STANDARDS BASED ENGINEERING OF DISTRIBUTION PROTECTION, AUTOMATION AND CONTROL SYSTEMS

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ABSTRACT

Improving the efficiency of the engineering process is one of the key requirements for a Smart Grid. The paper describes an engineering approach based on standard protection and control schemes developed by utilities and implemented using multifunctional intelligent electronic devices (IEDs) supporting the IEC 61850 standard. The use of substation configuration language files in the engineering process is also described in the paper.

INTRODUCTION

The requirements for improvements in the efficiency and quality of protection schemes at the distribution level of the electric power systems highlights the need for development of new methods and tools that can help the industry achieve these goals. That is why it is very important to start a discussion on the opportunities that exist to develop a set of engineering tools based on the development and experience with the use of utility standards and the IEC 61850 substation configuration language.

The first part of the paper describes an object-oriented engineering process for the development and implementation of protection schemes based on five stages in a utility's standardization process:

- definition of distribution system protection philosophy
- definition of a distribution protection scheme type
- selection of approved protection and control IEDs
- design of the protection scheme
- instantiation of the protection scheme as part of a substation protection system

The second part of the paper describes the IEC 61850 Substation Configuration Language (SCL) and the different types of files that it defines - SSD, ICD, SCD and CID. The need for a new SCL file named ISD (IED Specification Description) is introduced. Their use at the different stages of the engineering process is then presented. This covers the different components of the model, such as:

- Substation topology
- Distribution feeders
- Communications infrastructure
- Protection, automation, control, energy management and other functions
- Multifunctional intelligent electronic devices
- Their associations with the primary equipment and the communication system

The paper then identifies some missing components that require extensions to the existing models or development of new models.

The paper later describes the engineering process based on this concept and the use of different standard files to achieve different engineering tasks.

A four stage standardization process defined by CIGRE Working Group B5.27 is described in the paper. The use of IEC 61850 SCL files as envisioned by the working group is described as well.

Standards based engineering offers some significant advantages that are described at the end of the paper. At the same time this approach may require some changes in the organizations and the methods and tools used for engineering. It will also need some initial investment, but the long term savings will result in significant savings in time and money, as well as improved quality of the schemes and the reliability and security of the distribution power system.

OBJECT-ORIENTED STANDARDS BASED ENGINEERING OF PROTECTION SYSTEMS

Intelligent (microprocessor-based) Electronic Devices (IED) for data acquisition, protection, measurements 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 that can be defined as part of the standardization process.
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 (see Figure 1).
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 protection system/scheme hierarchy contains the Function Elements (FE), the smallest functional objects that are represented by Logical Nodes in the IEC 61850 model.

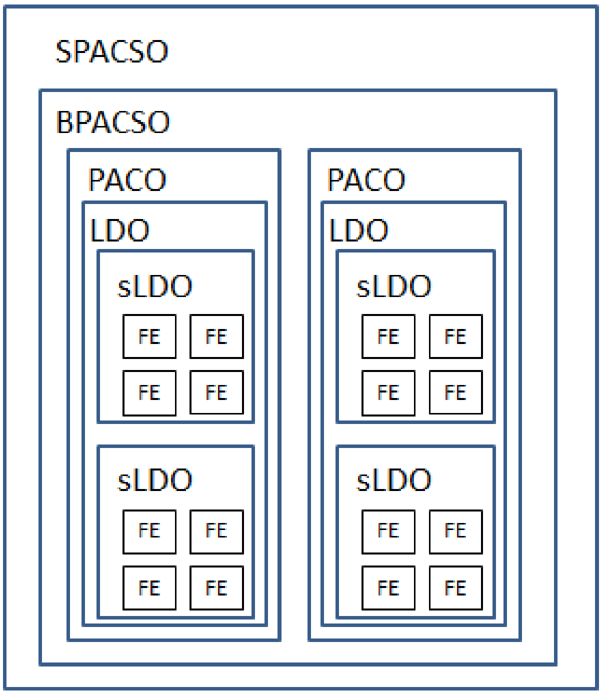

Fig. 1 Object model hierarchy

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 standardization process typically defines bay level objects, but more and more utilities are going in the direction of using standard substations, especially at the distribution level of the electric power system.
It is important to understand that standardization, like everything else, has benefits and drawbacks. The analysis of both clearly shows that the benefits are much more than the drawbacks, especially if we consider the long-term benefits against the short-term drawbacks. Even though it will impose an initial cost and resource burden, in the long run it will lead to significant cost savings and improvement in the quality of the secondary systems. The benefits of such an approach can be further improved if the standardization applies not only to the protection schemes' engineering, but also to IED configurations, settings, logic, etc.
Although some non-monetary benefits might be achieved in the short term, the standardized designs should be applied for a period of time in order to realize the anticipated full benefits, but this period should not be so long that the technology becomes obsolete or too far out of date compared with the latest available.
The development of standard secondary schemes is based on:

