IEC 61850 ALSO OUTSIDE THE SUBSTATION FOR THE WHOLE ELECTRICAL POWER SYSTEM

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Abstract – This paper describes how the new international standard series IEC 61850 is applied and extended to meet the requirements for almost the whole electrical energy supply chain, especially outside substations. Several activities are under way in the domains of power generation (wind power plants, hydro power plants, and decentralized energy resources), power transmission and distribution as well as the customer interface. Some domain specific requirements are discussed and common solutions based on the current version of IEC 61850 are given.

Keywords: IEC 61850, substation automation, wind power, hydro power, power system information, information exchange, power generation, transmission, distribution, power quality, distributed energy resources

1 INTRODUCTION

IEC 61850 "Communication networks and systems in substations" [1] is the global standard for information models and information exchange for substation automation. The project IEC 61850 has been started in 1995. Just a few years later, utility and vendor experts of non-substation related application domains began to realize both the benefits of a single international standard for the electrical energy supply system and the powerful approach and content of IEC 61850. Major users and vendors of wind turbines decided to apply the standard IEC 61850 and to extend it for the application domain of wind turbines. Therefore, the IEC TC 88 "Wind Turbines" started the project "Communications for monitoring and control of wind power plants" [2] in 2001. Experts in several other application domains of the electrical energy supply chain are now following in the footsteps of the TC57 and TC 88 experts. Therefore, IEC 61850 has become the base standard for modeling of power system information, for exchanging information between intelligent electronic devices (IEDs), and for the configuration of systems and devices applied in the whole electrical energy supply chain.

The current crucial activities with regard to IEC 61850 under way are

1. Maintenance of IEC 61850 (IEC TC57 WG10)
   a. IEC 61850 amendments of current version
   b. IEC 61850 extensions for Power Quality Monitoring
   c. IEC 61850 common extensions for Statistical and Historical Statistical information
2. Extensions of IEC 61850 with regard to control centers (IEC TC 57 AHWG07)
   a. The Harmonization of the information model in IEC 61850 with the CIM model defined in IEC 61970 (Energy management system application program interface (EMS-API))
   b. The use of IEC 61850 for information exchange between substations and control centers
3. Extensions of IEC 61850 for Line Protection (New work item proposal in progress)
4. Extensions of IEC 61850 for Wind Power Plants (to be published in the series IEC 61400-25-x of IEC TC 88 PT 25)
5. Extensions of IEC 61850 for Distributed Energy Resources (DER) (IEC TC 57 WG 17)
6. Extensions of IEC 61850 for Hydroelectric Power Plants (IEC TC 57 WG 18)
7. Profile and extensions of IEC 61850 for high voltage switchgears (IEC TC 17)
8. Information models for advanced metering networks and demand Response (Open AMI)

This paper describes how the new international standard series IEC 61850 is applied and extended to meet the requirements for almost the whole electrical energy supply chain, especially outside the substation as indicated in the activities 2, 4, 5 and 6. Because of all these commonalities it is no surprise that the IEC TC 57 Working Groups 10, 17, and 18 have proposed to the IEC Central Office in December 2004 to publish all non-domain specific extensions of IEC 61850 under the common standard number IEC 61850. The proposed new title for IEC 61850 "Power system IED communication and associated data models" reflects the harmonized efforts of defining one single, unique, and harmonized standard for the whole electrical energy supply chain.

The challenge of defining and standardizing the huge amount of information models for the electrical energy supply chain will be described in the following.

2 APPLICATIONS OF IEC 61850 OUTSIDE SUBSTATIONS

2.1 Information models for electrical energy supply systems

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, i.e., 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 models comprise hierarchically structured information to provide the semantic of the data to be exchanged.

Several information models are defined or are under way:

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 for monitoring and control of distributed energy resources (IEC 61850)
4. Information model for monitoring and control of hydro power plants (IEC 61850)
5. Information model for power quality monitoring (IEC 61850)
6. Information model of a power system as seen from a control center viewpoint (IEC 61970 CIM – common information model)

The first five models 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 6) describes the top view of the electrical energy supply system. The CIM models all visible information from/to the process related devices and further control center related information. 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.).

