Multi-Constrained Maximally Disjoint Routing Mechanism

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***Abstract*—in the smart grid, to improve the quality of service and to reduce the risk of network much further is the main research direction. How to choose a highly reliable, stable and low-risk routing is the most critical part of the smart grid. The factors considered by most of the existing algorithms are too single, which makes the optimization is not sufficient. Therefore, based on service path pressure and the special factors of the power communication network, this paper proposes a kind of multi-constrained maximally disjoint routing mechanism and states the superiority of this algorithm via experiment which is simulated on the power communication network of a certain province.**

***Key words*—power communication network; maximally disjoint; routing algorithm; quality of service; reliability**

I. INTRODUCTION

With the rapid development of the smart grid, the power system presents the increasingly frequent characteristics of cooperative communication between multiple systems. Power system also puts forward higher requirements and standards for power communication network. Therefore, in the smart grid, how to reduce the risk of power communication network effectively has become one of the most urgent problems that power system needs to solve. In addition, as the size of the power system continues to expand, the current routing algorithm is difficult to meet the increasing demand, therefore, to improve the quality of service (QoS)[1] of power communication network and further to reduce the network risk to adapt the ever-expanding demand is the main research direction.

When deploying services, power communication networks typically use route allocation policies based on availability routing (Availability-Aware Routing, AAR)[2] and Load Balancing (LB)[3-6]. In literature[2], the 3W algorithm with higher reliability is proposed based on AAR. In LB algorithm, literature [3] using the heuristic KSP algorithm, one of the realization strategies of KSP algorithm, finds the top K bandwidth of the largest route in order to improve the reliability. However, the shortcoming of 3W algorithm is that there is a phenomenon in which the service is too concentrated sometimes, so the quality of service cannot be guaranteed. On the other hand, the LB algorithm only takes bandwidth as a consideration and does not take into account the weight of the service and load balancing. Therefore, literature [4] considers the load balancing in the SDN network, [5] and [6] discuss the load balance based on the weight of the service in the power communication network, of which the reliability is higher than the 3W and the general LB algorithm. However, these algorithms do not take into account the backup routing of critical services, so the improvement of quality of service is limited.

In accordance with the requirements of the power industry, the key services in the power communication network, such as relay protection, need to configure the major and backup dual route[7] to ensure the high reliability of the service. And in order to deploy routing more reasonable, we should combine the equipment aging, dynamic environmental conditions, cable characteristics (such as whether type of cable is the same, whether route crosses high-speed / high-speed rail, etc.) and other special factors in the power network. Aiming at the above problems and combining with the actual situation of power communication network, this paper proposes a Multi-Constrained Maximally Disjoint Routing Algorithm (MCMDRA). The routing allocation strategy with multiple constraints can make the service route meet multiple requirements, which can guarantee the reliability and service quality better. Additionally, the backup of route is adopted for the key service, which can provide the loop protection for the service and further reduce the communication risk.

II. PROBLEM DEFINITION

As shown in Figure 1, in the communication topology, the provincial power communication network may span multiple areas and cross high-speed / high-speed rail. At the same time, the cable type (OPWG / ADSS) is not unified sometimes. Therefore, the route may use multiple cables and switch constantly among a variety of cable types. The switch of cable type has great influence on the quality of QoS. Meanwhile, the service route that crosses high-speed / high-speed rail also affects QoS, which we cannot overlook. After a lot of field investigation, we discovered that these new factors have great impact on the stable operation of the power communication network.

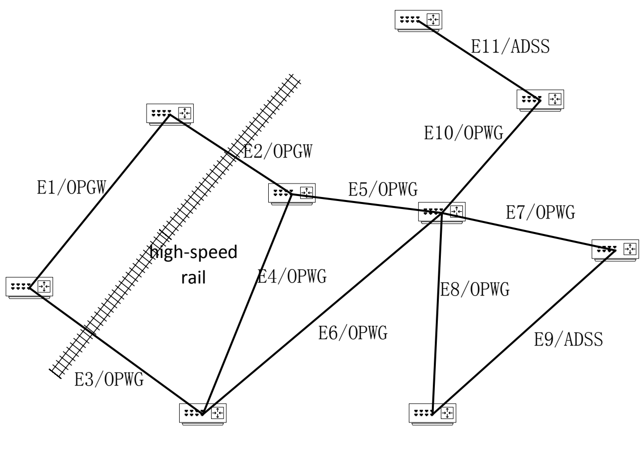


Fig 1 Power Communication Network Topology

In order to solve this problem, the concept of Node Risk Degree (NRD)[6], Edge Risk Degree (ERD)[6] , Service Path Pressure(SPP), Service Path Balance Degree(SPBD), Overall Service Path Degree(OSPD), Route Interaction Degree(RID), Route Reliability Degree(RRD)[8] is introduced.

