Research on a New Method of Power Grid Zoning and Layering Based on Dijkstra Algorithms

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Abstract. With the development of high voltage grid, it is the trend of future grid development to unlock the electromagnetic loop network and carry out grid layered and partitioned operation. Subarea operation of power grid can effectively alleviate the complex structure of current grid and the serious problem of short-circuit current exceeding the standard. A new power grid partitioning method based on Dijkstra algorithm is proposed. Firstly, according to the knowledge of graph theory, the power network is transformed into a network topology graph, and the impedance of stations and lines in the grid structure corresponds to the nodes and weights in the topology graph. Then, Dijkstra algorithm is used to find the shortest distance from the initial point within the prescribed distance, and the required site and the initial point are divided into the same partition. Taking 500 kV/220 kV power grid as an example, because the development trend of future power grid is that high voltage grade grid plays a supporting role, and the sections are connected through tie lines, so 500 kV stations are selected as the initial point, and finally several zones supported by 500 kV stations are determined. The proposed method can be programmed for fast computation without multiple solutions. Finally, the feasibility and practicability of the proposed method are verified by the example of IEEE30 bus system and the actual power grid in a certain area.

1. Introduction

With the development of national economy, the demand for electricity is increasing year by year. When the original grid structure can not meet the new load transmission requirements, high voltage grade grid emerges. In the early stage of the new high voltage level, the grid structure is not perfect. In order to ensure the reliability of power supply, it is necessary to run side by side with the low voltage grid, so the electromagnetic loop network [1] is generated. In the process of improving and optimizing the grid structure, the advantages of electromagnetic ring network are very obvious, such as increasing the safety and stability of the system, ensuring the transmission capacity and reducing the reserve. However, with the improvement of the grid structure, the shortcomings of the electromagnetic loop network are increasingly apparent [2]. Closed-loop operation of the grid reduces the electrical distance...
between stations, increases the short-circuit current and even exceeds the interruption capacity of circuit breakers. The grid structure is complex, which is not conducive to dispatch management, and is prone to cascading reactions when faults occur, which seriously threatens the safe operation of the power grid. At the same time, the parallel operation of the high-voltage grade grid and the low-voltage grade grid can avoid the excessive power flow transfer and overload of the low-voltage grade grid when the high-voltage grade grid fails, and the high-voltage grade grid can not give full play to its proper transmission capacity. With the continuous development of the grid structure, the above shortcomings are becoming increasingly obvious. Therefore, when the grid develops to a certain stage, it is the future trend of the grid to unlock the electromagnetic loop network and realize the layered and partitioned operation of the grid.

The concept of layered zoning is formed in the process of gradual development and improvement of the power grid. Hierarchical zoning refers to a basic supply-demand balance area with high-voltage grade grid as the backbone. Connections between zones are carried out through tie lines, which not only ensures the connection between zones, but also removes tie lines in case of serious faults to avoid cascading faults. Layered and partitioned operation can solve the problems of short circuit current exceeding the standard, system stability, operation economy and power supply reliability caused by the above electromagnetic loop network. The above advantages of layered partition correspond to the shortcomings of electromagnetic ring network, but at the same time layered partition also has its shortcomings [3]: after partition is completed, the connection of low-voltage grade grid structures in different partitions is weakened. When the high-voltage grid fails, it will cause a large area of power gap, which may threaten the safe operation of the grid. At the same time, due to the limited power that the tie-line can transmit, when there is a power gap in a certain area, the power supply between the zones may take a long time. In view of the above shortcomings, it is necessary to take into account the development of local grid structure and gradually carry out layered and zoned operation.

At present, there are many literatures on the research of loop-breaking and current-limiting. Document [4] has studied the problem of urban electromagnetic loop network decoupling, put forward the idea and guiding principle of active processing of electromagnetic loop network, and analyzed the importance of determining the decoupling point and timing reasonably. Literature [8] proposes an optimization algorithm to limit short-circuit current. The algorithm studies the influence of disconnected lines on several over-standard stations. By analyzing the sensitivity of grid adjustment, it seeks the overall optimal current limiting effect.

