IEC 61850 beyond Substations – The Standard for the whole Energy Supply System

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***Abstract*— This document gives an overview about the common aspects of the new international standard series IEC 61850 and how it is applied and extended to meet the requirements for almost the whole electrical energy supply chain. It discusses the reduction of total life cycle cost of power utility automation systems using standard compliant devices, communication and tools.**

I. Introduction

The standard series IEC 61850 "Communication networks and systems in substations" is the base standard for modeling of meaningful power system information, real-time and near real-time information exchange between intelligent electronic devices (IEDs), and the configuration of systems (e.g., substations, wind power parks), devices, and the communication networks for the whole electrical energy supply. The project "IEC 61850" of IEC TC 57 "Power systems management and associated information exchange " has been started in 1995. Just a few years later utility experts of non-substation related application domains began to realize the benefits of a single international standard for the engineering, automation and monitoring of the electric energy supply chain.

Major vendors and users of wind turbines decided in 2001 to apply the coming standard IEC 61850 and to extend it for wind turbines. The IEC TC 88 "Wind Turbines" started the project team 25 "Communications for monitoring and control of wind power plants" in 2001. Experts in several other application domains of the electrical energy supply chain followed in the footsteps of the TC 88 experts.

This paper first provides an overview about the common aspects of the globally accepted and used international standard IEC 61850 and how it is applied and extended to meet the requirements for almost the whole electrical energy supply chain including but not limited to the following application domains:

- IEC 61850 extensions for wind power plants including the new communication service mapping to web services (published in the series IEC 61400-25-x),
- IEC 61850 extensions for Power Quality Monitoring (edition 2 of IEC 61850-7-4)
- IEC 61850 common extensions for statistical and historical information (edition 2 of IEC 61850-7-4)
- IEC 61850 extensions for hydroelectric power plants (IEC 61850-7-410),
- IEC 61850 extensions for distributed energy resources (DER) (IEC 61850-7-420),
- IEC 61850 profile and extensions for high voltage switchgears (IEC 62271-3).

The IEC TC 57 has decided to publish all extensions of IEC 61850 under the single number "IEC 61850" with the following new and extended title: "Communication networks and systems for power utility automation" to reflect the harmonized efforts of having one single harmonized standard for the whole electrical energy supply chain.

Secondly, this contribution shows how the total life cycle cost can be reduced by using

- Tools for the design, engineering, configuration, testing, and diagnosis,
- Intelligent electronic devices for protection, control, monitoring and supervision, and the control and monitoring of primary equipment (circuit breaker, transformers, turbines, generators, etc.),
- Ethernet based Local Area Networks

Finally, the paper shows also how the various information models can be easily mapped to state-of-the-art communication protocols like MMS (ISO 9506 – Manufacturing Message Specification according to IEC 61850-8-1), web services, IEC 60870-5-101/104 and DNP3 (according to IEC 61400-25-4).

II. The basics of IEC 61850

A brief brush-up on the basics of IEC 61850 helps to understand which aspects of the automation and asset management systems are covered by IEC 61850 and by IEC 61400-25 respectively. All these aspects need (in one way or the other) be taken into account when we further discuss the benefit of SCL and tools.

IEC 61850 mainly provides solutions for:

- The information model (a circuit breaker model, protection models, measurement unit, nameplate information, condition information, wave forms, records, limit violations et cetera). Many hundred "signals" are already defined in these standards or draft standards (for substation automation, asset management and monitoring, wind power plants, hydro power plants and other domain).
- The communication services like Get, Set, Reporting events, Logging events, Control devices, exchanging GOOSE messages for real-time information, exchanging sampled CT and VT values, recording, transfer of COMTRADE (and other) files, retrieve

self description of the devices "content" and other services.

- The mapping of the information models and communication services to concrete communication protocols like MMS (Manufacturing Message Specification, ISO 9506).
- The communication networks (TCP/IP, Ethernet, switches, routers).
- The specification of the whole substation through IEC 61850-6 (SCL) comprising:
    - single line diagram,
    - binding of the information models to the single line diagram (lines, CTs, VTs, circuit breakers, …),
    - binding of the information model to the automation programs and primary equipment, and
    - engineering of all communication details: relations between IEDs and the message traffic

The SCL is the powerful language to describe the whole system. As such it can be used for many tasks not intended or foreseen in the very beginning of the standardization process of IEC 61850 in the late 90s. Even today many experts all over understand the information models and communication solution but have often (almost) no glue what it is all about the Substation Configuration Language (SCL). The name should be System Configuration Language – it can be used in any other application domain like in the wind power plant domain.

III. IEC 61850 Related Standards and Projects

The first 14 parts of the standard series have been published between 2003 and 2005. Several groups have requested extensions of the standards. Table I provides a list of currently published standards of the first edition, various extensions and documents under preparation for the second edition.

TR stands for Technical report, Ed1 for Edition 1, CD for Committee Draft, IS for International Standard, CDV for Committee Darft for Vote, FDIS for Final Committee Draft for Vote.

The working group 10 of IEC TC 57 is responsible one way or the other for these documents. The next meeting of WG 10 is scheduled for 17-21 November 2008 in Buenos Aires (Argentina).

