IEC 61850, IEC 61400-25, and IEC 61970: Information models and information exchange for electric power systems

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1 Introduction

The paper provides an overview about the application of advanced standards like XML and web services in the international standards IEC 61850 (Communication networks and systems in substations), IEC 61400-25 (Communications for monitoring and control of wind power plants), and IEC 61970 (CIM, Energy management application program interface – common information model). It introduces the comprehensive set of semantic definitions (process and meta information) for substations, wind power plants, and the whole electric power system. The information exchange – based on a set of very common services, MMS, SOAP, and TCP/IP – and the use of XML for easier configuration of devices and systems are introduced. The integration of substation configuration information into the control-center configuration (CIM, Common information Model) and vice versa will be discussed.

Process automation solutions are widely accepted for power systems. They are mostly based on a huge number of proprietary specifications or (de facto) standards. Globally, utility deregulation is expanding. It requires integrating, consolidating, disseminating, and interpreting real-time information quickly and accurately within a utility – from power plants to the power consumer in the shop floor or domestic user. Future electric power systems face a growing demand of configuration information (meta information) that describes the process data, the automation device, and – possibly – the primary equipment. To meet the future requirements, three new standards have been defined: IEC 61850, IEC 61400-25, and IEC 61970.

Systems that only produce, transmit, or distribute electric power need more and more – seamlessly supervised – automation systems that require little or no human intervention for the configuration and operation. Technologies bundled into the electric power system, therefore, have to include system configuration, protection and control equipment, as well as interfaces to supervisory control and data acquisition (SCADA) of control centers. Other applications that have already started to rely on these standards are: remote monitoring and fault diagnosis, power quality, automated dispatch and control, site optimization of electrical/thermal outputs, asset management, as well as condition monitoring, and diagnosis.

The future power systems will – thanks to a seamless information and communication system – be smart at the top and smart at the bottom, self-regulated by millions of communicating devices connected to form feedback loops, and permanently aware of the world around them.

Utilities and vendors take advantage of the new seamless use of the standards, and make the electric power systems safer and more efficient than before – all critical information is available (at any time and any where), is reliable, and could be understood easily and unambiguously when making control decisions.

2 The need for the seamless use of process information models and information exchange

2.1 Information on the way from its source to destination

Automation systems produce and consume a huge amount of information. The lowest level in the automation hierarchy, which is closely connected to the process (e.g., the current and voltage transducers, the primary equipment), provides (raw) process information: status information, measurements, and control information. The process information is communicated between the primary equipment and a local controller device by various means of wires and fieldbusses.

The local controller device may do a lot of calculations using the latest process information and the settings given by the configuration settings. The result may be for example:

- to notify an operator of a change of a status,
- an update of counter values,
- to log of status and related information in a local sequence-of-event (SoE) log,
- to control a primary equipment

Usually the program in the local controller knows the information it consumes (process information and settings) and it produces. As long as the information is processed and stored in the local controller, there is no external communication needed. As soon as the information (produced and consumed by the local controller) is used or provided by other devices, an exchange of the information is required. In many cases the information has to travel from the local controller to another controller, where it is processed for other purposes. As a result we get even more information to be communicated with a third controller, which may be located far away.

Assume the application depicted in Figure 1. The device "local controller" simply provides the raw measured value of the voltage of phase A. The local controller has a register or a variable that represents the current value of the process measurement (or status). The register or variable is addressed usually by a simple index, e.g., 2673. Independent of the information exchange method (polling or spontaneous transmission) the receiver understands the received information only if he "reads" the program or system documentation. The documentation defines that the value with the index 2673 represents the voltage value of phase A in kV – measured at a certain point, e.g., at location 1. The local controller does usually not provide this semantic of the raw process information.

The programmer of the receiving computer may rename the measured value (adding semantic to the value) as follows:

Loc1_VoltagePhaseA_kV	←	Index 2673

This name may be used to store the latest measured value in the computer or to report the value to another device over a network. Multiple voltage measurements are exchanged (see Figure 2, e.g., from location 2 and 3). The programmers can use different names for the very same voltage of different locations:

2_VPhA_k	←	Index 1233
Volt_A_Loc3	←	Index 524623

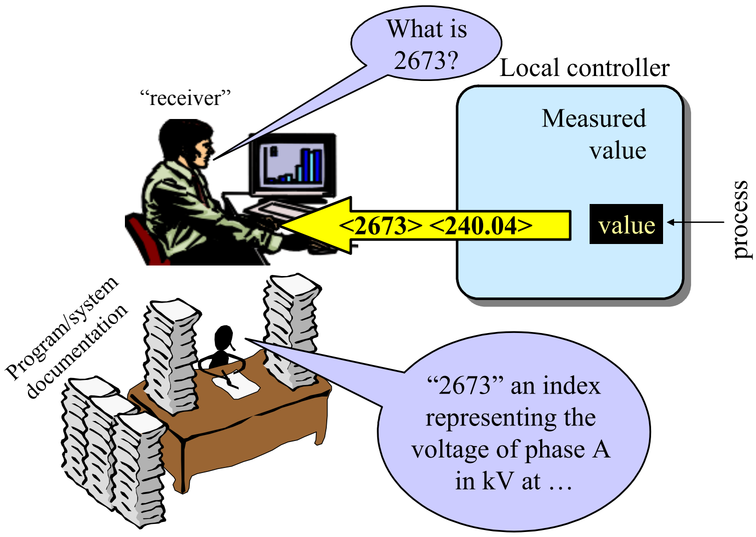

Figure 1 – Raw process information

This first mapping (of indexes to names) is depicted at the top of Figure 2. The indexes are mapped in the devices 1, 2, and 3 to different structured hierarchical names. The programmer of each device is free to select names they want to use. The number of possible hierarchies of names and the names used are just limited by the sky.

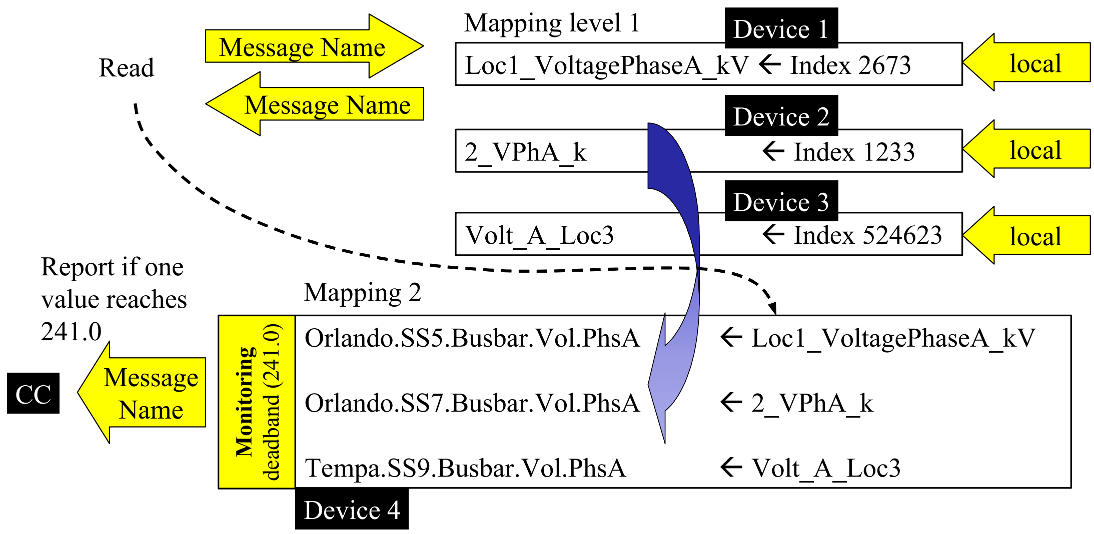

Figure 2 – Mappings of information during communication

The application in device 4 needs much information from various documents to correctly interpret the received information. A control center (CC) may be interested to receive an indication from device 4 in case one of the three values (from location 1, 2, or 3) exceeds the value 241.0 kV. To harmonize the names for the use in the control center, the names are mapped a second time to a common hierarchical structure as shown in the mapping 2. These names provide further information about the topology of the system and where the measured values are located.

The names of all important information like the name for the process value, the scale factors, and engineering units should be defined **as close as possible to the source of the raw process information**. This is the preferred approach to guarantee that the information exchanged is uniquely understood throughout the whole electric power system. It could be dangerous if the engineering unit is set to degrees Celsius in the information model but the receiver of the value interprets the value in degrees Fahrenheit. The use of a wrong multiplier – as part of the self-description of a device – could cause a severe damage of the whole system.

The availability of self-describing information and the online retrieval of this meta information could play a major role in future electric power systems as the following investigation of a power blackout shows. The recent power blackout in London (UK) affecting parts of South London at 18:20 on Thursday, 28 August 2003 would have been prevented if the protection relay (that did not function properly) would have had a self-describing function [1].

The investigation states (highlighted text has been highlighted by the author):

"108 The protection equipment that operated was an Inverse Definite Minimum Time (IDMT) relay, a commonly used type. It does not operate immediately, but starts to operate when the electric current on the circuit exceeds a certain threshold. The speed of operation depends on how far the measured current is above the threshold level.

109 The protection relay had been correctly specified during the design process and the settings sheet had been correctly produced. However the relay that had been physically supplied and installed at Wimbledon was a 1 ampere rated relay, not the 5 ampere relay specified on the settings sheet. In all other respects the settings on the relay were correct and were confirmed during several check points in the construction and commissioning process.

110 The effect of installing a 1 ampere relay instead of a 5 ampere, meant that the current flow at which the protection would operate was five times lower than the correct rating and below the rating of the circuit itself.

*111 The 1 ampere protection relay was set to operate at a current of 1,020 amperes on the transmission circuit and **was triggered on the day by a current of 1,460 amperes**. **This is significantly below the operating capability of the cable, at 4,450 amperes and the original specification of the protection relay, at 5,100 amperes** (see appendix 6).*

112 The protection relay was commissioned in June 2001 as part of a replacement scheme. Following a survey conducted as a result of the incident, all the automatic protection equipment in the area was surveyed and found to be correctly installed. A full survey of similar equipment at all substations in England and Wales has been initiated, and to date, having completed 20% of the total, no further cases have been revealed.

*113 The incident investigation found that **despite rigorous processes for commissioning protection equipment, the wrong protection relay was installed and commissioned** at Wimbledon substation and this caused the number two circuit from Wimbledon to New Cross to automatically disconnect unexpectedly, and caused the loss of supply."*

A simple (automated test) request (according to IEC 61850-7-2) to retrieve the **electronic name plate information** would have returned the name plate information of the relay installed. This would have unveiled that the wrong protection relay was installed at the Wimbledon substation.

The definition and retrieval of the selfdescriptive information are very important means to run **online commissioning and validation tests for plausibility checks**. The seamless use of standardized information models and the online validation of the:

- name plate information,
- information model, and
- values of the configuration attributes

could tremendously increase the reliability of the whole automation system, and therefore of the power generation, transmission, distribution, and use.

A simple question: "Who are you?" can validate that the intended device has been installed.

2.2 What does seamless mean?

The Merriam-Webster online Dictionary defines "seamless" as **having no seams** or as **having no awkward transitions or indications of disparity: perfectly smooth**. The second definition describes our situation.

Information traveling along from a source over many devices to a far application may be mapped multiple times due to the different systems, organizations, people, programming languages, and communication protocols involved: they all have disparate names and other information about the raw information.

Seamless information model means: there is no need to map one of the following definitions (while the information travels):

1. the value (including the Data type, e.g., Floating Point)
2. the scale (offset and factor – if applicable)
3. the engineering unit (e.g., SI Unit)
4. the name of the value, the scale, the engineering unit, etc.

Seamless information exchange means: there is no need to map one of the following definitions (while the information travels):

5. the service to be used for accessing the value and additional information,
6. the addressing of the information (e.g., via TCP/IP with IP-Addresses: 235.232.55.22),
7. the encoding of the information while "on the wire".

One important consequence of these requirements is that the **device which is the source of the process information (this may be information measured or locally processed) has to provide all information required to uniquely interpret the value**. Note that the additional information like scale factor and unit does not need to travel each time with the current value. It may be sufficient to transmit the name and the value. The scale factor and the unit can be retrieved when it is required, e.g., during device setup, site acceptance test, or for validation purposes.

The additional information is usually called **meta information**. Meta information just means: information about information. The unit (e.g., Volt) describes the nature of the process information; the name (e.g., Voltage.PhaseA) defines the semantic, it indicates the application to which the information belongs.

The information model and the information exchange are perfectly smooth if the (raw) information and the meta information are **defined at the source** and can be **exchanged with the same communication means from the source device to the final destination device**. The information may travel over multiple devices: from a local controller to a bay controller, from the bay controller to a substation host, from the substation host to a regional control center, and finally to the network control center. In all devices we have the same name of the process value and same names for the meta information. Some values like the scale factor may vary from device to device – but this value can easily be retrieved and understood..

An information model that can be used in a seamless manner is defined in IEC 61850-7-4 and IEC 61850-7-3[1]. IEC 61850-7-2 defines information exchange methods that can also be used in a seamless manner.

The highest priority in the power system domain is to implement a seamless information model for all common information like three-phase-voltages, three-phase-currents, common

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[1] The model as it is written in the standard cannot be seamless – only the use of the information model (from the source device up to the destination device) can be seamless.

measurements, etc. Domain specific information models are defined by domain experts of, e.g., hydro power plants, wind power plants, or other DER devices.

