Hierarchical Topology Analysis Method for Substations Based on Electrical Bays

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Abstract. According to the requirements of the advanced applications in smart substations，hierarchical topology analysis method based on electrical bays is proposed in this paper. Based on the node connection relationships of each device in the substation, all primary devices can be organized into the hierarchical structure as “transformer (winding) - bus - electrical bay”. The typical 3/2 circuit breaker connection and the inner bridge connection are also recognized. On this basis, the identification of the static topology and the judgment of the dynamic connectivity in the main wiring diagram of the substations are realized, which is helpful in the quick search of the devices. The topology analysis method introduced in this paper will effectively support the advanced applications for substations such as fault diagnosis, state estimation, the status analysis of electrical bays and so on.

1. Introduction

In the control and analysis of power grid operation, network topology analysis plays an important role as the premise of various advanced applications, including the state estimation [1]-[3], fault diagnosis [4] and the status analysis of electrical bays [5], etc.

The traditional network topology algorithm [6]-[9] usually uses the adjacency matrix method or the tree search method to store the connection relationship among nodes in the stack manner or the queue manner. In this case, there is no hierarchy among the connected devices. Also there is no detailed information about the electrical bay of the device and other devices in the same electrical bay. In the practical application, the topology search needs to be repeated by the repeated search of the connection relationship, resulting in the repeatability and cumbersomeness of the topology search. It is not conducive to the intuitive and convenient access to power grid structure information. Meanwhile, there is basically no corresponding method in the traditional network topology analysis to recognize the typical 3/2 circuit breaker connection and inner bridge connection.

In this paper, a hierarchical topology analysis method for substation based on electrical bays is proposed, which makes the connection relationship between devices more organized, and more convenient to meet the topology requirements in advanced applications such as fault diagnosis and the status analysis of electrical bays. At the same time, the identification and processing of the 3/2 circuit breaker connection and the inner bridge connection which involve multiple bays are proposed. It helps to expand the application range of network topology analysis method, and simplify the engineering configuration of substation automation system.

2. Hierarchical topology analysis based on electrical bays

The key of the electrical bay-based hierarchical network topology is to organize the primary devices of the substation in a hierarchical structure as “transformer (winding) - bus - electrical bay”.

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Firstly, according to the connection relationship in the main wiring diagram of the substation, the node numbers of the two ends of the device are obtained. Starting from the transformer, the windings of each side of the transformer are traversed according to the connection relationship of the nodes, thereby the transformer winding structure can also be obtained.
Secondly, the bus group (single-bus, double-bus or bypass-bus) connected to the end of the winding can also be obtained according to the device node number, and then the transformer (winding) - bus structure is identified. If the transformer does not exist, the corresponding transformer (winding) structure will not exist. So the topology analysis will start from the bus to get the associated bus group.
Thirdly, on the basis of the above connection relationship, each device group that belongs to the electrical bay can be obtained, which is connected to the same bus group. The device group of the electrical bay is a set of related devices, including the circuit breaker, the disconnector, the grounddisconnector and so on.
Finally, the relevant primary devices in the diagram of the substation have been organized according to the hierarchical structure of "transformer (winding) - bus - electrical bay", as shown in Figure 1.

