IEC 61850 AND DISTURBANCE RECORDING

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INTRODUCTION

The new international standard for substation communications will have a significant impact on the future of recording of short circuit faults, wide area disturbances or power quality events.

The paper first describes some of the key elements of an IEC 61850 based substation automation - the different levels of the functional hierarchy and the logical interfaces between the components of the system.

Different communication modes are presented later from the perspective of disturbance recording applications.

IEC 61850 defines three types of peer-to-peer communications:

- Change-of-state events using GSSE (Generic Substation State Event)
- Generic Object Oriented Substation Event (GOOSE)
- Sampled Analog Values

Different disturbance recording applications are described based on the peer-to-peer communications listed above. An example of a distributed disturbance recording system based on sampled analog values is presented.

Another important element of IEC 61850 is the object models of all typical functions in a substation automation system. The paper analyzes the components of the object model and then focuses on the specific Logical Nodes and data objects related to the disturbance recording functions. An example of a disturbance recording IED is used to demonstrate the application of the new standard.

DISTRIBUTED FUNCTIONS DEFINITIONS IN IEC 61850

Functions in the substation are performed by the protection, control, monitoring and recording system. A function can be divided into sub-functions and functional elements. The functional elements are the smallest parts of a function that can exchange data. These functional elements in IEC 61850 are called Logical Nodes [1].

In the case when a function requires exchange of data between two or more logical nodes located in different physical devices, it is called a "distributed function".

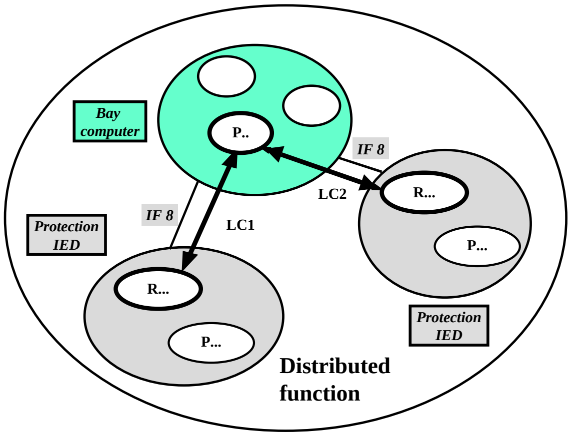


Fig. 1 Distributed Function definition in IEC 61850

The exchange of data is not only between functional elements, but also between different levels of the substation functional hierarchy. It should be kept in mind that functions at different levels of the functional hierarchy can be located in the same physical device, and at the same time different physical devices can be exchanging data at the same functional level.

As can be seen from Figure 1, Logical Connection (LC) is the communications link between functional elements - in this case logical nodes of the P and R groups. IEC 61850 also defines interfaces that may use dedicated or shared physical connections - the communications link between the physical devices.

The allocation of functions between different physical devices defines the requirements for the physical interfaces, and in some cases may be implemented into more than one physical LANs.

IEC 61850 defines functions of a substation automation system (SAS) related to the protection, control, monitoring and recording of the equipment in the substation. These functions can be executed within a single physical device - for example a protection IED - or can be distributed between multiple devices using hard wired or communications interface.

The functions in the substation can be distributed between IEDs on the same, or on different levels of the substation functional hierarchy. IEC 61850 [1] defines three such levels:

- Station
- Bay/Unit
- Process

These levels and the logical interfaces are shown by the logical interpretation of Figure 2.

IEC 61850 focuses on a subset of the interfaces shown in Figure 2 and listed below:

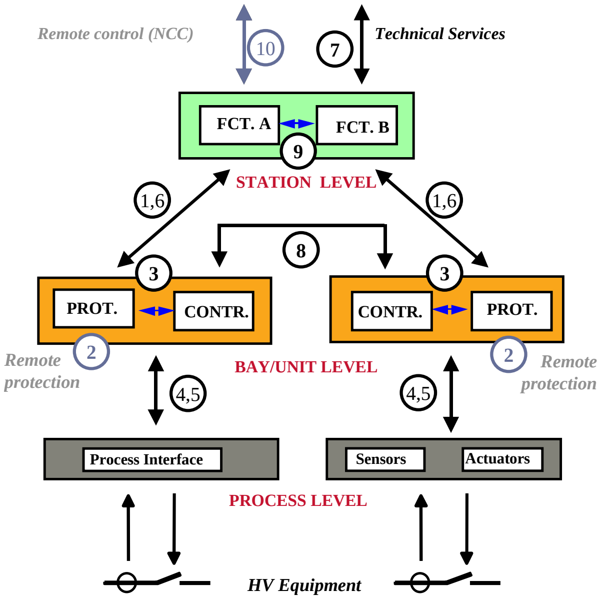


Fig. 2 Logical interfaces in Substation Automation Systems

The logical interfaces shown above are defined [1] as:

