IEC 61850 OBJECT MODELS OF MULTIFUNCTIONAL DISTRIBUTION PROTECTION IEDS

Fred STEINHAUSER
OMICRON electronics – Austria
fred.steinhauser@omicron.at

Benton VANDIVER
OMICRON electronics – USA
benton.vandiver@omicronusa.com

Alexander APOSTOLOV
OMICRON electronics – USA
alex.apostolov@omicronusa.com

ABSTRACT

The paper analyzes the IEC 61850 object models of multifunctional distribution protection IEDs. The functional hierarchy, protection and non-protection functions are described. A single logical device and multiple logical device models are presented.

INTRODUCTION

The new IEC 61850 international standard for substation communications defines the components that allow modeling of complex multifunctional distribution IEDs being integrated in substation automation systems.

The paper describes the object model hierarchy as defined in different parts of the IEC 61850 standard. Physical and logical devices, logical nodes, data objects and data attributes are described in sufficient detail in order to present the modeling of multifunctional elements.

The abstract functional hierarchy of a distribution protection, control and monitoring IED is presented later in the paper.

Multifunctional distribution protection devices are complex devices to model due to the fact that they may have characteristics with many different shapes and configuration parameters.

The paper analyzes the model of a multifunctional distribution protection IED including non-protection functions such as control, measurements, monitoring and recording being discussed. Two basic models are described in detail:

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

Some issues with the mismatch between the IEC 61850 object model hierarchy and the functional hierarchy of a distribution protection IED are discussed. An approach that allows the functional grouping of logical nodes based on the principles of IEC 61850 is presented.

Implementation of these modeling principles in the development of a common data format for protection IEDs configuration based on the XML schema defined in IEC 61850 is described at the end of the paper. This is an ongoing effort by working group H5a of the IEEE Power Systems Relaying Committee.

FUNCTIONAL HIERARCHY

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 communication visible aspects of the IED.

The functions in relatively simple IEDs, such as a low-end distribution feeder 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 transformer protection. The directional overcurrent protection function has different components that need to be taken into consideration in the model. Complex to represent are also advanced distribution feeder protection schemes that typically exist in today's multifunctional 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 the fact that just because one can model a function in a device or substation automation system does not mean that the standard attempts to standardize that function.

It is important to also remember that the evolving technology introduces new methods for interface between the instrument transformers or sensors in the substation and the distribution 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.

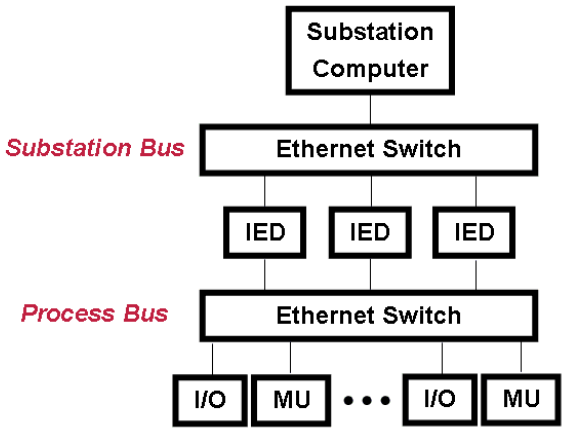

Fig. 1 IEC 61850 based communications architecture

A simplified diagram with the communications architecture of an IEC 61850 Process Bus based substation automation system is shown in Fig. 1. Merging Units (MU) multicast

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 are 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" [1]. 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 [1-4]. It has two main groups of functions – protection and non-protection.
The protection functions can be further divided into main protection functions, backup protection functions and protection related functions. The main protection functions in distribution feeder relays are:

- Instantaneous overcurrent protection
- Definite or inverse time delayed overcurrent protection

Local backup protection function example is Thermal overload protection or a Breaker failure protection.
Non-protection functions are of several categories:

- Measurements
- Control
- Condition monitoring and diagnosis
- Recording
- Analysis

Each of the above described functions can be divided into sub-functions that represent groupings of related functional elements.
In the protection group an example will be the overcurrent protection sub-functions, such as:

- Phase overcurrent protection
- Ground overcurrent protection
- Negative sequence overcurrent protection
- Sensitive ground fault protection

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 also can exchange signals or information with other elements within a device or a system, i.e. the logical nodes.
An example of a protection functional element will be a non-directional phase overcurrent element with extremely inverse characteristic. They are typically used to represent the different steps in an overcurrent protection sub-function.
Figure 2 shows an example of the functional hierarchy of a multifunctional IED.