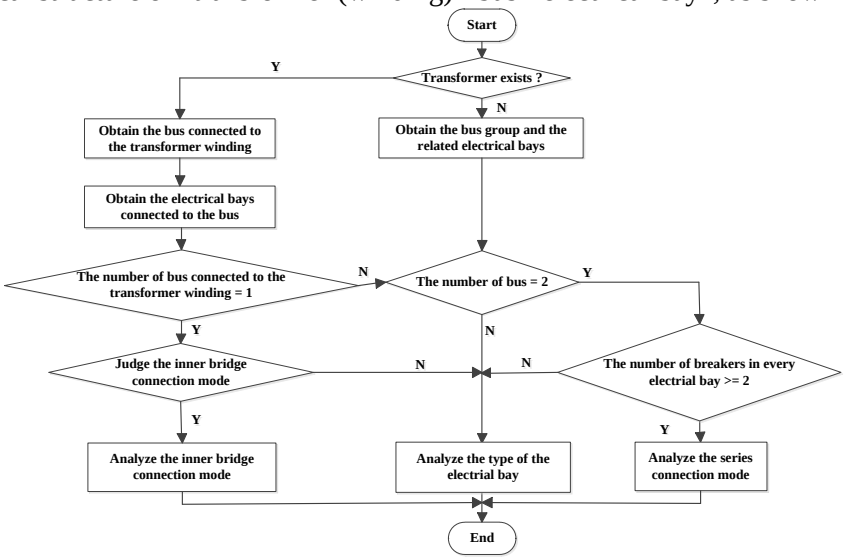

Figure 1. Flow chart of hierarchical topology analysis method based on bay.

The structure of the transformer is defined as shown in Figure 2.

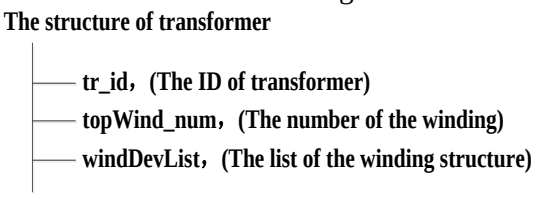

Figure 2. The structure of the transformer.

Furthermore, the structure of the windings under the transformer is defined as shown in Figure 3.

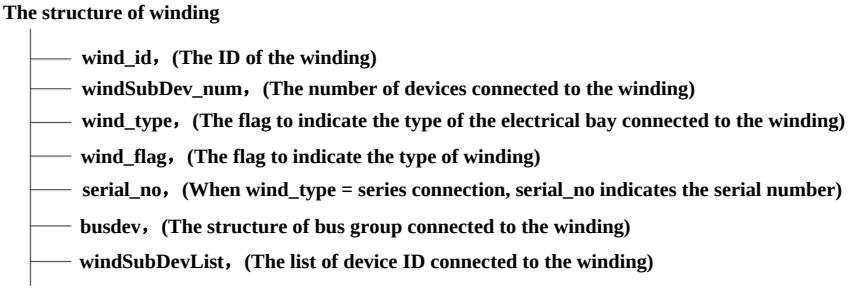

Figure 3. The structure of the winding.

The structure of the bus connected to the windings is defined in Figure 4.

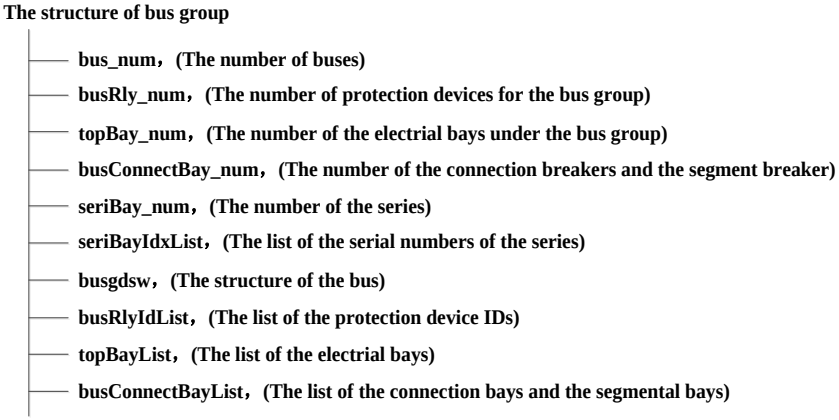

Figure 4. The structure of the bus.

According to the structure characteristics of the typical electrical bay, all the bays are divided and stored with different data structures, usually including the line bay, the connection bay and the segmental bay. In addition to the common single-bus structure and double-bus structure, the typical structures of the line bay also include the complex 3/2 circuit breaker connection and the inner bridge connection.

