Testing the Protection System in IEC 61850 Communication Based Substations

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Abstract -- **This paper describes the possible testing scenarios for commissioning IEC 61850 based substations. The paper presents the testing functionalities proposed by Edition 2 of the standard and discusses its impacts on current testing procedures for conventional substations. The paper gives special emphasis to the new testing methods and testing tool requirements needed for this application.**

Index Terms – IEC 61850, GOOSE, Sampled Values, Substation Automation, Protection System Testing

I. INTRODUCTION

The IEC 61850 international standard for power utility communications defines not only protocols but data models for substation equipment, abstract communication services and a standard format to represent the system's configuration, called Substation Configuration Language (SCL). In relation to communication services, the standard defines basically three classes of communication to be used for substation protection, control and automation: Client/Server, GOOSE and Sampled Values.

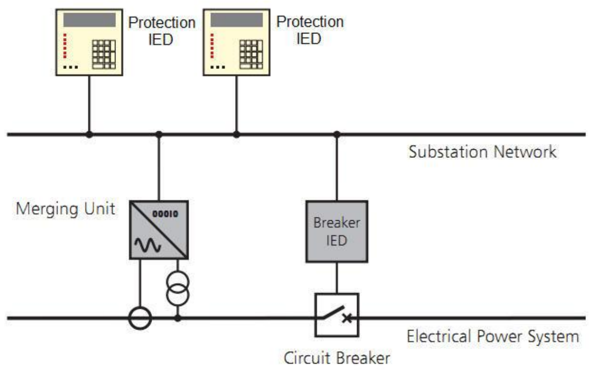
The Client/Server represents the services used by a Client to retrieve information and send control operations from/to Intelligent Electronic Devices (IED) Servers, forming a typical SCADA system for supervising and controlling the substation. For implementation of such communication services, the part 8-1 of the standard defines the mapping and use of the MMS protocol.

An alternative communication method defined is the GOOSE message. It is used for the fast and reliable exchange of real-time information between IEDs in the bay and process levels. It is a multicast layer 2 message published by an IED over the network that can be subscribed by any other IED connected to the same network. The message is repeatedly published, even when no changes occur, in order to increase its reliability. With the GOOSE message, any information (conventionally transmitted via binary outputs, copper cables and binary inputs) can be exchanged through the communication network.

The third service describes a multicast communication mechanism for the transmission of current and voltage sampled measured values through the substation network. It is called Sampled Values and replaces the classical secondary analog signals from CTs and VTs.

For the implementation of such automation systems, new components are introduced at substations. IEDs are used to interface with the primary equipment in the process level. An example is a Breaker IED that can be used to interface Circuit Breaker and Disconnector signals to the automation system. The distribution of the sampled (current and voltage) measured values through the network is performed by the Merging Units (MU) that create the interface between instrument transformers and the IEDs (protection and control devices). Network switches are also used and are an essential part of the system.

In Picture 1, a fully communication based substation is illustrated. In order for the protection system to operate properly, all components should function correctly. The system consists of instrument transformers, Merging Units for transmission of current and voltage values as Sampled Values, network switches, protection relays (IEDs), Breaker IED and circuit breaker primary equipment. Testing the complete system is a must but can be quite challenging for protection engineers when compared with conventional substations. Testing procedures are completely different from the ones used at conventional substations. Other testing tools and methods are needed.



Picture 1 Fully communication based substation

II. HYBRID SUBSTATIONS: DIFFERENT LEVELS OF IMPLEMENTATION

Contrary to the example shown in Picture 1, the majority of applications have a combination of conventional hard-wired connections and IEC 61850 communication. The usage level of communication based applications depends heavily on the utilities' philosophy and how well they know and trust in the new technologies.

Almost all utilities that claim to use IEC 61850, are referring to the MMS Client/Server communication for the SCADA system, and do not make use of the benefits of GOOSE and Sampled Values services. Some utilities do use GOOSE messages as well, however, for non-tripping applications, such as interlocking. In this case a Breaker IED is not used as an interface with the circuit breaker in the field and all signals from/to the circuit breaker are connected to the relay cubicles via copper cables. In a substation where GOOSE would be used for all applications, including tripping the breaker, copper cables would be used only between primary equipment and interface units. The relays (IEDs) would not need any binary input or output. The most advanced level of usage is when current and voltage measurements from CTs and VTs are also digitalized via the Merging Units.

As a result of the above, protection engineers nowadays have to deal with hybrid substations that combine both conventional analog and binary signals and network traffic. They need new testing and commissioning tools for working in this new environment.

