number of servers started, the amount of CPU and memory backup resources consumed and the BRC can be used as indicators to measure the performance of each algorithm. The final performance comparison between the changed AHP availability Fig. 6 shows the resource consumption comparison and the final BRC comparison of each algorithm under the changed AHP availability.

In the experiment of this scenario, the number of AHP to be mapped is 1000. The CPU BRC and memory BRC required for instantiating a VNF are both set to 20 units.

As shown in Fig. 4.2(a), it is a comparison of the final number of servers used by each algorithm. From the results, it can be seen that the number of servers used by the algorithm in this paper is the least. Compared with RAR _ RS _ BiG, JDBS _ s and GREP, they can use up to 29%, 29% and 42% of the servers respectively. JDBS _ s is the single-tenancy version of the roBS algorithm, that is, except for the difference in the implementation of VNF and IJ, other algorithms, such as AHP mapping algorithm, resource reservation algorithm, and VNFR merging algorithm of the same type, are the same as the method in this paper. By comparing the algorithms, it can be seen that when the availability requirement of AHP is lower than the initial availability of VNF, that is, the experimental scenarios with availability requirements of 0.90 and 0.99, the two algorithms have similar performance. This is because in this case, the availability of the current VNF can meet the needs of AHP. There is no need to reserve a backup for each original VNF.

2) Comparative analysis of algorithm performance: In this paper, based on the AHP algorithm, Matlab2014b is used as the simulation software to select the multi-domain network for the integrated automatic business of power grid resources in the enterprise middle station. The selection results are recorded for comparative analysis.

The electric power communication system requires high network security. There are many video surveillance services, which are interactive. The bandwidth is the key to ensure high-quality video streaming, so it requires a large communication bandwidth and a relatively high transmission delay. The demand for packet loss rate is weaker than the former two. The comparison matrix is shown in Table III.

The maximum eigenvalue $\lambda_{\max}(C)$ and eigenvector γ of the matrix C are obtained by using the eig function in MATLAB. It can be concluded that the CR value is less than 0.1 through formulas (10) and (11). The decision matrix meets the consistency requirements and can be used to calculate the weight vector. The weight vector is normalized to obtain the single factor and weight coefficient combination of service 1:

$$W' = \{w_1, w_2, w_3, w_4\} = \{0.0469, 0.0926, 0.3641, 0.4964\} \quad (10)$$

$$W^P = \begin{pmatrix} w_1, w_2, w_3, w_4 \\ w_1', w_2', w_3', w_4' \end{pmatrix} \quad (11)$$

According to the decision function, the distribution coefficient of the total hierarchy is calculated. The simulation results are shown in Fig. 7.

The results are:

$$ts = (0.2715, 0.7285) \quad f_1 = \max(ts) = 0.7345$$

Where 0.7285 represents the utility value f_1 of the best access domain 2 of the service, i.e., the distribution transformer video surveillance service in the current environment. Similarly, 0.2715 represents the utility value f_1 of the best access domain 1 of the service in the current environment. For the service f_1, domain 2 shall be selected as the best handover target network.