- Utility standards
- Utility best practice
- National standards
- International standards:
  - IEC
  - IEEE
- Industry best practice:
  - CIGRE reports
  - IEEE Power System Relaying Committee reports

Detailed analysis of the standardization of protection and control schemes, definition of a standardization process, the benefits and challenges of this approach based on the experience and practices of many utilities from around the world is available in the CIGRE Technical brochure 584 "Implications and Benefits of Standardized Protection and Control Schemes" prepared by working group B5.27.
The contributions of this work, combined with the best practices from the established standardization process within a utility provide the foundation for the standardization strategy described in this paper.

Standard bays

The efficiency of the standardization process can be significantly improved if the design of the substations is

based on standard bays.
Standard bay design includes the following elements:

- Bay scheme
- Bay layout
- Bay primary equipment
- Instrument transformers location
- Instrument transformers

The following distribution bay types are commonly used in a utility's distribution system and included in the standardization process:

- HV breaker-and-a-half
- HV single breaker
- MV single breaker
- HV transformer
- MV transformer

The functional and performance requirements in standard secondary systems are defined by the philosophy and criticality of the application.
The overall standard scheme design will be based on the combination of the bay type and voltage level or criticality factor.

Standard substations

The highest level of efficiency of the standardization process can be achieved using standard substations. It is possible to design standard distribution substations and it is already a common practice in some utilities.
Such strategy will offer significant benefits, since it will support the design of standard container style control houses that can be produced, configured and commissioned in a factory environment.
This will result in a significant reduction of the amount of work that needs to be done at the site, especially if standardized interface between the substation process and the control house is designed and implemented.

STANDARDIZATION PROCESS

A standard secondary scheme is defined as a single set of multifunctional IEDs integrated using process and inter-device interfaces in order to provide all required by the application functions, such as protection, control, status monitoring, measurements (including synchrophasors when required), communication, condition monitoring, recording, event reporting, fault locator and power quality.
For each standard scheme a four step standardization process is followed.

Standard scheme template

This is Step 1 of the standardization process and covers the definition of the functional requirement specification for a standard secondary scheme based on a utility's philosophy and practice.
It is a conceptual description of the scheme. This is typically the formalized description of the application of protection and control philosophy to a specific type of bay as described above. The templates should include all of the necessary components of the documentation of each subsequent stage.
At this stage the functional requirements and integration constraints need to be defined. These are detailed requirements associated with the bay topology, voltage level and criticality, communications requirements, etc., resulting in some interfaces and functions being defined.
This stage should also include primary single-line diagram, secondary functional diagrams, trip matrix, setting and testing philosophies.
Items that are left "generic" at this stage are types of primary equipment or IEDs. They may be considered, but are not specified at this stage.
In addition, the description of the functional specification in the form of an IEC 61850 Substation Specification Description (SSD) file is recommended, thus allowing the automation of the procurement process based on exchange of such files between a utility and its suppliers.
Step 1 of the standardization process is performed by a utility's secondary core group of experts responsible for the engineering of standard schemes at the company level.

Defined standard scheme

This is Step 2 of the standardization process and represents a development stage of a standard scheme that defines the primary plant and the hardware interfaces with the specific type of bay covered by the scheme. The CB, disconnectors, earth switches, CT/VT and auxiliary interface specifications, signals list/diagram (hardwired or communications based) are specified at this stage.
The defined standard scheme can be used for the same or similar types of new or existing installations without ANY changes in external wiring, signaling and equipment.
Allocation of functions to generic (abstract) IEDs is also defined at this stage. The required functionality of individual IEDs can be described also using the newly defined IED Specification Description (ISD) file, thus allowing the automation of the procurement process based on exchange of such files between the utility and its suppliers. This will support automatic selection of the IEDs that meet the requirement specification for a specific standard scheme by comparing the ISD file with the existing IED Capability Description (ICD) files.
The definition of the required interfaces (including quality) with the process at this stage also allows the definition of the scheme terminal blocks that are signal specific, but not product specific.
Step 2 of the standardization process is performed by the utility's experts responsible for the engineering of standard schemes at the company level.