TABLE I
Wind Turbine Specific Logical Nodes

Document	Title	Publication	Edition 2
1	Introduction and overview	TR Ed1:2003-04	CD 2008
2	Glossary	TS Ed1:2003-08	
3	General requirements	IS Ed1:2002-02	
4	System and project management	IS Ed1:2002-01	CD 2008
5	Communication requirements for functions and device models	IS Ed1:2003-07	CDV 2008
6	Configuration description language for communication in electrical substations related to IEDs	IS Ed1:2004-03	CDV 2008-02
7-1	Basic communication structure – Principles and models	IS Ed1:2003-07	CDV 2008-05
7-2	Basic communication structure – Abstract communication service interface (ACSI)	IS Ed1:2003-05	CDV 2008
7-3	Basic communication structure – Common data classes	IS Ed1:2003-05	CDV 2008
7-4	Basic communication structure – Compatible logical node classes and data classes	IS Ed1:2003-05	CDV 2008-05
7-410	Hydroelectric power plants - Communication for monitoring and control	IS Ed1:2007-08	CD 20xx
7-420	Communications systems for distributed energy resources (DER) - Logical nodes	FDIS Mid 2008	CD 20xx
7-500	Use of logical nodes to model functions of a substation automation system	Draft 2008	
7-510	Use of logical nodes to model functions of a hydro power plant	Draft 2008	
7-520	Use of logical nodes to model functions of distributed energy resources	Draft 2008	
8-1	Specific communication service mapping (SCSM) – Mappings to MMS (ISO/IEC 9506-1 and ISO/IEC 9506-2) and to ISO/IEC 8802-3	IS Ed1:2004-05	CDV 2008
9-1	Specific communication service mapping (SCSM) – Sampled values over serial unidirectional multidrop point to point link	IS Ed1:2003-05	
9-2	Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3	IS Ed1:2004-04	CDV 2008
10	Conformance testing	IS Ed1:2005-05	CD 2008
80-1	Guideline to exchange information from a CDC based data model using IEC 60870-5-101/104	TS Ed1:2008-??	
90-1	Using IEC 61850 for the communication between substations	Draft 2008	
90-2	Using IEC 61850 for the communication between substations and control centres	Draft 2008	
		current work in 2008	current work in 2008
updated 2008-05-13			

IV. IEC 61400-25 EXTENDS IEC 61850 FOR WIND POWER

A. Introduction

The application of the international standard series IEC 61850 (Communication networks and systems in substations) is growing rapidly in many projects all over. Historically the focus of IEC 61850 was on the communication between automation IEDs and with equipment in an electrical substation. The experts have believed from the very beginning that all basic definitions could be used in many other application domains in- and outside the electrical power delivery system. Various groups have already defined how the standard IEC 61850 can be used in other domains within the electric power system. The wind power plant industry has published four standards (IEC 61400-25 "Communications for monitoring and control of wind power plants") that describe the use and extensions of IEC 61850 for wind power plant applications.

IEC 61400-25 has been defined by the IEC Technical Committee 88 (Wind Turbines). The first four parts have been published in January 2007. IEC 61400-25 provides uniform information (e.g., rotor speed) and information exchange for monitoring and control as well as condition monitoring of wind power plants.

The standard helps to eliminate the many proprietary communication systems in wind power applications which utilizes a wide variety of protocols today. The definition of information and the exchange of this information with different wind power plants in-dependent of vendors is a crucial issue. It enables components from different vendors to easily communicate with other components, at any location and at any time. Object-oriented data structures make the engineering and handling of huge amounts of information provided by wind power plants less time-consuming, more efficient and less error-prone. The IEC 61400-25 standard is crucial for simplifying the roles that the wind turbine and SCADA systems have to play.

The standard series IEC 61400-25 builds a basis to which procurement specifications and con-tracts could easily refer to. Several wind turbine manufacturer and other third-party turbine controller manufacturers are implementing IEC 61400-25. Compliant products are already available. Due to the use of IEC 61850 for IEC 61400-25 it is possible to use IEC 61850 compliant implementations of SCADA systems and many standard compliant tools like engineering and configuration tools and network analyzers.

B. The Objectives of the Standard

Open standards for wind power monitoring and control, including enhanced condition monitoring, is becoming increasingly important to improve the optimized operation of wind power plants. Easy access to information with clear definitions, together with common open communication solutions are some of the key factors when integrating information and control systems for several wind turbines. The main purpose of the standard is to replace the vendor-specific solutions with a common solution that makes it possible to easily integrate equipment from different suppliers.

The main add-ons that are defined in part IEC 61400-25-2 are the many wind power plant specific names (Borkum-West_6/WROT.RotSpd.instMag.f – the current value communicated as FloatingPoint of the rotor speed of the wind turbine number 6 in Borkum-West, with WROT, RotSpd, instMag, and f as standardized names). Figure 1 shows various information models for wind power plants (names of the wind specific models start with "W").

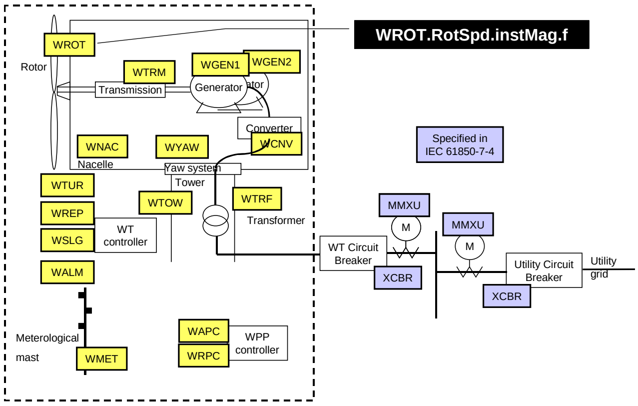

Fig. 1 Use of information models in a wind power plant with grid connection

A majority of the international key players on the wind power market, such as Vestas, Siemens (former Bonus), GE Wind, and others are represented in the IEC standardization group that has developed the standard. In addition to the main manufacturers the group also consists of representatives from power companies in Sweden, Norway, Denmark and Australia, plus several consultants and system integrators and software manufacturer from UK, Portugal, Spain, the Netherlands and USA. The project leader is from Vattenfall Sweden.

C. The Parts of IEC 61400-25

IEC 61400-25 defines all details required to connect wind power plant components in a multi-vendor environment and to exchange the information. This is done by definitions provided in the various parts of the series IEC 61400-25 or by reference to other commonly used standards, such as IEC 61850. IEC 61400-25 consists of six parts.
Four parts published as International Standards by July 2008:

Part 25-1: Overall description of principles and models: The first part offers an introductory orientation, an overview of crucial requirements and basic principles, and a modeling guide.

Part 25-2: Information models. The wind power plant specific name tagged information describes the crucial and common process data, meta-data (data about data, e. g. scale factor or engineering unit), and configuration data of a wind power plant. 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, time-stamp, and quality) or more comprehensive (adding more meta-data, for example engineering unit, scale, description, short hand reference, statistical and historical information of the process value). The information models are based on IEC 61850-7-3 and IEC 61850-7-4.

