Engineering Disturbance Analysis Systems in the Smart Grid

Dr. Alexander Apostolov

OMICRON electronics

The push for a smart grid will require significant investments not only in equipment, but also in the engineering of smarter systems for the analysis of the operation of protection, automation and control systems at the different levels of the electric power system. That is why it is very important to start a discussion on the opportunities that exist to develop a set of engineering tools based on the development and experience with the use of the IEC 61850 substation configuration language and CIM.

The paper describes briefly the different components of a hierarchical disturbance analysis system implemented in the smart grid, their associations and interfaces.

It then focuses on the existing components of such system model and the required extensions that will allow the development of a system information model (SIM) that covers:

- Transmission lines
- Substations
- Distribution feeders
- Communications infrastructure
- Protection, automation, control, energy management and other functions
- Multifunctional intelligent electronic devices
- Their associations with the primary and communication systems

The paper then identifies some missing components that require extensions to the existing models or development of new models.

The next part of the paper discusses some issues related to the development and implementation of the hierarchical model that supports widespread application of disturbance analysis systems based on the implementation of standard protection, automation and control schemes.

The paper later describes the engineering process based on this concept and the use of different standard data formats to achieve different engineering tasks.

1 IEC 61850 Model

IEC 61850 is a standard for communication networks and systems in substations. It 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 Technical Committee 57

In 1997 a conclusion was reached that due to the similarities of both activities it will 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 10, 11 and 12.

IEC 61850 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

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 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. Figure 1 shows the use of this process to model an overcurrent stage of a distribution protection relay as an IEC 61850 logical node.

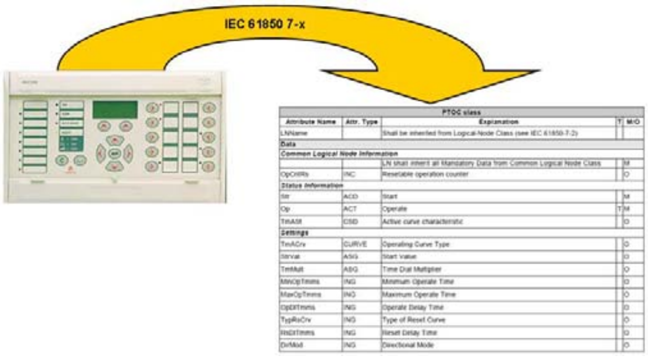

Fig. 1 Virtualization of a protection IED

This integration process in substations using IEC 61850 as the communications protocol is based on object models that require the use of appropriate tools to represent the complex architecture of the substation, the communication system and the multiple functions in the IEDs themselves.

A major part of the engineering of a substation automation system is related to the architecture and configuration of the secondary equipment in the substation. This requires the development of a formalized format that allows the description of all different elements and their relationships. IEC 61850 defines the object models of the different types of primary and secondary equipment, as well as their functionality in the substation.

A substation automation system also includes different tools for visualization and control of the primary and secondary substation equipment - the substation HMI. The user can navigate through the multiple views of the substation one line or communications diagrams, or check the status or settings of a specific IED. The development of the HMI and the mapping of the multiple analog and binary signals from the IEDs is a very labor intensive process that also can be subject to errors at different stages of the engineering process.

The development of IEC 61850 had as one of its goals the definition of a file format that describes the components of the substation and the protection and automation system in a way that allows most of the engineering tasks to be performed automatically.

In order to allow the exchange of data between different engineering tools required at different stages of the substation integration process, that file format has to meet the requirement for interoperability. At the same time the overall engineering process should be designed taking into consideration the fact that during the early stages of implementation of IEC 61850 it may be necessary to use also some proprietary data formats.

Part 6 of the IEC 61850 standard defined the Substation Configuration Language (SCL) and its use to describe the substation configuration, IED's and communication systems in a way that corresponds to the object models defined in different other parts of the standard.