Applied standard scheme

Step 3 of the standardization process is what is typically considered by the utility as a "standard secondary scheme".
This includes the use of approved specific IEDs or other secondary equipment. The IED selection should ensure that all functions and functional elements defined for the

scheme template in stage 2 are available in the selected IEDs.
The IED HW, SW and parameter-set versions, IED configuration tools, signal list (hardwired or communications based), wiring diagrams, cable lists and standard settings are specified at this stage
The global settings, including programmable scheme logic, of the IEDs are introduced at this level of standardization. However, at this stage there are still no local settings or other site specific configuration parameters.
In case that the utility wants to use a different supplier for the same scheme, it will result in a different scheme template implementation that meets the requirements of the above definitions.
Since at this stage all IEDs and their interfaces are defined, the functionality of the standard scheme is configured using IEC 61850 engineering tools based on the ICD files of the individual IEDs and documented as a Substation Configuration Description (SCD) file. From this file the individual IED Configuration tools extract the Configured IED Description (CID) files used to configure them for operation in the substation.
Step 3 of the standardization process is performed by the scheme supplier based on the documentation produced in step 2. The development of the standard scheme should also involve at least two members of the utility's group of experts responsible for the engineering of standard schemes at the company level.
The standard scheme should be subject to type testing before it is approved for use by authorized utility representatives.

Instantiated standard scheme

This is a site specific implementation of the standard scheme (i.e. an instantiated standard scheme from stage 3). Site and application specific settings are implemented at this stage, and all hardware is defined.
While instantiation excludes any modifications besides site specific setting-parameters and site specific naming, specialization on stage 4 offers the opportunity to adapt the standard scheme typically to variations in primary HW-components when used in existing sites.
At this stage the IED specific calculations and setting files as well as specific commissioning, maintenance and testing procedures are applied.
In special cases also other modifications can be considered. This may appear as a deviation from the standardization process, however it takes advantage of the developed standard scheme for a special application that may not justify going back to stage 3 of the process.
Step 4 is performed by the secondary scheme supplier based on setting files and procedures supplied by the utility. Test reports and other documentation produced during the production, configuration and commissioning of the scheme should be reviewed and approved by authorized utility representatives before the scheme is delivered to the site.

	Phase	Bay	PAC Devices	Plant Application / Substation	What it means
A	Standard scheme – template	G	G	G	Totally generic **SSD, ISD**
B	Standard scheme – defined	S	G	G	All HW interfaces fixed **SSD, ISD**
C	Standard scheme – applied	S	S	G	IEDs fixed **ICD, IID**
D 1 2	Standard scheme: Instantiated Instantiated with small variations	S	S	S	Everything fixed, also settings (= standard scheme applied in reality) **SCD, CID**

IEC 61850 STANDARD FILES

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

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.

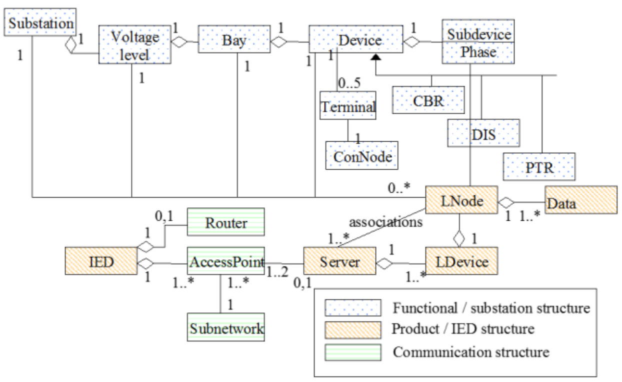

Fig. 2 IEC 61850, Part 6 - System Configuration Language (SCL) - UML

SCL FILES

IEC 61850 defines several 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 Specification Description

Allocation of functions to generic (abstract) IEDs is part of the engineering process. The required functionality of individual IEDs can be described also using the newly defined IED Specification Description (ISD) file format, thus allowing the automation of the procurement process based on exchange of such files between the utility and its suppliers. This will support automatic selection of the IEDs that meet the requirement specification for a specific standard scheme by comparing the ISD file with the existing IED Capability Description (ICD) files. This file will be included in the next edition of the standard.

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 shall be .ICD for IED Capability Description.

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 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 Configured IED Description file includes the substation specific names and addresses instead of the default ones in the ICD. It represents a single IED section of the SCD file described above.

CONCLUSIONS

A significant part of the engineering of a distribution 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.
An object-oriented standardization process based on standard bay types can help improve the efficiency and quality of the protection and control systems.
A four step standardization process takes advantage of the IEC 61850 Substation Configuration Language that allows standard representation of the system design and interoperability between different engineering tools.
IEC 61850 provides an excellent opportunity for the formalization of standards based object-oriented approach to the design of substation protection schemes or systems.