Reference [5] considering the mutual restriction between current limiting and improving system stability, the hybrid particle swarm optimization (HPSO) algorithm is applied to obtain the optimal set of current limiting schemes. Reference [6] According to the comprehensive decision-making model of current-limiting operation mode, several kinds of high sensitivity coefficients of weighted short-circuit current are selected.

The optimal breaking combination is determined by the combination of breaking lines. The methods proposed in reference [7] can effectively alleviate the phenomenon of short-circuit current exceeding the standard and improve the security and stability of the system. However, the proposed method does not consider the optimization of the grid structure and the problem of layered partition, which leads to the complex structure of the grid and inconvenience in management and dispatch, and has not played a positive role in the long-term development planning of the grid. Literature [11] uses the community discovery algorithm to divide the actual grid into new sections, and uses the community structure to analyze the characteristics of the grid. This method can well reflect the characteristics of the grid.

Document [8] applies the knowledge of graph theory to power grid partitioning, breaks the limitation of manual operation, and proposes an automatic power grid partitioning operation method aiming at balancing the load of 500 kV main transformer as much as possible. The traditional grid partition pays less attention to the grid structure, mainly depends on work experience and geographical area. With the expansion and improvement of the grid structure, if the original partition can not reflect the actual characteristics of the grid structure well after the change of the grid structure, there will be
problems such as complex grid structure, inconvenient dispatch, over-standard short circuit current and easy to occur cascading failures.

The goal of power grid partition is to increase electrical distance, reduce short-circuit current, sort out grid structure and facilitate operation and dispatch. After the partition is completed, the internal connection of the partition is relatively close, and the connection between the partitions is through the contact line. Aiming at the goal of power grid partitioning, a new power grid partitioning method based on Dijkstra algorithm is proposed in this paper, in which 500 kV grid is used as the backbone grid. Compared with the previous zoning methods, the proposed method fully considers the actual structure of the power grid. It can not only effectively alleviate short-circuit current exceeding the standard, carding the grid structure, but also quickly, simply and accurately partition by programming, so as to achieve the goal of optimizing the network layout and reducing short-circuit current. At the same time, this paper uses the representative algorithm of breadth-first search algorithm, Dijkstra algorithm [15-17], whose main feature is to extend from the beginning to the outer layer until the end point. In the absence of negative weights, Dijkstra has good timeliness and stability, and can achieve fast operation speed. At present, Dijkstra has been well applied in information communication, civil engineering and other fields. Firstly, the power network is transformed into a system topology diagram, and then Dijkstra algorithm is used to find several stations whose electrical distance from the initial point meets the requirements. The stations that meet the requirements are divided into the same partition with the initial point. At the same time, in order to ensure the reliability of power supply, two adjacent 500 kV stations are classified into the same partition. Finally, the feasibility and practicability of the proposed method are verified by the IEEE30-bus standard example and the actual power grid in a certain area.

2. Application of Dijkstra algorithm in power network partition

2.1. Distribution Concept of Power Grid
With the continuous development of the high-level grid, the regional power grid will gradually operate in different zones. At present, there is no clear guiding principle for power grid zoning, but the overall goal is to use high voltage grade grid as the support grid, the internal connection of the zones is close, and the connection between zones is through the tie line, which can ensure the connection of the zones and effectively avoid the occurrence of cascading failures [24]. In order to ensure the reliability of power supply, this paper takes 500 kV grid as the support grid. Each partition guarantees two 500 kV stations. If it can not meet the requirements, it implements a weak open-loop mode, and the adjacent sections are in reserve for each other to ensure the reliability of power supply.

2.2. The process of partitioning power grid based on Dijkstra algorithm

1) Using PSD power system analysis software to draw network topology map, eliminating suspended nodes, the vertices of network topology map correspond to power plants and substations in the actual grid, the connection lines between nodes correspond to transformers, transmission lines and equivalent lines in the actual grid, and the weights of lines correspond to the impedance values of transformers, transmission lines and equivalent lines in the actual grid.

2) Select each 500 kV station as the starting point, determine the specified value \( X_m \), according to Dijkstra algorithm, find the shortest path from the starting point to the specific node in the graph, and then determine whether the electrical distance from the 500 kV station is within the specified value \( X_m \).

3) Output the stations satisfying the electrical distance requirement at each starting point.

