



PS3 –S7-03



Requirements for Modeling of Advanced Distance Protection IEDs

Alexander APOSTOLOV
OMICRON electronics
USA

Alexander.Apostolov@omicronusa.com

1 INTRODUCTION

Advanced distance protection relays represent a significant challenge for many tasks that are performed by protection specialists during the engineering, commissioning and maintenance process. This is due to the fact that the design and implementation of these functions varies significantly from one vendor to another. This is also reflected in a large number of settings and further complicated by the fact that in some cases not all settings are visible to the user.

The requirements for a standardized model of the distance protection function in modern distance relays are different and depend on the specifics of the application. While IEC 61850 describes to a certain extent the communications visible parameters of the distance function that can be represented by several functional elements in the model, this may not be sufficient for protection coordination and testing purposes.

2 FUNCTIONAL HIERARCHY OF MULTIFUNCTIONAL DISTANCE PROTECTION IEDS

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.

In order to model a complex IED we need to keep in mind the purpose of the modeling, existing modeling methods and the functional hierarchy of the device being modeled.

The functions in relatively simple IED, such as a low-end 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 an advanced distance protection for extra high voltage level applications.

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 will be an extremely difficult task. Instead, the model represents the communications visible attributes and behavior of the device. This is one of the main reasons that there is a difference in the modeling requirements between IEC 61850 configuration applications and analysis or testing tools.

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 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 protection functions, backup protection functions and protection related functions. The main protection function in a distance relay is obviously the distance protection.

Local backup protection function examples are Directional Overcurrent 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 distance protection sub-functions, such as phase and ground distance protection.

Each device sub-function then can be split in functional elements. Functional elements can be defined as the smallest functional units that can exist by themselves and can exchange information with other elements within a device or a system. An example of a protection functional element will be a phase distance zone element used to represent the different zones in a distance protection– one per each zone.

Figure 1 shows an example of the functional hierarchy of a multifunctional transmission line protection IED.

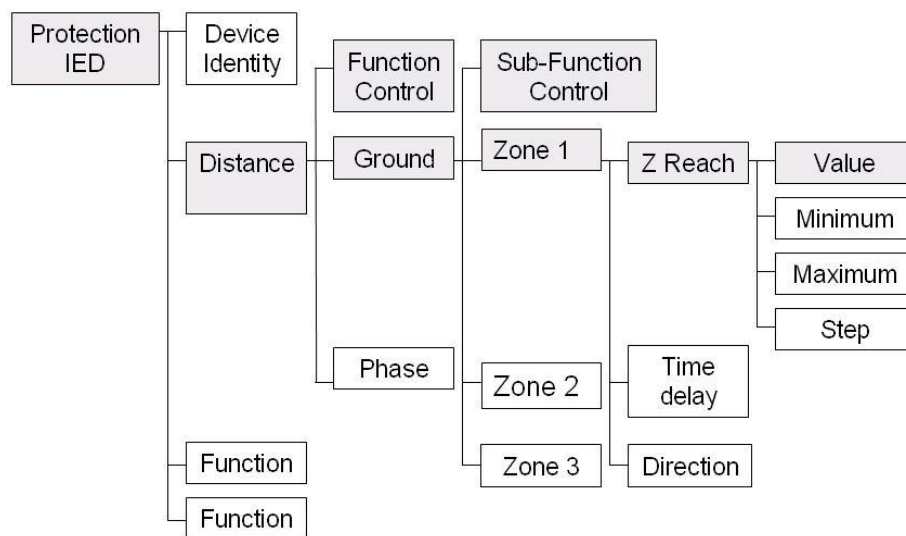


Fig. 1: Distance IED functional hierarchy

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

3 DISTANCE PROTECTION DEVICE MODEL

The functional hierarchy of a modern distance protection relay to a great extent is dependent on the application and the main protection function of the device – the distance function. A very simple low-end device may have a very simple and limited functionality, while a relay that supports IEC 61850 will typically have a more complex functional hierarchy. For distance protection relays used at high voltage and extra high voltage transmission level the model has to also consider the availability of multiple analog inputs – for example in the case of dual breakers, breaker-and-a-half or ring bus configurations.

