Dynamic Variance Equalization Planning Optimization Method for Power Grid System Protection Communication Network

Dongliang GAO1, Taorui LUO1, Peizhe XIN2, Yudong WANG2, Jun LU3, Peng CAI3

1State Grid Sichuan Economic Research Institute, Sichuan, China
2State Grid Economic and Technological Research Institute CO., LTD, Beijing, China
3School of Electric and Electronic Engineering, North China Electric Power University, Beijing, China
3 877593046@qq.com

Abstract. To improve the universality of the backbone communication network architecture model in Smart Grid, this paper proposed a dynamic variance equilibrium planning optimization method for the system protection service in the power grid. Firstly, based on the two-layer architecture model of the power backbone communication network, a network equilibrium optimization model is constructed. Secondly, based on the network equilibrium optimization model, a simulation experiment method with the node usage ratio as the optimization target and the delay in the transmission process as the constraint condition is designed. Finally, the model was quantified through simulation experiments. The simulation results show that the proposed optimization model has excellent applicability in network balance planning of grid protection services.

1. Introduction

The power communication network is a communication network dedicated to the operation and management of power systems, with obvious industrial characteristics and special requirements for safety and reliability[1]. With the continuous improvement of the automation level of power systems, the power communication network plays an increasingly important role in power production and power dispatching. Power systems are high-tech and intensive industries that require high reliability and power information security. This puts higher demands on the power communication network. How to provide high-quality and reliable information services for power system operation and production based on existing communication facilities is a new challenge for power system communication services[2]. Another solution may be Optical Transport Network (OTN) technology. OTN technology is based on wavelength division multiplexing and WDM technology. It guarantees similar SDH protection and management and maintenance functions through frame structure and overhead processing similar to SDH. The OTN architecture consists of an optical layer and an electrical layer. Both the optical layer and the electrical layer network have their own monitoring and management capabilities, and the optical layer and the electrical layer network have better survivability.
Many works have been done on the network architecture and smart grid and its related modeling optimization\cite{3-6}. In [3], a latency constrained dynamic routing algorithm is proposed in optical transport network for smart grid systems, in which the influence of spectrum slot size is revealed on traffic latency and blocking probability in grid communication networks. In [4], a label setting algorithm has been presented to solve the problem that the k-shortest path problem, which is given that departure and arrival are constrained within specified time windows. In [5], an optimal delay-based virtual topology is designed using integer linear programming for the smart-grid power backbone communication network, which can achieve superior smart-grid network performance. In [6], an energy-efficient multicast tree construction protocol is presented for real-time data streaming, which considers using real time estimated routing delay from source node to other nodes.

Given the fact that the power related services requires considering Quality-of-Service (QoS) in the power grid system protection communication network, this paper proposes a dynamic variance equalization planning optimization modelling. The rest of the paper is organized as follows. In section 2, the dynamic variance equalization planning modeling and the Dynamic Variance Equalization (DVE) algorithm is described. Section 3 discusses the simulation experiment. Finally, the conclusion is drawn in Section 4.

2. Dynamic variance equalization modelling

2.1 OTN two-layered architecture

The network technology in the power grid selects OTN, the basic architecture to optimize the channel equalization planning of the system protection service. The typical layered architecture of OTN is shown in Figure 1.

![Figure 1. General model of two-layer architecture.](image)

2.2 Dynamic variance equalization model

The dynamic variance equalization model for optimizing the OTN network planning is constructed. The proposed model considers the time-delay as constraint. Moreover, the optimal goal considers the average node access usage ratio, which supports the system protection services. Suppose there are $N_s^e$ grid-system-protection services (short for grid-service) in the related OTN communication network with nodes’ total number as $P$, a grid-service ID is symbolized as $d$, which is from 1 to $N_s^e$.

Assume $M_i$ is the number of the access capacity for each Node $i$ in the ONT Network, and $\xi_i^o$, which is set to 1, represents one access capacity for each Node $i$ in the optical layer. $L_o$ represents the
transmission link in the optical layer. If $\delta^o_{dl}$ takes 0 or 1 representing whether the given service $d$ transports from or to the Node, Node $i$ related access usage ratio $R_i$ in the optical layer may be formulated as (1).

$$R_i = \frac{1}{M_i} \sum_{l=1}^{L_i} \delta^o_{dl} \zeta_l$$  \hspace{1cm} (1)$$

Therefore, the optimization model for the dynamic variance equalization model may be formulated as (2).

