Actual Trends in Development of Power System Protection and Automation
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IEC 61850 Based Engineering of Protection Systems

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1 INTRODUCTION

The new IEC 61850 international standard for substation and power system communications is not just defining a new protocol, but also introducing abstract models of primary and secondary substation equipment, communications systems and the relationship between all of them. It also defines an XML based format for the description of the above in a standard way that can be used at different stages of the engineering process based on an object oriented approach.

The model used in the substation configuration language is based on the Unified Modeling Language (UML). The different UML diagrams are described with the focus being placed on the ones used by the SCL.

The paper then introduces the different components of the substation model:

- **Substation**: the part that describes the substation primary equipment and their connection on a single line diagram level
- **IED**: represents the functional hierarchy of multifunctional IEDs used at different levels and for different applications in the substation automation system
- **Communication**: the part that contains communication related object types such as communication access points and describes the communication connections between logical nodes as clients and servers

The different types of SCL files are then introduced:

- ICD for IED Capability Description.
- SSD for System Specification Description.
- SCD for Substation Configuration Description.
- CID for Configured IED Description.

The SCL based engineering process is described later in the paper. The use of SSD and ICD files to form SCD files, the differences between ICD and CID files are discussed.

2 OBJECT-ORIENTED ENGINEERING OF SUBSTATION PROTECTION SYSTEMS

Intelligent (microprocessor-based) Electronic Devices (IED) for data acquisition, protection, metering, and control have gained widespread acceptance and are recognized as essential to the efficient operation and management of substations. Their integration in hierarchical substation protection and controls systems over a substation local area network allows significant improvement in the functionality of the system without any increase in the cost. This integration process in substations using IEC 61850 as the communications protocol is based on object models that require the use of appropriate tools to represent the complex architecture of the substation, the communication system and the multiple functions in the IEDs themselves. A major part of the engineering of a substation automation system is related to the architecture and configuration of the secondary equipment in the substation. This requires the development of a formalized format that allows the description of all different elements and their relationships. IEC 61850 defines the object models of the different types of primary and secondary equipment, as well as their functionality in the substation.

The object-oriented approach to the engineering of the substation protection system is based on the system hierarchy and contains nested objects with different levels of complexity.

At the top of the hierarchy is the substation protection automation and control system (SPACS) that contains multiple instances of bay protection, automation and control schemes (BPACS), each defined as a complex object – SPACSO or BPACSO.

Each BPACS contains multifunctional IEDs, defined in the object-oriented design process as a protection, automation and control objects (PACO) with scheme specific functionality.
Each PACO contains multiple logical device objects (LDO) with specific functionality:

- Protection
- Automation
- Control
- Measurements
- Monitoring
- Recording
- Analysis
- Others

Each LDO can contain one to many sub-logical devices sLDO. The sLDO at the bottom of the protection system/scheme hierarchy contains the Function Elements (FE), the smallest functional objects that are represented by Logical Nodes in the IEC 61850 model.

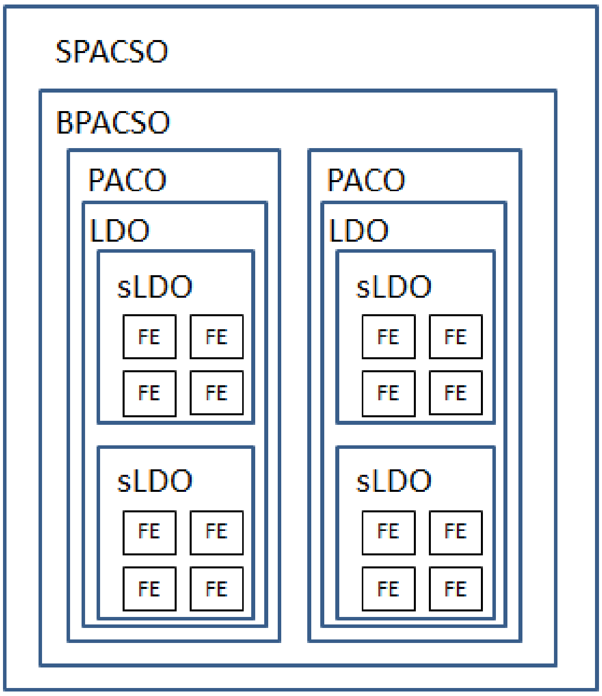

Fig. 1: Object model hierarchy

A substation protection and automation system also includes different tools for visualization and control of the primary and secondary substation equipment - the substation HMI. The user can navigate through the multiple views of the substation one line or communications diagrams, or check the status or settings of a specific IED. The development of the HMI and the mapping of the multiple analog and binary signals from the IEDs is a very labor intensive process that also can be subject to errors at different stages of the engineering process.

