Structured Design of Substations Automation Systems according to IEC 61850

Pedro F. M. Dias    J.L. Pinto de Sá
Instituto Superior Técnico, Lisbon, Portugal

Abstract - This work deals with the development of reusable specs for Substations Automation Systems, applying object-oriented concepts and SCL as defined in the new standard IEC 61850. System configuration tools were used in order to create, configure, view and edit all elements of the substation. With these tools, in addition to the graphical construction of the substation and the configuration of all elements associated with it, all kinds of SCL files defined by IEC 61850 are created. After the creation of these files, an SCL validator is used in order to detect any errors made at the XML code. The communication between tools for configuring the system and setting up IEDs is tested in order to see if they can achieve interoperability.

Keywords – IEC 61850, Substations Automation Systems, Interoperability, SCL

I. INTRODUCTION

There are a lot of papers published to date that demonstrate the potential of the IEC 61850 [6-9]. Many of these papers present the main foundations of the new standard and explain how they influence the processes of engineering automation worldwide. The demonstration of possible cases of application and the constant search for new solutions for different types of problems are the main objectives of that work.

This paper illustrates the application of the standard IEC 61850 to the structured design of the substations SAS.

II. IEC 61850

A. General

Parts 7-3 [4] and 7-4 [5] of IEC 61850 specify the object model of a substation. Fig. 1 shows the hierarchical organization within a physical device.

A physical device is an IED and is internally divided into a number of logical devices. The logic devices are in turn divided into a number of logical nodes, each one with its own data and services.

B. ACSI Models

The ACSI is a very useful architecture, in that the services are independent of the content of information and communication protocol. The models and information services for the exchange of information are linked. The services are heavily dependent on models of information, since they specify which services can be performed in a specific device.

The ACSI models allow:
• The specification of a basic model for defining models of information specific to the substation.
• The specification of the exchange of information on service models.

These models can be found in Part 7-2 [3] of IEC 61850.

III. SUBSTATION STANDARD PROJECT

The Substation Standard Project [12] presents a number of technical characteristics that a standard HV/MV substation must respect.

This project sets the SPCC (system protection, command and numerical control) that is responsible for protection, command and control of all organs of the plant. It consists in many modules for processing information which, properly linked, can perform all functions necessary for the operation of a substation.

The architecture of the substation consists of three hierarchical levels linked together:
• Level 0 - process. This level consists in all HV/MV equipment of the substation which interacts with SPCC;
• Level 1 – Bay Unit/Intelligent Electronic Device (IED). This level consists in bay units that perform functions of command and control of the process (Bay level). Each bay unit is associated with each other, one or more IEDs.
• Level 2 – Central Unit. This level is composed by the Local Command Post (LCP), Command Center (CC) and Remote Engineering Center (REC). This level performs the functions related to command and control of the entire installation on site and remotely.

The substation is composed by many types of bay units that have the responsibility to ensure the link between equipment, lines and buses. Each of the bay
units of the SPCC has a set of protection functions which can be blocked at any time.

![Figure 2. Architecture and functional organization of the SPCC](image)

Protection functions are able to detect the faults of the network and try to eliminate them as soon as possible to ensure both safe operation and high quality and continuity of service.

The use of the functions of automatism, which were formerly performed by operators, resulted in an increase of reliability, security and availability of the system, and contributed to a significant reduction in the time of interruption that consumers were submitted.

Given the improving conditions of the substation, the automatic functions aim to eliminate certain types of faults and ensure high quality levels of service. These functions act in a distributed manner in the bay units of the substation.

IV. SCL LANGUAGE

A. SCL Files

The IEC 61850-6 part defines the Configuration Language of the Substation IEDs. The SCL language (Substation Configuration Language) is based on XML (Extensible Markup Language) and is used to describe the single-line diagram of the substation, communications network, the instances of logical nodes and its association to the primary equipment. The major objective of this language used by automation systems for substations is to provide interoperability between different engineering tools of different manufacturers, thus allowing a configuration independently of the substation IEDs and their tools.

The IEC 61850 defines many types of files, identified by its length, each with a specific function.