The information exchange methods may vary depending on the requirements of the application domain. The seamless use of one standardized information exchange methods could not be expected for various reasons. The question if the value has to be communicated spontaneously on change only (e.g., after a 10 per cent change) or if it will be polled periodically leads to totally different solutions.

Another issue of the information exchange methods is the encoding of the information. There are two basic methods to encode the messages: binary and ASCII encoding. IEC 61850-8-1 (mapping to MMS, ISO 9506) uses a binary encoding (ASN.1 BER). The web services defined in IEC 61400-25 use XML (based on ASCII encoding). The second encoding may result in much longer messages.

A further crucial question is the exchange of the names of the various information elements. In both above mentioned mappings the names are encoded as ASCII names (in XML and in IEC 61850-8-1). Is it required to communicate the hierarchical names at any time? In one case it may be important. In another it would result in messages which may be too long to be communicated via a low speed communication link.

The methods to optimize the physical message exchange are discussed later.

3 Information models

3.1 Definition of information models and introduction

An information model is a representation of some aspects of real functions (respectively primary equipment) and the associated automation and communication systems. The purpose of creating an information model is to help understand and describe how information looks like and how to exchange this information between devices in the real world.

The model is restricted to information and information exchange. The automation functions – that is the programmed behavior of the automation devices that processes the information – are outside the standards discussed in this article. The behavior may be programmed using common programming languages like C, C++, IEC 61131-3 etc.

The information model comprises hierarchically structured information to provide the semantic of the data to be exchanged.

Three information models are presented and briefly discussed in this paper:

1. Information model for substation and feeder equipment (IEC 61850-7-x)
2. Information model for monitoring and control of wind power plants (IEC 61400-25)
3. Information model of a power system as seen from a control center viewpoint (IEC 61970 CIM – common information model)

Another three models of some aspects of electric power systems (extensions for IEC 61850) are under preparation:

4. Information model for power quality monitoring (IEC 61850 extension) [10]-[24]
5. Information model for Distributed Energy Resources (DER) [25]
6. Information model hydroelectric power plants – communication for monitoring and control [26]

The models under 1, 2, 4, 5, and 6 describe process related information that is commonly located close to the process equipment – or even inside the first level of intelligent controllers. The CIM (model 3) describes the top view of the electric power system. The CIM models all visible information from/to the process related devices. This model is used to manage the whole electric power system of a region or even the whole network. The CIM provides the whole topology of the power system (wires, substations, transformers, breakers, etc.).

The source and the destination respectively (of a subset) of the operational process information modeled in CIM is also modeled in the other models (models 1, 2, 4, 5, and 6). The process related devices control and monitor the primary equipment, and therefore get the measurements and status information from the process and controls the process respectively. The two levels (the CIM models and process related models) share some common information. This shared information is harmonized in the current models (models 1 and 3). Figure 3 shows the conceptual dependency of the two levels. The topology information is primarily provided by the CIM (generated during the resource planning process). The operational information required by the control center applications is provided by the substation and power resource information models. The substation and power resource information models provide a lot of information that is used by other applications that are outside the control center applications: owner of power resource, engineering, maintenance, etc.

The harmonization of the information models 2, 4, 5, and 6 will be harmonized in a joint effort of the corresponding IEC working groups.

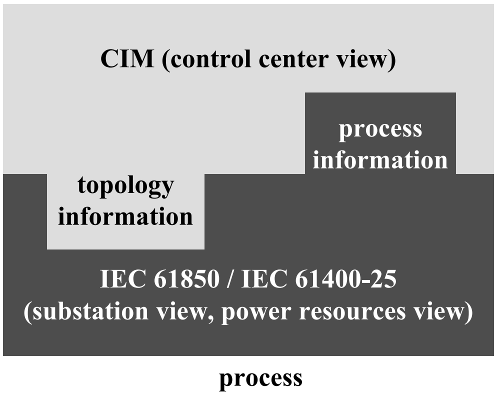


Figure 3 – Two levels of models (conceptual)

All information models are static, i.e., they specify common semantics of various aspects of electric power systems, e.g., a substation (IEC 61970), a circuit breaker (IEC 61850), or a wind turbine generator (IEC 61400-25).

The information model of IEC 61400-25 is based on the approach and content of IEC 61850-7-x. These two models are used for the information exchange between devices. Therefore the two standards use concrete communication protocols to let the information travel between devices. They do not define any application programmers interface (API). The APIs are a local matter and can be defined according to the environment in which they are used: in embedded devices, programmable controllers, or personal computers.

The standard IEC 61970 comprises an API for easier application integration in a control center. No protocol is defined so far on how to let the information travel between applications in a control center. The following table compares the two levels of information models.

	IEC 61850 / IEC 61400-25	IEC 61970
Application domain	Substations / Wind power plants	Energy Management Systems (EMS)
Information model	Yes / Yes	Yes
Serialization format	one / five	Yes
Information exchange methods	one / five	No
Communication protocol	one / five	No
Application programmers interface	No / one (WSDL)	Yes

The information models of IEC 61850 and IEC 61400-25 are introduced in the next clause. The information model defined in IEC 61970 is introduced after that.

3.2 The process related information models

3.2.1 Information model of IEC 61850

The standard IEC 61850 focuses on the information models (the **What to exchange**) and the information exchange (the **How to exchange**). Great efforts have been invested in the substation domain analysis, which resulted in a quite elaborate information model. The main abstraction of this model is the Logical Node (LN). Some 80 LNs are defined in IEC 61850-7-4. They serve to group related data objects (e.g., a status or measurement), and are contained in Intelligent Electronic Devices (IED). An LN represents the external view of one of the following:

1. a kind of **atomic functional building block** for substation automation functionality, such as a protection or a control function, or
2. a kind of **proxy object for the primary equipment** (e.g., an LN that groups data objects representing a circuit breaker or transformer).

LNs are composed of data, which are in turn composed of a nested hierarchy of other data and/or data attributes. At the bottom end, there are primitive data types, such as Boolean, integer, timestamp, and quality (these are defined in IEC 61850-7-2). The data and attribute names and types at each but the last level, carry the semantics of the domain, and are defined as common data classes (CDC) in IEC 61850-7-3.

Data contained in a LN is typically operational data (e.g., measured value, or position status, with their quality and time tags), but it comprises also many configuration data (e.g., the engineering unit of an analogue value, the device nameplate, or its last configuration version). This implies that an IED can describe itself. **The self-description can be retrieved directly from the device by appropriate communication means.**

For configuration purposes, IEC 61850-6 defines the Substation Configuration Language (SCL). SCL is an XML schema, with the elements and attributes reflecting the substation information model defined according to IEC 61850-7-x. In addition to the online retrieval of the self-description, the capability of IEDs can be made available in a second way: Through an XML SCL instance file. SCL allows also to configure the communication-related attributes of an IED (e.g., supported communication services, server address), as well as the equipment and communication topology within the substation. The physical hierarchical structure of the substation is defined in SCL only, whereas the rest of the standard focuses on LNs (and their data objects). The

LNs and their data model the **externally visible (produced and consumed) information** of the functionality of the devices.

IEC 61850 specifies its normative data model by means of tables in a Microsoft Word document (except for SCL, which is defined as an XML schema). The tables of the data model have been transformed to informative xml files and browsable html files [32].

The standard IEC 61400-25 references a subset of definitions of IEC 61850 and defines many domain-specific and common LNs, data objects, and common data classes.

Some100 logical nodes covering the most common applications of substation and feeder equipment are defined in IEC 61850. The applications are:

- System information
- Protection functions
- Protection related functions
- Supervisory control
- Generic references
- Interfacing and archiving
- Automatic control
- Metering and measurement
- Sensors and monitoring
- Switchgear
- Instrument transformer
- Power transformer
- Further power system equipment

Most LN provide information that can be categorized as depicted in Figure 4. The semantic of a logical node is represented by data and data attributes. Logical nodes may provide a few or up to 30 data objects. Data objects may contain a few or even more than 20 data attributes. Logical nodes may contain more than 100 individual information (points) organized in a hierarchical structure.

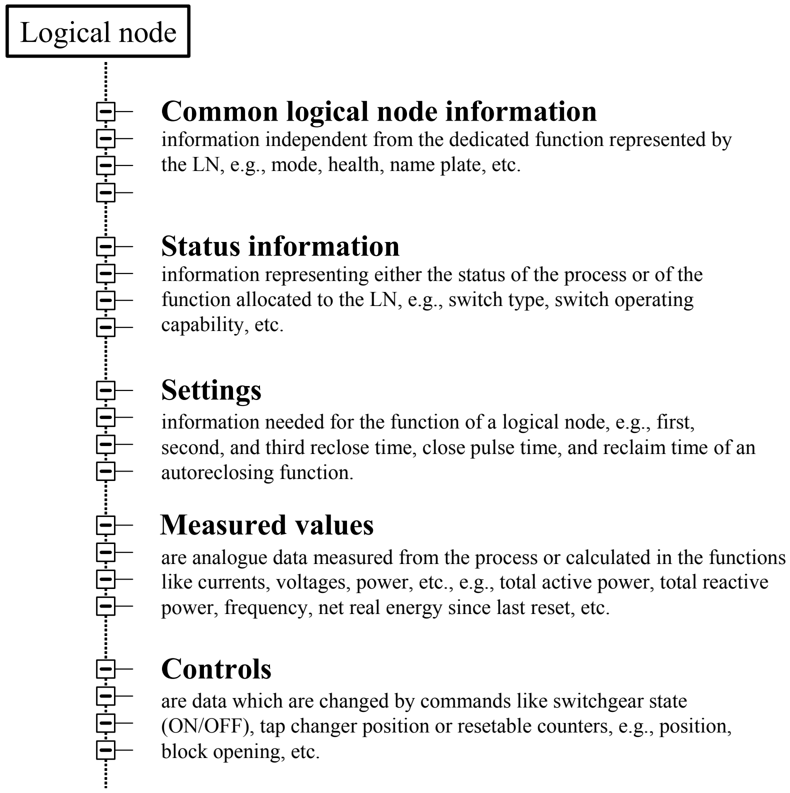


Figure 4 – Logical node information categories

The mean number of specific data objects provided by logical nodes defined in IEC 61850-7-4 is approximately 20. Each of the data objects (for example, position of a circuit breaker) comprises several details (the data attributes). The position (named "Pos") of a circuit breaker is defined in the logical node "XCBR" (see Figure 5). The position is defined as data object.

IEC 926/03

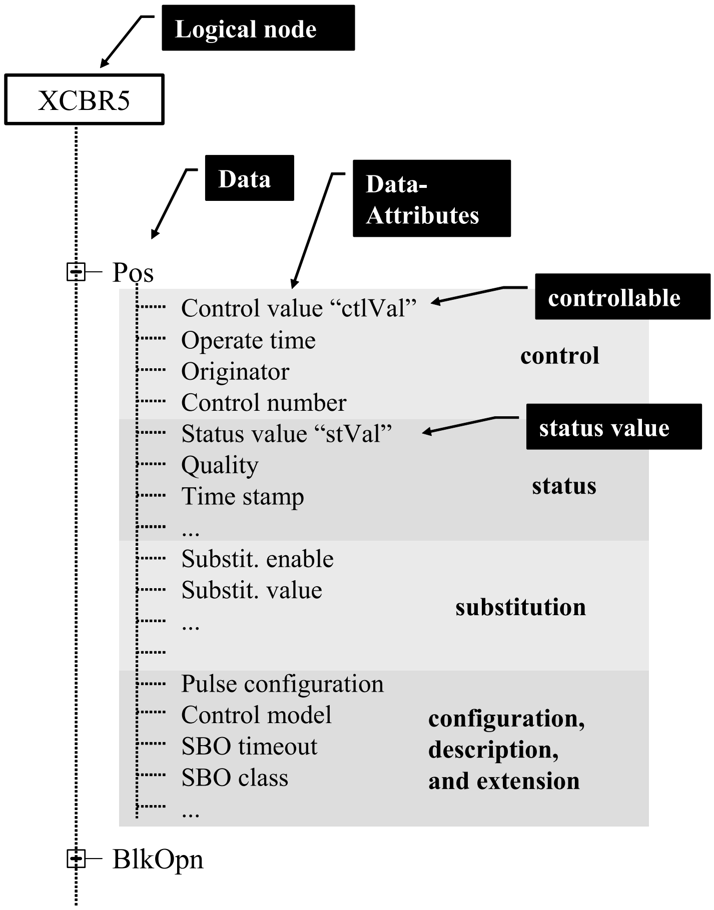


Figure 5 – Position information depicted as a tree (conceptual)

The position "Pos" is more than just a simple "point" in the sense of traditional RTU protocols. It is accompanied by several (descriptive) data attributes. The groups of data attributes are:

– control (status, measured/metered values, or settings),
– substitution,
– configuration, description and extension.

The data "Pos" has approximately 20 data attributes. The data attribute "Pos.ctlVal" represents the controllable information (can be set to "on" or "off"). The data attribute "Pos.stVal" represents the status of the real breaker (could be in intermediate-state, off, on, or bad-state).

The position has also information about when to process the control command (Operate time), the originator that issued the command, and the control number (given by the originator in the request). The quality and time stamp information indicates the current validity of the status value and the time of the last change of the status value.

The current values for "stVal", "q" (quality) and "t" (time stamp) can be read, reported or logged in a buffer of the IED.

The values for "stVal" and "q" can be remotely substituted. The substituted values take effect immediately after enabling substitution.

