Study Committee B5 Colloquium
August 25-31, 2013
Belo Horizonte, Brazil

116

Acceptance, Commissioning and Field Testing for Protection and Automation Systems

Michael Obrist, Stephan Gerspach, Klaus-Peter Brand
ABB Switzerland
Switzerland
michael.obrist@ch.abb.com

Summary

The introduction of the standard IEC 61850 for communication in power systems enables to build enhanced Substation Automation (SA) systems and to distribute requested functionalities in an optimal and standardized way. This brings new challenges and opportunities related to interoperability between compliant IEDs and tools as well as for testing and maintenance processes. The complete sequence of testing from products to systems is summarized and the impact of IEC 61850 to these tests is given.

The testing and maintenance requirements of the utilities for IEC 61850 based systems are discussed and the potential of IEC 61850 related to testing and maintaining a SA system is shown with some typical examples. The main result is the key role of the System Configuration Description (SCD) file and the importance of the system integrator. Since IEC 61850 is based on mainstream communication technology and any treatment needs powerful software based tools, utility maintenance staff has to possess the necessary skills and tools to exploit the potential for new testing and maintenance strategies.

Keywords

IEC 61850, Testing, Life Cycle Testing, System Test, Integration Test, Conformance Test, Factory Test, Factory Acceptance Test, Site Test, Site Acceptance Test, Testing Tools.

1 Introduction

The introduction of IEC 61850 opened up new possibilities for functionalities in multi-vendor SA systems. This new potential might lead to challenges for a user to observe if his specific requirements for a customized SA System are fulfilled according to his specification. At the same time IEC 61850 provides the mechanism to develop tools facilitating testing and maintenance processes for the users and to benefit from the opportunities provided by the standard. In the following the complete life cycle testing is described and the related support from IEC 61850 also regarding testing tools is discussed.

2 The testing in the life cycle of SA Systems

The complete sequence of testing, from product development to customized systems, is the base to fulfill the general and dedicated user needs for SA systems. Behind the life cycle of any Substation Automation System [2] there are the life cycles of all integrated products and related tools. From the development and production of a device (IED) and the required software tools to the on-site system tests, various different test phases have to be passed.

This **Life Cycle Testing** sequence was defined and described in a previous Cigre paper [4]. Generally, all testing improves the quality and reduces risks both for the supplier and users. This chapter refreshes the required **Testing sequence**, starting with the development process of single products (IEDs and Tools) until a commissioned system, customized to the user's needs represented by the project specific requirements. The base for reliable in-house testing is the quality system of the supplier and vendor according to ISO 9001/9002 as far as applicable.

The **Life Cycle Testing** sequence may be divided into three parts (**Figure 1**).

