Development of Dynamic Test System for Digital Relay Protection Based on IEC61850 Standards

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Abstract：In recent years, electronic mutual-inductor and IEC61850 serial standards are adopted in digital substation. Once electronic mutual-inductor has been used, the input signals of relay protection and other secondary devices are not the traditional analog quantities any more. The simulation system cannot offer such interface up to now, so the secondary devices which are based on electronic mutual-inductor in digital substation cannot be tested and researched in this way. A kind of testing system aiming to real-time digital relay protection is introduced in this paper. By adding secondary interface to the primary simulation system, such as ADPSS (invented by China Electric Power Research Institute), a closed-loop testing system which is based on IEC61850 standards is established. The testing results verify that the system has great significance on improving the application of digital substation, and it has great use value.

Keyword：**digital substation, IEC61850, secondary interface, photoelectricity transformer, dynamic test**

1 Introduction

In recent years, electronic mutual-inductor and IEC61850 serial standards are adopted in digital substation. Once electronic mutual-inductor has been used, the input signals of relay protection and other secondary devices are not the traditional analog quantities any more. The simulation system cannot offer such interface up to now, so the secondary devices which are based on electronic mutual-inductor in digital substation cannot be tested and researched in this way. Establishing a new platform of digital protection device detection has very important practical significance on the aspect of improving the technical performance of all-digital protection and secondary devices and the level of security and stability of digital substation.

A kind of testing system aiming to real-time digital relay protection is introduced in this paper. By adding secondary interface to the primary simulation system, such as ADPSS (invented by China Electric Power Research Institute), a closed-loop testing system which is based on IEC61850 standards is established. In this paper, the development ideas and technical requirements of the new system and the hardware components of the data conversion interface are illustrated in detail. The electromagnetic simulation model of transmission line is developed in this paper. By docking with the different devices and closed-loop test, it is verified that the system built is fully in line with the practical requirements of power system and has great use value.

2 Development Ideas

The ADPSS invented by China Electric Power Research Institute is a self-developed mature simulation device, the world's first real-time simulator which can simulate the large-scale complex AC-DC power system. It can conduct research on the 1000 units, 15 000 nodes large-scaled AC-DC power systems, such as electromechanical transient simulation and electromechanical, electromagnetic mixed transient simulation. Equipped with the high-power, high-precision, multi-channel power amplifier, integrating the system simulation and real-time test functions, ADPSS can make the closed-loop tests to the traditional relay protection and automatic safety devices.

The main difference between the digital substation and the traditional substation is a change in transmission medium and control method. The traditional transformer signal from the power amplifier is replaced by the optical digital signal-samples (Sample Value, SV) followed IEC61850 communication protocol, the circuit breaker control signal is replaced by GOOSE (generic object oriented substation event) message, while the various electrical and transient characteristics of the grid don't change. The basic design idea of the dynamic test system for digital substation in this paper is using original software simulation platform and to design the optical data conversion interface independent of the original system without changing the physical connection of the original test system, then it can simulate digital output from the photoelectric transformer(electronic current or voltage transducer, ECVT) + MU (merging unit).

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In order to constitute a closed-loop test system, the digital interface should have the ability to analyze GOOSE messages and can feedback the signals to simulation system by analog circuit breaker. The new closed-loop dynamic simulation test system is shown in Figure 1.

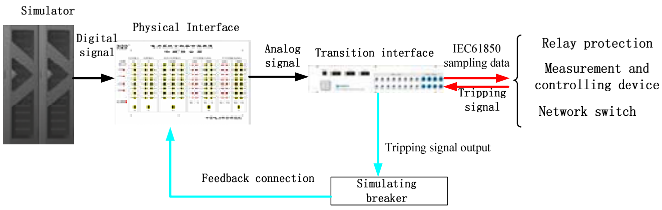

Figure 1 The closed-loop dynamic simulation test system based on IEC61850

As the digital substation is still an emerging things, the introduction of relevant domestic standards is little and the development concepts of manufacturers are different, so the new test system must meet the general requirements. Because of the use of point to point transmission, data transmission delay is relatively fixed, the synchronization of different sampling intervals is easier to achieve, the sample messages based on IEC61850-9-1 statute is more adopted in the early digital substation. The sample messages based on IEC61850-9-2 statute is for the network level, more in line with the digital substation's open design concept, so is widely used in the recent years. The 9-2LE version statute is currently used in China. It outputs signals of 8 channels, including 4 current signals and 4 voltage signals. But some manufacturers have expanded the number of 9-2LE channels, such as increasing the bus voltage, open-delta voltage and so on. In view of this, the new platform needs to meet the output requirements of 9-1 and 9-2LE message, to open the definition function of separate simulation signals for the 9-2LE statute, and to achieve a certain degree of expansion of channels (up to 12 channels), in order to achieve a flexible channel configuration, to achieve universal requirements.