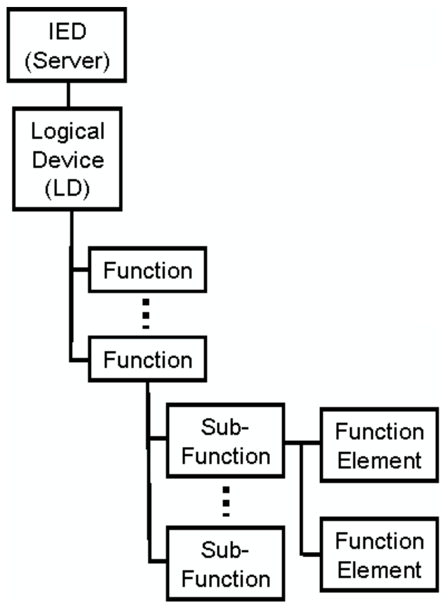

Fig. 2 IED functional hierarchy

The above described functional hierarchy needs to be appropriately represented based on the modeling hierarchy presented in Part 7 of IEC 61850 [2-4].Fig. 6 IEC 61850 test device.

DISTRIBUTION AND MODELING OF FUNCTIONS IN FEEDER PROTECTION RELAYS

The functional hierarchy of a modern protective relay to a great extent is dependent on the application and the main protection function of the device. A very simple low-end device may have a very limited functionality, while an IED that supports IEC 61850 will typically have a more complex functional hierarchy.
A more complex example is a relay protecting a transformer between the substation transmission and distribution buses that will interface the device with two or more voltage levels.
One of the most important concepts that need to be

understood at the very beginning of the IED modeling process is that the model includes only objects that are visible to the communications. The relay may contain a lot of data internal to the device, such as data exchanged between elements of fixed scheme logic. If this logic is represented to the outside world as a black box with certain inputs and outputs, these internal signals are not visible and as a result they are not included in the model.

The modeling of protection relays in IEC 61850 is in a way similar to the design of a protection panel with solid state or electromechanical relays. In this case each individual relay performs a specific function and hard-wiring between the relays is used to achieve more complex schemes.

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 or ring bus. In the case of distribution feeder protection relays the more common is a single breaker case.

The modeling of multifunctional distribution feeder relays needs to reflect the functional hierarchy described in the previous section, while at the same time use the modeling hierarchy defined in the IEC 61850 documents.

The first level is the Abstract Communication Service Interface (ACSI). It specifies the models and services for access to the elements of the specific object model, such as reading and writing object values or controlling primary substation equipment.

The second level defines Common Data Classes (CDC) and common data attribute types. A CDC specifies a structure that includes one or more data attributes.

The third level defines compatible logical node classes and data classes that are specializations of the common data classes based on their application.

Part 5 of IEC 61850 defines the logical node concept and the communications requirements for different functions and device models. Part 7-2 specifies the first level of modeling – ACSI. Part 7-3 covers the CDC, while Part 7-4 defines the compatible logical node and data classes.

The object hierarchy can be represented in a simplified way as shown in Figure 5. A Server typically is any physical device that is being modeled as part of a substation automation system. Usually a simple IED will be modeled as server with a single Logical Device.

The server represents the communications visible behavior of the IED. Each logical device is defined as "virtual device that exists to enable aggregation of related logical nodes and data sets".

Multifunctional devices are modeled using several types of logical nodes depending on the specific application of the IED. The logical nodes contain the information required by a specific function, such as a function setting or measurements being calculated by an IED. A Logical Device has a single Logical Node Zero, a single Logical Node Physical Device, plus one or more other logical nodes.

As discussed earlier, in case of protective relays with more complex functional hierarchy it might be necessary to group together several logical nodes in a functional group such as Overcurrent protection. The fact that a logical node belongs to a functional group of logical nodes can be represented by a functional group name. If the device has a very complex functional hierarchy, it is possible to use External Functional Group Name (EFGN) or Internal Functional Group Name (IFGN).

The modeling can be done in different ways. From the discussion of the functional hierarchy of relays it is clear that a model as server with a single logical device and multiple logical nodes (Figure 3) simply does not correspond to the functional hierarchy of a modern distribution relay.

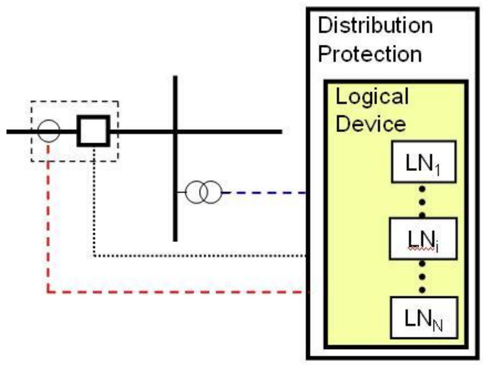

Fig. 3 Server abstract model with single logical device

When there are different functions and certain functional elements have to be grouped together, (for example for enabling or supervision of a group of functional elements) the modeling needs to be done using the available object hierarchy and the naming conventions for the data objects defined in IEC 61850. The model in this case will include multiple logical devices as shown in Figure 4.