Common data classes (templates) are used to define data attributes of data. The crucial common data classes defined in IEC 61850-7-3 are:

Common data classes for status information

– Single point status (SPS)
– Double point status (DPS)

– Integer status (INS)
– Binary counter reading (BCR)

Common data classes for measurand information

– Measured value (MV)
– Complex measured value (CMV)
– Sampled value (SAV)
– Phase to ground related measured values of a three phase system (WYE)
– Phase to phase related measured values of a three phase system (DEL)
– Harmonic Value (HMV)
– Harmonic value for WYE (HWYE)
– Harmonic value for DEL (HDEL

Common data classes for controllable status information

– Controllable single point (SPC)
– Controllable double point (DPC)
– Controllable integer status (INC)
– Binary controlled step position information (BSC)
– Integer controlled step position information (ISC)

Common data classes for description information

– Device name plate (DPL)
– Logical node name plate (LPL)

The minimum subset of data attributes of the common data class MV (Measured value) are:

"mag" Deadbanded value. Value based on a dead band calculation. The value of mag is updated when the value has changed according the configuration parameter db (deadband – online changeable configuration attribute).

"q" Quality of the attribute(s) representing the value of the data.

"t" Timestamp of the last change in one of the attribute(s) representing the value of the data or in the q attribute.

These three data attributes are the only mandatory attributes. These three can be used for immediate reading, reporting, or logging. Almost all RTU protocols like IEC 60870-5 or DNP3 communicate just these three data attributes.

The complete set of data attributes of the common data class MV are:

attribute category	data attribute	explanation
measured attributes	instMag mag range q t	instantaneous value deadbanded value (according to db in per cent) normal|high|low|high-high|low-low|... quality information timestamp
substitution	subEna subMag subQ subID	enable the subMag instead of the process value value to be used for mag value to be used for q substitution ID – who substituted the value?
configuration, description and extension	units db zeroDb	engineering units (SI units) deadband value (in per cent) mag is Zero as long as value is less than zeroDb

	sVC	scale and offset for INTEGER representation of mag
	rangeC	values for hhLim, hLim, lLim, llLim, min, max
	smpRate	Sampling rate used to determine the analogue value
	d	textual description
	dU	textual description (based on UNICODE)
	cdcNs	common data class name space
	cdcName	common data class name
	dataNs	data name space

Changes of the values of the data attributes "mag", "range", or "q" can be used to issue a spontaneous report to registered clients indicating the change. Or the change event can be used to log the new value in a log of the IED.

The logical nodes, data, and data attributes are defined mainly to specify the information required to perform an application, and for the exchange of information between IEDs. The information exchange is defined by means of information exchange methods (or communication services).

The standard IEC 61850-7-1 defines rules to extend the information model to meet specific requirements of an application domain that are not yet met by the current version of the standard. The "name space" concept allows to extended LNs, data objects, and common data classes or to define new ones. The name space information – contained in the model – separates the new definitions from the standardized LNs, data objects and common data classes.

3.2.2 Information model of IEC 61400-25

The IEC Technical Committee 88 has set up a new project to develop a communication standard for distributed generation (primary scope per TC 88: wind power plants) in 2001: IEC 61400 Part 25 – Communications for monitoring and control of wind power plants

This standard defines like IEC 61850 several levels:

- wind power plant specific information,
- information description methods (reference to IEC 61850),
- substation configuration method (reference to IEC 61850),
- information exchange for monitoring and control systems for wind power plants (reference to IEC 61850), and
- communications profiles (reference to IEC 61850 and definition of additional mappings)

The information defined in this standard comprises mainly wind power plant specific information like status, counters, measurements, and control information of various parts of a wind power plant, e.g., turbine, generator, gear, rotor, and grid.

The first committee draft standard IEC 61400-25 (IEC 88/179/CD) mainly defines additional information models and common data classes. The following wind-specific logical nodes comprise a total of some 200 data objects:

Logical node	description
WTUR	Wind turbine general information
WROT	Wind turbine rotor information
WTRM	Wind turbine transmission information
WGEN	Wind turbine generator information
WCNV	Wind turbine converter information
WGDC	Wind turbine grid connection information
WNAC	Wind turbine nacelle information

WYAW	Wind turbine yawing information
WTOW	Wind turbine tower information
WMET	Wind power plant meteorological information
WALM	Wind turbine alarm information
WSLG	Wind turbine state log information
WALG	Wind turbine analogue log information
WREP	Wind turbine report information
under preparation for the next version of the standard in 2004:	
WAPC	Wind power plant Absolut Power Constraint control
WGRA	Wind power plant Gradient Control
WDEL	Wind power plant Delta Control
WREA	Wind power plant Reactive Power Control
WFRQ	Wind power plant Frequency Control
WTCC	Wind turbine component condition monitoring

The data objects for analogue process information in IEC 61400-25 are much more comprehensive than those defined in IEC 61850. An analogue value for example may comprise the Instantaneous value, Deadbanded value, Average value, or Root-mean-square value (effective) as well as the following characteristics and historical information:

attribute category	**data attribute**	**explanation**
characteristics information	maxVal minVal totAvgVal sdvVal opRs tRs q	Maximum value Minimum value of data Total average value of data Standard deviation of data Operator identifier of last reset Timestamp at last reset Quality
characteristics control information	rsMan rsPer	Manual forced reset Time periodical reset: hly | dly | wly | mly | manual
historical information	hlyMax dlyMax mlyMax ylyMax hlyMin dlyMin mlyMin ylyMin hlyAvg dlyAvg mlyAvg ylyAvg tRs opRs	hourly max value of 25 hours daily max value of 32 days monthly max value of 13 months yearly max value of 2 years hourly min value of 25 hours daily min value of 32 days monthly min value of 13 months yearly min value of 2 years hourly average of 25 hours daily average of 32 days monthly average of 13 months yearly average of 2 years Operator identifier of last reset Timestamp of last reset
historical control and set-point information	rsHis d dU cdcNs cdcName dataNs	reset log hly | dly | mly | yly | all textual description textual description (based on UNICODE) common data class name space common data class name data name space

An analogue value may be defined with many attributes, i.e., it is very comprehensive (not complex!). But most data attributes defined in these templates are optional. That means if they are needed then the standardized names and types (not depicted in the table above) should be used. Most of this information is not required for realtime operation of the wind turbine. Owners and aggregators may need this information for system analysis and system optimization.

Many status and measurement information can optionally be stored in various logs for later retrieval. Advanced turbine controller may comprise several thousand information points to be reported and logged respectively. IEC 61400-25 defines many common logs, e.g., turbine commands, turbine status, high urgent alarms, low urgent alarms, counting information, and event timing information.

Figure 6 shows the current situation. Among other challenges, equipment having different proprietary protocols cannot be integrated without the installation of Remote Terminal Units (RTUs) to perform the translation work (Gateway), which is both expensive and labor-intensive. Usually raw data is exchanged cyclically.

The move to the new international standards IEC 61850 and IEC 61400-25 provides the basis for the migration of common SCADA processing functions, e.g., logging of historian and statistical information into the turbine controller. Self-identification and self-description may also be stored in the IED's data base.

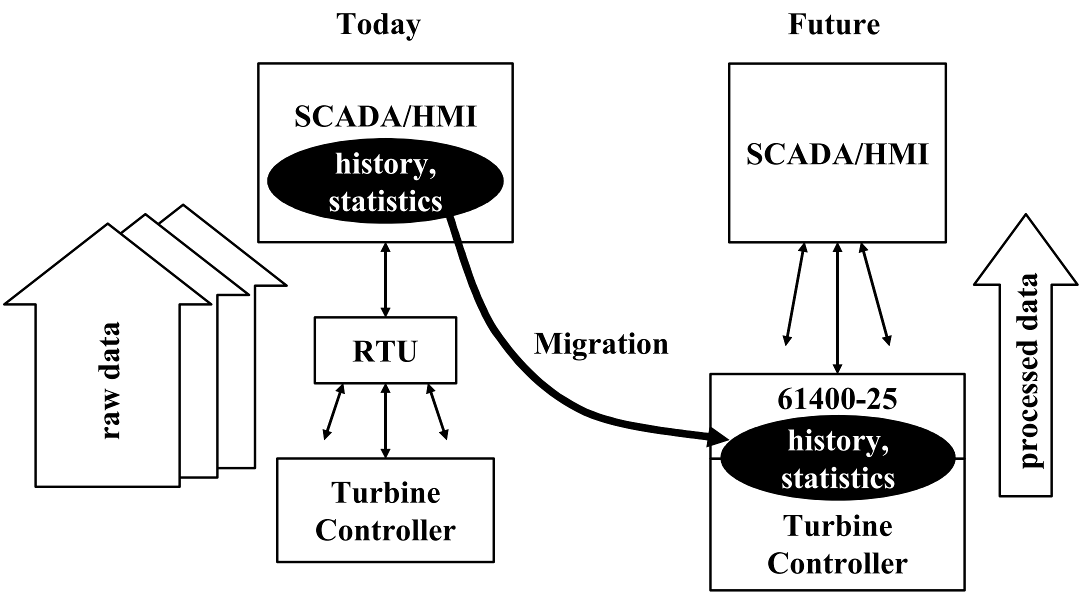


Figure 6 – Migration of processing to IEDs

Today's advanced controller provide already most of the historical and statistical information. In this regard the standard IEC 61400-25 follows the market – not vice versa.

The object oriented information description methods allow precise and complete specification of the process and meta information.

The information exchange provides:

– real-time data access and retrieval,
– controlling devices,
– event/alarm reporting and logging,
– self-description of devices,
– data typing and discovery of data types, and
– file transfer

IEC 61400-25 has been developed in order to provide a uniform communications basis for the monitoring and control of wind power plants. It defines wind power plant specific information, the mechanisms for information exchange and the mapping to communication protocols. In this regard the standard defines all details required to connect wind power plant components in a multi-vendor environment and to exchange the information made available by a component. This is done by definitions made in this document or by reference to other commonly used standards.

Process information is hierarchically structured and covers for example common process information found in the rotor, generator, converter, grid connection and the like. The data may be simple (value, timestamp, and quality) or more comprehensive (adding more meta information, for example engineering unit, scale, description, short hand reference, statistical and historical information of the process value). All information of a wind power plant defined in this standard is name tagged – it defines a comprehensive name space. A concise meaning of each signal is given. The meaning can be retrieved by respective services. The standardized wind power plant information can be easily extended by means of a name space extension rule.

3.2.3 Information models for further electric power system application domains

Based on the common definitions of the current standard IEC 61850 and draft standard IEC 61400-25 information models for further electric power system application domains are under development.

<u>a. Power Quality Monitoring Addendum to IEC 61850</u>

This addendum standardizes logical nodes and data objects for exchanging information about power quality.

The logical node classes and data classes defined in Parts 7-3 and 7-4 of IEC 61850 do not address an important category of substation equipment: The power quality monitor. A power quality monitor records and reports sags, swells, and interruptions in the power supply, also known as Root-Mean-Square (RMS) variations. It may optionally perform disturbance recorder functions related to the occurrence of these variations. This addendum defines logical nodes, data objects and if necessary, new data classes, for:

- setting thresholds and criteria for detecting variations,
- recording, reporting to the client and/or logging the critical information associated with variations,
- setting criteria for when a variation may trigger disturbance recorder functions,
- aggregating counts of the variations detected

The primary goal of this addendum is to address RMS variations. However, this addendum may also specify logical nodes, data objects, and common data classes describing other power quality phenomena. These phenomena may include flicker, transients, frequency variation, or mains signaling.

The project has started in May 2003.

<u>b. Communications Systems for Distributed Energy Resources (DER) Addendum to IEC 61850</u>

This Standard will comprise the object models and services for information exchange requirements for distributed energy resources (DER), comprising dispersed generation (DG) devices and dispersed storage DS) devices, including, but not limited to, reciprocating engines, fuel cells, microturbines, wind turbines, photovoltaic, and storage devices. The DER standard will be based on existing semantics, services, and protocols. It is intended to be compatible with IEC61850, IEC61970, IEC60870-5, and IEC60870-6 standards, and may include proposed extensions to IEC61850.

The initial input to this project is the outcome of the specification "DER Object Models" of the E2I/CEIDS project on "Open Communication Architecture for DER in ADA" [36]. It is intended to publish these information models as an IEC/IEEE dual logo standard.

The project is expected to start in December 2003.

c. Hydroelectric power plants – communication for monitoring and control Addendum to IEC 61850

This publication focuses on the communication between hydroelectric power plant components and actors within the power plant and its related systems. The publication provides a communication interface to devices and systems compatible to the IEC 61850 standard.

Typical examples of data objects are water level, water flow and related issues. The additional document must also cover data required for dam gate and turbine control etc. Although there are few new hydropower plants being built, the near future will see a large number of rehabilitation and refurbishment projects. Most such projects will include more or less complete replacement of the control systems.

At present IEC 61850 covers all required objects for the "substation" part of a typical power plant and will thus provide a perfect basis for most of the required functionality. At this time it is expected to cover only hydropower plants and not thermal or nuclear plants. The reason for this is to achieve a result within a limited timeframe.

The addendum will define logical node classes, data classes and, when required, new common data classes for:

- Water level and water flow
- Dam gates, gate positions
- Turbines, guide vane and turbine blade positions
- Hydraulic systems, lubrication and cooling systems
- Vibration monitoring
- Close Circuit Television systems for supervision inspection of e.g. dams
- Entrance control and safety
- Statistical and historical recording of e.g.:
  - Power production
  - Water levels
  - Turbine and generator vibrations
  - Temperatures

The project is expected to start in December 2003.