2.2 Relation between IEC 61850 and standards for control centers

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

Information produced and consumed by substations (modeled as logical nodes, data objects, and data attributes) are "imported" by the 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.

The source and the destination respectively (of a subset) of the operational process information modeled in CIM are also modeled in the other models (models 1 to 5). 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 to some extend. Figure 1 shows the conceptual dependency of the two levels. The topology information is primarily provided by the CIM (generated during the resource planning process). The process 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 re-source, engineering, maintenance, etc.

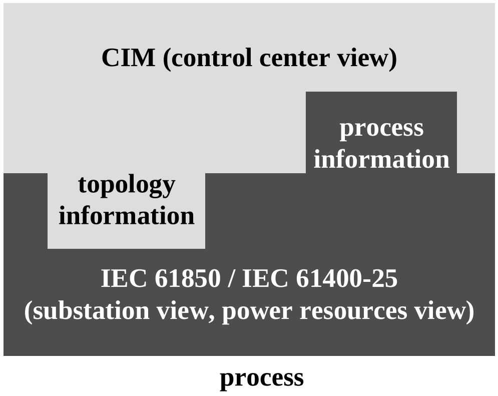

Figure 1: Two levels of models (conceptual)

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 defined and published as IEC 61970-301 (Energy Management System Application Programming Interfaces (EMS-API)). 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 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.

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 program 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. Table 1 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
API	no / WSDL	yes

Table 1: Two levels of information models

2.3 Communications for monitoring and control of wind power plants

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

The focus of IEC 61400-25 is on the communications between wind power plant components and actors, such as wind turbines, a SCADA System, or a condition monitoring system.

The IEC 61400-25 series (2nd Committee Drafts have been published end of 2004) consists of the following parts, under the general title "Communications for monitoring and control of wind power plants":

- Part 25-1 Overall description of principles and models
- Part 25-2: Information models
- Part 25-3: Information exchange models
- Part 25-4: Mapping to communication profile
- Part 25-5: Conformance testing

The information defined in these draft standards 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 wind power plant specific logical nodes (LNs) listed in table 2 comprise a total of several hundred data objects and data attributes. This is the first extension of the information models defined in IEC 61850-7-x – with regard to the number and nature of information models. Many of these new LNs specify statistical and historical statistical information – compared to IEC 61850 which defines primarily operational information.

LN	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
WAPC	Wind power plant active power control information
WREA	Wind power plant reactive power control information

Table 2: Wind power plant information models (LNs)

The part IEC 61400-25-4 defines a new common mapping of the information models (logical nodes, data objects, and data attributes) and services (defined in IEC 61850-7-2) to web services. The process related measurements and status information is additionally mapped to IEC 60870-5-104 and DNP3.

2.4 Communications systems for distributed energy resources (DER)

There is a growing interest in implementing DER devices throughout the world. The manufacturers of DER devices are facing the age-old issues of what communication standards and protocols to provide to their customers for monitoring and controlling DER devices, in particular when they are interconnected with the electric utility system. In the past, DER manufacturers developed their own proprietary communication technology. However, as utilities and other energy service providers start to manage DER devices which are interconnected with the utility power system, they are finding that coping with these different communication technologies present major technical difficulties, implementation costs, and maintenance costs. Therefore, utilities, DER manufacturers, and the customers they serve are increasingly interested in having one international standard that would define the communication and control interfaces for all DER devices. Such standards, along with associated guidelines and uniform procedures would simplify implementation, reduce installation costs, reduce maintenance costs, ease extensions, and improve reliability of power system operations.

An excerpt of the LNs for DER systems is listed in table 3 without further explanation.

LN	Description
DER Electrical Interconnection Characteristics	
DRCT	DER Plant Controller
DRAT	DER Generator Ratings
DRGN	DER Unit Generator Name
DSYN	DER Synchronization Control
DINV	DER Inverter Name
Reciprocating Engines	
DCIP	Reciprocating Engine
Fuel Cells	
DFCL	Fuel Cell
DSTK	Fuel Cell Stack
DFPM	Fuel Processing Module
Photovoltaics Systems	
	Photovoltaics System
Combined Heat and Power	
…	…

Table 3: Excerpt of DER information models (LNs)

2.5 Hydroelectric power plants – Communication for monitoring and control

The extension of the information models focuses on the communication between hydroelectric power plant components and actors within the power plant and its related systems.

