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IEC 61850 is an approved international standard for communications in substations that is creating opportunities for a revolution in the world of electric power systems protection and control. ■ It represents the next step in integration of multifunctional IEDs based on the development and implementation of advanced distributed protection and control functions. ■ But for this revolution to succeed, we need to understand what it is and how we can use it in order to take full advantage of its potential. ■ That is why IEC 61850 and its applications are and will be one of the key topics for discussions in our industry in the future.

BRAND NEW WORLD

When we plunge into the IEC 61850, we enter a world of numerous MLAs. Probably you never heard of MLAs – well this is nothing but a Multi-Letter Acronym. And you are going to see TLAs and FLAs (you have to figure these out). Coming up with these was one of the primary tasks in the development of the standard (actually this is a joke).

The reason we are starting by talking about acronyms is because their use can be very dangerous. If we look at a very typical use case – you need to take a new relay to a remote substation. So you put it in your carry-on bag and you go to the airport, check-in and get in line to go through security. Almost every time, someone will ask you what is this thing in your bag. The natural – to a protection engineer – answer will be to say that it is an IED (we all know that in our domain this means Intelligent Electronic Device). Well, in our use case situation this is definitely the wrong answer, since in the world of security the same three letter acronym (or TLA) means Improvised Explosive Device. So the moral of this story is – be careful and use an MLA only within the domain that you understand.

We hope that you are starting to realize that the standard was developed by some "out-of-the-box" individuals that were trying to transform the world of hard wired electromechanical relays into a world of virtual devices communicating over substation local area networks. When this all started many were saying that this is impossible. They were wrong. We just need to look around to see where the world is going.

So let's try to get more serious and see why and how we got to where we are and where we are going. IEDs are the standard in new or upgraded integrated substation protection, monitoring and control systems. Protective IEDs are sophisticated multifunctional devices designed to protect substation equipment and the electric power system from the effects of different abnormal system conditions. Since fault conditions are very rare in the system, to take advantage of their data acquisition and processing capabilities they also include multiple non-protection functions like metering, disturbance and event recording and some built in fault analysis tools. This makes them the typical device at the process level of a substation automation system.

Specialized control, power quality monitoring and disturbance recording devices may complement the protection IEDs by providing some specific functionality that may not be available within the relays. This allows the optimization of the integrated substation automation system, while at the same time meets the strict requirements for reliability and security.

The selection of the communications protocol used at the substation level is one of the critical factors to consider in the design of the substation automation system. The protocol should provide all required services that will allow the optimal implementation of different substation functions. This requires:

- Proper definition of the functional and performance requirements
- Good understanding of the substation communications protocol

That is why we need to discuss IEC 61850 and its applications, as well as the challenges, benefits and opportunities for future developments.

WHAT IS IEC 61850?

According to the names of the different parts of IEC 61850 it is a standard for communication networks and systems in substations. It was developed with the goal of meeting the requirements of all different functions and applications in the substation, such as:

- Protection
- Control
- Automation
- Measurements
- Monitoring
- Recording

At the same time it should support different tasks related to the above listed substation functions, such as:

- Engineering
- Operations
- Commissioning
- Testing
- Maintenance
- Event analysis
- Security

IEC 61850 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. Initially there were two separate activities:

- The development of GOMSFE (Generic Object Models for Substation and Feeder Equipment) as part of UCA (the Utilities Communications Architecture)
- The IEC 61850 project for development of a standard substation communications protocol under Tech Committee 57

The mix of professionals involved in the development included utility and manufacturer representatives, consultants and software developers. Many of them with a lot of experience and strong beliefs in their own opinions. So if you can imagine a group of such people in a room discussing a subject with a high level of importance, it will be easy to compare it to multiple collisions over the shared media of the meeting room.

That is why Fred (the frog beanie-baby) played such an important role in the development of IEC 61850. When we realized that collisions are slowing down the development, we at least agreed to change to a token-passing communications method. And Fred was the token. So only the person that held the token could speak. Everybody else had to shut up. Without Fred, probably we would still be arguing some issue in a meeting room somewhere around the world.

