Research on Acceptance and Testing Scheme of Intelligent Distributed Feeder Automation System

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Abstract. The intelligent distributed FA uses the peer-to-peer communication network between distribution terminals to realize the information exchange between terminals, and uses the line fault state quantity differential and bus fault state quantity differential to realize the fault monitoring, fault isolation and non-fault area restoration of power supply. In the distribution automation system, the proportion of terminals with intelligent distributed FA function is increasing. How to test and accept such terminals has become a research hotspot. This paper introduces the basic test contents of testing intelligent distributed FA through simulation system, and expounds the ideas and methods of test and acceptance in detail. Some suggestions are given for the test and acceptance of intelligent distributed FA terminal, which can be used for reference to improve the test standard and batch test.

1. Introduction
The intelligent distributed FA solves the problem that the centralized control method is difficult to deal with long-distance control, complex wiring, large energy consumption, and the central control unit is paralyzed once a problem occurs. At present, the testing of intelligent distributed FA is still in the stage of relying on the physical tools of the test system. Multi-point synchronous test verification has always been a difficult point in system acceptance, and the cost of acceptance is expensive. The use of model reproduction technology for simulation testing to achieve distributed feeder automation system testing and acceptance will become the mainstream of future development.

2. The main test content of the simulation test
Simulation test sends out test command through the master station, and the terminal uses the associated simulation data to conduct fault simulation test automatically. The operator can determine the correctness of the system network configuration, the reliability of the terminal function and the rationality of the corresponding protection setting value setting only through the simulation results. When there is a change in the grid structure, the simulation test can also assist in the protection analysis and prediction function.

The main items covered by the simulation test are: simulation of trunk, bus, and feeder failures
When the main line of the distribution network fails, the terminal can recognize the fault signal or analog characteristics of the switches on both sides of the line section, quickly locate the faulty line section, and isolate the fault. When a bus with a website room or a ring cage fails, the terminal can identify the bus fault quickly and isolate the fault based on the identification of the fault signal or analog characteristics of all switches on the bus. When the feeder fails, the terminal can identify and locate the corresponding feeder through the fault analog and isolate the fault¹.
Simulate system open-loop operation and closed-loop travel mode. When the line fault in open loop operation is successfully isolated, the terminal should carry out overload pre-judgment, close the contact switch when the conditions are met, and complete the load transfer in the non-fault power outage area. When there are multiple contact switches on the line, the terminal reliably locks the non-transferred contact switches. When the line is faulty, the terminal at the position of the tie-breaker shall make a decision to close or maintain the opening according to the isolation of the faulty section and whether it has the ability to transfer the load. The whole process should be completed before the substation outlet circuit breaker recloses (time is 5s). When there are multiple contact switches at the same time, the terminal can operate the multiple contact switches to transfer the load in the order of setting priority. When the line fault in closed-loop operation is successfully isolated, the power supply in the non-fault section returns to normal.

Analog switch and communication status: to simulate the change of contact switch, the terminal should be able to automatically recognize the contact switch according to the line grid. By simulating terminal distributed FA communication interaction abnormality, terminal operation abnormality, switch not in controllable state, operating mechanism and insulation status of any switch in the feeder circuit where it is abnormal, switch rejection during feeder automation, test terminal feeder automation blocking function. When in the above abnormal state, the terminal should be able to block the feeder automation and issue an alarm to the distribution main station and report the reason for the block. At the same time, without affecting the safety conditions, the logic strategy of appropriately expanding the isolation area can be adopted when an abnormality occurs, as far as possible to isolate the fault area to a smaller range, and restore the power supply of the non-fault area. When the communication fails, the terminal should be able to automatically switch from intelligent distributed to on-site feeder automation, with the adaptive function of switching between intelligent distributed and on-site feeder automation.

For analog switch protection opening and closing and switching opening and closing, the terminal should be able to start failure protection and expand the level 1 isolation.

