Monitoring and Checking Standard IEC 61850 Respect to the Manufacturer

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Abstract— Recently in the context of Smart Grid, it has worked to IEC 61850 standard, which application is getting more common. This standard defines an initial step towards a smarter grid. IEC 61850 "Communication networks and systems in substations", will bring open and interoperable systems for the automation domain substations. The development of the standard has generated requirements for manufacturers of devices compatible with it. These manufacturers are forced to have their equipment meets certain requirements regarding the functionality of the devices. The aim of this work is to specify the standard techniques for the development of conformance testing. The idea is to make a comparison between the concepts and guidelines that define the standard IEC 61850 for the development of conformance tests, compared to other guidelines and methodologies established in the electricity sector for compliance testing of different industrial communication protocols.

Key Words— IEC 61850, Conformance Testing, Substation automation, SCL, IED, LN, MMS, ACSI.

I. Introduction

The tests developed in devices in order to evaluate how the manufacturer implemented the standard features and capabilities of the IED IEC 61850 are covered by IEC 61850-10 "Conformance Testing". This defines some of the methods and test cases that must be applied to equipment in order to achieve compliance with IEC 61850. But compliance does not mean that devices must to fulfill all the functions and services that are specified in the standard. Compliance means that the device meets a limited way some of the functions provided by the standard.

The aim of this work is to specify the standard techniques for the development of conformance testing. The idea is to make a comparison between the concepts and guidelines that define the standard IEC 61850, with respect to other guidelines and methodologies established in the electricity sector, without losing sight of the concepts and tests developed by international laboratories.

The use of these techniques improve the ability to test system integration to easily link Intelligent Electronic Devices (IED), operate IED correctly and properly support different applications in SAS (Substation Automation System).

The aim of conformance testing is to generate security to the system integrators in order to reduce operating errors and problems that may arise in the field.

The tests presented in this article served as the basis for the development of a project that create a testing laboratory at the Faculty of Mines of the National University from Colombia with support from CODENSA SA ESP

II. Context of the Communications Sector in the Electricity Sector

Major advances in communications technology have made that communications technologies are developed for the power sector which is expanding rapidly.

In the early, communications systems in substations were unsophisticated. It had measuring and protection analog devices and electromechanical relays. It was required much wiring for the equipment signals.

The next breakthrough was the development of communication protocols by each relay manufacturer; they developed their own protocols to communicate their own devices, which lead to clients using specific applications from a specific manufacturer.

Currently with the development of IEC 61850 that situation could change, because the standard tends to standardize equipment manufacturers. The main objective of the standard is the interoperability, which means that equipment from different manufacturers can communicate among them, and perform common tasks.

III. Proposal for the Testing Methodology

The development of conformance testing is done based on Fig. 4, which represents a test model to follow with the devices.

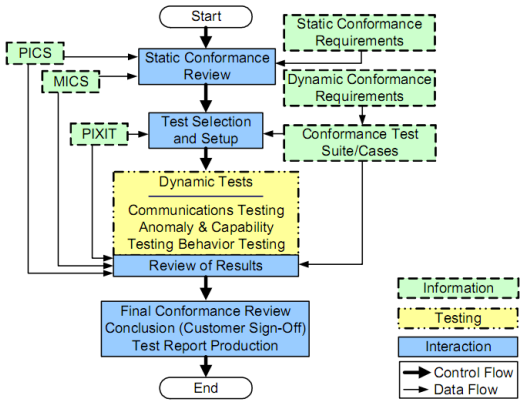

Fig. 1. Conceptual map of the conformance test process [1].

The following steps are intended to propose a methodology for making conformity test an IED with IEC 61850.

Step 0 (Test Environment)

This test environment must contain the following elements to initiate any compliance testing:

- DUT (Device Under Test)
- Test Simulators (Software)
- Test Analyzers (Software)
- Configuration Files (ICD, SCD)
- Ethernet Cords
- Switch

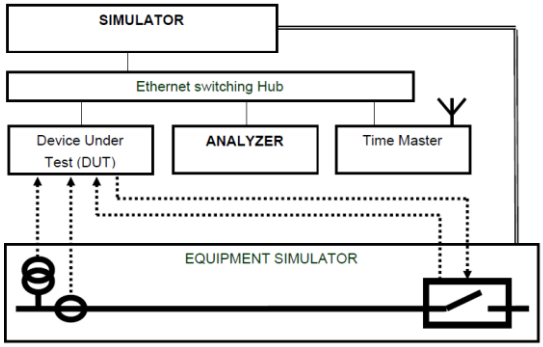

Fig. 2. Test Architecture [11].

