COMPARISON OF TESTING AND COMMISSIONING ACTIVITIES IN TRADITIONAL AND DIGITIZED SUBSTATION PROTECTION AND CONTROL SYSTEMS

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ABSTRACT

Modern communication standards and techniques are the way forward in the simplification and improvements of today's protection application. Different communication services in IEC 61850 standard Ethernet based station bus enable possibility to simplify the design of the medium voltage switchgear. This paper discusses the factors related to testing and commissioning works of protection and control systems on a primary distribution substation in case of traditional or fully digitalized application. With practical approach to the issue, differences in the actual testing works between the two scenarios during different test phases will be presented.

INTRODUCTION

Introduction of Ethernet communication media and IEC 61850 power utility automation standard to medium voltage switchgear has imposed new challenge to the protection and control design, engineering and testing. In this paper we consider the implications of the new technology to testing aspect.

Testing of switchgear is integral part of the switchgear delivery and maintenance. Without it the functionality of protection and control application is not ensured through the life-cycle of the switchgear. Testing is needed regardless whether switchgear is conventional or digital. Digital switchgear means in this paper a switchgear design where IEC 61850 communication services such as GOOSE and 9-2 are used for protection and control applications as far as possible omitting need of conventional bus wiring between switchgear cubicles [1].

TESTING RELATED FEATURES IN IEC 61850

IEC 61850 offers several features and functionality related to testing of protection relays. Intention of these is to help user with testing activities when signals are sent digitally in Ethernet based station bus instead of traditional signaling using hard-wiring [2]. Following describes two most commonly referred features.

Protection relay according the standard has modelling for mode which can have values: on, test, test-blocked and off. Test mode can be used to isolate part of the system for testing. For example relay in test mode sends GOOSE and 9-2 messages with information whether function is set to test mode. In case receiving peer relay is not in test mode the received data is not processed (Figure 1).

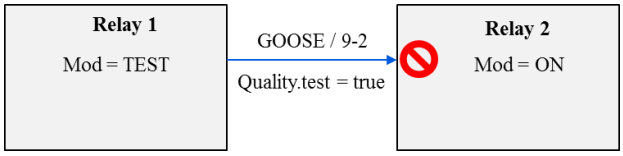

Figure 1. IEC 61850 mode handling in protection relay

Another feature available in standard is for the protection relay the possibility to subscribe GOOSE or 9-2 messages from a relay test set working as digital simulator. This is accomplished by switching the relay to receive messages from relay test set instead of actual publisher. Relay test set needs in this case to mark the messages with Simulation flag active (Figure 2).

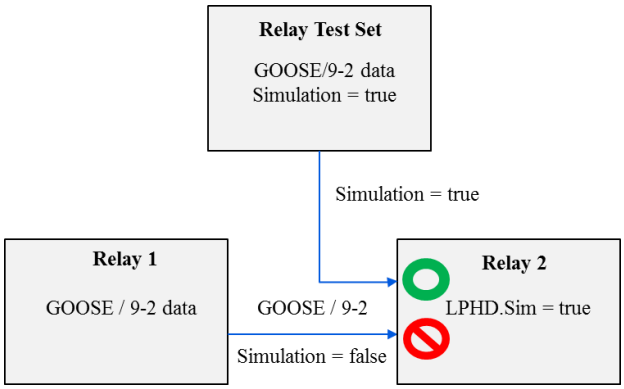

Figure 2. Simulation according IEC 61850

REFERENCE INSTALLATION

The reference installation is a medium voltage indoor air insulated metal enclosed switchgear (AIS). In order to limit our reference scope, this paper concentrates on two applications from the perspective of cubicles J1 and J2 in used example switchgear. The applications are directional overcurrent protection (DOC) and busbar earthing switch (+J1-Q9) interlocking scheme (Figure 3).

The directional overcurrent protection is a function of the feeder protection relay (+J2-A2). The DOC protection measures feeder currents locally and receives the polarizing voltage from a measurement point in the busbar.

The busbar earthing switch interlocking scheme drives the electromechanical coil within the manual operation device of the earthing switch. Once the coil is energized, it will enable the manual closing operation of the switch. Two conditions are set for the interlocking scheme. Firstly, all circuit breaker trucks have to in "Test" (withdrawn from service position but still within the cubicle) before the closing of the busbar earthing switch is enabled. Secondly, once the earthing switch is closed moving of the circuit breaker trucks is disabled.