The good thing about heated discussions is that they create an atmosphere for great ideas. For example in a small room at O'Hare airport discussions gave birth to the UCA GOMSFE "bricks" – the building blocks of the device object models that can help us model even the most complex IED, as well as the concept of the high-speed peer-to-peer communications represented by another acronym – the GOOSE (Generic Object Oriented Substation Event).

One of the great accomplishments of the development process was that all involved companies were not just talking about the development of a standard for substation communications, but were actually building devices to see if it works. We can say that probably this is the best example of a successful multi-vendor project that the electric utility industry knows. And to make sure that it really works, a couple of times a year we had the interoperability demonstrations, with the main goal of each participant to win the great prize – Lucy – Goosy (another beanie-baby) given to a vendor that has demonstrated exchange of GOOSE messages with another vendor's IED – verified by the present utility engineers, and to utilities implementing GOOSE messaging in their substations.

The situation was not very different on the other side of the Atlantic. In 1995, new work item to develop an international standard for substation communication protocol was accepted by the IEC TC57 plenary meeting in Minneapolis, USA. Already at the second meeting in San Francisco, first contacts with the UCA efforts were initiated. However, at that time, the technical background of the experts involved was too different. The UCA experts with a strong background in TCP/IP based communication had little common vocabulary to share with the relay engineers and the experts for telecontrol protocols. So it was almost impossible

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to have real discussions.

So for the next two years, the three IEC working groups responsible for the development of IEC 61850 continued more or less independent from the UCA activities. Quite remarkable that they developed independent from the UCA activities the concept of the logical nodes, which is basically equivalent to the UCA GOMSFE "bricks". The discussions in three working groups with a total of more than 70 experts were sometimes challenging. We soon realized that the three working groups could not act independently. However, since you can not produce creative work with 70 experts, task forces were created. So each meeting was a mix of parallel working group meetings and task force meetings. While we started with two or three day meetings, we soon ended with having full week meetings in order to get the optimum out of a meeting.

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In 1997 a conclusion was reached that due to the similarities of both activities it would be beneficial to the industry to have a single standard for substation communications and the members of the UCA working group were integrated in the IEC TC 57 working groups.

So the standard was completed with the efforts of three working groups:

- Working group 10 focused on the definition of the functional architecture and general requirements
- Working group 11 addressed the communications within and between Unit and Station levels that are now know as the Station Bus
- Working group 12 developed the communications within and between Process and Unit levels known as Process Bus

After the publication of the standard and its wide spread application in hundreds of substations, the UCA International Users Group is working on resolving the different technical issues. WG11 and WG12 have been integrated into WG10, so WG10 has now the full responsibility for IEC 61850. The solutions and new developments, such as the modeling of power quality monitoring functions addressed by WG 10 will be included in amendments and later in version 2 of the standard.

IEC 61850 was developed on the basis of some key requirements:

- It should be technology independent
- It should be flexible
- It should be expandable

By meeting the above requirements the standard allows us to meet the changing needs of the electric power industry and take advantage of the developments in computers, communications and sensors technology.

The IEC 61850 standard consists of fourteen different documents that cover a wide range of issues and make it clear that it is much more than a communications protocol definition. It defines not only how to communicate over the substation local area network, but also what to communicate. It provides an abstract model of the substation equipment and functions that can be used as the foundation of the development of different tools.

The standard also addresses the substation integration and automation engineering process and specifies the conformance testing for devices that support it.

It needs to be well understood that the IEC 61850 standard does not specify individual implementations, communication architectures or products. It also does not attempt to describe any details of the functionality of the different devices, such as algorithms, but focuses only on the specification of the externally visible functionality of primary or secondary equipment, functions or implementations in substation protection, control and automation systems.

THE IEC 61850 MODEL

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. The figure below shows the use of this process to model an overcurrent stage of a protection relay from any vendor as an IEC 61850 logical node.

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 data flow is used to understand the communication interfaces that must support the exchange of information between the distributed functional components for different applications, while the information modeling is used to define the abstract syntax and semantics of the information exchanged. It is presented in terms of the data object hierarchy that includes data object classes, types and attributes.

