Object Models of Disturbance Recording and Event Analysis Functions in IEC 61850 Based Devices and Systems

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INTRODUCTION

IEC 61850 is becoming very quickly a standard protocol supported by all major protection and control manufacturers. Considering the fact that system event analysis plays an important role in power delivery automation systems, all modern substation devices support different forms of fault or disturbance recording and event analysis functions. It is important to properly model these functions using the IEC 61850 object models. The paper analyzes the functional hierarchy of the multifunctional IEDs from the point of view of the disturbance and fault recording and event analysis functions. The next part of the paper describes the hierarchy of the object model in IEC 61850, including logical devices, logical nodes, data objects and their attributes. IEC 61850 does not specify the use of logical devices in IEDs. This creates some issues with the integration of multifunctional devices in substation automation systems.

The paper presents some ideas for the use of logical devices in the modeling of centralized or distributed fault or disturbance recording and event analysis functions. Detailed examples of the object models of fault and disturbance recording functions are given at the end of the paper.

DISTRIBUTED FUNCTIONS IN IEC 61850 BASED SUBSTATION AUTOMATION SYSTEMS

Protection, control, monitoring and recording systems perform different functions in a substation. 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".

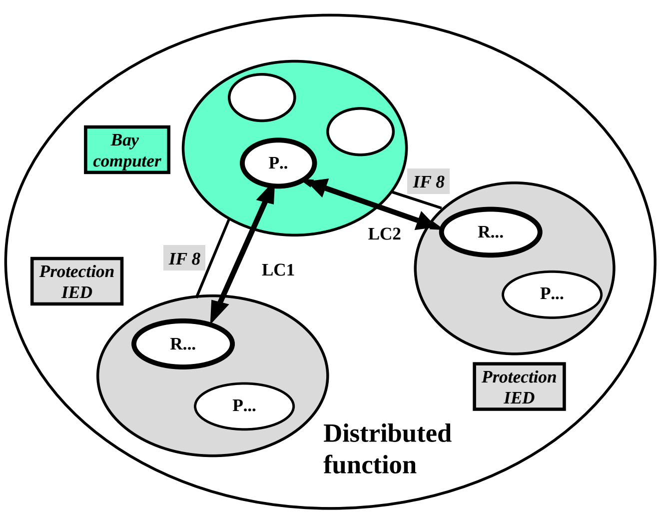

Fig. 1 Distributed Function definition in IEC 61850

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.

At the same time there is the hierarchy of the data model that needs to be taken into consideration.

IEC 61850 Model Hierarchy

The modeling of any function in the substation 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.

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.

A significant improvement in the functionality and some reduction of the cost of integrated substation protection, control, monitoring and recording systems can be achieved based on the modern devices (existing or under development) as described below.

Non-conventional instrument transformers with digital interface based on IEC 61850-9-2 eliminate some of the issues related to the conflicting requirements of protection and metering IEDs.

It is important to be able to interface with conventional and non-conventional sensors in order to allow the implementation of the system in different substation environment.

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

The Merging Unit (MU) multicasts sets of measured sampled values to multiple IEDs in the substation over the substation local area network. It is called the “process bus”. Status information for breakers and switches is available through an input/output unit (IOU). In some cases the merging unit and the input/output unit can be combined in a single device.

The receiving devices then process the data, make decisions and take action based on their functionality. The action of protection and control devices in this case will be to operate their relay outputs or to send a high-speed peer-to-peer communications message to other IEDs in order to trip a breaker or initiate some other control function.

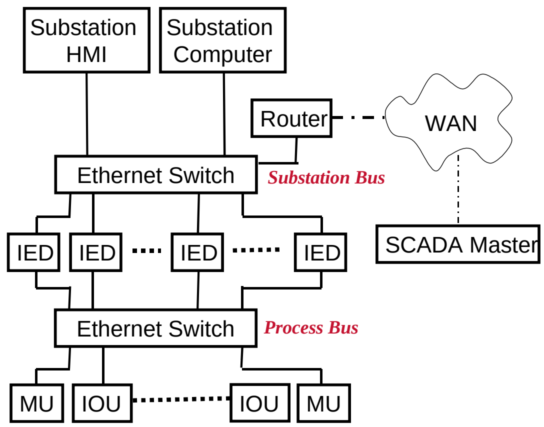

Fig. 2 Simplified IEC 61850 based communications architecture

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 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”. 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.