3.3 Control center view of process related information

In order to provide the exchange of electric power system models between the various applications in control centers, utilities needed to agree on common definitions of electric power system entities and relationships. To support this, a Common Information Model (CIM) has been published as IEC 61970-301 (Energy Management System Application Programming Interfaces (EMS-API)) [33] – [35]. The objective of CIM is to support the integration of independently developed applications between vendor specific EMS systems, or between an EMS system and other systems that are concerned with different aspects of electric power system operations, such as generation or distribution management.

CIM specifies common semantics for power system resources (e.g., a substation, a switch, or a transformer) defining attributes e.g., ampRating for a breaker, and relationships (e.g., a transformer has two or more windings). The "master" model is maintained as a Rational Rose™ model file, which can be browsed online at [33].

The complete CIM consists of several interrelated packages of models including Wires, SCADA, Load Modeling, Energy Scheduling, Generation, and Financial. These information models (also referred to as meta information) specify not the contents of the actual electrical power system, but how the structure and relationships of components of a electric power system can be represented in a standardized manner. Each CIM package contains descriptions of classes of objects.

Several attributes of a CIM production entity (the HydroGeneratingUnit) is shown in Figure 7. The attributes represent the control center view of the information of a hydro power plant production unit.

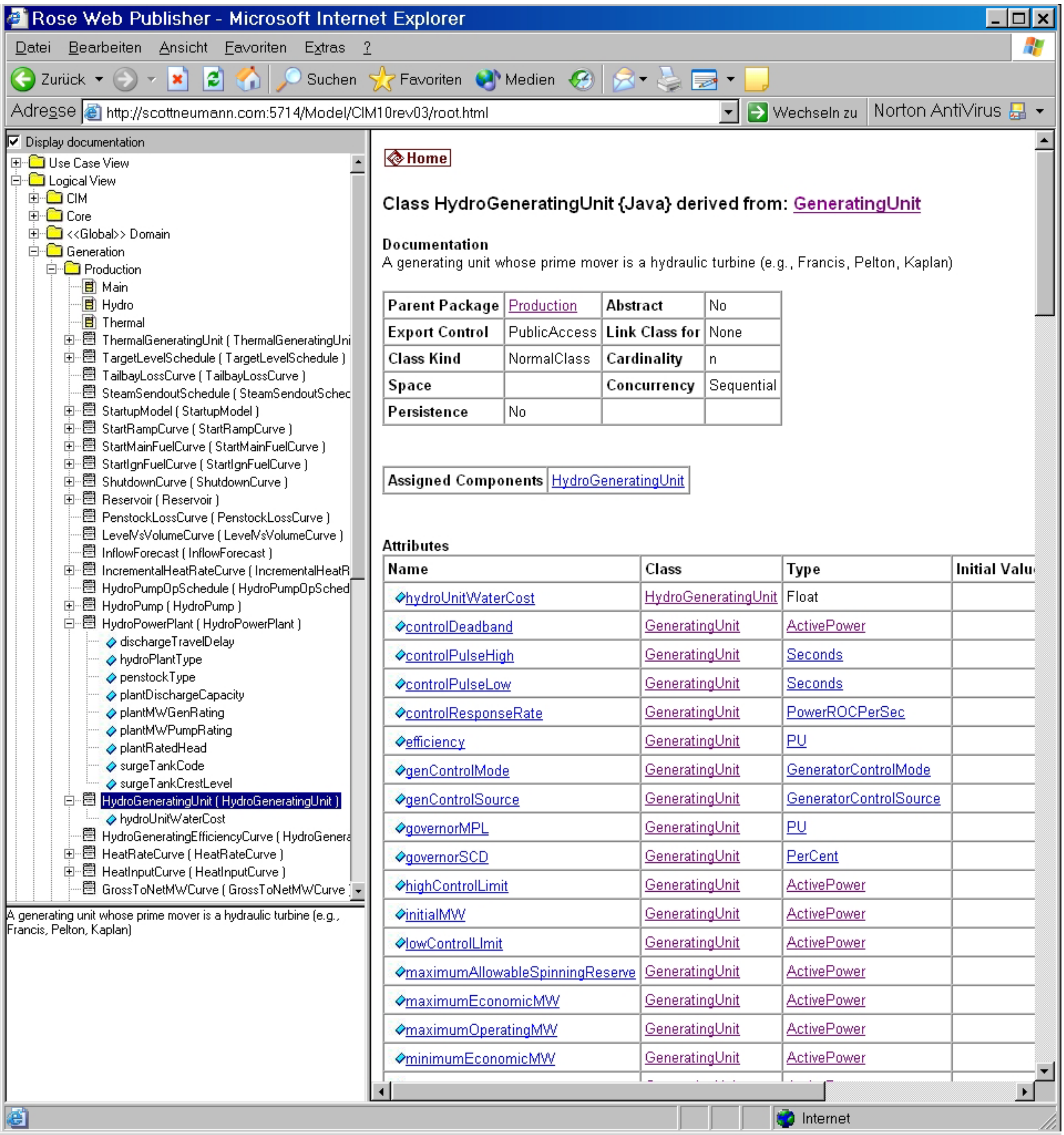


Figure 7 – CIM logical view of a hydro generating unit

The CIM logical view of a measurement is depicted in Figure 8. Applications in control centers can use this information models to provide access to the represented information. The dynamical values of the attributes may be retrieved by traditional RTUs (using IEC 60870-5-101/104 or DNP3) or by solutions conformant to IEC 61850. The data access from the control center to the substations and power resources are outside the CIM.

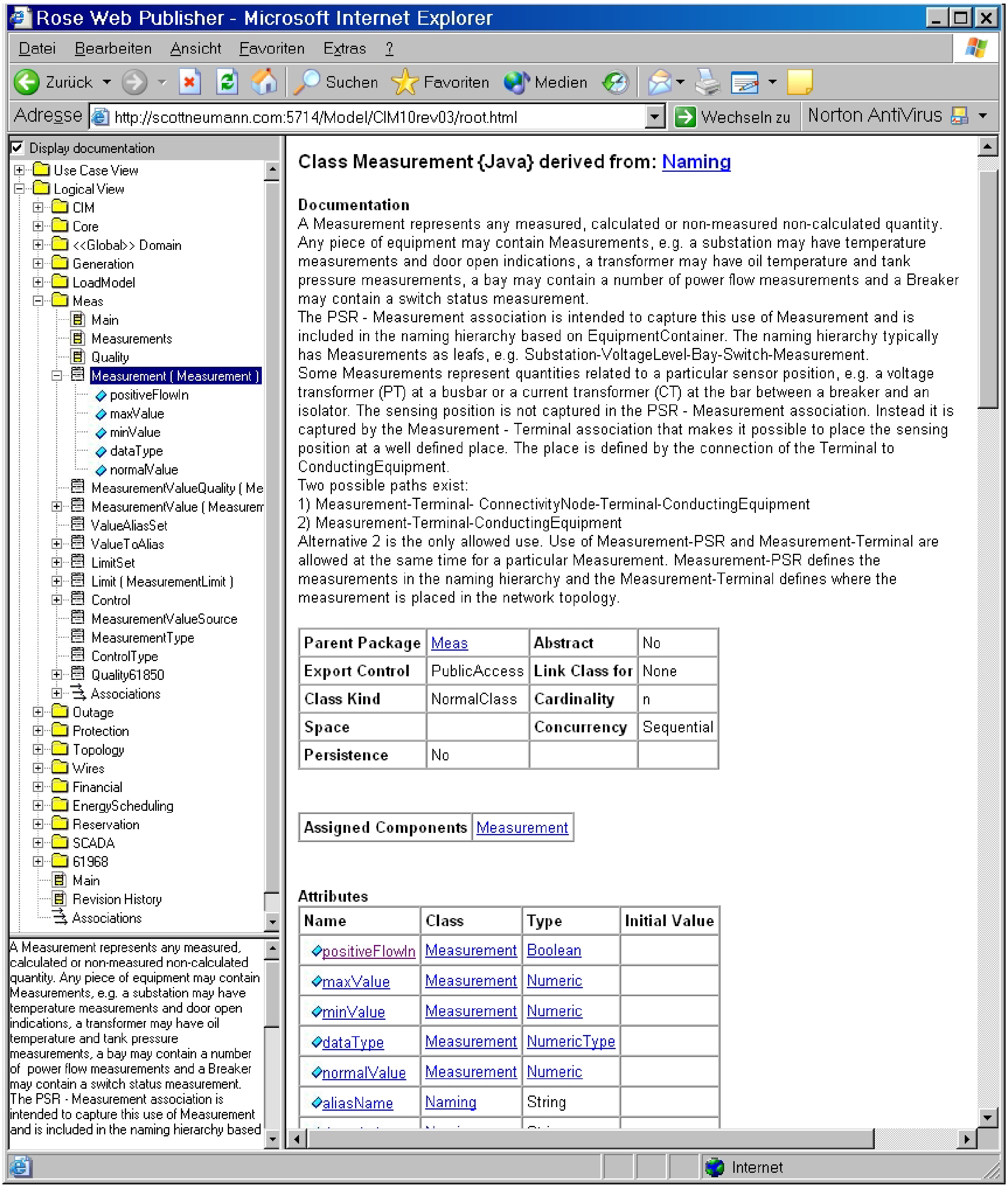


Figure 8 – CIM logical view of measurement

The CIM is defined using UML. To support the exchange needs of instances of the information model, an approach has been adopted that uses the semantic data definitions from the CIM with the syntax of XML. The XML files contain concrete operational power system models.

The CIM is an abstract model that represents all the major objects in an electric power system typically needed to model the operational aspects of a utility including substations and power resources.

Figure 9 shows the conceptual relation of the logical nodes, data, and data attributes (at the top) with the CIM.

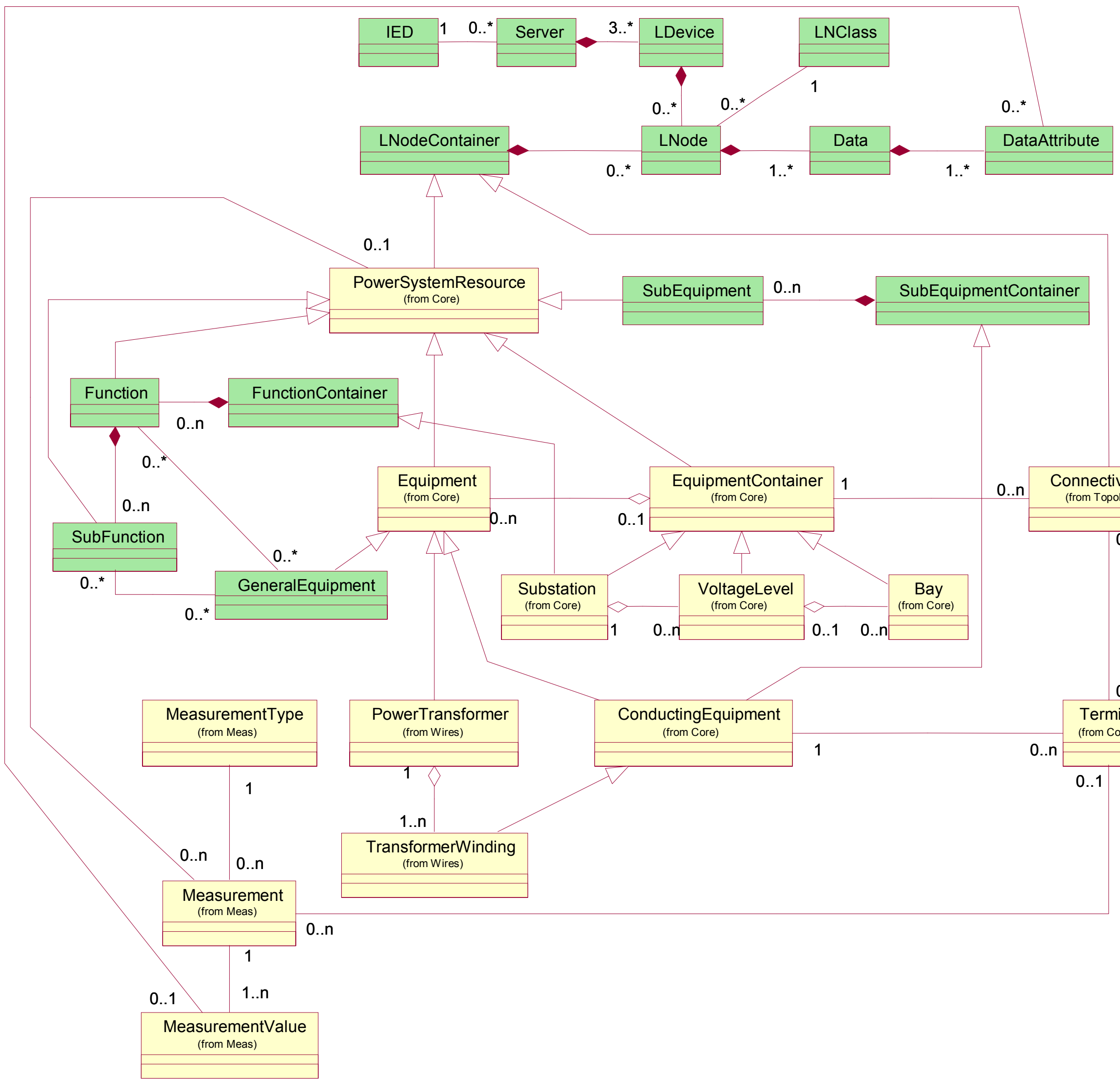


Figure 9 – CIM and models of IEC 61850 combined

Information produced and consumed by substations (modeled as LNs, data objetcts, and data attributes) are "imported" by CIM from the IEC 61850 models. The information of the physical topology of the electric power system required in the substation model according to IEC 61850 is "imported" from CIM (not depicted in the figure).

