Summary of Research on Quality Control Technology of Secondary Equipment Maintenance in Smart Substation

Meizi Hong¹, Hengxuan Li¹, Yongjun Xia¹, Zuowei Wang¹, Zhen’an Du¹, Hong Chen¹, Ke Chen²

¹State Grid Hubei Electric Power Research Institute, Wuhan, China
²State Grid Jingmen Power Supply Company High-tech Zone Power Supply Center, Jingmen, China

Abstract. According to the characteristics of secondary equipment technology of smart substation, the maintenance work specifications and precautions of smart substation are reviewed. The performance inspection methods of various types of solo equipments were analyzed. By comparing each process of solo device specification and the test method of interval group function, the precautions of various aspects of the risk management and control of secondary equipment maintenance were summarized, and the overall principle of specification on secondary equipments of smart substation was proposed.

1. Introduction

The inspection and repair work of the secondary equipments of the smart substation shall be carried out in accordance with the technical characteristics of the equipments, the technical maturity of the commissioning tools, the corresponding technical standards and inspection procedures. Smart substation secondary equipment technical features:

1) System equipment is dispersed in levels and horizontally arranged, and network connections are used between different levels of equipment;
2) According to the system engineering configuration, the individual functions of each IED can be configured and implemented, and the various system functions (or virtual circuits) are mostly realized by multiple links, multiple components or multiple devices;
3) Interval basic function, the device objects are relatively concentrated and can be operated independently at intervals;
4) Sub-system functions, which are implemented vertically based on each interval function;
5) Integrated monitoring function, implemented horizontally based on the subsystem and other sub-functions.

2. Solo equipment performance test

2.1. Merging unit sample value conversion performance inspection

The electronic transformer should be tested with the combined unit as a whole, and the combined unit of the conventional transformer can be tested separately. The verification of combining unit’s SV accuracy/stability of sample values [1-3], accuracy of the conversion delay time, correctness of time synchronization as shown in FIG.1.
Figure 1. Schematic diagram of combined unit detection

Figure (a) is a schematic diagram of the overall inspection of the electronic transformer. The standard transformer and test equipment are used. The standard transformer angle difference is ignored, and the whole conversion process is inspected by one time boost of current / voltage. If the components of the A/D acquisition board and the merging unit related to AC sampling are changed, the overall inspection and adjustment should be performed [4] [5].

Figure (b) is a schematic diagram of the analog quantity merging unit inspection, ignoring the inherent angular difference of the transformer relative to the primary side. The main content and requirements of the merging unit inspection:

1) SV data signal jitter error should be < 10μs , the ratio difference check meets the sampling conversion level requirements;

2) The SV data information carries the delay time constant, which should be consistent with the conversion time difference between the primary side sampling and the SV data signal output, and should be < 2ms ;

3) The calibration error of the SV serial number 0 frame data signal output time and the second pulse 1PPS rising edge should be < 1μs [5] .

2.2. Intelligent terminal performance inspection
The real-time response capability between the intelligent terminal's switch quantity input / output channels and GOOSE can be detected by the SOE test equipment and the interval level device, as shown in Figure 2.
Among them, SOE test equipment can verify intelligent terminal time synchronization and SOE performance. Based on the correct time stamp of the SOE information carried by the smart terminal output GOOSE, the real-time response capability of the smart terminal from the GOOSE information to the DO exit can be verified. The above figure contains the intelligent terminal time synchronization, SOE, DI/DO real-time response capabilities, the main inspection methods and requirements:

1) In the diagram (a), the tester is synchronized with the satellite signal to control the output displacement signal sequence to the intelligent terminal. The intelligent terminal SOE time scale should be consistent with the tester control output timing and timing, and meet the technical requirements that time synchronization 1ms, SOE resolution 2ms [5].

2) In Figure (b), the intelligent terminal operation output is connected to the displacement input, and the GOOSE command is output to the intelligent terminal by the measurement and control operation. The network analyzer can obtain the GOOSE input / output time and SOE time scale of the intelligent terminal, according to which the intelligent terminal DO output response time (should be less than 7ms) is measured.

2.3. Interval layer device function check
The digital test equipment can be used for IED functional inspection, IEC61850 message consistency check, etc., and can also be applied with the IED real-time response performance simulation qualitative inspection. Figure 3 shows the digital simulation inspection model of the interval level IED.
Figure 3. Schematic diagram of digital simulation detection of the spacer device

In the figure, the digital test equipment can simulate multiple merging units, intelligent terminals, and monitoring equipments [5-7].