A. Distribution and modeling of functions in physical devices

The functional hierarchy of a modern protective relay to a great extent is dependent on the application and the main protection function of the device. A very simple low-end device may have a very limited functionality, while an IED that supports IEC 61850 will typically have a more complex functional hierarchy. For protective relays used at high voltage and extra high voltage transmission level the model has to also consider the availability of multiple analog inputs – for example in the case of dual breakers, breaker-and-a-half or ring bus configurations.

A more complex example are the relays protecting transformers between the substation transmission and distribution buses that will interface the device with two or more voltage levels. The same applies to disturbance recording devices that need to record all current and voltage signals in the substation and can be distributed between multiple devices.

The modeling of complex protection, control and recording devices can be done in different ways. One option is to model them as servers with a single logical device and multiple logical nodes. In this case certain functional elements have to be grouped together using the available object hierarchy and the naming conventions for the data objects.

One of the most important concepts that needs to be understood at the very beginning of the IED modeling process is that the model includes only objects that are visible to the communications. 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. IEC 61850 considers three levels of data and services for the modeling of different substation automation functions.

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 specialization's of the common data classes based on their application.

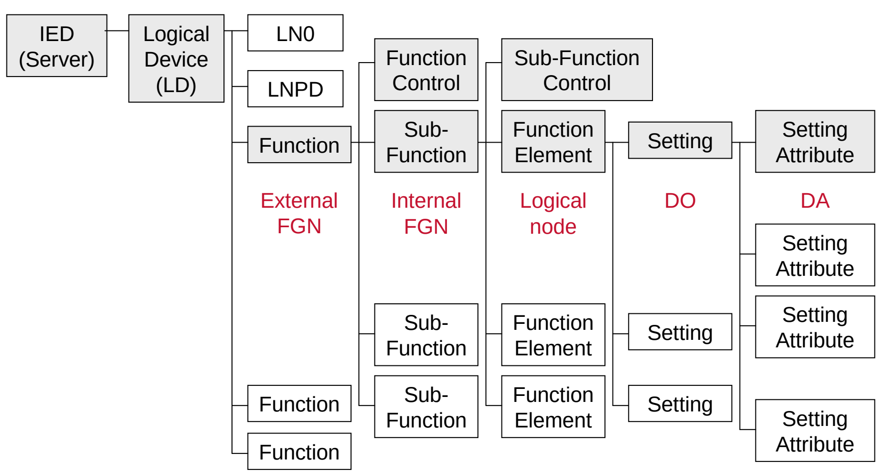

Fig. 3 Object hierarchy

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 [5] defines the compatible logical node and data classes.

The object hierarchy can be represented in a simplified way as shown in Fig. 3. A Server typically is any physical device that is being modeled as part of a substation automation system. Usually an IED will be modeled as server with a single Logical Device.

The server represents the communications visible behavior of the IED. Each logical device is defined as a “virtual device that exists to enable aggregation of related logical nodes and data sets”. Multifunctional devices are modeled using several types of logical nodes depending on the specific application of the IED.

The logical nodes contain the information required by a specific function, such as a function setting or measurements being calculated by an IED. A Logical Device has a single Logical Node Zero, a single Logical Node Physical Device, plus one or more other logical nodes.

In case of protective relays with more complex functional hierarchy it might be necessary to group together several logical nodes in a functional group such as Overcurrent protection. 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 Fig. 3.

The model of any device in IEC 61850 can be done by mapping the different substation functions supported by the relay to different logical devices. One logical device will represent the primary protection functions. Another will define the Measuring function and a third – the Disturbance recorder. A Fault Locator and a Circuit Breaker Monitor will be modeled with additional Logical Devices.

The functional hierarchy becomes even more complicated in the case of a devices performing the protection, control and recording of a three-winding transformer. As can be seen from Figure 4 below, the relay is connected to current and voltage transformers at different voltage levels and in some cases different breakers at the same voltage level.