It must implement the test architecture of Fig. 2 to continue with step 1.

Step 1 (Documentation)

After having the test architecture shown in Figure 2, it is proceed to gather the necessary documentation of the device under test:

- Model Implementation Conformance Statement (MICS).
- Protocol Implementation Conformance Statement (PICS).
- Protocol Implementation eXtra Information for Testing (PIXIT).
- File with .ICD extension (IED Capability Description).
- File with .SCD extension (Substation Configuration Description).
- Instruction manuals detailing IED Hardware/Software versions.

Step 2 (Sections of the SCL file)

This step is performed in order to verify that the SCL file sections are consistent with the provisions of the IEC 61850-6.

SCL Sections:

- **Header** (identifies the configuration file).
- **Substation** (identifies connections and electrical functions).
- **Communications** (identifies addresses and subnets)
- **IED** (identifies device functions and settings).
- **Data Type Templates** (used to construct the other sections).

Fig. 3 illustrates the hierarchical structure of an SCL file according to IEC 61850-6.

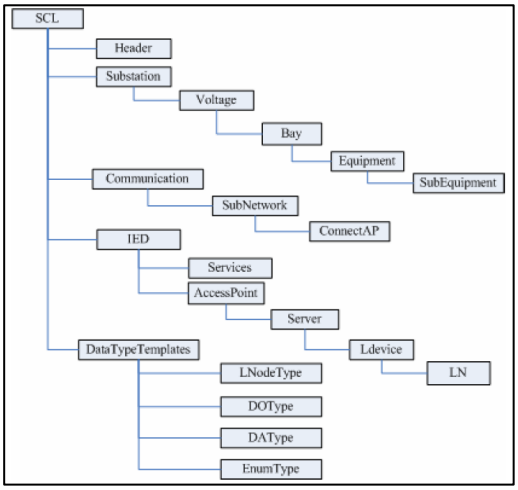

Fig. 3. Hierarchical structure of SCL files [13].

In Fig. 4 it is explain the necessary sections each SCL file.

Section	File Type			
	SSD	ICD	SCD	CID
	Substation One-Line and Functions	IED Template	Complete Substation	Particular IED Configuration
Header	Yes	Yes	Yes	Yes
Substation	Yes	Optional	Yes	Optional
Communications	Optional	One Instance	Yes	One Instance
IED	Optional	Yes, values optional	Multiple	Yes, including values
Data Type Templates	As needed	As needed	Multiple	As needed

Fig. 4. Sections of the SCL files [14].

After performing step 1 it must be checked the configuration files, which must be loaded and tested in the IED:

- It should be tested if ICD file configuration matches the schema of Substation Configuration Language (SCL), defined in [3].
- It should be verified if the ICD file configuration corresponds with current information, services and data types exposed by the DUT (device under test) in the network.
- Check if server capabilities in the ICD file, in the "Services" section correspond to the IED.

Step 3 (Communication Requirements for Functions and Device Models)

This test refers to the requirements for compliance testing. These requirements are classified into the following two categories:

a) Static Conformance Requirements

They refer to the verification of the documents that the device supports, which should be verified with the requirements of the standard. In a simple way it should be defined the requirements that the implementation must meet.

b) Dynamic Conformance Requirements

They refer to the real check in the device. Here it is verified that the device complies with the characteristics that were exposed in the documentation. In a simple way it is defined the requirements to be met by the protocol used in a particular implementation.

Step 4 (Verification of the data model [6],[7])

In this step it is performed the verifying of the data implementation given by the manufacturer in the device:

- Check for required objects for each Logical Node (Presence = M, Optional = O y Conditional = C).
- Check which conditional objects are present and are correct.
- Check conditional objects that are not present and are not right for each logical node.
- Check the data types of all objects of each Logical Node (LN).
- Check if the order of the data objects within the logical node types match the standard [7].
- Check if the order of the attributes of the data within the data objects types match the standard in [6] (Common Data Classes).
- Check if the manufacturer specifies extensions of the implemented data models in accordance with extension rules in [7] Annex A. (only when the extension is implemented).