Figure (a) is mainly for the function inspection of protection and stability device using direct collection and direct jumping mode. It can simulate the SV1 and SV2 outputs of multiple merging units in time synchronization or out-of-synchronization. It can be used to check the correctness of the collection logic and internal interpolation computation of protection equipment. It can also simulate SV1/SV2 faults and GOOSE latching, verify equipment working logic, and qualitatively verify equipment real-time response capability.

FIG. (B) for a network link combining unit, the intelligent terminal type interval layer monitoring and control device, either combined simulation and measurement unit identification function, may also be an intelligent terminal simulation testing interlocking feature, but also the monitoring device to verify the simulation monitoring control function. For the protection and security equipment of the network mining network jump, Figure (b) is also applicable to verify work logic and qualitatively verify real-time response capability[8].

2.4. Time synchronization equipment precision time signal inspection

The substation generally adopts main/standby or redundant mode to configure BD and GPS main clock devices, and uses extended clock devices for clock signal expansion. Substation precision time synchronization signals generally follow IRIG-B, PTP (i.e. IEC61588) and other standards, and adopt independent transmission and Ethernet transmission.

Figure 4 shows the IRIG-B and PTP precision time synchronization signal inspection models of the time synchronization device. Time synchronization test equipment can be used to verify the correctness of each function of the clock device and to inspect the accuracy of the clock signal output and transmission process of each device.
In order to ensure reliable clock signal, the clock device has BD/GPS, master/slave clock tracking, switching, and recovery functions, and the clock device has self-defense and self-recovery functions. In the clock device system structure shown in Figure (a), the inspection of the extended clock device can reflect the accuracy, stability, and switching capability of the master clock, and can also inspect the self-defense and self-recovery capability of the extended clock. Main test content and requirements:

1) BD tracking: BD and GPS signal tracking are effective, and the accuracy of device precision time information output should be better than 1 μs.

2) GPS tracking: disconnecting the BD antenna, the output signal accuracy should be better than 1 μs, and the deviation from 1) should be better than 200 ns.

3) Self-defense: sequentially disconnect the GPS antenna, backup tracking, and main tracking signals, and the output of the device should be better than 0.92 μs/min.

4) Self-recovery: Reverse recovery according to the disconnection steps of 2) and 3) above, the self-recovery process is correct and the accuracy meets the requirements.

For the intermediate process of network transmission in the PTP mode, refer to Figure (b), and verify the correctness of the transmission time information of the switch according to the PTP information network transmission application strategy [5-8].

3. Interval whole group function test

The entire group of IEDs divided by interval, in principle, is a virtual device function of the primary device and the process layer of the interval device, but each function should reflect the overall capability of the IED device (or IED group) it contains.

Figure 5-19 shows the function check of the interval group device, which mainly includes the interval formed by the interval layer device and the process layer device, the input/output channel of...
the primary device, the protection, measurement and control functions, and the corresponding functions of the interval layer public device associated with the interval.

![Diagram](image)

**Figure 5-19 Interval whole performance test**

In this figure, the input / output channel measurement, monitoring, operation, control and other functions of the device connected at intervals can be inspected by the comprehensive-auto-tester; the interval protection and stability function can be tested by the relay tester.

The interval group performance test can mainly include AC channel test, AC synchronous measurement, open / open and interlock check, protection function response, and merge unit time out-of-step test. Specific requirements:

1) AC sampling input inspection: The comprehensive-auto-tester can be used to perform the joint adjustment of the interval layer device and the merging unit. The AC measurement should meet the accuracy requirement of 0.2%, the frequency measurement should meet the accuracy requirements of 0.01 Hz, and the fault recording associated with the input channel. The network display and other devices should display the same results.

2) AC synchronous measurement test: Based on the AC sampling input test, the comprehensive-auto-tester can be used to jointly adjust the interval layer device and the combined unit of differential current and power measurement. The power measurement accuracy should meet the 0.5% technical requirement and the measurement accuracy of differential current should meet the protection function requirements; The results of equipment such as fault wave recording and network analysis should be consistent with the measurement test signal.

3) Opening / opening and interlocking test: The comprehensive-auto-test instrument can be used to joint adjust of the interval layer device and the intelligent terminal to verify the correctness of the interval interlocking logic; The interval layer device operation / test equipment simulation, corresponding opening / The signal should be correct, the SOE resolution should be less than 2ms, and the time-scale error should be less than 1ms. The test operation is opened and the test equipment is simulated, and the associated fault recording, network analysis and other equipment respond correctly.

