IMPACT OF IEC 61850 ON POWER QUALITY MONITORING AND RECORDING (AN UPDATE)

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

Frederic DUNET
OMICRON electronics – France
frederic.dunet@omicronenergy.com

Juan PARRA
OMICRON electronics – Spain
juan.parra@omicronenergy.com

ABSTRACT

Since the publication of the first edition of IEC 61850 the standard has continued to evolve in order to meet the requirements of different Smart Grid applications, including power quality monitoring and recording. The paper describes this evolution and its impact.

INTRODUCTION

Power quality monitoring devices are designed to detect and record different power quality events and report to the user their characteristics. However, using specialized devices in many cases is limited by the fact that they are an additional piece of equipment that needs to be purchased, installed, commissioned and maintained. At the same time, multifunctional protection or disturbance recording devices operate during system events and record the waveforms or profiles of the system parameters measured by the device. IEC 61850 has a significant impact on the implementation of power quality monitoring and recording functions.

The availability of sampled values from stand-alone merging units or optical sensors in IEC 61850 based substation automation systems allows the development of a substation level power quality analysis and recording system. The paper analyses the architecture of such a system. It considers the recording capabilities of protection relays and compares them with power quality monitoring or disturbance recording devices. It describes a centralized power quality monitoring and recording system and describes its benefits compared with conventional systems.

Requirements for time-synchronization of all IEDs used to record the power quality events are described, including the changes in the time-synchronization technology being used for high accuracy time synchronization.

Automatic disturbance records extraction of available records from the IEDs is one of the essential functions of the system.

Combining and aligning the records from the different devices in a data base builds the foundation of the analysis module of the system. Based on a user-defined period of time, the analysis module determines the parameters of the power quality events that occurred. It generates reports for individual events or performs statistical analysis.

The object modelling of power quality monitoring and recording system components in IEC 61850 is described as well, including specific logical nodes.

Testing of IEC 61850 based power quality monitoring and recording devices and systems is discussed at the end of the paper.

SIGNAL PROCESSING OF IEC 61850 BASED POWER QUALITY RELATED FUNCTIONS

IEC 61850 has been designed to support the development and implementation of a wide variety of applications required in substation protection, automation, monitoring and control. It defines both how data is represented in the system model and how devices and applications exchange data with each other. Support of different functions is based on the use of services defined in the standard and shown in Figure 1.

Several of the services shown above have the most significant impact on the implementation of power quality monitoring and recording functions:

- Sampled Measured Values (SMV)
- Generic Substation Events (GSE)
- Reporting

They allow the development of distributed systems for power quality monitoring and recording and the more efficient use of multifunctional IEDs in the substation environment following the changes in IEC 61850 Edition 2.

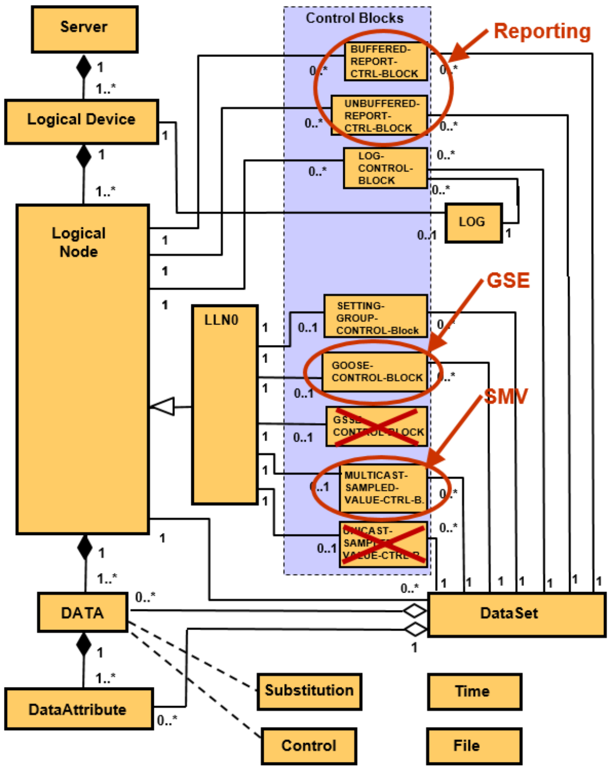

Fig. 1 IEC 61850 services

As can be seen from Figure 1, there are two significant changes in the services related to power quality monitoring and recording. While in Edition 1 the peer-to-peer communications between IEDs were based on Generic Substation State Event (GSSE) or Generic Object Oriented Substation Event (GOOSE), only the second one is used in Edition 2. This is because it supports different types of data in the GOOSE data set.

