Impact of IEC 61850 Edition 2 on the Object Modelling of Complex Multifunctional Protection IEDs

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

ABSTRACT

Edition 2 of IEC 61850 is the next step in the evolution of the standard that improves its functionality in order to better serve the Smart Grid. The paper discusses the changes in the object modelling of multifunctional transformer protection IEDs and how they improve the efficiency of engineering and maintenance of protection and control systems.

INTRODUCTION

IEC 61850 is a well-established standard that allows the transition of the electric power industry into the Smart Grid by supporting improved protection and automation functionality, system security and efficiency. It can play such a critical role because it is much more than a communications protocol – it defines a new engineering and operational environment based on a standardized and well defined semantical model of all components of protection, automation and control systems. The paper concentrates on the impact of Edition 2 of IEC 61850 on the object modeling of transformer protection Intelligent Electronic Devices (IEDs).

The first part of the paper analyzes the functional hierarchy of transformer protection IEDs. It then describes the challenges in modeling their functionality based on the IEC 61850 Edition 1 standard. The reason is the relatively flat hierarchy of the model – server containing Logical Devices which then contain Logical Nodes. This hierarchy did not match the multilayer hierarchy of the existing transformer protection IEDs.

The second part of the paper describes the changes in the modeling hierarchy in IEC 61850 Edition 2 with the main focus on the nesting of Logical Devices. The complex protection model of a transformer relay is presented as a multilayered logical device. The inheritance principles of the modeling are described considering specifically the Mode and Behavior of Logical Devices and Logical Nodes in the IED hierarchy.

The last sections in the paper analyze the benefits of the modeling of transformer protection IEDs using the principles defined in IEC 61850 Edition 2. Improving the efficiency of testing as well as maintaining the availability of protection and control functions, especially during their maintenance testing will result in improved reliability of the power system.

FUNCTIONAL HIERARCHY

The modeling of a complex multifunctional protection IED such as a modern transformer protection 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 a low-end transformer protection relay, 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 an advanced transformer protection IED. For example, the directional overcurrent protection function and breaker failure protection function at the different voltage levels have different components that need to be taken into consideration in the model. Even more complex to represent are also advanced transformer protection IEDs connected to breaker-and-a-half or ring, as well as distributed functions based on high-speed peer-to-peer communications between multiple IEDs.

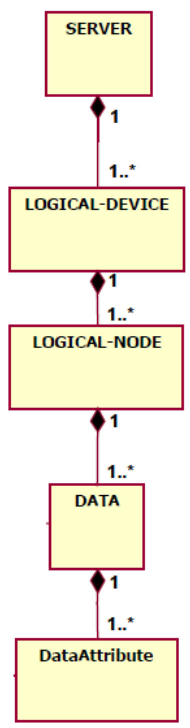

Fig. 1 IEC 61850 based abstract function model

A simplified diagram with the abstract object model of an IEC 61850 based server is shown in Fig. 1.

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 represents individual steps in a protection function.

A multifunctional transformer 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 protection functions, backup protection functions and protection related functions. The main protection function in transformer protection relays are:

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

Depending on the application, in some cases the overcurrent protection function may have to be directional. Local backup protection function example is Sudden pressure protection, Thermal overload protection or 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 in 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.

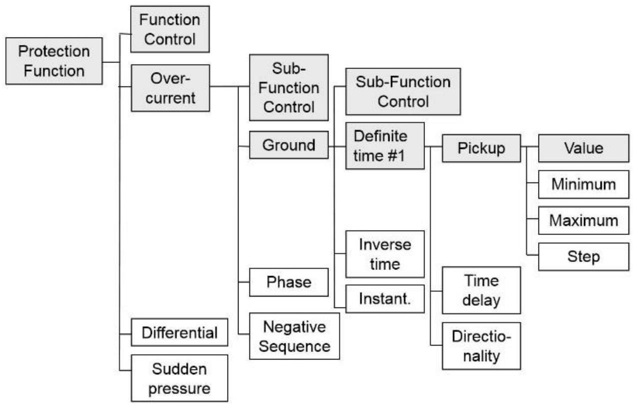

Fig. 2 IED functional hierarchy

The above described functional hierarchy needs to be appropriately represented based on the modeling hierarchy presented in Part 7 of IEC 61850 [1-3].

If we compare the functional hierarchy of the IED in Figure 2 with the abstract IEC 61850 functional hierarchy in Figure 1, it is clear that the Edition 1 hierarchy does not properly represent the complex multilayered hierarchy of the IED.

