Standardized Smart Grid Semantics using OPC UA for Communication

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Abstract: As many roadmaps and studies were developed focusing on smart grid standardization a set of core standards was identified. Some of them specify own data models and thus, create a need for harmonization to enable interoperability in terms of communications. On the level of data model integration, two data models play key roles in the future smart grid. On the one hand the Common Information Model and on the other hand IEC 61850-based models. Both were identified as core standards and are part of the IEC TC57 Seamless Integration Architecture, another recommended standard. In this contribution the OPC Unified Architecture, which is also a core standard specifying a server-client-architecture, is used to harmonize the two mentioned data models based on a common access layer. This leads to higher interoperability for, e.g., Energy Management Systems, Distribution Management Systems or SCADA systems.

Introduction

In the energy sector many studies and roadmaps are dealing with standardization for smart grids. Significant approaches were amongst others developed in the USA [NIS10], in China [SGC10] and in European countries like Germany [DKE10]. Detailed overviews on these and further approaches including the derived recommendations can be found in [Roh10] and [Usl10].
As a result, the following set of core standards was identified:

- IEC TR 62357: Reference Architecture
- IEC 61968/61970: Common Information Model for EMS and DMS
- IEC 61850: Intelligent Electronic Device (IED) Communications at Substation level and DER
- IEC 62351: Vertical security for the TR 62357

- IEC 60870: Telecontrol protocols
- IEC 62541: OPC UA – OPC Unified Architecture, Automation Standard
- IEC 62325: Market Communications using CIM

In the context of this contribution „A smart grid is an electricity network that can integrate in a cost efficient manner the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety"[1] as per the definition given by the Expert Group 1 of the EU Commission Task Force for Smart Grids.
In the context of data model harmonization and thus, fostering interoperability, this article addresses a subset of four core-standards. Interoperability on semantic level and on communication and access methods are important concerns in such complex and dynamic systems like smart grids including various different stakeholders exchanging data among each other. Harmonizing standardized data models is an issue, which is part of many important smart grid strategies, e.g., [NIS10], [DKE10]. Because of the importance of the interfaces connecting the Common Information Model (CIM) and the IEC 61850 data model, the harmonization of them is focused in different approaches like [EPR10] and [KPF05]. Specific object mappings are also represented as a key layer in the IEC TC57 Seamless Reference Architecture (see Figure 1).
Now, the development of the OPC Unified Architecture (UA) enables a new and very promising opportunity to harmonize data models. The UA specifies an abstract server-client-architecture based on a defined information model and services. The architecture provides that a domain specific information model is used to represent certain objects. Hence, a UA-server can be run, either with a CIM-based model or an IEC 61850-based model. A suitably implemented and configured UA-client however, could access both servers with the same mechanisms, independent from their data models, and make use of the information of both servers.
In the next sub-chapters the four covered standards will be introduced. Furthermore, the two mappings (CIM-UA and IEC 61850-UA) will be explained afterwards.

IEC 62357 - Seamless Integration Architecture

The Technical Report (TR) IEC 62357 helps the IEC TC57 to put their different standardization projects and series into a common context. This leads to a seamless integration architecture (SIA) for the utility domain, as shown in Figure 1. Moreover, it enables documenting and fixing inconsistencies in terms of using single standards in the overall context. Thus, the TR documents the relationships between all existing object models, services and protocols maintained by the TC57. [IEC03c]
The SIA consists of three major parts. The upper part (A) is divided into different layers and deals with business integration, data definition and applications. One of the most important components within this part is the CIM. Also the lowest layer, covering Specific Object Mappings, is of high importance, because it addresses

[1] www.cenelec.eu/aboutcenelec/whatwedo/technologysectors/smartgrids.html

amongst others the harmonization of data models and represents the interface between CIM and IEC 61850.
Beside IEC 60870, IEC 61850 is the predominant component in the lower part (B) of the SIA which consists of different pillars. Each of them addresses the communication for another category of field devices. The lower parts of the pillars specify the systems needed by the devices for communications. The lower parts are connected via Wide Area Networks (WAN) to the upper parts of the pillars, which contain standards for object models for field devices and device components, specific communication service mappings and protocol profiles.
The vertical part (C) of the SIA includes a cross-cutting standard series based on IEC 62351. It considers security as well as data management. For each layer and pillar of the rest of the SIA special requirements are met.
Currently, the IEC is working on a long term architecture vision for the SIA, going far beyond harmonization of single standards. In this vision the CIM will play a key role. [IEC03c]