Regarding the communications of sampled values – only multicast based on IEC 61850-9-2 is supported in Edition 2 of the standard.

POWER QUALITY MONITORING AND RECORDING SIGNALS PROCESSING

A distributed function model based on sampled measured values and GOOSE messages has many similarities and some differences when compared to the signal processing in multifunctional IEDs.

As can be seen from Figure 2, the different components of the signal processing system are located in different devices – i.e. we have a case of distributed function according to the IEC 61850 definitions. The processing of the secondary currents and voltages represented by the TCTR and TVTR is performed in a new type of device – the stand-alone Merging Unit. It is defined as interface unit that accepts multiple analogue CT/VT

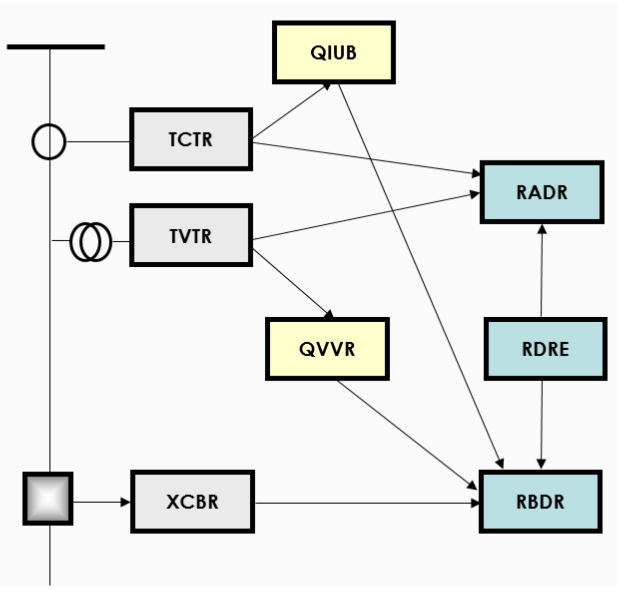

Fig. 2 Distributed power quality monitoring and waveform recording object model

The development of merging units was the result of the introduction and wide spread of microprocessor-based protection devices, combined with the advancements in non-conventional instrument transformers that required the development of digital interface between sensors and IEDs.

IEC 61850 further developed the sampled analog values interface at the process level of the substation automation system defined as logical interface 4 between the process and the bay levels.

Interoperability between merging units and protection, control, monitoring or recording devices is ensured through a document providing implementation guidelines. Two modes of sending sampled values between a merging unit and a device that uses the data are defined. For protection applications the merging units send 80 samples/cycle in 80 messages/cycle, i.e each Ethernet frame has the MAC Client Data containing a single set of V and I samples. For power quality analysis and recording applications such sampling rate may not be sufficient. That is why 256 samples/cycle was selected in the Implementation agreement created by the UCA International Users Group. The sampled values in this case are sent in groups of 8 sets of samples per Ethernet frame 32 times/cycle. It is important to highlight that the specified samples/cycle are at the nominal system frequency. This means that for protection in a 50 Hz system the sampling rate will be 4.0 kHz, while in a 60 Hz system it will be 4.8 kHz.

The new standard IEC 61869-9 defines the digital interface of instrument transformers and is based on IEC 61850-9-2. IEC 61869-13 defines the stand-alone merging unit.

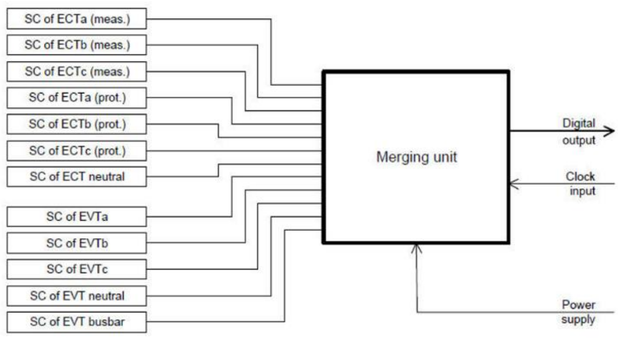

Fig. 3 Merging Unit model according to IEC 61869

The main difference between the two standards is that the sampling rate is fixed regardless of the system's nominal frequency. The defaults are 4.8 kHz for protection and 14.4 kHz for power quality monitoring and recording.