Part 25-3: Information exchange models. All process and meta-data can be exchanged by corresponding services. Access to the meta-data (including configuration information with regard to the wind power plant information model and services and communication stacks) provides the so-called self-description of a device. This part is based on IEC 61850-7-2

Part 25-5: Conformance testing. This part of IEC 61400-25 specifies standard techniques for testing of implementation conformance, as well as specific measurement techniques to be applied when declaring performance parameters. The part 5 uses mainly the content IEC 61850-10.

Two parts published as Draft International Standards by July 2008:

Part 25-4: Mapping of information models and information exchange services to communication profiles:

- Web services,
- MMS (mapping to Manufacturing Message Specification, ISO 9506, according to IEC 61850-8-1),
- OPC XML DA,
- IEC 60870-5-101/104, and
- DNP3.

Part 25-6: Logical Node classes and Data classes for Condition Monitoring. This part defines information models for use in condition monitoring systems for vibration and many other measurements.

Planned new work:

The configuration language (IEC 61850-6) needs some extensions to be fully applicable for wind power plant applications. A new work item proposal is expected by end of 2008.

D. The Information Model of IEC 61400-25

Wind power plant information is classified in wind power plant specific logical nodes (logical nodes are container for Data objects). In principle, classification of wind power plant information in different logical nodes is an arbitrary process and the modeling method offers flexibility. From the viewpoint of standardization it is preferable that all wind power plant information will be build unambiguously and in a similar way. Table II shows the wind power plant information break down into logical nodes

TABLE II
WIND POWER PLANT SPECIFIC LOGICAL NODES

LN classes	Description
WTUR	Wind turbine general information
WALM	Wind power plant alarm information
WMET	Wind power plant meteorological information
WAPC	Wind power plant active power control information
WRPC	Wind power plant reactive power control information

Table 2 shows specific information break down into logical nodes of a single wind turbine.

TABLE III
WIND TURBINE SPECIFIC LOGICAL NODES

LN classes	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
WTRF	Wind turbine transformer information
WNAC	Wind turbine nacelle information
WYAW	Wind turbine yawing information
WTOW	Wind turbine tower information
WALM	Wind power plant alarm information
WSLG	Wind turbine state log information
WALG	Wind turbine analogue log information
WREP	Wind turbine report information

Information is mainly modeled by a set of LN classes, which are classified by the de-composition of real turbines.

Separate logical nodes are defined for logged events (status, alarm, command, event-counter, state-timer) and logged analogue time series (long period, demands, transient recording), model historical logged information.

Besides common information for all turbines (manufacturer independent), most information will, in practice, be determined by the turbine concept, the manufacturer, the site and the state of the art of turbine technology. For this reason, as a modeling guideline, the data class attribute names representing the specific information in the wind power plant specific logical nodes are focused on the most prevailing modern wind turbine concept, namely 3-bladed, variable speed, active pitch (electric/hydraulic) and gearbox transmission. In case of additional information originated by other wind turbine systems or components, new data classes or specialized data classes to existing Logical Nodes could easily be defined. Additional user-specific Logical Nodes could also be defined. IEC 61850 has defined precise rules for extending information models (name space extension rules according to IEC 61850-7-1).

The logical node for general turbine information comprises the data that represent the wind turbine general information as listed in Table IV. This logical node is mandatory, which means that at least all mandatory defined data classes shall be available for compliance with this standard.

TABLE IV
WIND TURBINE GENERAL INFORMATION LOGICAL NODE

Data object	Description
Common information	
AvlTmRs	Turbine availability time (vendor-specific)
OpTmRs	Operation time (vendor-specific)
StrCnt	Number of turbine starts (vendor-specific)
StopCnt	Number of turbine stops (vendor-specific)
TotWh	Total (net) active energy production

TotVArh	Total (net) reactive energy production
DmdWh	Active (real) energy demand (default demand direction: energy flow from a substation busbar away and towards the wind turbine)
DmdVArh	Reactive energy demand (default demand direction: energy flow from a substation busbar away and towards the wind turbine)
SupWh	Active (real) energy supply (default supply direction: energy flow from the wind turbine and towards a substation busbar)
SupVArh	Reactive energy supply (default supply direction: energy flow from the wind turbine and towards a substation busbar)
Status information	
TurSt	Turbine status
Analogue information	
W	Active power generation
VAr	Reactive power generation
Control information	
SetTurOp	Wind turbine operation command
VArOvW	Windturbine reactive priority over active command
VArRefPri	Windturbine reactive setpoint priority command
DmdW	Turbine active power generation setpoint
DmdVAr	Turbine reactive power generation setpoint
DmdPF	Turbine power factor setpoint

V. EXTENSIONS FOR POWER QUALITY MONITORING

Several new Logical Nodes have been incorporated into the second edition of Part IEC 61850-7-4 (CDV published in 2008-05).

The Logical Nodes for power quality are defined in the Group with the first letter “Q”. The following Logical Nodes are defined:

- Frequency Variation (QFVR)
- Current Transient (QITR)
- Current Unbalance Variation (QIUB)
- Voltage Transient (QVTR)
- Voltage Unbalance Variation (QVUB)
- Voltage Variation (QVVR)

These Logical Nodes are defined for the modeling of power quality events detection and analysis functions. The modeling is similar to the models of protection Logical Nodes.

One example Logical Node of this group is shown in this paper (see Table V):

TABLE V
FREQUENCY VARIATION LOGICAL NODE

Data object	**Description**
Status information	
Str	Start (Frequency Variation Event in progress)
UnHzStr	Start (Underfrequency Variation Event in progress)
OvHzStr	Start (Overfrequency Variation Event in progress)
Op	Operate (Event finished but not Reset)
Measured values	
HzVaTmms	Frequency Variation Duration of the last completed event
HzVa	Frequency Variation Magnitude of the last completed event
EvtCnt	Event counter histogram
Settings	
UnHzStrVal	Underfrequency Set Point
OvHzStrVal	Overfrequency Set Point

The details of the functions of these Logical Nodes will be described in the second edition of part IEC 61850-5.

