Data sources for fault and disturbance analysis in IEC 61850 based digital substations

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1. Introduction

IEC 61850 has been used for more than 10 years and we already have thousands of digital substations in service all over the world. It brings significant benefits, such as improvements in the reliability, security and efficiency of the operation of electric power systems under different conditions.

One of the characteristics of this digitized substations world is the huge amount of data that is becoming available and can be used by fault and disturbance analysis applications in electric power systems.

The paper starts with a description of the components of an IEC 61850 based digital substation from the point of view of the requirements for data feeding into fault and disturbance analysis applications. It first describes the different types of data available in the digital substation, including the sampling rates and other factors that have an impact on the amount of data available.

The use of various combinations of the different types of data to be used as inputs to fault and disturbance analysis algorithms is presented based on specific examples.

This is followed by the analysis of the different types of devices in the digital substation and the types of data that they produce.

The next part of the paper is concentrated on the communications architecture of the substation protection, automation and control system and how the different types of devices described earlier are connected to the substation network. Different topologies, such as star, ring or hybrid are considered, as well as redundant communication protocols such as PRP and HSR providing higher level of reliability and better performance for protection applications.

The allocation of the fault and disturbance analysis applications within the components of the substation protection, automation and control system is then considered. Some of them that require extremely high sampling rates might be implemented at the process level, while others may reside in protection IEDs. However, it is expected that most of the fault and disturbance analysis applications will be running at a central substation server that is also receiving data from outside of the substation. Such data can provide additional information about the state of the electric power system that is helpful in the decision-making process and is not available locally at the substation.

2. IEC 61850 based digital substation

One of the main characteristics of the IEC 61850 standard is that it defines the object models of the different components of a protection, automation and control system but does not specify how it should be implemented. In traditional digital substations their architecture is typically distributed with some devices providing the interfaces to the primary substation equipment and other devices performing protection, automation, control, monitoring and recording functions by exchanging information between the process interface devices and themselves. What is common between a distributed system and a centralized system is that the process interface is identical between the two, while the interactions between the distributed devices over the station bus is replaced by interaction over the digital data bus of the central substation servers.

The process interface functions can be divided in three main categories:

- Switchgear interface
- Electrical interface
- Non-electrical interface

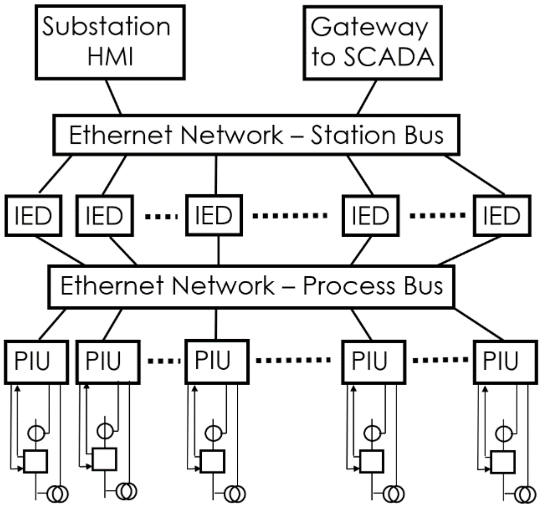

Fig 1 Digital substation

These functions can be implemented by grouping logical nodes in logical devices. For the logical devices we use the following naming conventions:

- Switchgear Interface Unit (SIU) provides a binary status and control interface for circuit breakers and switches
- Merging Unit (MU) converts analog signals (currents and voltages) into time-synchronized streams of sampled values according to IEC 61850-9-2 of IEC 61869
- Non-Electric Interface Unit (NEIU) converts analog signals from non-electric sensors into time-synchronized streams of sampled values according to IEC 61850 9-2 or GOOSE messages according to IEC 61850-8-1

These logical devices can be placed in individual boxes or can be grouped together in different ways such as:

- Process Interface Unit (PIU) that combines two or more of the functions listed above
- Process Interface IED (PIIED) combines the functionality of a PIU with local protection, control and/or other non-interface functions

The different process interface devices communicate with the rest of the substation protection, automation and control system using the required IEC 61850 services.

Today most of the existing digital substations have the distributed architecture shown in Figure 1 with the functions located in different multifunctional IEDs communicating over the substation station bus using GOOSE messages.

Based on the data from the process interface devices the IEDs perform different functions such as:

- protection
- measurements
- automation
- monitoring
- recording

Each of the function elements used in the implementation of the above listed functions produces a significant amount of information that can be used to improve the performance of different fault and disturbance analysis applications. It is very important to note that all the data from the process, as well as the outputs from the functional elements in the IEDs is time stamped based on the accurate time synchronization using IEC 61850 9- 3 which supports the precise alignment of the data from all different sources.