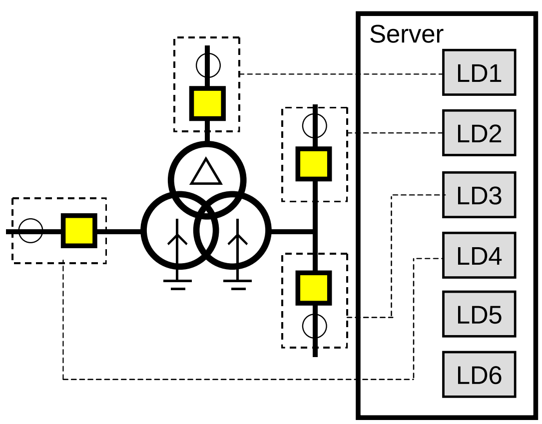

Fig. 4 Transformer device object model

One way of modeling this device is to use a Logical Device for each different physical interface (shown with dotted lines in Figure 4) and for some Transformer level functions. Then each of these Logical Devices will include Protection, Measuring and Recording functions. The transformer level LD will also contain the Disturbance recorder function.

Another approach will be to have a logical device for Protection, Measurements, Monitoring and Recording and then different functional groupings per voltage level and further down the functional hierarchy.

B. 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. Instead of a DataAttribute it is possible to have a SimpleCDC or Composite CDC (both are specialization's of the DATA class). DataAttribute's can be simple or nested. If they are nested, at each nesting level other than the first the DataAttributeName is called DAComponentName (see Fig. 5). The DataAttribute's are of certain data type that can be primitive (BasicType) or composite (DAType).

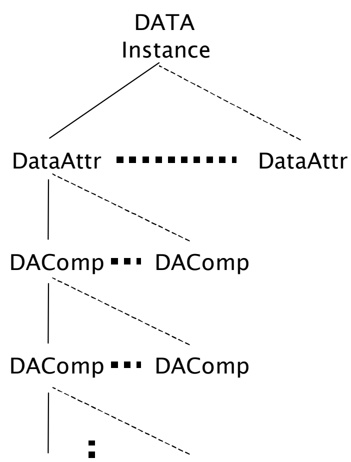

Fig. 5 Nested data attributes

The different DataAttribute's can be grouped based on their specific use. For example some indicate the status of the logical node, while other are used for configuration or measurements. The value of a data object can be read, substituted, logged or reported. The values of these DataAttribute's are normally based on processed data from the IED. After describing some of the typical data objects used to model measured values, we are finally at a point when we can give an example of a data path (the DAComponentRef) for a single phase measurement of the current in phase B represented as a floating point:

MMXU1.A.phsB.cVal.mag.f

where:

MMXU1 is an instance of the Compatible LN class MMXU defined in Part 7-4 [5]

A is an instantiation of the Composite DATA class WYE (defined in 7-3 [4]) used to represent the three phase currents and the neutral current

phsB is the value of the current in phase B as a Simple Common DATA class of type CMV (defined in 7-3)

cVal is the complex value of the current in phase B (of the Common DataAttribute type Vector

mag indicates that this object represents the magnitude of the complex value (of type AnalogValue - defined in 7-3

f is a DataAttributeComponent which is of the basic type FLOATING POINT (defined in 7-2)

All measurements in multifunctional IEDs are modeled in a similar way and grouped into special logical nodes described in the next section of the paper.

CROSS-TRIGGERING OF DISTURBANCE RECORDING

The peer-to-peer communications in an integrated substation protection and control system are based on what is defined as a GSE [2]. This is a Generic Substation Event (GSE) and it is based upon the asynchronous reporting of an IED's functional elements status to other peer devices enrolled to receive it during the configuration stages of the substation integration process. It is used to replace the hard wired control signal exchange between IED's for interlocking and protection purposes and, consequently, is mission sensitive, time critical and must be highly reliable.

The associated IEDs receiving the message use the contained information to determine what is the appropriate response for the given state change. The decision of the appropriate action to GSE messages or should a message time out due to a communication failure is determined by local intelligence in the IED receiving the GSE message.

The Generic Substation Status Event (GSSE) is the equivalent of the UCA 2.0 Generic Object Oriented Substation Event (GOOSE). The typical application of GSSE messages for distributed power system event recording will be to initiate simultaneously the recording by multiple IEDs in the substation automation system in order to capture the effect of the event throughout the substation. Each recording device will have to subscribe to GSSE messages from multiple IEDs, so it can be triggered by these devices when necessary.