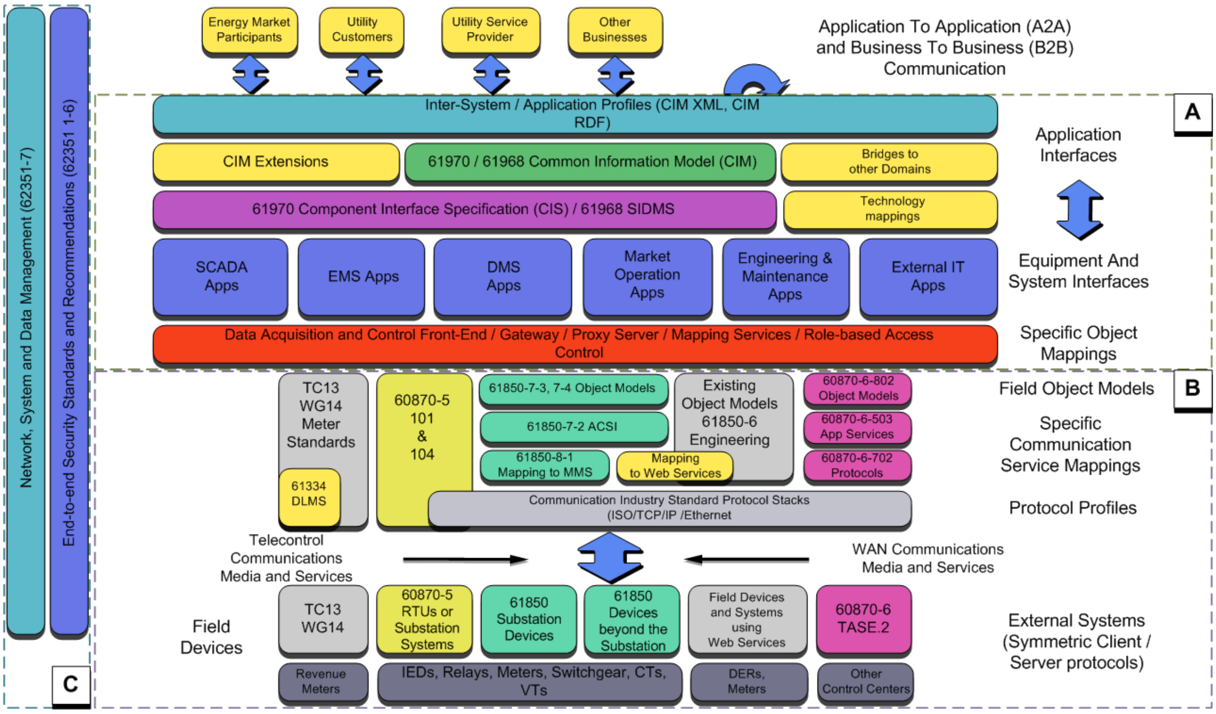

Figure 1: IEC TC57 Seamless Integration Architecture (based on [IEC03c]).

IEC 61970/61968 - Common Information Model

In the case of standardizing interfaces and data models for power system management and application integration into IT-landscapes of utilities, the IEC developed the Common Information Model (CIM). The development started in 1996 at the Electric Power Research Institute (EPRI) and was handed over to the IEC. Now, the CIM is the basis for the standard series IEC 61970 [IEC05] and IEC 61968 [IEC03b]. It is maintained as an Unified Modeling Language (UML) based model by the Cim users group[2] (CIMug).