MODEL HIERARCHY IN IEC 61850 ED. 2

In order to bring the IEC 61850 object model closer to the complex functional hierarchy of existing multifunctional protection IEDs, Edition 2 of the standard introduced the nesting of logical devices. This is especially important from the point of view of the management of the mode and behavior of the functional components of a function or a sub-function in an IED.

The nesting of logical devices in IEC 61850 Edition 2 was inspired by the use of the prefix in logical nodes instance names while implementing the IEC 61850 Edition 1 object model in order to indicate for example that several overcurrent logical nodes PTOC may share a single logical node RDIR for their directional supervision.

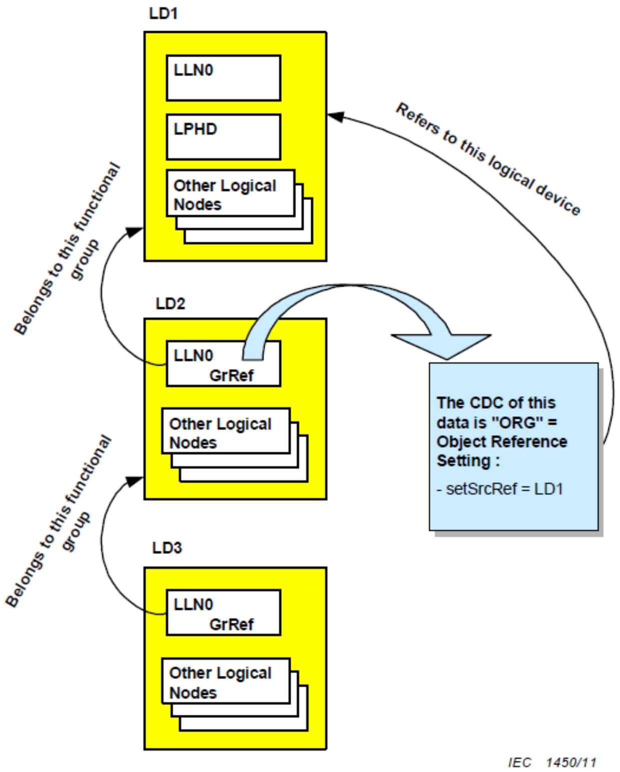

Fig. 3 IEC 61850 LD management hierarchy

This implementation group reference became the group reference GrRef defined in IEC 61850 7-4 Edition 2 as "Reference to a higher-level logical device (LD). The Mod of this higher-level (referenced) LD influences the Beh of the LD and the Beh of all LNs in the LD where the GrRef is contained …"

LLN0 of the nested logical device LD2 in Figure 3 contains the setting data object GrRef whose common data class is ORG, "object reference setting group". The referenced value of GrRef is LD1, meaning that the logical device function refers to the functional group represented by the parent logical device LD1. Similarly, LLN0 of LD3 refers to the functional group represented by the logical device LD2. Indicating that LD3 is a sub-function of LD2.

One of the main advantages of the nested logical device hierarchy is that it allows the efficient control of the behavior of the logical devices and logical nodes in the functional hierarchy. If for example we set the mode of LLN0 of a logical device at a specific level of the hierarchy to OFF, this will disable all sub-functions and their function elements regardless of their original Mod setting values.

FUNCTIONS MODELING IN TRANSFORMER PROTECTION IED

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.

The modeling of multifunctional transformer 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 [1] specifies the first level of modeling – ACSI. Part 7-3 [2] covers the CDC, while Part 7-4 [3] defines the compatible logical node and data classes.

The object hierarchy can be represented in a simplified way as shown in Figure 1. A Server typically is any physical device that is being modeled as part of a substation automation system.

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 containing them in a logical device. If the device has a very complex functional hierarchy, we need to use nested logical devices as defined in the previous section of the paper. This is especially true for transformer protection IEDs.

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.

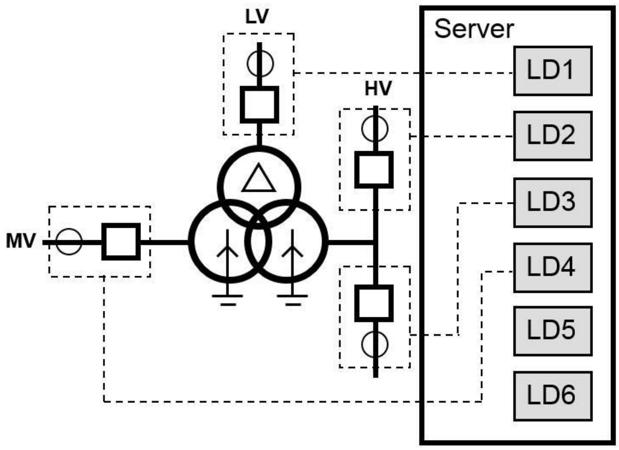

Fig. 4 Server abstract model with multiple logical devices

IEC 61850 Edition 2 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. That is why the industry needs to reach a common understanding of the principles of object modeling of complex hierarchical functions.