For protection there are 2 samples/message and for power quality there are 6 samples/message. This way the number of messages per second remains the same.

The sampled analog values model applies to the exchange of values of a DATA-SET. The difference in this case is that the data of the data set are of the common data class SAV (sampled analogue value as defined in IEC 61850-7-3). A buffer structure is defined for the transmission of the sampled values that are the output from the instrument transformer logical nodes TCTR and TVTR (Figure 2). The sampled values are transmitted as primary current and voltage values to the substation LAN using multicast. The network becomes the data bus that provides the interface between the instrument transformer logical nodes and the different logical nodes that are used to model the functional elements of the IED.

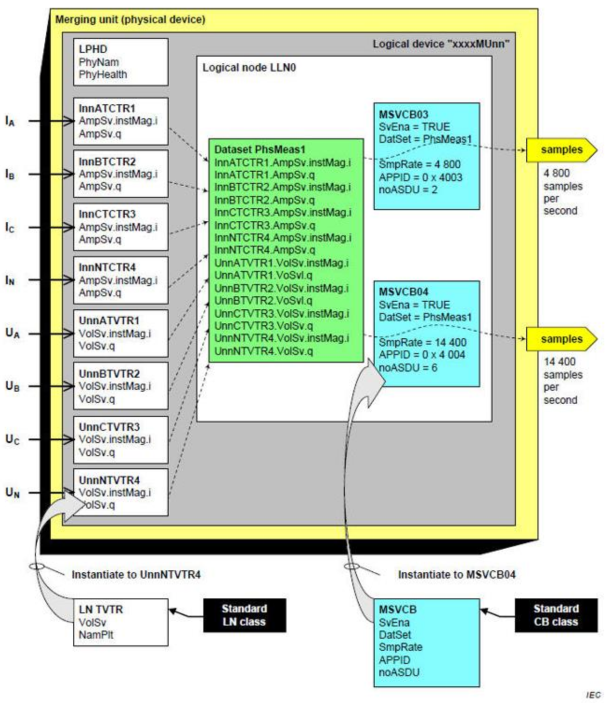

Fig. 4 Logical node LLN0 based control

The information exchange for sampled values is also based on a publisher/subscriber mechanism. A time stamp is added to the values, so that the subscriber can check the timeliness of the values and use them to align the samples for further processing.

The sampled values from TCTR and TVTR are directly used as analog signals by the waveform recording function when a power quality event occurs. There is a difference between conventional power quality monitoring IED's set of functions and the same distributed function implementation based on merging units and sampled measured values based IEDs. In the first case all sampled measured values exchanged between the Txxx logical nodes and protection and recording logical nodes are sampled at the same moment in time using a sample-hold type method and transmitted over the internal IED data bus for use by the different function modules. In the distributed applications (especially if there are multiple merging units involved) the sampling may occur at different times.

Figure 3 shows a simplified block diagram of a merging unit, while Figure 4 shows the data set and the control block related to LLN0.

The merging unit in its early implementations was synchronized using 1 PPS signal from a GPS receiver. Today the synchronization is done over the Ethernet based on the utility profile of PTP defined in IEC 61850-9-3.

The same messages are sent from an integrated merging unit in an optical or low-power instrument transformer (for example Rogowski coil).

IMPLEMENTATION OF POWER QUALITY MONITORING IN IEC 61850 SYSTEMS

Power quality monitoring functions are covered by a dedicated group of logical nodes – Q. This group of logical nodes refers to the modelling of power quality events detection and analysis functions. The models are based on the principles used for modelling protection functions.

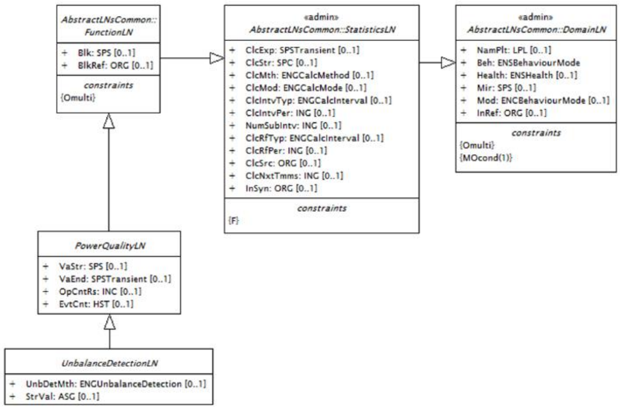

Fig. 5 Logical nodes group Q class diagram

There is a one-to-one relationship between the power quality event logical nodes in IEC 61850-5 and the logical node class definitions in IEC 61850-7-4.

