Study on the Adjustment of the Network Interface for the Station Domain Protection Device Based on RTDS

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Abstract. With continual development of smart grid construction, digital substation devices based on the specification IEC 61850, such as substation-area backup protection, have been widely applied. According to the “Technical requirements for the substation-area backup protection control device of the new generation of intelligent substation”, this paper put forward the debugging scheme of all digital network interface based on RTDS. Through the introduction of the RTDS software and hardware platform of the whole process building and commissioning, and by constructing substation simulation model and configuring GTNET-GSE card and GTNET-SV card, a closed-loop test system of substation-area backup protection device is completed, also this process development verification interface debugging method and configuration files have a certain practical value. The simulation of substation typical fault conditions and device data receiving processing mechanism can effectively meet the state grid enterprises standard Q/GDW11053-2013 for protection device test project requirements, and this test can significantly improve the smart substation integrated debugging efficiency.

1. Introduction
Since the State Grid Corporation put forward the new generation of smart substation in the working conference of 2012, the new generation of smart substation needs great improvement in terms of the perception of creative design, modular construction, deepening of fusion degree of the primary and secondary equipment, improvement of the reliability and integration of the protection equipment, and reduction of debugging and maintenance complexity. Especially as a series of ample switch isolation devices, transformer intelligent components, electronic transformers and intelligent substation equipment based on IEC61850 standard has been extensively applied to the power system, the motion performance, response characteristics and logic verification of these new equipment need experimental verification [1]. However, restricted by the cost of the integrators and the function of the unit debugging device, there is an urgent need in solving the new debugging problems, such as the universality of the transport protocol standards of the electronic transformer and the merging unit, and compatibility between the giga optical port of the substation-area protection device and the hundred gigabytes output of the relay protection tester. On the other hand, as one of the most technically mature and extensively applied real time digital simulation systems (RTDS), the RTDS is provided with a relatively mature process level board card which is configured to provide a safer and optimized access platform compared with the traditional analog wiring for the concentrated tests and system...
level dynamic simulation experiments of the intelligent assemblies and secondary equipment of all manufactures, and thus greatly shortens the site debugging time, which will be the development direction of indoor debugging of the complete equipment of intelligent power station system. This paper will erect a platform for the novel substation-area protection device with the RTDS digitized system based on the IEC61850 standard, and conduct closed loop tests on the in-station backup protection function by developing and configuring the appropriate network debugging port. Some of the technical terms that appear in the article are described in the following table 1.

**Table 1. Nomenclature table**

| RTDS          | Real Time Digital Simulator                                                                 |
|---------------|---------------------------------------------------------------------------------------------|
| GTNET         | Giga-Transceiver Network Communication Card Provides A Real Time Communication Link To And From The Simulator Via Ethernet |
| GPC           | Giga Processor Card                                                                          |
| GTA0          | Giga-Transceiver Analogue Output Card With 64 Optically Isolated Digital Channels            |
| GTDI          | Giga-Transceiver Digital Input Card With 64 Optically Isolated Digital Channels              |
| IED           | Intelligent Electronic Device                                                               |
| GOOSE         | Generic Object Oriented Substation Even                                                      |
| SV            | Sample Value                                                                                 |
| SCD           | Substation Configuration Description                                                         |
| CID           | Configured IED Description                                                                  |
| ICD           | IED Configuration Description                                                               |
| APPID         | Application Identification                                                                  |

2. RTDS software and hardware application analysis

2.1 Introduction of RTDS and GTNET board card application

RTDS is a digital dynamic model system developed by the Canadian Manitoba high-voltage direct current research center specially for real-time simulation of the power system. Composed of hardware and software, RTDS has a considerable numerical simulation accuracy and dynamics, can not only timely simulate the electromagnetic transient, electromechanical transient and medium and long term dynamic whole process of the whole system but also provide variables which are converted to the physical quantity or analog quantity for output through GPC, GTA0, GTDI, GTNET and other plates, so as to obtain the digital-physical experiment loop which is connected with the practical secondary equipment and flexible and convenient to build, thus providing conditions [2-5] for analyzing and evaluating the running condition of the control protection device in various working conditions.

![Figure 1. Closed loop for devices connection](image-url)
The GTNET board card provides a communication protocol packet which RTDS needs to interact with the equipment based on the IEC61850 communication standard application research, and supports four types of communication protocols: GSE, SV, DNP and PLAYBACK. The connection mode of the GTNET board card and the external protection device is shown in figure 1.