A very important differentiating factor of IEC 61850 compared to other communication protocols is that everything in this 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. Two basic modeling approaches are possible:

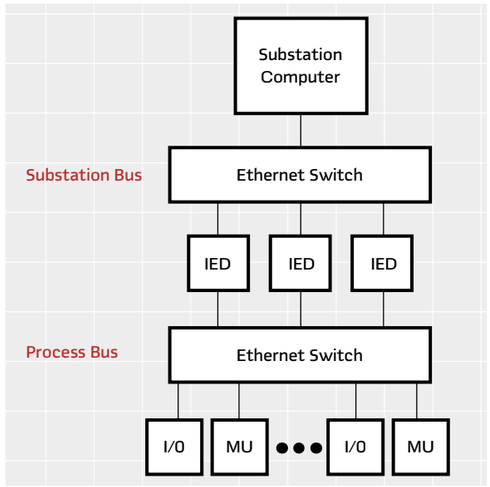
- Single Logical Device based model
- Multiple Logical Devices based model

The modeling of a complex multifunctional protection IED such as a modern distance relay is possible only when there is good understanding of the problem domain. At the same time we should keep in mind that the models apply only to the communications visible aspects of the IED.

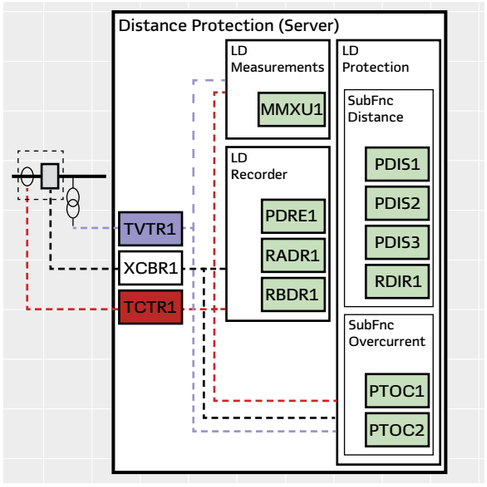
The functions in relatively simple IED, such as transmission line protection relays, are fairly easy to understand and group together in order to build the object model. That is not the case for the more complex devices like a distance protection. The distance protection function has different components that need to be taken into consideration in the model. Complex to represent are also advanced transmission line protection schemes that typically exist in distance relays, as well as distributed functions based on high-speed peer-to-peer communications between multiple IEDs.

IEC 61850 defines not only the object models of IEDs and functions in a substation automation system, but also the communications between the components of the system and the different system requirements. It is very important to understand that the fact that one can model a function in a device or substation automation system does not mean that the standard attempts to standardize the functions. This is especially true for the distance elements. There are so many different algorithms and characteristics, as well as preferences and opinions, that this would be an extremely difficult task. Instead, the model represents the communications visible attributes and behavior of the device. This is one of the main

1 Simplified IEC 61850 based communications architecture



2 Distance protection relay – simplified object model



A Logical Node is "the smallest part of a function that exchanges data"

reasons that there is a difference in the modeling requirements between IEC 61850 configuration applications and analysis or testing tools.

It is important to also remember that the changing technology introduces new methods for interface between the instrument transformers or sensors in the substation and the distance or other protection relays. They need to be able to interface with conventional and non-conventional sensors in order to allow the implementation of the system in different substation environments.

A simplified diagram with the communications architecture of an IEC 61850 Process Bus based substation automation system is shown in Figure 1.

The Merging Unit (MU) multicasts sets of measured sampled values to multiple IEDs in the substation over the substation local area network. In some cases it is called the "process bus". Status information for breakers and switches is available through an input/output unit (I/O). In some cases the merging unit and the input/output unit can be combined in a single device.

The receiving devices then process the data, make decisions and take action based on their functionality. The action of protection and control devices in this case will be to operate their relay outputs or to send a high-speed peer-to-peer communications message to other IEDs in order to trip a breaker or initiate some other control function, such as breaker failure protection, reclosing, etc..

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.

