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Functional and Interoperability Tests Using the IEC61850 Standard Applied to Substations – Research and Development in Brazil

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SUMMARY

The present paper focuses in the development and installation of a Test Lab for Protection and Automation of Electric Systems at the Rio de Janeiro State University - UERJ. This laboratory is being created, mainly, to give support to the researchers in the substation protection, automation, communication and computer science areas. It will have IEDs (Intelligent Electronic Devices), from several manufacturers, interconnected by a fiber optic LAN (local area network) in a ring type topology. The fiber optic LAN is connected, at the station level, to two workstations for data processing and storage, as well as for Man Machine Interface (MMI). Also, a time synchronization equipment (GPS) will be added to the architecture. IEC61850 standard compatible test equipment, together with XML language based engineering tools will be used to facilitate the tests.

One of the main objectives of the laboratory is the execution of functional and interoperability tests in the SAS (Substation Automation System) or IEDs under test, as well as the verification of the performance of the distributed functions specified. Different conditions of the optical fiber LAN will be considered, including those with very high data flow or with intense noise. The existence of a process bus will not be included in the initial stage.

It will be considered that each IED, individually, has been previously submitted to the conformance tests, defined in the IEC61850-10 standard, by the manufacturer or a third party. The tests will be performed step by step. In a first step it will be confirmed that the internal functions of each IED are operating properly. In this stage, only the non distributed functions supplied with the IED (protection, oscillography, sequence of events, measuring, signaling, alarms etc.) will be analyzed.

In the next stage, system tests will be initiated. Functional and interoperability tests will be performed on each of the distributed functions. These tests will include the IEDs and the communication network. They will begin with two IEDs and increasing the number of IEDs gradually, until the whole system has been completely tested.

KEYWORDS

IEC 61850 Standard, Functional Test, Conformance and Interoperability Tests, Protection and Automation System Integration, Protection IEDs Network.

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1 INTRODUCTION

The coming into view of the IEC61850 standard made it possible the use of Ethernet based high speed and reliable local area networks (LAN), allowing sharing of information among several IEDs, as well as the distribution of such information to the different utilities and industry users (local and remote operators, as well as personnel for protection engineering, fault analysis, maintenance and others). The above mentioned standard also helps to solve the problem of expanding the digital systems, as it offers the guarantee of interoperability between IEDs from different manufacturers, substantially reducing the cost of the expanded system.

However, the correct functioning of a SAS with IEDs of different manufacturers, using the IEC61850 standard, requires the performance of functional and interoperability tests, preferably in a commercially neutral environment. It shall be possible to verify whether the SAS, including the communication network and the IEDs, will adequately execute the protection and automation functions in use, maintaining the performance specified. The most critical point will be the operation of the distributed functions involving IEDs from different manufacturers and considering the most unfavorable scenario for data flow and other signals which may occur in the communication LAN.

On the other hand, this new technological stage represented by the IEC61850 standard still does not have the necessary development in the academic circles in Brazil, as well as in many other countries. It is urgent to join the several areas of the engineering courses involved, such as electrical, communications and computing science engineering, working together in laboratories with pilot projects using the IEC61850 standard, so that professors and students may participate in this development. This includes subjects such as electrical protection, substation automation and digital data communication, among others.

2 THE ELECTRIC PROTECTION AND AUTOMATION LABORATORY OF UERJ

The Electric Protection and Automation Laboratory of UERJ (LAPE-UERJ) is being developed as a Research and Development project, together with a large oil company and an integrating company. The main purpose of this laboratory is deepening the knowledge on the applications to substation design of the IEC 61850 standard and the development of procedures for functional, interoperability and performance tests, under severe data flow or with intense noise in the communication network, using IEDs of different manufacturers.

Another important purpose of this project is to provide the teachers and the students of the courses of electric power, communication and computing systems engineering with the opportunity to participate in the development of a SAS, using the IEC 61850 standard, knowing it more deeply and spreading its use. This way, UERJ will be contributing for the qualification of the new generation of electric engineering professionals to develop, specify, analyze the manufacturers proposals, as well as to follow up the functional, interoperability and performance SAS tests employing the IEC 61850 standard.