Currently, as most indoor dynamic model tests are conducted with the power amplifiers, there are problems of limited quantity of analog quantity ports and wiring potential risks. However, the new generation of intelligent substation-area protection devices adopt the network-sampling-and-network-tripping mode. To make sure the test process is safe and reliable and fits with the site practical condition and to simplify the test analysis means, the test sufficiently avoids the physical closed-loop test conducted by aid of GTA0 (analog quantity output) and GTDI (digital quantity input and output) board cards and the power amplifiers with merging units and switch analog devices, but adopts the analog virtual merging unit and the intelligent terminal. The GTNET board card with this connection can be imaged as a protocol converter which completes information uploading by accepting messages on the exchanger and can also accept the protocol data output by the RTDS software model.

2.2 Configurations of software model and board card

The Rtds-ctl-GTNET_SV9-2 model and the Rtds-ctl-GTNET_GSE9_v2 model are soft models in the RSCAD model base for IEC61850 protocol communication tests, and can be used for externally broadcasting data packets and subscribing packets. Meanwhile, each GTENT board card can only select one communication protocol [6] at the same time to complete simulation on the data information flow of the substation according to the wiring mode of figure 1. The two abovementioned modules are the main modules used in the research, and the configurations of typical parameters of the Rtds-ctl-GTNET_SV9-2 model is shown in figure 2.

![Figure 2. Parameter setting for Rtds-ctl-GTNET_SV9-2 module](image)

Modify corresponding document configurations according to the hardware connection condition of the board card in figure 1. As shown in figure 3, open the installation directory: configuration file (config_file) under C:\RSCAD3.002.2\HEWR, or directly enter the config File Editor menu of the software for port modification. This step is applicable to the new installation of the GTNET board card and the step which needs operations when the connection condition changes. This test completes the cascading setting of two GTNET board cards on the same RACK, and the protocols are respectively SV and GOOSE.
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Figure 3. Profile settings for RTDS

Hardware initialization of the GT-GSE and GT-SV board cards of Rtds needs to obtain all information signs of the board cards connected onto Rtds by aid of the IP of the Telnet GTWIF board card of the computer host: 10.234.235.60 (default), and access the board card information bars needed to observe through the per order.

IP of Telnet GT-GSE board card: 10.234.235.97, confirm the version information of the communication protocol to prevent too low version from failing to meet the domestic device compatibility requirement. As shown in figure 4, the test environment is applicable to GTNET-SV: 4.13, GTNET-GSE: 4.3 and higher versions, and the information such as the connection condition and version number of the port of the GT-SV board card can be obtained in the same way.

Figure 4. Card information query for the GT-GSE

2.3 RTDS test system based on IEC61850 standard

The test content includes firstly erecting in the RTDS a power system simulation model, including the primary system real-time model, the fault control subsystem model and the breaker control subsystem model. As the Rtds-ctl-GTNET_SV9-2 module and the Rtds-ctl-GTNET_GSE9_v2 module respectively have the abilities of simulating the merging unit and sending standard protocol messages through the smart terminal, the voltage and current value analog quantity obtained through real-time simulation calculation is input into the Rtds-ctl-GTNET_SV9-2 module, and sampling values are converted into the communication data format meeting the IEC61850-9-2LE standard by aid of the Rtds-ctl-GTNET_SV9-2 module and issued to the protection device of the sampling value by the Ethernet. In addition, Rtds-ctl-GTNET_GSE9_v2 sends GOOSE data to the substation-area protection device through the Ethernet, the substation-area protection device sends the GOOSE message containing operation instructions back to the Rtds-ctl-GTNET_GSE9_v2 module, and finally sends the tripping or closing instructions to the breaker, thus realizing data exchange [7-8] between the protection device and the simulation platform.
Particularly, as the new generation of substation-area protection has canceled “rated delay” virtual terminal connection, the in-station device needs to use the externally connected timing system to ensure synchronization of all access intervals, and the GTNET board card and the substation-area protection can simultaneously protect the IRIG-B and 1pps timing ways. The substation-area function involved in this test only collects the current and voltage amount of the single terminal, and the switching quantity belongs to the microsecond level in terms of transmission time in the exchanger with no accurate timing requirements. The structure of the test system in this research is shown in figure 5.