The development of IEC 61850 had as one of its goals the definition of a file format that describes the components of the substation and the protection and automation system in a way that allows most of the engineering tasks to be performed automatically.

In order to allow the modeling and exchange of data between different engineering tools required at different stages of the substation engineering process, that file format has to meet the requirement for interoperability. At the same time the overall engineering process should be designed taking into consideration the fact that during the early stages of implementation of IEC 61850 it may be necessary to use also some proprietary data formats.

3 UML AND XML

Part 6 of the IEC 61850 standard defined the Substation Configuration Language (SCL) and its use to describe the substation configuration, IED’s and communication systems in a way that corresponds to the object models defined in different other parts of the standard. SCL is based on UML and XML.

UML

Object modeling is one of the foundations of IEC 61850. The models in the standard represent the abstracts of the essential and communications visible parameters of the complicated real electric power systems world. This process of virtualization requires the use of modeling tools that can present the complex functionality of a substation and its protection and automation systems in a standardized way that can be processed by software and is also easy to represent and understand.

Several modeling tools are wrapped under the heading of the UML. It uses mostly graphical notations to express the design of software and other projects. Different types of diagrams can be used to present data structures, device and operator interactions or any other substation automation or protection related process. Using the UML helps project teams communicate, explore potential designs, and validate the architectural design of the system.

The use of UML requires good understanding of both the tools available and the problem domain they are applied to. In our case the problem domain is the substation, the substation protection and automation systems, including the communications system used by both.

The UML is applicable to object-oriented problem solving. That is why it is used in different parts of the IEC 61850 standard – to represent in a standardized graphical way the complex models of multifunctional IEDs and their interface with the primary substation equipment and the communications network.

From the abstract modeling point of view a model is an abstraction of the underlying problem, while the domain is the actual world from which the problem comes. There are three main components of a model:

- Functional model
- Object model
- Dynamic model

The functional model describes the behavior of the system under different conditions from the point of view of the user. The object model represents the structure, including sub-layers and basic objects, data types, attributes, services and associations. The dynamic model covers the internal behavior of the system, including the interaction between sub-systems and components, exchange of signals and conditions under which an action takes place.

The models of primary and secondary substation equipment consist of objects that interact by sending each other messages. The IEC 61850 object models include all three above mentioned components and the communications visible attributes of what they represent. They have hierarchical structure that corresponds to their functional hierarchy.

Different UML diagrams are used in the IEC 61850 standard to present the abstract models of the substation domain. They represent the foundation of the Substation Configuration Language and the different types of files used to describe the functional hierarchy of the system and data used for exchange between IEDs and applications.

The SCL files need to meet requirements related to the support of different phases in the engineering process. This is achieved through the use of XML.

XML

XML is a relatively new markup language based on existing markup languages that have been used for different applications for many years. XML is an abbreviation for eXtensible Markup Language.

The growing popularity of XML is the result of its flexibility and strength.

In XML the user can create the tags required by the application domain. That is why XML is extensible – it extends the ability to describe a document, letting you define meaningful tags for your applications. For example, since any IED typically provides current measurements, for the phase A current measurement that is available as a floating point we can create a tag called <PhsAf>. In a similar way we can create as few or as many tags as our document needs. It is obvious that we are extending the tags to identify elements by what they are -- not by how they look.

XML applies structure to documents and data. Since SCL documents are sets of related information, the structure is quite important. It is the way we put a skeleton behind the information, so that the pieces of information work together and make sense as a whole.

XML Schemas describes the structure of XML documents. An important property of XML schemas is that they are also extensible, i.e. if necessary the schema can be extended to meet new requirements.

4 UML AND XML APPLICATIONS IN IEC 61850

Part 6 of the IEC 61850 standard specifies a description language for configurations of electrical substations – the Substation Configuration Language (SCL), based on UML and XML Version 1.0.