1. Node Risk Degree

$$NRD_i = P_{v_i} \times \sum_{k=1}^{S(v_i)} W_k = (1 - A(v_i)) \times \sum_{k=1}^{S(v_i)} W_k \tag{2-1}$$

In Formula (2-1), $S(v_i)$ is the service set carried on the node, $P(v_i)$ is the probability of failure for node i, related to availability [2]. W_k represents the weight of k^{th} service carried on the node i, and the indicator of weight is given in the following sections. The essence of this formula is that the risk is defined by the product of the probability of failure occurrence and the impact of the failure[9].

2. Edge Risk Degree

$$ERD_{ij} = P_{e_{ij}} \times \sum_{k=1}^{S(e_{ij})} W_k = (1 - A(e_{ij})) \times \sum_{k=1}^{S(e_{ij})} W_k \tag{2-2}$$

$$P_{e_{ij}} = (1 - A(e_{ij})) = 1 - \frac{TTR_{e_{ij}}}{TTR_{e_{ij}} + TBF_{e_{ij}}} \tag{2-3}$$

In Formula (2-2), $S(e_{ij})$ is the service set carried on the edge e_{ij} , W_k represents the weight of k^{th} service carried on the edge e_{ij} , $P(e_{ij})$ is the probability of failure for edge e_{ij} , related to availability. Formula (2-3) expresses the calculation of the availability $A(e_{ij})$, $TTR_{e_{ij}}$ and $TBF_{e_{ij}}$ are time to repair [2] and time between failure [2].

***3.** Service Path Pressure*

$$SPP_{ij} = c \times \mathrm{ERD}_{ij} + \log_2 N_{e_{ij}} \tag{2-4}$$

$$c = \begin{cases} 1 & \text{Carry normal service} \\ 1.2 & \text{Low-voltage links carry high voltage service} \end{cases} \tag{2-5}$$

In Formula (2-4), $N_{e_{ij}}$ is the use time of the edge e_{ij} . c is a coefficient of carrying the service. In the power system, low-voltage links such as 220kv line sometimes carry 500kv or 1000kv high-voltage services as needed. When a low voltage link carries a high voltage service, the ERD is multiplied by the coefficient c . Based on literature [6], we take into account the actual factors of the power communication network and put forward the concept of Service Path Pressure (SPP). Finally, SPP is determined by ERD and $N_{e_{ij}}$.

4. Service Path Balance Degree

$$SPBD = \frac{1}{e} \times \sum_{\substack{i=1, j=1 \\ i<j}}^{e} \sqrt{(\mathrm{SPP}_{ij} - \overline{SPP})^2} + \frac{1}{v} \times \sum_{i=1}^{v} \sqrt{(\mathrm{NRD}_i - \overline{NRD})^2} \tag{2-6}$$

$$\overline{SPP} = \frac{1}{e} \sum_{\substack{i=1, j=1 \\ i<j}}^{e} SPP_{ij} \tag{2-7}$$

$$\overline{NRD} = \frac{1}{v} \sum_{i=1}^{v} NRD_i \tag{2-8}$$

Service Path Balance Degree is used to measure the average pressure of the path in the network. The smaller the SPBD, the more balanced each path. $\overline{SPP}$ is the average of the Service Path Pressure for the entire network, $\overline{NRD}$ is the average of the Node Risk Degree for the entire network.

5. Overall Service Path Degree

$$OSPD = \sum_{\substack{i=1, j=1 \\ i<j}}^{e} SPP_{ij} + \sum_{i=1}^{v} NRD_i \tag{2-9}$$

Overall Service Path Degree is the sum of the pressure of all nodes and edges of the whole network.

6. Route Interaction Degree

$$EID = \frac{E(\text{public})}{E(route1 \bigcup route2)} \tag{2-10}$$

$$VID = \frac{V(\text{public})}{V(route1 \bigcup route2)} \tag{2-11}$$

The route interaction degree (RID) represents the proportion of the nodes and edges shared by the major and backup routes to the total number of nodes and edges. In the actual case, the reliability of the edge is much lower than that of the node, so the reliability of the edge has a greater impact on the reliability of the route. Therefore, RID depends first on the EID. Only if EID is equal, the VID is compared. If and only if both RID and VID are equal, RID of the two major and backup routes are equal.