[2] http://cimug.ucaiug.org/

The main objective of the CIM is to reduce expenditure of time and costs for integrating applications into Energy Management Systems (EMS) and Distribution Management Systems (DMS). Furthermore, it provides protection of investments and the efficient operation of those systems. Thereby, the CIM can be used as an integration framework [McM07].
Beside the Common Information Model, which is the main part of the CIM (IEC 61970-301 and IEC 61968-11), the standard series includes two more interface specifications. On the one hand the Generic Interface Definitions (GID) providing a technology-independent interface for certain types of data and on the other hand the System Interfaces for Distribution Management (SIDM) defining specific interfaces, including XML-based messages and use cases, based on the IEC 61968 function blocks.
The CIM is basically used in the context of the following three use cases [McM07]:

- Exchanging topology data: Profiles are an established means to cope with large data models by describing a specific subset of data, including all needed objects and excluding redundant ones, for considered purposes. For the CIM three large profiles are defined, consisting of a subset of CIM objects and relations: CPSM (Common Power System Model), CDPSM (Common Distribution Power System Model) und UCTE (Union for the Co-ordination of Transmission of Electricity). Also two types of serializations are specified. On the the one hand based on XML (Extensible Markup Language) and on the other hand based on RDF (Resource Description Framework). Hence, it is possible to exchange static and dynamic data, describing power systems and their states, among different systems like, GIS (Geographic Information System) and SCADA (Supervisory Control and Data Acquisition), in utilities.
- XML-based messaging: CIM semantics, defined in the data model, can be used for XML-based messages. Beside GID and SIDM, own XML schemata can be defined using CIM objects. Thus, messages based on standardized semantics enable coupling of customized systems within Service-Oriented Architectures (SOA).
- Coupling of systems: Based on the technology-independent interfaces, specified in the two standard series, standard-compliant solutions can be implemented. Those interfaces can be used directly to couple different systems. A utility, for example, buying a system, can precisely expect how and what data is provided by the system. This leads to much easier system integrations.

IEC 61850

The standard series IEC 61850 [IEC03a] was originally focusing on protection equipment and substation automation. In the meantime, it is used far beyond substations to exchange information, like switching commands, status information and measurements, within the utility domain. A continuously increasing number of exchanged data and decentralized processes led to the development of the standard series, because existing standards and vendor-specific solutions were not sufficient [OSM09].

By an integrated communication architecture, IEC 61850 covers the information exchange among and within the three typical layers: process level (transformer and switch), field level (protection and control) and substation level (operation terminal and remote control). Thereby, the following four aspects which are independent from each other but based on one another are defined [OSM09]:

- IEC 61850 communication uses standardized information, e.g., for circuit breaker, measurements, control and meta data, including self-descriptions, specified in IEC 61850-7-4. Those information are based on a set of about 20 basic data types (status, measured value, etc.), defined in IEC 61850-7-3. The information can address both, substation-specific and general aspects. Furthermore, it is intended to provide simple definitions of further information by re-using the standardized information.
- For the communication, certain services for accessing, reporting and archiving values, and controlling devices etc. are standardized in IEC 61850-7-2. They can be applied to the above mentioned standardized information as well as to any other information.
- Standardized communication networks and systems can be selected to exchange the standardized information by the standardized services as specified in IEC 61850-8-1, -9-1 and -9-2.
- The sub-standard IEC 61850-6 defines a XML-based system description language, called Substation Configuration Language (SCL). SCL enables a standardized configuration to completely describe devices by configuration files. Those files can be interpreted by the devices or their configuration tools and a system configurator.

The main objective of the IEC 61850 standard series is supporting interoperability in terms of communication among control system devices. This means to enable IEC 61850-based information exchange among two or more Intelligent Electronic Devices (IED) from different vendors. Whereas, the information can be unambiguously interpreted and used to realize the functionalities required by the applications.

IEC 62541 - OPC Unified Architecture

The OPC Unified Architecture (OPC UA) is developed by the OPC Foundation[3] and standardized by the IEC 62541 [IEC10]. Classic OPC - the predecessor of OPC UA - is well accepted and applied in industrial automation. Classic OPC is implemented in almost every system targeting industrial automation. OPC UA unifies the functionality of the classic OPC specifications and brings them to state-of-the-art technology using SOA.
Security is built into OPC UA as security requirements become more and more important in environments where automation is not running separated in an isolated environment but is connected to the office network or even the internet and attackers start to focus on automation systems [Gin10]. OPC UA provides a robust and reliable communication infrastructure having mechanisms for handling

[3] http://www.opcfoundation.org/

lost messages, failover, heartbeat, etc. With its binary encoded data, it offers a high-performing data exchange solution.