The following is the list of logical nodes that at this stage belong to group Q:

- Frequency variation QFVR
- Current transient QITR
- Current unbalance variation QIUB
- Voltage transient QVTR
- Voltage unbalance variation QVUB
- Voltage variation QVVR

The implementation of the power quality monitoring function can be done using one of two methods:

- Direct processing of sampled values
- Processing of measured values

Direct processing of sampled values

Figure 2 shows an abstract model of a power quality monitoring and recording system. It shows an example with one power quality monitoring element using current samples – QIUB and one using voltage samples – QVVR. When a power quality event is detected, the data object VaStr becomes TRUE and through a GOOSE message initiates the recording of the power quality event.

When directly processing the sampled values by the power quality monitoring elements, it is important to understand what the values of the setting of the power quality detection element is – for example DipStrVal in QVVR. This is the Voltage dip start value setting. When the voltage in at least one phase goes below this setting, it will start the voltage variation function and the timer that will measure the duration of the voltage variation power quality event. The event ends when all monitored phase voltages return above the threshold.

Processing of measured values

The detection of the current unbalance or the voltage sag or swell can also be based on the processing of measured values – phase quantities or sequence components produced by the measurement logical nodes:

- MMXU - measurements
- MSQI - measured sequence and unbalance components

The V, I, V0, I0, V2 and I2 are processed by the power quality logical nodes, as shown in Figure 6 for a voltage-based function.

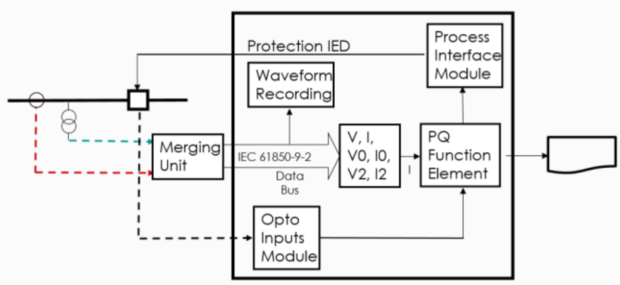

Fig. 6 Power quality monitoring based on measurements

Figure 6 shows an implementation of the power quality monitoring function for voltage or current variation related events. The phase (V or I) or sequence components (V0, V2, I0, I2) are calculated based on the stream of sampled values by the measurement function elements of the system represented by logical nodes MMXU and MSQI. The measurements are then used to detect a power quality event, trigger the waveform recording and report the characteristics of the event using the reporting services of IEC 61850.

DISTRIBUTED SYSTEM ARCHITECTURE

The distributed power quality monitoring and recording system architecture can be implemented in different ways depending on the system architecture. It can be completely distributed, or it can be hybrid.

Completely distributed architecture

In the completely distributed architecture the power quality monitoring and recording functions are performed in the individual IEDs that are used for protection of specific power system components – transmission lines, distribution feeders, power transformers, etc. They detect, record and report power quality events. This is especially related to the current related functions.
For voltage related power quality monitoring functions an IED at each voltage level of the substation needs to be selected to perform it.
The architecture of such system is shown in Figure 7.
In order to be able to analyze the reports of all IEDs that are part of the power quality monitoring and recording system, they need to be accurately time synchronized. For the purpose of this analysis time synchronization accuracy of 1 ms is sufficient. This can be achieved using time synchronization based on SNTP, but it is still better to use IEC 61850-9-3.

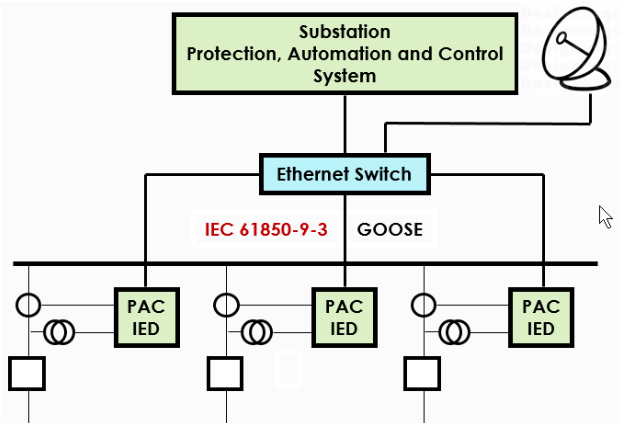

Fig. 7 Completely distributed architecture

Hybrid architecture

From the point of view of a power quality monitoring and recording system we can consider a hybrid system one that uses distributed functions for process interface (the Merging Unit) and a centralized power quality monitoring and recording function on a central location.
This system includes the following types of functions:

- Analog interface
- Time synchronization
- Measurements
- Power quality monitoring
- Recording
- Reporting

The time-synchronization is used to ensure that the analog interface devices meet the requirements for time-synchronization according to the implementation guidelines. In the initial implementations based on IEC 61850 Edition 1 this was based on a synchronization device that sends a 1 pulse per second (1PPS) signal through a dedicated network to all interface devices included in the system. Time-synchronization accuracy better than 1 microsecond is achieved by this solution. After the publication in 2016 of IEC 61850-9-3 Precision time protocol profile for power utility automation, time synchronization with similar accuracy is achieved over the Ethernet.
The interface units sample 256 times per cycle the three phase current and voltage inputs, as well as the opto inputs and generate the Ethernet messages that are sent using 100 Mb/s to the central device.
The power quality monitoring and recording device receives from the switch Ethernet messages from the interface units included in the system. Considering the size

of the Ethernet frames a single 100 Mb/sec port of the recording device can handle the traffic from up to seven interface units. Figure 8 shows the architecture of a distributed power quality monitoring and recording system with 3 interface units.
If the central recording unit needs to record currents and voltages from a larger number of interface units, a second Ethernet port may be used to expand the distributed system to a total of up to 14 interface units. Another alternative solution for more than seven interface units is to use a computer with 1Gb/sec Ethernet port connected to a 1 Gb/sec Ethernet switch with 100 Mb/sec ports connected to the interface units.

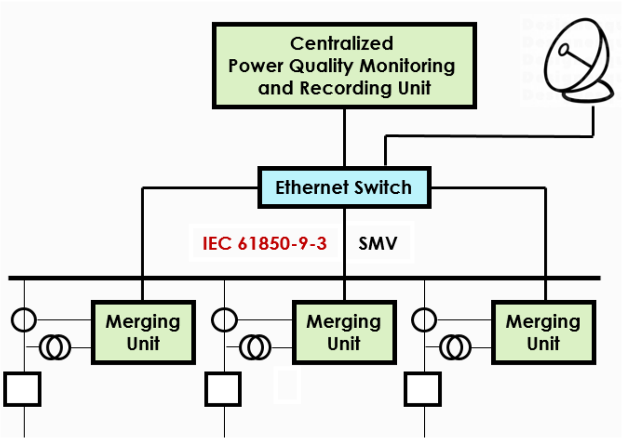

Fig. 8 Merging units based hybrid system architecture

The power quality monitoring and recording device runs the event detection and triggering algorithms, records the samples and generates the COMTRADE files that are stored in its memory for further processing and analysis.

TESTING OF POWER QUALITY MONITORING AND RECORDING SYSTEMS

IEC 61850 peer-to-peer communications based systems require a different approach and set of tools for proper testing of the individual components of the systems, as well as the evaluation of the performance of the distributed functions including:

- Configuration tool based on the Substation Configuration Language defined in Part 6 of IEC 61850.
- Simulation tool that generates the current and voltage waveforms
- Virtual Merging Units and IED simulators based on IEC 61850
- Test Evaluation tool
- Reporting tool

The need to verify the capability and reliability of power quality devices and systems requires appropriate test equipment. An advanced power quality signalg enerator turns a test set with high-precision voltage and current outputs into a calibration tool that generates all kinds of power quality phenomena according to IEC 61000-4-30 (-7, -15):

- Power Frequency
- Power Supply Voltage
- Flicker
- Dips & Swells
- Voltage Interruption
- Transient Voltages
- Voltage Unbalance
- Harmonics
- Interharmonics
- Rapid Voltage Changes

CONCLUSIONS

The new IEC 61850 international standard for substation communications enables the development of different power quality monitoring and recording systems. It allows a new approach to detection and recording of power quality events with sampling rate of 256 samples/cycle.
Sampled Analog Values from multiple interface units are multicast and used by a central power quality monitoring and recording unit.
IEC 61850 uses a dedicated Q group of logical nodes for modeling of different power quality monitoring function elements.
Time synchronization accuracy better than 1 microsecond is achieved using IEC 61850-9-3.
Testing of power quality monitoring devices and systems requires a set of specialized IEC 61850 and power quality related tools.