SCL is based on UML and XML. The following sections of the paper give a brief introduction to UML and XML and how they are used to describe the different elements of the substation automation system.

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. The information modeling on the other hand 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 the 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 a low-end distribution feeder or 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 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. These differences need to be addressed and the models extended to meet the needs of such applications.

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. This also needs to be taken into consideration in the model.

A simplified diagram with the communications architecture of an IEC 61850 Process Bus based substation automation system is shown in Fig. 2.

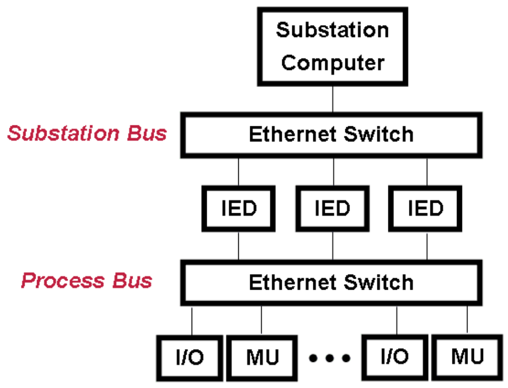

Fig. 2 Simplified IEC 61850 based communications architecture

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].

Logical nodes are grouped in logical devices, usually to represent specific functions that are part of a server. Sometimes if the IED has a more complex hierarchy it is necessary to introduce intermediate layers in the model – sub-functions.

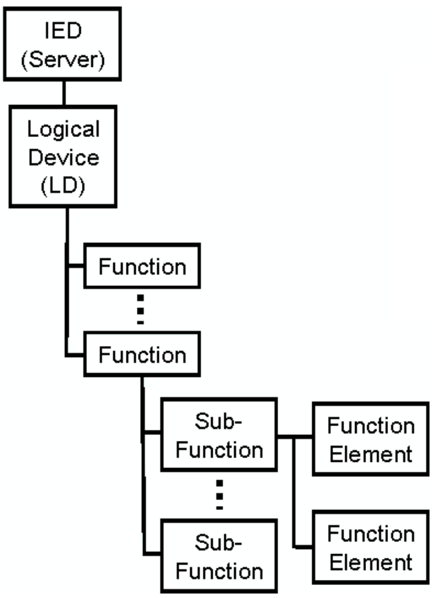

Fig. 3 IED functional hierarchy

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

The standard does not only model the IEDs, but also the communications architecture and the primary substation equipment. The substation model is based on CIM.

2 CIM (IEC 61968 and IEC 61970) Model

The computer industry created a Common Information Model (CIM) standard for defining the characteristics of devices and applications in a way that allows system administrators and management programs to control devices and applications from different manufacturers or sources in the same way. It takes advantage of XML (the Extensible Markup Language) and several defined XML schemas, so that hardware and software makers can supply CIM information about their product.

The EPRI/IEC Common Information Model (CIM) in a similar way describes data typically used in different utility control and operational systems. This includes data in an EMS or SCADA system, as well as data found in DMS, work, and asset management systems. More recently, the CIM is being extended to include transmission reservation and energy scheduling information.

The CIM was originally developed as part of the EPRI Control Center Application Programming Interface (CCAPI) project/ It was later standardized by IEC TC57 Working Group 13 as part of the IEC61970 standard for control centers. It includes information associated with control center applications such as:

- Supervisory Control and Data Access Systems (SCADA)
- Energy Management Systems (EMS)
- State Estimator
- Power Flow
- Topology Processing
- Security Analysis
- Network planning

IEC TC57 WG14 extended the CIM model in their IEC 61968 standard for Distribution Management Systems (DMS) related functions. It added information models associated with operational support applications such as:

- Asset Management Systems
- Work Management Systems
- Construction Management
- Distribution Network Management
- Geographic Information Systems (GIS)
- Outage Management

The CIM describes real world objects in terms of classes, attributes and relationships. The simplified block diagram in Figure 4 shows some of the classes defined in both standards.