VI. IEC 61850 COMMON EXTENSIONS FOR STATISTICAL AND HISTORICAL INFORMATION

The second edition of part IEC 61850-7-4 contains also the models for statistical and historical statistical data objects.

In many application domains such as wind power plants, it is required to provide additional information of an RMS analogue value:

- Statistical information (for example, minimum value calculated for a specified time period, for example, minimum value of last hour, day, week, …)
- Historical statistical information (for example, log of minimum values of the sequence of values calculated above, for example, maximum values of the last 24 hourly values)

This additional information may be derived from the basic analogue values. It may be the only information provided – depending on the application requirements.

The historical values make use of the log model implemented in the IEC 61400-25 server – this could be located in the turbine controller or in proxy or gateway device. A client can easily retrieve the logged values by time: between time1 and time2, before time3, or after time4.

The data values to be logged are specified by a DataSet. A DataSet may refer one, several or many Data Objects. Log Control Blocks refer to one DataSet. The historical data can easily be grouped so that – depending on the arrival rate of the values to be logged – for example a log can represent the monthly and yearly values, another may contain 15-minute values. The log for 15-minute values would not overwrite the logged yearly values. If the log for 15-minute values requires to store values for one week only, then the monthly values would not be overwritten. This allows an optimized use of memory.

VII. IEC 61850 EXTENSIONS FOR HYDROELECTRIC POWER PLANTS

The standard for the hydro power plant extensions are published in IEC 61850-7-410 (Hydroelectric power plants – Communication for monitoring and control). The standard is intended to be used for the control and supervision of a hydro power plant.

Within this standard, object models for the following applications are defined:

- Electrical functions. This includes logical nodes used for various control functions, essentially related to the excitation of the generator. New logical nodes defined within this group are not specific to hydropower plants; they are more or less general for all types of larger power plants.
- Mechanical functions. This includes logical nodes related to the turbine and associated equipment. The specifications of this document are intended for hydropower plants, modifications might be required for application to other types of generating plants. Some more generic functions are though defined under Logical Node group K.
- Hydrological functions. This includes logical nodes related to water flow, control and management of reservoirs and dams. Although specific for hydropower plants, the logical nodes defined here can also be used for other types of utility water management systems; see Table VI.
- Sensors. A power plant will need sensors providing measurements of other than electrical data. With a few exceptions, such sensors are of general nature and not specific for hydropower plants.

TABLE VI
HYDROPOWER SPECIFIC LOGICAL NODES

HBRG	Turbine - generator shaft bearing
HBRK	Braking system for the generator shaft
HCOM	Combinator (3D-CAM or 2D-CAM)
HDAM	Hydropower dam, water reservoir
HDLS	Dam leakage supervision
HGPI	Gate position indicator
HGTE	Dam gate
HITG	Intake gate
HJCL	Power plant joint control function
HLKG	Leakage supervision
HLVL	Dam water level indicator
HNDL	Needle control
HNHD	Net head data
HOTP	Dam overtopping protection
HSEQ	Start / stop sequencer
HSPD	Speed monitoring
HUNT	Hydropower production unit
HWCL	Water control function

The hydro power extensions are intended for the whole control and supervision of a hydro power plant. First projects using the new possibilities are under way.

It is quite important to understand that all services defined in IEC 61850-7-2 and mapped to MMS in IEC61850-8-1 can be used for these control and monitoring functions.

VIII. IEC 61850 EXTENSIONS FOR DISTRIBUTED ENERGY RESOURCES (DER)

TC57 WG 17 is preparing the standard IEC 61850-7-420 – Communication systems for distributed energy resources (DER) – DER logical nodes. The standard is to be used for information exchange between DER devices and any systems which monitor, control, maintain, audit, and generally operate the DER devices.

The working group is preparing a standard, which defines models for the following technologies:

- reciprocating engines ("piston engines")
- fuel cells
- photovoltaic systems
- combined heat and power devices

The FDIS will be published in fall 2008 for the final ballot. Further work is under preparation to use and (if needed) to extend the standard for the new domain of Smart Grid Vehicles (see http://www.smartgridvehicle.org/).

IX. IEC 61850 PROFILE AND EXTENSIONS FOR HIGH VOLTAGE SWITCHGEARS

The product standard IEC 62271-3 “High-voltage switch gear and control gear – Part 3: Digital interfaces based on IEC 61850” defines extensions for switch gears. It defines how to use IEC 61850 for intelligent switch gears and it extends the nameplate information for the switch gear.

Typically, IEDs like bay level controllers interface to switch gear. In that case, the data models of the switch gear are implemented in these devices. However, this is not the only realization. In the case where electronics are integrated directly into switch gear, the above-mentioned data models should be implemented within the switchgear and the switch gear needs to support a communication interface.

IEC 61850, being a horizontal standard series, leaves many options open in order to support present and future requirements of all sizes of substations at all voltage levels.

This International Standard is applicable to high-voltage switch gear and control gear (scope of IEC SC 17A) and assemblies thereof (scope of IEC SC 17C) and specifies equipment for digital communication with other parts of the substation and its impact on testing. This equipment for digital communication, replacing conventional wiring, can be integrated into the high-voltage switch gear, control gear, and assemblies thereof, or can be an external equipment in order to provide compliance for existing switch gear and control gear and assemblies thereof with the standards of the IEC 61850 series.

This International Standard is a product standard defining the use of the IEC 61850 series. It deals with all relevant aspects of switch gear and control gear, and assemblies thereof with a serial communication interface according to the IEC 61850 series. In particular it defines:

- A selection of the information models from the IEC 61850 series to be used for switch gear and control gear.

- Conformance classes for the set of communication services to be supported by the switch gear and control gear.
- Type and routine tests of switch gear and control gear that are required for the communication interface according to IEC 61850 (E.g., the use of GOOSE).
- An extension of the IEC 61850 series' object model for switch gear monitoring and name plate.

