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Conformance Testing for IEC 61850 Communication Protocol of Intelligent Electronic Devices

M. Pradish* and Amit Jain

Central Power Research Institute, Bengaluru – 560080, Karnataka, India; pradish@cpri.in, amitjain@cpri.in

Abstract

There are various Intelligent Electronic Devices (IEDs) placed in a Substation Automation System (SAS) based substations. These IEDs are meant for performing the respective functionalities that they are intended for, which includes protective relays, transformer tap changers, Bay control units, RTUs, Protocol Converters etc., present in a substation. These IEDs are also required to communicate with each other and that may include IEDs from various other manufactures also. This paper provides brief details of the IEC 61850 standards and the test procedures formulated by UCA International Users Group (UCA IuG) used for testing Server IEDs which are used to validate for their conformance to the standard. This paper also helps in addressing the interoperability of IEC 61850 based IEDs among the multivendor solutions subjected to conformance testing and are used in the Substations.

Keywords: Conformance Testing, Intelligent Electronic Devices (IEDs), Interoperability, Substation Automation System (SAS), IEC 61850

1. Introduction

A better visibility of the substations with its interconnection and availability of critical system information on real time are considered vital for taking any decision by the operator and for maintaining healthiness of the power system network. Like any other Power System components, the components placed in the substation are now going digital both with hardware and software advancements. These digital systems are designed for interacting with each other and to share information. Hence, it is expected that these digital systems with IEDs are interoperable. To reap the benefit of the technology and advancements, the existing electromechanical and other non-standard based electronic devices are being replaced with such standard based IEDs by the power utilities. By doing so the real time data from multivendor IEDs are available with the utilities and relevant data could be shared with its stakeholders. The data received shall be timely, secure, accurate and reliable. IEC 61850 standard for communications in substations has created opportunities in a standardised way of the design and implementation of the protection, automation and control in an IED for electric power systems. It helps in integration of IEDs based on the development of advanced protection and control applications[1].

IEC 61850 standard for substation has provided the requirements for protection, monitoring, control, etc. in a simpler and standardised way. The features available in this standard have improved the functionalities of the IEDs and have also reduced the cost of erection and implementation of SAS based substations[2]. In earlier time, communication for the functions and automation within the substation was by using traditional approach of hard copper wiring between all the communicable electronic devices that may include protective relays, RTU, Bay

**Author for correspondence*

control unit, transformer tap changers, etc. Multiple protocols exist for substation automation, which includes proprietary protocols with custom communication links. IEC 61850 standards defines data models and abstract communication services that have also mapped over standard protocols and IED such as TCP/MMS and the ethernet switches which makes this standard a future proof standard[3]. Previously, any integration between the IEDS in a system was manual and it used to be expensive and labour intensive to put in the system in place and each integration project used to be different for such projects[4].

Interoperation of devices from multiple vendors would be preferred and benefit the users of substation automation devices. IEC 61850 is one such standard which is most common among utilities and most countries are adapting to this standard. Most of the SAS related issues for integration and operations are addressed and this standard also has one dedicated part IEC 61850 – 10 exclusively for the purpose of testing for communication protocol conformance.

UCA International Users Group (UCA IuG) has been in forefront in assisting and brining out common test procedures for IEC 61850 conformance testing and also has been a nodal group accrediting the testing laboratories world-wide. This group consists of experts including researchers, consultants, testing laboratories, manufacturers, utilities, academia etc. from world-over. The UCA users group is very active and keeps updating the testing requirements, procedures, accreditation process etc. to meet the recent updates and providing clarifications as per the requirements of the standard and end users.

The type testing or conformance testing of IEDs involves verification of the data flow on to the communication channels concerning access, formats and bits, the sequences, timing related details, time synchronisation, response to errors and error handling[5]. The conformance testing also covers the overall implementation of all testing features of the standard as discussed in section IV.