EID is the proportion of the number of public edges to the total number of route edges. $E(\text{public})$ is the public edge number, $E(route1 \bigcup route2)$ represents the number of concurrent sets of major and backup routing edges. $V(\text{public})$ is the public node number, $V(route1 \bigcup route2)$ represents the number of concurrent sets of major and backup routing nodes.

7. Route Reliability Degree

$$R(\text{P}) = \prod_{v_i \in P} R(v_i) \cdot \prod_{e_{k \in P}} R(\text{e}_k) \qquad (2\text{-}12)$$

$$\begin{aligned} & R(\text{major} \bigcup backup) \\ & = 1-(1-\text{R(major)})(1-\text{R(backup)}) \\ & = \text{R(major)} + R(\text{backup}) - \text{R(major)} \cdot \text{R(backup)} \end{aligned} \qquad (2\text{-}13)$$

In Formula (2-12), $R(\text{P})$ defines the reliability of the service route[8], $R(v_i)$ represents reliability of node i, $R(e_k)$ represents reliability of edge k. Formula (2-13) measures the reliability of the major and backup routes of the service[8].

Based on the above definition, this paper will optimize the network so that the OSPD, SPBD and RID is as low as possible.

III. MCMDRA ALGORITHM

1. Service weight analysis

The MCMDRA algorithm requires the weight of the service as the basis for analyzing the node risk, so the first part is the service weight analysis.

The weight of the service represents the degree of impact of a service interruption or failure on the power grid, the greater the impact, the higher the weight of the service. After years of development, relay protection, dispatch automation and other large number of services bear on the service path, which makes the service path of network become an important factor affecting the safe operation of the power grid. Any communication failure may cause a grid safety accident. In the security events mentioned in [10] and [11], the classification of communication events has been very clearly described, which are qualitatively and quantitatively evaluated from the scope, duration, and consequences of communication failures. These contents should be the most direct basis for safety risk analysis. According to the contents of [11] and [12], various categories of service in the power communication network and its importance as shown in Table 1.

According to the value in Table 1, we can calculate NRD of every node and SPP of every link by formula (2-1), (2-4). Based on the above results, we can further get OSPD and SPBD by formula (2-9), (2-6). So we could have a clear understanding of the status of the network through these defines.

Table 1 the importance value of different service

Service Category	Service Importance
Safety control	10
Relay protection	10
Dispatch phone	9.38
Scheduling data network	5.98
Conference TV	5.05
Scheduling all communication services for nodes	7.97
Administrative phone	0.8
Integrated data network	2.9
Class I information service	2.7
Class II information service	1.5
Class III information service	0.8

2. Algorithm Details

If links or nodes has failed, the traditional routing algorithm needs to exclude the failed edges and nodes, and then run again for the route allocation of service. But when the service importance is high, this approach is inefficient and cannot meet the current power communication network on the failure time requirements. Therefore, the backup of the key service such as relay protection is very necessary. Moreover, if the dual routing services adopt the single constraint maximally disjoint routing algorithm, which will make service is too centralized and the pressure of link is congested and non-balanced. In addition, according to the actual operation of the grid, we also need to consider the type of service cable, crossing high-speed / high-speed rail and other factors.

The MCMDRA algorithm is based on the KSP algorithm [13] and the improved Bhandari maximally disjoint algorithm [14, 15] First of all, based on the path pressure, the major route use KSP algorithm to select the former K alternative routing for the service. Then combining with the cable type, crossing high-speed / high-speed rail and other factors, The MCMDRA algorithm filter out two of the best routes for the next step. The major route and the backup route usually do not work at the same time. The purpose of the backup route is that the major route can be switched when the service is interrupted, which can minimize the loss. In general, the backup route uses the RF (RF, Remove-find) algorithm. It uses Dijsktra algorithm to find a shortest path, then modifies the shortest path of all the link weights to make it large enough and uses the Dijsktra algorithm to find the backup route again. However, this algorithm is inherently flawed, which cannot find the optimal solution in many topologies. So we use the improved Bhandari maximally disjoint algorithm to complete the entire algorithm.

A. KSP Algorithm

The KSP algorithm [13] is based on Dijstktra, and the core of that is to find the next optional shortest path by looking for an alternative arc. The following description of the algorithm is given.

S: The set of available nodes. The initial situation is the starting node.

Q: The set of the nodes that distance have not been determined. The initial case is $\{V-S\}$, V is the set of all nodes.