- **ICD (IED Capability Description):** describes the capabilities of the IED described by the manufacturer in terms of communication functions and data models.
- **SSD (System Specification Description):** describes the single-line diagram of the substation with the functions implemented in the primary equipment, in terms of logical nodes.
- **SCD (Substation Configuration Description):** describes the configuration of communication and functions of the substation automation system and its relationship with the substation. Contains all the IEDs, a section for the substation description and a section for the substation configuration.
- **CID (Configured IED Description):** describes a fully configured instance of an IED.

B. SCL Models

The IEC 61850 defines SCL models to describe the substation, IEDs and communication system. The models can be found in Part 6 [1] of IEC 61850.

C. SCL/Standard Project

One of the objectives of this work is to discuss the appropriateness of the SCL to the Standard Project. A proper match between the configuration language of the standard and this project must be reached so that all configurations of the substation are implemented.

With the analysis of Standard Project and SCL models defined by IEC 61850, it’s clear that there is an almost natural correspondence between them. The substation architecture defined by the Standard Project can be easily implemented using the SCL models specified in IEC 61850. The protection functions can be represented through logical nodes; however, automatic functions are not defined by SCL and must be implemented by programmable logic defined in IEC 61131-3.

The adequacy of these two realities, Standard Project/SCL, is shown below using the system configuration tool and its communication with the IEDs configuration tool.

V. DESCRIPTION OF THE SUBSTATION CONTROL AND PROTECTION SYSTEMS

A. System engineering tools

The creation of SCL files defined according to IEC 61850, can be achieved by many tools available on the market. These tools provide the creation of the Single-Line Diagram, specification of the substation automation system functions and creation of SCL files.

Some of this system configuration tools [13-14] were used for the preparation of this work. Some examples come from these two tools.

B. IED Configuration Tool

Terminal Protection Units (TPU) are designed to perform the supervision and control of specific elements of the network, such as airlines, batteries of capacitors, transformers, among others.

In order to get all data from a Terminal Protection Unit (TPU), it’s necessary to use a configuration tool specific for IEDs [20]. This tool is composed by several modules that allow the parameterization of individual protections. Any function can be set to compare different parameterizations between relays and copy data from one relay to another.
The IED configuration tool has a function that allows IEC61850 view and configure the parameters of IEC 61850 protocol. This unit consists of 4 buffered Report Control Blocks (BRCB) and two Unbuffered Report Control Blocks (URCB) that can be configured through the list of variables associated with the dataset (Fig. 3).

Figure 3. Group data BRCB_A

The publication of GOOSE messages can also be parameterized by the retransmission curve and by data on each GOOSE published. For each control block of GOOSE (GoCB) you can configure a number of parameters, including the contents of the dataset (Fig. 4).

After all the parameters are configured, the changed SCD and ICD files can be exported to be used in the system configuration tool.

Figure 4. Group data GoOut1

C. MV Feeder Bays

With the use of TPU S420 found in the laboratory of Energy, two MV feeder bays and all functions associated with them, can be represented. The standard project specifies a set of protection functions which should be implemented for the proper functioning of each MV feeder bay. Each function is associated itself with a logical node that represents:

<table>
<thead>
<tr>
<th>Logical Node</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>XCBR1</td>
<td>Circuit Breaker</td>
</tr>
<tr>
<td>GDXXSWII</td>
<td>Earthing Switch</td>
</tr>
<tr>
<td>PFDP-TOC1</td>
<td>Phase Overcurrent + Homopolar</td>
</tr>
<tr>
<td>RGFDP-TOC1</td>
<td>Earth Resistant Homopolar</td>
</tr>
<tr>
<td>RBRF1</td>
<td>Breaker Failure</td>
</tr>
<tr>
<td>RFLO1</td>
<td>Fault Locator</td>
</tr>
</tbody>
</table>

Some of the functions specified in the Standard Project to the MV feeder bays cannot be represented by logical nodes, since they don’t exist in TPU S420. Due to this limitation, the representation of the MV feeder bays is made with the logical nodes above.

Through the system configuration tool, the ICD files are imported and the single-line diagrams of the MV feeder bays are made. Each MV feeder bay, according to what is specified by standard project, has a circuit breaker, an earthing switch and current transformer. Through the observation of the design of the MV feeder bays (Fig. 5), logical nodes which are associated to IEDs can be represented by the functions specified in the Standard Project.

D. Exchange of GOOSE between IEDs

The exchange of information between IEDs is one of the most important aspects to demonstrate the validity of using IEC 61850. For this, it’s necessary to configure GOOSE messages that are sent/received by the IEDs found in the substation. The best way to configure these messages is to use both tools for system and IEDs configuration, taking advantage of the Windows environment.