These standard will be integrated in future intelligent switch gears. Today almost all switch gears do not have any intelligence in the switch gear. It will take some years before intelligent controllers will be placed in the switchyard. These controllers will in a few years likely provide more information than we have today provided by wires.

Many experts understand that the use of more intelligent controllers in the switchyard and the merging units for current and voltage samples are accompanied by the use of the IEC 61850 "Process Bus". IEC 61850 does not define a specific "Process Bus". The use of Ethernet, GOOSE and Sampled Values is one use case for the interface to the switchyard. The intelligent controllers of switch gears may also comprise a more comprehensive model of an IEC 61850 server providing information models and services like reporting, logging, and self-description.

X. The Marshalling of Process Signals

The many copper wires used to connect the many sensors and actuators of the switchyard with intelligent devices in the control room (protection relays, control and monitor devices) may be replaced by a remote-I/O system. This remote-I/O system may be a simple IED that serves to expose the current and voltage samples (merging unit) and any binary signal provided by sensors (contacts) of the switchyard through an IEC 61850 network. The GOOSE messages may be used to send any control signal from the control room to the switchyard.

This approach lowers the costs for wires, terminals, and mainly labor costs. This approach replaces just wires. More intelligent functions will migrate to the switchyard, e.g., monitoring functions, self description of configuration parameter, name plate, point-on-wave switching (which requires also sampled value subscriber), et cetera.

The philosophy of IEC 61850 is that more and more intelligence will be implemented in the switchyard in the long term – and not only to replace wires. Replacing wires is a first step towards the future more intelligent IEDs in the switchyard.

The higher the cost of copper and labor the more likely it will be to use IEC 61850 in the sense of a remote-I/O communication system.

This is what is used in the industrial or factory automation to get rid of the many copper wires: Fieldbus. It is still a success-story in this domain. With the event of the use of Ethernet in the factory automation this remote-I/O approach is still an important (or the most important) use case of fieldbusses. The difference between this approach in the factory world and the world of IEC 61850 in the power system automation domain is here: IEC 61850 defines one standard solution (GOOSE and Sampled Values) using standard Ethernet; IEC 61158 (the international fieldbus standard as per July 2008) comprises some 20 traditional fieldbus solutions and some additional 20 Ethernet-based solution. The new standard has 66 (sixty six) parts.

XI. Tools

With the event of digital communication and microprocessor based devices for the control and supervision of the electrical power delivery system, significant progress regarding the automation of the power system was achieved. Soon, the vision for integrated communication architecture was created. When EPRI (Electric Power Research Institute; Palo Alto USA) introduced the Utility Communication Architecture (UCA) in the early nineties, this was based on the vision of an integrated utility communications highway.

The vision of a global communication infrastructure with integrated applications has several elements that will result in benefits for users, vendors, and system integrators of the utility automation system.

Information integration reduces costs and provides greater flexibility. The vision includes the "single entry of data" where configuration information required by multiple functions in the utility automation system shall only be entered once. An automatic transfer of the standardized configuration information between the different tools and applications is now available. This not only reduces the costs related to the engineering process, it reduces as well the risk of inconsistent configurations. A typical use case for a "single entry of data" is the extension of the power network. If a new power line is built, the information from the network planning tool can be used to update the network control centre application and for the engineering of the extension of the substations at the two ends of the line.

Seamless sharing of information between IEDs and between tools is now possible. For instance, process data could be available for all applications in the utility automation system in real time ac-cording the requirements of the application and without unnecessary data conversion. As an example, the information from a circuit breaker may be required within the substation for local operation, in different network control centres and in the control system of a power plant that is connected to that feeder.

In a modern electrical power system, at least two infrastructures need to be managed. These infrastructures are the power networks and the communication and automation infrastructure. A global access to intelligent electronic devices (IED) will facilitate the management of the entire infrastructure. As an example, it is possible to access all devices from a single point in the automation network. In addition, nameplate information and information about the device status is made available for IEDs as well as for primary process equipment. This has facilitated the application of IEC 61850 for asset management applications. Self description of process data, parameter settings, and diagnostic information can be retrieved and presented to the user by generic off the shelf tools that "talk" IEC 61850 protocols.

The Substation Configuration Language (SCL, defined in IEC 61850-6), is an XML schema based document format that can be used to exchange useful information between design, engineering, and configuration tools. Based on a system specification and the device capability description files the system configuration tool is used for the configuration of the substation. The result is the substation configuration description file that is then used for the IED configuration tools to create the configuration to be download to the individual IEDs.

With the configuration information available in a standardized file format, it is possible to use that information as well for many applications inside and outside the substation automation system.

The crucial focus of IEC 61850 is the provision of interoperability. Interoperability in IEC 61850 is defined for the communication between engineering and configuration tool and with and between intelligent electronic devices (IEDs). Interoperability means the ability of two or more tools or IEDs from the same or multiple vendors, to exchange information and use that information for correct configuration by tools or execution of specified functions in an IED.

The fist step of interoperability requires that all interconnected engineering tools understand the XML schema of part IEC 61850-6 (SCL, substation configuration language), generate and ex-change compliant SCL files. In the second step the SCL files (providing the crucial input for the configuration of systems and IEDs) must be interpreted according to the XML schema. The definitions selected from the standard, e.g., details on data models, services, stacks, and networks et cetera guarantee that the configured IEDs interoperate according to the standard.

Tools for various tasks support the engineers in reaching a high level of interoperability and doing their job safer, more reliable, faster, and cheaper than before. These tools and the experts using these tools are being said to slash expenses of building substation automation and asset management systems. First experiences show that this is true. An essential question is still to be answered. Who will benefit most from the reduction of costs: utilities, system integrators, or vendors? There is a simple answer: The system integrator with a comprehensive set of smart tools and skilled experts (peopleware) will really benefit from the application of the standard.

The role of system integration can be played by the utility, third party system integrator or by the system and device vendor. Whoever wants to reduce his costs has to focus on the system integration – supported by the right tools. Utilities that do not care about the system integration may end up in a quite serious dependency on the third parties or vendor playing the role of system integration with the help of powerful tools. Who has the tools has the power.