IF1: protection-data exchange between bay and station level

IF2: protection-data exchange between bay level and remote protection

IF3: data exchange within bay level

IF4: CT and VT instantaneous data exchange (especially samples) between process and bay level
IF5: control-data exchange between process and bay level
IF6: control-data exchange between bay and station level
IF7: data exchange between substation (level) and a remote engineer's workplace
IF8: direct data exchange between the bays especially for fast functions like interlocking
IF9: data exchange within station level
IF10: control-data exchange between substation (devices) and a remote control center

Interfaces 2 and 10 have been identified outside of the scope of IEC 61850 at the time of the development of the standard. However, the availability of Ethernet interface in multiplexers over SONET rings or other communication links results in applications using high-speed peer-to-peer communications between relays in different substations, for example in a directional comparison transmission line protection.

In order to better understand the distributed functions as they are defined in an IEC 61850 based system, we need first to clarify the meaning of some of the terms used in the logical interfaces list above.

Disturbance Recording System Functional Hierarchy

A distributed disturbance recording system has an hierarchical structure that may have a different number of levels for the communications and logical point of view. The three levels in the functional hierarchy in IEC 61850 are defined as follows:

Process Level Functions: These are all functions interfacing to the process (the primary equipment in the substation), such as analog signals, binary status signals or binary control signals. In the conventional disturbance recording systems this is hard wired current and voltage circuits, as well as the hard wired auxiliary contacts of switching devices. These functions communicate via the logical interfaces 4 and 5 to the bay level. In the IEC 61850 based substation these functions are performed by a sensor IED with a digital interface to the bay level defined in the standard. This interface can be used for distributed disturbance recording applications based on analog sampled values.

Bay Level Functions are the ones using mainly the data of one bay and acting mainly on the primary equipment of one bay. A substation consists of closely connected subparts with some common functionality. Examples are the breakers and switches between the substation bus and a transmission or distribution line, a transformer with its related switchgear between two or three buses with different voltage levels, etc.

In conventional systems the disturbance recording for such part of the substation is typically performed by a single recording device. This subpart is defined in IEC 61850 as a "bay", and for recording tasks a "bay recorder" will be used. The functionality of these devices represents an additional logical level below the overall station level and is called “bay level”.

The bay level functions can be implemented in physical devices that also perform process level functions or substation level function, i.e. there is a difference in the logical and physical functional hierarchy.

These functions communicate via the logical interface 3 within the bay level and via the logical interfaces 4 and 5 to the process level, and 1 and 6 with the substation level.

Station level functions are related to the overall operation of equipment in the substation. They are divided in two groups:

Process related station level functions are functions using the data of more than one bay or of the complete substation and acting on the primary equipment of more than one bay or of the complete substation. These are protection and control functions that in conventional systems use hard wired connections between relay outputs of one device and opto inputs of another device. An example of such interface will be the triggering of station-wide disturbance recording by a protection device. In IEC 61850 based systems these functions communicate mainly via the logical interface 8.

Interface related station level functions are functions representing the interface of the SAS to the substation HMI (human machine interface), to SCADA or to a remote engineering station. These functions communicate via the logical interfaces 1 and 6 with the bay level and via the logical interface 7 and the remote control interface to the outside world. This may include the extraction of disturbance records.

DISTURBANCE RECORDING FUNCTION AND THE IEC 61850 OBJECT MODEL

Disturbance recording functions are available in almost every microprocessor based IED. They may vary based on the main function of the device and this will also affect the recording of an abnormal system condition. They are typically connected with hard wires to the voltage and current transformers and the auxiliary contacts of the breakers or other devices in the substation. This is changing in the IEC 61850 distributed applications environment.

The analog signals go through several transformations before they can be recorded by the different elements in the disturbance recording module.