The development platform of the LAPE-UERJ that is being acquired will be constituted by the following main components: one set of IEDs for the protection of motors, feeders, generator and transformer; communication equipment including a LAN with a double ring bus topology; workstations and notebooks; micro processed testing equipment, including a set of software tools consistent with the IEC 61850 standard, GPS Equipment, Testing Giga, as well as one IED for voltage regulation and supervision of parallelism of generators.

As a general philosophy, at least 3 different manufacturers are being considered for each of the protection functions described above. Figure 1 shows how the several pieces of equipment are interconnected.

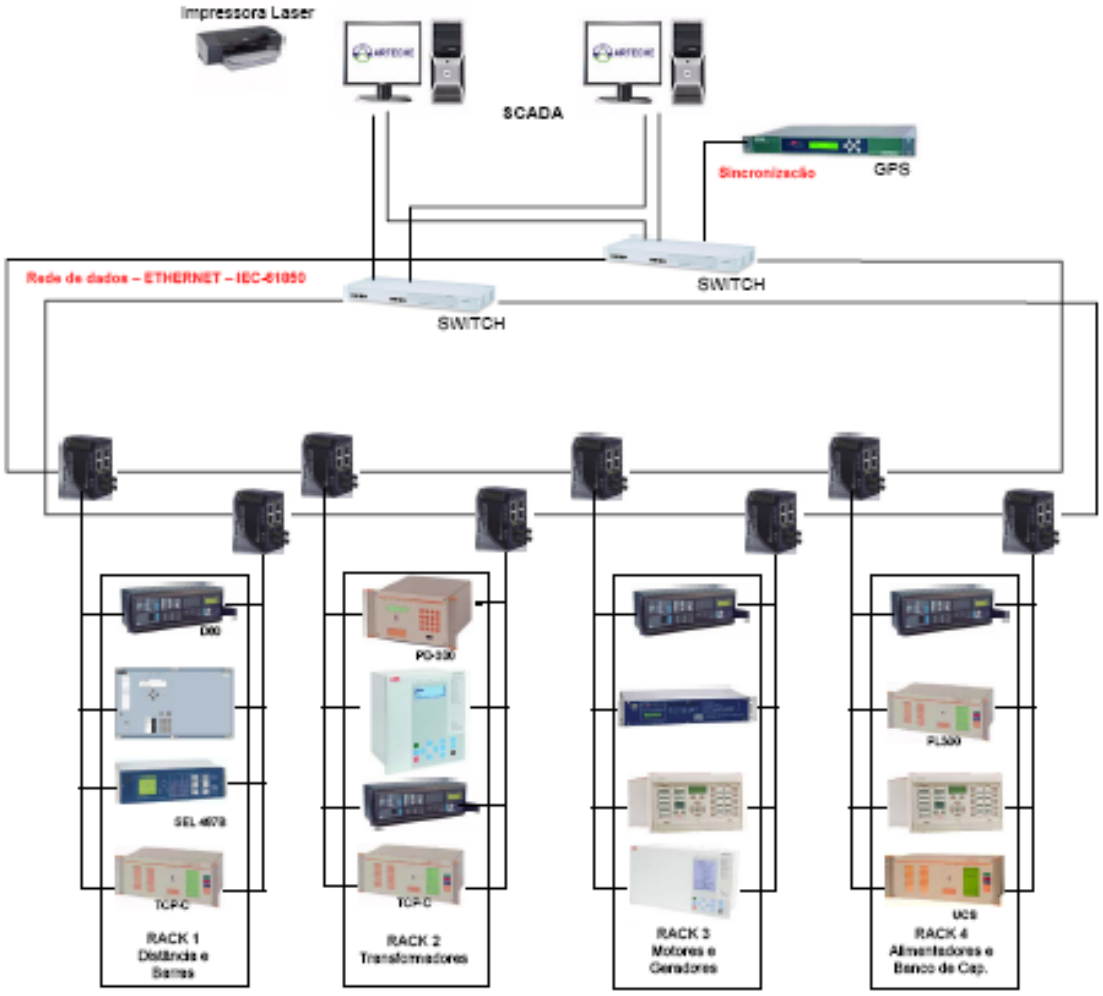

Figure 1 – Architecture of the IEC 61850 Development Platform of UERJ

3 SPECIFIC FUNCTIONALITIES TAKEN IN CONSIDERATION

In order to comply with the protection and automation operational needs of the sponsoring company, the following specific functionalities shall be considered: automatic load shedding; re-acceleration of motors; generation control; automatic synchronism of generators; disconnect switches interlocking; start up and shut down of motors; automatic transfer of sources; logical selectivity or reverse blocking (bus protection using the overcurrent relays instantaneous unit of the incoming feeders); breaker failure protection; measurement of electrical quantities; sequence of events recording; supervision of the circuit breaker tripping circuit; oscillography.

Among the functionalities above, the most critical are the ones involving distributed functions, i.e., the ones that use logical nodes located in distinct IEDs. Special care will be given to those distributed functions involving different manufacturers.

4 CONFORMANCE TESTING

The conformance testing objective is to verify if the relay or other IED under test (device under test – DUT) conforms with the IEC 61850 standard requirements. This is normally done by exchanging carefully selected array of test messages to the DUT and recording the responses of the DUT. The messages are selected to exercise all the features of the DUT communication that are to be verified or certified. Appropriate message simulation and message analyzing tools are used during the tests.

The methods and testing sequences are thoroughly specified in IEC 61850-10 – Conformance Testing.

In order to run a conformance test, the tester initially reviews the design information available on the DUT. Along with the IED itself and its instruction literature, the standard specifies the format for the following product feature descriptions:

- ✓ MIPS file (*Model Implementation Conformance Statement*) – details the standard data object model elements supported by the system or device;
- ✓ PICS file (*Protocol Implementation Conformance Statement*) – summary of the communication capabilities of the system or device to be tested;
- ✓ PIXIT file (*Protocol Implementation extra Information for Testing*) – contains specific information regarding the communication capabilities of the system or device to be tested that is outside the scope of the IEC 61850 series standards. This PIXIT file is not subject to standardization of its format or contents.

The conformance tests are normally performed by accredited and independent organization, which issues a Test Certificate of Conformance.

5 GENERAL INFORMATION ABOUT THE SYSTEM TESTS

Normally, system tests could be classified as Factory Acceptance Test (FAT) and Site Acceptance Test (SAT). The FAT is a complete test of the integrated system at the factory, with all application functions, HMI, displays, database and logs. Regarding the IEC 61850, it has to be proven that the data model, the communication services and the performance defined in the standard and implemented is in accordance with the project specification. There may be limitations regarding the equipment available in the factory, e.g. normally the switchgear is not included at all. Also, some IEDs may be missing during the FAT and must be simulated by an appropriated tool.

The SAT is a complete test of the integrated system at the site. It is similar to the FAT, with the difference that now, all components of the system, including the link to the remote control centers and the related switchgear must be available and tested together.

The FAT and SAT are actually, functional tests.

Before performing the SAT, an intermediate process with a Lab-staging and Acceptance Test (LAT) may be done. The LAT allows testing of devices to conform with the IEC 61850 standard in a controlled environment condition and check performance of operation with other IEDs. It also allows the simulation of the switchgear equipment and the missing IEDs using appropriated tools. Additionally, the LAT offers a much more comprehensive coverage of the failures scenarios.

This Lab-staging and Acceptance Test (LAT) is the idea of the Electric Protection and Automation Laboratory of UERJ (LAPE-UERJ), which will also be used to provide the teachers and students with the opportunity to participate in the development of a SAS, using the IEC 61850 standard.