Step 5 (Mapping of the ACSI models and services)

In this step it is defined the communication requirements for IEC 61850 products and it is evaluated the necessary communication skills to support the SAS (Substation Automation System) environment.

It is valid to clarify that the letter 'A' in ACSI means "abstract", and that the test of the services is performed without explicitly invoking ACSI service requests by name. The ACSI test is done through the MMS services which have its equivalent in ACSI.

IED manufacturers give the Protocol Implementation Conformance Statement (PICS) document, which contain a series of tables which identify the communication features that may or may not be implemented on a device.

Fig. 5 shows the communication stack of IEC 61850.

ACSI Compliance Statement (Annex A):

The following ACSI compliance statements are used to provide an overview and give details of a device that demand conformance with ACSI [5]:

- ACSI basic compliance declaration.
- Compliance declaration with ACSI models.
- ACSI compliance declaration service.

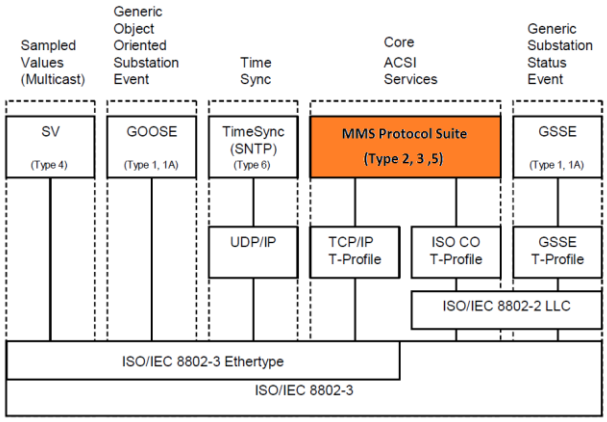

Fig. 5. IEC 61850 Communication Model [6].

To specify the communication functions assigned to a SCSM. NOTE: The statements in this annex are summarized in the sense that ACSI models and services are assigned to the applications layer models, services and protocols. Additional details on the compliance are defined in SCSM.

Declaration of ACSI Compliance Services:

In this step of conformance declaration it is defined what ACSI services are required. ACSI conformance declaration services are defined in Fig. 6.

The AA header column refers to the type of association, TP/MC:

- TP: It refers to *two-party*, in other words TCP/IP.
- MC: It refers to *Multicast*, is used mainly for GOOSE/GSSE.

These protocols work in the Ethernet layer.

	Services	AA: TP/MC	Client/ subscriber	Server/ publisher	Comments
Server (Clause 6)					
S1	ServerDirectory	TP		M	
Application association (Clause 7)					
S2	Associate		M	M	
S3	Abort		M	M	
S4	Release		M	M	
Logical device (Clause 8)					
S5	LogicalDeviceDirectory	TP	M	M	
Logical node (Clause 9)					
S6	LogicalNodeDirectory	TP	M	M	
S7	GetAllDataValues	TP	O	M	
Data (Clause 10)					
S8	GetDataValues	TP	M	M	
S9	SetDataValues	TP	O	O	
S10	GetDataDirectory	TP	O	M	
S11	GetDataDefinition	TP	O	M	
File transfer (Clause 20)					
S57	GetFile	TP	O	M	
S58	SetFile	TP	O	O	
S59	DeleteFile	TP	O	O	
S60	GetFileAttributeValues	TP	O	M	

Fig. 6. Declaration Models of ACSI Conformance [2].

Step 6 (Acceptance criteria in compliance testing)

This step corresponds to the format documentation required by IEC 61850. In the test structure and the test cases which indicates what it is wanted to test, must be completely filled the data. The document shows the test procedures used in the device, as there are listed the steps and compliance of the

standard parts involved, test results, description of the steps, problems and observations during the test.

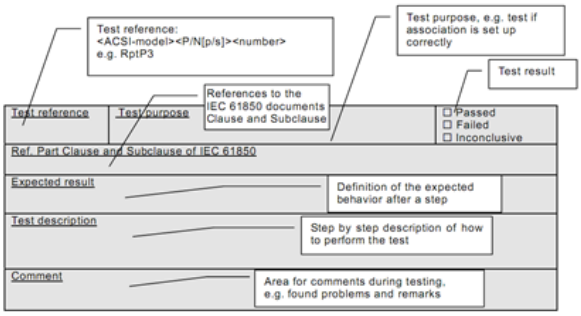

Fig. 7. Format of test procedures [1].