An example of the cross-triggered recording is the case when the protection IED acts as the Publisher and the recording IEDs (RIED) are the Subscribers. The protection IED will detect the fault or other abnormal system condition and send a GSSE message to the RIEDs (see Figure 6) that need to record it. In the subscribing RIEDs it will trigger a waveform recording with a high-sampling rate (for example 128 samples/cycle) to record the fault for future replay during testing. At the same time this may trigger high-speed disturbance recording (for example one or more cycles/sample of the rms voltage profile) for analysis of the voltage sag caused by the fault.

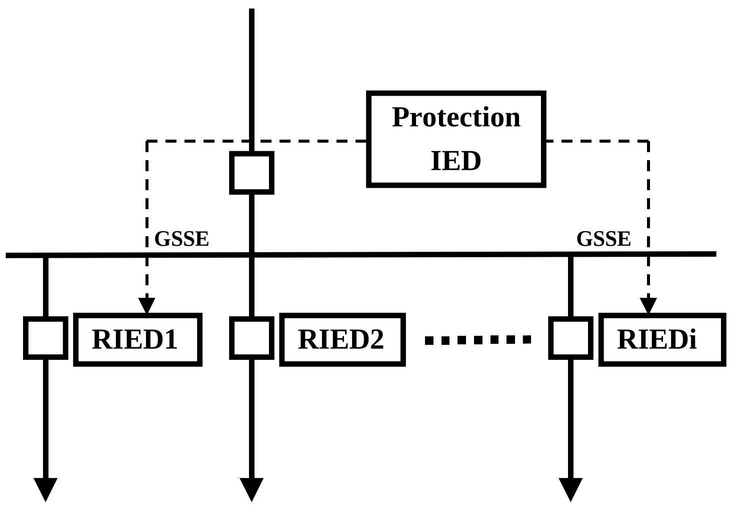

Fig. 6 Cross-triggering of disturbance recording

WAVEFORM RECORDING BASED ON SAMPLED ANALOG VALUES

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

Digital interface in a point-to-point communications scheme was defined by IEC in the IEC 60044-8 standard. The development of Merging Units that convert the optical signal into a digital message containing sampled values and protection devices with a digital interface that perform multiple protection functions resulted in demonstration projects that show the advantages of this technology.

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

The frame format from IEC 60044-8 is reused, but the new standard defines the transmission of sampled analog values over the Ethernet in both a point-to-point (unicast) or multicast mode.

The transmission of sampled values requires special attention with regard to the time constraints. The model provides transmission of sampled values in an organized and time controlled way so that the combined jitter of sampling and transmission is minimized to a degree that an unambiguous allocation of the samples, times, and sequence is provided.

Similar to the GSSE and GOOSE models, 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 part 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 7).

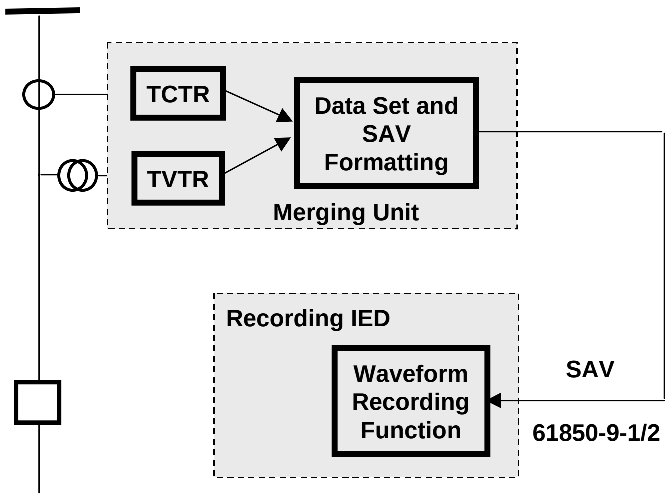

Fig. 7 Waveform recording based on Sampled Analog Values

The information exchange for sampled values is also based on a publisher/subscriber mechanism. The publisher writes the values in a local buffer at the sending side (see Figure 7), while the subscriber reads the values from a local buffer at the receiving side. 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 communication system shall be responsible to update the local buffers of the subscribers. A sampled value control (**SVC**) in the publisher is used to control the communication procedure.

