Remote Maintenance Testing of Protection Devices and Schemes – Why We Need It and How We Can Do It?

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1 Introduction

The transition of the electric power industry towards a smarter grid is characterized with significant efforts to improve the efficiency in performing all tasks and reducing the duration of outages in case of events related to the operation of multifunctional protection IEDs. The wide spread implementation of IEC 61850 based substation protection and the increased interest in digital substations based on the sampled values interface with the substation process is providing an opportunity to develop and implement protection, automation and control systems that can be tested remotely.

The testing of hardwired protection and control systems requires a crew to drive to (in many cases) a remote location to perform maintenance testing. Replacing the hard wired interfaces with IEC 61850 based communications interfaces allows remote access to the substation for remote testing.

The replacement of part or all of the hardwired interfaces with communication links requires the development and implementation of methods and tools that maintain the same level of security during the testing process, while at the same time take advantage of all the benefits that IEC 61850 provides.

The paper first introduces the definitions of maintenance testing and remote testing and answers the question "Why do we need remote testing?" It then describes the principle requirement for isolation of IEDs from the point of view of the maintenance testing in an energized substation - related to the testing of a specific function element, a local protection scheme or a distributed function are discussed. The specialists involved in the testing of protection, automation and control schemes are used to a physical isolation of the test object based on the use of test switches that allow on one hand to open the circuit that trips the breaker and at the same time to replace the analog signals from the secondary of the current and voltage transformers with signals coming from the test equipment.

The second half of the paper describes the features in Edition 2 of IEC 61850 that can be used for virtual isolation of components of the protection scheme.

The last part of the paper discusses the methods and tools that can be used to perform the testing based on the IEC 61850 Ed. 2 definitions and how they meet the requirements for virtual isolation from a practical point of view. The benefits and challenges related to remote testing of IEC 61850 communications based protection, automation and control IEDs and schemes are summarized at the end of the paper.

2 Remote Maintenance Testing

One of the key requirements for correct maintenance testing is the reason for the test. Maintenance testing in general is that testing which is performed to diagnose and identify equipment problems or confirm that different actions taken to change settings, upgrade or repair the protection device or another component of the fault clearing system have been effective. The tests to be included in the maintenance test will depend on which of the listed above measures have been implemented.

2.1 Maintenance Testing in Case of Incorrect Protection System Operation

Problems of the different elements of the fault clearing system can be of two main types – if the system does not operate when it has to and if it operates when it should not. These two types of problems are usually detected when the system is in service and an event occurs. The operation needs to be analyzed in order to determine the reason and take some corrective action to prevent future incorrect operation of the system.

2.2 Failure to operate

The main role of a protection relay is to detect when a fault occurs in the electric power system and to take the necessary actions to clear the fault by disconnecting the faulty equipment from the rest of the system. In some cases, such as transmission line or distribution feeder faults of temporary nature the protection system may also attempt to restore the pre-fault system topology using autoreclosing functions.

Failure to operate under fault conditions may have severe impact on the stability of the electric power system due to the increased duration of the fault caused by the operation of backup protection functions and the switching-off of healthy system components.

2.3 Undesired operation

As many system disturbances and blackouts have shown, one of their main causes have been operations of the protection system under non-fault conditions. These failures also need to be prevented since they may also have a negative impact on the stability of the electric power system and result in deterioration of the conditions and a wide area disturbance.

2.3.1 Maintenance testing requirements in case of incorrect operation

The maintenance testing in case of incorrect operation are of two types:

- tests used to determine the reason for the operation
- tests used to confirm that a required corrective action has been successfully implemented

Determining the reason for the incorrect operation is typically done using as a first step replay of waveform records available from the relay itself or from other recording equipment at the substation. The second method is preferred for several reasons:

- the record in the failed relay may be affected by the failure of the device itself or a component of the fault clearing system – for example instrument transformers or the wiring between them and the relay
- the sampling rate of the recording by the relay may be too low which will not correctly represent the abnormal system condition

In some cases comparison of the recording from the relay that operated incorrectly and the record from another device can indicate the reason for the operation and which component of the system has failed.