In addition that the digital substation construction is at the initial stage recently, the fiber-optic current differential protection of the transmission line composed by one end digital station while the other end traditional station will exist a period of time. Therefore, the new test system also needs to meet the output requirements of analog signal and digital signal simultaneously. The two simulation signals through different transmission media should have a better synchronization.

3 Development of Data Conversion Interface

3.1 Development program selection

The new data conversion interface development can use two technical solutions: The first option is to collect -10V ~ 10V analog signal output from the original physical interface box, and send messages in line with IEC61850statute using AD conversion and processing methods. The advantage of this programs is that it does not change the software environment and hardware configuration of the existing test system, can output messages separately and does not take up the host system's CPU resources. The disadvantage is after several transformations which from the system digital signal →analog signal from physical interface → packet, the sampling accuracy and multi-channel synchronization issues need to be solved. The second program is to develop the new PCI card on the basis of original physical interface, and to provide functions of converting protocols for digital simulation signals and sending messages. The advantage is the simulation signal can be converted from digital signal to the IEC61850 message directly, reducing the middle process of analog conversion. While the disadvantage is taking up more CPU resources and of has higher requirements to the system servers and other hardware devices.

Making comprehensive comparison of these two kinds of technical solutions, no doubt the second solution is technically more advanced. Because the developer has not completed the development of relevant products, this article uses the first option as a feasible plan during a transitional period.

3.2 Hardware components

Data conversion interface should fulfill the following four functions:

(1) Collect the analog signals from the physical interface, and convert them to digital signals;

(2) Process the digital signals above-mentioned, and generate sampling messages in line with IEC61850 standards.

(3) Send the sampling messages to digital relay devices waiting for test.

(4) Receive GOOSE messages and convert them to electrical switch signals

In accordance with the functions data conversion interface needs to implement, the design of the hardware structure is shown in Figure 2.

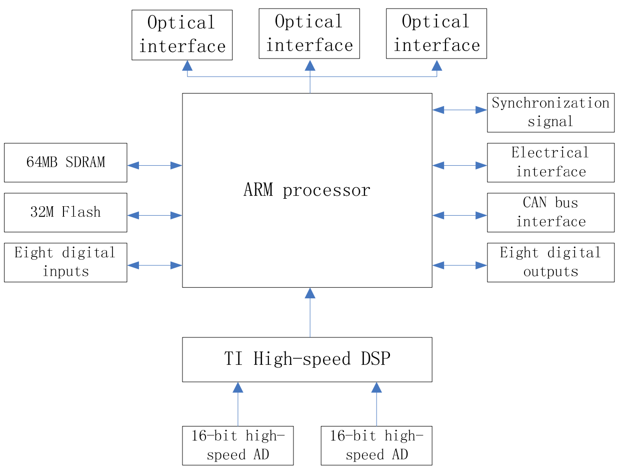

Figure 2 The hardware structure of data conversion interface

The two 16-bit high-speed A/D converter chips are in charge of analog signal acquisition and digital conversion.

The two chips run in parallel, enabling the simultaneous sampling of 12 channels' analog signals, to meet the IEC61850-9-1 and 9-2LE statute's requirements of output channels. The A/D converter chip used the high-performance conversion chip introduced by TI, and the conversion rate is up to 250kSPS (kilo sample per second)(Note: Conversion rate refers to the reciprocal of the time AD conversion required for the completion of an analog to digital conversion, 250kSPS represents that a AD conversion time is only 6 microsecond), fully meet the maximum demand of 3 optical interfaces output the IEC61850-9-1 messages (255 points per cycle) at the same time.

High-speed DSP (digital signal processor) is for controlling the sampling process of AD chip, while receiving the digital signals converted by AD chip and sending them to the ARM processor. ARM processor will convert the digital signals to sampling massages in line with the IEC61850-9-1 and 9-2LE standards.