In the case when any other function requires exchange of sampled data between two or more logical nodes located in different physical devices, we can call it a "distributed analog function".

The currents and voltages from **TCTR** and **TVTR** accordingly are delivered as sampled values over 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 5 shows a simplified block diagram of the logical nodes used to model the different components of the waveform recording function. **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, as shown in Table 1.

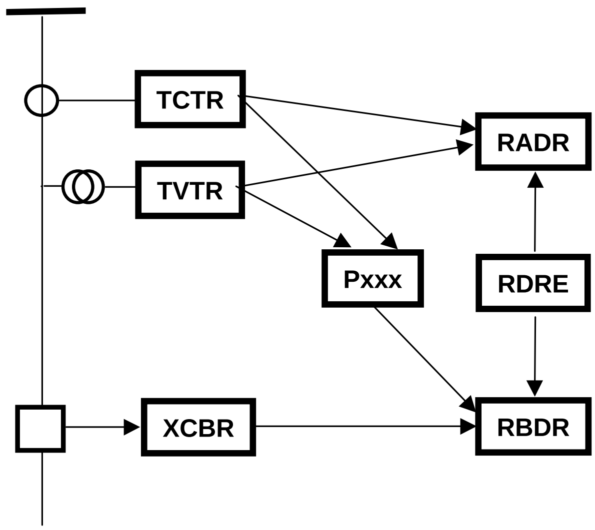

Fig. 8 Logical Nodes for waveform recording

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 device with as many instances of RADR and RBDR logical nodes as analog and binary channels are available.

The sampled values from TCTR and TVTR are directly used as analog signals by the waveform recording function.

Any disturbance recording device has to be configured to perform this 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.

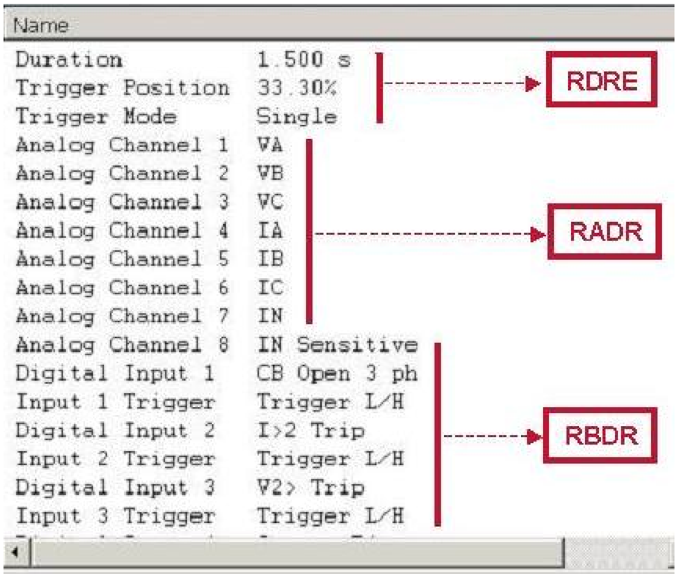

Fig. 9 Mapping to disturbance recording LN

Figure 9 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.

Table 1 shows the different data objects in the RDRE class.

Table 1

RDRE class		
Attribute Name	**Attr. Type**	**Explanation**
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
OpCntRs	INC	Resetable operation counter
Controlls		
RcdTrg	SPC	Trigger recorder
MemRs	SPC	Reset recorder memory
MemClr	SPC	Clear Memory

Status Information		
RcdMade	SPS	Recording made
FltNum	INS	Fault Number
GriFltNum	INS	Grid Fault Number
RcdStr	SPS	Recording started
MemUsed	INS	Memory used in %
Settings		
TrgMod	ING	Trigger mode (int. /exter.l)
LevMod	ING	Level Trigger Mode
PreTmms	ING	Pre-trigger time
PstTmms	ING	Post-trigger time
MemFull	ING	Memory full level
MaxNumRcd	ING	Maximum number of records
ReTrgMod	ING	Retrigger Mode
PerTrgTms	ING	Periodic trigger time (sec)
ExclTmms	ING	Exclusion time
OpMod	ING	Operation mode (Sat., Overwrite)

DISTURBANCE RECORDING BASED ON IEC GOOSE MESSAGES

These applications can be considered as a transition between the distributed applications based on status change information in GSSE messages and the applications based on sampled analog values.

