ENGINEERING THE DISTRIBUTION SYSTEMS OF THE FUTURE

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ABSTRACT

This paper describes the engineering process for distribution systems based on the definitions of object models and the different substation configuration language files defined in IEC 61850, as well as in the Common Information Model (CIM).

INTRODUCTION

IEC 61850 is a new international standard for substation communications that is gaining popularity because it defines a new way for exchange of information between different substation devices and systems using client-server or peer-to-peer communications. Another reason is that it lays the foundation for the development of a new generation of tools that can help in every step of the engineering process of a distribution system.

The paper describes the impact of IEC 61850 on the distribution systems engineering process. The modeling of the functional hierarchy of different intelligent substation devices allows the development of tools that can create solutions for automatic configuration and testing of individual devices or distributed applications.

DISTRIBUTION SYSTEMS ENGINEERING PROCESS

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 distribution systems. 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. At the same time the changing utility environment and the requirements for operation of electric power systems closer to their limits combined with the availability of advanced functions and high speed communications is leading to an increase of the development and implementation of distribution automation systems. While Substation Automation Systems have been the hot topic over the last decade, Power System Automation is the future of the industry. This means not just substation integration, but power system integration and distribution automation.

The industry has reacted to these needs and has developed different solutions through different standardization or other activities.

One of the characteristics of such developments has been the work on individual parts of the overall power system automation, protection and control domain by groups with a narrow set of goals. Even that there has been some global view of the system, the focus until recently has been on the system level applications and the substation level applications. The changing environment is forcing us to start looking at the problems from a different perspective in order to improve the operation of the system under normal and abnormal conditions, while at the same time reducing the engineering costs.

Many years of development of software and the needs for improved quality and shorter delivery have resulted in the establishment of object-oriented methods and the availability of tools to support them. This is also having impact on the electric power industry and is reflected in the publication of IEC 61850 and other international standards developed using object-oriented approach.

The development of substation and control center to control center communications protocols has addressed some of the challenges and created at set of models of different electric power system components. However, since they have been domain specific, they have not necessarily covered everything. In order to fill the gaps, the industry has initiated several activities aimed at meeting the needs of substation-substation and substation-system level applications. As a result it is becoming clear that there is a need for a global system model that will allow the development of distributed applications covering all different system applications.

Substation and distribution automation systems are one of the building blocks of the modern utility protection and control system. They are used not only to interface with the primary substation equipment – transformers, breakers, transmission lines, distribution feeders, etc. – and provide measurements and status information to the upper layers of the system, but also to detect any abnormal system or substation conditions and execute the necessary action to prevent further deterioration of a disturbance or damage to equipment.

The complete engineering of any substation automation systems includes not only the selection of devices to be used and their integration as part of the design of the system. The configuration and setting of individual devices based on the knowledge of the topology of the system and the parameters of lines, power transformers and other primary system equipment are essential parts in that process. The testing of the individual devices, distributed applications and schemes also plays an important role that is influenced by the developments in IEC 61850.

In the core of any substation protection, automation and control system are multifunctional intelligent devices that perform a wide range of functions under different system conditions. These devices operate independently, but are also used in more complex schemes by communicating with some of their peers over the local area network in the substation.

Due to the increased performance requirements in order to reduce the impact of any event on the stability of the electric power system or on sensitive loads in industrial facilities, the substation protection and control devices need to continuously adapt to the changes in the substation or electric power system configuration or state, thus optimizing their behavior.

The intelligent substation devices (ISD) can have a pre-defined by the manufacturer functionality, or the user can configure them to operate as devices dedicated to meet some specific to the site requirements. Even if the functionality is pre-defined, due to the fact that not all applications need the use of all available in a device features, they have to be enabled or disabled by the user.

The exchange of signals between the devices in the substation in conventional installations is based on hard wiring between the outputs of the sending devices and the inputs of the receiving devices. It is represented as wiring in one or three line diagrams that are used for installation, commissioning and maintenance purposes. In the IEC 61850 environment the hard wiring between individual devices is replaced by communication interfaces defined in the standard for different purposes. Publishing and subscription mechanisms are implemented to perform the different protection, automation and control functions in the substation.

The intelligent devices in the substation do not only exchange signals with their peers, but they also interface with substation level applications, such as the substation event recorder, the human machine interface, gateways that provide the link with the control center, and many other possible systems.

The successful integration of intelligent substation devices in complex systems that meet all the above-described functional requirements is a very complex process that is even more complicated when devices from different manufacturers using a variety of communication interfaces and protocols have to interoperate in the substation environment. That is why IEC 61850 defined not only the way to exchange data between different devices and systems, but also created the Substation Configuration Language that can be used to build a new generation of tools and bring a new era in all aspects of the substation protection, automation and control engineering process.