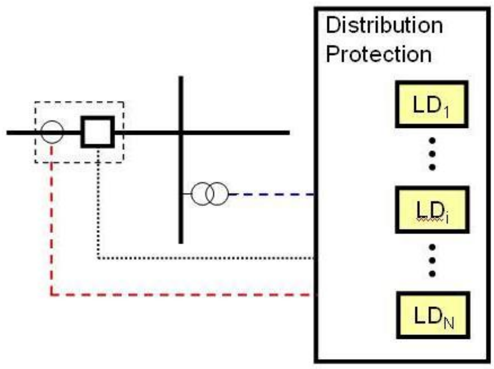

Fig. 4 Server abstract model with multiple logical devices

IEC 61850 clearly defines the model hierarchy that can be used for different multifunctional IEDs. But it does not specify how exactly they should be used for grouping of

functional elements. This provides a lot of flexibility of the model. However, it creates problems with interoperability in the sense that development of third party tools that rely on standardized functional model is not possible.
If the grouping of functional elements represented by logical nodes in standardized logical devices is accepted by the industry in a way similar to the standardization of logical nodes, it will create the foundation for the development of many applications with a standard interface as required by both users and vendors.
The model of such devices in IEC 61850 should reflect the functionality of more complex devices and can be done by mapping the different functions supported by the relay to different logical devices. This task is easier to achieve for distribution protection relays due to the fact that they typically are associated with a single breaker, i.e. they interface with a single set of current and voltage inputs. One logical device will represent the primary protection functions. Another will define the Measuring function and a third – the Disturbance recorder. A Fault Locator and a Circuit Breaker Monitor (if available) will be modeled with additional Logical Devices. A simplified block diagram of this model corresponding to its functional hierarchy is shown in Figure 5.

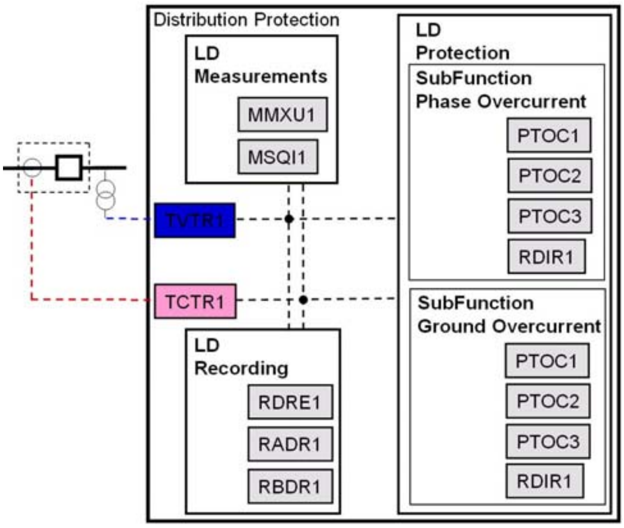

Fig. 5 Feeder protection relay – simplified object model

In order for the logical nodes to interoperate over the substation LAN, it is necessary to standardize the data objects that are included in each of them.
If we go further down in the functional hierarchy from Figure 2, the Protection Logical Device will include multiple protection functions. Each of these protection functions can be Enabled or Disabled. For example the Phase and Ground Overcurrent protection functions are typically Enabled, while the Negative Sequence, etc. might be Disabled. When a protection function is Disabled, it means that all Functional elements (Logical Nodes) included in it become Disabled as well. This is one of the reasons that require the functional grouping of multiple logical nodes as described above.
TCTR and TVTR are the logical nodes that represent the analog input module of the distribution feeder relay that converts the signals to sampled values transmitted over the device internal data bus for recording (represented by the logical nodes RDRE1, RADR1 and RBDR1) or processing by the measurements (MMXU1) and protection PTOC1 functional elements. Each of these logical nodes has data object hierarchy as defined in IEC 61850.
Logical nodes typically include not only data, but also data sets, different control blocks, logs and others as defined by the standard.
The DATA represents domain specific information that is available in the devices integrated in a substation automation system. It can be simple or complex and can be grouped in data sets as required by the application.
Any DATA should comply with the structure defined in the standard and should include DataName, DataRef, Presence and multiple DataAttribute’s.
The DataName is the instance name of the data object, while the DataRef is the object reference that defines the path name of the DATA object instance.
The Presence is a Boolean type attribute that states if the data object is Mandatory or Optional.
Each instance of a DATA class object must contain at least one DataAttribute. Instead of a DataAttribute it is possible to have a SimpleCDC or Composite CDC (both are specializations of the DATA class). DataAttribute’s can be simple or nested. If they are nested, at each nesting level other than the first the DataAttributeName is called DAComponentName. The DataAttribute’s are of certain data type that can be primitive (BasicType) or composite (DAType).

CONCLUSIONS

The modeling of IEC 61850 based multifunctional distribution feeder protection relays requires good understanding of their functional hierarchy, as well as the object modeling principles.
Complex devices 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.