Automatic Generation System of Distribution Network Switch Test Scheme based on Topology Analysis

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Abstract. With the continuous improvement of the automation level of the distribution network, more and more switches can be controlled remotely. The reliability of switch remote control directly affects the stability of the entire distribution network system, so it is very important to test the switch regularly to ensure that it can be operated remotely in an emergency. At present, the switch test scheme is mainly artificially generated, which is very inefficient, and the review process is simple, which is easy to cause safety problems. This paper proposes an automatic generation system for switch test scheme based on topology analysis, which greatly improves the efficiency of scheme generation, and adds multiple roles for review, which improves the accuracy of the scheme. This system has been applied in practice and achieved good results.

1. Introduction
With the rapid development of society and the continuous improvement of people's living standards, people have put forward higher requirements for the stability and reliability of the power system. In response to this demand, the construction of distribution automation is developing rapidly. Nowadays, the proportion of remote control switches in the distribution network is increasing. The reliability of switch remote control directly affects the stability of the entire distribution network system[1]. Due to the harsh environment and other factors, some switches will rust and jam if they are not operated for a long time, and remote control will not be possible. When an emergency occurs and remote operation is required, the remote control may fail, which brings a series of serious consequences. Therefore the significance of switch test regularly is particularly important.

According to the current operation mode of the power grid, the distribution network dispatcher selects some switches for testing. Switch which is used infrequently or located on important feeders is easier to be selected. The switch located in the area where failures are likely to occur is also the focus of the test. The selected switches will be turned on and turned off in order in the early morning when the load is low. When the test fails, the maintenance personnel should go to the site to repair in time.

The power supply mode called “designed in closed loop and operated in open loop” is applied in the urban distribution network structure[2]. Using this architecture, when an electrical fault occurs, part of the load can be transferred to the opposite line by closing the connective switch to reduce the scope of the power outage. In actual operation, the distribution network can have a short-term closed loop state which will not affect the users. Yu J.H. et al have done an in-depth study on the feasibility and safety of closed loop in distribution network[3]. Based on these studies, in the early morning, we can turn on and off the switch remotely to test whether the switch is jammed without affecting the
users. At present, the switch test scheme is generated by manual selection of switches, which is relatively inefficient and the review process is also simple.

The structure of this article is as follows. The second part gives the overall flow of the switch test. The third part focuses on the method of automatically generating test scheme based on topology analysis. The review process and execution of test plan is given in the fourth part. Conclusion is in the last part of this article.

2. System Structure
This distribution network switch test system includes three steps: generate, review and execute. Figure 1 shows the overall flow of the switch test.

![Switch test flow diagram](image)

Figure 1. Switch test flow.
The distribution network switch test scheme is generated in the unit of feeder. First select the feeder to be tested, then search switches belong to this feeder by topology analysis and filter out the switches which can be controlled remotely only. Switches can’t be controlled remotely needn’t to be tested. Secondly, sort the switches according to the order of switches in this feeder side, connective switch, and opposite switches. Finally, generate the switch opening and closing steps according to the switch test rules. The switch test follows the rule: first close the connective switch, then open and close other switches in turn, at last open the connective switch to ensure the distribution network is back to the state before test.

In this system, the review of the switch test scheme includes three roles: business department, operation planning department and dispatch department. Every department has the power to reject the plan scheme. When the scheme is modified, it can re-enter the review process. After all departments have passed the review, the plan will be executed by dispatcher. A statistical result of abnormal switches will be sent to the maintenance personnel when execution is end. The test scheme ends after all abnormal switches are repaired. More information about review and execution will be given in the fourth part.

3. Topology Analysis
As mentioned in prat two, the distribution network switch test scheme is generated in the unit of feeder. Han G.Z. et al have done a lot of research on the feeder model[4]. This article simplifies the model, only includes substation, feeder, section switch and connective switch. A typical feeder connection scenario is shown in figure 2.

In figure 2, there are 2 substations A and B, 4 feeders from F1 to F4, 12 switches from S1 to S12. Among these switches, S4 and S9 are connective switches and others are section switches. When the distribution network is running well, the connective switch is opened.

Let’s take feeder F1 as an example to illustrate the process of topology analysis. Consider F1 as the root node of a tree and search along the feeder. Each switch acts as a node of the tree, and the leaf node can only be a substation. Another constraint is that there can only be one connective switch on each path from the root node to the leaf node. According to the depth-first algorithm, the paths searched for feeder F1 can be converted to the tree in figure 3.

![Figure 2. A typical feeder connection scenario.](image-url)

![Figure 3. The tree searched for feeder F1 in figure 2.](image-url)
It can be seen from figure 3 that F1 has two transfer paths. Path 1 includes connective switch S9, local section switch S1, opposite side section switches S8 and S7. Path 2 includes connective switch S4, local section switches S1, S2 and S3, opposite side section switches S5 and S6. For each path switch test rule is: (1). close connective switch, (2). open and close local section switches, (3). open and close opposite side section switches, (4). open connective switch. In addition, if the same switch is included in different paths, this switch is tested only once. According to the above rules, the switch test scheme for F1 is shown in table 1.

