Interoperability of Distribution Automation Terminals Based on IEC61850

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Abstract. At present, in the distribution automation system, the test of the power distribution terminal requires external input to the power distribution terminal through a tester simulation protection test. After the status of the power distribution terminal changes, upload the signal to the client (master station). The client compares the received signal with the local signal of the power distribution terminal, and artificially determines whether the communication behavior of the power distribution terminal is correct. It can also simulate multiple power distribution terminal information uploads through several avalanche tests to simply understand the network load and the signal is correct rate. However, this test method has the following disadvantages: it is not possible to comprehensively test the communication capability of the client (master station); the correctness of the ICD model provided by the manufacturer can be verified only through the point test of the tester; the distribution automation cannot be fully understood Peak network communication load of the system. The IEC 61850-based power distribution terminal simulator designed and developed in this article makes up for the above shortcomings. It can simulate the external communication behavior of all power distribution terminals at the whole station and conduct comprehensive tests on power distribution terminal equipment, so as to better use IEC 61850 communication standard. In this paper, a simulation experiment is performed to set a fault in the section where load node 2 is located, set the remaining capacity of switch S1 to 450A, set the remaining capacity of switch S2 to 350A, and set the remaining capacity of switch S3 to 470A, and the modeling time is 1.85s. Contact switch power supply conditions. The power distribution terminal simulator runs on a computer,
eliminating the need for testers and other equipment, which can reduce the workload of the staff and greatly shorten the project commissioning time.

**Keywords:** IEC61850, Distribution Automation, Distribution Terminals, Terminal Interoperability

### 1. Introduction

With the rapid development of the global economy today, smart grids have been upgraded to a national strategy, which has become the future development direction of meeting power demand and improving traditional grids. The integration of "power flow, information flow, and business flow" in the smart grid requires a strong information and communication platform as the support. The information and communication standard system is indispensable. The IEC 61850 standard has become one of the three mainstream standards for building a smart grid. At the same time, with the development of substation integrated automation systems, the unification of communication protocols in substations has become an urgent issue for the industry. The IEC 61850 communication standard is proposed in this context. Its goal is to form a standard open substation automation communication system, to achieve interoperability between IEDs from different manufacturers, in order to adapt to the integration of substation integrated automation communication towards unified construction. Model, unified application of the trend of seamless communication system development.

IEC 61850 is the first complete communication standard system for substation automation systems in the world. Products based on IEC 61850 will become the trend of smart grid investment and equipment industry demand [1-2]. The IEC 61850 communication standard enhances interoperability between devices by uniformly modeling objects in substation automation systems, and adopting object-oriented technology and Abstract Communication Service Interface (ACSI) independent of the network structure. Seamlessly connect devices from different manufacturers. This standard has the characteristics of flexible configuration, high reliability and strong security, and represents the future development direction of substation automation [3-4]. At present, in the actual engineering debugging of the distribution automation system based on IEC61850, various protection / measurement values are externally input to the server (distribution automation terminal) through the tester to simulate various protection tests. After the server receives the status change, it processes the information Then send it to the client (master) [5-6]. The client compares the received information with the protection test simulated by the tester, and artificially judges whether the communication method between the server and the client is correct; the tester can also simulate several avalanche tests to send multiple server information to test the network communication load. Value and signal accuracy [7-8]. However, this test method has the following disadvantages: (1) it is impossible to comprehensively test the communication
capability of the client (master station). (2) The correctness of the ICD model provided by each distribution terminal manufacturer can only be verified by the point test of the tester. (3) The network communication load value of the entire distribution automation system cannot be simulated.