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 of 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.

The Logical Nodes and Data Objects defined in this document are divided in groups:

- **Electrical functions.** This group includes LNs already defined in IEC 61850, where additions or modifications are required in order to be used in a power plant. New LNs defined within this group are not specific to hydropower plants; they are more or less general for all types of power plants.
- **Mechanical functions.** This group includes functions 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.
- **Hydrological functions.** This group of functions includes objects related to water flow, control and management of reservoirs and dams. Although specific for hydropower plants, the LNs defined here can also be used for other types of utility water management systems.
- **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.

An excerpt of the LNs for hydro power plants is listed in table 4 without further explanation.

LN	Description
AFCO	Flow Controller
AKVR	Automatic Voltage/var regulator
ALCO	Level Controller
AMWR	Active Power regulator
ASPC	Speed controller
CCGR	Cooling group control
DPC	Controllable double point
GAPC	Generic automatic process control
HBRAK	Brakes
HGOV	Hydraulic Governing system
HJCL	Hydraulic Joint control
HPPU	High Pressure pumping unit
MMDE	Density logical node
MMDP	Dewpoint logical node
MMFE	Flow element logical node
MMHE	Humidity logical node
MMLE	Level element logical node
MMPE	Pressure element logical node
MMRF	Rainfall logical node
MMSF	Snowfall logical node
PPAM	Phase angle/out-of-step
PSDE	100% stator earth-fault
PSDE	Directional earth-fault
PSDE	100% stator earth-fault
RTEM	Temperature monitoring system
RVIB	Vibration monitoring system
VPCO	Valve opening position controller
WMET	Meteorological station
WHYD	Hydrological station
ZTCR	Thyristor controlled reactive component

Table 4: Excerpt of hydro power plant information models (LNs)

2.6 Power quality monitoring

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

The logical node classes and data classes defined in Parts IEC 61850-7-3 and 7-4 do not address the power quality monitoring. 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 common 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.

An excerpt of the LNs for power quality monitoring is listed in table 5 without further explanation.

LN	Description
Steady State	
MMXU	General power parameters
MSQI	Sequence and unbalance
MHAI	Harmonics and interharmonics (according to IEC 61000-4-7)
MADV	Power in non-sinusoidal situations (according to IEEE 1459)
MFLK	Voltage Fluctuations (flicker according to IEC 61000-4-15)
Events	
QVVR	RMS Voltage Variations (sags/swells/momentary according to IEC 61000-4-30 and IEEE 1159)
QFVR	Frequency Variations (according to EN 50160 and 61000-4-30)
QUBV, QVUV, QIUV	Unbalance Variations
QTRN, QVTR, QITR	Transients (according to IEEE 1159)
RDXX	augment to hold recorded data specified in QXXX elements

Table 5: Excerpt of PQM information models (LNs)

3 EXTENDED COMMON SPECIFICATIONS

3.1 Most common information in current IEC 61850

The most common logical node in all IEDs typically available in all automation systems is the one used to model the multiple measured quantities by a device in a Three phase system. It is mainly used to provide measurements from an IED to any kind of users: MMXU (Measurement unit).

Table 6 shows the data object names and types of the different measured values included in the MMXU.

Name	Type	Description
PPV	DEL	Phase to phase voltages
PhV	WYE	Phase to ground voltages
A	WYE	Phase currents
W	WYE	Phase active power (P)
VAr	WYE	Phase reactive power (Q)
VA	WYE	Phase apparent power (S)
TotW	MV	Total Active Power (Total P)
TotVAr	MV	Total Reactive Power (Total Q)
TotVA	MV	Total Apparent Power (Total S)
TotPF	MV	Average Power factor (Tot. PF)
Hz	MV	Frequency
PF	WYE	Phase power factor
Z	WYE	Phase Impedance

Table 6: Measured values data objects in MMXU

The types are DEL for Phase to phase related measured values of a Three phase system, WYE for Phase to ground related measured values of a Three phase system, and MV for Measured values.

As can be seen from table 6 most of the data attributes in this logical node are of WYE type, i.e. they model the Three phase and neutral values of measured voltages (PhV), currents (A), impedance (Z) etc.

