

A Station Domain Islanding Detection Method Based on Topology Analysis

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SUMMARY

The communication-based islanding protection in the station domain can quickly realize the islanding detection without detection blind area and no disturbance will be injected into power system. However, the current station domain islanding detection method does not have universal applicability. In this paper, the topology analysis method is introduced into the islanding detection in the station domain. The islanding detection of power systems with different topological structures can be realized by modifying the parameters. The voltage grade of each node of the power system is used to optimize the search path of topology analysis. In addition, the circuit breaker position is checked to enhance the reliability of the islanding detection method.

KEYWORDS

Station domain islanding detection method; Topology analysis method; Voltage grade; Circuit breaker position check

0 Introduction

In recent years, energy demand and environmental protection have promoted the explosive growth of Distributed Generation (DG). The problems of unplanned island operation such as threats to personnel safety, out-of-phase reclosing, and degradation of power quality are more and more obvious[1-3]. Therefore, how to safely, quickly and accurately remove the DG becomes a hot spot of research when unplanned islands are generated.

During the past years many methods for detecting the islanding condition have been proposed and developed. They can be divided into three categories:

- active methods,
- passive methods,
- communication-based methods.

Passive islanding detection method adopts voltage and frequency criterion. The principle is simple and easy to implement, but there are some problems, such as blind detection area, and the trip time must cooperate with other protection, which lead to late tripping.

Active islanding detection method[4] injects disturbance into the power system. This method does not depend on the power mismatch level in the island. However, it reduces power quality and interference resulting from multiple DG sites may lead to the failure of islanding detection.

In recent years, with the development of intelligent substation [5-6], network communication technology based on IEC61850 is becoming more and more mature [7], and the concept of station domain islanding detection is proposed. Station-domain islanding detection is a communication-based islanding detection method. It uses the information sharing platform of the whole station to collect the information of related switching and analog signals on the side of the station-domain and carry out system state analysis to judge the islanding status. When islanding occurs, it will issue the trip command to remove DG, which is fast and effective. The method has no detection blind area and does not inject disturbance into power system.

The current station-domain islanding detection method is generally based on fixed network topology[8], which does not have universal applicability. To solve this problem, a topological analysis method based on voltage grade is proposed to realize islanding detection in station domain[9-11]. Topological analysis can adapt to different power system topologies by modifying interface parameters. Based on the traditional depth-first search method, the node voltage grade is incorporated into the algorithm, which greatly improves the search efficiency. At the same time, the position of circuit breaker is checked to ensure the accuracy and reliability of the algorithm. Finally, different algorithms are simulated with MATLAB, and the feasibility and efficiency of the proposed algorithm are verified by an example analysis.

1 Topological analysis of power system

Topological analysis method first needs to analyze the system's topological structure [12]. This section briefly introduces the formation process of topological structure of the system to be analyzed in station domain islanding detection.

1.1 Node classification

This paper takes the complex system in Figure 1 as an example to conduct topological analysis of the power system. As shown in Figure 1, the nodes in the power system are divided into four categories: power supply, bus or branch intersection, DG and load. Bus and branch intersections are classified as one kind of nodes because of their similar functions, such as nodes 4, 5, 6, 7, 8, 9, 10, 11, 12. For substations, the incoming line is regarded as the power supply node of the system, as shown in nodes 1, 2 and 3. Load does not affect the result of islanding detection and does not take into account the topological analysis. DG is shown in nodes 13 and 14. The connectivity between nodes is determined by the position of the circuit breaker. If the circuit breaker is closed, the nodes are connected.

As can be seen from matrix A, the adjacency matrix is symmetric, so only the upper triangular data need to be stored to reduce the required storage space. When there are too many nodes in the system, the adjacency matrix may be too large. Since there are fewer non-zero elements in the adjacency matrix, sparse matrix can be adopted to further reduce the required storage space.

2.2 Topology Analysis Method Based on Voltage Grade

Adjacency matrix is a matrix representing the direct connection between nodes. The connectivity between any two nodes can be further analyzed by full matrix self-multiplication [14-15] and tree search [16-18].

Total matrix self-multiplication is to obtain the fully connected matrix of connectivity between any two nodes by matrix self-multiplication calculation. The system with total number of nodes N carries out N-2 matrix self-multiplication at most. This method is not suitable as a protection algorithm due to its large amount of computation and time-consuming computation. Moreover, the islanding detection only needs to judge the topological connectivity between DG nodes and power nodes of the system[19-20], and does not need to obtain the connectivity of all nodes, so the full matrix self-multiplication is not used.

Tree search method is mainly represented by Depth-first Search (DFS) and Breadth-first Search (BFS). There are many traversal sequences of DFS and BFS, and different traversal sequences have different search efficiency for islanding detection in station domain. For islanding detection in station domain, there are unnecessary searches in DFS backtracking mode and BFS layer-by-layer searching mode.

