Research on Fault Self-healing Based on Quick-acting Distributed FA Active Distribution Network

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Abstract. With the rapid development of intelligent distribution network, a large number of distributed generation (DG) penetrated into the distribution network, changing the original unidirectional current flow direction of the distribution network, which made the direction of the flow is bidirectional or multi-end flow. When a fault occurs, the traditional centralized feeder automation and in-situ feeder automation solutions have not been able to satisfy fast accuracy requirements and have presented severe challenges to fault self-healing. In view of the existing problems, a control method based on quick-acting faults distributed FA is researched. It uses stacked topology recognition. After detecting current and interacting with the peer-to-peer through GOOSE communication, the smart terminal determines the fault area and jump on the local monitoring switch on the spot. After the fault is isolated, the power supply recovery operation is initiated. Taking a typical distributed power distribution network as an example, the different faults are studied. The experimental finally results show that the scheme can adapt to faults in various situations, and the entire fault self-healing process is controlled within 200 ms.

1. Introduction

As the end of the power line, the distribution network is directly connected to users, and as the size of the power grid gradually increases, it also supports the access of various distributed generation and microgrids, making the original protection mechanism have a certain degree. The impacts such as failure of reclosing, protection against refusal or misoperation, therefore, require higher and higher power supply reliability of the distribution network[1-2]. Traditional feeder automation technologies such as in-situ FA and centralized FA require active power distribution networks to require the distributed generation to be taken out of operation after a fault to ensure the correct operation of the protection mechanism. With the expansion, complexity and intelligence of the power grid, the use of the first two FAs has been difficult to meet the requirements for accurate line fault removal, and the fault processing time is relatively long [3-5]. For this reason, many scholars and researchers have conducted in-depth research on this issue. Reference [6] researched a fault location method for distributed power distribution networks with distributed power sources based on particle optimization algorithms. Reference [7] proposed a principle and method for adaptive current protection tuning based on local information. Reference [8] proposed a high-permeability microgrid adaptive current protection method based on intelligent protection center.

Distributed FA relies on intelligent terminals at various distribution switches to communicate and cooperate with each other to achieve fault location, fault isolation, and power restoration through the communication network. As the fastest FA self-healing speed, it has perfect control functions. The fault location does not require the cooperation of the outlet circuit breaker, which greatly reduces the
requirements for communication bandwidth, also shortens the fault processing time, shortens the power outage time in the non-fault section to the second level, and has good development prospects [9-10].

According to the current research status, distributed feeder automation can be divided into two types of cooperative and agent-based implementation models [11]. An agent-type distributed FA selects an intelligent terminal in the feeder as the master control terminal. The role of this master control terminal is similar to that of the centralized FA master station, and it assumes the task of self-healing of the entire feeder fault. Compared with the agent-type FA, the fault-solving speed of the cooperative FA is faster. Cooperative FA is divided into slow-acting type and quick-acting type [12-13]. The slow-acting type is suitable for the line where the section switch of the distribution line is a load switch. After a fault occurs, there is a substation exit circuit breaker to protect and remove the fault. Since it is difficult to directly connect the substation exit circuit breaker to the distributed FA system in actual engineering, this method is rarely used in practical applications. The quick-acting FA is suitable for the circuit where the section switch is a circuit breaker. After the faulty current is detected by the intelligent terminal, the faulty area is independently determined, and the control command is sent locally. After the fault is isolated, the power supply recovery operation is started to realize the intelligent distribution. Intelligent distribution network realizes fault self-healing.

This article studies and analyzes the fast-acting FA control strategy, and analyzes the fault handling process in different situations based on the active distribution line topology and related operating parameters. Effectiveness of self-healing of distribution network faults.

2. How distributed FA systems work

Distributed feeder automation (referred to as distributed FA) consists of distribution terminals and corresponding communication equipment with distributed feeder automation. The distributed FA can independently rely on the distribution main station, automatically realize the functions of fault location, isolation and restoration of power supply in the feeder through mutual communication between the distribution terminals, and report the processing process and results to the distribution automation main station. Figure 1 shows a typical intelligent distributed FA system with distributed power. In the picture, CB1 ~ CB2 are outbound switches of the substation, SW1 ~ SW4, SW6 ~ SW7 are section switches, SW5 is a contact switch, DG1 and DG2 are distributed power sources. In order to meet the requirements of quick action, all the section switches are circuit breakers.

![Typical grid structure distributed FA system](image)

**Figure 1. Typical grid structure distributed FA system.**

2.1. Network topology identification
As far as the distribution network is concerned, the network topology information is divided into static network topology information and dynamic topology information. The static topology information is manually configured and generally does not change, including information about its own STU and neighboring STUs. When it is first configured, the static topology information stored in each STU is shown in Table 1.