The simulation system coincides with the point of failure. When the manual closing or self-healing control is closed to the fault, the terminal quick-action distributed FA should accelerate the trip corresponding switch. After the fault isolation is successful, the terminal can complete the restoration of power supply in the non-fault area according to the pre-set self-healing processing logic.

Simulating the change of the grid structure, the switchgear should have the function of automatically identifying the topology. When the line needs to be reconnected or connected to new switchgear, the newly-connected switchgear distribution terminal sends access information to the other switchgear distribution terminals on the line. Other power distribution terminals shall have the function of automatically recognizing the topology structure, without reconfiguration. When a switch cabinet needs to be returned in the line, the distribution terminal of the switch cabinet that simulates the return shipment sends the return information to the distribution terminals of other switch cabinets on the line. Other power distribution terminals shall have the function of automatically recognizing the topology structure, and no reconfiguration is required.

3. Acceptance standards for simulation tests
During the simulation test, the fault point and fault type should be determined according to the system, and a detailed test outline should be prepared to cover all test items. The following figure shows a system that uses intelligent distributed FA for distribution management.
Figure 1. Distribution management system

Figure 1 shows the distribution management system. FS1–FS5 and LS1 are FTU terminals, S11, S12, S13, S21, S22, and S24 are DTU terminals, and S14 and S23 are system reserved switches. No terminals are configured during the test. In the system example, each terminal is connected through a 100M Ethernet switch to form a non-equivalent communication network. Each terminal station control layer communicates with the set analog master station through the exchange through the 104 protocol. The system is in open-loop operation mode. When LS1 and S22 are in normal mode, they are in contact mode and open.

According to the type of fault, system faults can be divided into phase-to-phase faults and ground faults. The fault point of the feeder terminal FTU system can be set to d1, d2, d3, d4, and d5. The fault point of the mixed system of the terminal DTU and feeder terminal can be set as d6, d7, d8, d9, d10, and d11.

3.1. Failure of analog feeder terminal FTU system

When the phase-to-phase fault and the ground fault respectively occur at the simulated fault point d1, the terminals FS1–FS4 do not operate to open, and LS1 does not operate to close. When the switch FS1 is put into the function of the first-end switch voltage loss opening, FS1 detects the closing and there is pressure on both sides for 3s, then it detects that there is no pressure and no flow on both sides, then it will open after the setting delay [2]. If the switch FS1 does not refuse to operate, the switch LS1 should be switched on and closed when the conditions for permitted transfer (charging) are met. If the switch FS1 refuses to move, the switch FS3 acts to open the brake, expanding the level 1 isolation. When LS1 satisfies the condition of allowable transfer (charging), after FS3 action opens, it transfers to close.

Simulated fault point d2 occurs interphase fault and ground fault respectively. When the reclosing of the right neighborhood FA of the switch FS1 exits, the terminals FS1–FS4 will act to open and the other terminals will not act to open. If the switch FS3 does not refuse to operate, LS1 will switch on and close when it meets the conditions for allowed transfer (charging). If the switch FS3 refuses to move, the switch FS4 acts to open the brake, expanding the level 1 isolation. When LS1 meets the conditions for allowable transfer (charging), after the FS4 action is opened, the transfer is closed.

When the FS1 right neighborhood FA reclosing switch is put into operation, the terminal FS1 will act to open after a fault, and after setting the FA reclosing delay, the FS1 will close. If it is a transient fault, FS3 will start the fault isolation delay. After the delay is satisfied, the conditions of no pressure and no flow on both sides will not be met, and FS3 will not open the brake. When LS1 meets the
conditions of allowed transfer (charging), it will not switch on and the other terminals will not open. If it is a permanent fault, FS3 starts fault isolation delay. FS1 recloses to the permanent fault point, FS1 action opens, no longer recloses. After the FS3 fault isolation delay is satisfied, the conditions of no pressure and no flow on both sides are met, and the FS3 opens and the fault is isolated. When LS1 meets the conditions of allowable transfer (charging), the transfer is closed, and the other terminals do not open.