OPC UA scales very well in different directions. It can be applied on embedded devices with limited hardware resources as well as on very powerful machines like mainframes. Whereas an application running on limited hardware can only provide a limited set of data to a limited set of partners an application running on high-end hardware can provide a large amount of data with several decades of history for thousands of clients. Also the information modeling capabilities scale. An OPC UA server might provide a very simple model or a very complex model depending on the application needs. An OPC UA client can make use of the model or only access the data it needs and ignore the metadata accessible on the server.

OPC UA consists of 13 parts of which the parts three to six are in this context the most important ones. They specify abstract services like read, browse, or write for client/server communications and technology mappings for example for a web service-based communication. In addition, a meta-model (called Address Space) is defined with a very generic information model containing concepts like a base object type. This is the basis for domain specific information models. The abstract approach of OPC UA enables extensions of the application area, so that the focus is on general data exchange within any domain and it can be used for integrated automation concerns. The base principals of OPC UA information modeling are [MLD09]:

- Using object-oriented techniques including type hierarchies and inheritance
- Type information is exposed and can be accessed the same way as instances
- Full meshed network of nodes allowing information to be connected in various ways
- Extensibility regarding the type hierarchies as well as the types of references between nodes
- No limitation on how to model information in order to allow an appropriate model for the provided data by allowing various extension mechanisms
- OPC UA information modeling is always done on the server-side. The model can be accessed and modified from OPC UA clients but an OPC UA client is not required to have an integrated OPC UA information model.

This allows providing very simple as well as very complex and powerful information models. The base concepts of OPC UA are nodes that can be connected by references. Each node has attributes like a name and id. There are different node classes for different purposes, e.g. representing methods, objects for structuring the Address Space or variables containing current data. Each node class has special attributes based on their purpose. The variable, for example, contains a value attribute. Therefore OPC UA may serve as basis for generic information modeling.

Mappings

With its information modeling capabilities OPC UA offers a high potential for becoming the standardized communication infrastructure for various information models from different domains. Several information models are already defined based on OPC UA making use of the generic and powerful meta-model of OPC UA. The following information models have already been released:

- OPC UA for Devices: Defined in a combined effort of the FDT-Group, Fieldbus Foundation, HART-Communication Foundation, OPC Foundation, and PROFIBUS-Nutzerorganisation (PNO), a generic model was developed representing devices. This model is the foundation for FDI (Field Device Integration), the currently new developed solution for field device integration, combining the advantages of FDT (Field Device Tool) and EDD (Electronic Device Description).
- OPC UA Information Model for IEC 61131-3: In a joint effort of the OPC Foundation and PLCOpen and information model for the programming model of IEC 61131-3 is defined allowing a standardized mapping of function blocks, variables etc. defined in IEC 61131-3 to OPC UA.
- OPC UA for Analyzer Devices: Developed by a working group of the OPC Foundation the analyzer devices model defines a concrete model of several different types of analyzer devices like spectrometers or chromatographs.

In the following, mappings of existing information models in the power domain to OPC UA are described. These are namely the CIM and IEC 61850. By providing a mapping to OPC UA the information of those models can be made available to any OPC UA client like HMI (Human-Machine Interface), historians, etc. allowing a secure and reliable access over standard internet technology.

OPC UA meets CIM

The mapping of CIM to OPC UA is already discussed within the IEC who are working on a draft version of the mapping (IEC 61970-502-8). In this context CIMbaT is developed as a publicly available Enterprise Architect Add-In implemented with C# in Visual Studio supporting the generation of CIM-based Address Spaces. The overall approach of CIMbaT is introduced in [RUA10].
CIMbaT is constructed as a step-by-step wizard in which a CIM-model can be mapped to an UA Address Space. The Address Space will be written into a XML-file. The wizard also includes design-steps where the engineer can do settings for single CIM-elements. For main and default settings, such as the namespaces and the prefixes for the stereotypes needed to save UA-specific information in the CIM-UML-model, there is a XML configuration file which can be manipulated manually. The default values can also be manipulated in the first wizard step. The configuration file is needed for pre-selecting the default values in the design-steps and also for setting default values in the mapping.
In the design-steps the user gets the possibility to set OPC UA properties like IsAbstract, SupportsEvents, Historizing, DataType etc. for each CIM-class and their attributes and associations. That means, for example the engineer can override the default OPC data type integer or float. Also the decision whether a CIM-class attribute shall be mapped to a OPC Property or DataVariable is possible in the CIM-designer. The manipulable CIM-elements can be easily selected within a tree-structure.
For each setting there is a specific stereotype within the CIM-UML-model which will be added to the updated CIM-element. These UA-specific stereotypes are unique and include a value like true or false. They will be recognized in the mapping. If