Table 1. Switch test scheme for F1 in figure 2.

| Step | Switch name | Switch type          | Control type |
|------|-------------|----------------------|--------------|
| 1    | S9          | Connective switch    | close        |
| 2    | S1          | Section switch       | open         |
| 3    | S1          | Section switch       | close        |
| 4    | S8          | Section switch       | open         |
| 5    | S8          | Section switch       | close        |
| 6    | S7          | Section switch       | open         |
| 7    | S7          | Section switch       | close        |
| 8    | S9          | Connective switch    | open         |
| 9    | S4          | Connective switch    | close        |
| 10   | S2          | Section switch       | open         |
| 11   | S2          | Section switch       | close        |
| 12   | S3          | Section switch       | open         |
| 13   | S3          | Section switch       | close        |
| 14   | S5          | Section switch       | open         |
| 15   | S5          | Section switch       | close        |
| 16   | S6          | Section switch       | open         |
| 17   | S6          | Section switch       | close        |
| 18   | S4          | Connective switch    | open         |

In the same way, it can be analyzed that feeder F2 and F3 each has a transfer path, but feeder F4 has no transfer path. Transfer paths for feeders in figure 2 are shown in table 2.

Table 2. Transfer paths for feeders in figure 2.

| Feeder name | Transfer path                                      |
|-------------|---------------------------------------------------|
| F1          | Path 1:(S1,S9,S8,S7); Path 2:(S1,S2,S3,S4,S5,S6) |
| F2          | Path 1:(S7,S8,S9,S1)                              |
| F3          | Path 1:(S6,S5,S4,S3,S2,S1)                        |
| F4          | None                                              |

According to switch test rules, test schemes can be generated for feeder F2 and F3. In view of space reasons, the results will not be listed here.

4. Review and execution

After the switch test scheme is generated, it enters the review process. In order to ensure the accuracy of the switch test step, it is necessary to pass the review of multiple roles include business department, operation planning department and dispatch department. Each role can reject the test scheme if they find a problem with it. If all roles approve, the dispatcher will execute the scheme and report the failed results to maintenance personnel for repairing.

4.1. Review

There are three roles to review the test scheme, but the focus of each role is different. For business department, they will check whether the tested feeder and connective switch are correct and if the tested switches are out of order. They are also responsible for the opening and closing sequence of the
switches. Switches tested in the last three months do not need to be tested again. A switch with unresolved defect should not be tested too.

For operation planning department, they will evaluate the safety of the execution of the test scheme based on current operation mode of the power grid. According to the regulation of the loop closing operation, before the loop closing, the amplitude difference of the buses at the two ends should be within 10%, and the phase difference is generally within 5 degrees[5]. Otherwise the system circulation current will increase after the loop is closed, which may cause power outages. In severe cases, the sudden increase of instantaneous current may even cause an explosion. Load transfer will occur during the switch test, and it must ensure no overload happens after the load transfer. If the test affects important users, the test is not allowed. If a switch is marked for debugging or maintenance, it should not appear in the test list.

Before the dispatcher executes the scheme, he also needs to review because a long time may have passed after the operation planning department approved the test scheme and the running mode of the grid may have some changes. Dispatchers generally have rich experience and they have a good understanding of the operation status of the power grid. They know which operation will cause safety incidents. They are the last pass before the scheme is executed.

4.2. Execution
After all departments have passed the review, the dispatcher will start to execute the test scheme. According to the test steps in the scheme, the dispatcher execute corresponding remote operations on the switch in turn. Through the communication line, the switch execution result will be fed back to the dispatcher in real time. Next step can be executed only after the current switch control is successful. If failure occurs, it needs to send maintenance man to the site to resume the operation before proceeding with the follow-up test.

After the execution is completed, it is necessary to ensure the running state of the power grid is restored to the state before test. Test results are counted after the test, if failure exists, it must be reported to the maintenance department in time. The maintenance department should send maintenance to repair or replace the switch as soon as possible to ensure the switch can be remotely controlled normally. The maintenance of distribution automation switch can refer to the method introduced by Qian Y.N. et al[6]. At this point, the entire process of switch test is complete.

5. Conclusion
With the rapid development of society, the automation level of distribution network continues to improve, and remote control switches are becoming more and more popular. When an electrical fault occurs, we can quickly locate and isolate the fault by opening or closing some switches remotely to reduce the scope of the fault. However, many switches will not be remotely controlled for a long time under normal circumstances, which leads to the fact that the switch is abnormal when remote control is needed in an emergency, which brings serious consequences. Therefore, it is necessary to regularly test the remote control switch. Now, the generation of the switch test scheme is mainly to manually add the switches one by one to the test step according to the circuit diagram. The efficiency is very low, and the plan is executed only after the dispatcher's review, which may cause security issues. This paper proposes an automatic generation system for switch test schemes based on topology analysis, which greatly improves the efficiency of scheme generation. Moreover, the test scheme can only enter the implementation stage after being reviewed by three departments, which ensures the accuracy of the test. This system has already been applied in practice and achieved good results.

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