

IEC 61850 based OPC UA Communication - The Future of Smart Grid Automation

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Abstract - Within this contribution, we outline the use of the new automation standards family OPC Unified Architecture (IEC 62541) in scope with the IEC 61850 field automation standard. The IEC 61850 provides both an abstract data model and an abstract communication interface. Different technology mappings to implement the model exist. With the upcoming OPC UA, a new communication model to implement abstract interfaces has been introduced. We outline its use in this contribution and also give examples on how it can be used alongside the IEC 61970 Common Information Model to properly integrate ICT and field automation at communication standards level.

Keywords - smart grid, IEC 61850, OPC Unified Architecture, standardization, automation, ICT

1 Introduction

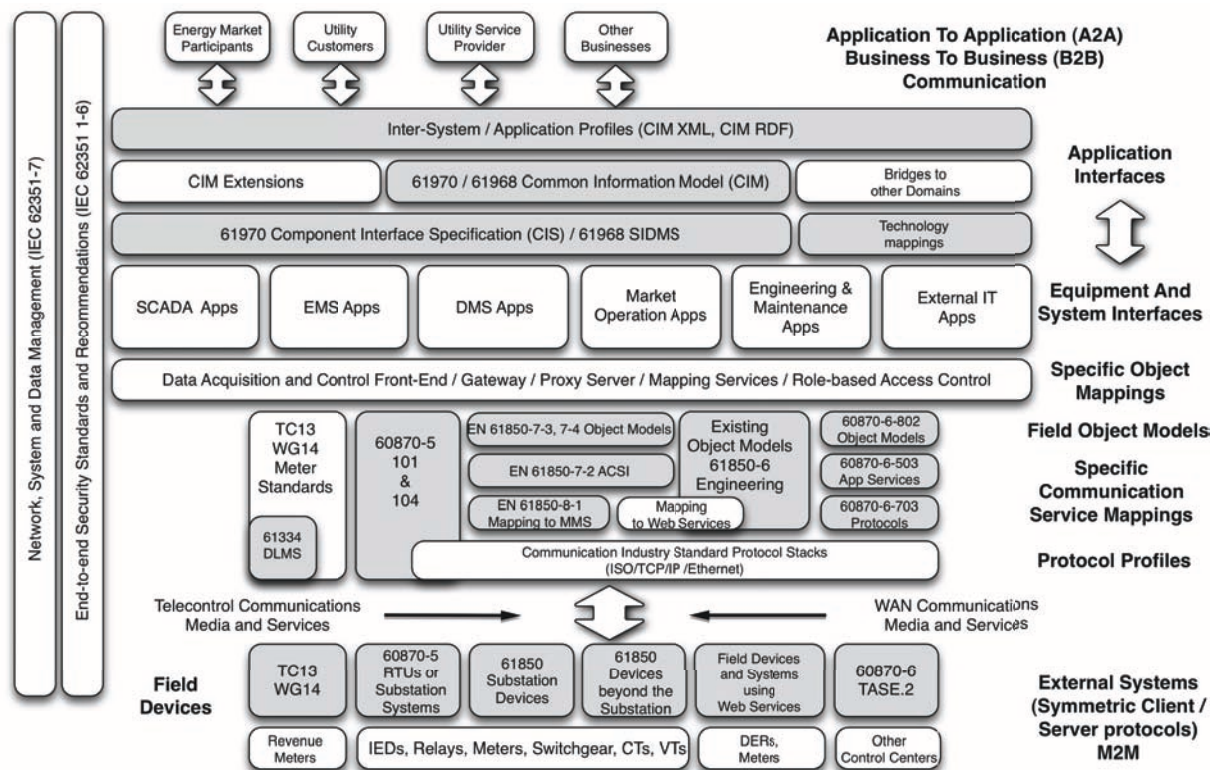
NOWADAYS, in the energy domain smart grids are a much discussed and controverse topic. However, a lot of views on smart grids exist and that leads to many definitions of what is understood as a smart grid [23], [1]. Almost all of them have one thing in common, they define an intelligent participation of various stakeholders in the future energy system. Thus, the resulting overall power system must be an open interoperable and connected system to allow the necessary amount of access between participating parties like devices in the grid but also market stakeholders. Only then, a smart evolution of the power system is possible. An open system, in turn, needs standardization to fulfill several interoperability requirements and to be run in an efficient way. Without standardization e.g. in terms of data models and interfaces the costs for integration of components as well as applications would be enormous [18]. Therefore, it is not surprising that many national and international studies and roadmaps were elaborated focusing on smart grid standardization [22], [25]. In this regard, one of the most relevant areas for standardization is ICT. International experts point out that the International Electrotechnical Commission (IEC) provides an appropriate starting point for smart grid Information and Communications Technology (ICT) standardization [17], [3], [24]. A set of core standards was identified including the IEC 61850 for substation automation and the

IEC 61970 Common Information Model (CIM) as an Energy Management System - Application Programming Interface (EMS-API).