In order to solve the above shortcomings, this paper proposes the development of a distribution terminal simulator based on IEC 61850. The power distribution terminal simulator can set various fault phenomena, operating characteristics and other scenarios, and amend the scenarios according to various commands downstream from the man-machine interface. The collected information of each simulated power distribution automation terminal is sent to the master station according to the standard protocol for power distribution automation. The test of the master station fault processing logic and operation control function provides a field simulation data environment to perform multi-point complex faults and operation optimization control application functions [9-10]. The power distribution terminal simulator can simulate the communication behavior of all the terminals of the entire power distribution automation system, thereby conducting a comprehensive test between the power distribution terminal and the main station [11-12]. The power distribution terminal simulator runs on one computer to simulate multiple power distribution terminals, eliminating the need for tester equipment, which can be tested in advance before the equipment is installed, which greatly shortens the engineering commissioning time; it can also be a technician who has just been exposed to the IEC 61850 standard. Provide a simulation operation platform to enable them to understand the application of IEC 61850 standard in power distribution automation in a short time.

2. Method

2.1. IEC61850

The IEC61850 standard enhances interoperability among devices by uniformly modeling objects in substation automation systems, using object-oriented technology and abstract communication service interfaces that are independent of the network structure, and can be seamless between devices from different manufacturers Connection, IEC61850 is the first complete communication standard system for substation automation systems. IEC61850 has four outstanding features in technology as follows.

(1) Use a layered system

The IEC61850 standard has layered the substations, and logically divides the substations into 3 layers, namely the substation layer, the bay layer and the process layer.

The function of the substation layer is mainly to communicate with the equipment in the
bay layer, complete the monitoring and control of the equipment in the entire station, and upload the information to the control center and accept the control commands from the control center. The function of the interval layer is mainly to use the equipment of the interval layer to receive various data information collected by the process layer to complete the monitoring, protection and automatic control of the equipment in the station. The process layer mainly completes the functions of collecting analog signal and digital signal of a device, and sending control commands.

(2) Use object-oriented modeling techniques

The IEC61850 standard abstracts the data information of substation automation into a hierarchical model according to the idea of hierarchical classification. The IEC61850 standard defines in detail the logical nodes required for substation automation in Part VII. Each logical node contains multiple data objects, and each data object has multiple data attributes. Multiple logical nodes are combined to form a logical device. The logical device has certain functions. A server contains multiple logical devices, which are the server, logical device, logical node, data, and data attributes.

(3) Use abstract communication service interface and specific service mapping

The IEC61850 standard provides an Abstract Communication Service Interface (ACSI), which separates specific services and functions from specific communication protocols. The services provided by ACSI are bound to the specific communication protocol through SCSM (Specific Communication Service Mapping). Even if the underlying communication protocol changes, only the SCSM needs to be changed. It does not affect ACSI, which can make the substation better adapt to the communication protocol. And the development of communication technology.

(4) Implement the self-describing function of the device

IEC61850 defines various data required for substation automation in detail, and provides extension methods. The IEC61850 standard uses the substation configuration description language SCL (Substation ConfigurationLanguage) to describe the functions and parameters of the IED. The SCL language describes the data carried by itself, and the receiver receives the self-describing information, which realizes the substation equipment Self-describing feature.

2.2. Distribution automation terminal

The research object of this subject is mainly the FTU feeder switch monitoring terminal. According to the electric power industry standard DL / T721-2000 "Remote Terminal for Distribution Network Automation System", FTU is defined as: installed on the pole of the
feeder circuit of the distribution network, and has a remote Remote terminals with functions such as signal, telemetry, remote control and fault current detection (or fault detection with fault indicator). The FTU should have the following functions:

(1) Telemetry: collection and processing of analog information, FTU collects analog values such as voltage, current, active power and reactive power of the line.

(2) Remote signaling: collection and processing of digital information, FTU can collect important digital quantities such as the current position of the switch, whether the communication is normal, and the completion of energy storage.

(3) Remote control: accept and execute instructions, FTU can accept local and remote commands to control switch closing and tripping, and start energy storage process.

(4) Time calibration function: The FTU receives the time calibration command issued by the power distribution master station, which keeps the device clock synchronized with the master station clock.

(5) History record function: It can record the number of times the switch is operated, the time of the operation, etc., and it can realize that the history record information is not lost after power off.

