INTEGRATION OF DISTRIBUTED ENERGY RESOURCES IN SMART GRIDS

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ABSTRACT

Protection operation analysis in smart grids can be sufficiently improved based on the functionality of the intelligent electronic devices and the different common data formats for recording and reporting of power system events that can be used for the development and implementation of smart tools for IED operation analysis..

INTRODUCTION

Distributed generators are becoming a major part of the drive towards a cleaner environment. They are of different sizes and types and are being connected at all different levels of the electric power system – transmission, distribution and low voltage.

Since in many cases the distributed energy resources are not only used to partially cover the energy needs of the user, but also to export power to the electric power system, they need to be integrated into the different protection, automation and control systems.

IEC 61850 is the dominant communications protocol that brings significant benefits to the industry and allows the more efficient integration of devices of different types into systems. It is clear that distributed generators have to be included in the IEC 61850 based modeling in order to support their integration with substation automation systems.

The paper analyses first the principles of object modeling in the IEC 61850 standard. It focuses on the modeling of the functional hierarchy, as well as the Substation Configuration Language and its use.

The different requirements for modeling of distributed energy resources of different types are then discussed.

An example of the model of a distributed generator and its integration in an IEC 61850 based system is presented. Existing logical nodes and their use are first considered. New logical nodes specific to the distributed generation domain are then described.

The need for development of extensions to the Substation Configuration Language is discussed at the end of the paper.

REQUIREMENTS FOR DER INTEGRATION

The challenges that distributed energy resources of different types introduce require that utilities and customers work together in order to make these new systems work, and at the same time improve the quality of power supplied to the user. A lot can be achieved based on the advanced functionality of state-of-the-art protective relays and other Intelligent Electronic Devices. Existing and new communication technologies, the development and implementation of substation automation systems and distribution automation systems can significantly improve the operation of the power system and meet many of the requirements of the critical applications in the distribution or demand levels of the system.

One of the key solutions is to properly define the control hierarchy of the system in order to support controlled separation of the different parts of each level of the electric power system in relatively balanced sub-systems. This will reduce, or even eliminate the effects of wide area system disturbances on most of the customers.

One of the main goals of the Distribution Control System is its efficient operation under normal and abnormal system conditions. Below are some examples of control functions in systems that include distributed generation.

IEC 61850 MODELING CONCEPT

The modeling of complex systems with distributed energy resources is possible only when there is good understanding of the problem domain, as well as the modeling principles developed in the IEC 61850 standard. At the same time we should keep in mind that the models apply only to the communications visible aspects of the modeled system.

The functions in relatively simple devices, 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 the control system for a site with multiple DERs. It has different components that need to be taken into consideration in the model. Complex to represent are also distributed protection and control functions based on high-speed peer-to-peer communications between multiple devices.

The modeling of complex multifunctional devices 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 between multiple devices over the 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. 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 device has a complex functional hierarchy that needs to be modeled according to the definitions of the IEC 61850 model [1-4]. The model can be used to represent both primary and secondary equipment. When modeling secondary equipment, there are several main groups of functions:

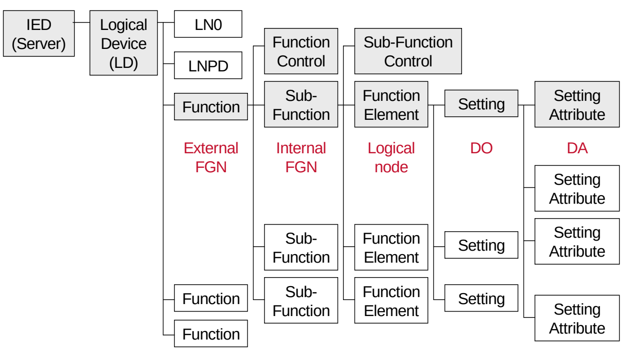
- Protection
- Measurement
- Monitoring
- Control
- Event reporting
- Recording

If we take as an example the protection functions, they can be further divided into main protection functions, backup protection functions and protection related functions. The main protection functions in a DER facility are:

- Directional Overcurrent protection
- Voltage protection
- Frequency protection

Local backup protection function example is Thermal overload protection or a Breaker failure protection.