IV. Application of the Methodology in a Study Case

The next development is the application of the proposed methodology to the IED REL 670 ®, where is specified and showed the execution of the steps in the IED.

Step 0 (Test Environment)

The device under test is the ABB REL 670 ®. Fig. 8 shows the architecture used for conducting the tests:

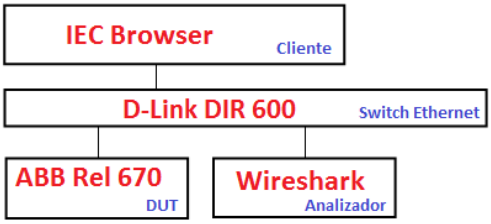

Fig. 8. Test Architecture [11].

Step 1 (Documentation)

The following documentation was supplied by ABB:

- 1MRK117-792, rev G; IED 670, version 1.2, MICS.
- 1MRG000835, rev C; IED 670, version 1.2, PICS.
- 1MRG000707, rev C; IED 670, version 1.2, PIXIT.
- Files downloaded from the current configuration of the relay.
- File_Rel_670.icd.
- File_Rel_670.scd.

Step 2 (Configuration Files)

It should be tested if the configuration of ICD file matches the schema of Substation Configuration Language (SCL), defined in [3].

- It should be verified if the configuration of ICD file corresponds with the current information, services and data types exposed by the device under test (DUT) in the network.
- Verification of the information contained in the .ICD file.

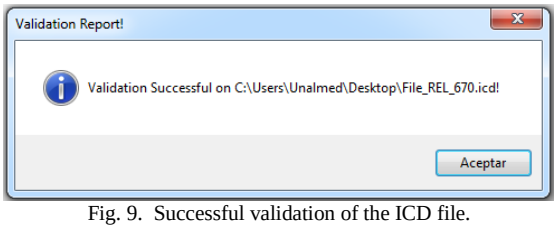

Fig. 9. Successful validation of the ICD file.

Step 3 (Static and Dynamic Compliance Requirements)

Statics Requirements:

These refer to the functional requirements of the device regarding the protocol which are defined according to the PICS document. Review the documentation that must be supported by the device.

Conformance of the models
That the server supports SCSM: IEC 61850-8-1

- General parameters in the MMS request.
- General parameters in the MMS response.

For the client and the server must support:

- Logical Devices
- Logical Nodes
- Data
- Data set
- Reporting
- Buffered report control
- File transfer

Dynamic Requirements:

It is defined the scope that the device should meet. These refer to the performance requirements of the device regarding the protocols, which are defined according to the PICS document.

That the server and the client support:
Create, delete and edit:

- Logical Devices
- Logical Nodes
- Data
- Data set
- Reporting

That supports multiple clients connected to the device for download the files.

At the level of services, that supports the ACSI services

- GetAllDataValues
- GetFile
- DeleteFile

Conformance of the services

- LogicalDeviceDirectory
- LogicalNodeDirectory
- Report
- Data-change (dchg)

- File transfer
- GetFile
- DeleteFile

Step 4 (Verification of the data models)

In this verification is taken into account first the devices and logical nodes present in the IED ABB REL 670 ®.

For the logical devices (LD) present int the device, it is carried the following conformance testing methodology concerning to model validation of data contained in the IED:

- Check the presence of required objects for each Logical Node (Presence = M, Optional = O y Conditional = C).
- Check the conditional objects that are not present and are not right for each logical node.
- Check that the order of the data objects within the logical node types match the standard [2].

In the verification of the data model is take into account the MICS document (Model Implementation Conformance Statement). In this document there is a description of the types of logical nodes and data contained on the device. Along with this document it should be verified the ICD file, which displays the current settings related to the data model contained in the kit.

Logical Node LLN0

This logical node belongs to a class of common logical node and its data are defined in the standard.