4 Process information exchange

4.1 Abstract information exchange methods

The information exchange methods for IEC 61850 are defined in IEC 61850-7-2. The draft standard IEC 61400-25 re-uses these methods.

Figure 10 shows an example of a typical future hierarchical automation system (substation). At process level there are the process interfaces hard-wired in the past and serially linked by the process bus in the future. The protection and control devices are connected by the inter-bay/station bus. At station level, there is very often a station computer with HMI (human machine interface) and a gateway to the control center at the higher network level. The focus of IEC 61850 is the support of substation automation functions by information models and information exchange methods for (numbers in brackets refer to the figure):

– sampled value exchange for current and voltage sensors (1),
– fast exchange of I/O data for protection and control, e.g., tripping and blocking (2),
– control signals (3),
– engineering and configuration (4),
– monitoring and supervision (5),
– control-center communication (6),
– time-synchronization

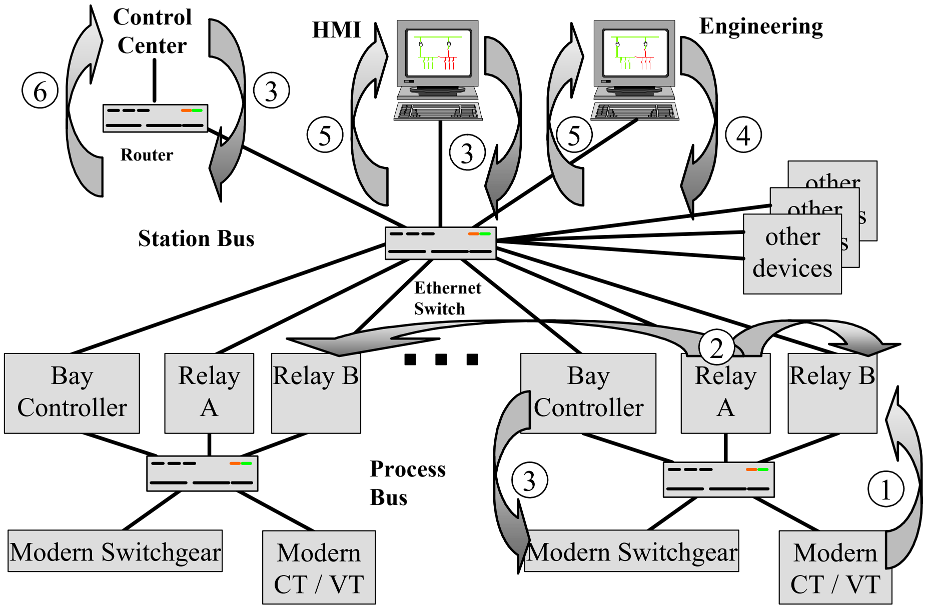


Figure 10 – Modern substation topology

The information exchange mechanisms access well defined instances of the information models. These information models and the modeling methods are crucial for IEC 61850. The IEC 61850 uses the approach of modeling the common information found in real devices as shown in Figure 11. All common information made available to be exchanged with other devices is defined in the information model. The information contained in real devices is mapped to the virtual model comprising LN and data objects.

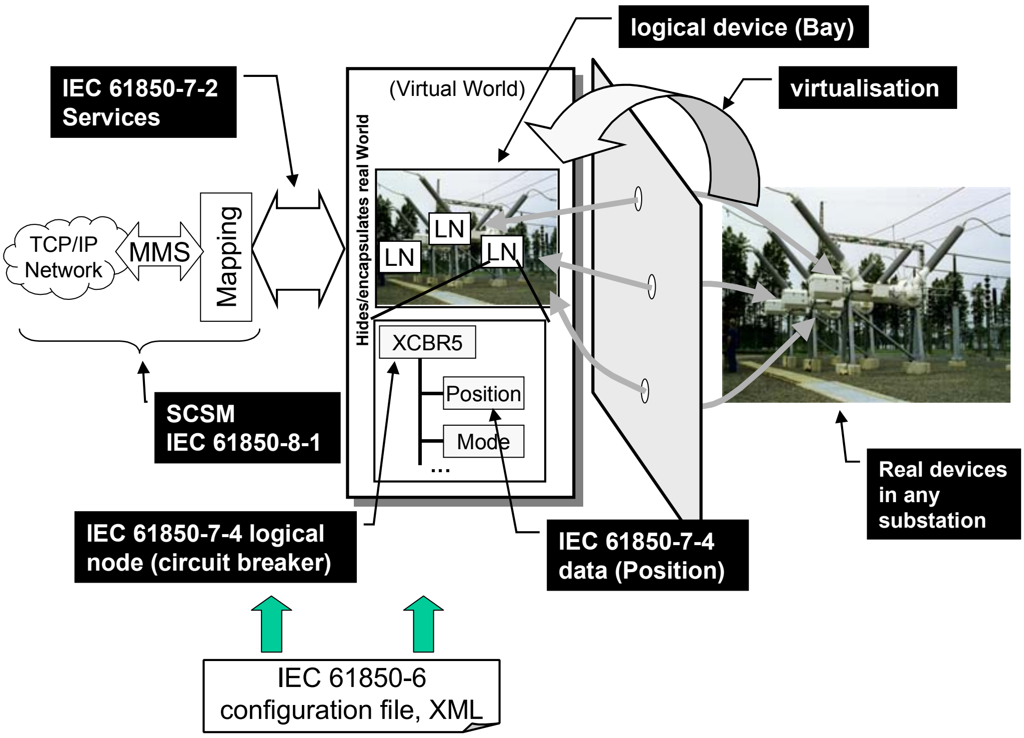


Figure 11 – Conceptual modeling and mapping approach

IEC 61850 defines the information and information exchange independent of a concrete implementation (i.e., it uses abstract models). The abstract information exchange methods (ACSI – abstract communication service interface) are defined in IEC 61850-7-2.

Real devices on the right hand side of Figure 11 are modeled as a virtual device model in the middle of the figure. The logical nodes defined in the logical device (for example, a bay) correspond to well known functions in the real devices. In this example the logical node "XCBR5" represents a specific circuit breaker of the bay to the right.

Based on their functionality, a logical node contains a list of data (for example, position) with dedicated data attributes. The data have a structure and a well-defined semantic (meaning in the context of substation automation systems). The semantic is partly very common (status or measurement). Other information is substation-specific (e.g., the directional mode information of a distance protection function). The information represented by the data and their attributes are accessed by various services. The abstract services are mapped to specific and concrete communication protocols (for example, using MMS, TCP/IP, and Ethernet among others).

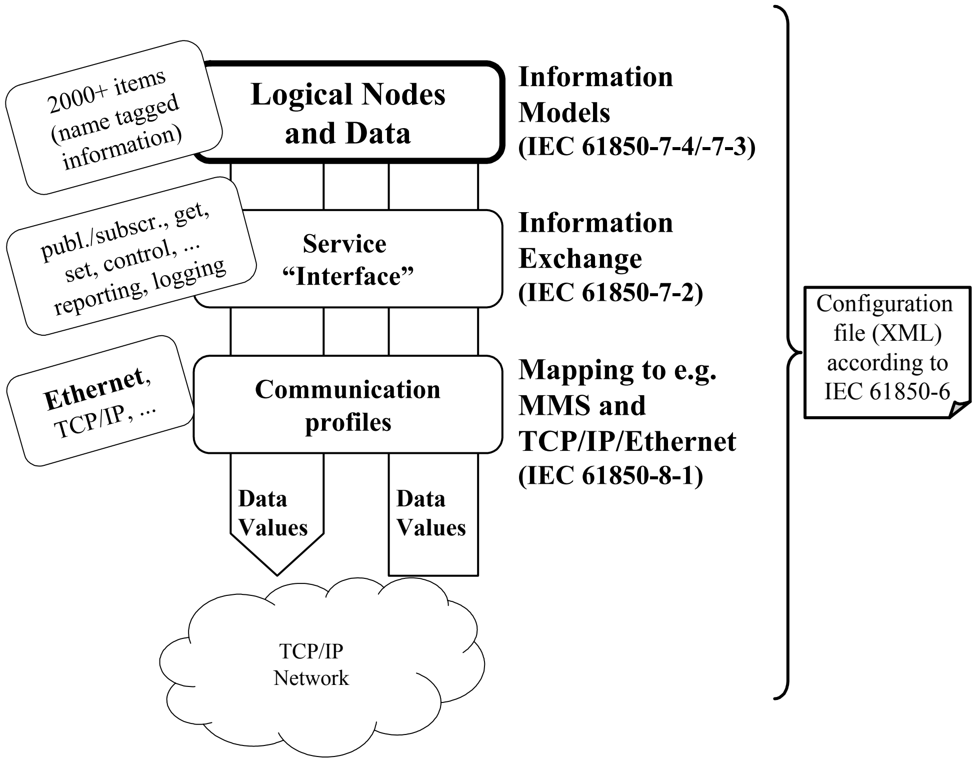


Figure 12 – Levels of the IEC 61850 model

The main building blocks of the standard are (see Figure 12):

<u>Substation automation system information models</u>

IEC 61850-7-4 defines **substation-specific** information models for substation automation functions (for example, breaker with status of breaker position, settings for a protection function, etc.) – **what** is modeled and could be accessed for information exchange. Includes an electronic data sheet embedded in the IED for self-identification and self-description.

IEC 61850-7-3 defines a list of **commonly used** information templates (for example, double point control, 3-phase measured value, etc.) – **what** is the common basic information,

<u>Abstarct information exchange methods</u>

IEC 61850-7-2 provides the services to exchange information for the different kinds of functions (for example, control, report, log, get and set, etc.) – **how** to exchange information. The information to be accessed comprises also the IED's self-identification and self-description.

Mapping to concrete communication protocols

IEC 61850-8-1 defines the concrete means to communicate the information between IEDs (for example, the application layer, the encoding, etc.) – **how** to serialize the information in corresponding messages.

Configuration of a substation IED (SCL – substation configuration language)

IEC 61850-6 offers the formal configuration description of a substation IED including the description of the relations with other IEDs and with the power process (single line diagram) – **how** to describe the configuration. This off-line data sheet completely describes the IED. The SCL file (XML document) eliminates the need to manually input this data when configuring an IED. This not only reduces system configuration time, but also increases the general integrity and reliability of systems by reducing human error.

These building blocks are to a high degree independent of each other. The information models can easily be extended by definition of new logical nodes and new data according to specific and flexible rules – as required by other application domains (e.g., wind power plants). In the same way, communication stacks may be replaced following the state-of-the-art in communication technology.

The information is separated from the concrete representation and from the information exchange services. The information exchange services are separated from the concrete communication profiles.

An excerpt of the information exchange services that operate on the information model is displayed in Figure 13. The circles with the numbers refer to the bulleted list below.

The operate service manipulates the control specific data attributes of a circuit breaker position (open or close the breaker). The report services spontaneously inform another device that the position of the circuit breaker has been changed. The substitute service forces a specific data attribute to be set to a value independent of the process.

The categories of services (defined in IEC 61850-7-2) are as follows:

- get values of data attributes,
- control devices (operate service or by multicast trip signals) (1),
- fast and reliable peer-to-peer exchange of status information (tripping or blocking of functions or devices) (2)
- reporting of any set of data (data attributes), SoE – cyclic and event triggered (3),
- logging and retrieving of any set of data (data attributes) – cyclic and event triggered (4),
- substitution (5),
- handling and setting of parameter setting groups,
- transmission of sampled values from sensors,
- time synchronization,
- file transfer,
- online configuration (6), and
- retrieving the self-description of a device (7).