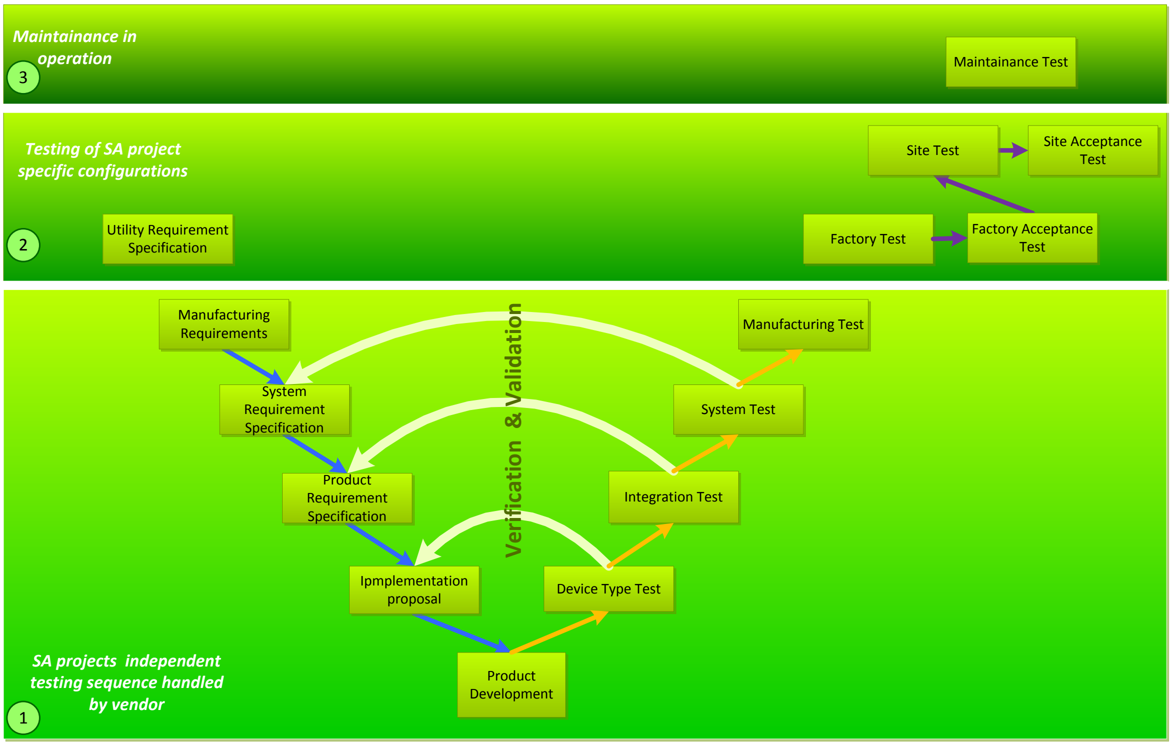

Figure 1 - V-Model used for life cycle testing in SA systems

2.1 SA System project independent testing sequence handled by the vendor

The classic testing sequence starts with the Device **Type Test** and ends with the **Integration Test** to ensure the proper functioning of the new product (IED and Tool). The **Conformance Test** is part of the device type test according standards like **IEC 61850**. Normally the conformance of the IED or Tool[1] is confirmed by a **Certificate** issued by a UCA International Users Group [3] qualified test center. The test requirements of IEC 61850-10 and the derived test procedures defined by the UCAIug are focused only on IED (single product) testing. As a result, today's conformance certificates are no guarantee for interoperability from a system perspective, but they are for sure an important step to reach interoperability.

The goal of IEC 61850 is interoperability of the IEDs and Tools in Substation Automation systems. Therefore, a generic **System Test** should also belong to the **Vendor's Testing sequence.** In this step the interoperability between the different system components and tools are verified and validated. Also part of this validation is the overall system performance

[1] with IEC 61850 Edition 2 conformance testing for Tools is introduced

of the provided services, tested in a reference system. Nevertheless this project independent test is thereby reducing substantially the risks for all SA system projects to be executed. As spin-off, the system configuration tool and its interfaces with the product tools are also tested. The System Test described in e.g. [4] is not yet formally defined by IEC 61850 or by the UCAIug.

Routine Tests or **Manufacturing Tests** in the production chain ensure a constant quality of delivered devices.

2.2 Testing of project specific configurations

The whole SA system project testing sequence consists of project related tests, based on the user specification for the ordered substation automation system. They are performed by the system integrator (supplier, customer, third party, etc.) with the testimony of the user. These tests confirm that the delivered individual SA system is running as specified.

The SA system project testing sequence starts with the **Factory Test**. It is a project related test to prepare the customized system for the **Factory Acceptance Test** (FAT). The FAT is conducted to determine that the equipment operates according to its specifications and covers all functional requirements. The FAT witnessed and confirmed by the user ends with a shipping release to site.

On site, after the installation, the **Site Tests** are carried out. During these tests especially the system interface to the real process will be verified and the SA System prepared for the **Site Acceptance Test** (SAT). The SAT witnessed and confirmed by the user is the final acceptance of the delivered system. Then the warranty and maintenance phase starts if applicable.