$\{v_n | \forall v \in V, n \in \{1,2,\cdots,k\}\}$: V_n is the nth replaceable node of node v. $\{V_n\}$ represents the set of replaceable node.

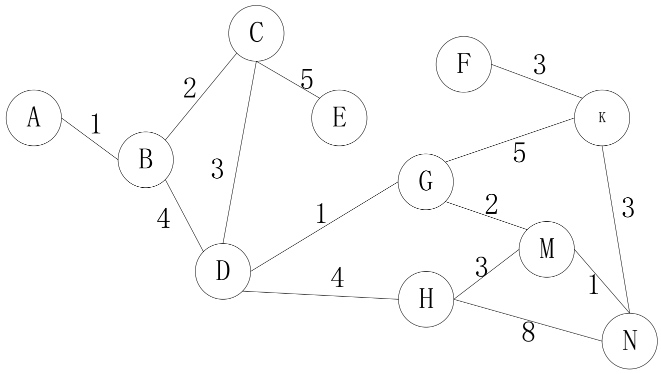
1) From the adjacency that satisfies the conditions $v_c \notin Route(v_n)$ and $v_c \notin S$ (avoids the loop), we select the node v_c with the shortest weight, and add v_c to S. Update the distance $\{d(v_n)\}$ and route $\{Route(v_n)\}$ of all adjacent nodes of v_c.

2) Repeat the process of 1 until the destination is added to for the K times, that is, $v_k \in S$, and we can obtain the first k shortest path from the beginning to the end.

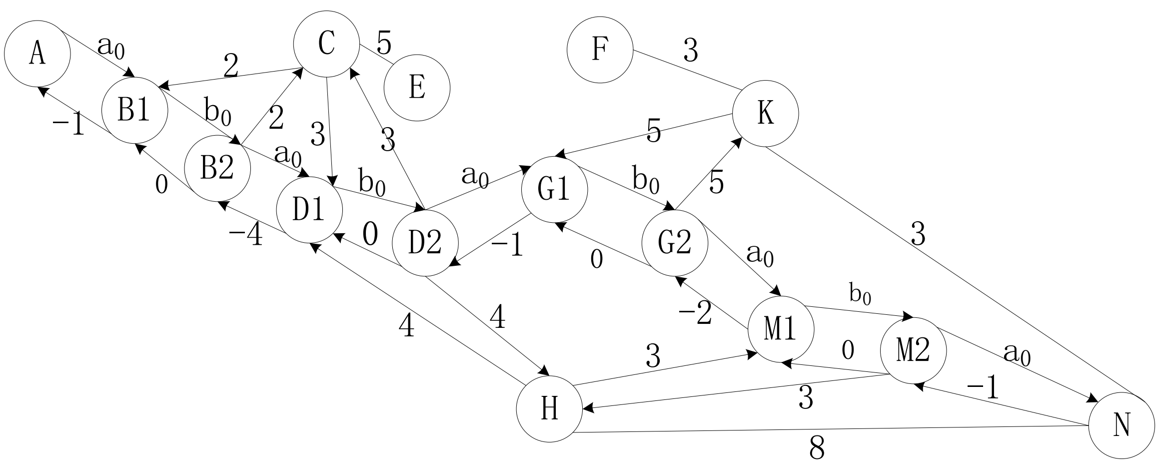
B. Improved Bhandari Maximally Disjoint Routing Algorithm

Based on Bhandari algorithm, literature [8] proposes a method of maximally disjoint dual routing configuration for power communication network. But the algorithm is based on Dijkstra as the major route, and the configuration of the dual routing only considers RID (Route Interaction Degree). At the same time, in order to ensure that the major and backup route is maximally disjoint route, the algorithm will change the major route, and this approach will make the major route is not the optimal solution. So we improved the Bhandari algorithm to find the maximally disjoint backup route under the condition that the major route is changeless. This section gives the process of how to find backup route via the improved Bhandari algorithm. And the selection method of the major route is based on the KSP algorithm and SPP (service path pressure) and it will be given in the next section.

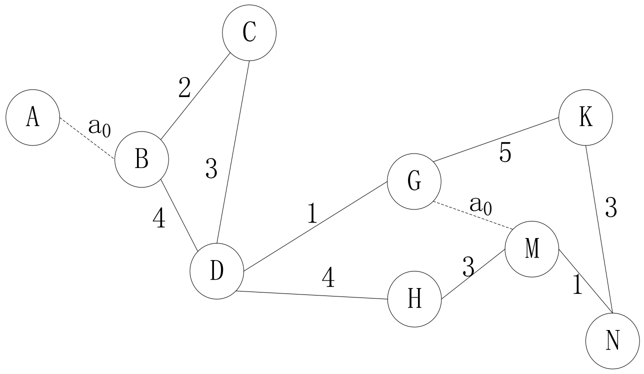
Examples of algorithms are as follows:



(a)



(b)



(c)

Fig 2 Graph of the improved Bhandari algorithm

Figure 2 shows the topology change from A to N for the major and backup routes. Figure 2(a) is a topology of a communication network.