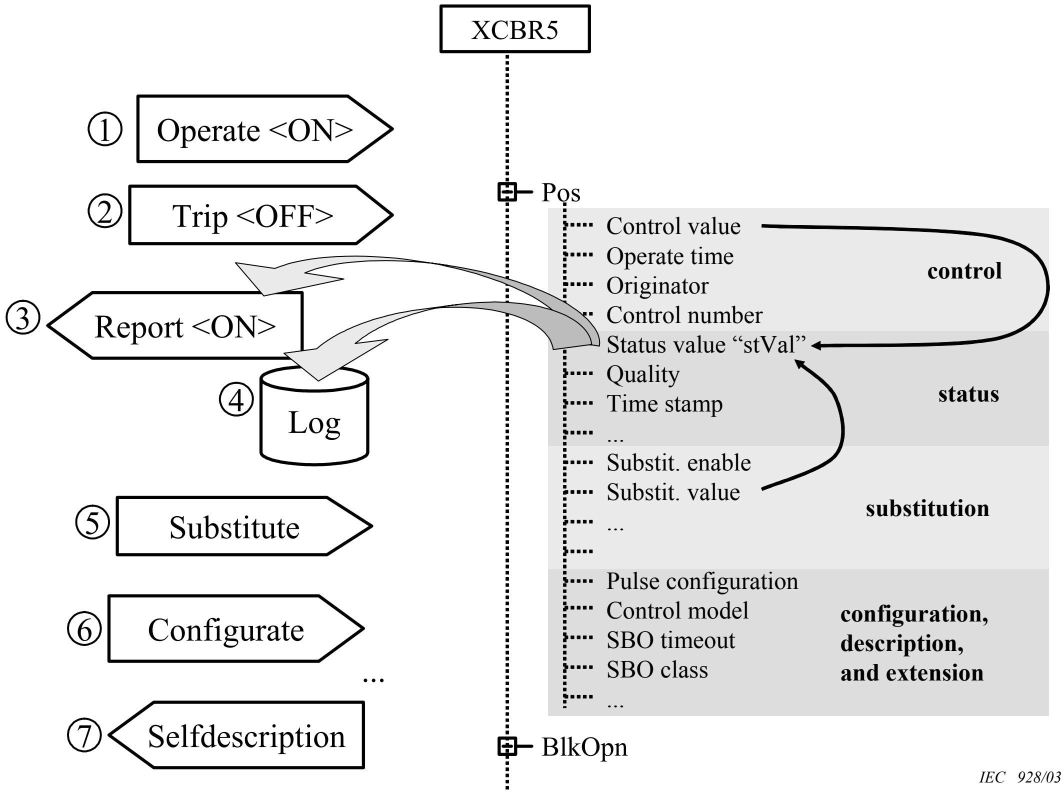


Figure 13 – Service excerpt

The information exchange for SCADA like applications supports various methods to access process data. The following methods are provided:

Retrieval method	Time-critical information exchange	Can loose changes (of sequence)	Multiple clients to receive information
Polling (GetDataValues)	NO	YES	YES
Unbuffered Reporting	YES	YES	NO
Buffered Reporting	YES	NO	NO
Log (used for SOE logging)	NO	NO	YES

The polling is the most common method. The use is restricted to applications that do not rely on sequence-of-events (SOE). Data values may be lost because the value may have been overwritten by the application between two GetDataValue requests.

The buffered and unbuffered reporting starts with the configuration of the report control blocks. The basic buffered reporting mechanism is shown in Figure 14. The reporting starts with setting the enable buffer attribute to TRUE; setting to FALSE stops the reporting.

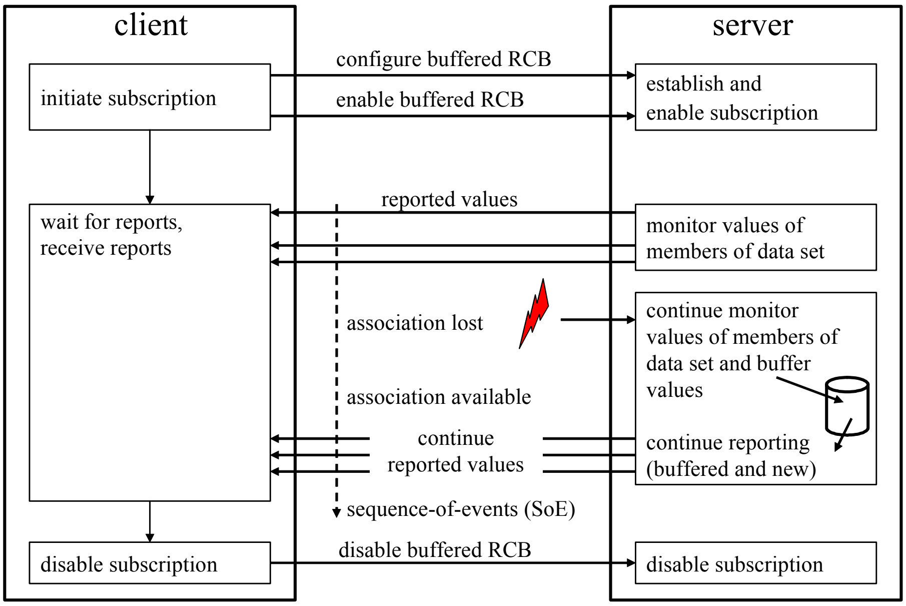


Figure 14 – Buffered reporting (conceptual)

The specific characteristic of the buffered report control block is that it continues buffering the event data as they occur according to the enabled trigger options in case of, for example, a communication loss. The reporting process continues as soon as the communication is available again. The buffered report control block guarantees the sequence-of-events (SoE) up to some practical limits (for example, buffer size and maximum interruption time).

Figure 15 shows an example of a log and three log control blocks. The first step is to configure and enable log control blocks. After enabling the association with that server may be closed. The log entries are stored into the log as they arrive for inclusion into the log. The logs are stored in time sequence order. This allows retrieval of a sequence-of-events (SoE) list.

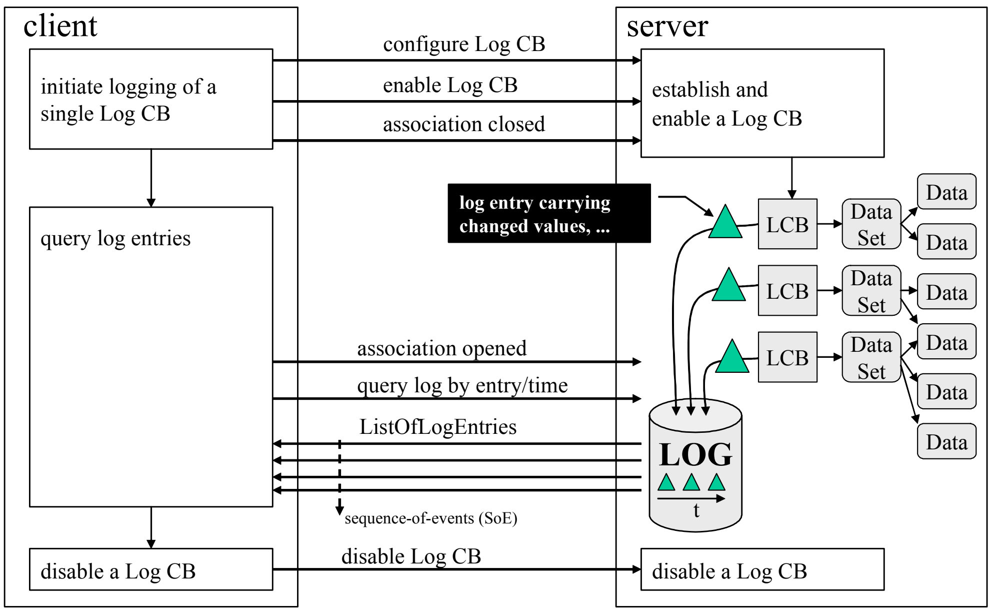


Figure 15 – Log control block (conceptual)

The different log control blocks allow storage of information from different data sets into a log instance. Each log control block is independent of the other control blocks.

The above listed information exchange methods (except GOOSE and SV) are mapped in IEC 61850-8-1 to MMS (Manufacturing Message Specification, ISO 9506).

Two models are dedicated to the transmission of information with high priority:

GOOSE (Generic Object Oriented System Event) is used to model the transmission of high priority information like trip commands or interlocking information. The model is based on cyclic and high-priority transmission of status information. Information like a trip command is transmitted spontaneously and then cyclically at increasing intervals. GOOSE uses a multicast exchange.

SV (Sampled Value) is used to model the exchange of the sampled measured values from current and voltage transducers to any IED that need the samples. The model is based on an unconfirmed transmission of a set of sampled values. A counter is added to time correlate samples from different sources and to detect the loss of a set of samples. SV may use a multicast or a unicast exchange.

The abstract GOOSE and SV service models are defined in IEC 61850-7-2. The mapping of the SMV model to a concrete communication system is specified in IEC 61850-9-1 and in IEC 61850-9-2.

IEC 61850-9-1 defines an unidirectional serial communication interface (Ethernet, ISO/IEC 8802-3) connecting current/voltage transducers with digital output to electrical metering and protection devices. The information to be exchanged is very restricted. It is compatible with the interface defined in IEC 60044-8.

IEC 61850-9-2 uses the full flexibility of the standard ISO/IEC 8802-3 and it supports the full flexibility to define and use any set of values to be transmitted in a single sample (analogue and binary values).

The sampled value exchange and the GOOSE exchange are very crucial for future substations. Almost all vendors of substation equipment have implemented these two or they are planning to implement them.

4.2 The concrete communication protocols used to exchange information

4.2.1 General and introduction

Information encoding

The information models and the abstract information exchange methods need to be mapped to concrete objects and protocols that can be implemented into IEDs. The mappings of the abstract messages fall into two categories:

– **binary encoded** messages (used mainly by IEC 61850-8-1)
– **ASCII encoded** messages (used for the OPC XML-DA and SOAP based web services in IEC 61400-25)

The length of binary encoded messages is optimized compared to messages using ASCII characters. ASCII based messages may be 10 or even 20 times longer than binary encoded messages.

The binary encoding of messages is used mainly in IEC 61850-8-1 which defines the mapping of the information model and the abstract information exchange methods to MMS and ASN.1 BER (Abstract syntax notation one's basic encoding rule). The naming hierarchy, e.g., the name "XCBR.ST.stVal" is communicated in MMS as ASCII string. The names of the model appear unchanged in the MMS messages – if the names are transmitted all.

Two other mappings (of simple signals) using binary encoding are defined: mapping of signals to IEC 60870-5-101 (and -104) and to DNP3 are defined in IEC 61400-25.

ASCII encoded messages are used for the mapping to OPC XML-DA and the SOAP based web services as defined in IEC 61400-25.

The summary of the mappings in IEC 61850 and IEC 61400-25 is shown in Figure 16.

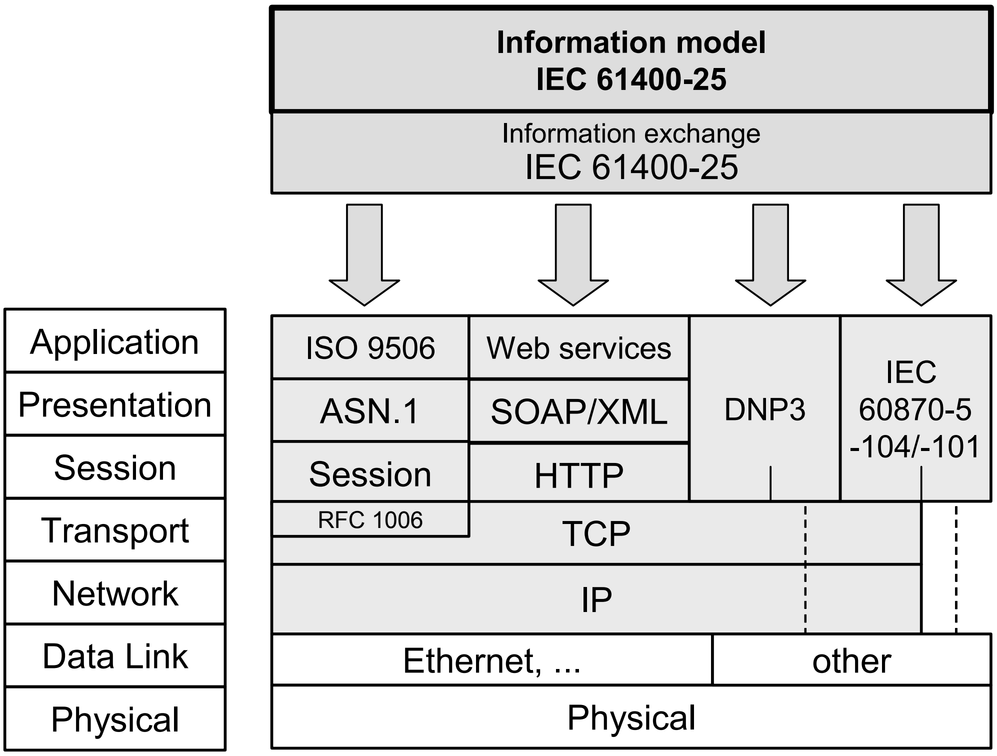


Figure 16 – Mappings and communication profiles

Security definitions for the various IEC protocol stacks (MMS, IEC 60870-5 and IEC 60870-6) will be published in new standards within IEC TC 57 WG 15 [27] - [31].

Implicit information encoding in messages

In addition to the encoding (binary versus ACSII) there is a second issue that has a crucial impact on the efficiency of the message exchange: How many attributes of the information model have to be communicated in each message? An efficient approach is to define some information in a message implicitly – i.e., this information needs not to be carried in a message at all. Some information can be omitted during the real-time exchange. The following example explains how information can be omitted in a message without loosing the semantic. A set of nine values of process information, e.g., all currents and voltages of a three-phase system, may have a well-defined order as follows:

Set	IEC 61850 names of members of the Data Set
Voltages	
PhaseA to PhaseB	MySubstation/MMXU5.PPV.phsAB.cVal
PhaseB to PhaseC	MySubstation/MMXU5.PPV.phsBC.cVal
PhaseC to PhaseA	MySubstation/MMXU5.PPV.phsCA.cVal
PhaseA to Ground	MySubstation/MMXU5.PhV.phsA.cVal
PhaseB to Ground	MySubstation/MMXU5.PhV.phsB.cVal
PhaseC to Ground	MySubstation/MMXU5.PhV.phsC.cVal
Currents	
PhaseA	MySubstation/MMXU5.A.phsA.cVal
PhaseB	MySubstation/MMXU5.A.phsB.cVal
PhaseC	MySubstation/MMXU5.A.phsC.cVal

The name of the Logical Device (a container defined in IEC 61850-7-2 that just comprises LNs) is "MySubstation". "MMXU5" is the fifth LN instance of the standardized measurement LN class "MMXU". The data attribute "cVal" is the vector value comprising the magnitude and angle values.