4) Protection / Annual function response test: The relay protection tester (or comprehensive-auto-tester) can be used to simulate the fault signal (or automatic signal condition) to the merging unit AC input terminal, and the merging unit is protected / installed by the unit. To the smart terminal open end, the overall protection function joint test. The interval of the whole set of protection and the far-end
fault response time should be better than 20ms and 30ms respectively, and the self-function can meet
the requirements.

5) Consolidation unit time out-of-synchronization test: The test equipment keeps the output stable,
before and after the disconnection of the merging unit time synchronization signal and restarting to
normal sampling, the measured value and phase difference angle of the interval protection device
should be consistent, and the protection function exception should not occurs because of the recovery
of the time synchronization signal of merging unit [5].

4. Secondary equipment maintenance risk management
In order to ensure the safety and high quality of the relay protection and maintenance work of the
smart substation, standard operations on the site are standardized, and the operation safety risk
management and control is realized. The site survey, construction plan preparation, operation
instruction book preparation, risk assessment and pre-control, operation process, Technical measures
for risk control are proposed throughout the whole process of operation termination and supervision
and assessment.

(1) Site survey
Before surveying, the survey personnel should know the work content, query the equipment
drawings, status evaluation, equipment defects, etc. in advance, and be familiar with and master the
relevant situation of the survey objects. During the survey, it is necessary to focus on understanding
the operation status of the equipment, check whether the equipment operation status, drawing
materials, material materials, working environment, etc. meet the operational needs, and analyze the
various dangerous points and propose pre-control measures. After the survey is completed, a written
site survey form shall be formed.

(2) Construction plan preparation
For large-scale, high-risk, high technological requirements maintenance operations, and other
maintenance work need the construction plan, the work unit is required to prepare the construction
plan, detailed arrangements of detailed work process, group organization and technical support
measures related content, and strictly implement the grading approval procedures.

(3) Compile of work instructions
A site standardization work instruction system covering all inspection levels and test items should
be compiled, and ensure that the work instructions meet the on-site construction work requirements.

(4) Risk assessment and pre-control
The maintenance unit shall, based on the risk assessment situation, carry out, organize and
implement the corresponding operational risk pre-control work in conjunction with its own work.

(5) Operation process
We will conscientiously implement various measures to ensure safety, confirm various dangerous
points and safety control measures, and conscientiously implement the relevant requirements of the
on-site standardization operation instructions to ensure safe, efficient and high-quality completion of
on-site work [5-8].

5. Conclusion
Based on the technical characteristics of secondary equipment of smart substation and the standardized
secondary system technical documents of national, industry and State-Grid, this paper analyzes the
performance inspection methods of various types of solo equipment and the test methods of interval
whole group functions, summarizes the precautions in all aspects of risk management and control
of secondary equipment maintenance and has certain guiding significance for the quality improvement
of secondary equipment maintenance of smart substation.

References
[1] Yang Fei. Analysis of intelligent substation relay protection detection and debugging
technology [J]. Science and Technology & Innovation, 2019 (15): 79-80.
[2] Liu Zhigang, Zhang Feng, Li Yao, Wang Kexin, Xie Zhanyin. Discussion on Detection and Debugging Technology of Relay Protection in Intelligent Substation [J]. Automation & Instrumentation, 2019 (5): 183-186.

[3] Yu Jing, Xin Pengfei. Thoughts on the Contents of Relay Protection and Maintenance of Intelligent Substation and the Implementation of Ancuo [J]. Shandong Industrial Technology, 2018 (12): 185.

[4] Huang Hua. Intelligent Substation Relay Protection Detection and Its Debugging [J]. Low Carbon World, 2016 (35): 81-82.

[5] QGDW11145-2014 Standardized Site Commissioning Specification For Secondary System In Smart Substation [S].

[6] Gen Hongjie. Research on Detection Method of Relay Protection Device Based on Intelligent Substation [J]. Electronics World, 2018 (19): 69-71.

[7] Liang Zhihua. Analysis of intelligent substation relay protection detection and debugging [J]. Electronics World, 2017 (18): 181.

[8] Fan Yi, Qiu Yanzhuang. Intelligent substation relay protection automatic detection method [J]. Technology Innovation and Application, 2016 (26): 158.