The Phase to phase voltages are modeled using PPV which is of DEL type.

The total values of active, reactive and apparent power, as well as the total power factor are of type MV.

Relays and power quality monitoring devices measure different system parameters that are used to determine unbalanced system conditions. Such measurements are modeled in the logical node MSQI (Sequence and imbalance). The sequence components of the currents and voltages are modeled as attribute type SEQ (Sequence).

In order to analyze the behavior of the electrical system, it is sometimes necessary to calculate the average, minimum and maximum values of a system parameter over a pre-defined period of time. These values of system parameters are modeled as MV type and are available in the logical node MSTA (Metering Statistics).

Advanced metering and power quality monitoring devices, as well as specialized energy metering devices calculate the energy that is then used for billing or other purposes. Different energy values are available in the logical node MMTR (Metering).

Power quality monitoring devices calculate hundreds of different system parameters, such as harmonics or interharmonics. Their modeling is based on a dedicated to these measurements logical node MHAI (Harmonics or interharmonics).

3.2 Statistical and historical statistical information

Almost all common information models defined in the current version of IEC 61850 represent actual measured values only. In many application domains described in clause 2 of this paper it is required to represent additional information of the (instantaneous or actual) analogue values:

- **statistical information** (e.g., minimum value calculated for a specified time period, e.g., minimum value of last 1 hour)
- **historical statistical information** (e.g., log of minimum values of the sequence of values calculated above, e.g., last 24 hourly values)

WG 10 of IEC TC 57 is currently defining the required common extensions of the information models. The basic idea is to use the existing logical node model and specify some simple extension rules.

The basic rule is: various specializations of a specific existing LN (with actual analogue values) describe statistical information for the actual values. A LN instance X may represent the actual analogue values. The instance X1 may represent the minimum values of the last hour. LN X2 may represent the maximum values of the last hour. The configuration information like calculation period and start time needs to be defined and added to the existing LNs.

The historical statistical values are simply defined by log entries of the existing log model defined in IEC 61850-7-2. The statistical data are stored in the log as they are calculated at the end of the calculation period.

The statistical and historical statistical information define a very powerful, common, and yet simple extension of the existing logical node models.

3.3 Future specification of information models to rely on XML

The current technique to define information models (LNs, data objects, and data attributes) is simply a table notation. Table notations are easy to read – as long as there are not many hierarchies in the information model. The defined models and those models under way show that the table notation is very restricted with regard to readability and tool support for consistency checking of the models.

All groups specifying information models based on IEC 61850 have decided to publish their information models as XML documents. The current models will be transformed to XML documents as well. The XML documents would be the only normative model specifications. For easier re-use of the comprehensive information models it has been proposed to the IEC Central Office to post all corresponding XML documents of the various information models at the IEC website. For implementations the models could be retrieved from the website. There would be no need to re-type all the hundreds or thousands of tag names of the hierarchical information models.

The XML based notation also allows for easier conversion to web based representations for browsing the models [3].

4 FURTHER APPLICATION AREAS

4.1 Equipment, IED and application monitoring

The instantaneous information is of the main focus of the models in IEC 61850. The equipment, IED and application monitoring is one of the areas that need extended information models. The transformer monitoring information model as depicted in table 7 is briefly introduced to indicate the possible requirements for monitoring. These models have been prepared for a new standardization project.

Name	Description
SAMC	Monitoring of ambient conditions
SARC	Monitoring and diagnostics for arcs
SBSH	Monitoring of Bushing
SDRV	Monitoring of drive
SLTC	Monitoring of tap changer
SPDC	Monitoring and diagnostics for partial discharges
SPTR	Monitoring of power transformer
SSW	Monitoring of switch

Table 7: Excerpt of transformer monitoring LNs

4.2 Condition monitoring for wind power turbines

A new work item for Communications for monitoring and control of wind power plants is under way in IEC TC 88.

The information models and the information exchange of the various condition monitoring systems for wind power plants are very diverse. The communication with the variety of proprietary solutions produces unnecessary high costs for the design, engineering and maintenance of the information to be exchanged with condition monitoring systems and for the training of personnel.