The modeling of a complex multifunctional transmission line protection device can be compared to the design of transmission line protection panels in the past – individual physical devices installed on a panel, performing specific protection and control functions.

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.

At the same time the relay manufacturer needs to make visible to the communications some settings that may not be visible through the user interface due to the fact that they are not settable. However, they might be necessary to completely define the characteristic of a distance element. For example in some relays with quadrilateral characteristic the resistive reach line angle may be the same as the angle of the protected transmission line, i.e. it is not settable. It needs to be included in the model depending on the purpose of the modeling. If we are to model just the settings available in the setting file – then they don't have to be included. But in order to perform relay coordination or testing – these settings need to be made visible and included in the model.

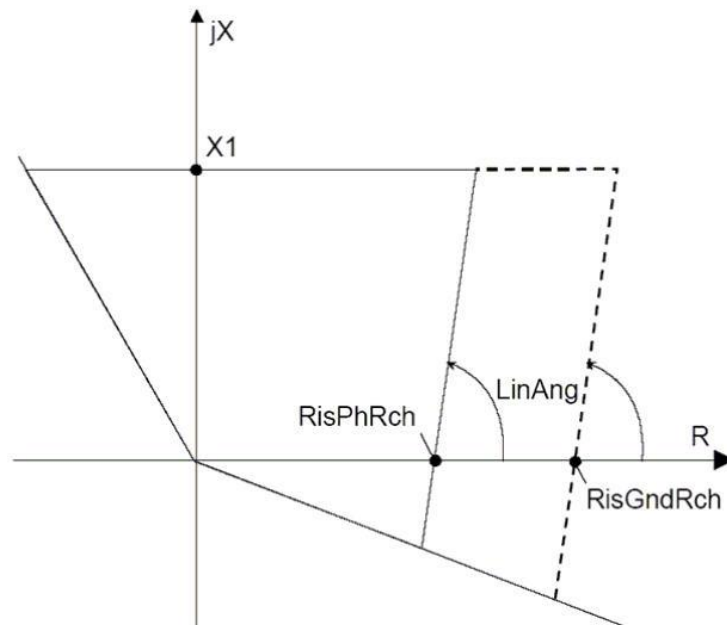


Fig. 2: Quadrilateral distance characteristic

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. This is due to the fact that the analog interface of the device may be different. In

many relays there is a single set of three phase current inputs. This corresponds to the typical case of a single breaker used in case of transmission lines with lower voltage levels.

However, at the extra high voltage level in many cases the requirements for improved reliability and availability lead to the use of breaker-and-a-half or ring bus configurations.

Distance relays with a single set of current inputs can be used to protect such configuration, but with some limitations in the use of some functions. For example most advanced multifunctional distance relays have a built-in breaker failure protection. A single set of current inputs limits the functionality of the IED and does not allow the use of the breaker failure protection because it is impossible to determine which of the two breakers has failed to trip.

Figure 3 shows an abstract model of a distance relay connected to a segment of a breaker-and-a-half bay. In this case the transmission line protection relay will need the currents from current transformers on each breaker and voltages from voltage transformers on the protected line.

The modeling of multifunctional distance 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 multifunctional distance protection relay is modeled as a Server - typically any physical device that is being modeled as part of a substation automation system. The server represents the communications visible behavior of the IED. It may contain one to many Logical Devices. 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.

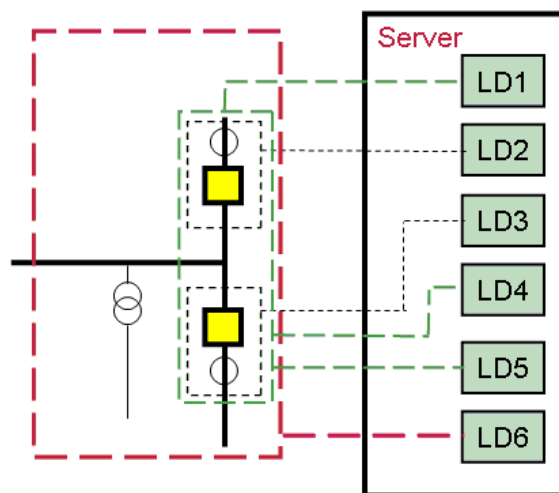


Fig. 3: Server abstract model with multiple logical device

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 Distance

protection. The fact that a logical node belongs to a functional group of logical nodes can be represented by a functional group name. 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 simply does not correspond to the functional hierarchy of a modern distance relay.