![Figure 5. The structure of the test system based on IEC61850 standard](image)

3. Principle analysis of debugging interface

3.1 Overall structure framework of substation-area backup protection

Taking the whole transformer substation as the object, the substation-area protection control device is mainly used to complete functions of functional redundancy of single set of configuration protection, functional optimization of in-station protection and safety automatic control. The substation-area protection device adopts the modular design so that all transformer substations can decide the protection modules according to the practical conditions. The substation-area protection device adopts the new generation of 32-digit PowerPC-based high-performance hardware platform, with the functional plug-ins formed by the liquid crystal display board, CPU board, the station level communication board, the process level interface board, the stabilized voltage supply board and the backup board. Except the liquid crystal display board, all the other plug-ins adopt the back pull-and-plug mode, and the process level interface plug-in provides two Ethernet interfaces and mainly completes communication between the protection device and the process level network. The plug-in also provides a function of IEEE1588 timing for the process level network. The overall case structure of the device is shown in figure 6.

![Figure 6. Chassis structure for the station domain protection device](image)

Before establishing the connection with the GTNET board card, the integrators need to eventually form the full station configuration file SCD according to the full station ICD file. The file includes the virtual terminal links of all devices of the full station, and the CID file downloaded into the substation-area protection device needs to be exported by the final version SCD file and conducts corresponding communication configurations for the substation-area protection device.

The device can modify the networking sending internet port before downloading, and needs to be restarted after deciding the internet port and selecting downloading.
3.2 GTNET_SV interface debugging
The domestic current intelligent in-station protection adopts double AD sampling, and two paths of AD values are sent to the protection device by aid of the merging unit, while the Rtds-ctl-GTNET_SV9-2 module only provides one sampling path. The SCD file configuration software is needed to conduct special treatment on the sub-coupling of the virtual segment in the way of one-to-twoconnection [9].

The content of the SCD file IED assembly adopted in this test is shown in the SCL browser part. The specific debugging process is the PRS-739X series of merging unit/protection A phase current 1 (external address: MU1/PATCTR1.Amp1) is connected with the double addresses (2-A:PISV02/SVINGGI01.AnIn1 and 2-A:PISV02/SVINGGI01.AnIn2) inside the circuit protection 02_Ia2 device, and the other phases of the voltage and currents are treated in the same way.

According to the abovementioned description, the Rtds-ctl-GTNET_SV9-2 module is not the practical merging unit so that it cannot provide the practical ICD file. In the debugging, the site practical merging unit ICD and the substation-area protection device ICD file configuration are adopted to initialize gtnet.scd which exports the CID file for the substation-area protection device to download, while the effect of the Rtds-ctl-GTNET_SV9-2 module is to make the message sent by the GTNET board card to be the same as that sent by the practical site merging unit.

3.3 GTNET_GSE interface debugging
The test system also needs to use the Rtds-ctl-GTNET_GSE module to realize closing signal receiving conversion of the protection device and GOOSE information transmission of the switch position state quantity of the Rtds primary system model. The parameter setting of the virtual terminal of the Rtds-ctl-GTNET_GSE module is shown in figure.7, in which the red line 1 is the connection drawing of the virtual terminal connected with the output volume of the protection device, including tripping, reclosing and permanent tripping switching quantities of the protection device; the red line 2 is the virtual terminal data set GOOSE_outputs_control of the switch position state quantity of the Rtds system. The parameter setting of the Rtds-ctl-GTNET_GSE module is complicated, including the following steps:
(1) Determining the information quantity needed to be issued and subscribed by Rtds and IED connected with Rtds;
(2) Adding the physical intelligent terminal ICD into the gtnet.scd file to complete the basic communication address and virtual terminal configuration work, then completing the CID file extraction of the substation-area protection device in gtnet.scd by aid of the SCD Editor software of Rtds, and further interrelating the tripping, reclosing and permanent tripping switching quantities of the protection device; the red line 3 is the virtual terminal data set GOOSE_outputs_control of the switch position state quantity of the Rtds system.
(3) The GOOSE_outputs_control module provides a switch position external interface for Rtds, and the attribute of the GOOSE_outputs_control module is referred to the site intelligent terminal setting as shown in the red line 4, including the settings of the key information such as IEDname, MAC-Address, Appid and Goid;
(4) The special emphasis is that as the logic device, the logic node, the logic data, and the logic data attribute structure and type provided by the Rtds-ctl-GTNET_GSE module are CTRL.BOUT_GGIO1.Ind.q{Quality} and CTRL.BOUT_GGIO1.Ind.stVal{BOOLEAN}, the data attribute name and type are different from those of the site intelligent terminal ICD but cannot be changed, and the data attribute sequence is fixed, as shown in the red line 5, so that the site intelligent terminal should complete corresponding modifications of names of the related logic devices and logic nodes in the IED so as to realize consistence of the messages. The specific modification process is shown in the gtnet.scd file configuration process.
Then the modification configuration of the Rtds part is finished. The configuration of the gtnet.scd file is as follows:

1. Opening the Altoa XMLSpy software and importing the gtnet.scd file;
2. Changing the IEDname of the intelligent terminal and the original names of logic equipment from the PRS7789L1 and RPIT to PRSL and CTRL in a batching processing way;
3. Opening the SCL Configurator software, changing DataSet, Name, APPID and other message fields of the intelligent terminal by comparing the MAC-Address, Appid and Goid bytes at the red line 4 of figure 7(b), and ensuring that the binary code of the control module PRSLCTRL/LLNOSGOSGOOSE_outputs_control (position uploading) sent by the intelligent terminal is consistent with the content sent by Rtds;

4. Similarly, it should make clear that as shown in figure 8 about the dataset sent by the intelligent terminal in gtnet.scd, the specific data in the dataset needs to be modified so as to reach the effect consistent with the dataset quantity sent by Rtds, which needs to select the data attributes of the Quality and BOOLEAN types from the CTRL logic device of the PRSL device, and alternately arrange these attributes according to the sequence shown in the red line 5 in figure 7. Then the key problem is that the GOOSE_outputs_control dataset sent by Rtds only contains BOOLEAN and Quality types of...
data attributes, while the current mainstream domestic manufacturers uniformly adopt the two-point state information DPS type stval (CODED ENUM) to indicate the switch position, and as a result, the BOOLEAN type and the CODED ENUM type cannot be matched for assignment. Of the two solutions to the above problem, one solution is to upgrade the GTNET board card so that the Rtds-ctl-GTNET_GSE module can provide the CODED ENUM type data, which however is not adopted due to limitation from device upgrading and transformation and cost. This paper tries the method of assigning the CODED ENUM type data by aid of the Quality type data, the specific steps of which are as follows:

(1)It’s known that the goose message frame format is transmitted [10-11] by aid of ASN.1 grammar related to basic encoding rules (BER), and the transformational grammar of BER adopts the T-L-V (Type-Length-Value) or T-L-V(Tag-Length-Value) mode. For BOOLEAN type data, tag=0x83, length=0x01 and the value=00 or 01; for CODED ENUM type data, tag=0x84, length=0x02, and the value takes up two bytes; for the Quality type data, tag=0x84, length=0x03 and the value takes up three bytes. We observed that the tags of the Quality type data and the CODED ENUM type data are the same. The length byte protection device only conducts self checking, and sends switch tripping and closing messages to the substation-area protection device through the relay protection tester during the test. The WS Explorer is observed as shown in figure 9.

Figure 9. The closing position packet for intelligent terminal switch

It can be seen that the tripping message stval (CODED ENUM) at the switch position is 84 02 06 40 and the closing message at the switch position is 84 02 06 80, there is only difference at the second byte of stval.value with the first byte unchanged. The CTRL_BOUT_GGIO.Ind.q (Quality) sent by Rtds is 84 03 03 00 00, of which the second byte of q.value can be manually set through the simulation platform, so that the position displacement of the primary switch model in Rtds can be reflected onto the second byte of q.value to be equal to the byte of the stval message, and the effect of consistence between the q type message and the stval type message in terms of the stripping and closing at the switch position can be achieved.

(2)Due to the fixed ranking of the GOOSE_outputs_control dataset, the first byte of data in the dataset sent by the intelligent terminal in gtnet.scd is modified into the breaker position, virtual terminal linking is completed; meanwhile, to ensure that the messages sent by the GOOSE_outputs_control dataset and the intelligent terminal are totally consistent, other data with the same quantity and type are added in gtnet.scd as the filling item, gtnet.scd re-exports and downloads the substation-area protection CID file, and the closing message at the switch position and the message of the switch position of the protection device sent by the Rtds-ctl-GTNET_GSE module are grabbed, as shown in figure 10.
4. Simulation application

According to the fifth chapter [12] of GB/T26864-2011 and the article 7.13 [13] of W11053-2013, combining the new technological requirements of the current power system and relay protection, when conducting the dynamic model test of the new generation of the substation-area protection device of the intelligent substation, the protective backup function should be connected into the system and tested [14-15] as required. Limited by the length of this paper, only the dynamic model test results of zero-sequence protection and distance protection are shown as follows.