A substation can contain voltage levels that contain equipment. Conducting Equipment is a general class that has subtypes such as Breakers and Transformers.

Measurements are associated with Breakers that have terminals or Transformers that have windings.

In order to ensure interoperability, TC57 WG13 is in the process of developing a series of interface standards called the Generic Interface Definition (GID). It is an umbrella term for:

- Generic Data Access (GDA) – A request/reply oriented interface that supports browsing and querying randomly associated structured data
- Generic Eventing and Subscription (GES) – A publish/subscribe oriented interface that supports hierarchical browsing of schema and instance information.

- High Speed Data Access (HSDA) – A request/reply and publish/subscribe oriented interface that supports hierarchical browsing about high-speed data.
- Time Series Data Access (TSDA) – – A request/reply and publish/subscribe oriented interface that supports hierarchical browsing about time-series data.

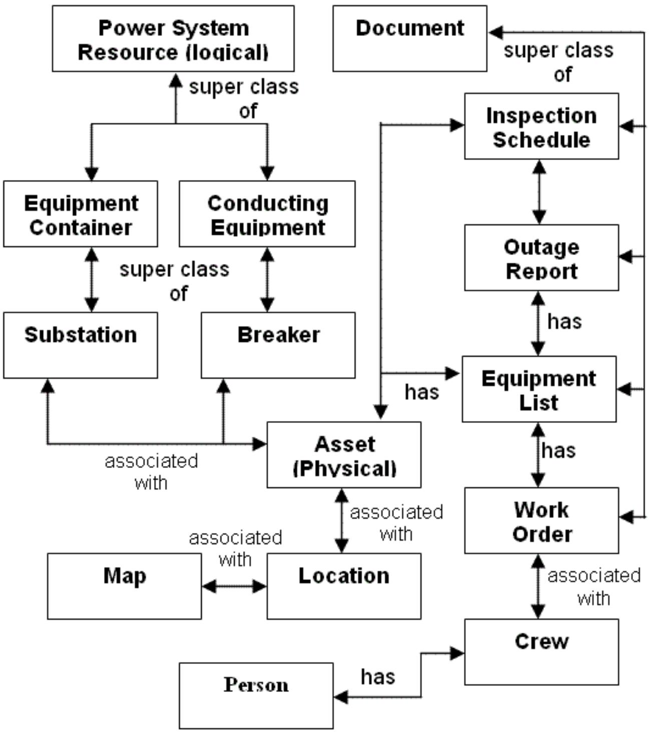

Fig. 4 Simplified CIM class model

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We need to understand that the classes defined in the IEC 61968 and 61970 standards have attributes based on the needs of the different system level applications listed earlier in the paper. However, they do not address properly the needs of protection and some other related applications that require topology or network modeling information. This is where the needs for harmonization and extension of the models come into play.

3 Harmonization Requirements

Based on multiple use cases related to transmission line protection and their settings and coordination, the analysis of wide area disturbances or other system events, combined with the analysis of the CIM and IEC 61850 models, it is clear that there is significant work that needs to be done in order to meet the requirements of multiple system and substation level applications. Following is an incomplete list of some of the required harmonization and extensions of the models.

A general observation is that the CIM model is very basic with many data objects missing related to applications such as dynamic stability studies or other system level applications.

The object hierarchy in IEC 61850 is defined much better and any functional elements that are modeled in IEC 61850 can be reused for system level applications in the CIM model.

The existing IEC 61850 and CIM models of the different electric system components – lines, transformers, generators, capacitors need to be compared between themselves and with the modeling requirements for steady-state short circuit studies or electromagnetic transient analysis programs.

Connectivity model for transmission and distribution lines is needed to describe a line with multiple segments. The main issue is that currently a connectivity node belongs to a substation. However, when defining a segment of a transmission line that is mutually coupled with a segment from another line running on the same tower or right-of-way, the connectivity nodes defining the segments typically do not belong to a substation, but to the transmission line. This will need to be addressed in the model.