The development and especially the application of tools for various tasks and the new relations between utilities, system integrators and vendors seem to be the pivotal point.

SCL is a crucial key element in the lifetime of future substation automation and asset management systems and other application domains. There are many tasks for which IEC 61850-6 provides the right (configuration) information to simplify mainly the following tasks (the table shows also a rough classification of the developer of the tools (IED or system vendor (V), third party or system integrator (TP), utility (U)):

Table VII shows a set of usages of part IEC 61850-6. The blue sky seems to be the limit of the use cases of SCL.

Almost all tools listed above can be developed by all three parties. There is one exception: the IEC configuration tool has to be provided by the vendor of the IEDs. To some extend it is possible to create the IED's data dictionary by importing the corresponding IED section of an SCD file. IED 61850 server software is available to build the dictionary and some simulation of process variables directly from the SCD file.

The IEC working group for IEC 61850 (TC 57 WG 10) discusses an additional level of formal specification: The domain of logic (function) modeling, e.g., modeling an AND or OR function. The discussion was about the use of additional logical nodes or the use of either IEC 61131-3 (PLC programming) and IEC 61499 (Function blocks). Utilities would like to export and import logic function specifications independent of the IED vendor. And they would like to link the function specification with the SCL specification.

Vendors of IED programming tools have already converted logical nodes (e.g., CILO, XCBR, CSWI, …) to their function block library of the programming tool. These function blocks can directly be used in the specification of the function logic, e.g., for inter-logging control.

Today (end of 2006) there are first tools available for various tasks in the whole chain of engineering and for the whole life cycle. Availability of tools does not automatically mean that it is easy to use the tools nor that the tools can be used by everybody. Tools are usually developed and owned by companies or individuals – for a specific business case. Their use will normally depend on a license agreement between the vendor and user of the tools. Some tools will be available under the GNU license agreement, e.g., the MMS Ethereal analyzer tool to analyze the messages according to IEC 61850-8-1 and 9-2.

A very powerful and comfortable tool from vendor X may really reduce the total cost of owner-ship of a substation with IEC 61850 based automation and asset management systems. But vendor X may decide to use his comprehensive set of optimized and interrelated tools for his own IEDs only! This would allow him to maximize the use of a set of tools that are well harmonized and coordinated. Why to allow other people to use his tools? This may be not at all his business case!

With the event of more and more powerful tools we have to understand that each vendor (of IEDs, systems, and tools) has a business case: To reduce his own cost and maximize his profit. It usually does not help him to give good tools away. On the other side it is quite crucial to apply tools for the various tasks described above. The license policy of the tool vendor and the negotiation with potential users of the tools is very important. To really tap the benefits of IEC 61850 it is required to have the right tools and the skilled people that can use the tools.

TABLE VII
USE CASES OF SCL FILES

Task	Description	Provider
Design	generate and use SCL files	TP, V, U
Validity check	to verify that the SCL file is well formed and valid	TP, V, U
Engineering	of the whole substation including IEDs from one or several vendors	TP, V, U
Evaluate ICD files	in a procurement process to compare what is provided by the IED, figure out differences and extensions	TP, V, U
Tool to expand the ICD (CCD, SCD) files	tool to expand the XML element types to get the complete tree of the information model, i.e. SCL data type references in the IED sections are replaced by the types defined in the section <DataTypeTemplates>…</DataTypeTemplates>. This would make the information models easier to read.	TP, V, U
Tool to browse ICD (CCD, SCD) files	tool to add hyper links to the XML element names to easily browse SCD files	TP, V, U
IED configuration	configure directly or indirectly the IED (e.g., programmable controller	V
Consistency checks	checks of whole substation and each IED if for each signal consumed a source is defined	TP, V, U
Validation of the information model implemented in IEDs	validation if the model is as it has been engineered, validation that the model conforms to the standard, generating an SCL file from the self description of the device retrieved by communication	TP, V, U
Configuration of clients	configure the points in the data base and the mapping of the communicated data to the data base	TP, V, U
Traffic engineering	the SCL file contains the sources and sinks of any communication; this allows to calculate the expected traffic – number of messages per time – based on the configured relations	TP, V, U
Application wizards	the single line diagram is part of the SCL file; a wizard can figure out the nearest sampled value source for currents and voltages and can use the corresponding logical node as a source of sampled values	TP, V, U
Generating mapping tables for function programming, gateways or RTUs	rules for programming automation functions and data generated for the functions and consumed by the functions could be used to bind the program input to a data communicated	TP, V, U
Providing maintenance data to be stored in the IED	the IED may later on update the values according to dedicated rules for monitoring	TP, V, U
Protection parameter setting groups	groups of protection parameter settings can be stored in the SCL and used for the initial setting of an IED, these settings can be edited later on through communication services	TP, V, U
Error diagnosis and network traffic analysis	analyzers use the SCL file to interpret the content of the messages exchanged; which device sent which data to which destination, …	TP, V, U
Conformance, interoperability, and performance tests	SCL file for the configuration of the test system to run automated tests	TP, V, U
Testing HMIs	HMI and IED configured through SCL file. Tasks: test HMI or substation computer ← IED ← process interface (I/Os) test HMI or substation computer ← IED ← I/O simulator configured through SCL fiel test HMI or substation computer ← Replace missing IED by a simulation configured through the IED section of the SCL file	TP, V, U
Protection function test	test equipment and IED can be configured for the tests	TP, V, U
…		

It is recommended to start early negotiations with the tool vendors. The negotiation should cover the use of the tools for IEDs of competitors, the training, the service, the updating and upgrading policy et cetera.

One could expect that (to some extend and some time down the road) a vendor may give away the IEDs for free if he could do the system integration (by some finger tips for his own tools) and the service for the whole system for its complete life time.

IEDs without tool support from the IED vendors may be very powerful – but it may be quite costly and time consuming to integrate them into a system with other IEDs from multiple vendors. If tools are not bundled together with IEDs then it would be quite costly to integrate these devices. Again: It is up to the users and system integrators to early start negotiations with the vendors with regard to the availability and use cases of their tools.