III. Testing Scenarios for Communication Based Substations

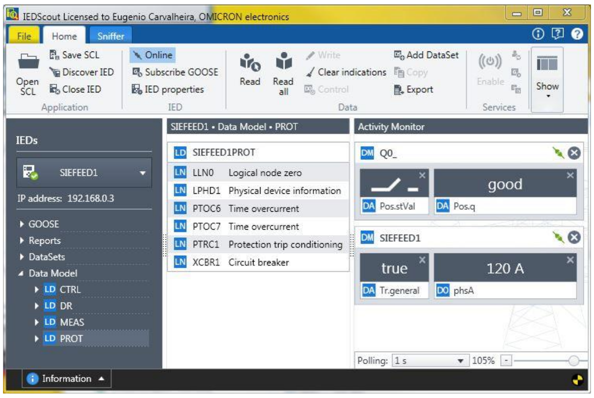
The testing of IEC 61850 based applications needs to be performed under different scenarios. Factors that influence such scenarios are: the level of automation implemented and services used, devices that are used in the automation system, and the purpose of the test. Different testing methods and tools will be needed for these different scenarios. Examples of testing purposes are: Type test of an IED, Acceptance test of an automation system, commissioning, or a simple maintenance check.

The test equipment should be able to adapt to all situations.

A. *Wiring Verification and Monitoring of Signals*

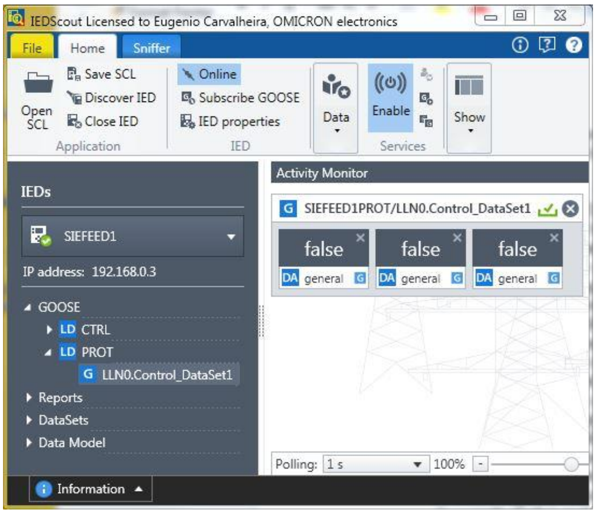
One of the basic things executed at the beginning of every acceptance or commissioning test is to verify that all signals exchanged between IEDs are correctly “wired”. In a conventional environment this can be done by checking that relay signals are correctly routed to the relay binary outputs, then checking the cable from one relay to the other is wired correctly and assigned to the right binary input of the receiving relay. The check of the cable is usually performed by measuring continuity with a multimeter. However, for applications where information is exchanged through GOOSE messages, a multimeter cannot be used to check that the relay output is actuating correctly or for checking cable continuity. Software tools are used instead.

Software tools can be used for investigating the IEC 61850 data model of each IED and to monitor the IED communication activity.



Picture 2 Investigation of IED Data Model and Data Monitoring

For verifying an IED is sending a GOOSE message correctly a software tool is used to monitor the message in the network. As a next step, the user should check the message is being received by another IED. For this purpose the IEC 61850 standard defines a logical node, as part of the IED data model, for monitoring GOOSE subscriptions. By supervising this data, the user can ascertain that the message is being received.

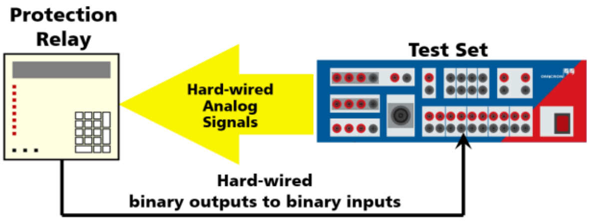


Picture 3 Monitoring of GOOSE message in the network

The “virtual wiring” between IEDs is then fully checked using software tools. However, the “old” multimeter is still necessary where conventional copper wiring is used.