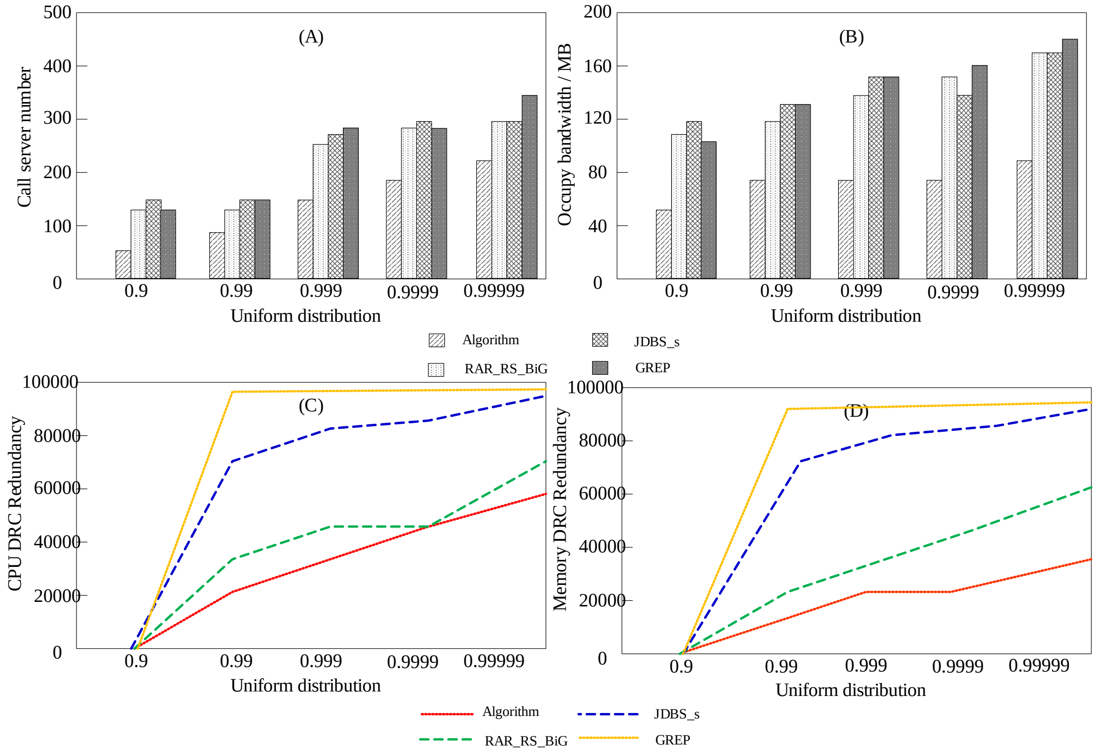

Fig. 6. Resource Consumption Comparison of each Algorithm and the Final BRC Comparison.

TABLE III. DISTRIBUTION VIDEO SURVEILLANCE SERVICE COMPARISON MATRIX

Comparative indicators	Time delay	Bandwidth	Packet loss rate	Hop count
Time delay	1	1/3	5	5
Bandwidth	3	1	8	9
Packet loss rate	1/5	1/8	1	2
Hop count	1/5	1/9	1/2	1

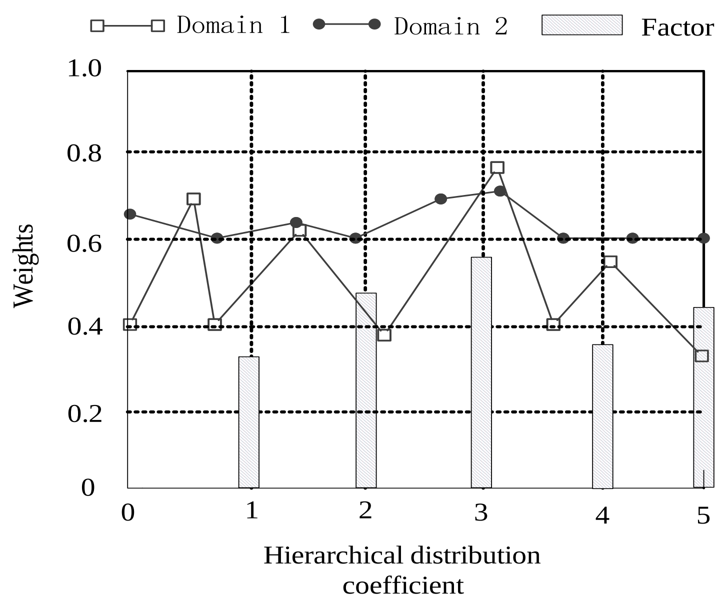

Fig. 7. Simulation Results.

In the aspect of electric power business, this paper selects typical business to study. In view of the intelligent electric power business, the analysis of its demand for the electric power communication network is more conducive to practical application. In addition to the control system, the intelligent electric power equipment is also an important component of the electric power communication network. Based on the analysis of the overall control system, this paper carries out a more in-depth and comprehensive study of the control system of the electric communication network.

VI. Conclusion

In this paper, the key technologies of the future electric power data Wan communication are studied. Through the research of network intelligent operation and maintenance and business scheduling strategy in enterprise platform environment, the research of resource elastic configuration and integration technology for IP network and optical transmission network, the efficient use of the IP layer and the optical layer network resources is realized, and the reliable operation of business is ensured, which is beneficial to that access of new equipment of a subsequent network and the rapid open of new services. Main work is as follows:

1) Design the overall framework of software defined network centralized control for the new business of electric power communication network.

2) The realization of network resource operation, maintenance management and control under centralized control architecture combined with typical application scenarios such as virtual power plant is done.

3) The simulation software is used to verify the realization of typical functions of SDN centralized control system.

The intelligent power equipment is also an important component of the electric power communication network. This paper is only based on the overall control system, and does not conduct in-depth research and design of intelligent power equipment. In the future, the optimization objectives and constraints in the construction of resource aggregates can be further improved, for example, the aggregation degree of resources can be optimized when considering spatial differences to achieve the simultaneous optimization of the characteristics and regions of resource aggregates.

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