1) In the network of Figure (a), suppose the major route is calculated to get the optimal path route1 (A-B-D-G-M-N).
2) The node splitting method is used to modify the values of the nodes and edges in the network, as shown in Fig (b). The specific approach: we specify the path from the starting to the destination node is the positive direction, and the reverse of the path is the opposite direction; the nodes on route1 are divided into two nodes except for the start node and the destination node, such as B split to B_1 and B_2. And B_1 points to B_2 as the forward and the forward weights is set to b_0. B_2 points in the direction of B_1 is in reverse, the weight is 0. The revised principle is that the weight of the reverse direction edge in route1 is changed to the additive inverse of the original value, and the weight of the positive direction edge is changed to a_0. If the remaining nodes that are not in route1 have an edge with the node in route1, the edge will be also changed to the directed edge. Take node C as an example, $C \rightarrow B_1$, $B_2 \rightarrow C$ and $B_1 \rightarrow B_2$, directed edges should form a loop and loop must contain positive direction edge $B_1 \rightarrow B_2$. The weight of $C \rightarrow B_1$ and $B_2 \rightarrow C$ is the same as weight in the original topology. a_0 and b_0 should satisfy the following conditions: we assume that $\sum_{\substack{i=1, j=1 \\ i<j}}^{e} W_{ij}$ is the sum of the weights of all edges of the topology. And we assume C is a constant. C should be greater than the number of public edges on the major and backup routes. In order to ensure that the conditions are satisfied, we can make C equal to the minimum of the number of major route nodes and the number of backup route nodes, that is, $C = \min\{n_{route1}, n_{route2}\}$. So a_0 and b_0:

$$\begin{cases} b_0 \geq \sum_{\substack{i=1, j=1 \\ i<j}}^{e} W_{ij} \\ a_0 \geq C \cdot b_0 \end{cases}$$

3) In Figure (b), we use Dijsktra algorithm to get the route2 (A- B1-B2-C-D1-D2-H-M1-G2-K-N). Then we merge the split nodes and get the Fig (c). In the Fig(c), we set the weight of the public edge of the route1 and route2 is a0. Finally, the backup route is (A-B-C-D-H-M-G-K-N).

C. *Multi-Constrained Maximally Disjoint Routing Algorithm*

Based on KSP and improved Bhandari maximally disjoint algorithm, MCMDRA algorithm could reduce the total network pressure and make the RID (Route Interaction Degree) of the major and backup route is the lowest.