After the reason for the incorrect operation has been determined, a corrective action is required, followed by maintenance testing to ensure that the measure has been successful. The maintenance tests in this case can be based on replay of the same files used to determine the cause of the incorrect operation, or some other tests to verify changes in settings or programmable scheme logic.

2.4 Remote testing requirements and benefits

One of the benefits of digital substations is that all devices (PAC IEDs, substation computers and test devices) are connected to the substation communications network. If there are testing tools that are connected to the network in the substation on a permanent basis, it becomes possible to perform the tests from a remote location. This can be useful in many cases:

- long distance between the substation and the base of the test staff team
- difficult terrain with bad roads
- difficult weather conditions
- requirements for reduction of outage time because of maintenance

In order to be able to perform remote testing the system needs to meet the following requirements:

- Analog and digital interfaces between the process and the protection, automation and control system are communications based (IEC 61850 sampled values and GOOSE)
- Support of virtual isolation of test objects
- Remote secured access to the substation's test system

3 Requirements for Isolation During Testing

The requirements for isolation depend mainly on what is being tested and the purpose of the test. In the sections below we will highlight in which cases the test should be performed using normal operating configuration and when we should use the different operating modes that support virtual isolation.

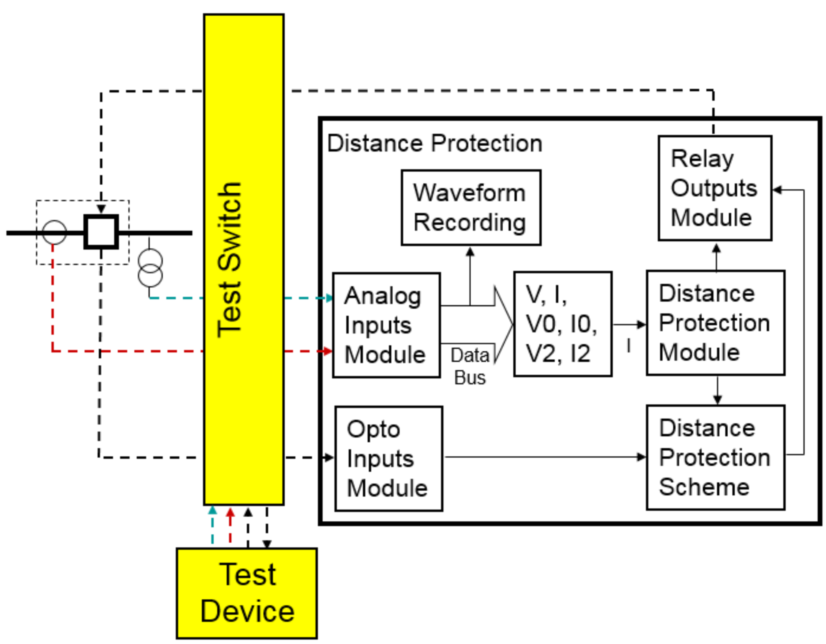

Figure 1: Physical isolation for testing

The requirements for functional testing of devices and distributed functions also determine the methods for testing of both types of systems are proposed based on the following order of system components tests:

- Functional testing of individual IEDs used in the scheme
- Functional testing of distributed functions within a substation

In conventional hardwired protection devices the isolation is physical (Figure 1) using a test switch that completely disconnects the tested device from the substation environment.

In an IEC 61850 based digital substation the physical isolation is not possible, so it is necessary to implements the test related features defined in the standard.