The simulated fault point d3 has phase-to-phase fault and ground fault respectively. When the fault occurs, the terminal FS2 over-current or zero-sequence over-current action opens, and the other terminals do not open. If the switch FS2 does not refuse to operate, LS1 will not switch on and close when it meets the conditions for allowed transfer (charging). If the switch FS2 refuses to operate, the terminals FS1 and FS3 will act to open. When LS1 meets the conditions of allowed transfer (charging), it will switch on and close.

Simulated fault point d4 occurs interphase fault and ground fault respectively. When the reclosing of the left and right neighboring FAs of FS3 and FS4 exits, the terminals FS3 and FS4 will act to open and the other terminals will not act to open. If the switches FS3 and FS4 do not refuse to operate, the LS1 will switch on and close when the conditions for allowing the transfer (charging) are met. If the switch FS3 refuses to operate, the terminal FS1 will open and expand the isolation. When LS1 meets the conditions of allowed transfer (charging), it will switch on and close. If the switch FS4 refuses to operate, LS1 will not switch on and close when it meets the conditions for allowed transfer (charging).

When the FS3 and FS4 left and right neighborhood FAs are reclosed. If it is a transient fault, the terminal FS3 will be opened after the action, and the FS3 will be closed after the FA reclosing delay is set. FS4 start fault isolation delay, after the delay is met, the conditions of no pressure and no current on both sides are not met, and FS4 does not open the brake. LS1 will not switch on and close when it meets the conditions of allowed transfer (charging). The other terminals do not operate and open. If it is a permanent fault, the terminal FS1 will open after the action, and after setting the FA reclosing delay, the FS1 will close. FS3 start fault isolation delay. FS1 recloses to the permanent fault point, FS1 action opens, no longer recloses. After the FS3 fault isolation delay is satisfied, the conditions of no pressure and no flow on both sides are met, and the FS3 opens and the fault is isolated. When LS1 meets the conditions of allowed transfer (charging), it will switch on and close. The other terminals do not operate and open.

Simulated fault point d5 occurs interphase fault and ground fault respectively. When the reclosing of FA in the right neighborhood of FS4 exits, the terminal FS4 will act to open and the other terminals will not act to open. If the switch S11 does not refuse to operate, S22 transfers to the closing switch when the conditions for allowing the transfer (charging) are met. If the switch S11 refuses to operate, the terminal FS3 will open and expand the isolation. LS1 will not switch on and close when it meets the conditions of allowed transfer (charging).

When the FA reclosing of the right neighborhood of FS4 is put into operation, after the fault, the terminal FS4 will act to open and, after setting the FA reclosing delay, the FS4 will close. If it is a transient fault, LS1 will not switch to the closing switch and the other terminals will not act to open the switch when the conditions for allowing the transfer (charging) are met. If it is a permanent fault, the FS4 will reclose to the permanent fault point, and the FS4 will trip and no longer reclose. When LS1 meets the conditions of allowed transfer (charging), it will not switch on and the other terminals will not open[3].

3.2. The fault of the mixed system of the terminal DTU and feeder terminal of the analog station
In the case where each terminal FA recloses and exits, the following test is performed.

Simulated fault point d6 occurs interphase fault and ground fault respectively. When the FS5 right neighbor FA recloses and exits, the terminals FS5 and S11 will act to open and the other terminals will not act to open. If the switch S11 does not refuse to operate, S22 transfers to the closing switch when the conditions for allowing the transfer (charging) are met. If the switch S11 refuses to operate, the
terminal S12 acts to open and expand the isolation. When S22 satisfies the condition of allowable transfer (charging), after the action of S12 is opened, the transfer is closed.