To illustrate the exchange of information between IEDs, a GOOSE message with the status of the position of a circuit breaker is sent. For this, it’s necessary to set the parameters of the TPU that sends this GOOSE message (publisher) and the TPU that receives it (subscriber).

In the IEC 61850 section of TPU that publishes the message, a “GoOut1> Config DataSet” is configured, with the status of the position of a circuit breaker.

In the IEC 61850 section of the TPU that subscribes the created GOOSE message, an entry GOOSE is set “GoIn1> Setup DataSet”. This opens a dialog box of the subscribed GOOSE, with the option of which unit
publishes the desired output GOOSE message, in this case IB1S420:

After choosing the output GOOSE, in this case the “GoOut1> 3” which corresponds to the position of a switch, it automatically opens a window for the configuration of the dataset of the input GOOSE.

It’s also possible, at any moment, to check the status of many digital entities of the TPU that are tested (Fig. 8). In this case it’s important to check the “state of the circuit breaker (open/closed) and” GOOSE Lock “(active/inactive).

The purpose of the test that follows is to check if the publisher (TPU-E) sends a GOOSE message to the subscriber (TPU-R). For this, TPU-E is in test mode and an order of command for opening the circuit breaker is given. Through this order is possible to verify that both units change, i.e. the circuit breakers open (Fig. 10). This means that the TPU-E was ordered to command the opening of the breaker and sent a GOOSE message to the TPU-R to change the position of circuit breaker.

Another way to test the validity of the GOOSE message is to block it. For this, there is an order of command to block the emission of GOOSE in TPU-E (Fig. 11).

When the order for opening the circuit breaker is given, only the TPU-E receives this order, through the opening of its circuit breaker. The synoptic observation of the TPU is the best way to verify these changes. This way you can verify that the circuit breaker of the TPU-E is open, while the circuit breaker of the TPU-R is in undefined state (Fig. 12).

The settings of each IED should not be made repeatedly to each IED. It should be possible to configure all systems of all substations without the need to know the manufacturer of each IED. This configuration
should be made on the system configuration tool, how-
ever, it has limitations that render it.

It should be expected that in a near future these system configuration tools are more developed to enable all kinds of settings for the proper functioning of any substation.

E. ICDs of different manufacturers

The structure of an ICD file should follow the model of the IED specified in part 6 of IEC 61850. This structure is very important to guarantee the success of the imported file by system and IEDs configuration tools.

It’s important to demonstrate that the communication between system and IED configuration tools is possible, no matter what is the manufacturer of the SCL files. For this, two ICD files from different manufacturers were imported to the system configuration tool. These files are successfully imported and visible in the tool section of the IEDs. The differences between ICD files are significant. One manufacturer (M1) separates the logical device in five distinct categories (Control, Measurements, Protection, Records and System), each composed by logical nodes LLN0 and LN. The IEDs don’t differ in LLN0, Report and GOOSE blocks, however, the difference on the logical device structures is critical because it prevents the SCD file from M1 to be successfully imported into the IED configuration tool.

VI. CONCLUSIONS

The introduction of IEC 61850 has a number of possibilities for developing new solutions for automation of substations. In particular, the principles of interoperability and free allocation of functions open new perspectives regarding the design of automation systems using the most modern resources available.

The work began by stressing the importance of IEDs in the current context of automation systems, given that most of the information in the communication network comes from IEDs. The description and understanding of IEC 61850, introduced himself as a very important step to understand how this can be implemented in substations.

To ensure a more uniform engineering configuration, two system configuration tools were used. A number of obstacles were encountered during the use of these tools, however with their maturity, it’s expected that these obstacles can be overcome in the future.

Communication between system and IED configuration tools is one of the most important aspects related to IEC 61850. The data exchange between tools cannot and should not, depend on particular manufacturer. For this, it’s necessary to have some flexibility and openness on the part of suppliers to make the standard applicable in any substation.

Although the IEC 61850 standard, its application and its tools are still in a stage of development, it is possible to believe that this is certainly the future of automation of substations.

REFERENCES

[5] IEC TC 57, “IEC 61850-7-4: Communication Networks and Systems in Substations, Part 7-4: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data classes”.