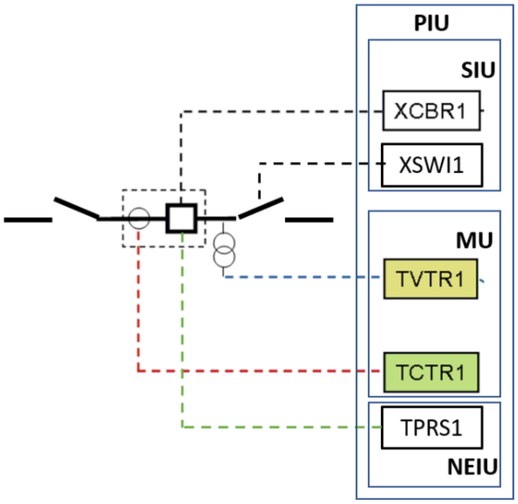

Fig. 2 Process Interface Unit (PIU)

It should be noted that even that most of the decisions of fault analysis related applications can be made using the locally available data and information, some of them might be misleading if they did not take into consideration the actual topology of the substation and the electric power system and the impact of remotely located equipment. That is why it is important also to receive timestamped information from SCADA or system integrity protection schemes.

3. Data in digital substation

The IEC 61850 based digital substations use various sensors connected to the primary system equipment. All function elements in such systems are represented in the IEC 61850 model by Logical nodes that belong to different groups according to their role in the system.

The sensors in a protection, automation, control, monitoring and recording system belong to the group T. While in Edition 1 of the standard they were only for currents (TCTR) and voltages (TVTR), Edition 2 added many new sensor logical nodes – for temperature, vibration, etc. that are required by condition monitoring functions of the asset management system, but also can be helpful for fault and disturbance analysis.

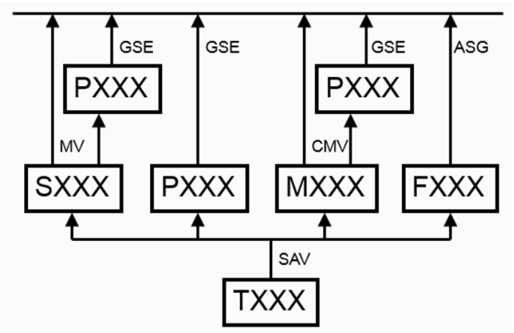

Fig. 3. Abstract logical nodes interface model.

Figure 3 shows an abstract block diagram of the functional decomposition in the IEC 61850 model with the sensor T logical nodes at the bottom sending sampled analog values (SAV) to the function elements that need them – protection (P group), measurements (M group), monitoring (S group). Each logical node represents a function element in the system that is a data source providing data using the services defined in the standard.

The data model hierarchy includes Logical Devices (LD) representing the different functions – protection, control, measurements, monitoring, recording - in the device. The logical device may contain child logical devices representing sub-functions in a hierarchical structure.

Logical devices contain logical nodes representing function elements – the building blocks in the model.

The logical nodes contain data objects belonging to various common data classes. Each data object contains attributes. Some of the data objects and attributes are mandatory, but most of them are optional.

The communication services represented by the control blocks are associated to data sets containing data objects and data attributes. This is the data that is available over the substation communications network and becomes an input into the artificial intelligence-based components of the system.

The amount of available data in digital substations can be huge, especially when the merging units are publishing streams of current and voltage samples for both protection and power quality and disturbance recording purposes. Today this is based on the implementation agreement known as IEC 61850-9-2 LE. It defines for protection and control applications a sampling rate of 80 samples/cycle at the nominal system frequency. The digital output publishing rate is 4000 frames per second at 50 Hz and 4800 frames/sec at 60Hz with one ASDU (Application Service Data Unit) per frame. For power quality monitoring and disturbance recording the sampling rate is 256 samples/cycle at the nominal system frequency with 8 ASDUs per frame. It is not difficult to imagine the huge amount of data that this represents.

The switchgear interface units send GOOSE messages anytime when there is a change of state of the breakers or disconnecting switches.

Since most of today’s advanced IEDs also have embedded phasor measurement units (PMU) that calculate M and P class synchrophasors that may be published 4 times per cycle, the amount of data to be processed by the system further increases.

Any operation of a function in an IED also can be configured to send an event report or to log the data, further adding to the data to be processed by the fault and disturbance analysis applications.

Depending on the type of function in some cases we may need to process sampled values streaming in real time, while in others we will be working with recorded data. It is impossible all this data to be processed by humans, that is why we need the help of fault and disturbance analysis tools that may be assisted by artificial intelligence platforms to solve the big data problem.