A further improvement will be the standardization of the commonly used logical devices naming as presented later in the paper. 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 device 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 transformer 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 (PROT) will represent the protection functions. Another will define the Control function (CTRL) and a third – the Measuring function (MEAS). 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.

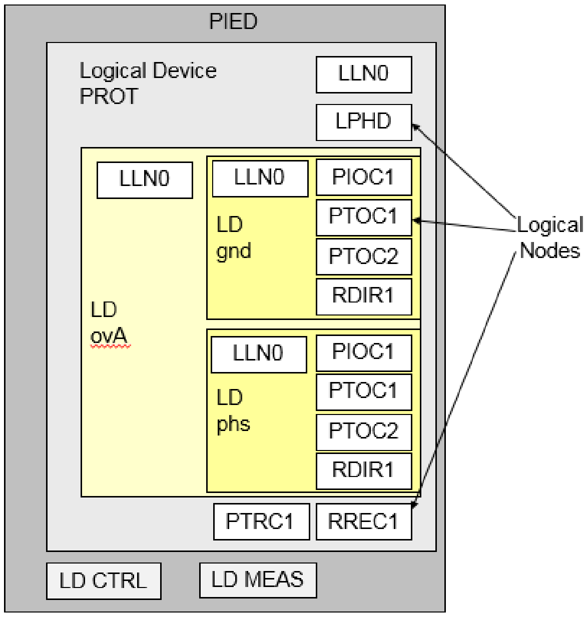

Fig. 5 Logical device hierarchy – simplified object model

In the case of the transformer protection IED from Fig. 4 each logical device – from LD1 to LD4 will have a nested functional hierarchy similar to the one shown in Fig. 5.

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 and can be achieved by changing the Mod setting of LLN0 at the logical device level of the functional hierarchy.

The model in Figure 5 shows the hierarchy of the overcurrent protection in a transformer protection IED. The grouping of several instantaneous and time delayed functional elements represented by the logical nodes PIOC and PTOC shows that they all can use the same directional function element represented by logical node RDIR. 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.

Two new data objects have been added to the model in Edition 2 of IEC 61850. They are the BlkRef and InRef.

BlkRef is the Blocking reference which shows the receiving of dynamically blocking signal; this data object is multiinstantiable, which means that there might be different input signals coming to the logical node that can be used to block it.

InRef is Reference to the data object what is binded to this input. The Input reference also may have multiple instances depending on the functionality of the logical node.

The use of the nesting of logical devices as defined in IEC 61850 Edition 2 and corresponding to the object model from Figure 5 is shown in Figure 6.

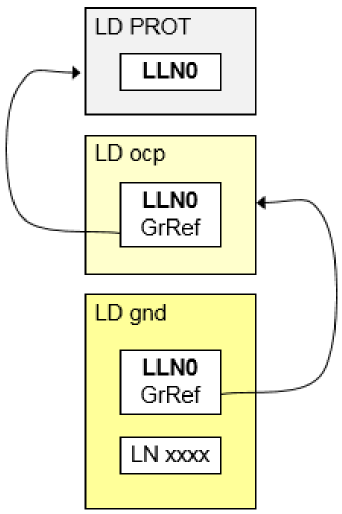

Fig. 6 IEC 61850 LD management hierarchy example

CONCLUSIONS

The modeling of IEC 61850 based multifunctional transformer protection relays requires good understanding of their functional hierarchy, as well as the object modeling principles and their extensions in Edition 2 of the standard.

Complex devices are modeled based on IEC 61850 Edition 2 as servers with multiple nested Logical Devices that correspond to typical substation functions, such as Protection, Control and Measurements.

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 in order to improve the efficiency of the device functional management.

REFERENCES

[1] IEC TR 61850 7-2 Communication networks and systems in substations – Part 7-2: Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)

[2] IEC TR 61850 7-2 Communication networks and systems in substations – Part 7-3: Basic communication structure for substation and feeder equipment – Common data classes

[3] IEC TR 61850 7-2 Communication networks and systems in substations –Part 7-4: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data object classes