B. *Protection Testing*

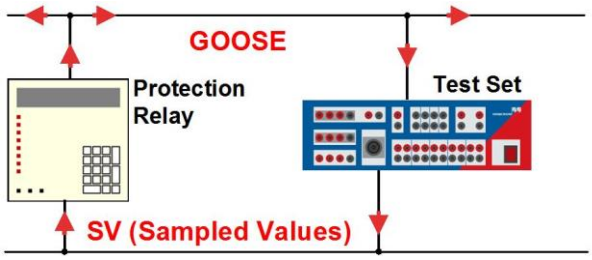
The purpose of this test is to evaluate the behavior of the protection relay. In a conventional system, analog voltages and currents are generated by the test set in a classical “secondary” injection protection testing. To measure the relay response, binary signals are connected back from the relay to binary inputs of the test set.



Picture 4 Testing the protection relay in a conventional substation

In substations where GOOSE and/or Sampled Values are used, the same test methods can be used, however, the interface between the relay and the test set is performed via the network.

The test set should be able to generate the Sampled Values streams containing current and voltage values that will be subscribed by the protection relay. The test equipment should be able to simulate the Sampled Values stream according to the specific implementation that is being used (example 9-2LE). The relay will react to the simulations by sending signals out (for example, Trip, Pickup, and Close) through GOOSE messages. The test set should subscribe to these messages to assess the relay's response.



Picture 5 Testing the protection IED with Sampled Values and GOOSE

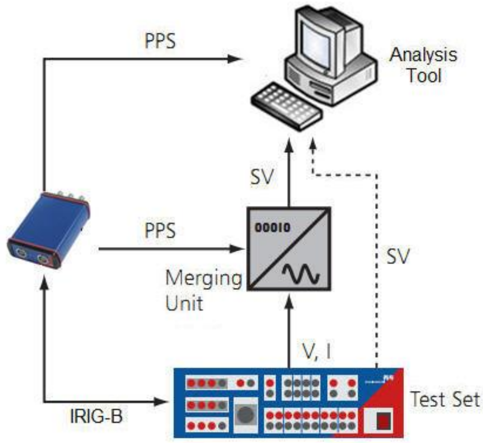
Depending on the function to be tested, it may be necessary for the test set to also simulate GOOSE messages. An example is the simulation of an Autoreclosure cycle performed during a factory acceptance test where the circuit breaker is not involved in the test. The test set should then simulate the breaker reaction and send its status signals to the relay via GOOSE.

Any other hybrid scenario as variations of Picture 2 and Picture 3 is possible. There might be, for example, an application where the signals needed for the test come from GOOSE messages, but the relay measures analog currents and voltages.

C. *Testing of the Merging Unit*

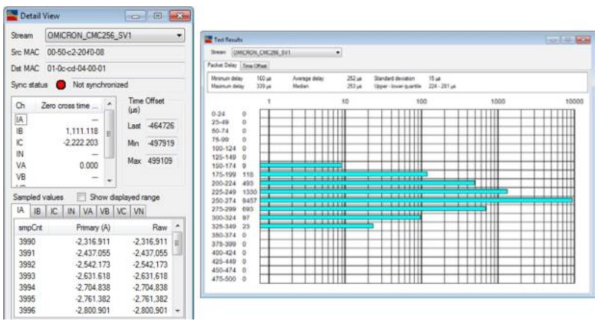
For substations using Sampled Values, the protection engineer may need to work with new equipment introduced by this technology, the so called Merging Unit. In general, there are two types of Merging Units: a Stand Alone Merging Unit (SAMU) used to convert the analog signals of conventional instrument transformers to digitized signals; or a Merging Unit integrated in the electronics of an optical instrument transformer.

Testing of the Merging Unit is a task usually undertaken by manufacturers during the development phase. However, evaluations during acceptance tests or even during the design phase of specific projects may be also performed. The aim is to ensure the specifications are met according to the claimed implementation.



Picture 6 Merging Unit test setup

For Stand Alone Merging Units (SAMU), this task can be performed by using a high-precision test set. It is very important for the test set to provide an extremely accurate analog signal and that both the test set and the merging unit are synchronized to the same time reference. The test set injects secondary values to the merging unit and, at the same time, sends the same values of current and voltages through Sampled Values. A separate analysis tool is used for subscribing to the two streams: the one from the test set and the one from the merging unit. Magnitude and phase errors can be verified. A timing measurement of the network packets can also be performed.