The test sample system structure adopts the site wiring mode of a certain transformer substation. The breakers of the 110kV lines 1 and 2 transmit power to the #1 and #2 main transformers through the inner bridge 3 breaker looped network. The #1 main transformer carries 35kV I segment and 10kV I segment of loads, the #2 main transformer carries the 35kV II segment and 10kV II segment of loads, the 10kV section switch is in the hot spare state, and the 110kV and 35kV sides of the #1 and #2 main transformers are in the parallel operation state. The fault point is arranged at the outlet of line 1 (near the transformer substation side) and simulates the single-phase grounding instantaneous metal grounding fault, lasting for 70ms. The basic conditions of short-circuit currents when fault occurred are as follows:

![Figure 10](image1)

**Figure 10.** Message sending for Rtds-ctl-GTNET_GSE module and switch position message for protection device

According to analysis on the simulation result, for example, the effective value of short-circuit currents in the figure 11 (a) is 1.9A (secondary side), the switch is turned off after 72ms and then is turned on after 1,000ms, and the protection tripping upon fault and reclosing deflection signals are reflected in the deflection bar graph in Rtds through the goose virtual terminal. #0 in the figure 11 (b)

![Figure 11](image2)

**Figure 11.** The fault signal source and test record
stands for the tripping signal goose, and #3 stands for the reclosing signal goose. The protection device protects the I section motion outlet from the grounding distance at 35ms, and restores normal operation when the reclosing instruction is sent after 1,055ms. Modify the fixed value, exit the grounding section I section of the substation-area protection device, conduct zero-sequence I section protection and corresponding fixed value modification, and simulate the tripping condition of the protection device when the switch fails to work in the permanent fault condition.

![Image](a) The instantaneous single-phase grounding fault

![Image](b) The open position change for Rtds

Figure 12. The fault signal source and test record

In the simulation analysis process and distance protection case, the short-circuit currents are 16.2A (secondary side). The protection device sends the single tripping instruction and permanent tripping instruction. The #0 channel in figure 12(b) stands for tripping signal goose, the #2 channel stands for the permanent signal goose, and zero sequence protects the I section motion outlet at 18ms. After 275ms, the permanent tripping instruction is sent, and fault currents exist permanently due to switch failure. The simulation test is finished after the fault lasts for 7,223ms, as shown in figure 12(a).

5. Conclusion
With the popularization and construction of the new generation of smart substations in China, to adapt to the change of the optical fiber communications mode in the smart substations, the author studies and analyzes the overall structure of the RTDS-based novel test system, and tests the intelligent device IED with the closed-loop test circuit in the RTDS in various fault conditions.

- Analyzes and solves the network interface debugging problem of the substation-area protection device and the GTNET_GSE、GTNET_SV board card, and innovatively proposes the specific operation methods of mutual assignment between different data attribute types of different intelligent IED equipments.
- Completes the hardware and software configuration detailed descriptions of the dynamic model test platform of the substation-area protection device, as well as detailed test and analysis on the backup protection functions on the test object. The verification proves that the design scheme is feasible and has a certain engineering practice value. In addition, the simulation network can be applied to testing the process level network communication performance [16] after the transformer substation structure is expanded.

6. Discussion
The RTDS Simulator is the world standard for real time power system simulation. It is used by all of the world’s major protection and control equipment manufacturers, as well as by leading electric utilities, educational institutions, and research facilities around the world. Especially in the power
system industry, the RTDS Simulator tool used worldwide for the closed-loop testing of protection and control equipment, HVDC and FACTS scheme testing, phasor measurement unit (PMU) simulation, power electronics simulation, distributed generation studies, and more.

With the increasing maturity of large-scale electric power long-distance transmission technology and new energy grid-connected power generation technology, the development of new-generation intelligent substations plays an important role in ensuring the security and stability of long-distance transmission of electricity and the interconnection of large-scale new energy grid-connected networks. Accelerating the improvement of relay protection performance and device development will play a positive role in the construction of energy Internet. The complexity of large-scale grid systems and the high degree of dependence on real grid simulation are dependent on the effective real-time dynamic simulation system, so the research and application of this paper is a good example.

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