4) Dijkstra algorithm uses a single vertex to initiate a search to form a partition, but in the actual power grid partition, the fault of a single 500 kV station and the standby situation of another 500 kV station should be considered, so the partition formed by two nearest 500 kV stations as the starting point should be merged into one network partition.
Also note: The cut-off reactance Xm value should be considered as large as possible to ensure that all stations in the grid are included in the partition, but the specific value should be determined according to the specific structure of the grid. The principle is to enable all sub-stations to find the grid partition with 500 kV station as the starting point, so that there are no isolated nodes in the partition process. At the same time, the larger the cut-off reactance Xm value will also cause a sub-station to enter two sub-stations with 500 kV stations as the starting point at the same time. In this case, the sub-station is selected to be divided into the sub-areas determined by 500 kV stations with closer electrical distance. After the power grid partition is completed, the sections are connected through tie lines. On the one hand, it is necessary to consider combing the grid structure so as to find the nearer sub-stations for 220 kV stations. At the same time, the problem of overload caused by power flow transfer should be avoided in the process of disconnection.

3. Example analysis

3.1. IEEE30 Node System

The steps of Dijkstra algorithm are checked by IEEE30 node system, the suspended nodes are eliminated, and the network topology is determined as shown in Figure 1. The starting points are 4, 15, 22 and 28 nodes, and the line reactance is used to replace the edge length. Because IEEE30-bus system is not an actual power grid, it does not consider the situation of each other as standby, but uses Dijkstra algorithm to verify the steps of partitioning. The results after partitioning are shown in Figure 2.

![Figure 1. Network topology](image1)

![Figure 2. Structure diagram of network partition](image2)

Conclusion: When partitioning according to geographical location, it is found that 5 nodes are closer to 4 nodes than 5 nodes to 28 nodes. But when calculating according to Dijkstra algorithm, it is found that the electrical distance between 5 nodes and 28 nodes is shorter. When partitioning power grid, 5 nodes should be classified into 28 nodes. In the actual architecture of the grid, nodes

Because of the large number of stations, the power grid partition method based on Dijkstra algorithm can effectively divide the stations with close electrical connections into the same partition.

3.2. A Real Area Power Grid

In this paper, a regional power grid in Hebei Province is selected for zoning planning. After eliminating the suspended nodes, the topological structure diagram shown in Figure 3 is obtained. The
PSD-SCCPC short-circuit current program is used to simulate and analyze the short-circuit current of power system. Three stations with short-circuit current exceeding the standard and three stations close to 50 kA are HY220 kV, AZ220 kV, TPZ220 kV and TBZ220 kV, ZDZ220 kV, YL220 kV. The short-circuit current sizes are 59.365 kA, 54.473 kA, 51.648 kA and 49.633 kA, 47.532 kA and 47.434 kA, respectively.

Dijkstra algorithm-based power grid zoning method is applied to zoning planning and searching according to the programming. The zoning with HY500 kV, AZ500 kV, TBZ500 kV, YL500 kV and TSX500 kV as initial points is found. With the completion of CG 500 kV station near TSX500 kV station, some 220 kV lines near TSX500 kV station can be disconnected, and the newly built CG 500 kV station can be used as power supply source. At that time, the area can be divided into three zones.

After the partition is completed, the grid structure is clear, and each partition is connected by tie lines. The section tie lines are mainly based on line power flow judgment. The lines with larger power flow are selected to disconnect, while the lines with smaller power flow are retained. The PSD power system analysis software is used to check the lines after disconnection to ensure that there is no overload caused by power flow transfer. The partition is shown in Figure 4.