2.3 Maintenance testing in operation

Using the advantages of self-supervision provided in modern numerical system components, many of the tests described in the previous chapter must not be repeated as part of some periodical maintenance test during the operational phase of the SA System. Especially vendor tests may be excluded). During the operational phase of the life cycle the testing is focused on:

- Identifying faulty system components by periodic tests or self-supervision
- Exchanging and reconfiguration of faulty system components
- Testing of the repaired system

Periodic functional testing is especially related to the hardwired process interface due to its limited self-supervision capabilities. Maintenance activities like extensions of the substation or its functions need appropriate testing of the changed system. In any case the traceability of configuration changes has to be ensured.

3 Changes in the testing process introduced by using IEC 61850

Modern IEC 61850 substation automation systems are distributed software applications based on exchanging standardized information over the substation local area network. So instead of testing the functionality of single components as in the past, today there are system tests performed showing more similarities between testing of software applications and testing of functions in substation automation systems. Because the different SA system components have to share common system functionalities the interoperability between those components is the prerequisite.

With the introduction of IEC 61850 Edition2 the on-line testing capabilities are enhanced. Several additional features like identifier for simulated messages are introduced and the definition of the Mode/Behavior introduced already in IEC 61850 Edition1 is clarified to be usable.

3.1 Conformance versus interoperability

Standard conforming products (IEDs & Tools) from different suppliers or different standard conforming products from the same supplier need not to fulfill the same functional scope of supply. They may have different communication profiles.

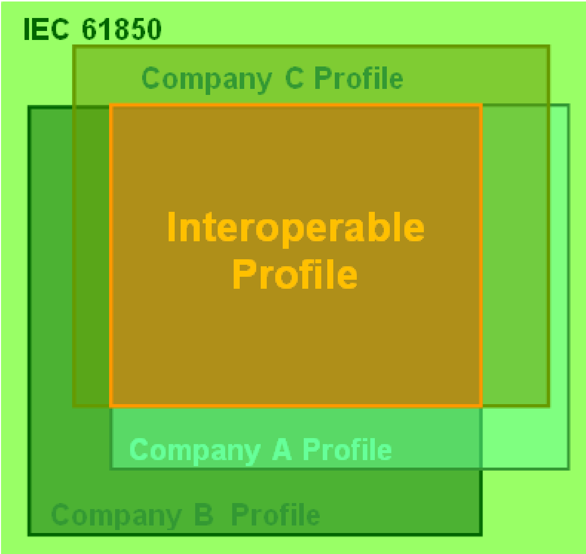

Figure 2 – Interoperability Profile

A communication profile defines the mandatory subset of the standard with selected options and vendor specific extensions that are implemented. Different profiles provided by different products may conform to the standard but still not be 100% interoperable to each other.

It is the responsibility of the system integrator to check the interoperability of two or more products based on the conformance statements of the different products and the required system functionality. Also the performance of services, including delays caused by communication equipment like switches, has to be verified. These tests are done with preference independently from SA system projects as a kind of generic System Tests and will heavily reduce the risks for all projects (see chapter 2).

3.2 Re-use of formal system description in the testing process

With the Substation Configuration description Language (SCL) the IEC 61850 standard has introduced an interoperable and machine readable description that is used for the standardized exchange of configuration data between engineering tools. Based on this configuration language, several file types have been defined in the standard. One of these files is the Substation/System Configuration Description (SCD) file providing the full documentation of the SA System as built. The typical content of the SCD file is:

- Description of complete topology of the primary equipment of the substation (single line diagram)
- Relationship between SA functionality defined by Logical Nodes (to be implemented in the selected IEDs) and the primary equipment
- All IEDs (servers) & station level equipment (clients) including their data models
- Complete communication system with addressing and logical data flow

From the communication system point of view, the interfaces for each device, client or server, connected to the system are described in this file. This allows also a comprehensive evaluation and documentation of the physical dataflow between all system components. These results stay valid if the configuration of related datasets and control blocks is only changed at engineering time but not created dynamically at runtime. Therefore, the static configuration is recommended.