In this contribution, we focus on communication technology mappings of the IEC 61850 and introduce the OPC Unified Architecture (UA; IEC 62541) as being an alternative way capable of communication based on the IEC 61850 model. The OPC UA is the successor of the established Classic OPC standards OPC DA (Data Access), OPC A&E (Alarms and Events) and OPC HDA (Historical Data Access) which are mainly used for process automation by exchange of real-time plant data. New requirements like platform-independence and internet capability lead to the development of the UA which includes an abstract data and information model (Address Space) being the basis for a domain-specific model, abstract service for server-client-communications and technology mappings for a web service-based or binary communication. The abstract approach of the 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. Thus, we introduce a mapping between the Address Space and the IEC 61850 data model. The result is a communication architecture with many advantages, e.g. in terms of security, internet communication and interoperability to the OPC world with general purpose Human Machine Interfaces (HMI), over the current IEC 61850-based ways of communication like Manufacturing Message Specification (MMS) [15]. Finally, we provide an overview on how this approach can also be applied to the CIM and the web service mapping of the OPC UA on transport protocol layer.

2 Motivation of the new approach

The main motivation of the suggested approach can be seen when looking at the IEC TC (Technical Committee) 57 Seamless Integration Reference Architecture [13]. The so called SIA is the basic concept where the IEC has put together the standards from the IEC TC 57 in a layered context. Current standardization roadmaps have outlined the importance of IEC TC 57 standards throughout the world [16]. Therefore, one has to get to know the facts and fallacies of this architecture.



Overview on IEC/TR 62357 Seamless Integration Architecture - CENELEC adopted Standards in light grey

Figure 1: IEC TC 57 Seamless Integration Architecture (SIA)

The TC 57 SIA has three main scope components:

- Application and business integration (top and middle)
- Power system integration (bottom)
- Security and data management (left, vertical functions)

On the top layer, the communication models and requirements for the business communications are defined. Those standards mostly fall to national regulation and are therefore specific to each country - only suggestions for the regulators are imposed by the IEC. At application level, the SIA includes object and data models, services and protocols as well as interfaces between systems, communication architectures (e.g. SOA - service oriented architecture), processes and data formats. The basic data model and domain ontology for the future smart grid is the CIM (IEC 61970/61968), which provides interfaces for the primary and secondary IT in terms of EMS and DMS (Distribution Management System). Leading communication protocols are standardized in IEC 60870 (transport protocols) and IEC 61850-7-4xx (substation automation and DER (Distributed Energy Resources) communication). In the field of smart metering, the SIA tries to standardize applications and functions not too much to leave enough space for innovations and vendor specific implementations - and of course, work done by other TCs. Of particular interest is the aspect of safety and security

providing security for the whole vertical data exchange and communication chain.

Within our work, the OPC UA will be presented in the very context with the IEC 61850 being the most recommended field automation standard nowadays, focusing on substation automation and DER. We show how a technology mapping can be achieved and why the OPC UA can be a useful ACSI (Abstract Communication Service Interface) interface implementation. The contribution is therefore organized as follows. First, we provide a short introduction into the new OPC UA which will show the new concepts and changes from the existing Microsoft driven OPC DA. Next, we elaborate more on the two most important IEC standards for smart grids, the IEC 61850 family and the IEC 61970/61968 CIM [21]. In the demonstration and technical part of this contribution, we show an application of the OPC UA Binary serialization and mapping for the 61850 logical node model, namely the most used logical node MMXU for measurements. We discuss further examples for the PLCopen view and the CIM view, providing more insight to the general applicability of the OPC UA standard. Finally, we provide a conclusion of our work and outline future perspectives for the technology and recommend work to be done in certain scopes.

3 OPC Unified Architecture

The OPC UA is developed by the OPC Foundation¹ and standardized by the IEC 62541 [14]. Classic OPC - the predecessor of OPC UA - is well accepted and ap-

¹<http://www.opcfoundation.org/>

plied in industrial automation. There are over 22.000 OPC products on the market from more than 3.500 companies, including all major automation vendors [2]. As a consequence, almost every system targeting industrial automation implements classic OPC. With its flavors OPC DA, OPC A&E and OPC HDA classic OPC provides interoperability between automation components like controllers and HMI running in Microsoft Windows environments.