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 3.

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.

Figure 4 shows the functional configuration of a transmission line protection relay. The model of such device in IEC 61850 can be done by mapping the different functions supported by the relay to different logical devices. 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 will be modeled with additional Logical Devices.

If we go further down in the functional hierarchy from Figure 1, the Protection Logical Device will include multiple protection functions. Each of these protection functions can be Enabled or 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.

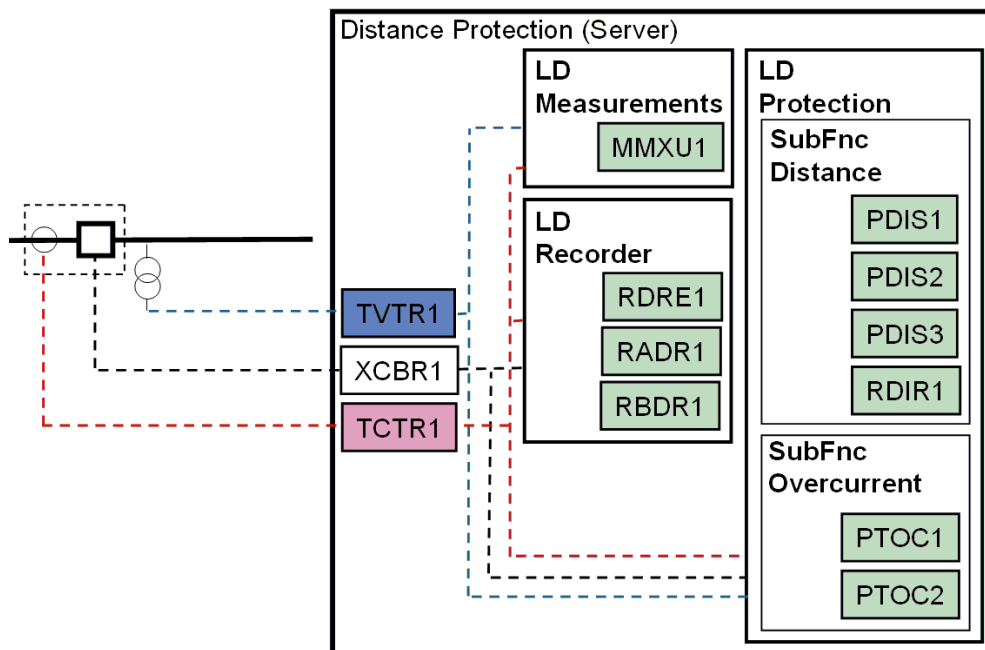


Fig. 4: Distance protection relay – simplified object model

The functional hierarchy becomes even more complicated in the case of an advanced distance protection relay connected to a breaker-and-a-half or ring bus (Figure 3). One approach to the modeling will be to have a logical device for Protection, Measurements and Recording and then if necessary different functional groupings for the line and per breaker, and further down the functional hierarchy.

Another way of modeling this device is to use a Logical Device for each different physical interface (shown with dotted lines in Figure 3) and for some line level functions. Then each of these Logical Devices will include Protection, Measuring and Monitoring functions. The Line level LD will also contain the Disturbance recorder function. Edition 1 of IEC 61850 does not allow nesting of logical devices, so some form of naming convention is required to represent the functional hierarchy. This will change with the coming Edition 2 of the standard.

XCBR1 in Figure 4 is the logical node that models the breaker that the relay is connected to. TCTR and TVTR are the logical nodes that represent the analog input module of the distance 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 PDISi, PTOCj functional elements. Each of these logical nodes has data object hierarchy as defined in IEC 61850.