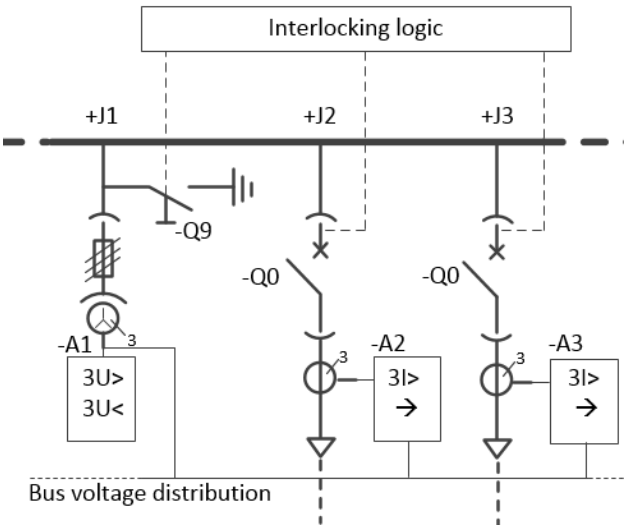

Figure 3. Reference application with bus voltage sharing and interlocking using hard-wired signals.

DIFFERENT PHASES IN TESTING

To better facilitate discussion on the paper's topic, the different testing phases have been divided into five; panel testing, panel line-up testing, pre-commissioning testing, commissioning testing and periodical testing. Very commonly used terms in this context are also Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT). Typically testing activities under terms FAT and SAT contain certain level of commercial contractual drivers, like certain percentage of the total contract amount is payable after successful passing of defined acceptance tests. The listed acceptance tests greatly vary from case to case and might, or might not, include technically relevant ones. The approach of this paper is purely technical and therefore terms FAT and SAT are not referred to [3].

The following discussion is limited to the above mentioned functionalities and the devices related to those. A complete switchgear testing includes numerous other activities which are not discussed here.

Panel Testing

Switchgear status

The installation and wiring works within the low voltage compartment has been finalized. The compartment is ready for panel testing.

Target of the testing

During this testing phase the wiring between the protection relay and other devices within the panel are tested. Target is to confirm that the wiring in low voltage compartment has been done according to the design.

Testing method in conventional switchgear

Basic conductivity testing equipment like a "beeper" or a multi-meter. With some protection relays also specific testing facilities are provided to verify the binary connections to and from the relay. At this point the switchgear's primary circuitry is not available yet, thus analogue connections to the measurement transformers cannot be verified.

Testing method in digital switchgear

As the analogue connections are not yet available and the communication network components are not energized, there is no additional testing related to digital connections in this phase. IEC 61850 station bus is not available.

Panel Line-up Testing

Switchgear status

Complete switchgear panels are placed in a row and secondary wiring connections between the panels (bus wires) are in place. The primary circuitry is complete per each panel, but typically the primary busbar connectors between the panels are not installed. Auxiliary power for the secondary circuits is connected and the relays are fully programmed. Ethernet station bus in switchgear is up and running.

Target of the testing

During the testing the analogue circuitry within the panel, as well as between the panels, is tested. Correct phasing and ratio of the measurement transformers is verified along with the connected protection core performance data. The mechanical operation of the busbar earthing switch together with its' electrical interlocking coil circuitry is checked. The mechanical operation of the circuit breaker truck together with its' electrical interlocking circuitry is checked.

After the basic circuitry and mechanical functionality testing is performed, the scheme testing can start. During the scheme testing target is to simulate the requested scheme performance as close to the actual usage as possible. Final protection relay parameter values are not necessarily available.

For the interlocking scheme this means testing the

performance with different position combinations of the busbar earthing switch and the circuit breaker trucks. For the DOC protection the testing continues by feeding current to the current transformer secondary side using terminals in the low voltage cabinet of the feeder +J2. Simultaneously the polarizing voltage signal is feed to the secondary side of the voltage transformers at the bus voltage measurement point +J01. The relay protection characteristic and relay output signaling is verified, including circuit breaker +J2-Q0 tripping action.

Testing method in conventional switchgear
Operating the primary equipment in a predefined sequence. Secondary injection of current and voltage signals with a relay test set.

Testing method in digital switchgear
As the target of this testing phase is to also test the analogue circuitry and measurement chain the testing is done just like with conventional switchgear. In case of voltage sharing with IEC 61850-9-2 the injected secondary voltage is shared by the relay +J1–A1. Interlocking is tested by operating primary equipment like in conventional case.

In this phase it could be possible to simulate digitally, with relay test set, the bus voltage reference with 9-2 and GOOSE based interlocking signals. However, the drawback is that then it is deviating more from switchgear normal service conditions and some faults can remain unnoticed.