Common Logical Node class				
Attribute Name	**Attr. Type**	**Explanation**	**T**	**M/O**
LNName		Shall be inherited from Logical-Node Class (see IEC 61850-7-2)		
Data				
Mandatory Logical Node Information (Shall be inherited by ALL LN but LPHD)				
Mod	INC	Mode		M
Beh	INS	Behaviour		M
Health	INS	Health		M
NamPlt	LPL	Name plate		M
Optional Logical Node Information				
Loc	SPS	Local operation		O
EEHealth	INS	External equipment health		O
EEName	DPL	External equipment name plate		O
OpCntRs	INC	Operation counter resetable		O
OpCnt	INS	Operation counter		O
OpTmh	INS	Operation time		O
Data Sets (see IEC 61850-7-2)				
Inherited and specialised from Logical Node class (see IEC 61850-7-2)				
Control Blocks (see IEC 61850-7-2)				
Inherited and specialised from Logical Node class (see IEC 61850-7-2)				
Services (see IEC 61850-7-2)				
Inherited and specialised from Logical Node class (see IEC 61850-7-2)				

Fig. 10. Common Logical Node (LN) class [2].

Verify that the data contained in the IED are identical and have the same structure presented in Fig. 10. From those data objects verify that are present the obligatory:

- Check the data type of all objects of each Logical Node (LN).
- Check if the order of the attributes of the data within the data objects types match the standard in [3] (Common data classes).
- Verify that the data types which correspond to the data contained in logical nodes are consistent with the types of information required in [3].

Watching the relay files it can be recognized that the data contained in attributes are type LLN0:

- INC
- INS
- LPL

Data types of the logical nodes.

It is verified that the data types correspond to the data category INC (Controllable integer status). The data type corresponds to the data set Controllable status information.

Attributes of data contained in the data object "Mod" of the ICD file.

- Mod
- Oper
- ctlVal
- origin
- ctlNum
- stVal
- q
- t

Data for the class INC. must be commensurate with the information specified in [3].

INC class					
Attribute Name	**Attribute Type**	**FC**	**TrgOp**	**Value/Value Range**	**M/O/C**
DataName	Inherited from Data Class (see IEC 61850-7-2)				
DataAttribute					
control and status					
ctlVal	INT32	CO			AC_CO_M
operTm	TimeStamp	CO			AC_CO_O
origin	Originator	CO, ST			AC_CO_O
ctlNum	INT8U	CO, ST		0..255	AC_CO_O
stVal	INT32	ST	dchg		M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
stSeld	BOOLEAN	ST	dchg		AC_CO_O
substitution					
subEna	BOOLEAN	SV			PICS_SUBST
subVal	INT32	SV			PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
configuration, description and extension					
ctlModel	CtlModels	CF			M
sboTimeout	INT32U	CF			AC_CO_O
sboClass	SboClasses	CF			AC_CO_O
minVal	INT32	CF			O
maxVal	INT32	CF			O
stepSize	INT32U	CF		1 ... (maxVal – minVal)	O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M
Services					
As defined in Table 31					

Fig. 11. Controllable integer status [3].

It is observed that the attributes *ctlVal*, *origin*, *ctlNum*, *stVal*, *q* and *t* correspond to the control category, and *ctlModel* attribute corresponds to the configuration category and all these in turn are part of the INC attributes. This shows that the attributes/objects match the requirements stated in the standard [3].

Check if the manufacturer specifies the data model extensions implemented in accordance with extension rules in [2] Annex A (only when the extension is implemented).

To verify the data model extensions implemented in the device, it should take a look at the MICS document (Model Implementation Conformance Statement) and check the standard [2] to verify the correct extension in the data model.

Extension Rules of Logical Nodes and Data.

The Extension Rules for a Logical Node are [2]:

- If there is any logical node class that fits the function to be modeled, an instance of the logical node will be used with all mandatory data (M).
- If there are specialized versions of this function with the same basic data (e.g. ground, phase, zone A, zone B etc.), different instances of this class of logical node will be used.
- Other extensions are not allowed in the field of substation automation.

Fig. 12 shows an example for *time overcurrent*.

Logical Node Class Name: PTOC (Time overcurrent)		
LN Instance Name	Meaning	Meaning of "Start value" StrVal
GFDPTOC	Ground Fault Detection	"Ground Start Value"
PFDPTOC	Phase Fault Detection	"Phase Start Value"

Fig. 12. Extension of functions of a Logical Node (LN) Example [2].