Picture 7 Merging Unit timing assessment

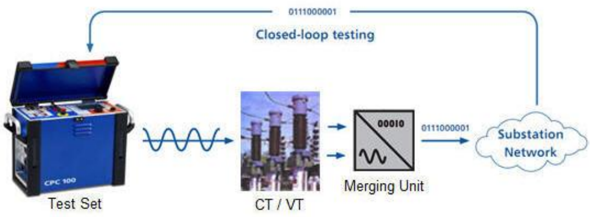
D. *Primary Injection Testing*

On-site, it is important to check the entire currents and voltages paths are correct. In the case of substations where Merging Units are in use, tests should be performed to verify the correct transmission of Sampled Values by instrument transformers. Being different from the detailed secondary injection tests of Merging

Units as explained above, the objective of this test is not to verify precision but to check the correct scaling of magnitudes, polarity of connections and Sampled Values parameters.

The primary injection of high currents and voltages to the primary of instrument transformers is an option.

This test can be carried out in applications that use conventional instrument transformers and Stand Alone Merging Units, but it is even more relevant in installations where non-conventional instrument transformers are used. In this case there is no other possibility to perform the test, because the interface between the sensors and the merging unit cannot be accessed.



Picture 8 Sampled Values commissioning with primary injection

This test is illustrated in Picture 8, with the test set injecting currents and/or voltages to the primary side of the instrument transformer. The instrument transformer system publishes the Sampled Values to the substation network. The test set subscribes to these Sampled Values from the network closing the test loop. This test verifies the whole instrument transformer system, including sensors and associated Merging Units.

The user can verify that the Sampled Values is being published with correct parameters (svID, AppID and MAC-Address), and perform a ratio and a polarity check.

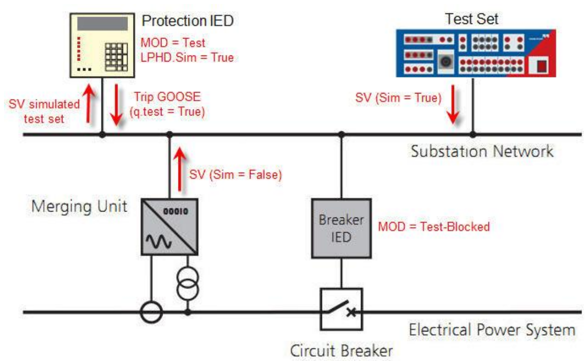
E. *Functional Testing and On-Site Test Isolation*

Several tests are performed On-site during different phases: commissioning of a new substation performed prior to energizing the substation, commissioning of a new bay in an existing substation, maintenance testing due to a modification in the system or maintenance due to a failure in the system.

The tests described previously to evaluate the protection relays and Merging Units are ideally performed prior to commissioning. During commissioning, the main objective is to check all connections are correct and to verify that the integration of different components is working properly. Protection schemes are tested during commissioning, as an end-to-end test between two substations, rather than as individual components.

For commissioning of de-energized substations, the test can be completed without too much worry. However, for commissioning of already energized substations or during maintenance activities, special precautions should be taken in order to isolate the IEDs under test. This will avoid any accidental breaker trip or undesired exchange of signaling between IEDs due to the test. One easy option would be to disconnect the device under test from the network. However, it is not recommended that IEDs are disconnected from the substation network. Sometimes it is not even possible, depending on the network architecture. Edition 2 of IEC 61850 provides more enhanced features that can be used to accomplish the test isolation [3]. Some of these features are: the possibility to put a function or IED in Test Mode and a Simulation Flag in GOOSE and Sampled Values.

In Picture 9, an example is given for commissioning the interconnection of the relay trip signal to the circuit breaker without opening the primary contacts of the breaker. Firstly, the protection IED under test should be set to TEST Mode (MOD = Test). In this case, all GOOSE messages that will be sent by this IED are signaled as for test purposes (q.test = true). Other IEDs connected to the network that are in normal operation mode will ignore these messages. Secondly, the IED should be set to subscribe only to simulated messages, ignoring all messages coming from the process (LPHD.Sim = true). Note that these two procedures to set the IED to test mode and simulation mode could be achieved in one unique step if this is programmed in the IED. All signals generated by the test set, both Sampled Values and GOOSE, should be flagged as Simulated. If the breaker controller is also set to TEST mode, it will receive the trip GOOSE and will open the breaker.



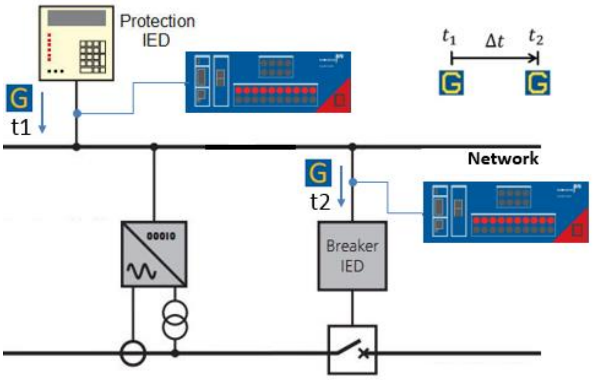
Picture 9 On-Site test isolation

In case the opening of the primary breaker is not desired, the breaker IED can be set to TEST-BLOCKED, so the trip GOOSE will be received and processed but outputs to the breaker will not operate.