By comparing the short-circuit current of some stations before and after partitioning, it is found that the short-circuit current of the stations decreases to the interruption capacity of the circuit breaker, as shown in Table 1.
Table 1. Comparison of short-circuit current before/after partition

| Site name | Breaking capacity of circuit breaker/MVA | Three-phase short circuit current/kA | Partitioned Back Short Circuit Current/kA |
|-----------|----------------------------------------|------------------------------------|----------------------------------------|
| HY220kV   | 50                                     | 59.232                             | 47.411                                 |
| AZ220kV   | 50                                     | 54.921                             | 47.121                                 |
| TPZ220kV  | 50                                     | 51.122                             | 44.651                                 |
| TBZ220kV  | 50                                     | 49.121                             | 45.121                                 |
| ZDZ220kV  | 50                                     | 47.981                             | 43.642                                 |
| YYL220kV  | 50                                     | 47.122                             | 43.214                                 |
| GS220kV   | 50                                     | 45.562                             | 41.521                                 |
| JK220kV   | 50                                     | 45.232                             | 43.921                                 |
| YN220kV   | 50                                     | 44.761                             | 41.221                                 |
| JSJ220kV  | 50                                     | 43.442                             | 41.553                                 |
| LG220kV   | 50                                     | 43.453                             | 40.212                                 |
| HY500kV   | 63                                     | 54.321                             | 47.762                                 |
| YYL500kV  | 63                                     | 51.441                             | 40.652                                 |

Conclusion: The overall short-circuit current in this area is relatively high. There are three stations whose original short-circuit current exceeds the standard, and more stations whose short-circuit current is close to the interruption capacity. When the power grid partitioning method based on Dijkstra algorithm is completed, the short-circuit current decreases to below the breaking capacity of the circuit breaker, and the overall short-circuit current level decreases, which achieves the overall better effect. At the same time, after the power grid is partitioned, the sections are connected through tie lines, the grid structure is clear, and it is more convenient for dispatching and management. With the continuous development and expansion of the grid structure, this zoning method still has good applicability.

4. Conclusion

With the development of power grid, electromagnetic loop network exists. However, with the development and perfection of the grid structure, the drawbacks of electromagnetic loop network gradually appear, such as reducing electrical distance, exceeding short-circuit current standard, inconvenience in operation and dispatch, complex grid structure and easy occurrence of interlocking faults. In order to solve the above problems, this paper proposes a new method from the point of view of power grid partition.

A new method of power grid partition based on Dijkstra algorithm. This method can quickly search the path by programming, find the site whose electrical distance from the starting point meets the requirements, and divide the area according to the electrical distance.

The Dijkstra algorithm model steps are checked by IEEE30 nodes, which proves the feasibility of the algorithm. Finally, use a certain area in Hebei Province

An example of power grid is simulated and analyzed. The short-circuit current and power flow are calculated by PSD power system analysis software. The conclusion proves that this method has good applicability for reducing short-circuit current and optimizing grid structure.

References

[1] BAI Hongkun, LI Gansheng. Discussion on weak open-loop mode of electromagnetic loop [J]. Power System Protection and Control, 2010, 38 (2): 60-63.
[2] LIU Mingsong, ZHANG Jian, ZHANG Wenchao, et al. Problems and countermeasures for operation and control of weak electromagnetic loops [J]. Automation of Electric Power Systems, 2014, 38 (4): 109-114.
[3] ZHOU Limei, FAN Mingtian, ZHANG Zuping, et al. Analysis of electromagnetic loop network in Hefei City [J]. Power System Technology, 2008, 32 (20): 73-76.
[4] SUN Yan, LING Wuneng, LI Ruqi, et al. Power flow control of electromagnetic loop network based on distribution coefficient and phase angle matching analysis [J]. Power System Protection and Control, 2015, 43 (17): 22-28.

[5] ZHANG Baohui, HAO Zhiguo, BO Zhiqian. New development in relay protection for smart grid [J]. Protection and Control of Modern Power Systems, 2016, 1 (1): 121-127. DOI 10.1186/s41601-016-0025-x.

[6] LIU Ying-shang, WU Wen-chuan, FENG Yong-qing, et al. Black-start zone partitioning based on ordered binary decision diagram method [J]. Proceedings of the CSEE, 2008, 28 (10): 26-28.

[7] HUANG Fei, SONG Xuankun, ZHOU Hui, et al. Study on the comprehensive evaluation index system of power grid intelligent level based on the interaction of effect and foundation [J]. Power System Protection and Control, 2016, 44 (11): 142-148.

[8] ZHANG Zuping, FAN Mingtian, ZHOU Limei. Research of breaking up electromagnetic ring in urban power network [J]. Power System Technology, 2008, 32 (19): 42-44.