the tool cannot find an UA-specific stereotype for a CIM-element, then the default values from the configuration file will be used. It is also possible to design UA Views and manage them. The Views are used for limiting the visible Nodes and References. The designed Views will also be saved as UA-specific stereotypes and mapped to an OPC View-Node. Because the changes can be saved as stereotypes in the CIM-model, the design choices are preserved without changing the CIM-Model except of the added stereotypes.
In coordination with the IEC and the decisions from the engineer the CIM-elements will be mapped as shown in Figure 2. Thereby, the two branching arrows mean that the designer can choose between different options. It depends on his flavor of modeling and on the overall environment. Merging arrows only express that different CIM-elements can be mapped to the same OPC UA structure.

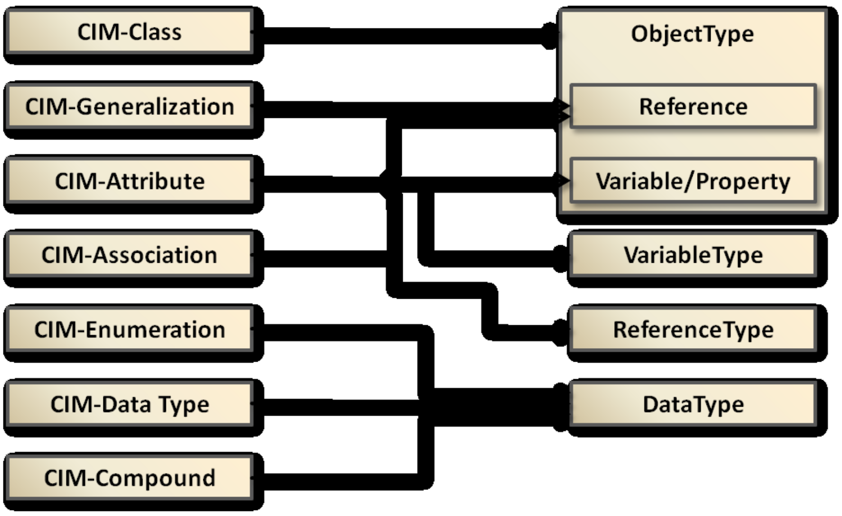

Figure 2: Mapping CIM objects to OPC UA Address Space.

OPC UA meets IEC 61850

Unlike the CIM the IEC 61850 does not only provide a simple data model but in addition mechanisms for the communication infrastructure like Functional Constraints (FC) for filtering the data, or timestamps and quality of the exchanged data. The IEC 61850 uses its own mechanisms to define its model and is not based on a pure object-oriented approach using the UML (although the latest version of the IEC 61850 uses UML to document their approach). Thus the mapping cannot be done in the same way as the CIM.
Different approaches can be chosen to map the IEC 61850 model to an OPC UA information model. For example, it has to be decided whether specific attributes of the IEC 61850 like quality and timestamp should be mapped the same way as all other attributes or handled specifically using the built-in OPC UA mechanisms having status codes and timestamps on each value. Furthermore the FC defined for attributes in IEC 61850 could be made available in OPC UA using different modeling alternatives. In this section one possibility for the mapping is introduced. For the introduced mapping the following decision were made and depicted in Figure 3:

- LN Classes as defined in IEC 61850-7-x are generally mapped onto UA object types.
- LNodeTypes are generally mapped onto UA object types subtyping the LN Class.
- LN are generally mapped onto UA objects as instances of LNodeTypes.
- LN Data as the attributes of LN are mapped onto UA objects.
- CDC are also generally mapped onto UA object types.
- CDC DataAttributes as the attributes of CDC are mapped onto UA variables.
- CDC DataAttribute Types are the types of the CDC attributes and mainly mapped onto existing UA standard data types like Integer, Float and String.
- FC are mapped onto UA objects.

To structure the objects three standard UA reference-types are used:
- HasComponent describes a part-of relationship between LN and its attributes as well as between CDC and its attributes. Furthermore it is used for the grouping by FC.
- Organizes is used to group the CDC attributes by FC.
- HasTypeDefinition connects the LN attributes with the according CDC.