Step 5 (Mapping of the ACSI models and services)

This step is the evaluation of the performance of services by the IED. Here it is verified that the device supports the execution of a specific service and besides that make capturing and analysis with regard to IEC 61850-7-2.

Declaration of ACSI conformance services

In the declaration of ACSI conformity services defined in standard, occurs the compliance condition for file transfer services.

	Services	AA: TP/MC	Client/ subscriber	Server/ publisher	Comments
File transfer (Clause 20)					
S57	GetFile	TP	O	M	
S58	SetFile	TP	O	O	
S59	DeleteFile	TP	O	O	
S60	GetFileAttributeValues	TP	O	M	

Fig. 13. ACSI Statement of Compliance Services. [5]

The terms of compliance with the standard regarding the IED 670 are exposed in the PICS document.

	Services	AA: TP/MC	Client (C)	Server (S)	Comments
S57	GetFile	TP		Y	
S58	SetFile	TP		N	
S59	DeleteFile	TP		Y	
S60	GetFileAttributeValues	TP		Y	

Fig. 14. ACSI Statement of Compliance Services for file transfer [7].

To perform the following tests of the ACSI services it was required the use of IEC 61850 client software. Using the client software it is checked the performance of services by the IED.

It was checked the parameters of the services provided by IEC 61850-7-2:

- File services
- GetFile

GetFile service is used to transfer files from a server to a client.

Parameter name
Request
FileName
Response+
File-Data
Response–
ServiceError

Fig. 15. Parámetro del servicio GetFile [5].

The *FileName* parameter is the name of the file. A positive response indicates a successful request and the *FileData* owns the data transferred. A negative response indicates that the service failed and therefore returns the *ServiceError* service.

ACSI services for transferring files have an MMS equivalent as shown in Fig 16.

IEC 61850 Services	MMS Services
GetFile	FileOpen/FileRead/FileClose
SetFile	ObtainFile
DeleteFile	FileDelete
GetFileAttributeValues	FileDirectory

Fig. 16. IEC 61850 Partial Service Mapping [20].

To test the performance of the services of ACSI, it is used the MMS Wireshark software to monitor communication.

Figs. 17 and 18 show the obtained results.

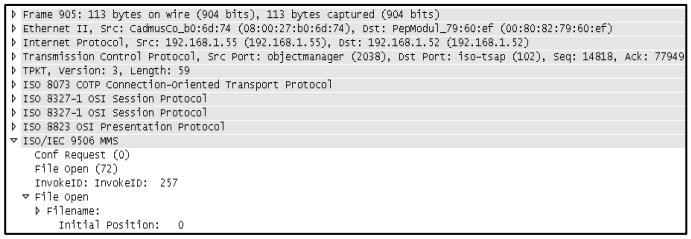

Fig. 17. Service Request "fileOpen".

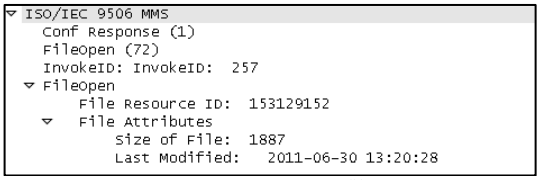

Fig. 18. Service Response "fileOpen".

Performing a Test Case

In the test cases for each model and the ACSI services exist the following categories:

- Positive: Checking the normal conditions. Usually produce a positive response (+).
- Negative: Verification of abnormal conditions. Usually cause negative responses (-).

Positive Test Case

Server & Logical Device & Logical Node & Data

Srv5	Issue one GetDataValues request with the maximum number of data values and check response

Fig. 19. Positive Test Case for Logical Node [9].

It is verified the parameters of the service given by IEC 61850-7-2.

GetDataValues

GetDataValues service will be used by the client to request the *DataAttributes* from a logical node.

Parameter name
Request
Reference
Response+
DataAttributeValue [1..n]
Response–
ServiceError

Fig. 20. Parameter of the GetDataValues service [5].

ACSI services have an MMS equivalence as is showed in Fig. 21.

IEC 61850 Services	MMS Services
LogicalDeviceDirectory	GetNameList
GetAllDataValues	Read
GetDataValues	Read
SetDataValues	Write
GetDataDirectory	GetNameList

Fig. 21. IEC 61850 Partial Service Mapping [8].