The dynamic topology information is the result of topology identification, and it will change accordingly due to distribution network failure or the increase or decrease of switches. For the distribution
network shown in Figure 1, a step-by-step query is used to automatically identify the network topology. The identification process is as follows: In the distribution network, all STUs have been pre-configured with their own information and the IP addresses of neighboring STUs, and GOOSE is passed between the STUs. This side query instruction is completed. STU1 communicates with STUA, determines that the switch monitored by STUA is a substation outlet switch, and the query on that side ends. STU1 sends a topology query instruction to STU2. STU2 does not need to immediately return information about its local network topology and switch status. STU2 continues to forward instructions to STU4 after receiving instructions from STU3. STU4 continues to forward query instructions to STU5. The switch monitored by STU5 is a contact switch. Therefore, the instruction forwarding stops, STU5 returns its local network topology information and switch status to STU4, and STU4 returns itself and the network topology information and switch status of STU5 to STU3, and STU3 returns itself and the network topology information of STU5 and STU4 and The switch status is returned to STU2. Finally, STU2 returns the local network topology of itself, STU3, STU4, and STU5 together with the switch status information to STU2. This topology method can adapt to the addition, reduction, or rename of a certain device, with less modification content, so the topology query time is also greatly shortened.

Table 1. STU static network topology information table

| Category                  | name                                      |
|---------------------------|-------------------------------------------|
| Switch attributes         | Whether it is a substation outlet switch STU |
|                           | Whether it is STU at PCC                   |
|                           | Whether it is a contact switch STU         |
| IP address related information | The IP address of its own STU            |
|                           | IP address of neighboring STU              |

2.2. Fault location

When the distribution network fails, the intelligent terminal corresponding to the upstream node of the fault point will detect that the phase current flowing through the node is greater than the setting value or the zero-sequence current is greater than the setting value. The current disappears after a period of time and the distribution is started. FA function. At this time, the STU and the neighboring STU perform information interaction, including switch position, overcurrent information, etc., and perform distributed fault location according to the self-monitoring switch and the overcurrent information of the adjacent switch. If the adjacent switch is monitored by the same STU, such as a ring network cabinet switch, the STU can directly detect whether a fault current flows through the adjacent switch, otherwise it needs to communicate with the adjacent STU. If the adjacent STU collects overcurrent information, the fault area is not between the nodes where the STU is located; if the adjacent STU does not collect overcurrent information, it is determined that the fault area is between the nodes where the adjacent terminals are located, and the fault is completed positioning. When judging the fault in this section, the “node fault” GOOSE output signal is triggered instantaneously, and this signal is maintained with the over current status, which should be at least 300 ms.

According to the distribution network shown in Figure 1, when a short-circuit fault occurs, the substation outlet switch CB1 and the circuit breaker SW1 can both detect an overcurrent fault, and the circuit breakers SW3, SW4, and SW5 cannot detect a short-circuit fault. CB1 sends the detected fault information to SW1; SW1 sends the detected fault information to SW2 and CB1; SW2 does not detect the fault information to SW1 and SW3; SW3 does not detect the fault, and SW3 sends the undetected fault The information is sent to SW2 and SW4; SW4 does not detect a fault, and SW4 sends the undetected fault to SW3. Based on this information, CB1 can detect the fault and receives the fault detected by SW1; SW1 detects the fault and receives the fault detected by CB1; SW2 does not detect the fault and receives SW1 detects the fault, and receives SW3 not detected To the fault information; SW3 did not detect a fault, and received neither SW3 nor SW4 detected a fault; SW4 did not detect a fault and received SW3 did not detect a fault. Based on this information, SW1 can determine that the fault location is downstream, and SW2 can determine that the fault location is upstream. It can be concluded that the
fault occurred in the power distribution area between circuit breaker SW1 and circuit breaker SW2, and the fault location is complete.

2.3. Fault removal logic action mechanism

After the positioning is completed, according to the switch information, if the node is the last switch, and the phase current is greater than the setting value or the zero-sequence current is greater than the setting value, no node on the left and right sides and only one side have not issued a "node fault" GOOSE Signal, the switch of this node will be tripped after the setting fault removal delay; if this node is the last node and the phase current is greater than the setting value or the zero-sequence current is greater than the setting value, the “node fault” GOOSE signal will trip the node switch after a set delay. If the switch hasn't tripped within the failure time, the “switch rejection trip” GOOSE output signal is triggered.

The fault isolation charging is completed and the GOOSE communication of this node is normal. If the node does not detect a fault and receives a "node fault" GOOSE signal on either side with only one node, after a set delay, the switch of this node trips. If during the switch failure time, the switch changes from closed to open and there is no current, it will trigger the “fault isolation successful” GOOSE output signal; if the switch of this node has not tripped during the switch failure time, then the “switch rejection trip” will be triggered GOOSE output signal.

In Figure 1, when a fault occurs, according to the fault isolation mechanism described above, after the fault location is completed, the intelligent terminal controls the circuit breakers SW1 and SW2 to trip to complete the fault isolation.