Each of the above described functions can be divided in sub-functions that represent groupings of related functional elements



.Fig. 1 Functional hierarchy

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 are 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.

An example of a protection functional element will be a phase overcurrent element. They are used to represent the different steps in an overcurrent protection sub-function. Figure 1 shows an example of the functional hierarchy of a multifunctional intelligent electronic device. Settings and their attributes are used as an example for the different data objects and their attributes used in the IEC 61850 model hierarchy.

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

MODELING OF FUNCTIONS IN DER SYSTEMS

The functional hierarchy of modern devices to a great extent is dependent on their application and main function. A very simple low-end device may have a very limited functionality, while a device that supports IEC 61850 will typically have a more complex functional hierarchy. For example devices used to protect and control a single DER the model may be simple, while a controller used at a DER plant level may have to consider the availability of multiple analog and binary signals.
One of the most important concepts that need to be understood at the very beginning of the DER modeling process is that the model includes only objects that are visible to the communications. The devices may contain a lot of internal data, such as data exchanged between elements of fixed control functions. If a function 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 should not be included in the model.

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

The modeling of complex DER systems depends not only on their functionality, but also on the configuration of the substation where they are installed and connected to the electric power system.

The modeling of DER based systems 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 of can be used for any physical device that is being modeled as part of a substation or DER plant automation system. Usually a simple IED will be modeled as server with a single Logical Device.

As discussed earlier, in case of devices with more complex functional hierarchy it might be necessary to group together several logical nodes in a functional group. 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) as shown in Figure 1.

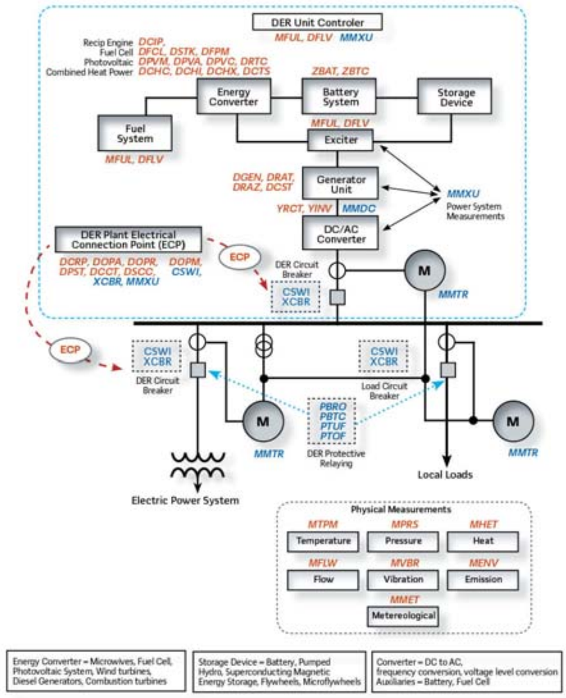


Fig. 2 DER system model

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.

The modeling of DERs in IEC 61850 can be done by mapping the different functions supported by the devices to different logical devices. One logical device will represent the primary protection functions. Another will define the Measuring function and a third – the Control function.

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

Each logical node has a data object hierarchy as defined in IEC 61850 and described in more detail below.

Data object hierarchy

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. which can be simple or nested.

The modeling of systems with DERs reuses many existing logical nodes already defined in IEC 61850. For example XCBR1 in Figure 2 is the logical node that models the breaker that the system controls. PTUF and PTOF are the well-known underfrequency and overfrequency protection elements. Electrical quantities measurements are represented by MMXU.

It is obvious that since we are covering a domain different then the substation automation, protection and control domain subject to the IEC 61850 standard, it has to be extended by a range of new logical nodes specific to DER based systems.