6 INDIVIDUAL TESTS

Before the system tests are initiated, it is necessary to test every IED individually. The following functional test procedures are programmed:

6.1 Checking of the Documentation and Conformity of the IEDs

It is considered that all the components of the development platform of the LAPE-UERJ have been previously submitted to the conformity tests with the IEC 61850 standard and approved. Such tests are usually performed by an independent organization, which submits the IED to a series of tests, and certifies that such IED is in compliance with all the requirements of the standard, including the use of the SCL language, object oriented data model, communication via Ethernet, TCP/IP, with vertical messages (between the IED and the SCADA) using the client-server mode. The horizontal messages (between IEDs) shall use the editor-subscriber mode and employ GOOSE messages.

Additionally, it will be verified whether the documentation provided with the IED complies with the requirements of the standard. The following documents shall be supplied with each IED:

- ✓ Certificate of conformance;
- ✓ ICD File (IED Capability Description);
- ✓ MIPS file (*Model Implementation Conformance Statement*) , PICS file (*Protocol Implementation Conformance Statement*) and PIXIT file (*Protocol Implementation extra Information for Testing*);
- ✓ IED Catalogue, containing the description of all the functionalities, adjustments, parameters, typical logics, etc.
- ✓ Configuration (SCL), as per IEC 61850 Part 6
- ✓ Data object model, as per IEC 61850 Parts 7-3 and 7-4.
- ✓ Communication services, as per IEC 61850 Parts 7-2, 8-1, 9-1 and 9-2

Cases of positive and negative tests will be considered. Also, it will be checked whether the documentation PICS, MICS and PIXIT is compatible, as well as whether the ICD files are conformant with the SCL-XML configuration defined for the substation.

It is important to observe that a certification test must be issued in a per product basis, because PICS/PIXIT combination may be changed for different products.

6.2 Individual Functional Tests

In order to assure that the several functions of the IED will operate in a proper manner in the stage of the complete system tests, a functional tests of each of the functions and of each of the internal logics will be performed for every IED.

7 CONFIGURATION FOR THE FUNCTIONAL AND INTEROPERABILITY TESTS

7.1 The Use of Engineering Tools for Test Preparation

Before the system tests are performed, it is necessary to convert the conventional system specification (text and drawings), in to an SCL based specification. This is obtained with the add of an engineering tool. The file generated is called SSD (*System Specification Description*) file and includes all the information about the SAS configuration and functionalities, as well as on the LAN topology and characteristics.

Every IED must be supplied with a file called ICD (*IED Capability Description*) file, which is a description of the possibilities and functionalities available in a specific IED. The SSD file, together with the ICD file of every IED, are integrated using another SCL based engineering tool. The resulting file is called the SCD (*System Configuration Description*) file.

A specific file for every IED is than generated, using the SCD file and an engineering tool. The specific files obtained are called CID (*Configured IED Description*) files. These CID files are then loaded in to the corresponding IEDs.

7.2 Functional and Interoperability Tests

For the interoperability tests, two or more IEDs shall be connected to the LAN, with generation and transmission of messages in the IEC 61850 standard way. For this purpose, the testing equipment shall be capable of simulating such messages. The complete set of the equipment will be installed at the UERJ LAB and extensibly tested. Vertical and horizontal messages will be generated, transmitted and analyzed to check the consistency with the IEC 61850 standard.

It is known that it is neither practical nor possible to test all the communication possibilities of a relay with all the other IEDs of a SAS, as the number of possibilities is very big and exponentially grows with the number of IEDs. What is practical and can be performed, in a realistic way, is to establish probable testing scenarios, representing the most unfavorable conditions expected. The situations of heavily loaded traffic in the LAN can be simulated by an additional computer connected to the network.

It is considered that each IED has been previously tested in relation to its conformity with the standard and the functional requirements, and that the operation of the non distributed functions has previously been checked as well, with the observation of messages generated and received by the IED in relation with the switching equipment status, commands, alarms and information for the MMI.