The connectivity model needs to be extended to cover lines with multiple segments and mutual coupling on double circuit or parallel lines.

Load and generation models required in IEC 61850

Harmonization of measurements and status monitoring or control models is also necessary.

Positive, negative and zero sequence components of the impedances need to be extended and harmonized in both models.

A three phase impedance model (3x3 matrix) for single transmission line is needed.

A three phase impedance model for a double circuit line or a section of lines in parallel (6x6 matrix) is needed.

A multi-step test file format will be required as well.

An Event reporting model will need to be harmonized between IEC 61850 and CIM (based also on COMFEDE.

Definition of Virtual Measurements is required for both models.

Some Test Evaluation logical nodes will also need to be developed.

The CIM and IEC 61850 models need to be extended and harmonized to support the creation of a table with different system topologies and the corresponding setting groups of the IEDs included in the system.

The CIM model needs to be harmonized to be able to issue a change of setting group command

Development of SPS and RAS object models for CIM and IEC 61850

Load models required in IEC 61850 for substation SPS or RAS functions.

The CIM and IEC 61850 models need to be extended and harmonized to support the creation of a table with different system topologies and the corresponding actions for specific events that may lead to a disturbance.

The Protection definition in the CIM model is very basic and practically limited to a very simplified model of an overcurrent protection. This model extension needs to be addressed in the next phase of this project based on a logical device use implementation agreement.

Designation of Primary and Backup IEDs required in a harmonized manner in both CIM and IEC 61850

Designation of Primary and Backup Merging Units required in a harmonized manner in both CIM and IEC 61850

A method for the definition of the bus differential protection zone of protection needs to be developed and implemented both in CIM and IEC 61850.

Development of controlled islanding starting function object models for CIM and IEC 61850.

The harmonization and extension of the models listed above will allow the development of many new tools that support automatic configuration, analysis or other applications that are part of the control, protection, engineering, commissioning and operations processes.

4 Disturbance Analysis System Architecture

An IEC 61850 based disturbance analysis system can have a different architecture depending on the level of implementation of IEC 61850 based components. It can be of two main types:

- IEC 61850 Station Bus based
- IEC 61850 Station Bus and sampled values based

The disturbance analysis functions in the first case are based on the subscription of the disturbance analysis client to different types of communications messages defined in IEC 61850:

- GOOSE messages related to the operation of different switching devices that determine the topology of the substation where the disturbance analysis system is located
- GOOSE messages related to the operation of different protection elements
- Reports containing information related to the analyzed system event

The disturbance analysis system in some cases may also require waveform records in COMTRADE format and/or setting files of multifunctional protection devices whose operation is subject to the analysis.

Figure 5 shows a simplified block diagram of a disturbance analysis system without the use of IEC 61850 sampled values. The application is running on the substation computer and receiving messages from the different components of the system:

- The Process Interface Units (PIU) provide the information for changes in the state of switching devices that define the real-time system topology.
- The Intelligent Substation Devices (ISD) provide information on:
    - Operation of different protection elements defined as Logical Nodes
    - Information about time of fault, type of fault, fault location, fault duration, pre-fault and fault current and voltage values

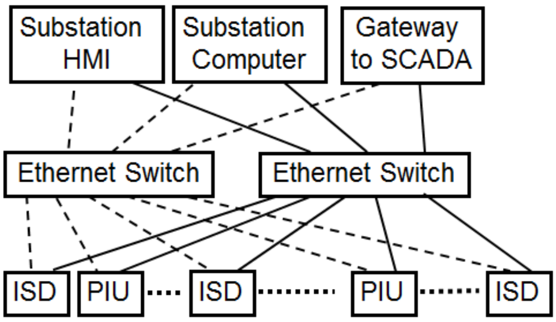

Fig. 5 Simplified block diagram of disturbance analysis system

In case when the system is based on sampled values, the currents and voltages are provided by the merging units, as shown in Figure 6. The rest of the system remains the same as described above.