However, the existing definitions in IEC 61850 do not address all requirements for the complete engineering process, because the focus on the standard is the substation environment. The electric power system topology and parameters are not part of the IEC 61850 model, but are required for the calculation of the settings and the optimization of the performance of the different components of the protection, automation and control system. This is where the need for use, harmonization and extension of both the IEC 61850 and CIM models has to be addressed.

The engineering of the substation automation system first needs to answer some key questions:

- What is the importance of the substation in the system?
- What is the topology of the substation?
- What is the functional specification?
- What will be the IEC 61850 implementation?
- What are the expected operating conditions?
- What and how should be tested?

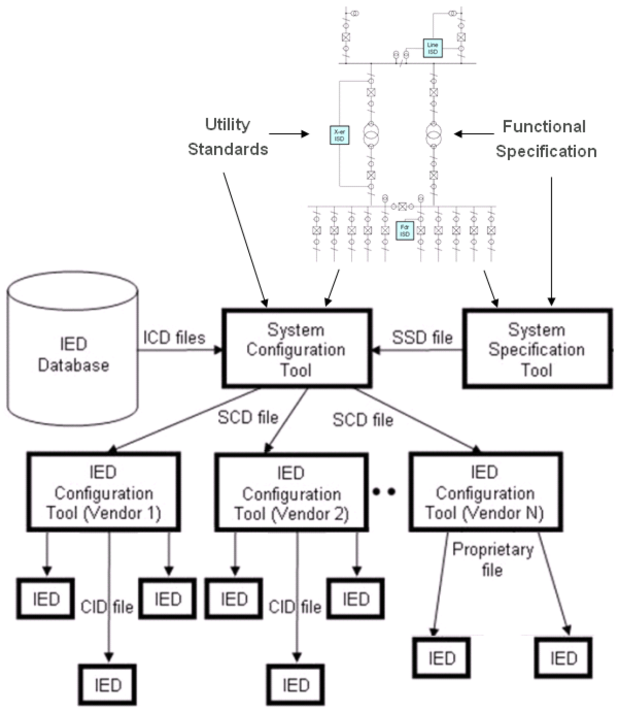

Fig. 1 Simplified engineering process diagram

Different actors in the engineering process can provide the answers to these questions and their work can be significantly simplified by the use of the appropriate tools based on IEC 61850.

We can describe the intended engineering process (shown in a simplified diagram in Fig. 1) as follows:

- Development of substation one-line diagram that defines the voltage levels, topology, power transformers, instrument transformers and their location, etc.
- Definition of required substation, transmission line and other protection functions
- Definition of performance, redundancy, reliability, availability, security and other requirements
- Definition of the substation communications

architecture

- Selection of protection and other intelligent substation devices from the data base of approved devices based on the utility standards
- Calculation of the settings of the intelligent devices based on the applied protection philosophy, power system model and coordination tools
- Development of distributed applications and schemes, including the definition of signals exchange between the different devices that are included in these applications or schemes
- Definition of the event reporting, trend, disturbance and waveform recording requirements
- Development of test plans for individual devices, as well as distributed applications and schemes

Based on the use of IEC 61850 and CIM models, including some required harmonization and extensions it will be possible to achieve many of the above tasks in an automatic manner. The following sections of the paper discuss both models used in the engineering process.

IEC 61850 MODEL

IEC 61850 is a standard for communication networks and systems in substations. It was developed over a period of about 10 years and was the result of the combined efforts of numerous industry experts from around the world. IEC 61850 was developed with the goal of meeting the requirements of all different functions and applications in the substation, such as protection, automation, control, measurements, monitoring and recording.

At the same time it should support different tasks related to the different substation functions, such as engineering, operations, commissioning, testing, maintenance, event analysis and security.

The modeling approach in the standard uses the principles of functional decomposition and UML notation. It is used to understand the logical relationships between components of a distributed function and is presented in terms of the model hierarchy that describes the functions, sub-functions and functional interfaces.

The foundation of the IEC 61850 is the concept of virtualization, i.e. providing a virtual representation of the behavior of real primary or secondary substation devices.

As mentioned earlier, the virtualization covers only the relevant and communications visible components of the model. Figure 2 shows the use of this process to model an overcurrent stage of a distribution protection relay as an IEC 61850 logical node.

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.

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 exchange of data between different engineering tools required at different stages of the substation integration 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.

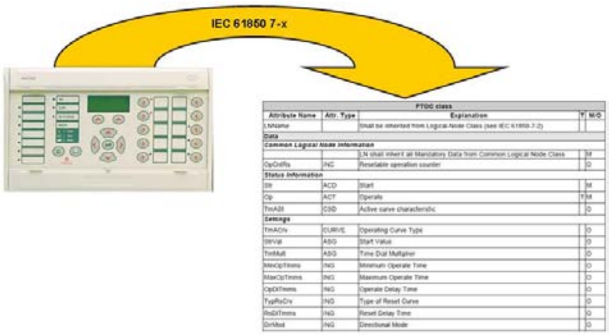

Fig. 2 Virtualization of a protection IED

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 stands for Unified Modeling Language, while XML means Extensible Markup Language – both very popular and widely used.