It is used to describe the substation connectivity, IED configurations and communication systems according to parts 5 and 7 of this standard. Description of the relations between the substation automation system and the substation (switchyard) itself

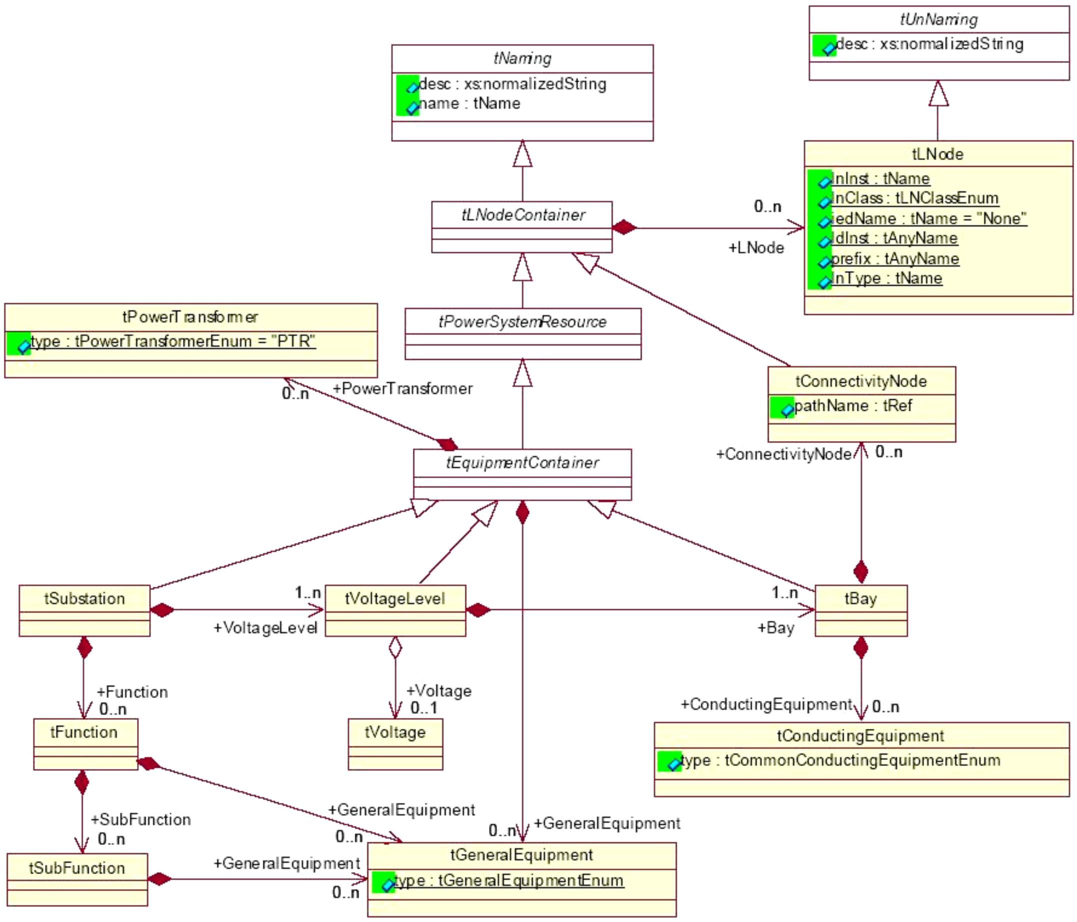

Fig. 2: Example from IEC 61850, Part 6 - Substation Configuration Language (SCL) - UML

SCL was developed to support easier engineering of substation automation systems and application functions. It allows the description of a substation or an IED's configuration to be passed to a communication and application system engineering tool.

Its main purpose is to allow the interoperable exchange of communication system configuration data between an IED configuration tool and a system configuration tool from different manufacturers.

The substation configuration language supports the development of engineering tools that are capable of describing:

- The substation one line diagram representing the different voltage levels, busses, transformers, bays and switching devices. The functional requirements should also be included in terms of allocation of logical nodes to the primary substation equipment.
- The IEDs to be used to perform the required functions based on a fixed number of logical nodes (LNs)
- The communication interface of the different IEDs – specifically their connection to the substation local area network
- The Client-Server and Peer-to-Peer communications for the specific substation automation system implementation

It needs to be understood that the standard does not define any specific software tools that support the intended engineering process. This is a task that the IED manufacturers, substation automation system vendors or third party providers have to develop based on the requirements of the market using the different types of files defined in the standard.