For islanding detection in station domain, the process of finding the path between DG node and power node is similar to the idea of tree search method. Therefore, this paper adopts tree search method for topology analysis and introduces voltage grade to improve the efficiency of tree search.

In the power topology of substation, the voltage grade of system power supply is the highest. Therefore, the tree search starts from the DG node, and the node with the highest voltage grade among the connected nodes is selected as the next search object. If there are several nodes with the same voltage grade, the tree search is carried out sequentially. This can effectively avoid searching low-voltage grade nodes and reduce invalid searching. For example, starting from node n, the nodes connected with node n are m, k and j. If the voltage grade of node m is higher than k and j, the priority of searching m will be given. If the voltage grade of m is same to k and higher than j, search m and k in turn.

To avoid searching nodes repeatedly, table Tab is used to record the search history. For example, when searching for node m from node n, if the table Tab (n, m) is found to be 1, indicating that node m has been searched, then node m will no longer be searched, but the next node connected with n will be searched. Table Tab is symmetrical and sparse, so sparse matrix technology can be used to save storage space. Through the above methods, the number of search nodes can be greatly reduced and the search efficiency can be improved.

When all nodes are searched, if no power node is searched, the DG is judged to be in an island running state; If the power node is searched, the search stops and the DG is determined to be connected to the large power grid. For example, when searching node m, k and j from node n, if node m, k and j do not connect to other nodes that have not been searched and are not power nodes of the system, DG is judged to be in an island operation state and the search is ended; If there is a power node in nodes m, k and j, it is determined that there is no island running state and the search is ended; otherwise, the search continues.

The flow chart of the algorithm in this paper is shown in Figure 3. The total number of nodes is defined as N, and the initial search node number is m. The node type vector NT stores each node type, and the node voltage grade vector Nv stores the voltage grade of each node. Record loop number n to prevent abnormal loop death in search and check the algorithm.

From the above algorithm introduction, it can be seen that the method in this paper has nothing to do with the grid structure, and can be applied to the chain structure, the ring structure and the network structure.

2.3 Error Prevention Mechanism of Circuit Breaker Position Check

This algorithm needs to collect circuit breaker position signal of the whole station in practical application. GOOSE transmission is generally adopted to transmit location information of circuit

breakers in smart substations. Whether GOOSE signal transmission mode is point-to-point or networking mode, there is a possibility that the position signal of circuit breaker is invalid due to communication failure. In addition, the circuit breaker position signal itself may be abnormal. The abnormal or invalid signal of different circuit breaker positions may have different influences on the results of the algorithm. Some circuit breaker positions have no influence on the search results, while others will directly decide whether to form an island.

When the position signal of circuit breaker is abnormal, the alarm signal is sent out first, and in order to ensure the accuracy of island detection, there are two processing schemes: one is direct locking protection; the other is to use the error-proof mechanism of position check of circuit breaker to further analyze.

As shown in FIG. 1, node 13 is a DG node. When the position of a circuit breaker on its search path is abnormal, such as the position of circuit breaker between node 7 and node 8 corresponding to A78, the algorithm first sets A78 as 0 to continue the search. If the search result is not an island, the search is terminated; if the search result is an island, set A78 to 1 to search again. If the search result is the same as that in the state of 0, it means that the position of the circuit breaker has no influence on the island detection result of the DG. The DG is in the island operation state and the trip command is issued to trip the node 13. If the search results are different, indicating that the location of the circuit breaker has a decisive impact on the island determination of the DG, the command of node 13 will not be issued.