4. Digital substation architecture

The communications architecture depends on the specifics of the substation and the requirements for performance, reliability and security. It can be star, ring, mesh or hybrid – combining them in order to meet the specific requirements of the substation and the applications.

Redundancy protocols such as PRP and HSR are used to improve the reliability of the system. The price to pay is that the amount of data that is published over the substation local area network is doubled, but on the other hand monitoring the traffic will allow the fault and disturbance analysis applications to detect issues with the substation devices and the communications network.

One of the main characteristics of the IEC 61850 standard is that it defines the object models of the different components of a protection, automation and control system and the communications services for data exchange. However, it does not specify how it should be implemented.

In traditional digital substations their architecture is typically distributed with some devices providing the interfaces to the primary substation equipment and other devices performing protection, automation, control, monitoring and recording functions by exchanging information between the process interface devices and themselves as shown in Figure 1.

The new trend of virtualization and digitalization of the electric power grid is leading to the separation between hardware and applications. As a result we already see digital substations with centralized architecture as shown in Figure 4.

What is common between a distributed system and a centralized system is that the process interface is identical between the two, while the interactions between the distributed devices over the station bus is replaced by interaction over the digital data bus of the central substation servers.

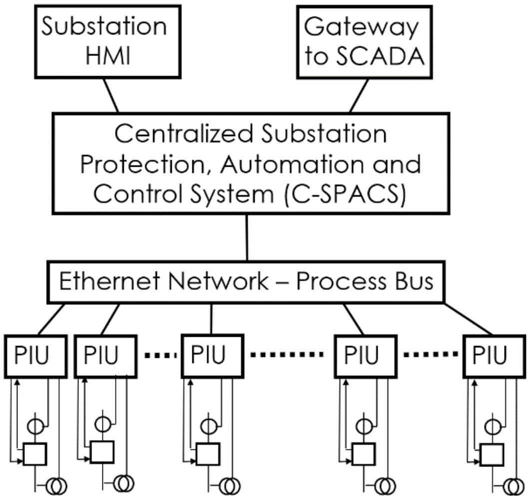

Fig. 4 Centralized digital substation

5. System topology data

Successful fault and disturbance analysis requires not only real time or recorded data from the different substation devices, but also knowledge of the substation topology any state at the time when an event occurs.
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, including the fault and disturbance analysis to be performed automatically.
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.
It is used to describe the substation connectivity, IED configurations and communication systems according to parts 5 and 7 of this standard. Description of the relations between the substation automation system and the substation (switchyard) itself.
SCL was developed to support easier engineering of substation automation systems and application functions. It allows the description of a substation or an IED's configuration to be passed to a communication and application system engineering tool.
Its main purpose is to allow the interoperable exchange of communication system configuration data between an IED configuration tool and a system configuration tool from different manufacturers.
The substation configuration language supports the development of engineering tools that are capable of describing:

- The substation one line diagram representing the different voltage levels, busses, transformers, bays and switching devices. The functional requirements should also be included in terms of allocation of logical nodes to the primary substation equipment.
- The IEDs to be used to perform the required functions based on a fixed number of logical nodes (LNs)
- The communication interface of the different IEDs – specifically their connection to the substation local area network

- The Client-Server and Peer-to-Peer communications for the specific substation automation system implementation

It needs to be understood that the standard does not define any specific software tools that support the intended engineering process. This is a task that the IED manufacturers, substation automation system vendors or third party providers have to develop based on the requirements of the market using the different types of files defined in the standard.