As seen from the definition the comprehensive SCD file is the central part of the system documentation and can be used as standardized reference for all testing activities related to IEC 61850. This allows comparing data models, configuration version information and the dataflow of the actual IEDs with the information as engineered in the SCD file. As a result, configuration mismatches can be easily detected in the entire SA system.

Also the messages analysis of the communication between IEDs at application level requires the information about the content of the IEC 61850 datasets. Without this information the transmitted values cannot be assigned to the related attributes of the data model and therefore an analysis at user level i.e. a user friendly analysis is not possible.

To fully benefit from the version information contained in the SCD file, it is required that all engineering tools follow the rules to handle configuration changes as defined in IEC 61850 i.e. to update all relevant configuration indices of the impacted IEDs. Keeping the SCD file up to date with the commissioned SA system ensures to have one common reference also for later extensions or maintenance tasks.

The information in the SCD file is also the basis for simulating physically nonexistent IEDs for communication (GOOSE, SV and MMS services) e.g. during factory testing where not the complete SA system is available.

4 Tools for acceptance, commissioning and field testing

In a previous Cigre paper [5] it was confirmed that there are different tool requirements in the different phases of the life cycle of the SA Systems. Testing tools are generally required in the whole life cycle for the related testing sequences.

4.1 Testing tool

Testing tools are used in all phases and have to support the testing process and to automate testing activities as far as possible. As discussed in [5] the testing activities during acceptance, commissioning and field testing can be divided in “integration testing” and “functional testing”. The SA system has to be tested for correct communication and configuration by an integration test tool. With the help of the function test tool, the SA system functions are tested according to their user depended specification. For both testing tasks it is required to simulate missing components crucial for the correct behavior of the SA system. Therefore it is efficient when the testing tool provides simulation capabilities as well.

During testing activities in process bus environments, a test engineer needs a way to measure the analog values sent from a merging unit to the IEDs. In this case the testing tool will act as enhanced Volt and Ampere meter. It shows in addition to these classic measured values useful information like phase angles and all quality attributes to the test engineer.

For SA functions with embedded GOOSE functionality like protection, the testing tool guides the test engineer to select the IED under test resulting in setting the impacted functions of all involved IEDs in the necessary modes (as defined in IEC 61850 Ed.2). One example is the TestBlocked mode to avoid sending out unwanted trip signals to a circuit breaker in the process (switchyard). Additionally under test condition it monitors the reaction of the complete involved IED chain to verify the expected result for the specific test case.

4.2 Diagnosis tool

A diagnosis tool is required to isolate the root cause of problems, reported by the self-supervision of the SA system or detected during testing. To identify configuration issues often it is enough to detect that different version of the configuration files are used within the system. This information helps to pinpoint the parts that need to be re-loaded with the latest version. In case the version information is consistent, an in-depth comparison of the data models may help to identify further implementation problems of the functions.

Finally the application level protocol analysis mentioned already above allows easily detecting whether the information is sent from one IED to the other one is correct. This application level information captured on top of the Ethernet can even be enriched by adding information from the SCD file such as links to the Substation Section or signal texts.

In the IEC 61850 world, switched Ethernet is used as a communication backbone. Since managed switches are used, communication problems can also be related to the configuration of these active network components (e.g. wrong defined multicast or VLAN filters). Also here a diagnosis tool will help to check if the configuration of the Ethernet equipment matches the logical and also the physical needs. Again these parameters can be retrieved online and later be compared with the documented values in the project specific SCD file.

For the horizontal IED-IED communication services (GOOSE, SV) it is helpful if the tool includes also the graphical representation of the messages content at application level. This helps the engineers to focus on the application level, rather than to count bits and bytes.