In India, Central Power Research Institute is the only laboratory that has been accredited by UCA IuG for carrying out conformance testing for IEC 61850. The laboratory is accredited as Level A laboratory that means the laboratory is a third party independent laboratory certified for ISO 9001 or ISO/IEC17025. CPRI laboratory is accredited for ISO/IEC 17025:2015 by National Accreditation Board for Testing & Calibration Laboratories (NABL).

2. IEC 61850 Standard Series

The IEC 61850 series of all the parts of the standard are published by IEC under the general title "Communication networks and systems for power utility automation"[6–13]. The intention of this standard is to offer interoperability between all devices for power utility automation systems. The details of the parts of the standard considered for conformance testing are listed in Table 1 and their significances are briefly described subsequently.

Table 1. Standards used for conformance testing

IEC 61850-5	Communication requirements for functions and device models.
IEC 61850-6	Configuration description language for communication in electrical substations related to IEDs.
IEC 61850-7-1	Basic communication structure – Principles and models.
IEC 61850-7-2	Basic information & communication structure – Abstract communication service interface (ACSI).
IEC 61850-7-3	Basic communication structure – Common data classes.
IEC 61850-7-4	Basic communication structure – Compatible logical node classes and data object classes.
IEC 61850-8-1	Specific communication service mapping (SCSM) – Mappings to MMS (ISO/IEC 9506-1 and ISO/IEC 9506-2) and to ISO/IEC 8802-3
IEC 61850-10	Conformance testing.

IEC 61850-5: Communication requirements for functions and device models: As the name suggests, this part of the standard series defines the requirement of communication networks with its systems for power utility automation, and also the communication architecture for the subsystems like substation automation. The subsystems put together may result in the description of communication architecture for the overall power system management. Communication between the devices in the subsystems and within the power utility automation system fulfils all the functions to be performed. Performance requirement of the data exchange does not mean only for the data transfer time taken between the

IEDs but also for data exchange quality that avoids the loss of information in the communication.

IEC 61850-6: Configuration description language for communication in electrical substations related to IEDs: This part of the standard series specifies format for the file describing communication related to IEDs, its configuration and parameters for IED communication configurations, functions of switch yard structures and their relation. The purpose of providing the format is to standardise the IED descriptions capability, and SAS descriptions between various IED engineering tools provided by the manufacturers and system integrators and system engineering tool of various manufacturers could be exchanged in a harmonious way. The language is defined as System Configuration description Language (SCL). The IED and the model for communication system in SCL is as per the IEC 61850 series. The language for the configuration is based on the Extensible Markup Language (XML).

IEC 61850-7-1: Basic communication structure - Principles and models: This series of the standard provides an overview of the communication architecture and exchange of information and data between systems for power utility automation like the protection relays, switchgears, transformers, etc. This part of the document also provides a set of specifications which details a layered communication architecture for power utility automation. Also, it provides details regarding the abstract definitions of classes and services which helps in the specifications that are independent of specific protocol stacks, the implementations, and the operating systems.

IEC 61850-7-2: Basic information & communication structure – Abstract communication service interface (ACSI): This part of the standard series defines the abstract communication service interface (ACSI) to be used in the utility application. It requires cooperation of intelligent electronic devices on real time basis. The defined ACSI is independent of the underlying communication systems.

IEC 61850-7-3: Basic communication structure – Common data classes: This part of the standard is used to provide specifications of the abstract common data class and it provides constructed attribute class definitions. The abstract definitions are mapped into a concrete object definition that would be used for a certain protocol.

IEC 61850-7-4: Basic communication structure – Compatible logical node classes and data object classes: All the data objects in the data model requires a strong definition as far as the syntax and semantics are concerned. The semantics of data objects are given by the names assigned to common logical nodes described in this part of the standard and the data objects they comprise. Interoperability would be possible if the data objects are properly defined and is made mandatory. Also, data objects with full semantics are not the only elements required to realise interoperability, the data objects and services presented by IEDs with a proper device model are also required. To describe both the device abilities and the communication of the IEDs in the connected system, the configuration language used is the SCL.