The modeling of multifunctional distance protection relays is similar between different vendors, but at the same time there are differences that are sufficient to make it impossible to automatically process the data models by different testing, analysis or coordination tools. Also, to the best of the author's knowledge, no protection settings have been implemented by the manufacturers. This is due to the fact that the settings part of the object models, especially the distance function, is not complete in Edition 1 of the standard.

Ongoing work by industry experts in the IEEE Power Systems Relaying Committee's Working Group H5-a is aimed at completing this model in order to allow the definition of a common data format for the settings of multifunctional protection IEDs.

4 DISTANCE FUNCTION MODEL

The distance function is the main protection function in non-communication transmission line protection relays and represents one of the more complex protection logical nodes. The name of the logical node class is PDIS (shown in the table below) and the distance function model will include as many instances of this logical node as distance elements are available in the protection relay.

This class contains many different data objects that represent the status of the distance zone (Start or Operate), as well as the settings. A setting can be mandatory or optional.

It is clear that the setting data objects in the PDIS defined in Edition 1 of the IEC 61850 standard are not sufficient to represent the complete complex distance function. Figure 5 shows a simplified block diagram of the different components and factors that have an impact of the definition, description and configuration of the distance function model.

The configuration of the distance function is based on the impedance of the protected transmission line and setting criteria. The line impedance can be in the phase or sequence domain, depending on the implementation of the distance function.

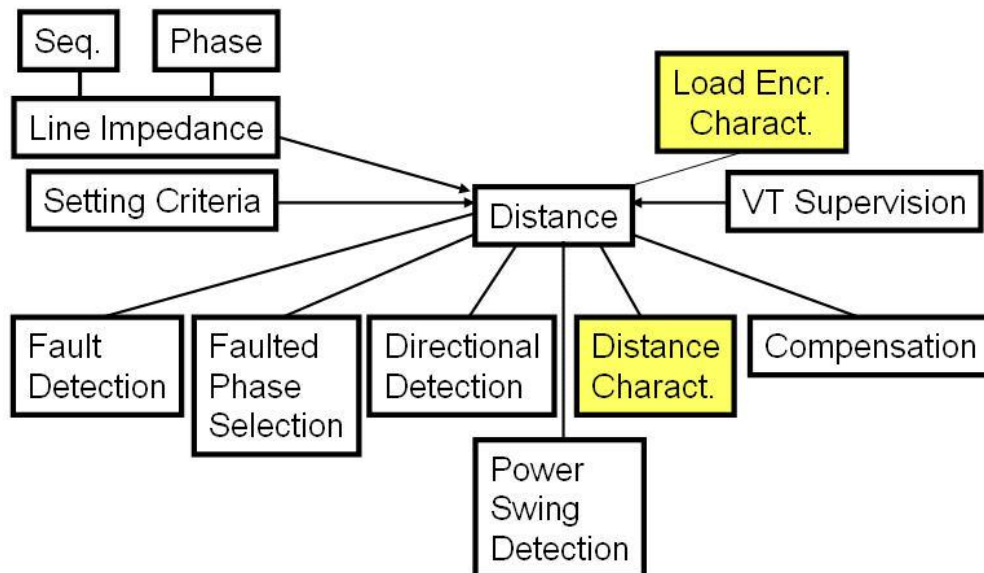


Fig. 5: Simplified distance function model

Voltage circuit supervision can be used to block the operation of the distance function in case of failure of any of the elements of the voltage circuit.

The operation of the distance function can be relatively simple or quite complex depending on the used protection algorithms.

Fault Detection

Advanced multifunctional distance relays can use event driven logic, i.e. the initiate the distance protection function when they detect that a fault occurred in the system.

The fault detection can be based on different operating principles:

- Overcurrent
- Undervoltage
- Underimpedance
- Superimposed components of current and voltage

The modeling of the fault detection element can be achieved using logical nodes representing each of the above listed elements.

Faulted Phase Selection

The faulted phase selection is used to determine the type of fault and which of the loops is going to be used to identify if the fault is within the characteristic of the distance zone. Methods similar to the ones listed under fault detection are typically used.