4 IEC 61850 Edition 2 Testing Related Features

In order to support the testing of IEC 61850 system components in energized substations, Edition 1 of the standard already had many different features that could be used for testing. These features included:

- The possibility to put a function or a functional element (logical nodes or logical devices) in a test mode
- The possibility to characterize a GOOSE message as a message being sent for test purpose
- The possibility to characterize a service of the control model as being sent for test purpose
- The possibility to flag any value sent from a server in the quality as a value for test purpose

However, Edition 1 was not very specific on how to use these features. As a consequence, they were not supported by all vendors since interoperability could not be guaranteed.

This has been improved with Edition 2. Besides more detailed specifications on how to use the existing features, additional features have been added.

4.1 Test mode of a function

A logical node or a logical device can be put in test mode using the data object **Mod** of the LN or of LLN0. The behavior is explained in Figure 2 and Figure 3. A command to operate can be either initiated by a control operation or by a GOOSE message that is interpreted by the subscriber as a command. If the command is initiated with the test flag set to FALSE, it will only be executed if the function (LN or logical device) is "ON". If the device is set to test more, it will not execute the command (Figure 2).

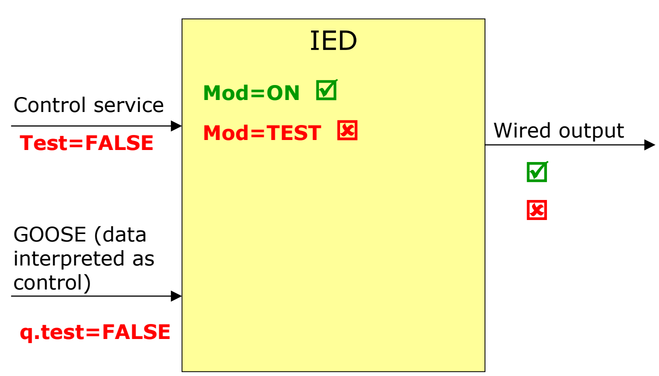

Figure 2: Command with Test=FALSE

If the command is initiated with the test flag set to TRUE, it will not be executed, if the function is "ON". If the function is "TEST", the command will be executed and a wired output (e.g. a trip signal to a breaker) will be generated. If the function is set to "TEST-BLOCKED", the command will be processed; all the reactions (e.g. sending a command confirmation) will be produced, but no wired output to the process will be activated (Figure 3). The mode "TEST-BLOCKED" is particularly useful while performing tests with a device connected to the process.

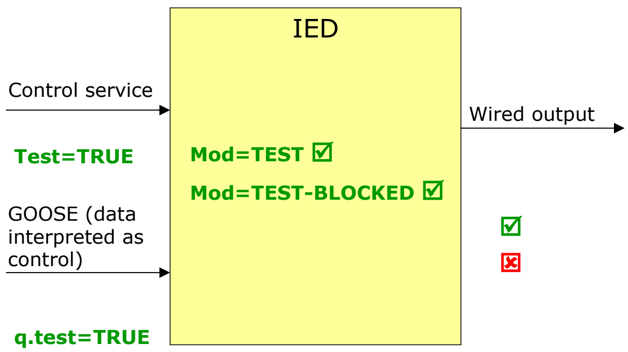

Figure 3: Command with Test=TRUE

4.2 Simulation of messages

Another feature that has been added to Edition 2 is the possibility, to subscribe to GOOSE messages or sampled value messages from simulation or test equipment. The approach is explained in Figure 3. GOOSE or sampled value messages have a flag indicating if the message is the original message or if it is a message produced by a simulation. On the other side, the IED has in the logical node LPHD (the logical node for the physical device or IED) a data object defining, if the IED shall receive the original GOOSE or sampled value messages or simulated ones. If the data object Sim is set to TRUE, the IED will receive for all GOOSE messages it is subscribing the ones with the simulation flag set to TRUE. If for a specific GOOSE message no simulated message exists, it will continue to receive the original message. That feature can only be activated for the whole IED, since the IED shall receive either the simulated message or the original message. Receiving both messages at the same time would create a different load situation and therefore create wrong test results.