F. *Assessing the Communication Network*

As a crucial component of the protection and automation system, the substation network should also receive special attention. The network should be well designed with an appropriate topology and a limited number of IEDs connected that fits with the applications used. Network switches are configured to perform different tasks, such as prioritization of traffic, quality of service, virtual LAN segregation (VLANs), redundancy protocols, among other things.

Tools should be available to assess the communication network by measuring network load and propagation delays. There should also be a way to check the network switches functionalities.



Picture 10 Propagation delay measurement

Picture 10 shows an example of a setup for measuring propagation delay of a GOOSE message through the network. It measures the time from when a message is published by an IED (t1) and enters in the network to when the same message is delivered to a certain location (t2). This distributed and time-synchronized measurement can be made at any point of a Local Area Network or even over Wide Area Networks, such as the communication between two different substations.

G. *Troubleshooting*

Very often protection engineers need to analyze occurrence of events in the system. A pre-defined condition is used to trigger a recording of events that will be analyzed afterwards.

In hybrid substations, as discussed previously, the protection engineer should now take into consideration that signals in the substation are not only in the form of analogs and binaries, but are also present in the network.

So, for a proper and coordinated analysis, the measurement equipment that is used needs to record simultaneously the conventional signals and network traffic. The network traffic of IEC 61850 GOOSE and Sampled Values should be shown as electrical quantities that are understandable by engineers.

IV. CONCLUSION

IEC 61850 became the widely used standard for power utility automation. Methods are defined to exchange information via a communication network. With the usage of this new technology, new components are introduced into substations. Network switches, Merging Units and Breaker IEDs are now also part of the protection system and are essential for its correct operation.

Implementation of communication based substations differs greatly depending on utilities' philosophies. Hybrid substations are the common form found today in the majority of the applications, where both conventional signals and network traffic are used for exchanging information. Protection engineers need to deal with very different scenarios as well as the challenges imposed by the new technology. The maintenance methods and testing procedures used in pure conventional substations can no longer be used and need to be adapted to the new reality. The differences begin even during the preparation for the test. The isolation of the devices under test from the rest of the system, which remains in operation, is no longer only performed via physically installed test switches, but also virtually via software in the IEDs. Edition 2 of IEC 61850 defines ways on how to accomplish this task without interfering with the system. The testing procedures need to be carefully defined to assure the entire protection and automation system works properly.

New testing tools are available that make it possible to test different scenarios at hybrid substations. Software applications are replacing multimeters and test sets are having their firmware updated to work with GOOSE and Sampled Values messages. Development of new software tools is crucial for fulfilling the testing requirements of this new application.

LITERATURE

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V. BIOGRAPHIES

Eugenio Carvalheira received his BSc in Electrical Engineering from the Federal University of Pernambuco and his MSc in Computational Engineering from the University of Erlangen-Nuremberg.

He started his career in 2001 as a Project Engineer at ESC Ltda. responsible for the design, planning, implementation and commissioning of protection and control systems for electrical substations and power plants. In 2008 he joined OMICRON electronics Germany as a Training and Application Engineer, designing and developing test automation solutions for protection relays and being also responsible for the IEC 61850 training courses of OMICRON.

He is presently Regional Application Specialist and Training Manager for Latin America with OMICRON electronics Corp. USA in Houston, TX.

Jesus Coronel received his BSc in Electrical Engineering from the National Autonomous University of Mexico. He started his career in 1998 as a Sales and Application Engineer at Multi-mex Medicion y Calibracion, S.A. de C.v. responsible for the training courses, technical support, and the preparation of tenders for power system testing and diagnostic solutions. In 2011 he joined OMICRON Energy Solutions de Mexico as an Application Engineer responsible for the training and support for Mexico and Central America .

OMICRON is an international company serving the electrical power industry with innovative testing and diagnostic solutions. The application of OMICRON products allows users to assess the condition of the primary and secondary equipment on their systems with complete confidence. Services offered in the area of consulting, commissioning, testing, diagnosis and training make the product range complete.

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