5 SCL FILES

Edition 1 of IEC 61850 defines four types of files required to support the intended engineering process. In order for an IED or a system solution by a manufacturer to be compliant with the standard, they have to support the use of the files described below directly from the IEDs or through tools delivered with the system.

System Specification Description

The description of the system is the first step in the engineering process and until now has not been based on any standardized approach. The IEC 61850 engineering process envisions the use of substation specification tools that allow the user to describe the substation design and associated functional requirements for the substation protection and automation systems.

The data exchange from such a system specification tool and other tools utilized in the process should be based on the System Specification Description files defined in the standard. They have an SSD extension.

The SSD file describes the single line diagram of the substation and the functional requirements represented by logical nodes. The logical nodes can be abstract in the sense that they are not allocated to specific IEDs.

IED Capability Description

The default functionality of an IED in the substation configuration language is represented by the IED Capability Description (ICD) file. It is used for data exchange from the IED configuration tool to the system configuration tool.

This ICD file describes the capabilities of an IED. It contains exactly one IED section for the IED whose capabilities are described. Since it represents the default functionality (i.e. before it has been configured), the IED name in this file is **TEMPLATE**. The file also includes the different logical node types as they are instantiated in the device.

The file extension is .ICD for IED Capability Description.

IEC 61850 does not specify where the ICD file comes from. In IEDs designed for the IEC 61850 environment and with large memory, this XML file may be available from the device itself. For IEDs that are based on existing platforms that were adapted to support the standard, the manufacturer is required to provide tools that output ICD files.

Substation Configuration Description

The configuration of the system is represented by the substation Configuration Description (SCD) file. It contains substation description section, communication configuration section and all IEDs.

The IEDs in the SCD file are not anymore in their default configuration, but as they are configured to operate within the substation protection and automation system. These files are then used to configure the individual IEDs in the system.

Configured IED Description

The difference between the IED Capability Description (CID) file and the Configured IED Description file is that the second includes the substation specific names and addresses instead of the default ones in the first.
The CID file represents a single IED section of the SCD file described above.

6 IEC 61850 ENGINEERING PROCESS

The first step of the engineering of an IEC 61850 based substation protection and automation system is to define the functional specification according to the approved protection, automation and control concepts and user's standards. This is done using the substation one line diagram and as a first step defining the types of bays available in the substation, for example:

- Transmission line bay
- Transformer bay
- High voltage busbar bay
- Distribution feeder bay
- Distribution busbar bay