The next test pretends to show the reading in the hierarchies of the data from a logical node. To check this, Wireshark catches were made to observe the mapping.

Fig. 22 shows the reading of LLN0$ST.

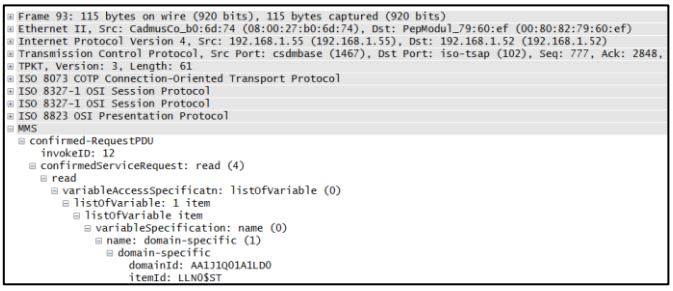

Fig. 22. Request Service "Read".

Fig. 23 shows the response of the "*Read*" service. This will return the read values corresponding to the LLN0$ST data.

Step 6 (Test Report)

In this step it is given the detailed test procedures executed on the device and is performed the filling of test formats. In these formats are compiled the respective procedures, requests, comments and observations to the tests done on the device, and as final part it gives the test verdict.

Fig. 24 shows a test format or test report for the GetDataValues test with test code AssN4.

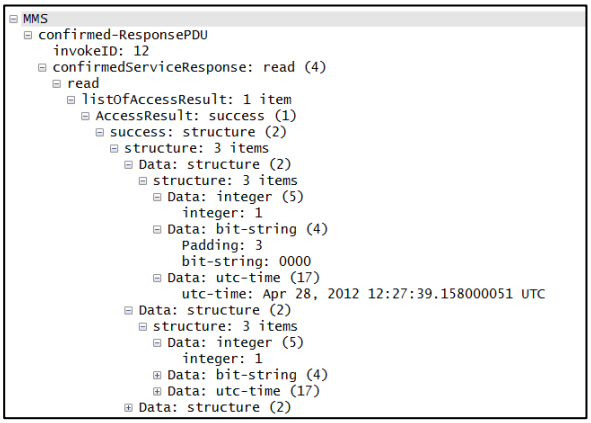

Fig. 23. Service Request "Read".

AssN4	Detección de perdida de enlace	☐ Pasó ☐ Falló X Inconcluso
IEC 61850-7-2 clause 7.4, IEC 61850-8-1 clause 10.2 PIXIT		
Resultados esperados 1. El DUT envía una response+ a la Associate 2. El DUT envía una response+ a la GetDataValues 3. El DUT no envía ninguna response		
Descripción de la prueba 1. Se Configura el SIMULATOR y el DUT con una correcta asociación y autenticación de parámetros. 2. El cliente solicita la asociación 3. El cliente solicita un correcto GetDataValues 4. Se desconecta el enlace físico, entre el switch y el cliente, se espera unos segundos hasta el KEEP ALIVE, en el PIXIT se especifican los tiempos fuera. 5. Conecta el enlace físico. 6. verifique la perdida de asociación del DUT por el envió de una solicitud GetDataValues		
Comentarios Al realizar una conexión del Nuevo del enlace físico no se envia ninguna solicitud, pues se ha perdido la conexión totalmente.		

Fig. 24. AssN4 Test Format [11].

V. CONCLUSIONS

This paper presents the application of a methodology for testing IEC 61850 Ed.1.0 in which files, data and services are checked in the protective device ABB REL 670. This test contemplated a positive test case exposed in IEC 61850-10. The positive test case was the verification of the requests of a data value of the relay.

This paper highlights the importance of developing capabilities for testing conformance to IEC 61850 devices in the country. The tests are primarily aimed to generate security to system integrators, reduce operating errors and problems that may arise. The results obtained in the methodology were achieved based on a standard test architecture given by IEC 61850-10.

This work was limited to testing compliance. But today there are other tests such as interoperability, performance, testing architectures, which can be treated in future developments where new methodologies were proposed to implement this type of testing.

It is necessary to note that the implementations that are done under the IEC 61850 are based on Ethernet networks so it cannot lose sight the cyber security parameters on the network.

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Fig. 25. Available devices in the Laboratory of the Faculty of Mines.

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