There is an important role for utilities and third party system integrators when it comes to the definition and application of rules to be build-in in the engineering tools of IED vendors. Tools rely on the standards and on many rules for using or not using the various options in the information models and the configuration language. Optional things may be used or not. A more crucial issue is how the tools fill out the areas where the standards give the freedom to fill out those parts of the specification that were intentionally left "open, or to fill it out completely different com-pared to the competitors (example follows).

One example is how to build or organize logical devices. The standard requires the mandatory use of logical devices (logical devices are not at all optional!). But the standard gives freedom how to package logical nodes into logical devices. One vendor may put all logical nodes in a single logical device and may allow the engineering tool to assign any name from "myDevice" to "FizzliPutzli" to the logical device. Another tool may provide always five logical nodes which may be fixed, i.e., they cannot be changed by the system integrator. One logical device "CON-TROL" may contain all control related logical nodes, the logical device "MEAS" may contain all measurements, et cetera.

Another vendor may have a completely different philosophy how to package the logical nodes to logical devices. But all these methods to organize the data and logical nodes are compliant with IEC 61850 – no question. If – during system engineering – the system integrator wants to organize them in a utility specific way, it may not be possible because the tool of a vendor may not support this (not foreseen in the rules that have been applied). The IED of that vendor may sup-port other organizations of data and logical nodes. The tool may restrict these free allocations to logical devices.

Tools may also follow strict rules on how to name logical node instances. A logical node class XCBR may be instantiated as MyXCBR or as Q0XCBR01 according to the build-in rules. The development of tools needs special attention by the third party or utility system integrators. The expectations in the standards may not be met, because the implementations of IEDs and tools may restrict the possibilities specified by the standards. The implemented IEDs and tools are be-tween the standards and the users of the IEDs and tools. Not everything supported by the stan-dards may be supported by the IEDs and tools.

There is another aspect we need to briefly look at: The skills needed to efficiently use tools. Tools could only help to reduce costs and safe time when the user of the tool knows what the tool provides and how to use it. Training and experience is crucial to tap benefits from a tool.

XII. MAPPINGSS

The following optional mappings are incorporated in the FDIS (out for final ballot until 01 August 2008):

- Definition of new web services and (full) mapping of IEC 61950-7-2 ACSI and Information Models (LD, LN, DATA, DA, …) to these web services
- (full) Mapping according to IEC 61850-8-1 MMS
- (subset) Mapping to OPC XML DA
- (small subset) Mapping to IEC 60870-5-104
- (small subset) Mapping to DNP3

Figure 2 shows all mappings of both standard series.

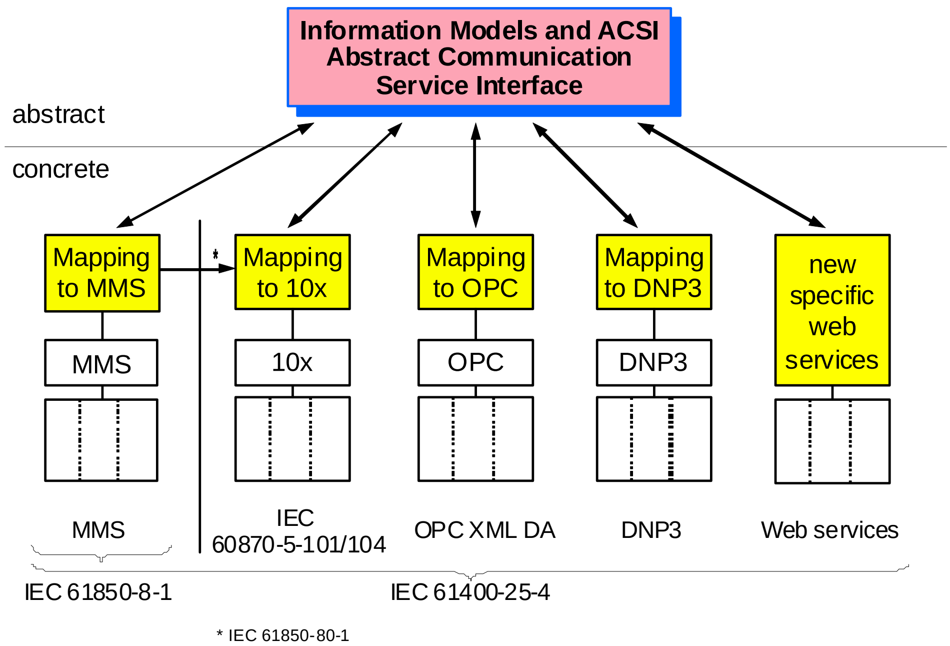

Fig. 2 Mappings defined in IEC 61850 and IEC 61400-25

Table VIII provides an overview of the information exchange services specified in IEC 61400-25-3 (the same as in IEC 61850-7-2 except two simple extensions) and the degree of fulfillment provided by the specified mappings to protocol stacks. For each mapping a column is provided which describes the compliance to the services required. The M/O column indicates whether the service is defined in IEC 61400-25-3 as mandatory or optional. A "Y" in the column for a certain mapping stands for Yes, the service is supported, "N" means no support, and "P" means partial support, i.e. the service as defined in IEC 61400-25-3 is not completely supported.