In accordance with the universal design requirements of the new system, 3 optical interfaces can output the IEC61850-9-1 and IEC61850-9-2 messages, at the same time, can also be configured to GOOSE subscribe/publish port.

Conversion interface has eight switch inputs and eight switch outputs. Eight switch inputs can detect an empty node or active node (15V-250V), mainly for GOOSE publishing function. As the output terminals of GOOSE subscription function, eight switch output contacts can convert the GOOSE messages from optical interface into switch signals and feedback to the system, in order to achieve an important part of the closed-loop testing.

In addition, in order to achieve multi-output synchronization of data conversion interfaces, it's also equipped with the GPS receiver unit and can receive second pulse synchronization signals.

4 Development of Data Conversion Interface

4.1 System model

After the development of the data conversion interface, with a combination of original simulation system, a closed-loop test system is established. It's shown in Figure 1. For the detection of the new test system's overall characteristics, in accordance with the relevant requirements of the DL/T871-2004 "power system protection product dynamic simulation", a model of 220kV double circuit transmission line is established, shown in Figure 3.

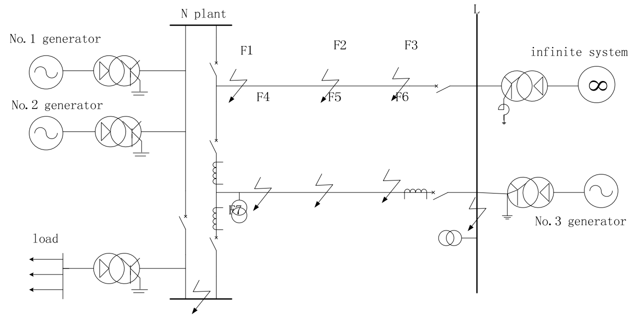

Figure 3 220kV double circuit transmission line model

1, # 3 generator's parameters are: P_n=600 MW, X_d=2.61, X'_d =0.3825, X''_d =0.3045, X_q=2.5425, X'_q=0.6435, X''_q=0.321, terminal voltage is U=20 kV; # 2 generator's parameters are: P_n=350 MW，X_d=5.2552，X'_d =0.7276，X''_d =0.48，X_q=5.2552，X'_q =0.7276, X''_q=0.48，terminal voltage is U=20 kV.

1, # 3 transformer's parameters are: ratio is 230 kV/20 kV, Ynd11 wiring, U_k=13.4%，I_0=0.26%，P_0=109 kW，P_k=437 kW; # 3 transformer's parameters are: ratio is 230 kV/20 kV, Ynd11 wiring, U_k=13.6%, I_0=0.12%, P_0=188.4 kW, P_k=693.9 kW.

The line's parameters are: R_1=0.000111 *pu*, X_1=0.00562 *pu*, C_1/2=0.000926 *pu*, R_0=0.000589 *pu*, X_0=0.002054 *pu*, C_0/2=0.00063 *pu*, S_n=100MVA, U_n=220kV, the length L=300km.

The ratio of CT(current transformer) is 1200/1, the ratio of PT(potential transformer) is 2200/1.

3.2 Synchronization test

Synchronization is the main problem to be resolved during the sampling transmission process in digital substations. If the data conversion interface is not synchronized with the device under test, sample frame will be lost and the differential protection constituted will also have difference failures and other issues.

Figure 4 is the connection diagram of the synchronization devices. Data conversion interface is generally connected with the relay device under test directly, and can also be interconnected by the switch-formed SV network. Synchronization device provide clock signals for the relay equipment under test and the data conversion interface. Data conversion interface receives the GPS second pulse signals by hard synchronization (RS485). The relay device under test can use the coding synchronization (IRIG-B code) or the hard synchronization (RS485) and other methods. From the test results, no matter by what kind of connection or synchronization method, the sampling value of protection devices can guarantee a very high accuracy. Meanwhile, the line differential protection's constituted by figure 3 differential current is zero when in steady-state or outside-fault. As a result, the output of different data channels has met the synchronization requirements.