Once a fault or other abnormal condition has been detected and a decision to trip has been made, the protection module sends a command for the relay output module to close the required contacts and trip the breaker to clear the fault. Figure 1 shows a very simplified block diagram of a multifunctional protection IED connected to the substation primary equipment.

The analog input module provides the interface between the IED processor board(s) and the voltage and current signals coming into the device. This input module may consists of one or more boards. The number of current and voltage inputs depends on the primary function of the device. The input transformers are used both to step-down the currents and voltages to levels appropriate to the relay’s electronic circuitry and to provide effective isolation between the device and the power system. The connection arrangements of both the current and voltage transformer secondaries provide differential input signals to the input board to reduce noise.

An analog input board is shown as a simplified block diagram in Figure 3. It provides the circuitry for the analogue-to-digital conversion for the analogue signals. Hence it takes the differential analogue signals from the current and voltage input transformers and converts them into digital samples and transmits the samples to the protection (or other processing modules) via the data bus. On the input board the analogue signals are passed through an anti-alias filter before being multiplexed into an analogue-to-digital converter chip. The A-D converter provides a sampled data stream output.

The signal multiplexing arrangement depends on the number of analog signals and provides for multiple analogue channels to be sampled. The sampling rate for protection applications is usually maintained at a fixed number of samples per cycle of the power waveform by a logic control circuit which is driven by the frequency tracking function of the device. A calibration memory (usually an E2PROM) holds calibration coefficients which are used by the processor board to correct for any amplitude or phase error introduced by the transformers and analogue circuitry.

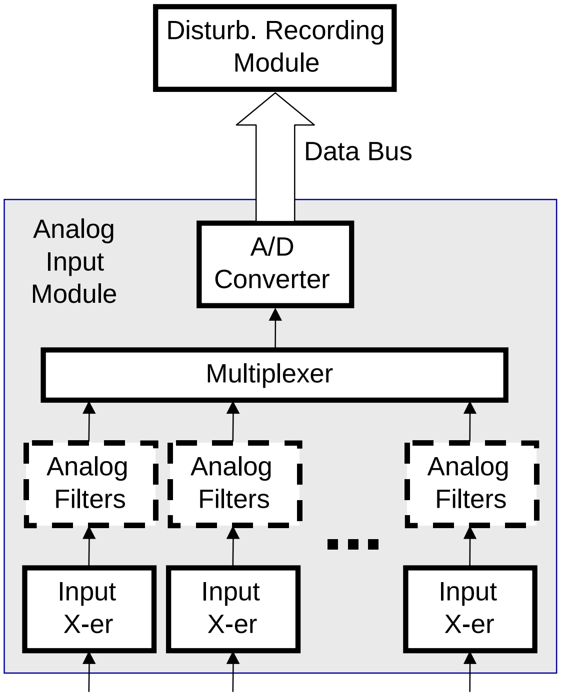


Fig. 3 Simplified block diagram of an analog input module

The analog input function in IEC 61850 is modeled by multiple instances of two logical nodes from the Instrument Transformers group T [1] - **TCTR** and **TVTR** Both use one instance per phase. These three or four instances of TCTRs and TVTRs may be allocated to different physical devices mounted in the instrument transformer per phase.

The currents and voltages from TCTR and TVTR accordingly are delivered as sampled values. The sampled values are transmitted as engineering values, i.e. as “true” (corrected) primary current values. This means that some configuration date stored in the memory of the IED will be used to calculate these primary values from the outputs of the A/D converter. The sampled values are sent to the substation LAN using one of the communication modes described earlier in the paper. In this case 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.

The status of the breakers in the substation is modeled using the **XCBR** logical node. It will provide information on the three phases or single phase status of the switching device, as well as the normally open or closed auxiliary contacts. Figure 4 shows a simplified block diagram of the logical nodes used to model the different components of the waveform recording function.