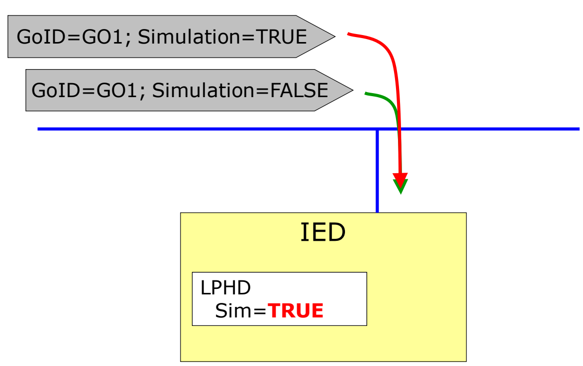

Figure 4: Simulation of a GOOSE message

4.3 Mirroring control information

A third feature that has been added is the mirroring of control information. This supports the possibility, to test and measure the performance of a control operation while the device is connected to the system.

A control command is applied to a controllable data object. As soon as a command has been received, the device shall activate the data attribute opRcvd. The device shall then process the command. If the command is accepted, the data attribute opOk shall be activated with the same timing (e.g. pulse length) of the wired output. The data attribute tOpOk shall be the time stamp of the wired output and opOk.

These data attributes are produced independently if the wired output is produced or not – the wired output shall not be produced if the function is in mode TEST-BLOCKED. They allow therefore an evaluation of the function including the performance without producing an output.

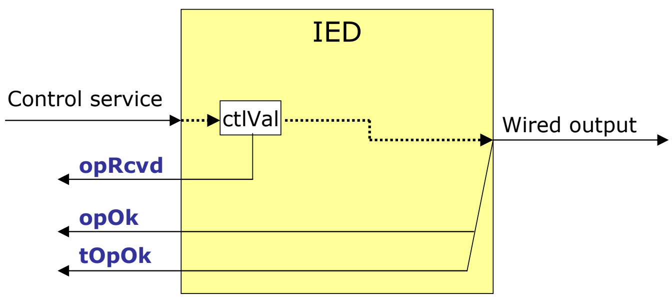

Figure 5: Mirroring of control information

4.4 Isolating and testing a device in the system

Combining the mechanisms described in the previous sections, it is possible to test a device that is connected to the system. We will explain that with a short example.

Let's assume we want to test the performance of a main 1 protection that receives sampled values from a merging unit. In the LN LPHD of the main 1 protection relay, the data object Sim shall be set to TRUE, the logical device for the protection function shall be set to the mode "TEST" and the logical node XCBR as interface to the circuit breaker shall be set to the mode "TEST-BLOCKED". A test device shall send sampled values with the same identification as the ones normally received by the protection relay but with the Simulation flag set to TRUE.

The protection device will now receive the sampled values from the test device and will initiate a trip. The XCBR will receive and process that trip; however no output will be generated. The output can be verified through the data attribute XCBR.Pos.opOk and the timing can be measured through the data attribute XCBR.Pos.tOpOk.

4.5 Advanced simulation possibilities

Finally, enhanced simulation possibilities that can be used for functional testing have been added. The concept is explained in Figure 6. As described earlier, with Edition 2, the possibility do describe references to inputs of a logical node has been added. This is done through multiple instances of data objects **InRef** of the CDC ORG. That data object has two data attributes providing object references: one as a reference to the object normally used as input; the other one as a reference to a data object used for testing. By activating the data attribute **tstEna**, the function realized in the LN shall use the data object referred to by the test reference as input instead of the data object used for normal operation.