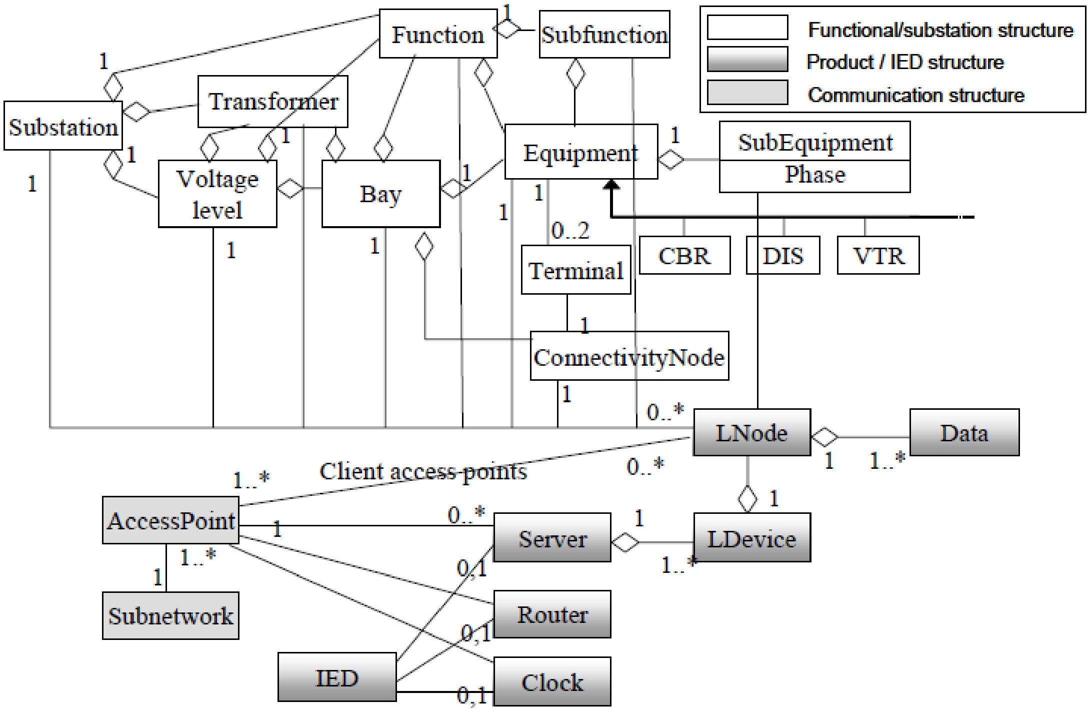

Fig. 5 System configuration language model

The configuration of the system is represented by the substation Configuration Description (SCD) file. It contains substation description section, communication configuration section and all IEDs.
The IEDs in the SCD file are not anymore in their default configuration, but as they are configured to operate within the substation protection and automation system. These files are then used to configure the individual IEDs in the system.

6. Fault and disturbance analysis applications allocation

The allocation of the fault and disturbance analysis applications within the components of the substation protection, automation and control system depends on the system architecture and the kinds of applications being used.

For example, applications that require very high sampling rate, such as traveling wave based fault location or partial discharge detection should be located at the process level devices, because no other applications typically require search high sampling rates and they will represent a significant burden on the communications network.

Applications such as protection operation analysis that use as inputs streaming sampled values and information about the status of the switchgear can be implemented in the process interface devices, the IEDs using this data or at the substation level, especially in the case of centralized protection and control systems.

Applications that require sampled values and status information from multiple bays, such as busbar protection operation analysis, should be implemented at the substation level.

Since typically the protection and control IEDs today do not support artificial intelligence based applications, it is expected that most of these applications will be running at a central substation server that is also receiving data from outside of the substation. Such data can provide additional information about the state of the electric power system that is helpful in the decision-making process and is not available locally at the substation

7. Conclusions

The digitization of the electric power grid is leading to the development of IEC 61850 based digital substations with thousands already in service.

The process interface devices and the multifunctional IEDs generate huge amounts of data that can be processed by fault and disturbance analysis applications which will help solve many of the challenges created by the changing grid.

Different types of data is available in the digital substation with different sampling rates, as well as status and event information. All data is timestamped based on a PTP profile which allows accurate alignment of the data from all different sources.

The data from the different sources can be grouped in the following categories:

- Raw data represented in the model by streaming sample values from electrical or non- electrical sensors
- Status data from the switchgear and other primary equipment in the substation
- Synchrophasor measurements from the P class or M class
- Status data from multi-functional protection and control IEDs
- Event report from multi-functional protection and control IEDs
- Time synchronization data from different clocks
- Output data from substation level applications
- Data received from remote substation
- Data received from system integrity protection schemes
- Data received from the control center

Various combinations of the different types of data can be used as inputs to fault and disturbance analysis tools together with the SCD file to support advanced protection operation or wide area disturbances analysis applications.

Biography

Dr. Alexander Apostolov received MS degree in Electrical Engineering, MS in Applied Mathematics and Ph.D. from the Technical University in Sofia, Bulgaria. He has 48 years' experience in power systems protection, automation, control and communications.

He is presently Principal Engineer for OMICRON electronics in Los Angeles, CA. He is IEEE Life Fellow and Member of the IEEE PES Power Systems Relaying and Control (PSRC) Committee and the Power System Communications and Cybersecurity (PSCC) Committee. He is past Chairman of the Relay Communications Subcommittee and serves on many IEEE PES Working groups.

He is member of IEC TC57 working groups 10, 17, 18 and 19.

He is Convener of CIGRE WG B5.69 "Experience gained and Recommendations for Implementation of Process Bus in Protection, Automation and Control Systems (PACS)" and member of several other CIGRE B5 working groups.

He is Distinguished Member of CIGR and IEEE Distinguished Lecturer.

He holds four patents and has authored and presented more than 600 technical papers.

He is Editor-in-Chief of PAC World and Chairman of the PAC World conference.