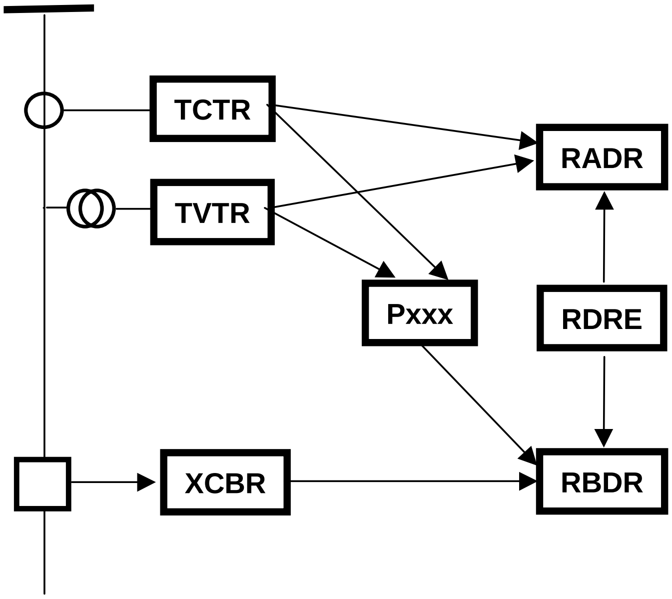


Fig. 4   Logical nodes for waveform recording

In the figure above **Pxxx** is used to indicate any protection functional element whose status is recorded in the waveform record.

RDRE is the logical node representing the acquisition functions for voltage and current waveforms from the power process (CTs, VTs), and for position indications of binary inputs. Calculated values such as frequency, power and calculated binary signals may also be recorded by this function if applicable. RDRE is used also to define the trigger mode, pre-fault, post-fault etc. attributes of the disturbance recording function. The RDRE class is shown in Table 1 below:

Table 1

RDRE class				
Attribute Name	**Attr. Type**	**Explanation**	**T**	**M/ O**
LN Name		Inherited from Logical-Node Class (see IEC 61850-7-2)		
Data				
Common Logical Node Information				
		LN Inherits all Mandatory Data from Basic Logical Node Class		M
OpCntRs	INC	Resetable operation counter		O
Controlls				
RcdTrg	SPC	Trigger recorder		O
MemRs	SPC	Reset recorder memory		O
MemClr	SPC	Clear Memory		O

Status Information				
RcdMade	SPS	Recording made		M
FltNum	INS	Fault Number		M
GriFltNum	INS	Grid Fault Number		O
RcdStr	SPS	Recording started		O
MemUsed	INS	Memory used in %		O
Settings				
TrgMod	ING	Trigger mode (internal trigger or external)		M
LevMod	ING	Level Trigger Mode		O
PreTmms	ING	Pre-trigger time		O
PstTmms	ING	Post-trigger time		O
MemFull	ING	Memory full level		O
MaxNumRcd	ING	Maximum number of records		O
ReTrgMod	ING	Retrigger Mode		O
PerTrgTms	ING	Periodic trigger time in seconds		O
ExclTmms	ING	Exclusion time		O
OpMod	ING	Operation mode (Saturation, Overwrite)		O

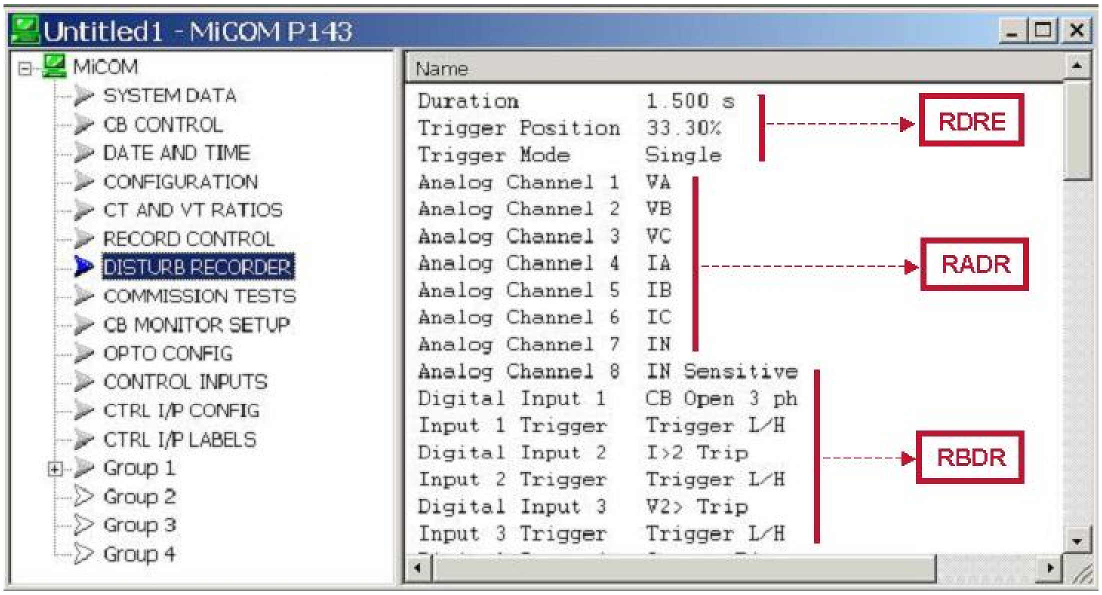
The logical node class **RADR** is used to represent a single analog channel, while **RBDR** is used for the binary channels. Thus the disturbance recording function is modeled as a logical devices with as many instances of RADR and RBDR logical nodes as analog and binary channels are available.