Pre-commissioning testing

Switchgear status
The switchgear installation at site is completed. All the internal and external wiring is done and auxiliary power connected. The protection relays are parametrized with the final project specific parameters. Possible upper level systems are connected and ready to exchange signals.

Target of the testing
Target of the testing is to verify that the installation works at site have been done correctly and the equipment have not suffered damages. Interlocking testing is done as in panel line-up testing phase. With the DOC protection, additional target is to verify that the project specific setting parameters are entered correctly and the resulting protection characteristic is in accordance to the requirement. Also connections and correct signaling to an upper level, for example to a SCADA, system(s) are verified.

Testing method in conventional switchgear
Operating the primary equipment in a predefined sequence. Secondary injection of current and voltage signals with a relay test set. Signal verification in upper level system(s).

Testing method in digital switchgear
In this phase it could be possible to simulate with IEC 61850-9-2 test set the bus voltage reference. However, to make sure that the switchgear works as a complete system the testing method needs to cover the whole measurement chain. Methods are therefore the same as in conventional switchgear.

Commissioning testing

Switchgear status
The switchgear has successfully passed earlier testing phases and is ready to be energized and to carry load.

Target of the testing
Target of this testing phase is to ensure the testing results of voltage and current measurement circuitry with live primary circuit. Once the busbar and the feeder +J2 are energized, measurements to verify voltage transformers ratio in +J1-A1 and correct phase order in +J2-A2 are carried out. The test will continue by loading the feeder +J2. While the load current flowing, the current transformer ratio will be reconfirmed and the actual measurement direction of the DOC protection checked against the requested settings. Interlocking is not typically required to be tested separately in this testing phase.

Testing method in conventional switchgear
With primary voltage applied, stepwise loading of the feeders while carrying out predefined observations and measurements in the secondary circuitry.

Testing method in digital switchgear
As the testing is based on actual loads from the primary circuitry the testing is the same as for conventional switchgear.

Periodical testing

Switchgear status
The switchgear is energized and carrying load that is under commercial operation. One feeder/cubicle at a time is taken out of service for the periodical testing, while the other feeders and their related service will remain in full operation. When a feeder is taken out of operation, the circuit breaker is opened and the circuit breaker truck is moved to test position.

Target of the testing
Target is to verify the feeder's capability to sense, disconnect and report a primary fault situation correctly and within the specified time window. For DOC protection this means that the measurement chain, relay's internal processes and circuit breaker operation mechanism have to be fully operational. Typically the testing is carried out using secondary injection method resulting circuit breaker operation in test position. While the other parts of the switchgear are in use, the secondary voltage injection point has to be disconnected from the measurement bus wires.

Usually interlocking is not tested in periodical testing phase as only one cubicle at a time is under testing. Failures in interlocking schemes are detected under normal operation because interlocking circuit should be designed in a fail-safe way.

Testing method in conventional switchgear

Cubicle wise secondary injection testing with relay test set. Circuit breaker is in test position and all the primary compartment doors closed. The test results are recorded and compared to the results of earlier tests. Outcome can vary between "in fully operational condition", "need for maintenance foreseen, not urgent" or "immediate actions required before returning to commercial service".

Testing method in digital switchgear

Periodical testing is the only phase where testing differs a bit in the digital switchgear. In addition to the voltage injection location the test method in this phase is the same as for conventional switchgear. Because the voltage is shared from +J1-A1 also to the +J3–A3 which is under normal service, we cannot do the secondary injection to +J1–A1. Instead the relay test set needs to have capability to send digitally voltages either directly to relay +J2–A2 Ethernet port or via station bus, e.g. connecting to Ethernet switch. It is also possible to simulate and test the interlocking signals with the relay test set.

In case relay test set is connected directly to the relay rear port the relay under test is isolated from rest of the system and it is not communicating anymore with other relays. Rest of the switchgear continues active operation. Relay test set sends 9-2 and possibly also GOOSE messages in normal mode, in other words, relay is not necessarily set to Test mode and it does not have to expect simulated 9-2 or GOOSE messages from relay test set (Figure 4).

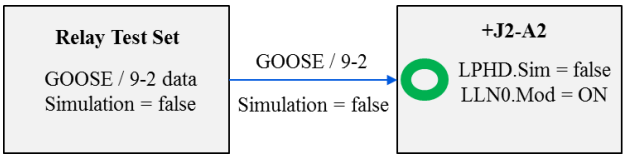

Figure 4. Periodical relay testing by connecting test set directly to the relay.