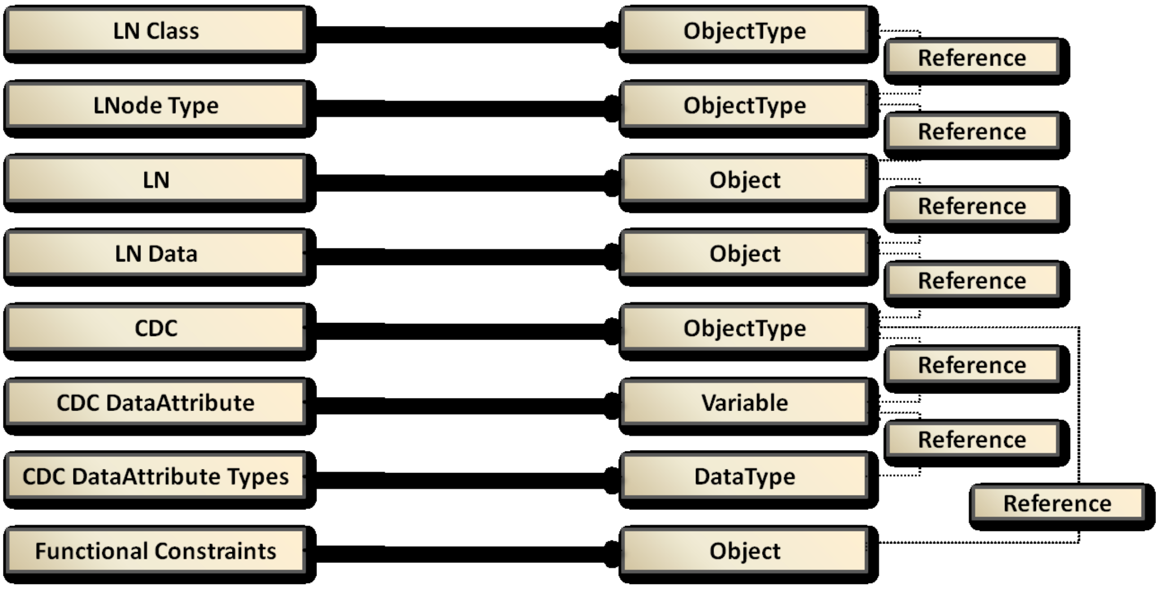

Figure 3: Mapping IEC 61850 objects to OPC UA Address Space

The example shown in Figure 4 includes the Logical Node Class (LN Class) MMXU and the Common Data Class (CDC) MV as well as their attributes. MMXU is a LN Class which shall be used for calculation of currents, voltages, powers and impedances in a three-phase system. The main use is for operative applications. The CDC MV represents measured values. We focus on only three attributes of the MMXU: TotVA (Total Apparent Power), TotVAr (Total Reactive Power) and TotW (Total Active Power). Also for the MV, we consider a limited number of attributes which can be divided by the FC. FC shall indicate the services that are allowed to be operated on a specific attribute. The attributes instMag (magnitude of a the instantaneous value of a measured value), mag (current value of instMag considering deadband), q (quality of the measured value), t (timestamp of the measured value) and range (range in which the current value of instMag is) belong to the FC MX (Measurands)

and the attributes subEna (used to enable substitution), subMag (used to substitute the data attribute instMag) and subID (shows the address of the device that made the substitution) to the FC SV (Substitution). Figure 3 shows a mapping providing FCs but making it optional whether to consider them when browsing or querying the UA Address Space by providing different paths to the variables. This is similar to modeling parameters for devices as defined in [OPC09].
The mapping shows that it is possible to expose the IEC 61850 model in OPC UA. By providing the LN Class and the LNodeTypes in the UA Address Space, it is possible that pure OPC UA clients without any previous knowledge of the IEC 61850 can make use of the type model and design for example specific HMI elements for any MMXU.