When the FS5 right neighborhood FA reclosing switch is put into operation, the terminal FS5 will act to open after a fault, and after setting the FA reclosing delay, the FS5 will close. If it is a transient fault, S11 starts the fault isolation delay. After the delay is satisfied, the conditions of no pressure and no flow are not met, and S11 does not open the brake. When S22 meets the condition of allowable transfer (charging), the switch is not switched on, and the other terminals do not open. If it is a permanent fault, S11 starts fault isolation delay, FS5 recloses to the permanent fault point; FS5 action opens, and no longer recloses. After the S11 fault isolation delay is satisfied, the conditions of no voltage and no flow are met, and the S11 opens and the fault is isolated. When S22 meets the condition of allowable transfer (charging), the transfer is switched on and the other terminals do not open.

The simulated fault point d7 has interphase fault and ground fault respectively. In the event of a fault, terminal S11 opens and S12 initiates a fault isolation delay.

If the switches S11 and S12 do not refuse to operate, after the S12 fault isolation delay is satisfied, the conditions of no voltage and no flow are met, S12 opens, and the fault is isolated. When S22 meets the conditions for allowable transfer (charging), after S12 opens, it transfers to close. The other terminals do not operate and open. If the switch S11 refuses to operate, the FS1 terminal action opens and the isolation is expanded. When S22 satisfies the condition of allowable transfer (charging), the switch is not switched on, and the other terminals do not open.

Simulated fault point d8 occurs interphase fault and ground fault respectively. In the event of a fault, the terminal S13 overcurrent or zero sequence overcurrent action opens. If the switch S13 does not refuse to operate, the other terminals will not operate to open or close. If the switch S13 refuses to operate, the terminals S11 and S12 will act to open and expand the isolation. When S22 meets the condition of allowable transfer (charging), the transfer is switched on and the other terminals do not open.

Simulated fault point d9 occurs interphase fault and ground fault respectively. In the event of a fault, the terminal S21 will open. If the switch S21 does not refuse to operate, and S22 meets the conditions for allowing the transfer (charging), the switch will not be switched on, and the other terminals will not open or close. If the switch S21 refuses to operate, the S12 terminal will open and expand the isolation. When S22 meets the condition of allowable transfer (charging), the switch is not switched on, and the other terminals do not open.

Simulated fault point d10 occurs interphase fault and ground fault respectively. In the event of a fault, the terminals S12 and S21 will open. If the switch S12 does not refuse to operate, S22 will transfer to close under the condition that the allowable transfer (charging) condition is met, and other terminals will not act to open or close. If the switch S12 refuses to operate, the S11 terminal action opens and the isolation is expanded. When S22 meets the condition of allowable transfer (charging), the transfer is switched on and the other terminals do not open. If the switch S21 refuses to operate, S22 will not switch on the closing of the switch if the conditions for allowing the transfer (charging) are met, and the other terminals will not operate and open.

The simulated fault point d11 occurs interphase fault and ground fault respectively. In the event of a fault, the terminal S24 overcurrent or zero sequence overcurrent action opens. If the switch S24 does not refuse to operate, the other terminals will not operate to open or close. If the switch S24 refuses to operate, the terminals S12 and S21 will act to open and expand the isolation. When S22 meets the condition of allowable transfer (charging), the transfer is switched on and the other terminals do not open.
4. The advantages of simulation testing

The simulation test can simulate the entire system architecture through several devices. After the main station sends a simulation test command, the device automatically simulates the system operation mode and line fault through the simulation database, which can help the operation and maintenance personnel to get out of the field, perform the reliability test of the terminal function before the line is put into operation, verify the rationality of the protection settings and carry out the protection analysis and pre-judgment after the conversion of the grid structure, which greatly reduces the time of FA field testing\textsuperscript{[4][5]}.

5. Conclusions

The intelligent distributed FA narrows the outage range as much as possible within the controllable range when the outage accident cannot be completely avoided. With the increasing use of intelligent distributed FA in the distribution network automation system, the testing and acceptance of intelligent distributed FA has also become an important part of ensuring the effective function of the terminal. This article mainly discusses the method of testing through the simulation system. In the process of performing the simulation test, the fault point and fault type are determined according to the system, and a detailed test outline is prepared to cover all test items. When the terminal action in the simulation system is consistent with the acceptance standard, the acceptance is passed.

References

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