When periodical testing of a relay in digital switchgear is executed by connecting the relay test set to IEC 61850 communication bus, the testing is not physically isolated from system in service. This means tested part must be isolated logically using IEC 61850 features. When starting the test, the user must activate the simulation feature from relay test set and switch the relay to use the simulated 9-2 and possible GOOSE messages as well. Additionally the relay under test is set to IEC 61850 test-mode in which case other relays are not using the signals which the relay under test is possibly activating during testing (Figure 5).

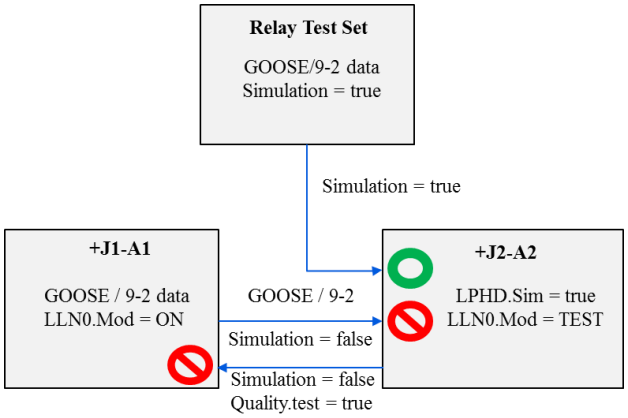

Figure 5. Periodical testing connecting relay test set to IEC 61850 communication bus

Connecting the relay test set directly to relay has the benefit that the relay under testing can remain under its normal operation mode thus ensuring that the testing case is as close as possible to commercial operation.

FAULT FINDING AND SOLVING

Fault fixing is part of the testing and it has two main parts; identifying the fault root cause and correcting it. Full installation documentation forms an integral and important part of this work. Without proper and up-to-date documentation the task is unnecessarily complicated. Table 1 lists the needed documents in conventional switchgear and their role.

In digital switchgear exactly the same documents are still needed as there are always some wiring involved, either physical or over digital communication. In addition to the circuit diagram and wiring table, the digital connections needs to be documented separately. IEC 61850 signal matrix and the signal usage in the relay application are just another way to represent the circuitry and wiring between different components in the system.

Document	Description	Purpose
Single line diagram	Complete system wise. Describes the primary circuitry.	Orientation within the complete system
Principal functional diagram	Complete sub-system wise. Describes a sub-system from functionality perspective. Forms a bridge between single line and circuit diagrams.	For understanding the subsystem functionality on a principal level

Circuit diagram	Cubicle wise. Can be divided into sub-sets as per functionality.	For understanding functionality on a detailed level. Describes involved cubicles, devices and terminals, including their full identification with physical location reference
Wiring table	Cubicle wise.	Details of the wiring, provides means to locate a dedicated wire within the actual installation.

Table 1. Typical documents involved in switchgear delivery.

Problem solving in digital switchgear doesn't generally differ from the conventional switchgear. Key item for fault locating is still the principal functional diagram, which gives understanding of the switchgear behavior. After the functionality of the switchgear is clear the fault solving in both cases is locating the misbehaving logical connection and fixing it either by altering physical wiring or changing the digital connection.

CONCLUSION

In every testing phase it is important to imitate the switchgear's final service conditions as far as possible. This is why the traditional secondary injection of the currents and voltages is a good way to test also the digital switchgears. Also the fault finding and solving starts by isolating the problematic parts using principal functional diagrams to understand the logical functionality of the switchgear. In case of IEC 61850 the principles are similar with conventional switchgear but the used tools for fault solving might differ.

For described test phases, the biggest difference between conventional and digital switchgear testing is in periodical testing. In case of digital switchgear and isolating the relay under test IEC 61850 gives possibilities to connect relay test set to system. However, connecting the relay test set directly to relay has the benefit that the relay under testing can remain under its normal operation mode thus ensuring the testing case is as close as possible to commercial operation.

IEC 61850 digital switchgear introduces new possibilities for testing but the conclusion is that it is fully possible to sustain known good testing practices without extensive knowledge on the IEC 61850 standard.

REFERENCES

[1] J. Starck, W. Wimmer, K. Majer, 2013, *"Switchgear optimization using IEC 61850-9-2"*, CIRED, Stockholm.

[2] C. Brunner, R. Hughes, 2011, *IEC 61850 Edition 2 – what does it mean for end user*, SEAPAC, Sydney

[3] W. Baass, KP. Brand, S. Gerspach, 2008, *"Exploiting the IEC 61850 potential for new testing and maintenance strategies"*, CIGRE, Paris.