IEC 61850-8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO/ IEC 9506-1 and ISO/IEC 9506-2) and to ISO/ IEC 8802-3: This part of the standard provides specification details for layered utility communication architecture. It provides detailed information on how to create and interchange communication messages that implement abstract services and models specified in IEC 61850-7-4, IEC 61850-7-3, and IEC 61850-7-2. The mapping permits for data exchange over ISO/IEC 8802-3 LAN between all kinds of utility devices and IEDs

IEC 61850-10: Conformance testing: This part of the standard specifically discusses about the requirements of Conformance testing. The methods and abstract test cases for the requirement of conformance testing of server, client and sampled value devices used in utility automation systems are defined. Also, the methods and abstract test cases for carrying out the conformance testing of the engineering tools used in the automation systems are described. This part of the standard also specifies the details pertaining to the techniques for carrying out conformance testing of client, server and sampled value on the IEDs and for the engineering tools. It also describes the specific measurement techniques that are to be used while declaring the performance parameters. It is envisaged that the use of these techniques would improve the ability of the system integrator to integrate and support the IED's and its applications as intended.

3. UCA IuG Conformance Test Procedure

The detailed Conformance Test procedure for carrying out testing as per IEC 61850 is provided by the UCA International Users Group[14]. The procedure provides in detail the test description steps and the expected results

for each step. The results received by the test system from the Device Under Test (DUT) for each step are validated by the tool with reference to the expected results and the same are logged, analysed and validated.

The test procedure document also provides the list of documents to be provided by the manufacturer in a prescribed format for providing inputs and to carry out the test using the conformance test tool. Also, based on these documents provided by the manufacturer, applicable test blocks and applicable test cases under conditional test cases are identified by the test engineer. The details regarding the documents and the formats to be provided by the manufacturer are described in the next section.

4. IEC 61850 Conformance Testing

IEC 61850 conformance testing is carried out as per the test procedures brought out by UCA International User Group. The testing is carried out using Conformance Testing software tool. This test tool is a third party software tool specifically designed only for carrying out conformance testing of IEDs for IEC 61850 conformance. The Device Under Test (DUT) is connected to the ethernet port of the test system though its fibre/ copper ethernet port. The test system is a computer to which the conformance testing software is loaded. The software has the following three parts for carrying out the test:

1. Client Simulator
2. Analyzer
3. Time Master

Typical test environment for carrying out the conformance testing is shown in the Figure 1.

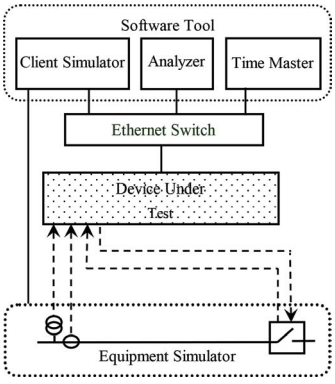

Figure 1. Conformance test setup for IEC 61850.

The client simulator will act as a client and the IED which is the DUT will be the server. The client simulator will simulate the test cases as per the test procedures provided by UCA IuG and all the steps are executed. During this process, for every request sent by the client simulator, the DUT is expected to respond and communicate as per the requirement of the standard. The request and response are captured and analysed by the Analyzer. The time master will act as the SNTP server and the time synchronization of the DUT is validated. The equipment simulator is used to apply suitable voltage and current to simulate parameters including the data change, measurement value, quality change etc., as required for carrying out testing.

The list of all the test blocks and services for which conformance testing could be carried out as per IEC 61850 are listed in Table 2. The number provided in the bracket against each service in the table is the maximum number of test cases available for that particular service and those many tests could be performed on a DUT.