TABLE VIII
MAPPING OVERVIEW OF IEC 61400-25-3 SERVICES

Services as per IEC 61400-25-3 (IEC 61850-7-2)	**M/O**	**Web services**	**OPC XML-DA**	**IEC 61850-8-1 (MMS)**	**IEC 60870-5-104**	**DNP3**
Associate	M	Y	Y	Y	Y	Y
Release	O	Y	Y	Y	Y	N
Abort	O	Y	Y	Y	N	N
GetServerDirectory	O	Y	Y	Y	N	Y
GetLogicalDeviceDirectory	O	Y	Y	Y	N	Y
GetLogicalNodeDirectory	O	Y	Y	Y	N	N
GetDataValues	M	Y	Y	Y	Y	Y
SetDataValues	M	Y	Y	Y	Y	Y
GetDataDirectory	O	Y	Y	Y	N	N
GetDataDefinition	O	Y	Y	Y	N	N
GetDataSetValues	M	Y	P	Y	N	Y
SetDataSetValues	O	Y	N	Y	N	Y
CreateDataSet	O	Y	N	Y	N	N
DeleteDataSet	O	Y	N	Y	N	N
GetDataSetDirectory	O	Y	N	Y	N	N
Report	O	Y	Y	Y	Y	N
GetBRCBValues	O	Y	N	Y	N	N
SetBRCBValues	O	Y	N	Y	N	N
GetURCBValues	O	Y	N	Y	N	N
SetURCBValues	O	Y	N	Y	N	N
AddSubscription	O	Y	Y	Y	N	N
RemoveSubscription	O	Y	Y	Y	N	N
GetLCBValues	O	Y	N	Y	N	N
SetLCBValues	O	Y	N	Y	N	N
GetLogStatusValues	O	Y	N	Y	N	N
QueryLogByTime	O	Y	N	Y	N	N
QueryLogAfter a	O	Y	N	Y	N	N
Select	O	Y	Y	Y	Y	Y
SelectWithValue	O	Y	Y	Y	Y	Y
Cancel	O	Y	Y	Y	Y	N
Operate	M	Y	Y	Y	Y	Y
CommandTermination	O	Y	Y	Y	Y	Y
TimeActivatedOperate	O	Y	Y	Y	N	N

XIII. CONCLUSIONS

In highly automated substations and power plants, almost no limitations exist concerning the information from the process made available to any entity that needs the information. The acquisition of any needed process information increases the controllability of the system. Seamless information exchange and distribution of pre-processed information as required opens a new area of automation functions.

With a global communication infrastructure this information can be accessed from anywhere in the system. As a result, a function is not bound to be implemented at a specific physical location anymore. If an IED implementing a specific function fails, that function can be processed by another IED with the equivalent function. Thus a self healing or fault tolerant automation system can be realized.

The data model provides the self description to be retrieved by any other application. This means that any client (HMI or other IED) can browse a server device for available data and it can retrieve the data values including the format specification. In addition, description attributes with an explanation of the semantic of the data can be retrieved.

The electric power delivery system will soon use IEC 61850 and its extensions in substations, in power quality monitoring applications, for the control and monitoring of wind power plants, control and monitoring of distributed energy resources (DER), and the control and monitoring of hydro power plants.

Part IEC 61850-6 is the most crucial part of the standard series IEC 61850 and IEC 61400-25 – even many experts have not yet a glue what that means.

One of the real challenges in the power industry is the education of the people responsible for the future power systems. The knowledge about the possibilities of the standard, the IEDs, the tools, and the network is the basic prerequisites for utility people to tap the benefits IEC 61850 provides.

REFERENCES

[1] IEC 61850-1, Communication networks and systems in substations – Part 1: Introduction and overview

[2] IEC 61850-2, Communication networks and systems in substations – Part 2: Glossary

[3] IEC 61850-3, Communication networks and systems in substations – Part 3: General requirements

[4] IEC 61850-4, Communication networks and systems in substations –- Part 4: System and project management

[5] [IEC 61850-5, Communication networks and systems in substations – Part 5: Communication requirements for functions and devices models

[6] IEC 61850-6, Communication networks and systems in substations – Part 6: Configuration description language for communication in electrical substations related to IEDs

[7] IEC 61850-7-1, Communication networks and systems in substations – Part 7-1: Basic communication structure for substation and feeder equipment – Principles and models

[8] IEC 61850-7-2, Communication networks and systems in substations – Part 7-2: Basic communication structure for substation and feeder equipment – Abstract communication service interface (ACSI)

[9] IEC 61850-7-3, Communication networks and systems in substations – Part 7-3: Basic communication structure for substation and feeder equipment – Common data classes

[10] IEC 61850-7-4, Communication networks and systems in substations – Part 7-4: Basic communication structure for substation and feeder equipment – Compatible logical node classes and data classes

[11] IEC 61850-8-1, Communication networks and systems in substations – Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO/IEC 9506-1 and ISO/IEC 9506-2) and to ISO/IEC 8802-3

[12] IEC 61850-9-1, Communication networks and systems in substations –- Part 9-1: Specific communication service mapping (SCSM) – Sampled values over serial unidirectional multidrop point to point link

[13] IEC 61850-9-2, Communication networks and systems in substations – Part 9-2: Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3

[14] IEC 61850-10, Communication networks and systems in substations – Part 10: Conformance testing

[15] IEC 61400-25, Wind turbines – Part 25: Communications for monitoring and control of wind power plants

[16] Schwarz, Karlheinz, "Impact of IEC 61850 on system engineering, tools, people-ware, and the role of the system integrator", DistribuTech 2007, san Diego, February 4-6, 2007-02-28

[17] Brunner, Christoph, "IEC 61850 – a new standard that will change the industry", Metering International, Issue 3, 2006, page 70 – 73

[18] Andersson, Lars; Brunner, Christoph; Engler, Fred, "Substation automation based on IEC 61850 with new process-close technologies", IEEE PowerTech 2003, Bologna, Italy

[19] Schwarz, Karlheinz, "Wind Power Communication - Verification report and recommendation"; Elforsk Rapport Number 2-14; Stockholm, April 2002. www.nettedautomation.com/download/02_14_rapport.pdf

[20] Schwarz, Karlheinz, "Wind Power Communication - Design & Implementation of Test Environment for IEC61850/UCA2"; Elforsk Rapport Number 2-16; Stockholm, April 2002. www.nettedautomation.com/download/02_16_rapport.pdf

[21] Schwarz, Karlheinz, "Advanced Condition Monitoring of Primary Equipment with the Standard Series IEC 61850 AND IEC 61400-25"; CEPSI 2008, Macau

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http://iec61850-news.blogspot.com

Hands-on-training:
http://nettedautomation.com/seminars/uca/sem.html#standardpublic