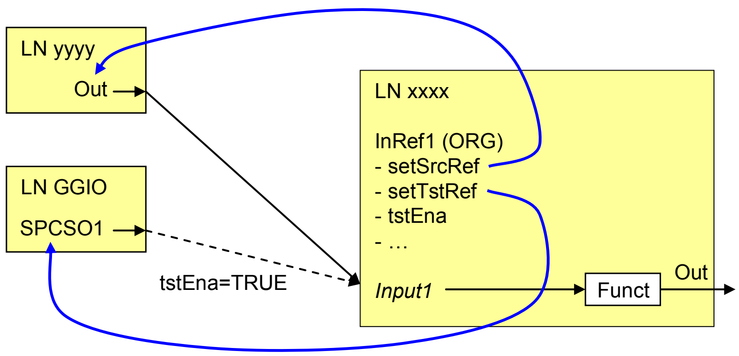

Figure 6: Simulated inputs

With that feature, it is as an example possible to test a logic function like a interlocking function. Instead of taking the real position indications of the different switches as inputs, the logical node (in that case CILO), can be set to use inputs from e.g. a logical node GGIO. A test application can now easily modify the different data objects of the LN GGIO to simulate the test patterns that shall be verified. That logical node can be external (the data objects being received through GOOSE messages) or it can be implemented in the IED itself for testing support.

Note that while that method allows a detailed functional testing with individually simulated inputs, it may not necessarily be used for performance testing. Since individual inputs are switched, that may change the situation concerning the GOOSE messages to be subscribed in order to receive the new inputs and therefore, the dynamic behavior may be changed.

4.6 Service tracking

While tracking of events in the application process was already possible in Edition 1 by logging or reporting of function related data that was not the case for events in the communication.

For that purpose, the concept of service tracking has been added to Edition 2. For that purpose, a data object instance has been defined for each kind of service, which mirrors the values of the service parameters. That data object can be included in a dataset for logging or reporting.

5 Testing Tools Requirements

It is clear from the previous sections of the paper that the testing tools need to support the requirements for all the different types of test described earlier.

There are two types of tools:

- Hardware – the different test devices that generate analog signals or communications messages as required by the application
- Software – the different software tools that are used for specific types of test, test configuration, power system conditions simulation, test assessment and documentation

To support the virtual isolation, the test devices should be configurable to operate in a “normal” operating mode, i.e. by sending messages with all test mode related data objects and attributes set to False. As described earlier, these will be all use cases when there is no need for virtual isolation.

In cases like maintenance testing or commissioning of new bay protection and control schemes in an energized substation, the test equipment should send messages with the simulation bit or test bit set to True, in order to prevent undesired tripping of circuit breakers.