2.4. Power restoration

After a fault occurs in the distribution network system, the faulty upstream area connected to the power supply controls the corresponding segmented switch through the intelligent terminals around the faulted area, so that the load in the faulty upstream area is not affected, so the power supply reconstruction of the distribution network For restoration of power downstream of the fault area. This requires that the segmented switches and contact switches in the system be changed to meet the various operating constraints of the distribution network to find the optimal power recovery strategy for non-faulty areas. After the distribution network failure occurs, it is the most important goal to restore the power loss load area as much as possible.

\[
\max f = \sum_{i=1}^{n} \lambda_i P_i
\]

In the formula, \(f\) is the total amount of power failure load in the non-fault area, \(n\) is the total number of feeder segments in the fault downstream area, \(\lambda_i\) is the weight coefficient of the power failure load, and \(P_i\) is the size of the power failure load.

After the fault isolation is successful, each node in the area forwards the ‘fault isolation successful’ GOOSE signal to both sides in turn. When the power recovery of this node is completed and the voltage is lost on the power and load sides, the GOOSE signal is received. After the setting delay, the switch of this node is turned on to complete the process of transferring power.

For multi-contact power distribution networks, the priority of different contact switches is determined by the power recovery time limit \(T_{set}\) (generally set 300 ms ~ 5000 ms)\(^{[13]}\). A contact switch with a short recovery time has a high priority, and vice versa.

In Figure 1, when the distribution network fails, after the circuit breaker SW2 trips to complete the fault isolation, one side of the contact switch SW5 loses voltage due to a fault in this area, and the fault area is not in the distribution with the contact switch as the endpoint. In the electrical area, the contact switch SW5 is closed to restore power to the healthy area on the fault side.

3. Simulation Verification of Active Distribution Network Based on Quick-acting Distributed FA

In order to verify the effectiveness of this method, a typical active power distribution network was selected as the research object, and the fault processing flow of distributed FA was simulated and verified.
As shown in Figure 2, all switches in the figure are circuit breakers. The analysis of DG access at different locations is now performed to verify the effectiveness of the self-healing method studied.

As shown in FIG. 2, the fault F1 occurs between the outlet switch CB1 and the first switch SW1 of the substation, and a distributed power source DG1 is connected to the network. Because the substation outlet switch is not included in the distributed FA, SW1 cannot receive the fault information of CB1, and it does not monitor the fault current itself. When the fault occurs, the substation outlet switch CB1 trips due to the over current protection action, so the first switch SW1 tap box 601 switch loses pressure on both sides. The first switch SW1 detects no voltage and no current on both sides, and activates the first switch voltage loss protection logic. After a delay, the first switch SW1 tap box 601 switch trips to successfully isolate the fault, and at the same time sends a "fault isolation successful" GOOSE signal to both sides. The “Fault Isolation Successful” signal was forwarded to SW2 and forwarded to SW3. After SW3 received the signal and detected its own unilateral voltage loss, it started closing.

![Substation Diagram](image)

**Figure 2.** Three power sources contact the active power distribution network.

Set the system to fail at 0.2 s. The fault type can be selected. The simulation result is shown in Figure 3. In the simulation result graph, it can be seen that the outlet switch CB1 senses the fault current. After 40 ms, the circuit breaker is tripped and the fault current is cut off. At this time, the 601 switch on SW1 detects no voltage on both sides. Flow, trip after 50 ms, complete fault isolation. At the same time, the power recovery process was started. After 80 ms, the contact switch SW3_602 was closed to complete the power recovery. The entire self-healing process took only 170 ms. The entire fault self-healing process is within 200 ms.

![Simulation Result Graph](image)

(a) CB1, SW1_601, SW3_602 circuit breakers operation sequence

(b) Current IL1_A waveform

**Figure 3.** Simulation results of the distribute generation supply connected downstream of the fault.
According to the above analysis, this solution only uses smart terminal to perform GOOSE through the peer-to-peer communication with neighboring terminals, which can quickly determine the faulty section, isolate the fault on the spot, and realize the power distribution recovery of the intelligent distribution network.

4. In Conclusion

According to the current structural characteristics of active power distribution networks and the application status of various intelligent technologies in the power grid, this paper studies the application of a fast-acting intelligent distributed FA in active self-healing of power distribution networks. For topology identification, STU detects whether the phase current is greater than the set value or whether the zero-sequence current is greater than the set value. Based on GOOSE peer-to-peer communication, fault location is completed. After the setting delay, the switch trips to complete fault isolation. After the ‘GOOSE signal is successful’, the setting is closed for a delay to complete the transfer of power. Finally, through a simulation analysis of a typical distribution network, the operating time of the circuit breaker does not exceed 200 ms from the occurrence of the fault to the restoration of the power supply, which greatly shortens the entire self-healing process and verifies the effectiveness of the scheme.

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