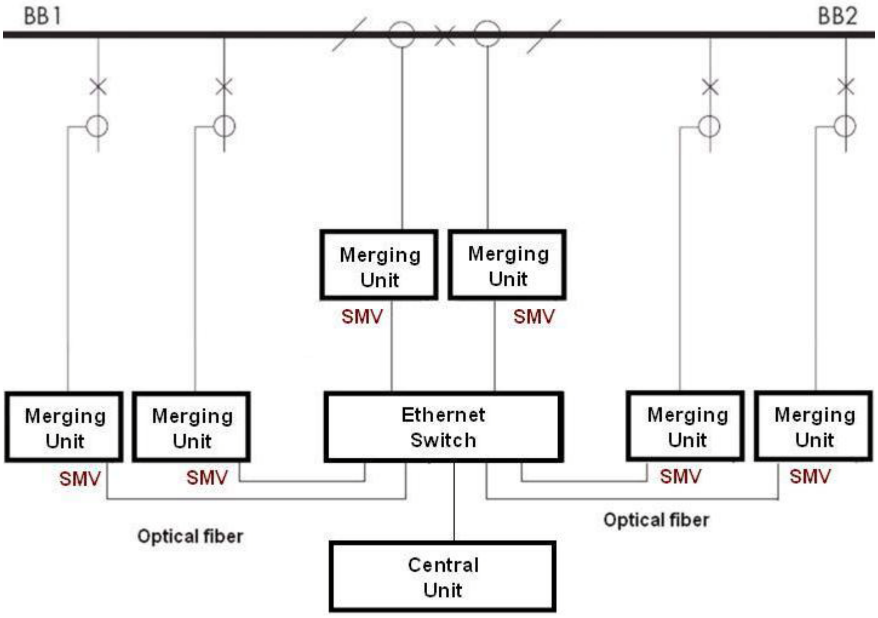

Fig. 6 Disturbance analysis system using IEC 61850 sampled values

5 Engineering of IEC 61850 Based Disturbance Analysis Systems

The engineering of a disturbance analysis system based on IEC 61850 is done using tools that support object-oriented design and the use of the models described earlier in the paper.

The electric power system topology is defined based on a CIM model, while the substation topology is made available in an SSD file. This file also contains information on the functional requirements for protection, automation and control and the allocation of logical nodes to the primary equipment in the substation.

Once it is clear what devices will be used in the system, their ICD files are used by the engineering tool together with the SSD file to generate the SCD file that defines the required interfaces and subscriptions of the disturbance analysis system to:

- sampled values
- GOOSE messages
- reports
- time synchronization
- any other relevant information required by the disturbance analysis system

Once the SCD file is ready, it is used by the setting tools of each IED included in the system to configure it for operation as part of the system.

Another part of the engineering of the system is the configuration of the analysis part, which to a great extent will depend on the methods and tools used in the analysis. In order to formalize the engineering of this last step it will be necessary to establish a task force within IEC 61850 TC 57 Working Group 10 to define the object models of disturbance analysis functions.

6 Conclusions

IEC 61850 and CIM represent a good foundation for the creation of a global power system model that will meet the needs of all applications and domains and can be used to formalize and automate the engineering of disturbance analysis systems.

In order to meet all requirements it is necessary to harmonize the IEC 61850 and the CIM models.

Both models need to be extended in order to cover substation - substation and substation - system level, as well as some other applications.

The engineering of disturbance analysis systems includes the selection of the system architecture and the information to be used by the system, including the interfaces and messages exchanged between the elements of the system.

Definition of disturbance analysis functions' object models as part of the IEC 61850 model is required to cover this kind of applications.

7 References

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