In view of the great complexity represented by a SAS with distributed functions, the tests will start with the simplest situations and then slowly increase the level of complexity. Two IEDs, will be used to initiate testing of the least complex distributed functions and with the communication network with low traffic. The tests will be continued until all the distributed functions involving the two IEDs have been tested. Only then a third IED will be added, and then another, until the entire SAS has been tested. The most critical situation for the interoperability occurs when IEDs from different manufacturers are operating with distributed functions.

As an example, we may simulate a failure involving two or more control or protection IEDs, and analyze the messages exchanged by these IEDs, including the vertical messages to the IHM (status, alarms and commands), and the horizontal messages (GOOSE or GSSE). Each one of the distributed functions shall be tested, with the simulation of the several situations that may occur. The future IEDs, or those not available during the tests, can be simulated by proper software tools. Typically, all the interactions among the IEDs which are connected through the LAN are to be sample-tested.

A set of IEDs connected to a communication LAN, together with a GOOSE message simulator, protocol analyzer, MMI, plus means for storage, capture and visualization of the testing data, in addition to a controlling and generating source of the analogical signals, is shown in Figure 3. The GPS (*Global Position System*) equipment, although not shown, is also part of the set.

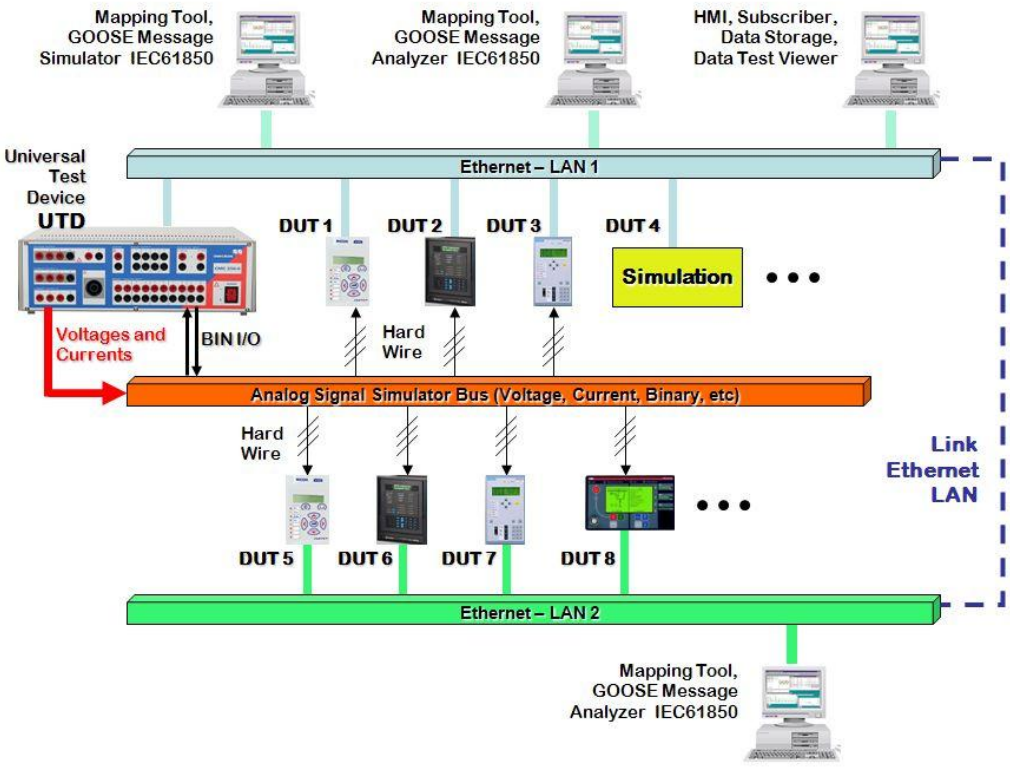

FIGURE 3 – System for the Interoperability Test of Several IEDs

Even taking into account that all the IEDs that are part of a SAS have been approved during the conformance tests under the responsibility of the manufacturer, there may exist some differences between the IEDs that will make the interoperability tests more difficult. If all IEDs are from the same development team, at the same manufacturer, there is a good possibility that the IEDs will

interoperate. However, if the IEDs developers are not from the same team, different choices during the software design may create difficulties for the software of two IEDs to operate together.