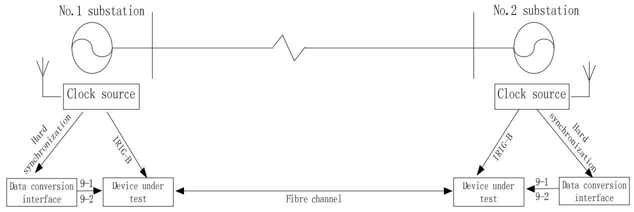

Figure 4 synchronization system

3.3 The overall function test

To further test the system's availability, according to DL/T871-2004 "power system protection product dynamic simulation" , more testing programs are drawn up, including the metal fault inside and outside the zone, the transition resistance failure, the conversion failure, CT saturation, power backward, the system oscillation, the weak-fed and other projects. Hundreds of trials are made to the PCS-931-type optical transmission line differential protection of NR. Experimental results show that the new system is fully in line with the dynamic simulation testing requirements of the digital substation secondary equipments.

The following just to name two cases to illustrate the overall performance of the new system.

Figure 5 is the PCS-931 recorded waveform of N side, simulating the A-phase transient ground fault at F1. The frequency variation, differential protection and Ⅰ segment of earth protection of N side take actions. The protection trips A-phase at 11.3ms and overlaps after 0.4s.

Figure 6 is PCS-931 waveform of N side when the adjacent line has A-phase metallic ground fault. The protection actions have resulted in power backward. A significant phase change of A-phase current occurs, indicating that transmission power of the line has a direction change. The line differential protection has not taken malfunctions because of the power backward. The differential protection of N side has reliable non-actions before or after the power backward.

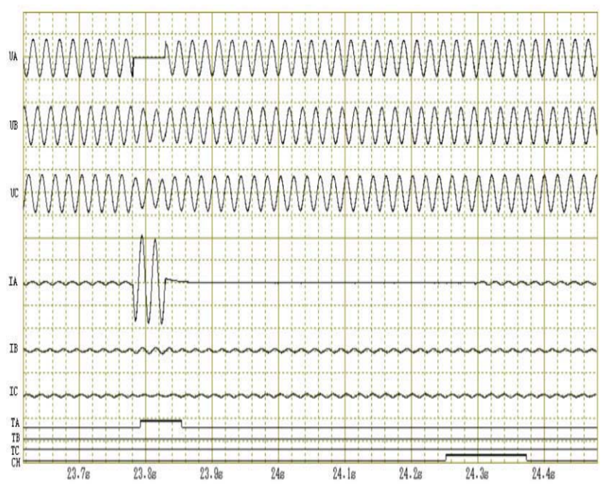

Figure 5 Single-phase transient metal ground fault inside zone

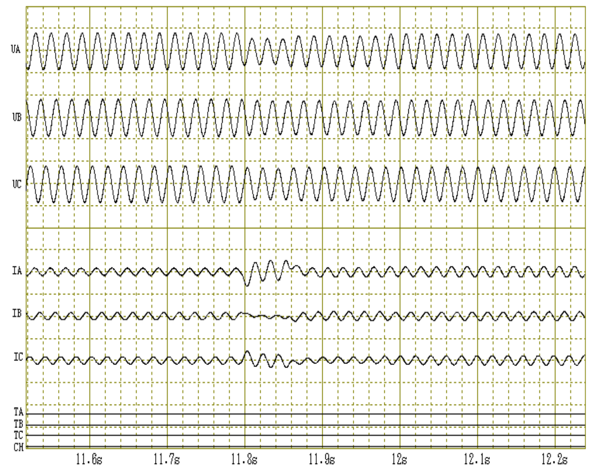

Figure 6 Power backward

To further test the versatility of the new platform, the new platform has been respectively interconnected with the line protection devices from five manufacturers, including NARI-RELAYS, Beijing SiFang, XJ and so on. It can be proved that the new platform can meet the requirements of the closed-loop test for the relays and other related intelligence secondary equipments of mart grid digital substation.

5 Conclusion

To meet the testing needs of digital substation equipments based on IEC61850 communication standard, based on the original ADPSS, by developing the data conversion interface, the closed-loop test of new protection devices has been achieved. The electromagnetic simulation models of 220kV transmission line are established based on the new platform and a large number of simulation tests are carried out depending on the power standards. It has verified the system can provide the necessary secondary characteristics and test environment of digital protections, and has good versatility. The new closed-loop real-time simulation system provides an experimental research tool for the upcoming digital substation building. It has practical value to improving the technical performance and health level of the all-digital protection and other second equipments.

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