3. Identification of complex connection

3.1. Identification of 3/2 circuit breaker connection

The 3/2 structure connection is formed by three circuit breakers connected to two sets of busbars with two devices (line or transformer unit). Each circuit is connected to the bus by a circuit breaker. The two circuits make up a series connection together, so it is called the 3/2 circuit breaker connection mode, also known as a series connection mode, as shown in Figure 5(a). In view of the small scale of 500kV substations, there is an incomplete series connection structure compared to the complete series connection mode formed by three circuit breakers. In this structure, there are only two bus breakers connected to the same line, as shown in Figure 5(b). No matter what kind of the series connection structure is, it has the advantages of high reliability, good running flexibility, convenient operation and maintenance.

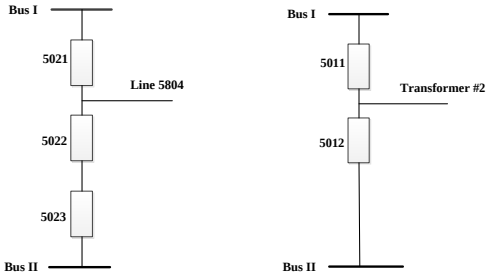

Figure 5. The series connection mode.

According to the connection mode of the series structure, when the bus layer is recognized as the double-bus, the connection mode is further identified by the constraints of the number of breakers in every electrical bay which connects to the bus, that is, if there are two or more breakers, it is identified as a series connection structure. Combined with the topology connection mode, the breaker which connects directly to the bus is recognized as the side breaker. And the middle breaker can also be recognized as its two ends respectively connect to the other breaker. So far, the identification of the series connection structure has been completed. Furthermore, according to the topological connection

between the side breaker and the line equipment, the corresponding series-line structure can also be identified.

The definition of the 3/2 circuit breaker connection structure is shown in Figure 6.

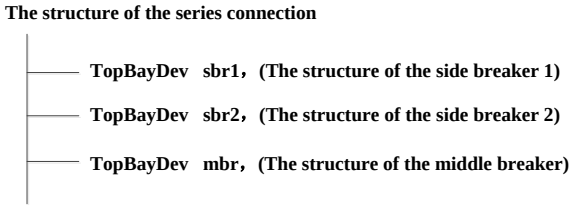

Figure 6. The structure of the series connection.

The TopBayDev represents the detailed structure of the breaker in the 3/2 connection, as shown in Figure 7.

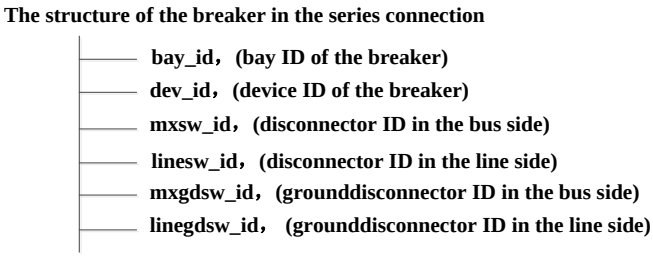

Figure 7. The structure of the series breaker.

Through the series structure and the series-line structure obtained above, the other devices in the structure can be obtained directly and conveniently by any of the devices, which greatly improves the topology efficiency.

3.2. Identification of inner bridge connection

The bridge connection is formed by a circuit breaker and two disconnectors, which connect two transformer-line groups horizontally. The bridge breaker of the inner bridge connection is located at the outlet of the transformer (close to the transformer), as shown in Figure 8. This connection mode is often used in the 110kV substation system, which decreases the number of devices compared to the ordinary bridge connection. Moreover, one line failure will not affect the operation of another line and the transformer.

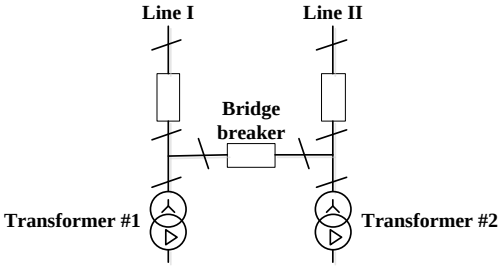

Figure 8. The inner bridge connection.