It is important to point out that the performance of the interoperability and functional tests in a controlled laboratory environment is much superior to the search for flaws and their correction in the field. In the laboratory, the tests are performed step by step, and computing tools are available for analysis, which facilitate the identification of the problems. In the substation environment, there may be some simultaneous flaws, which will make more difficult their search and repair and may extend in a non controlled manner the commissioning time.

Availability of a laboratory environment allows also the simulation of faults on each IED, like wrong logical node parameters, and their impact on functionality and performance. Component faults can be generated in order to avail a test case coverage, or its capability to detect any kind of failure. This can be instrumental, for instance, to generate and test maintenance procedures, and for training purposes.

8. TEST OF THE ETHERNET SWITCHES

Considering that the Ethernet switches are a critical component of the SAS, as they are now part of the substation protection system and they must be capable to provide VLANs, it is recommended that they are tested very carefully. A suggestion for this test is given in [ ]. A very brief idea is as follows:

The goal of the VLAN tests is to verify the multicasting of VLAN tagged IEC 61850 GOOSE messages. The goal of the functional priority tests is to verify that higher priority messages will prevail lower priority messages. It is expected on a network with mixed priority packages that no high priority packages will be dropped.

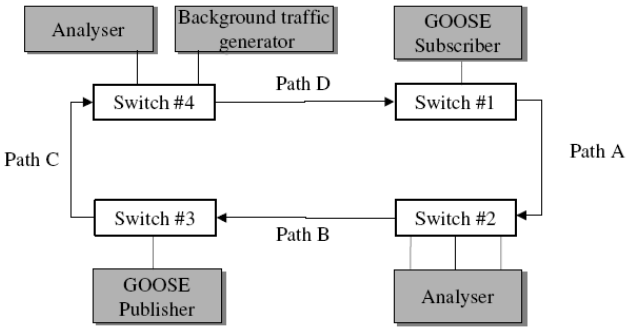

Figure 4 – Suggested Test for the Ethernet Switches

Details on the proposed testing method are given in [7]

9. PERFORMANCE TESTS

The performance tests have the purpose of checking whether the performance of each function is kept within the specified limits, even when the communication network is submitted to critical traffic conditions or noise. They are applied both to the distributed and to the non distributed functions. During the performance tests the maximum periods of time for the operation of certain functions are verified, as well as the maximum amount of time that each message (especially the GOOSE messages) will take from its generation in the IED until it is received by the subscriber IEDs that will use the information.

It shall be noted that the IEC 61850 does not specifies the performance tests. However, for certain critical behavior features, the IEC 61850-10 requires that this behavior be tested. For instance, an IED supporting a GOOSE or GSSE client or subscriber service must be tested for time latency, which is the time from receipt of the GOOSE or GSSE message to the physical control action output.

10. CONCLUSION

The use of IEDs based on the IEC 61850 standard requires the employment of new testing methodologies and equipment. The use of the SCL language for the IEDs of a substation allows the development of new computational tools and the adaptation of others already existing, greatly facilitating and automating the execution of the tests. By using the SCL language, the IEDs may self describe. Consequently, there is a significant decrease in the amount of errors which would arise from the manual configuration work. During the test of distributed functions, the future IEDs or the IEDs not available at the moment of the test may be simulated by testing tools.

In addition to the conformity tests of each specific IED, the complete SAS test, including IEDs of different manufacturers interconnected by a communication network, shall be performed in the factory or laboratory, so as to identify and correct any problem, shortening the time required for the commissioning.

Bearing in mind the importance and the complexity of the subject, the authors call the attention to the need of suitable preparation of the technicians and engineers who will be involved with the areas of protection and control of substations, so that the IEC 61850 standard may be more readily assimilated and used in the several applications.

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