The length of all names of the data set members is 285 characters! To report a new value of one of the members would be very inefficient if the message carries each time these 285 characters. Two optimizations are applied in IEC 61850-8-1 (MMS mapping):

1. **The names are not transmitted at all**. The structure of the list is defined and implicitly known. Only the values are transmitted – in the order defined in the data set. The type of the value is defined as well: e.g., two floating point values for the magnitude and angle value. The structure of the data set can be retrieved online from the device (part of the self-description of the device).
2. In many cases it is sufficient to **transmit only the values of those members that have been updated since the last transmission**. The members for which a value is transmitted must be uniquely identified. A simple bitstring of the length 9 bits precedes the process values. For each member that provides a new value the corresponding bit in the bitstring is set to TRUE. This bitstring is defined in IEC 61850-8-1.

By the way, if a receiver knows how to interpret an empty message then communication with empty messages would be sufficient [37].

Polling versus spontaneous reporting

The polling and spontaneous reporting methods have a crucial impact on the efficiency and reaction time of communication devices. This is independent of the encoding rules.

A **polling schema** has advantages and drawbacks. It is a simple communication method where a master (or client) requests the slave (or server) to respond with the values of the specified information. The request may specify the information to be returned either by an explicit parameter (index or name) or implicitly (next value in the send queue – no random access of the information model possible).

The polling schema will congest the communication network if the polling rate is too high! High polling rates are required to reach short reaction times. If the polling rate is low then the data values may already be too old when the values are received.

The **spontaneous reporting** optimizes the bandwidth utilization. The reports are usually sent only when a value has changed (RBE – report by exception). In addition to the transmission on a change the reporting mechanism could autonomously send the values in long periods for integrity reasons. The device can send a report as soon as it has detected a change of the value. The spontaneous reporting is characterized by extremely short reaction times.

The spontaneous reporting mechanism may additionally provide the transmission of sequences of events (SoE). A buffer time allows "collecting" changes of a list of values and sending them at the end of the buffer time together in one message.

Discussion of efficiency of message transmissions

The question which method is the best and most efficient needs to take many aspects into account. First of all: The answer mainly depends on the required functionality! If it is not known what a standard conformant solution is going to solve, the answer may be: The cheapest solution is right. Crucial questions to take into consideration are:

1. What are the requirements?
2. What is the reaction time to receive a changed value?
3. What is the available bandwidth?
4. Is it required to configure (reconfigure) the dynamical behavior online (e.g., to set deadband values)?
5. Is a sequence of events required?
6. Is it required to store the sequence of events in a log of the IED for later retrieval?
7. Is random access to any data attribute of the information model required (i.e., selectively read a value)?
8. Is it required to retrieve self-descriptive information with each message or on request?

There is no single solution that fits all requirements! In any case if the requirements are very low a simple protocol should be selected. A simple protocol does not mean to have no or a simple information model. A simple service may be applied to a comprehensive information model.

The next clauses briefly discuss the different protocols and the relation between information models and information exchange methods.

4.2.2 Use of binary encoded messages

The most comprehensive set of mappings is defined in the current draft of IEC 61400-25 (first CD, 2003) as shown in Figure 16. Due to the market relevance of the five protocol stacks (IEC 61850-8-1, IEC 60870-5-101/104, OPC XML-DA / web services, and DNP3) the Project Team 25 of IEC TC 88 has agreed to incorporate all five for the time being.

The three mappings with binary encodings are:

Mapping to	Specification	Main characteristics
ISO 9506 (MMS)	IEC 61850-8-1	– maps all services to binary encoded messages (highly efficient encoding) – maps spontaneous reports (SoE) – maps logging (offline collection and later log query)
IEC 60870-5-101/104	IEC 61400-25	– maps process data value exchange (mainly signals) and provides file transfer of logs
DNP3	IEC 61400-25	– maps process data value exchange (signals)

The mapping of the data exchange model for retrieving the wind power plant information model of a device (self-description) is defined in the MMS mapping and in the web service mapping. In case a device supports the possibility to retrieve the wind power plant information model, one of these two mappings for retrieval of the self-description shall be supported by the device.

These three protocol stacks are available in many IEDs.

4.2.3 Use of ASCII encoded protocols

The use of SOAP and XML is currently backed by the market trend in the business and the automation applications. To follow this trend the following two mappings have been specified in IEC 61400-25:

Mapping to	Specification	Main characteristics
web services	IEC 61400-25 (based on OPC XML-DA)	– maps a subset of services (for the exchange of process data values) to ASCII encoded messages defined in OPC XML-DA
	IEC 61400-25 (enhanced web services)	– maps additional services to SOAP/ASCII encoded messages – maps spontaneous reports (SoE) – maps logging (offline collection and later log query)

The latest development in XML applications has been announced during the ISA 2003 Show in Houston Texas in October 2003:

News posted on the Control Engineering web:

"Houston, TX — October 22, 2003 – OPC Foundation underlines its intent to transition away from "component-based" architecture to a more unified architecture by using Web services and XML. … Moving away from component-based architectures will allow OPC to provide "a richer user experience through the use of vendor products that will now be totally interoperable with full Internet connectivity and unlimited scalability across platforms of the end-users choice. …"

5 Information models and information exchange implemented in real devices

All the standards introduced in this paper are useless unless they are implemented in real devices and unless these devices are used in electric power systems. Devices compliant to a non-trivial subset of IEC 61850 information models and services are expected to be available in 2004 and 2005.

These standards offer numerous possibilities at the level of information models, information exchange methods, and mappings to real communication protocols. The standards define the maximum possibilities.

One key issue is, which subset out of the standards are to be implemented, to be used? The answer is simply: It depends on the requirements. A precise requirements specification should be written prior to any selection of information models and services etc.

The standards provide specifications that allow scaleable products. Simple requirements can be met by simple subsets of the standards. The approach of scalability is conceptually explained in the following.

Figure 17 shows for one analogue data a very simple information model: The data attribute with the name "instMag" (Instantaneous magnitude value). The data type is Floating Point.

The semantic of the value (if it is a voltage or a speed) and other details are not shown for simplification reasons.

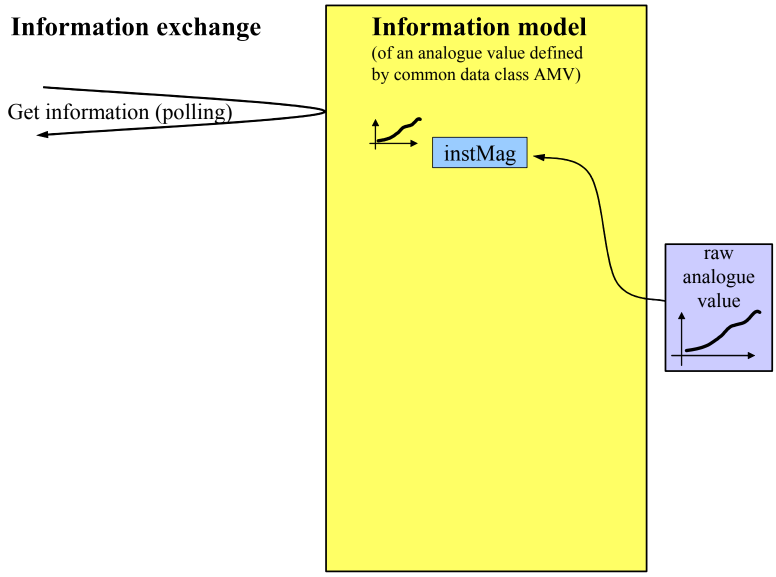
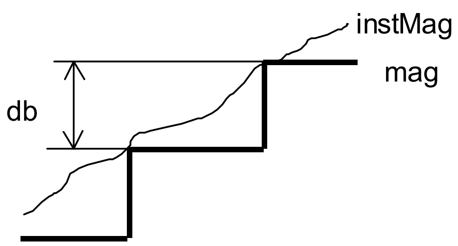


Figure 17 – Simple information model and simple service (conceptual)

The value of "instMag" can be polled with simple means. In case of the mapping to MMS it is a Read.request (instMag). Receivers according to IEC 60870-5-101/104 and DNP3 just receive the information by polling the device.

In the mapping to web services a GetDataValuesRequest will be sent via SOAP/HTTP to the device. The values are returned by the corresponding reply message.

The information model may be more comprehensive as shown in Figure 18. In addition to the simple attribute "instMag" there are many more attributes provided by the device. The data attribute "mag" defines the deadbanded value. This value is based on a dead band calculation from instMag as illustrated below. The value of mag is updated to the current value of instMag when the value has changed according the configuration parameter db (in percent of the difference between min and max values).



The figure above is an example. There may be other algorithms providing a comparable result; for example as an alternate solution, the deadband calculation may use the integral of the change of instMag. The algorithm used is a local issue. This value mag is typically used to create reports of analogue values (see Figure 19).

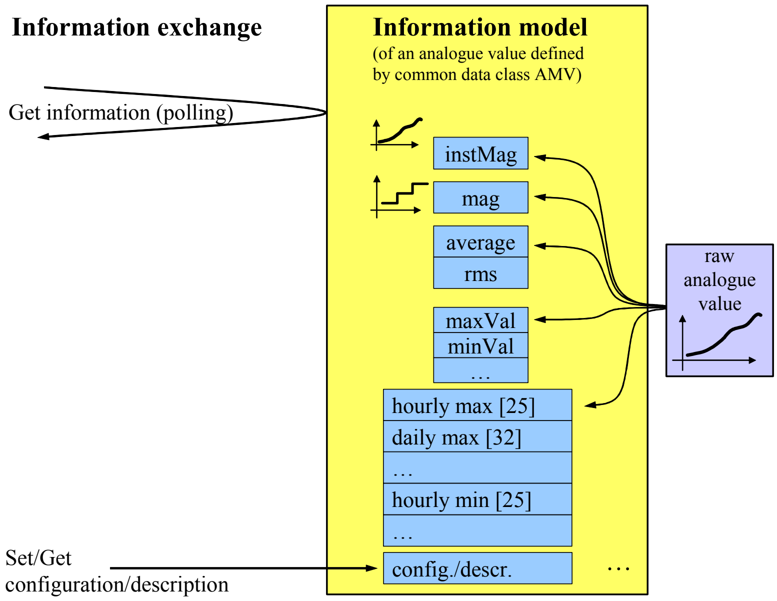


Figure 18 – More complex information model and simple service (conceptual)

The information model could be simple and the information exchange methods could be more advanced (see Figure 19). In addition to the simple polling schema the reporting of spontaneous changes and logging of sequences of events could be applied to simple process information.

The IED with these information exchange methods could provide a wide range of possibilities how and under which conditions to send information from the IED to one or more other devices, e.g., SCADA masters.

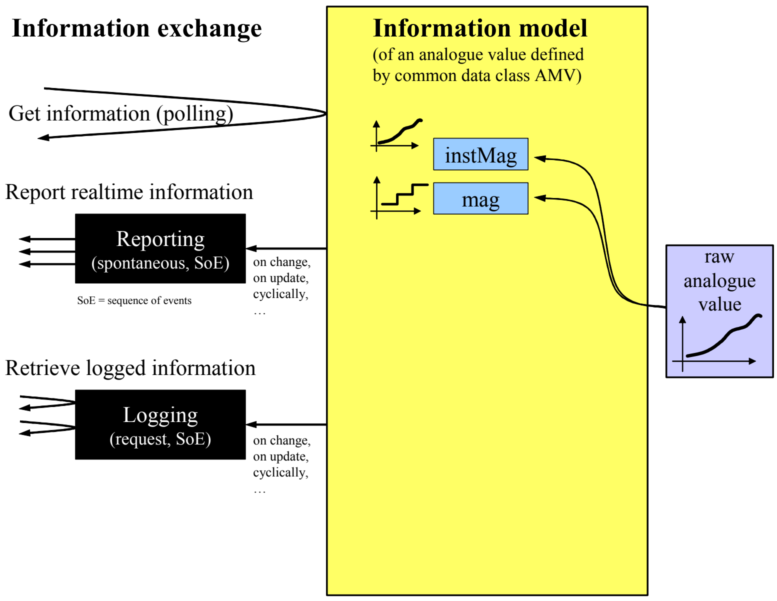


Figure 19 – Simple information model and complex services (conceptual)

Finally an IED may support most (or all) of the elements of the standardized information models in IEC 61850 or IEC 61400-25 and most (or all) of the information exchange methods as depicted in Figure 20.

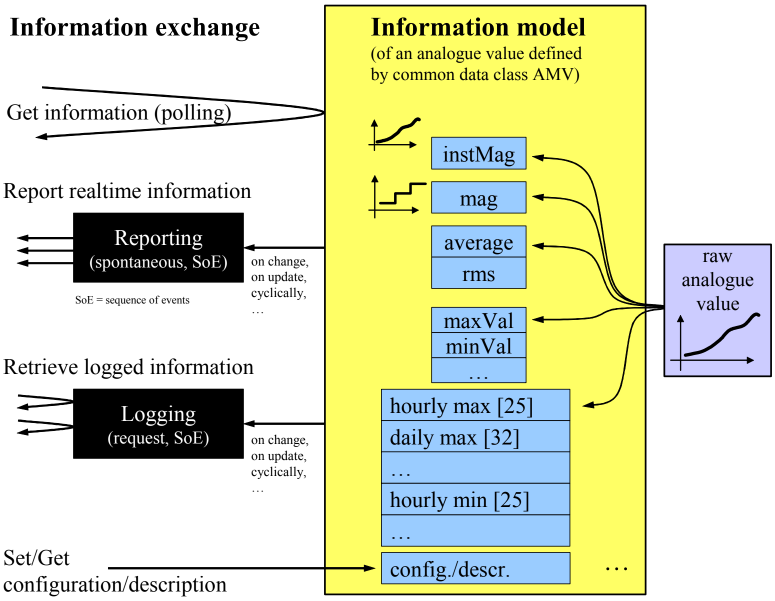


Figure 20 – Complex information model and complex services (conceptual)

To summarize the discussion above, real IEDs may provide a wide variety of standardized information models and standardized information exchange methods. Which one to select depends on the requirements to be met by the IED.