The IEC TC 88 Project Team (PT) 25 “Communications for monitoring and control of wind power plants” specifies information models and information exchange models for the operation of wind power plants. PT 25 has identified the need for a standard on wind power plant specific information models for condition monitoring systems. The definition of the common information models requires domain experts of condition monitoring for wind power plants. The PT 25 has mainly members dealing with operational issues of wind power plants. To get support from the domain experts of condition monitoring, members of the PT 25 proposed to define such information models in a separate project – in close cooperation with PT 25 members.

The key definition of this standard will be on information models with regard to any crucial kind of information produced and consumed by the condition monitoring system for diagnosis and subsequent prognosis as well as for machine protection.

The main areas for which information is described and modelled are:

- Structure
- Tower
- Foundation
- Nacelle
- Components
- Gearbox

- Generator
- Bearings
- Rotor blades
- Hydraulics
- Pitch
- Transformer
- Brake
- Clutches
- Azimuth drive

Examples of crucial measurements to be defined in this standard are:

- Temperatures (Contact measurements and Thermographs)
- Oscillations, Vibrations
- Pressure (absolute/differential)
- Particle concentration oil
- Electrical Measurements (U, I, P, Q,...)
- RPM (Rotor, Generator)
- Force/Torque
- Rotor position (Rotor angle)
- Wind speed and -direction
- Material condition (fatigue, wear, stiffness, corrosion, ...)

The information models defined in this standard are intended to be extrapolated from the information models for the electrical power system already defined in IEC 61850.

5 CONCLUSION

The paper has shown the manifold of new application domains of IEC 61850 and IEC 61850 based standards. The various efforts will provide manifold standardized information models for the corresponding domains.

The electrical power industry and research is faced with two crucial challenges due to the publication of these new and extended information models respectively:

- the migration of information and information processing capabilities into IEDs and
- the specification of very comprehensive and consistent information models (common and specific models)

Figure 2 shows the current situation of information models and information exchange. The basic process related information provided by IEDs is cyclically retrieved by RTUs (Remote Terminal Units) and communicated to the next higher level. Many different simple and proprietary protocols are implemented on both sides of the RTUs. The RTUs perform the translation work (Gateway), which is both expensive and labor-intensive. The manifold of communication protocols limit the use of unified solutions required to handle the comprehensive information models and their configuration in IEDs and in the SCADA and HMI devices.

The move to the new international standards based on IEC 61850 provides the required stable basis for the migration of common SCADA and further processing functions, e.g., logging of statistical and historical statistical information into the IEDs or various kinds of controller. It also provides the self-identification and self-description which will be stored in the IED’s data base.

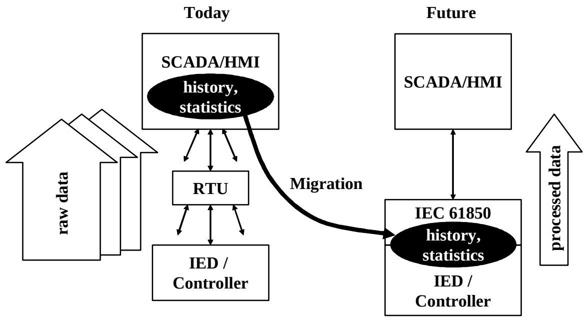

Figure 2: Migration of processing to IEDs

This migration requires tremendous efforts in the implementation and education of the IEC 61850 based solutions – for vendors and users.

The second challenge is to get and maintain unique and consistent information models for the whole electrical energy supply chain.

Due to the deregulation of the power industry the various divisions of utilities focus on their core business. Experts involved in the standardization often have a very specific and restricted scope – reflecting their core business. Only a few experts in the standardization process have the whole electric energy supply chain in their focus.

On the other side we have seen in this paper that consistent and unique information models for the whole power system are under way and fast growing. The coordination of the various projects under way and those expected is the key factor of the deployment of the IEC 61850 based standards in the whole power industry. Cooperation of the industry and research would help to stabilize the specifications and help to disseminate the IEC 61850 approach in the whole power industry.

Today’s loosely coupled information models defined in the various standardization groups and published in independent standards need to be coordinated and harmonized. A tool support, e. g., based on UML could help to reach a unified and unique information model for the whole electric power supply chain with different views for control centers, substation automation, equipment maintenance and asset management etc.

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