2.3 principles of power restoration

Considering the operating characteristics of the distributed FA system, combined with the normal power supply recovery plan of the power distribution system, a power supply recovery target suitable for the agent-type quick acting distributed FA system is established. After a line failure occurs, a delayed trip is set at the exit circuit breaker. The terminal switch corresponding to the terminal around the fault zone is opened within a specified time. The power supply of the load in the upstream area of the fault is not affected. You only need to pay attention to the downstream area of the failure. Load power is restored.

1) After a fault occurs, maximizing the restoration of load power supply in the downstream area of the fault is the first task.

\[
\max f = \sum_{i=1}^{n} x_i f_{loss}^i
\]

In formula (1), \( n \) represents the total number of feeder segments in the faulty downstream area; \( f \) is the total load to restore power supply in the non-fault area; \( x_i \) takes 0 or 1 to indicate that the load of the feeder segment \( s_i \) is in a power outage or recovery state; \( f_{loss}^i \) represents the non-fault area The power loss load of the inner feeder line \( s_i \).
2) The number of switching operations has a negative correlation with its life, and the number of switching operations must be effectively controlled.

\[ \min T = \sum_{i=1}^{m} (1 - t_i) \]  

(2)

In formula (2), \( m \) represents the total number of switches on the power distribution line; \( T \) represents the number of switching operations; \( t_i \) takes 0 or 1, which indicates that the switching state has changed or remains unchanged.

3) If most or all of the loads in the faulty downstream section must be coordinated and coordinated in order to restore power supply, first consider the constraints of the network topology and secondly try to balance the load rate of the line.

\[ \frac{\sum_{\text{left}} I_{n}^{i}}{\sum_{\text{left}} I_{m}^{i}} \approx Q_{\text{left}}^{m} \]  

(3)

Equation (3) indicates that the faulty downstream power failure area is divided into several areas and partitioned recovery is performed by multiple power sources. In these areas, the ratio of any two areas \( C_{dn} \) and \( C_{dn} \) power loss load should be equal to the corresponding remaining power supply capacity The ratio of \( Q_{\text{left}}^{m} \) and \( Q_{\text{left}}^{n} \).

3. Experiment

In this article, the IEC61850 client software running on a laptop computer is used to simulate a power distribution master station. The laptop computer is connected to the power distribution terminal through a switch. At the same time, the notebook computer is also connected to the power distribution terminal through an RS-232 serial port. HyperTerminal to monitor the internal program running of the power distribution terminal.

(1) Power on the power distribution terminal. At this time, the VxWorks hyper terminal shows that the Vx Works system is started, the SISCO communication library is successfully loaded, the SCL file is successfully parsed, and the parsing time is 1000 ms.

(2) Open the IEC61850 client software, configure the IP address of the power distribution terminal to be connected, and read the IEC61850 model file of the power distribution terminal normally.

(3) Connect the DIVDD of the remote signal board of the power distribution terminal to the 1.3, 5, and 7 remote signal terminals, and use the IEC61850 client software to read the remote signal status of the power distribution terminal. The remote signal display status of 1.3.5.7 is TRUE. Can read the remote signal status in real time. Repeat the test many times,
and the client software can read the remote signaling status of the power distribution terminal in real time.

(4) Change the telemetry data of the power distribution terminal. Use the Sverker750 single-phase electrical protection tester to add 1A, 2A, and 3A currents respectively. Use IEC61850 client software to read the telemetry data of the power distribution terminal, which can correctly read the real-time current value. Change the current value and repeat the test several times. The client software can read the telemetry monitored by the power distribution terminal in real time. Through the above four-step experiment, it is proved that the communication between the power distribution terminal and the master station is normal.

4. Discuss

4.1. Fault self-healing analysis of distribution automation

As shown in Figure 1, the table shows the parameter settings of each load node, and faults are set in the sections where load nodes 2, 3, and 5 are located.

![Figure 1. Load parameters](image_url)

As shown in Table 1, set a fault in the section where load node 2 is located, set the remaining capacity of switch S1 to 450A, set the remaining capacity of switch S2 to 350A, set the remaining capacity of switch S3 to 470A, and modeling time 1.85s, Meet the single contact switch power supply conditions.