The heart of IEC 61850 is the object model of the different substation equipment. Object-oriented problem solving relies on the construction of a model that abstracts the essential details of the underlying problem from its usually complicated real world. This is especially true for advanced multifunctional protection device. Since object-oriented design is widely used, there have been many attempts to create appropriate modeling tools.

A very important differentiating factor of IEC 61850 compared to other communication protocols is that everything in the model has a name. This allows the definition of standard device models that support self-description and use of meta-data to be used for development of different engineering tools.

The models of multifunctional protection IEDs that include both protection and non-protection functions such as control, measurements, monitoring and recording are discussed.

A simplified diagram with the communications architecture of an IEC 61850 Process Bus based substation automation system is shown in Fig. 3.

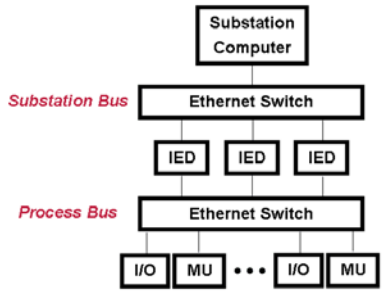

Fig. 3 Simplified IEC 61850 based communications architecture

The modeling of complex multifunctional IEDs from different vendors that are also part of distributed functions requires the definition of basic elements that can function by themselves or communicate with each other. These communications can be between the elements within the same physical device or in the case of distributed functions (such as substation protection schemes) between multiple devices over the substation local area network. The basic functional elements defined in IEC 61850 are the Logical Nodes.

A Logical Node is “the smallest part of a function that exchanges data”. It is an object that is defined by its data and methods and when instantiated, it becomes a Logical Node Object. Multiple instances of different logical nodes become components of different protection, control, monitoring and other functions in a substation automation system. They are used to represent individual steps in a protection function.

A multifunctional protection IED has a complex functional hierarchy that needs to be modeled according to the definitions of the IEC 61850 model. Logical nodes are grouped in logical devices, usually to represent specific functions that are part of a server. Some times if the IED has a more complex hierarchy it is necessary to introduce intermediate layers in the model – sub-functions.

The above described functional hierarchy needs to be appropriately represented based on the modeling hierarchy presented in Part 7 of IEC 61850.

The standard does not only model the IEDs, but also the communications architecture and the primary substation equipment. The substation model is based on CIM.

CIM (IEC 61968 AND IEC 61970) MODEL

The CIM model is in the foundation of the Substation Configuration Model shown in a simplified UML diagram in Figure 4. It has three basic parts:

- Substation - describes the primary substation equipment and their connection on single line level – the topology (shown in white in Fig. 4)
- Product - used to describe all IEDs and their logical node implementations (in yellow).
- Communication - contains communication related object types such as communication access points and sub-networks, as well as the communication connections between the IEDs (in grey).

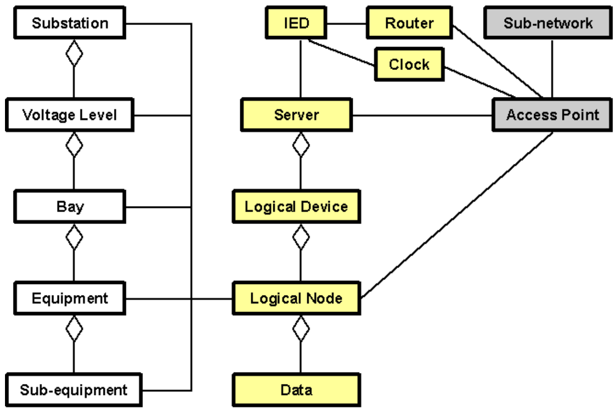

Fig. 4 Simplified UML diagram of the SCL model

The EPRI/IEC Common Information Model (CIM) in a similar way describes data typically used in different utility control and operational systems. This includes data in an EMS or SCADA system, as well as data found in DMS, work, and asset management systems. More recently, the CIM is being extended to include transmission reservation and energy scheduling information.

CONCLUSIONS

The engineering process of a modern distribution system is complex and with multiple steps that require good understanding of the functionality, requirements and available tools.

IEC 61850 is not only a protocol for communications in substations, but also a definition of a language that allows the exchange of information regarding different aspects of the substation automation system between engineering tools.

IEC 61850 and CIM represent a good foundation for the creation of a global power system model that will meet the needs of all applications and domains.

In order to meet all requirements it is necessary to harmonize the IEC 61850 and the CIM models.

Both models need to be extended in order to cover substation - substation and substation - system level, as well as some other applications.

The harmonization and extension of the models is going to take some time. The process is already under way involving experts from all working groups that participated in the development of both groups of standards. The understanding of the need for harmonization is common and some progress has already been made. The completion of this process will help in the development of a wide range of tools that will allow the automatization of the engineering process.