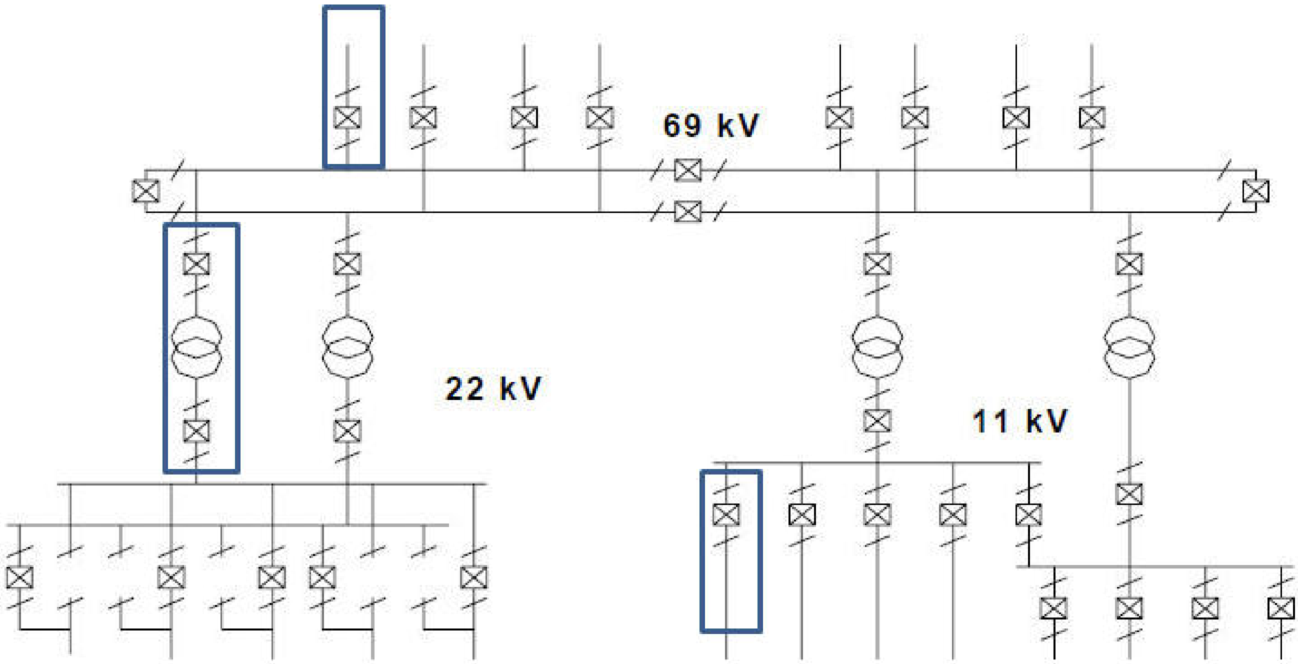

Fig. 3: Bay examples in a substation oneline diagram

After it is clear what BPACOs will be required for the system, the functional requirements for each type of bay are specified:

- Protection functions required
- Measurements and status information needed
- Controls to be used

- Reporting requirements
- Monitoring and recording requirements
- Redundancy requirements
- Communications architecture
- Substation level functions
- Other as necessary

All of the above for each BPACO should be produced by a system specification tool that provides as an output an SSD file corresponding to the function hierarchy in Figure 1. Within the BPACO SSD file the user should be able to define the requirements for allocation of function elements to specific IEDs based on the protection philosophy and represented by the PACO in the object hierarchy. Currently there are discussions within IEC TC 57 Working group 10 to represent it as an ISD (IED Specification Description) file.

A standard substation can then be defined as SPACO. It contains multiple instances of BPACOs.

Once it is clear what protection, automation, control, monitoring and recording functions are required, the system designer needs to select approved by the user IEC 61850 compliant IEDs that contain all data objects and attributes defined by the requirements of the functional specification. This means that they successfully had passed at least the conformance tests defined in Part 10 of the standard and by the UCA International Users Group Testing Subcommittee. Functional and interoperability testing of the IEDs as part of the acceptance process within the user's organization is recommended. In this case this indicates also that the ICD file of the device needs to be a superset of the ISD file.

After the selection of the IEDs, their ICD files and the SSD file become inputs into the System Configurator – the tool used to configure the substation protection and automation system. The key requirement for this tool is that it should support the import and export of the different types of files defined as the SCL. It is also important that such tools should be user friendly in order to simplify the system engineering process.

The output of the System Configurator is an SCD file that can be later used for many different applications. The future success of IEC 61850 is to a great extent dependent on the settings, implementation agreements on the use of logical devices and development of advanced tools that take full advantage of the SCD files that will then provide the complete configuration information for the substation protection, automation and control system.

The SCD file becomes an input to any of the IEDs configuration tools and is used to produce the CID file for the specific IED. Today this typically is limited to the communications section. In the future this should include all settings of the IED as well.