**Table 1. Power restoration process (fault at node 2)**
### Time-Switch Table

| Time  | Switch | Operation type | Amount of power | Restore quantity |
|-------|--------|----------------|-----------------|-----------------|
| 0.16s | CB1    | Open           | 465A            | 0               |
| 1.16s | CB2    | Open           | 465A            | 0               |
| 4.92s | S3     | Close          | 50A             | 415A            |

This article introduces two types of fault self-healing methods for distributed FA systems. The first is a cooperative distributed FA self-healing solution that works with the master station. First, a network operation model is established to pave the way for specific power supply recovery processes. Then, a cooperative distributed FA single contact switch power supply restoration method was proposed. When the single contact switch could not achieve power restoration, the master station took over the power restoration work of the line at this time to achieve fault recovery. The second is an agent-based distributed FA fault self-healing scheme based on no master station. First, the power recovery target is established, and a load evaluation model is established. Second, an agent power distribution terminal is selected on the line. This terminal is responsible for the establishment of the topology model and power recovery. At the same time, according to the specific situation, the power recovery algorithm for single contact switch, the load recovery algorithm for single contact switch and the power recovery algorithm for multiple contact switches were proposed respectively. Both types of distributed FA control algorithms have been verified by simulation.

#### 4.2. Analysis of operating steps

1. Load the simulation business scenario file. Load the business scenario file generated by UML, which is used as the verification file of the actual scenario to monitor the IED of the power distribution terminal based on IEC61850 modeling.

2. Load the IED project configuration file and check the syntax format of the file. Load the ICD file, which is a file generated based on the IEC61850 modeling part. The file includes a check of the IEC61850 message part and a check of the CIM message part.

3. Set the initial value of the IED data attribute. For the data attribute value in the information model, the initial value of the attribute can be set by manual setting.

4. Start the test. First, as the test progresses, changes in attribute values are simulated based on the settings. For analog or integer variables, changes can be random or fixed increments; for Boolean variables, the value must be changed manually; second, various events are triggered according to the event settings of the business scenario. For example, the online monitoring scenario will trigger a time event when the test is started, and periodically pass the attribute value of the IED device to the upper computer system; and the trigger of the low current ground alarm event is set to a displacement event, that is, IDpro / PTEF1 in the IED attribute. Str.general can trigger an alarm when it changes from False to True; finally,
according to the business process settings of the business scenario, control the triggering of events and the simulation of message delivery according to the requirements of the sequence process, and monitor the completion of the sequence.

(5) Complete the test. The software is running. The upper left part of the work area is the visualization area of the simulation business scenario, which displays the timing chart list of the current business scene and the currently selected timing diagram. The upper right part of the work area is the visualization area of the power distribution terminal IED device information model. The hierarchical structure shows the IED information model and the data attributes of the IED device in the list mode; the lower left part of the work area is the visual area of the message, showing the currently generated message list and message content; the lower right part of the work area is the upper computer simulation Monitoring area, real-time monitoring of important variables.

After the test of the above content is completed, a test result dialog box will pop up, in which the results of the test are displayed, including the final conclusions and details of the completion of the business process timing process and message format check.

5. Conclusion

In order to improve the reliability of the power distribution network and realize the intelligent distributed protection function of the power distribution terminal, based on the IEC61850 standard and the functional requirements of the power distribution terminal, this paper establishes an information model of the intelligent power distribution terminal and delves into the IEC61850-80-1 The standard realizes the mapping of the CDC data in the power distribution terminal IEC61850 to IEC60870-5-104, and uses the MMS-EASE Lite software package of SISCO to achieve the communication between the power distribution terminal and the power distribution master station, using IEC60870- The 5-104 protocol realizes peer-to-peer communication between power distribution terminals, and adopts the principle of longitudinal current differential protection to implement the differential protection function of power distribution terminals. After experimental verification, the intelligent power distribution terminal designed in this subject can accurately determine the fault area To achieve rapid removal of faulty and non-faulty areas to restore power.

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