Each test block is classified with mandatory and conditional test cases. The mandatory test cases are those test cases which are to be mandatorily supported by the DUT if the literatures pertaining to that DUT are mentioning about the implementation of that particular conformance block. Once all the mandatory test cases are supported by the DUT as per the literatures and input documents, then it shall mean that the DUT supports that particular service. Then, there are also conditional test cases and each of the conditional test cases is to be assessed for applicability for testing from those test service block for which the mandatory test cases are supported. This assessment is based on the inputs provided by the manufacturer as input documents for testing in a standard template recommended by UCA International Users Group. Now, all those test cases supported by the DUT under the conditional test case also become mandatory for testing. This is to say that if a particular service is supported by the DUT then the entire mandatory test cases and all those supported test cases from the conditional test are tested for conformance.

The test input documents for the DUT are to be provided by the manufacturer in the format prescribed

by the UCA IuG which includes Protocol Implementation Conformance Statement (PICS), Protocol Implementation eXtra Information for Testing (PIXIT), model implementation conformance statement (MICS) and Technical Issues Implementation Conformance Statement (TICS)[5,14]. The details provided in these documents are taken as inputs to the conformance test tool. Also, these documents decide the applicable conditional tests and the applicable conformance blocks supported by the DUT.

Table 2. Test blocks for services for which conformance testing could be carried out

Particulars	Maximum Test cases
• Basic Exchange	(26)
• Data Sets	(7)
• Data Set Definition	(24)
• Substitution	(3)
• Setting Group Selection	(4)
• Setting Group Definition	(13)
• Unbuffered Reporting	(21)
• Buffered Reporting	(30)
• GOOSE Publish	(13)
• GOOSE Subscribe	(14)
• Direct Control	(18)
• SBO Control	(27)
• Enhanced Direct Control	(20)
• Enhanced SBO Control	(28)
• Time Synchronization	(7)
• File Transfer	(8)
• Service Tracking	(17)

The actual laboratory setup is shown in Figure 2 where one IED is connected to the test system as a sample DUT. All the applicable tests were carried out on this server IED those are applicable based on the documents provided by the manufacturer as per the test procedures[5,14].

Figure 2. Laboratory conformance test set up.

Conformance testing was carried out on this particular DUT (an IED in this case) for Basic Exchange, Data Sets, Setting Group Selection, Unbuffered Reporting, Buffered Reporting, GOOSE Publish, GOOSE Subscribe, Direct Control, SBO Control, Enhanced Direct Control, Enhanced SBO Control, Time Synchronization and File Transfer based on the documents provided by the manufacturer in the prescribed format provided by UCA IuG. The following IEC 61850 conformance blocks have been tested with a positive result (number of relevant and executed test cases / total number of test cases) for this particular IED:

Basic Exchange (24/26), Data Sets (4/7), Setting Group Selection (4/4), Unbuffered Reporting (18/21), Buffered Reporting (25/30), GOOSE Publish (12/13), GOOSE Subscribe (14/14), Direct Control (6/18), SBO Control (12/27), Enhanced Direct Control (7/20), Enhanced SBO Control (12/28), Time Synchronization (4/7), File Transfer (7/8).

The test logs were analysed and it is found that the sample IED, on which the conformance test was performed, has not showed to be non-conforming to IEC 61850 Edition 2 Parts 6, 7-1, 7-2, 7-3, 7-4 and 8-1 standard for communication networks and systems for power utility automation. Hence, the DUT is affirmed that the IED is meeting the standards requirements and confirming to all the tests accomplished on the IED.

5. Conclusion

IEC 61850 standard has brought in a revolution in the substation environment and this standard provides greater insight on defining the services and data classes that helps in achieving interoperability. As the way of communication is standardised, it facilitates the conformance testing for IEC 61850 series of standards and helps in reducing field issues during integration and commissioning of SAS. The conformance test procedures brought out by UCA IuG are used by all the accredited laboratory for carrying out conformance testing to IEC 61850. Conformance testing was carried out on a DUT as per the test procedure and it was found that the DUT meets all the conformance requirements for IEC 61850 communication.

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