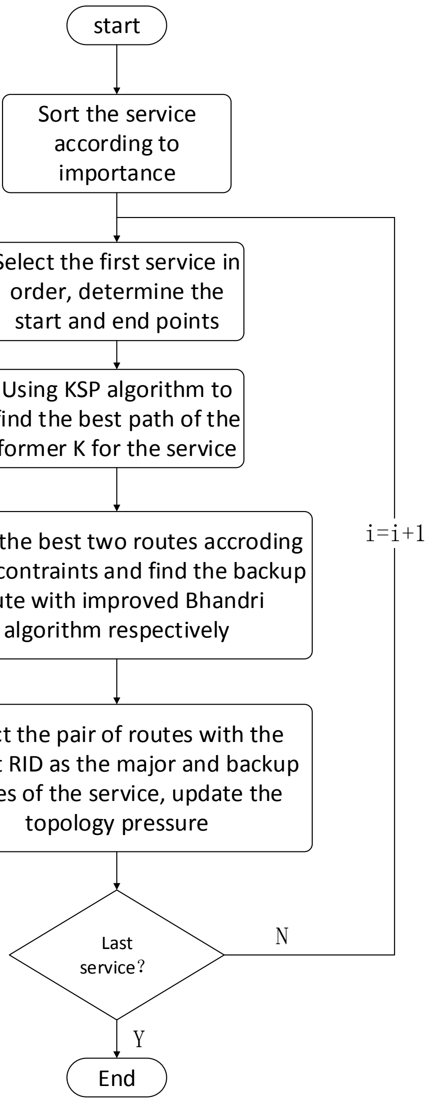


Fig 3 Multi-Constrained Maximally Disjoint Routing Algorithm

1) In order to ensure route of the important service such as relay protection assigned firstly, we should sort the service set according to the importance of service.
2) Based on the KSP algorithm, we select the former K optimal (that is the least pressure route) routing for the service. Then, we sort these routes by a new algorithm. This sort of algorithm is as follows:
   First of all, the former K service should sort from small to large according to the switching times of cable type (O/A). When the switch times of cable type of the route is equal, we should sort further in order to make these routes distinguishable. While switch times of cable type is equal, we should sort the route by whether it crosses high-speed / high-speed rail. If the SPP of the crossing high-speed / high-speed rail route is higher than non-crossing of that, which means the route not crossing high-speed / high-speed rail is obviously better. Another situation is when the SPP of the non-crossing one is not higher than a suitable constant value ($Const$) compared to the SPP of the crossing high-speed / high-speed rail route ($Const \geq 0$). We also think that the non-crossing one is better despite its higher SPP. So the non-crossing one should be ranked ahead by the sort algorithm under the condition that the switch times of the cable type is equal. But if the SPP of the non-crossing one is too high, which means $SPP_{non-crossing} - SPP_{crossing} \geq Const$, the crossing high-speed / high-speed rail route should be ranked ahead.
3) When we finish this sort of route, we select the former two best service route. Next, we find the backup route for the selected route by the improved Bhandari algorithm and choose the one which RID (Route Interaction Degree) is lower as the major and backup route.
4) After the service routing is allocated, we should update the SPP to the current topology due to the increase of the service route by formula (2-2), (2-4).
5) Judge whether the allocation is complete, if YES, it ends; if NO, jump to 2).

IV. SIMULATION AND DISCUSSION

A. Simulation scenario

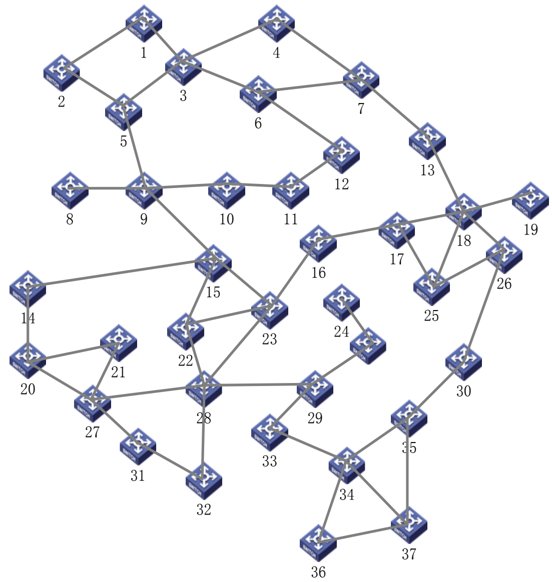


Fig 4 Topology of a Power Grid in a Province

As shown in Figure 4, the simulation is based on the network topology of a provincial company. Before simulation, we need to set some parameters. We set the availability of node is randomly generated between 0.95-1 and the availability of edge is randomly generated between 0.9-1 because the availability of node is better than that of edge. The service category is randomly generated in each simulation, and the range is given in Table 3-1. In addition, the K value of the KSP algorithm is 10, and the number of service is not less than 100. And we set $Const = 50$ which is used to select route through lots of experimental adjustments. The program is implemented in Java language of version 1.8, IDE for the eclipse.

B. Simulation results

The simulation experiment analyzes the performance of the algorithm from three aspects: OSPD, SPBD and RID. MCMDRA algorithm is compared with SRBM algorithm [6] and 3W algorithm [2] in the OSPD and SPBD, compared with traditional RF algorithm in RID. The experimental results are shown in Fig 5 and Fig 6.

Table 4 Parameter list

parameter	value
Availability of edge	0.9-1
Availability of node	0.95-1
K	10
$Const$	50