$$\min f = \left( \frac{1}{P} \sum_{i=1}^{P} (\frac{R_i - \bar{R})^2}{P} \right)^{1/2}$$  \hspace{1cm} (2)$$

s.t.  \hspace{0.5cm} T_d \leq T_{upper} \hspace{1cm} (2a)$$

$$\hspace{0.5cm} R_i \leq R_{upper} \hspace{1cm} (2b)$$

In (2), $\bar{R}$ is the average node usage ratio for the OTN network, which may be calculated by the mathematic-mean operation of $R_i$. The restraint (2a) represents the time-delay restraint for the grid-service $d$ (generally less than 60ms). In (2a), $T_d$ is the transmission total time-delay for the service $d$ including the electric layer time-delay and the optical layer time-delay, while $T_{upper}$ is the upper limitation of the transmission time-delay for the grid-service $d$. The restraint (2b) represents the node access usage ratio restraint for the grid-service $d$ (generally less than 50%). In (2b), $R_{upper}$ is the upper limitation of the node access usage ratio.

2.3 DVE flow chart
The flow chart of the proposed DVE algorithm to implement the proposed model is shown in Figure 2.
Calculate the corresponding second shortest path by Dijkstra algorithm. Calculate the node equilibrium degree for each scheme. Select the smallest node equilibrium degree. Any node usage ratio more than 50%. Permanently remove nodes with usage ratio more than 50%. Count link usage ratio.

Figure 2. DVE flow chart.

Firstly, for a service between \( \text{Node}_i \) and \( \text{Node}_j \), four shortest paths are obtained by K shortest paths (KSP) algorithm. For each candidate scheme, to implement the physical 1+1 backup, the nodes passing through the candidate path are deleted, and the second shortest path that satisfies the physical 1+1 backup is obtained by the Dijkstra algorithm. The node equilibrium degree of each scheme is calculated, and the scheme with the smallest node equilibrium degree is selected to update the node usage ratio. At the same time, if the service is added and the node usage ratio exceeds 50%, the corresponding node is temporarily deleted, and then the next set of nodes is solved.

3. Simulation and analysis

3.1. Experimental parameters settings

The simulation experiment is carried out according to the DVE algorithm mentioned above. In the simulation experiment, the total delay includes the transmission delay and the node forwarding delay. The simulation network is the cost 239 network of Figure 3. 70 random services are generated in the simulation, and services are added sequentially by DVE algorithm and KSP algorithm respectively. KSP algorithm is the comparison algorithm, which directly generates two shortest link path between \( \text{Node}_i \) and \( \text{Node}_j \). The node usage ratio and node equilibrium degree are counted for each 10 pieces of service added. Finally, the usage ratio of each node in the added network is analyzed.
The simulation experimental parameters of OTN technology are set as follows: $T_G$ represents the optical cable delay with the value as 5 us per 100 kilometers, while $T_z$ represents the direct connection delay with the value as 200 us. Moreover, $T_e$ represents the mapping delay with the value as 40 us and $T_q$ represents the canceling mapping delay with the value as 40 us. In the following part, we compare the KSP algorithm with our proposed DVE algorithm in terms of node usage ratio and node equilibrium degree.

3.2. Node equilibrium degree experiment

Firstly, the experimental comparison of the node balance of the proposed DVE algorithm and KSP algorithm when adding services is carried out. The simulation results are shown in Fig. 4. The X axis represents the number of added services, ranging from 0 to 70, and the node equilibrium degree is recorded every 10 times in the simulation. The Y axis represents the node equilibrium degree.

It can be seen from Figure 4. that: (a) As the number of services in the network increases, the node equilibrium degree of the proposed DVE algorithm and KSP algorithm increases. Because with the number of services increasing, the network complexity increases, and the network balance decreases. (b) As the number of services increases, the proposed DVE algorithm is more gradual than the KSP algorithm. This shows that the proposed algorithm has more advantages than the KSP algorithm in adding new services, which can reduce the fluctuation of the network when adding services. (c) When adding the same amount of services, the balance of the DVE algorithm is significantly better than the KSP algorithm, and the more services, the more obvious the advantage.
3.3. Node equilibrium degree experiment

Secondly, when 70 services are added to the network, the two algorithms are simulated. The experimental results are shown in Figure 5 and Table 1. In Figure 5, the X axis represents the node number, ranging from 1 to 11. The Y axis represents the node usage ratio, between 0 and 1. In Table 1, $R_{\text{node}}$ represents the average node occupancy, $\sigma_{\text{node}}$ represents the node balance, and Maximum and Minimum represent the maximum and minimum values of the two algorithms.