Logical Nodes for the DER Domain

As can be seen from Figure 2, there is a significant number of functions in the DER domain that are not covered by the existing logical nodes defined in IEC 61850. They can be grouped in several categories related to their association with specific functionality and types of DERs and defined by the members of the IEC TC 57 working group 17 in an extension to the standard.

Logical nodes for the DER plant electrical connection point (ECP)

These logical nodes belong to a new D group specific to the distributed energy resources domain. Every DER has to be connected somehow to the electric power system – at the microgrid, distribution or sub-transmission system level. Plant Electrical Connection Point (ECP) includes a group of logical nodes that can be used in a logical device and define the characteristics of the DER plant at the point of electrical connection. Usually there is a switch or circuit breaker at this point of connection.

The model is capable of supporting simple DER configurations, such as a single DER unit, as well as large and complex hierarchical systems.

An example of a logical node that belongs to this sub-group is DSCC which is used to model the DER energy schedule control.

Logical Nodes for the DER unit controller

The existence of a variety of DER devices does not mean that they don't have some similarities – for example the existence of a different prime mover. Any DER needs to be controlled in order to perform its functions. The DER device controller defines the operational characteristics of a single DER device, regardless of the type of generator or prime mover. Different logical nodes can be grouped together in a logical device that models the control functions of a DER.

An example of a logical node from this sub-group is DRCT, representing the DER controller characteristics.

Logical Nodes for DER Generation Systems

Many DER units (for example hydro, wind, tidal, etc.) have a generator. Each different prime mover requires a different logical node. However the general operational characteristics of the generators are similar across different DER types, requiring only one DER generator model.

The DER generator logical device describes the generator characteristics of the DER unit. These generator characteristics can vary significantly, depending upon the type of DER device.

The generator model is based on several groups of logical nodes: DER generator, DER excitation system, DER speed/frequency controller, DER inverter/converter

Logical Nodes for Specific Types of DER

As mentioned earlier, different types of DERs require some specific logical nodes for their models. The following is a list of groups of logical nodes used for this: reciprocating engine devices, fuel cells, photovoltaic (PV) systems, combined heat and power (CHP).

Logical Nodes for Auxiliary Systems

Different types of auxiliary systems need to be modeled to cover the complete range of functions and components of a DER system. Below is a list of several groups of logical nodes used to meet these needs: fuel system, battery system, fuse device, sequencer, physical measurements.

DER SYSTEM CONFIGURATION LANGUAGE

The Substation Configuration Language (SCL) is one of the main differentiators of IEC 61850 that allows the development of engineering tools which can be used to improve efficiency. It is clear that DER systems will benefit also from the extension of SCL.

The SCL in this case should indicate System Configuration Language. It should be very similar to the existing SCL and should be extended using all existing elements of the CIM model, plus some additions to be determined through the joint efforts of modeling and distributed energy resources domain experts.

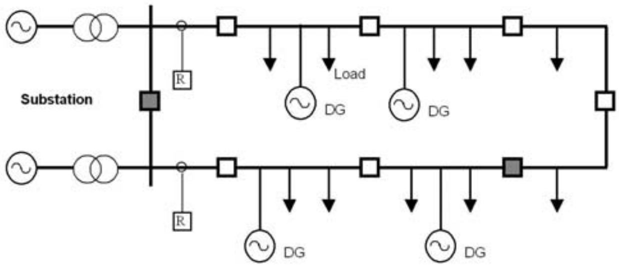


Fig. 3 Distribution system with DERs

CONCLUSIONS

The continuing increase of installations and use of different distributed energy resources, especially in light of the global energy crisis and global warming, as well as the need for integration of such devices and systems with the electric power system resulted in the development of a new group of logical nodes that can be used for modeling of DER based systems.

Modeling of IEC 61850 based DER systems requires good understanding of their functional hierarchy, as well as the modeling principles defined in the standard.

The model of an Electrical Connection Point (ECP) and a Generator can be used regardless of the prime mover used by a DER. Different types of prime movers require specific logical nodes. Extensions of the Substation Configuration Language should support the description of large and complex DER systems.