These sampled values are directly used as analog signals by the waveform recording function. They are also processed by other functional elements in the IED. A measuring function represented by an **MMXU** logical node is used to calculate phasor or RMS values of currents and voltages, frequency, power or any other system parameter. These calculated values can be recorded with user defined sampling rates as a disturbance record.

It is possible to define several groups of distributed applications based on the design of the IEDs and the location of the different logical nodes that are used to perform a specific function.

A protective relay or a specialized disturbance recording device has to be configured to perform its function. The available configuration parameters in a specific device are mapped to the mandatory or optional data objects in the different disturbance recording related logical nodes described above.

Figure 5 shows the mapping of the different configuration parameters of a disturbance recording function in a protection relay to the RDRE, RADR and RBDR logical nodes defined in parts 5 and 7 of IEC 61850.



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Duration            1.500 s
Trigger Position    33.30%
Trigger Mode        Single
Analog Channel 1    VA
Analog Channel 2    VB
Analog Channel 3    VC
Analog Channel 4    IA
Analog Channel 5    IB
Analog Channel 6    IC
Analog Channel 7    IN
Analog Channel 8    IN Sensitive
Digital Input 1     CB Open 3 ph
Input 1 Trigger     Trigger L/H
Digital Input 2     I>2 Trip
Input 2 Trigger     Trigger L/H
Digital Input 3     V2> Trip
Input 3 Trigger     Trigger L/H
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Fig. 5 Mapping to disturbance recording logical nodes

TIME SYNCHRONIZATION

Time-stamping of the sampled or calculated analog values is very critical to the distributed disturbance recording applications, because it is used to align the values coming from different devices and build the disturbance record. Accurate time-stamping is impossible if the different IEDs are not properly synchronized.

Special purpose receivers are available for many time-dissemination services, including the Global Position System (GPS) and other services operated by various national governments. For reasons of cost and convenience, it is not possible to equip every IED with one of these receivers. However, it is possible to have a device connected to the network acting as primary time- server.

Time synchronization over the IEC 61850 based substation automation system LAN is accomplished through the use of the Simple Network Time Protocol (SNTP). [6]

SNTP is in essence a subset of NTP (Network Time Protocol) - it lacks some internal algorithms that are not needed for all types of servers. NTP uses UTC (Universal Time Coordinated, Temps Universel Coordonné) as reference time.

UTC is an official standard for the current time and evolved from the former GMT (Greenwich Mean Time).

The UTC second has been defined by the 13th General Conference of Weights and Measures in 1967 as "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom."

The distributed network clock synchronization protocol is required to be used for any implementation claiming conformance to IEC 61850 and declaring support for objects containing an attribute of type TIMESTAMP - in our case the distributed analog measured or sampled values applications.

CONCLUSIONS

Distributed disturbance recording in IEC 61850 substation automation systems can be done directly within an IED or can be based on the published analog values that allows the user to take full advantage of the standardization of substation communications.

Analog interface units or Merging Units located in the substation yard send the current and voltage values over fiber, thus significantly reducing (actually eliminating) the copper wires between the substation primary equipment and the protection and control devices.

Process, bay and substation level functions related to disturbance recording are modeled using dedicated to the recording logical nodes, as well as interface, measurements and protection logical nodes.

Examples of their application and mapping to configuration parameters of a disturbance recording functional element in a protection IED demonstrate the use of the logical nodes in the model.

Accurate time-synchronization over the substation LAN and based on SNTP is essential to the time-stamping of the analog values and their alignment for the waveform and disturbance recording applications.

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