Figure 10 shows simplified block diagram of the disturbance recording function based on IEC GOOSE. As described earlier, the input transformer logical nodes convert the analog signals to sampled values and send them over the IED data bus to the main processing module. The MMXU is the logical node that represents a function in the IED that calculates from the sampled values different system parameters, such as the frequency or voltage.

The voltages in MMXU are modeled with the attribute V of type WYE. WYE represents phase to ground related measured values of a three phase system. It includes values of phases A, B, C and the neutral. The names of the attributes are phsA, phsB, phsC neut, net and res. They have been simultaneously acquired or determined.

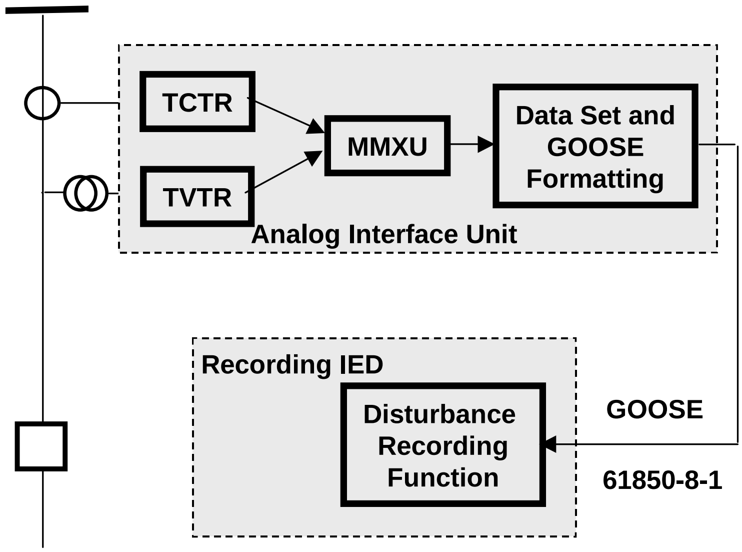

Fig. 10 Disturbance recording based on IEC GOOSE

The logical nodes involved in the distributed disturbance recording function are shown in Figure 11.

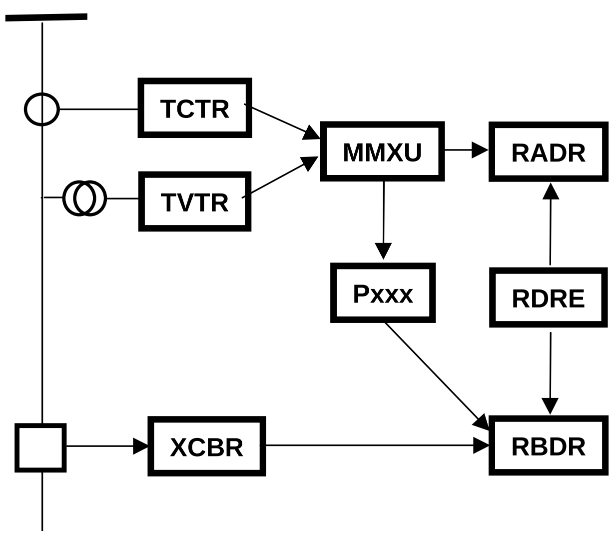

Fig. 11 Logical nodes for disturbance recording

The same approach can also be used for recording of load trends. The difference in this case will be in the recorded system parameters, as well as the sampling rate that will be in the range of minutes, compared to the cycles used for the disturbance recording.

CONCLUSIONS

The new IEC 61850 international standard for substation communications enables the development of different distributed applications. This allows a completely new approach to the recording of transients, faults or wide area system disturbances.

In the case of specialized disturbance recording devices GSE messages can be used for cross-triggering over the substation LAN.

Sampled Analog Values from Merging Units are multicast or unicast and used for waveform recording.

The IEC GOOSE messages are used to send the measured voltage, frequency or other values for high or low speed disturbance recording or load trends.

The object models for disturbance recording use the specialized logical nodes designed to represent:

- RADR - Analog channels
- RBDR - Binary channels
- RDRE - Recording function

The use of logical devices for disturbance recording should follow the functional hierarchy of the primary system and more specifically – the available current and voltage transformers.