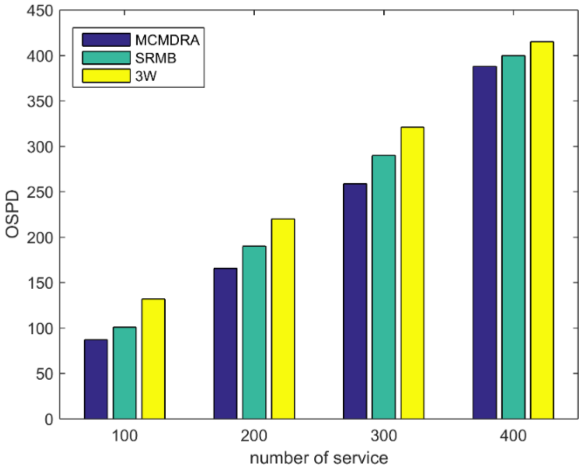


Fig 5 OSPD changes with the number of service

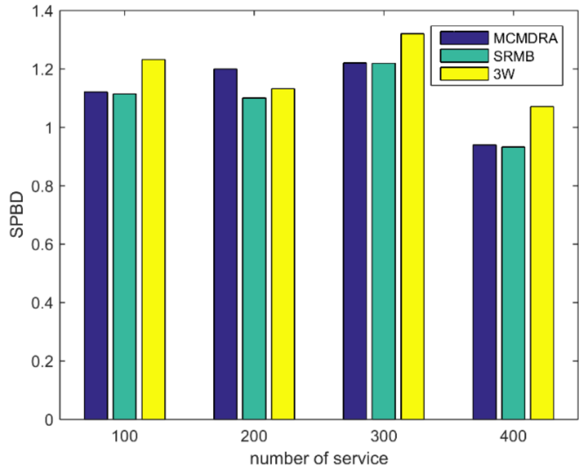


Fig 6 SPBD changes with the number of service

Figure 5 shows the change of the OSPD affected by number of service. It can be found that the MCMDRA algorithm has lower OSPD than SRMB and 3W algorithm, so it is obviously that the reliability of the whole network is improved while using MCMDRA algorithms. In Fig 6, MCMDRA algorithm is not better than the SRMB algorithm, only slightly better than the 3W algorithm. Because the MCMDRA algorithm considers the factors that whether crossing the high-speed or high-speed rail and the number of cable-type switching times. These factors have a great impact on the reliability of the power communication network, so it is reasonable to give priority to this factor and properly sacrifice the SPBD.

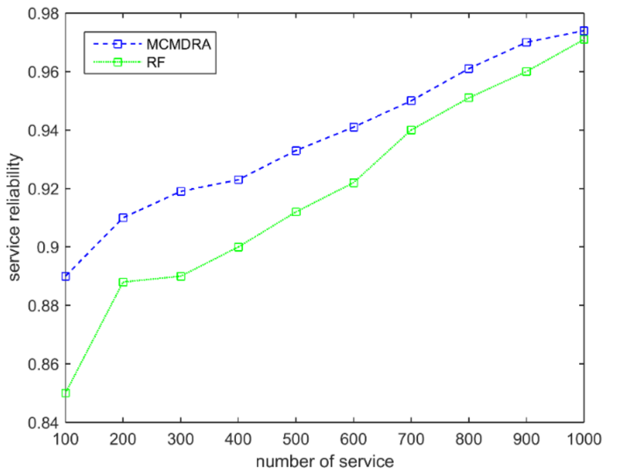


Fig 7 service reliability changes with the number of service

The reliability of service is given by Formula (2-13). As can be seen from Fig 7, reliability of MCMDRA algorithm compared with the reliability of RF algorithm has improved significantly in the case of a few services. And in the case of lots of services, the discount line of the two algorithms will be very close. So when the quantity of service is small, MCMDRA algorithm is a more reliable algorithm.