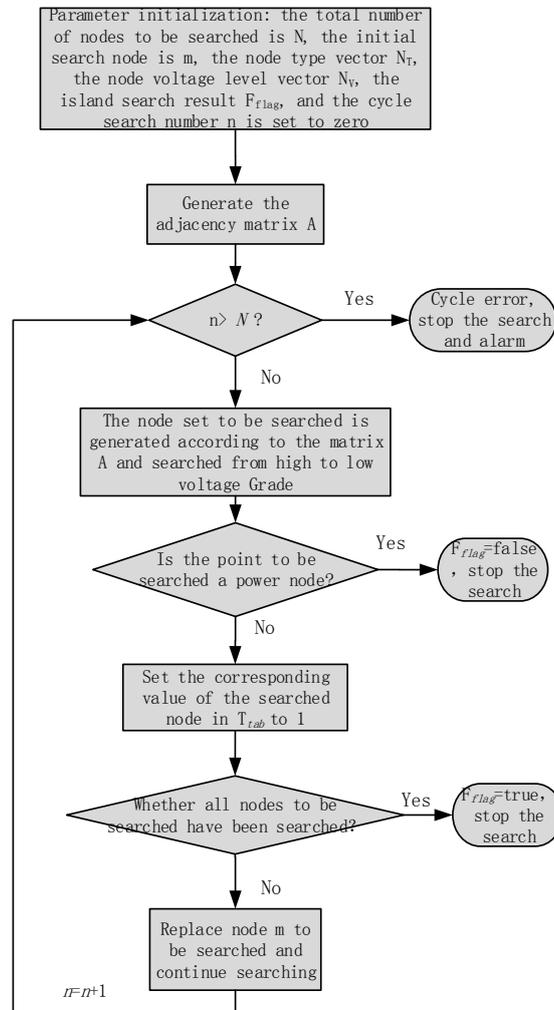


Fig. 3 Algorithm flow chart

2.4 Comparative analysis of different algorithms in theory

From the view of time complexity and space complexity, full matrix self-multiplication, tree search and topological analysis based on voltage grade are analyzed and compared. The results are

shown in table 1:

Tab. 1 Complexity comparison of three algorithms

algorithms	full matrix self-multiplication	tree search method	the proposed method
time complexity	$O(V^4)$	$O(D \times (V+E))$	$O(D \times V)$
space complexity	$O(V^2)$	$O(2V+E)$	$O(3V+E)$

In Table 1, V denotes the number of nodes in the topological graph, E denotes the number of edges in the graph, and D denotes the number of DG nodes. It can be concluded that the time complexity and space complexity of the full matrix self-multiplication algorithm are the largest, and it is not suitable for protection algorithm. The tree search algorithm and the algorithm proposed in this paper have better time complexity and space complexity. The latter has more space complexity than the former because of the need for voltage grade information, but the time complexity decreases by $D \times E$. For the protection algorithm, it is more important to reduce the time complexity, and the space complexity of the proposed algorithm is enough to meet the actual operation requirements.

3 Simulation analysis of an example

At present, the method of islanding judgment based on voltage grade topology analysis has been implemented in protective devices. Taking Figure 2 and Figure 4 as examples, MATLAB uses different algorithms to realize the islanding judgment of two topological states in the station domain. By comparing and analyzing the simulation results, the validity and efficiency of the proposed method are further verified.

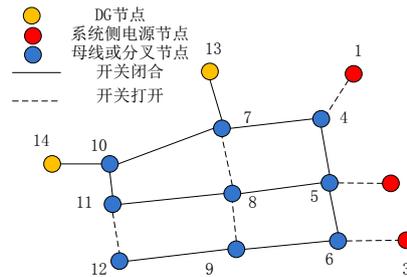


Fig. 4 Topology diagram in the case of island

3.1 Search path comparison

Table 2 is the simulation results of the proposed method and BFS algorithm.

Tab. 2 The search path of the two algorithms

algorithms	the proposed method		BFS	
	Starting Node of Search	Starting Node of Search	Starting Node of Search	Starting Node of Search
Starting Node of Search	Node 13	Node 14	Node 13	Node 14
The search path and results of Figure 2	13-7-4-1, No island	14-10-7-4-1, No island	13-7-4-10-1, No island	14-10-7-11-4-13-8-1, No island
The search path and results of Figure 4	13-7-4-5-6, Islanding status	14-10-7-4-5-6, Islanding status	13-7-4-10-5-11-14-6-8-9-12, Islanding status	14-10-7-11-4-13-8-5-6-9-12, Islanding status
conclusion	Correct and short search path	Correct and short search path	Correct and long search path	Correct and long search path

It can be seen from the table that the proposed voltage grade topology analysis method can quickly and effectively judge the island state. Compared with BFS search path, the search path based on voltage grade topology analysis method is the optimal search path.

3.2 Search time comparison

Taking the system structure in figure 2 as an example, three algorithms were simulated and tested with MATLAB. The search time record of 50,000 runs is shown in table 3.

Tab. 3 Running time comparison

algorithms	full matrix self-multiplication	tree search method	the proposed method

times	9.786	8.271	7.177
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For relay protection, quick action is more important. Compared with theoretical analysis and simulation results, the method proposed in this paper has the fastest operation speed and is more suitable for application in protection devices. In fact, with the complexity of the network structure and the increase of nodes, the speed advantage of the proposed method in this paper will be more obvious.

4 Conclusion

In this paper, a method based on voltage grade topology analysis is proposed to realize islanding judgment in station domain. The tree search path is optimized by using the voltage grade characteristics of power system, which effectively avoids the shortcomings of the traditional full matrix self-multiplication algorithm, such as large computational load and low search efficiency of the traditional tree search algorithm, and significantly improves the speed of the algorithm. At the same time, the error-proof mechanism of position check of circuit breaker is adopted to ensure the reliability of the algorithm results.

Finally, Analysis results in this paper show that the station domain islanding detection method based on topology analysis is reliable, effective, fast. The method can be applied to different system grids by modifying parameters, especially for power systems with high density photovoltaic access.

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