Directional Detection

The overall distance characteristic can be achieved using a single element, for example an offset mho characteristic, or can be based on directional supervision of an element.

The directional detection can be achieved using polarized quantities or using superimposed components based methods. The second method has significant advantages, because it is much faster and is not significantly affected by the changes in the polarizing quantities that might be used in the different conventional directional detection methods.

Power Swing Detection

Power swings may result in the apparent impedance seen by the distance element entering the characteristic and resulting in undesired operation. Power swing detection can be used to block the operation of the distance elements.

Different methods for power swing detection are used by relay manufacturers. Usually they are based on the time it takes for the apparent impedance to go through different characteristics used for this function. Some advanced relays use the changes in the superimposed currents to ensure early detection of such condition.

Compensation

Considering the impact of different system configurations, instrument transformers or system parameters on the behavior of the distance function, many vendors use different forms of compensation in order to improve the performance of the distance function.

Some compensation examples are:

- Zero sequence
- Mutual coupling
- CVT transients
- Charging current

Distance Characteristic

The distance characteristic is one of the key elements that require a lot of attention in the modeling process. It can be simple or complex and is typically based on the use of Circle, Blinder (resistive or reactive) or Directional line elements.

IEEE PSRC WG H5-a is close to the completion of a model that can be used to cover all known distance characteristics. Figure 11 shows some of the settings of a Zone 3 offset mho distance characteristic and the corresponding data object names used in the IEC 61850 model.

As can be seen from the figure, on the right side of the table are the data object names corresponding to the settings of the distance zone. On the left side are the descriptions of the settings and in the middle their values. The first setting – the characteristic – is not in the Edition 1 PDIS logical node class. That is why it is indicated as new. There are other missing common settings from the IEC 61850 model.

In some relays it is possible to model the reach of the characteristic as a direct setting or as a percentage of the line impedance (as in Figure 6). The line impedance data in this case is available in the Fault Locator logical node RFLO or in the transmission line model.

<i>PHASE DISTANCE</i>		<i>PhsPDIS</i>
Phase Chars.	Mho	DisChr (New)
Zone 3 Ph Status	Enabled	Mod
Zone 3 Ph Reach	250.0%	PctRch
Zone 3 Ph Offset	Enabled	ModOfs
Z3Ph Rev Reach	10.00%	PctOfs
tZ3 Ph. Delay	600.0ms	PhDITmms
Zone P Ph Status	Enabled	Mod
Zone P Ph Dir.	Forward	DirMod
Zone P Ph Reach	200.0%	PctRch

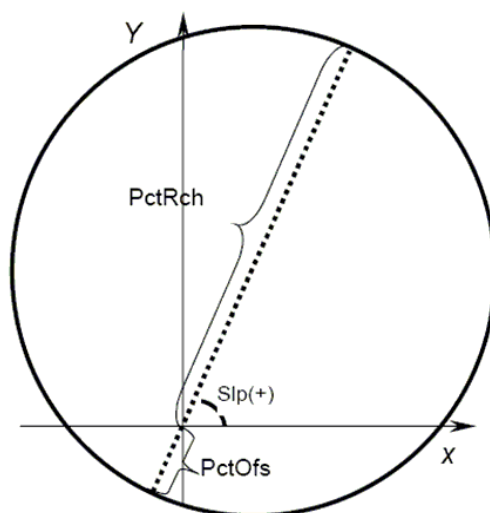


Fig. 6: Model of phase distance element with Mho characteristic

The distance elements should be grouped together as multiple instances of PDIS logical nodes in functional sub-groups – one for phase and one for ground. We should remember that each logical node instance name consist of at least the logical node class name (four capital letters) followed by the instance number – for example PDIS3 for a Zone 3 distance element.

The starting element – when available – should be modeled by a separate logical node. The same applies to the Load Encroachment characteristic and any other distance protection related elements.

5 CONCLUSION

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 also use the model hierarchy defined in the standard. The different components representing or related to advanced distance protection functions should be included in the model.