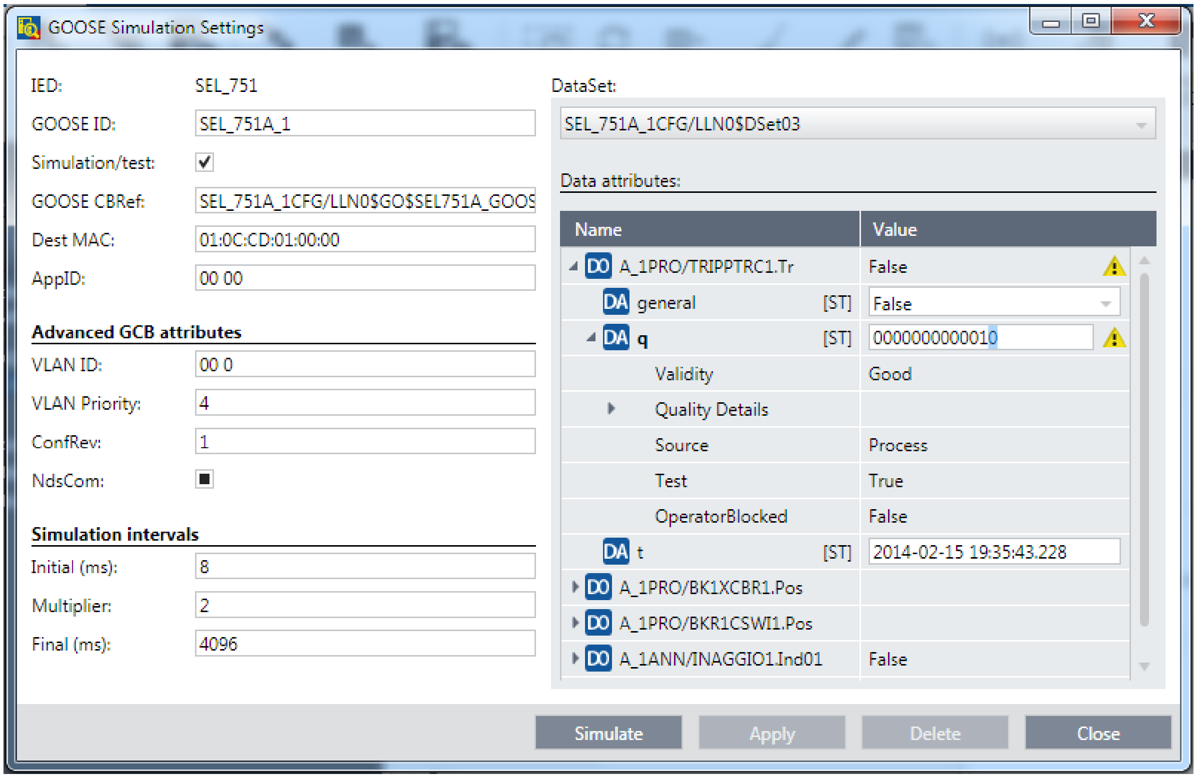

Figure 7: Virtual isolation test configuration

The remote testing concept can be implemented using different methods. One of these options is shown in Figure 8.

The test system in the remote substation includes several components:

- Test computer which runs the testing software supporting IEC 61850 Edition 2 testing features and the required functional testing tools
- Test devices performing simulation and evaluation of the results from each test

The interface to the test computer is over a private cloud and requires the use of cybersecurity technology available for remote access from the engineering station by an authorized and authenticated user.

The test engineer and technician accesses the test computer in the remote substation using a remote control tool with advanced cyber security features.

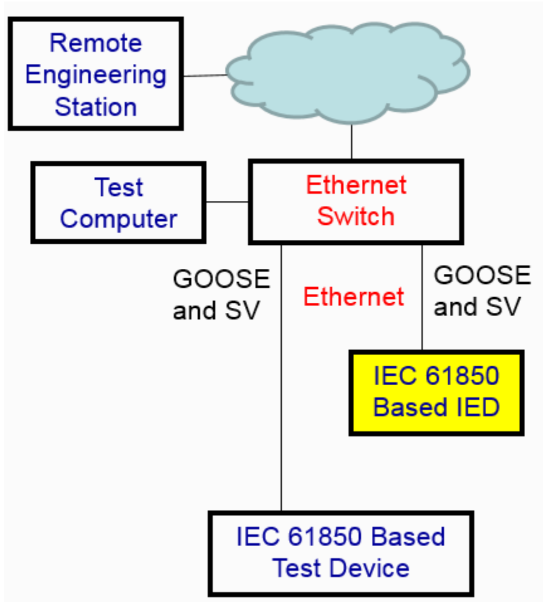

Figure 8: Remote test system

Depending on the requirements for the test defined by the type of maintenance testing that needs to be performed the logical nodes, logical devices or complete IEDs are set in the required mode in order to ensure their virtual isolation.

6 Conclusions

Edition 2 of IEC 61850 introduced many new features that further enhance the power of the standard.

There are new features that should make the life of the end user easier – assuming the features are supported by future products. They are designed to support not only automated configuration and execution of test procedures, but also remote testing for some specific test cases.

Using remote testing by controlling the test system in a remote substation from the convenience of the engineering office brings significant benefits by improving efficiency and safety, as well as reducing outage times.