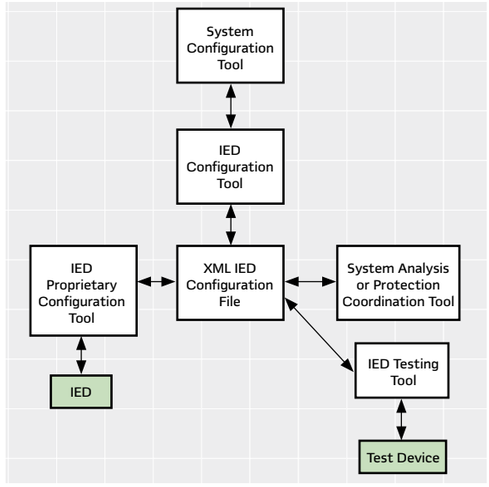
A Logical Node is "the smallest part of a function that exchanges data". It is an object that is defined by its data and methods. When instantiated, it becomes a Logical Node Object. Multiple instances of different logical nodes become components of different protection, control, monitoring and other functions in a substation automation system. They are used to represent individual zones or 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. It has two main groups of functions – protection and non-protection. The protection functions can be further divided into main, backup and protection related functions.

Each device sub-function then can be split in functional elements. Functional elements can be defined as the smallest functional unit that can exist by itself and exchange signals or information with other elements within a device or a system.

The modeling of complex protection devices depends not only on their functionality, but also on the configuration of the substation where they are installed. The model will be different if the transmission line is connected to a bus with a single breaker compared to the case of a breaker-and-a-half.

3 SCL based configuration process



The modeling of multifunctional devices needs to reflect the functional and modeling hierarchy described earlier.

SUBSTATION CONFIGURATION LANGUAGE

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. And finally, it defines the instantiated data model of the different IEDs .

SCL allows the development of engineering tools for configuration, protection coordination and testing that use a common standard data format.

The overall functionality of any IEC 61850 compliant device is available in a file that describes its capabilities. This file has the extension "ICD" meaning IED Capability Description. The system specification tool supplies to the system configuration tool information such as the single line diagram of the substation and the required logical nodes. The file extension is "SSD" – System Specification Description.

The system configuration tool then provides information to the IED configuration tools regarding all IEDs, communication configuration and substation description sections. This information is in a file with the "SCD" extension meaning Substation Configuration Description. This information also needs to be provided to the other tools in order to allow them to configure the set of functions to be performed.

The Standard IED configuration tool sends information to the IED upon its instantiation within a SAS project. The communication section of the file contains the current address of the IED. The substation section related to this IED may be present and then shall have name values assigned according to the project specific names. This file has an extension of "CID" meaning Configured IED Description. Currently there is ongoing work to expand the content of this file to include all settings, thus providing the required configuration data for both the IED itself, and also for the different functional tools.

THE BENEFITS

IEC 61850 is the new communications standard that allows the development of a new range of protection and control applications that result in significant benefits compared to conventional hard wired solutions.

It supports interoperability between protective relays and control devices from different manufacturers in the substation which is a necessity in order to achieve substation level interlocking, protection and control functions and improve the efficiency of microprocessor based relays applications.

The modeling of IEC 61850 based multifunctional distance protective relays requires good understanding of their functional hierarchy, as well as the modeling principles defined in the standard.

Complex devices, such as transmission line protection relays are modeled as servers with multiple Logical Devices that correspond to typical substation functions, such as Protection, Measurements and Recording.

The model needs to properly represent the functional hierarchy of the protection relay and at the same time use the available model hierarchy defined in the standard.

High speed peer-to-peer communications between IEDs connected to the substation LAN based on exchange of GSE messages can successfully be used to replace hard-wiring for different protection and control applications such as the protection of distribution buses, distributed recording or load-shedding in substations with varying configuration.

Sampled Measured Values communicated from Merging Units to different protection and control devices connected to the substation Process bus replace the copper wiring between the instrument transformers in the substation yard and the IEDs.

Such systems provide some significant advantages over conventional protection and control systems used to perform the same functions in the substations:

- Reduced wiring, installation, maintenance and commissioning costs
- Easy adaptation to changing bus configuration

The Substation Configuration Language allows interoperability and a seamless integration process. The common substation or IED configuration files can be exchanged between different configuration, coordination, analysis or testing tools in a way that significantly improves the efficiency of the engineering process.