![Figure 5. Node usage ratio (Nservice =70).](image)

**Table 1. Comparison of statistical results of node usage of DVE and KSP algorithms.**

| Algorithm | $R_{\text{node}}$ | $\sigma_{\text{node}}$ | Maximum | Minimum |
|-----------|-------------------|------------------------|---------|---------|
| DVE       | 0.27              | 0.009                  | 0.40    | 0.10    |
| KSP       | 0.24              | 0.030                  | 0.53    | 0.02    |

It can be seen from Fig. 5 and Table 1: (a) When the number of added services is 70, the fluctuation of the node usage ratio of the proposed DVE algorithm is smaller than that of the KSP algorithm. (b) The maximum node usage ratio of the KSP algorithm is 53%, and the minimum value is 2%. (c) The DVE algorithm has a maximum node usage ratio of 40% and a minimum of 10%. (d) The node equilibrium degree of the proposed DVE algorithm is lower than that of the KSP algorithm. At the cost, the average node usage ratio is slightly higher than the KSP algorithm.

3.4. Node equilibrium degree experiment

Finally, when adding services, the average node usage ratio of each stage is simulated. The experimental results are shown in Figure 6. In the figure, the X axis represents the number of added services, from 0 to 70. The Y axis represents the average node usage ratio of 11 nodes for each ten services added.

![Figure 6. Average node usage ratio.](image)
Table 2. Comparison of statistical results of average node usage and node equilibrium degree.

| $N_{\text{service}}$ | 10  | 20  | 30  | 40  | 50  | 60  | 70  | Average |
|-----------------------|-----|-----|-----|-----|-----|-----|-----|---------|
| **Increment**         | 18% | 10% | 10% | 11% | 12% | 12% | 12% | 13%     |
| **Reduction**         | 58% | 55% | 58% | 64% | 66% | 69% | 70% | 63%     |

It can be seen from Figure 6 and Table 2: (a) When the number of services increases, the average node usage ratio of the proposed DVE algorithm in each stage is slightly higher than the KSP algorithm. (b) In Table II, Increment represents the increment of the average node usage ratio of the DVE algorithm relative to the KSP algorithm, and Reduction represents the decrement of the DVE algorithm node equilibrium degree with respect to the KSP algorithm. It can be seen that although the average node usage ratio of the DVE algorithm increases, the advantage of node equilibrium degree is obvious. It can be seen that the DVE algorithm is relatively better than the KSP algorithm.

4. Conclusion
This paper proposes dynamic variance equalization planning optimization modeling for power grid system protection communication network, which is suitable for adding new services to an existing network. Through simulation and analysis, it can be seen that the dynamic variance equalization planning optimization model proposed in this paper can meet the power system protection delay specified in the power system protocol to meet the requirement of less than 50ms. And our DVE algorithm has better equalization performance than KSP algorithm.

Acknowledgements
This work is funded by China State Grid Science and Technology Project (No. SGSCJY00GHJS1800018 and No. SGXT0000ASJS1700054).

References
[1] M. N. Mohr Warp, I. Antonovich, etc. Energy Efficient Partition-light path Scheme for IP over WDM Core Network. Procedia Computer Science, 2015, 52: 324-348.
[2] K. D. Dambulla, F. M. About, H. T. Chua. Impact of SRS and XPM on the Performance of IP Traffic over a WDM Ring Network. Journal of Optical Communications, 2007, 28(3): 231-246.
[3] Fan Bo Meng, Tai Yi Fu, Jun, etc. Performance Evaluation of Ethernet Passive Optical Network for Smart Grid. Applied Mechanics and Materials, 2014, 356-360.
[4] Amit Kumar Garg. An efficient fault localization or detection mechanism for high speed optical networks[J]. Optic - International Journal for Light and Electron Optics, 2013, 124(21).
[5] Pagadian Shashikant, Yilmaz Melittin, Alluri Prayut. Smart-Grid Backbone Network Real-Time Delay Reduction via Integer Programming. IEEE transactions on neural networks and learning systems, 2016, 27(8): 231-219.
[6] Konstantinos N. Androutopoulos, Konstantinos, etc. Solving the k-shortest path problem with time windows in a time varying network. Operations Research Letters, 2008, 36: 1393-1404.