According to the connection mode of the inner bridge structure, when the bus layer is recognized as the single-bus, the connection mode is further identified by the constraints of the connection breaker and the line breaker in every electrical bay which connect to the bus, that is, if the bus is only connected to two electrical bays which are the connection bay and the line bay respectively, the inner bridge structure, together with the corresponding bridge breaker and the line breaker can be identified.

The definition of the inner bridge connection structure is shown in Figure 9.

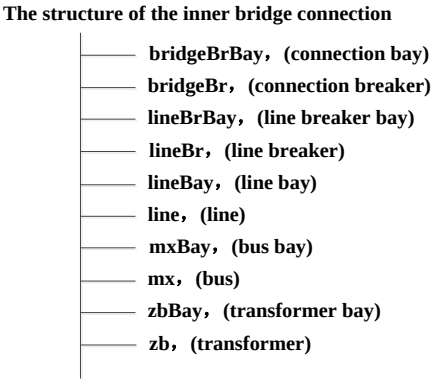

Figure 9. The structure of the inner bridge connection.

According to the inner bridge structure obtained above, the transformer, the bus, the bridge breaker and the line are obtained in the basic structure of the inner bridge, which avoids the repeated search of the topology structure in the advanced application.

4. Identification of the static topology and judgment of the dynamic connectivity

Based on the hierarchical structure of "transformer (winding) - bus - electrical bay", the following static topology identification functions are available:

1) Judgement of the breaker type: such as the ordinary line breaker, the side breaker, the middle breaker, the connection breaker, the segment breaker, etc.

2) Judgement of the disconnector type: such as the disconnector of the main busbar, the disconnector of the secondary bus, the line disconnector, etc.

3) Judgement of the grounddisconnector type: such as the line grounddisconnector, the grounddisconnector in the bus side of the breaker, the grounddisconnector in the line side of the breaker, etc.

4) In one electrical bay structure, the other types of devices can be obtained from one device.

Based on the static topological relationship of the primary devices and the actual state of breakers and disconnectors, the following query functions of the dynamic connection can be provided:

1) Determine whether the two primary devices are connected.

2) Get another type of device that is connected to a specified device.

5. Applications of bay-based hierarchical topology

5.*1. Fault diagnosis*

In the traditional substation monitoring system, network topology analysis is often used in the topological coloring application and the logic blocking application. Fault diagnosis has put forward higher requirements for the network topology, which not only needs regular functions, but also can automatically identify the connection mode of power devices (such as the series connection, the single-bus connection, the double-bus connection) and subtypes of power devices (such as the bus disconnector, the line disconnector). In addition, network topology analysis is also required to obtain electrical connections between fault bays, including retrieving and providing all electrical bays connected to the designated bus to confirm the fault.

5.2. The status analysis of electrical bays

The status analysis of the bay is mainly used to analyze the bay status such as the operation, hot standby, cold standby and maintenance status, so as to improve the control capability of the devices. This function depends greatly on the status of the breaker and the disconnector in the same electrical bay. When it comes to the analysis of the operating status of each device in the series connection, the network topology function is required to provide the state of the side breaker or the middle breaker in the same series.

6. Conclusion

The hierarchical topology analysis method based on electrical bays is presented in this paper. And the primary devices of the substation is organized according to the hierarchical structure as "transformer (winding) - bus - electrical bay". On this basis, the identification and processing of the 3/2 circuit breaker connection and the inner bridge connection have been proposed, which are helpful for the advanced applications such as fault diagnosis and the status analysis of electrical bays.

In the follow-up work, based on the hierarchical topology introduced in this paper, the identification of the static topology and the judgment of the dynamic connectivity will be improved gradually, combined with engineering application experience. It will help to promote the advanced applications in smart substations.

7. References

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Acknowledgments

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