A question could be: Which standard should be selected if the device has to provide just a few standardized process data values to be communicated by a simple polling schema? A mapping solution based on IEC 60870-5-101 would probably meet the requirement.

The amount of the information to be exchanged and the required information exchange methods determine which solution meets best the requirements (see Figure 21).

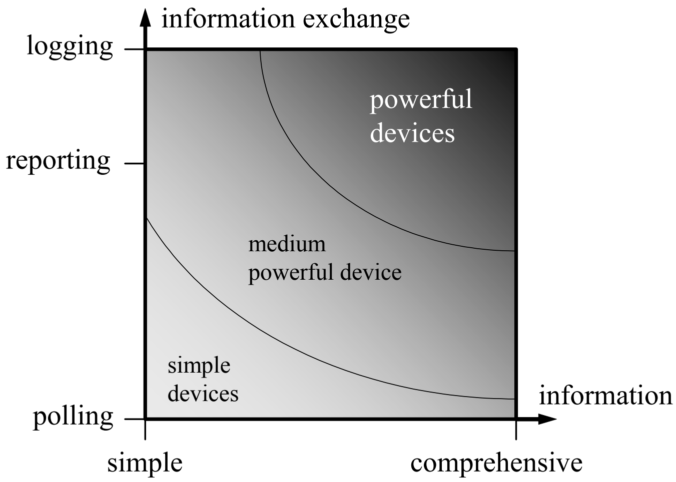


Figure 21 – Possible complexity of IEDs (conceptual)

The decision of using one or the other standardized solution depends also on the market in which the standardized solution is planned to be used. In a nation-wide installed process communication system according to IEC 60870-5-104 it is likely to use the mapping to IEC 60870-5-104 as per IEC 61400-25 Annex B for the communication of process values from a device with a standardized wind power plant information model.

6 Implementations and applications of compliant devices

There is a wide range of possibilities to implement the standards. Current products may provide almost all services defined in the standard. This could lead to products that do not meet the requirement to realize a very simple device. IEC 61850 conformant products are developed (are under development) by most vendors involved in the electric power system market. These products can be used to some degree also for wind power plant applications and other domains which have their specific information models. The basic IEC 61850 compliant software can be used because the software implementing the mapping to concrete protocols, the information exchange methods like reporting and logging, and the concrete information data base are totally independent of the information models. Any information model could be used to build the device's information data base.

A simple software architecture (based on a DLL – Dynamic Link Library) that can be used to get started with IEC 61850 compliant software is shown in Figure 22. The DLL approach (applicable for PCs) can be used for wind power plant and further applications as well. A successful pilot project at Vattenfall utility (Stockholm, Sweden, in 2002) is documented in two Elforsk reports [7] – [8].

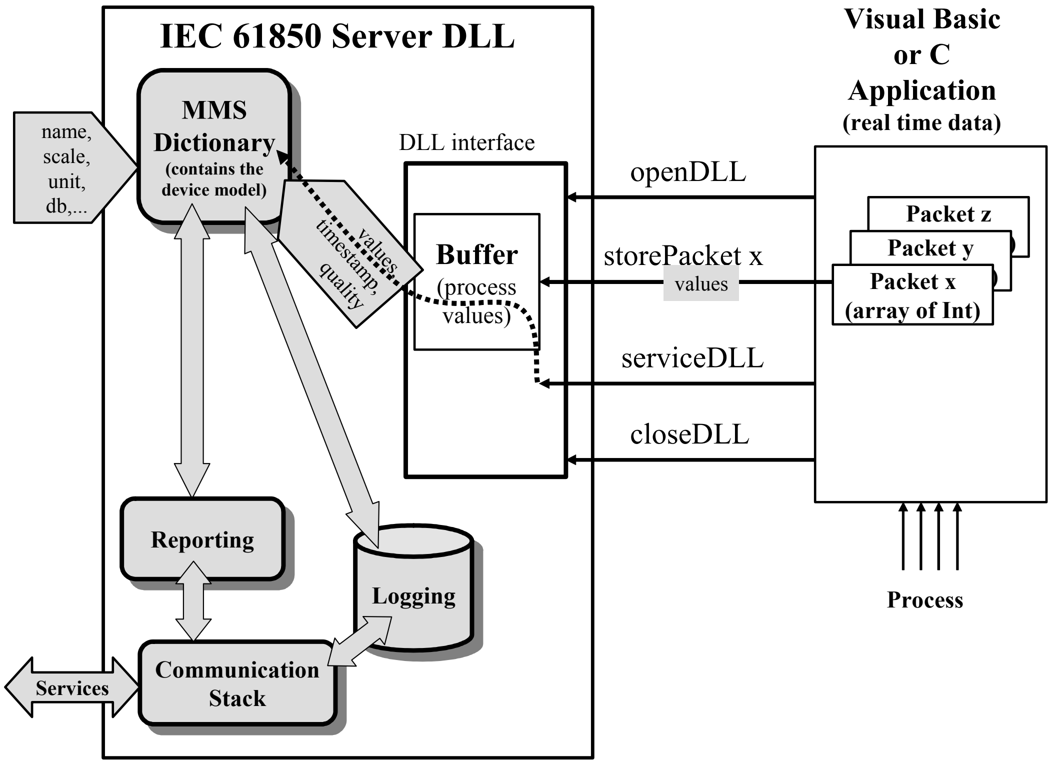


Figure 22 – IEC 61850 DLL software

The DLL approach is an easy way of integration of an IEC 61850 server into an existing software environment. The DLL makes use of the Winsock interface of a PC. The server DLL "serves" one or more clients for real-time information exchange implemented in the IEC 61850 server. This approach does not require any specific knowledge about the standard IEC 61850 because the information models and the information exchange is totally hidden in the DLL. The application just needs to provide the raw process values – the rest is run by the DLL.

The server provides additional software for the HTTP access (exchanging HTML and XML coded pages, SOAP messaging is also possible) providing values in a non-real-time manner.

The interface between the application and the server DLL is defined by four local calls: openDLL, storePacket x, serviceDLL, and coseDLL. The application controls the DLL. The first action is to open the DLL (openDLL). The process data values are stored in the server applying the "storePacketx" calls. When all data values are store, the application calls the "serviceDLL" call. This call starts the processing of the server DLL.

The information model is stored in the DLL. All services like reporting (including the monitoring process if the data value has changed more than specified by the configuration attribute "db" since the last report) and logging are autonomously processed inside the DLL. The application is freed from dealing with the information models, services, and communication stacks.

This DLL approach is the easiest way to get started with IEC 61850 (61400-25) compliant software. The interface between the communication software and the application may require another approach than a DLL. The DLL runs only when it is called by the application. As a consequence of this DLL-typical behavior, the server DLL processes incoming and outgoing messages as often as the application calls the server DLL.

Implementation of IEC 61850 compliant software in embedded systems requires a sound design of the architecture of an implementation. One crucial issue is the interface between existing applications and the communication related software.

The standards discussed in this paper are primarily written for electric power systems. The approach and common parts of the standards are applicable in other application domains as well (like gas and water supply systems).

New information models would be needed for gas and water utilities. The gas industry has already published a specific information model based on the UCA ™ version 2.0 [2]. This information model may be converted to the IEC 61850 modeling concepts of LNs, data objects, and common data classes.

The standards IEC 61850 and IEC 61400-25 are independent of the use case in which they may be used. The following topologies are possible. The standards do not demand one of these applications. It is up to the market to decide how and where the standard will be used.

Products providing the information models and information exchange methods could be installed close to the physical process or at any higher level (see Figure 23). The small boxes represent simple devices with simple information models and/or information exchange methods. S stands for IEC 61850 compliant server devices, C stands for IEC 61850 compliant client devices. Simple or comprehensive information models (information exchange methods) may be implemented in a electric power system – dependent on the specific requirements.

Aggregator (concentrator) devices depicted in the yellow box in the middle allow building hierarchies of client/server devices. Server devices may "serve" to a "higher server" or may directly be accessed by the control center client. The server devices that act as a aggregator (concentrator) may also be fed by non-standardized protocols (see dashed lines). From the top client level point of view it is important to be connected by IEC 61850 to the corresponding IEC 61850 server devices (solid lines).

The comprehensive concentrator server at the bottom of the figure may be a central device that represents the whole wind power park. This central device may talk to servers that represent a cluster of wind turbines or a central substation IED and so on. The direct connection of the control center client to a simple server device at the bottom can be used for a restricted direct access of setting attributes of the server. The control center may change the deadband value for reporting or may substitute measured process information because of a defect sensor. The operational information (e.g., status or other event notifications) flows from the process level over two hierarchical server devices before it reaches the control center. Each hierarchy level may reduce the number of notifications that go directly to the control center.

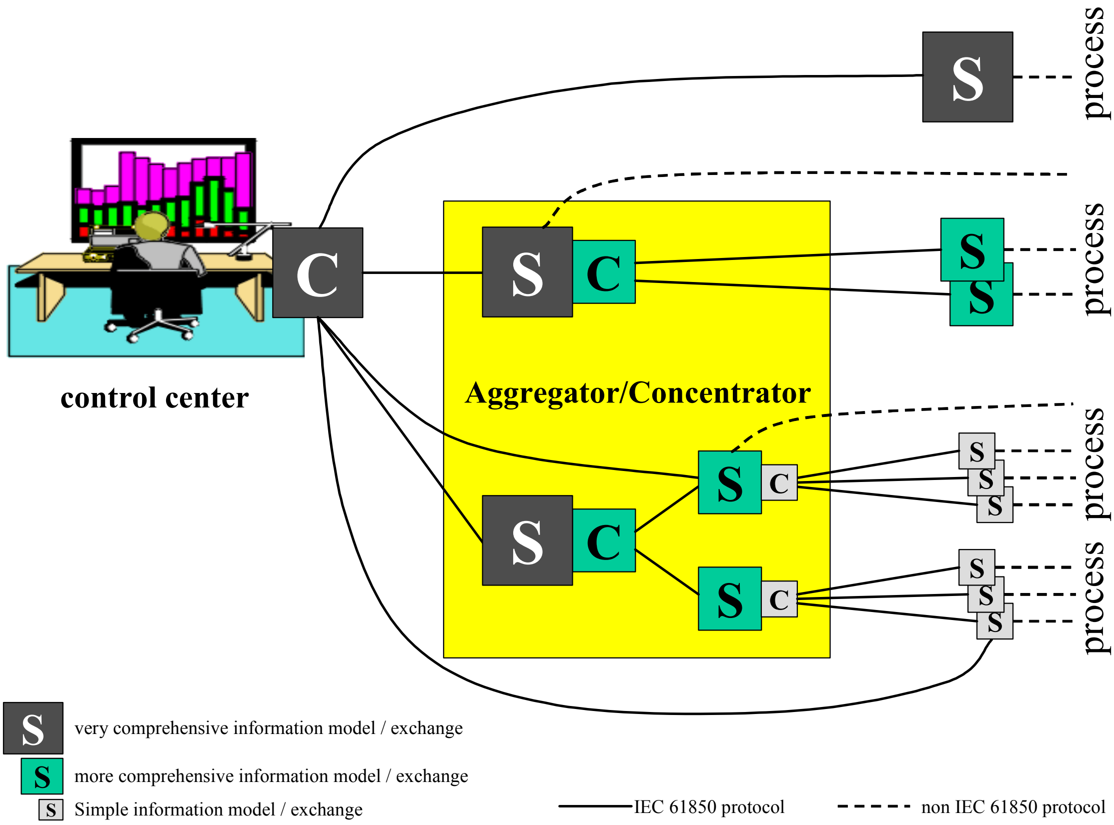


Figure 23 – Client/server use cases for SCADA applications (conceptual)

A utility, an operator, or owner may restrict the variety of possibilities to a few topologies. The best cost to benefit ratio depends on various requirements. These are outside the definitions of the standards and the discussion in this paper.

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"A young father proudly telegraphs to the parents of his wife: "Rebekka happy given birth son". This scarce but quite informative text is written in the typical telegram style. One certainly cannot reproach this text for language abundance. Nevertheless the father-in-law takes the sender of the telegram to task and bombards him with the following reproaches: "How can one be so reckless and throw his money down the drain for superfluous words in a telegram! Look for yourself: You write "Rebekka" – who else? Would you actually telegraph if a completely strange woman is going to have babies? And then "happy" – Since when does one telegraph if a birth does not go well? And now even "given birth" – what else? Were you afraid I might believe, the stork had brought the child? And finally "son" – with daughters the joy is never so great that one would run to the telegraph office. Therefore, we would have guessed this certainly!"

The teaching of this story is that the adequate knowledge of the context of an empty message (implicit information) suffices to convey a complete message to the receiver. However, our language generally lives on even superfluous statements or redundancies. These have the feature that they often help to recognize and to correct errors. This is valid also in the domain of communication between advanced automation systems.

If the communication between automation systems is predominantly defined by implicit suppositions, then it is frequently difficult for receivers (these can be applications like diagnostic tools) to recognize errors in the structure and in the contents.