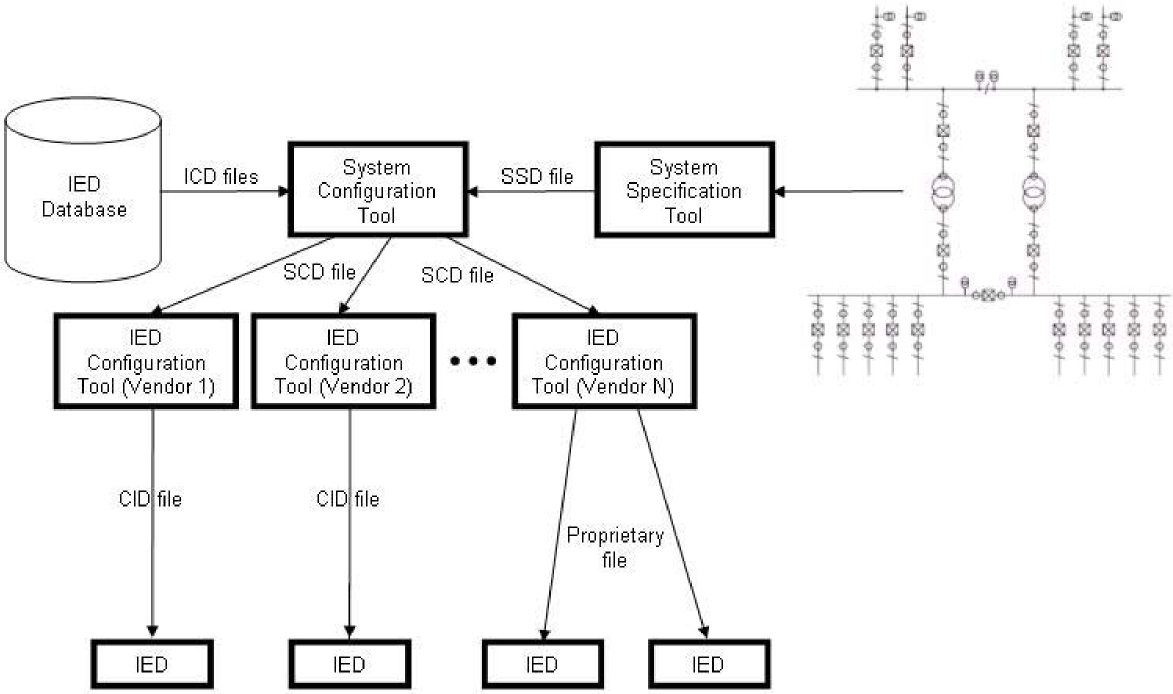

Fig. 4: IEC 61850 based engineering process

The use of the CID file depends on the implementation of IEC 61850 in the IED. One option is to directly download the file in the device. Another is to convert it to a proprietary file format that is then downloaded in the IED.

7 THE ENGINEERING PROCESS REVOLUTION

The engineering process described in the previous section is based on the current implementation of the standard. It is just the first step in what may become a real revolution in the field of electric power systems protection, automation and control. For this to happen there is a need for some further development, including:

- Completion of the settings parts of the logical nodes class models
- Inclusion of the settings in the ICD and CID files
- Harmonization between the CIM model and the IEC 61850 model
- Extensions in the system model to cover the needs of coordination and analysis tools
- Addition of IED setting configuration functions in the System Configuration tools

As a result it will be possible to extend the use of the SCD files for the following substation automation systems engineering tasks:

- Automatic creation of the graphical user interface from the SCD file, including the different screen layouts
- Automatic mapping of the different measurements and status information from the IEDs to the substation HMI
- Automatic configuration of the IED or substation protection and control system testing process
- Automatic substation event analysis

The benefits from such developments will be quite significant and will not only reduce the costs for system design, factory and site acceptance testing and maintenance, but also will improve the overall quality of the substation automation system.

8 CONCLUSIONS

A significant part of the engineering of a substation automation system is related to the architecture and configuration of the primary and secondary equipment in the substation. This requires the development of a formalized format that allows the description of all different elements and their relationships.

UML and XML provide a standard way of describing the complex structure of substation protection and control systems and a format for exchange of data between different tools that are used in the engineering process.

One of the key advantages of IEC 61850 based systems is the availability of the Substation Configuration Language that allows interoperability and a seamless integration process. The SCL is basically a system specification of the substation equipment connections in a single line diagram. It also documents the allocation of Logical Nodes to devices and equipment of the single line to define functionality, access point connections, and sub network access paths for all possible clients.

IEC 61850 provides an excellent opportunity for the formalization of standards based object-oriented approach to the design of substation protection schemes or systems.

The different SCL files create the foundation for a revolution in the substation automation systems engineering process based on the use of the SCD files as the common file shared between substation engineering tools, system analysis and coordination tools, event analysis and testing tools. Most of the tasks that require manual processing today can become initially partially and later completely automatic. This will result in reduced costs and improved quality and reliability of the protection and control systems.