4.3 Simulation Tool

In case simulating a server IED a client that acts e.g. as HMI or protocol converter towards a control center could be tested. The simulation is restricted to the pure IEC 61850 data model simulation. Any vendor specific functional implementation cannot be provided by a generic tool. A simulation will not replace the point to point test from the physical process to the HMI or gateway. But it can be used to separate the testing processes to allow sequential tests with minimal effort. In this case the HMI will be tested with signals from the process ensuring correct wiring up to the IED, but the gateway functionality can be tested by generating artificial signals with an IED simulator.

Protection or control IEDs could be tested using a generic IEC 61850 client simulation. Such a client will browse the content of an IED and based on the result provide an intuitive interface, for example to send commands to an IED and display the resulting feedback in the event list.

Another use case for IED simulation is the usage of GOOSE and SV messages. In case a GOOSE or SV sender is not physically available a simulation can be used to produce the required messages on the bus for the IED under test as mentioned above

The key to ensure consistency of simulation is the re-use of the SCD file also for the simulation. All required information including configuration information is contained in the SCD file making additional configuration of the tool superfluous.

The simulation tool should contain a way to block unintended simulation of an IED. In case an IED with the same addressing information as the IED to be simulated is already available on the network, simulation must be blocked to avoid duplicated sending of potential different values.

4.4 Documentation Tool

At the end of the commissioning, a documentation tool should gather all maintenance relevant information from the commissioned SA system such as IED firmware and configuration versions, serial numbers, etc. and store them in a report. This information is implicitly contained in the final updated SCD file since it presents a kind of standardized project database. This may be a very large file and linear searching in is very time consuming. Therefore, the equivalent project information is normally stored in a vendor specific project data base for fast access. As complement a documentation tool reading out the information of interest (e.g. as listed above) directly out of the installed system is very convenient.

5 Required skills and experience for testing of IEC 61850 systems

IEC 61850 Systems demand additional skills to the operational and process know how of an SA system. These skills are essential on side of the project engineers as well as on side of the maintenance personal in the utilities.

With the introduction of communication in the SA systems, basic data communication know-how for a field user was required. With the introduction of IEC 61850 at least the major principles of IEC 61850 such as the data model and functional representation in logical nodes (LN) have to be known. The same applies also for using Ethernet and switches. In any case the maintenance engineer needs to be trained in relevant techniques to isolate and fix problems in a structured way.

Engineering and Testing Tools can help to fulfill the related new requirements, but a tool does not replace the knowhow of an engineer. The main objective of the tool must be to facilitate the configuration process, to hide the system complexity and to provide the required information in adequate level. Not an IT and communication (ITC) specialist is needed for every project, but a substation engineer with all his skills! The ITC expertise shall be embedded in the tools.

6 Conclusion

On one hand IEC 61850 allows to combine system components from different vendors to one SA System with enhanced and distributed functionality and a complex interaction between these components. On the other hand IEC 61850 supports the simplification of the related configuration, testing and maintenance activities by providing SCL to be used by tools in all phases of the testing life cycle. To ease the handling of software updates and licensing for testing tools, it is most convenient if all of the above mentioned tool types are combined in a single software package.

Bibliography

[1] IEC Standard 61850, “Communication networks and systems in substations”.

[2] K.P.Brand, V. Lohmann, W.Wimmer, Substation Automation Handbook, ISBN 3-85759-951-5, 2003, http://www.uac.ch

[3] UCA International Users Group - http://www.ucainternational.org

[4] W.Baass, K.P.Brand, S.Gerspach, M.Herzig, A.Kreuzer, T. Maeda “Exploiting the IEC 61850 potential for new testing and maintenance strategies” Cigre B5-201, 9 pages, 2008

[5] K.P.Brand, T, Maeda, P. Owen, W. Wimmer. “Requirements for different tools over the life cycle of IEC 61850-based substation automation systems” Cigre B5.PS119, 8 pages 2011