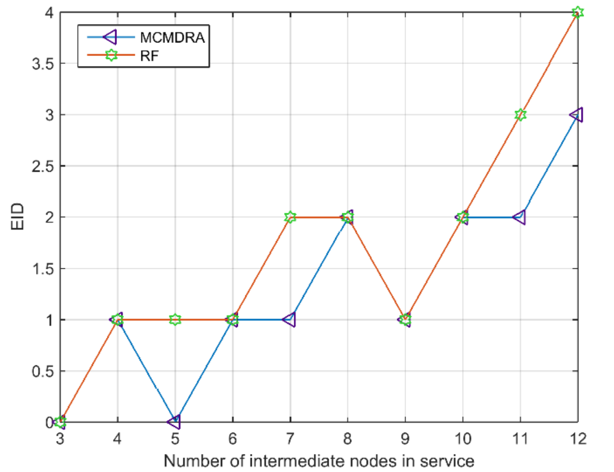


Fig 8 EID changes with the number of intermediate nodes in service

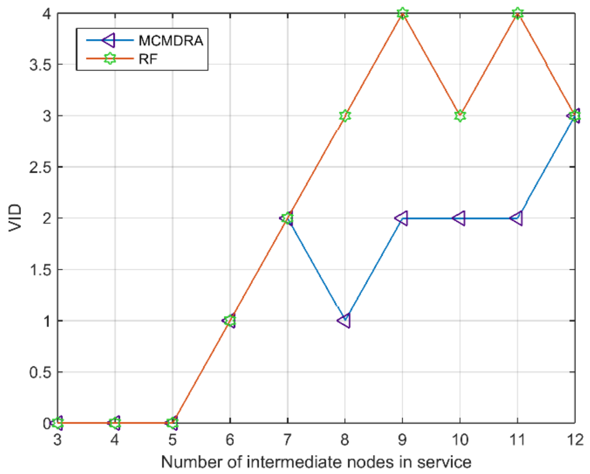


Fig 9 VID changes with the number of intermediate nodes in service

From the EID and VID, it can be seen that the improved Bhandari maximally disjoint algorithm still has the maximally disjoint property and the RID of traditional RF algorithm cannot be lower than the improved Bhandari maximally disjoint algorithm. Moreover, major route of it is the optimal solution which considering a variety of constraints and combing with the advantages of the service path pressure. In summary, MCMDRA algorithm improves QoS and reliability much further.

V. CONCLUSION

In order to improve the quality of service in power communication network, to meet the new requirements and new challenges put forward by power communication network, we propose a multi-constrained maximally disjoint algorithm in this paper. It eliminates the defect of route which is limited to the single constraint and takes into account the actual situation of the power communication network. Experiments show that MCMDRA algorithm has better performance compared to other algorithms. The next work will study the failure recovery mechanism of power communication network based on the above research and ensure the QoS of power communication network better.

VI. ACKNOWLEDGEMENT

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References

[1] Hung, Mao-Hsiung, Chia-Hung Wang, and Yao He. "A Real-Time Routing Algorithm for End-to-End Communication Networks with QoS Requirements." Computing Measurement Control and Sensor Network (CMCSN), 2016 Third International Conference on. IEEE, 2016.

[2] Tornatore, Massimo, Ferhat Dikbiyik, and Biswanath Mukherjee. "(3W-) availability-aware routing in optical WDM networks: When, where and at what time." Transparent Optical Networks (ICTON), 2011 13th International Conference on. IEEE, 2011.

[3] Liu, Nianzu, and Xiao Chen. "Overlay multicasting at a path-level granularity for multihomed service nodes." Information Science and Technology (ICIST), 2011 International Conference on. IEEE, 2011.

[4] Attarha, Shadi, et al. "A load balanced congestion aware routing mechanism for Software Defined Networks." Electrical Engineering (ICEE), 2017 Iranian Conference on. IEEE, 2017.

[5] Xing, Ningzhe, et al. "Load balancing-based routing optimization mechanism for power communication networks." China Communications 13.8 (2016): 169-176.

[6] Zeng, Qingtao, et al. "Risk Balancing Based Routing Mechanism for Power Communications Service" Journal of Electronics and Information Technology 35.6 (2013): 1318-1324.

[7] Yu, Zhanke, et al. "An efficient approximate algorithm for disjoint QoS routing." Mathematical Problems in Engineering 2013 (2013).

[8] He, Yujun, et al. "A maximally disjoint routing algorithm for power communication networks" Power System Protection and Control 44.5(2016):60-68.

[9] Aven, Terje. "Practical implications of the new risk perspectives." Reliability Engineering & System Safety 115 (2013): 136-145.

[10] Power Grid Dispatching Communication Center of Guangdong Province. “Quantitative Evaluation Method of Safety Risk in Guangdong Electric Power Communication Network”. Guangdong Power Grid Company, 2010.

[11] Xing, Ningzhe, et al. "Security Event Quantitative Model and Forecasting Method for Power Communication Network." Journal of Electronics and Information Technology 10(2016):120-126.

[12] Zhao, Puyuan, et al. "Risk assessment and optimization for key services in smart grid communication network." Integrated Network and Service Management (IM), 2017 IFIP/IEEE Symposium on. IEEE, 2017.

[13] Martins, Ernesto de Queiros Vieira, and Jose Luis Esteves Dos Santos. "A new shortest paths ranking algorithm." 1999.

[14] Bhandari, Ramesh. "Optimal diverse routing in

telecommunication fiber networks." INFOCOM'94. Networking for Global Communications., 13th Proceedings IEEE. IEEE, 1994.

[15] Bhandari, Ramesh. "Optimal physical diversity algorithms and survivable networks." Computers and Communications, 1997. Proceedings., Second IEEE Symposium on. IEEE, 1997.