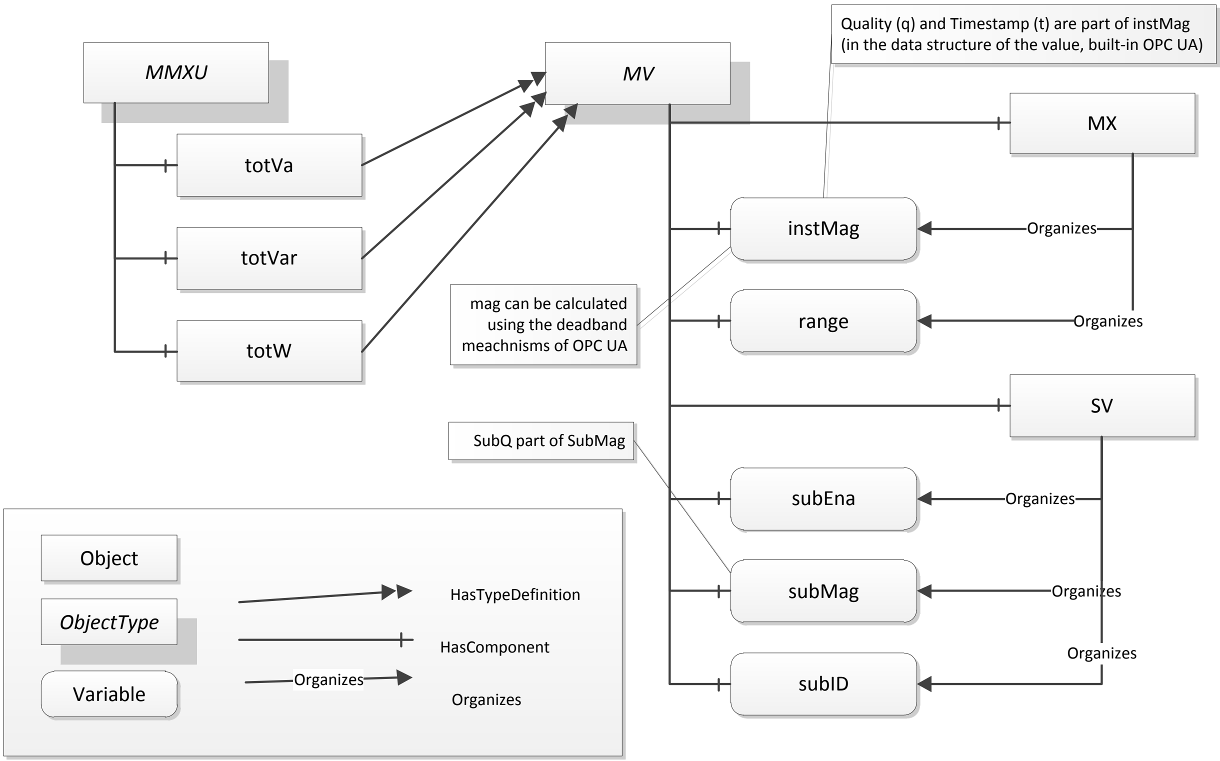

Figure 4: Concrete example of OPC UA and IEC 61850 mapping.

Conclusions and Outlook

In this paper we have presented the SIA having the CIM and IEC 61850 as integral part and the OPC UA, having its root in industrial automation. The CIM provides a pure data model based on the UML whereas the IEC 61850 defines its own model and also considers the communication.
We have shown, that the OPC UA information modeling capabilities can not only be used to define standardized information models in the domain of industrial automation by having standardized models for devices, analyzer devices and the IEC 61131-3 languages, but also for the electrical integration, mapping the CIM as well as the IEC 61850. This leads to a harmonized access layer for various data sources providing not only a standardized protocol accessing data but also allows accessing the metadata and thus, understanding the semantic of the provided data.

In order to increase this understanding it is not only useful to provide some metadata but ideally standardized metadata clearly defined and understandable by all communication partners. By using standardized information models like the CIM, this goal can be achieved.
There is a high benefit from mapping the CIM and IEC 61850 in a standardized way to OPC UA in order to provide the information of the CIM and IEC 61850 easily understandable and interoperable to the world of OPC UA providing access to HMI, historians, MES (Manufacturing Execution System), and connecting the industrial world and the power domain.
To achieve this goal, the approaches defined in this paper need to be refined, discussed in a wider range of interested participants and finally standardized in order to provide interoperability on the level of information models. The OPC Foundation currently investigates the creation of two new working groups, one providing a general mapping of UML models to OPC UA, which can be applied to the CIM, and another, defining a standardized mapping of the IEC 61850 model to OPC UA.

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