OPC Unified Architecture unifies these existing standards and brings them to state-of-the-art technology using service-oriented architecture. By switching the technology foundation from Microsoft's retiring COM/DCOM (Component Object Model/Distributed Component Object Model) to web service technology OPC UA becomes platform-independent and can be applied in scenarios where classic OPC cannot be used today. OPC UA can run directly on controllers and intelligent devices having specific real-time-capable operation systems where classic OPC would need a Windows-based PC on top to expose the data. It can also be seamlessly integrated into Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) systems running on Unix / Linux using Java applications and still fits very well in the Windows-based environment where classic OPC lives today.

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 [4]. OPC UA provides a robust and reliable communication infrastructure having mechanisms for handling 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. Of course, an application running on limited hardware can only provide a limited set of data to a limited set of partners whereas application running on high-end hardware can provide a large amount of data with several decades of history for thousands of clients. But 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 meta data accessible on the server.

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. OPC UA has built-in support allowing several different standardized information models to be hosted in one OPC UA 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 [15]:

- *Using object-oriented techniques including type hierarchies and inheritance.* Typed instances allow clients to handle all instances of the same type in the same way. Type hierarchies allow clients to work with base types and to ignore more specialized information.
- *Type information is exposed and can be accessed the same way as instances.* The type information is provided by the OPC UA server and can be accessed with the same mechanisms used to access instances.
- *Full meshed network of nodes allowing information to be connected in various ways.* OPC UA allows supporting various hierarchies exposing different semantics and references between nodes of those hierarchies. The same information can be exposed in different ways, providing different ways to organize the same information depending on the use case.
- *Extensibility regarding the type hierarchies as well as the types of references between nodes.* OPC UA is extensible in several ways regarding the modeling of information. Besides the definition of subtypes it allows - for example - to specify additional types of references between nodes and methods extending the functionality of OPC UA.
- *No limitation on how to model information in order to allow an appropriate model for the provided data.* OPC UA servers targeting a system that already contains a rich information model can expose that model "natively" in OPC UA instead of mapping the model to a different model.
- *OPC UA information modeling is always done on the server-side.* OPC UA information models always exist on OPC UA servers, not on the client-side. They can be accessed and modified from OPC UA clients. An OPC UA client is not required to have an integrated OPC UA information model and it does not have to provide such information to an OPC UA server.

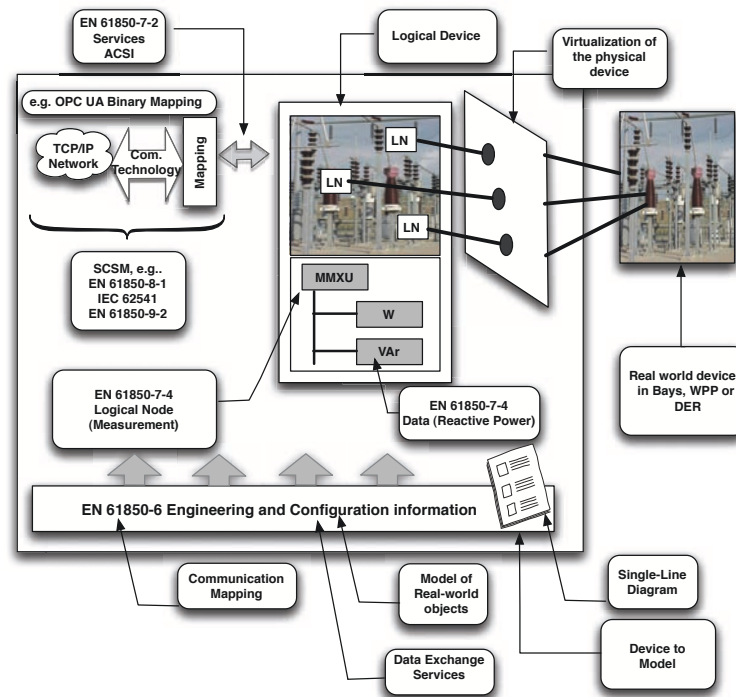


Figure 2: IEC 61850 logical model and implementation

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.

4 IEC 61850 - Communications for substation automation and DER

The IEC 61850 standard was developed by the IEC TC 57 working group 10 [6]. The standard itself consists of several sub-standards dealing with communication protocols, data models, security standards, etc. The overall focus of the family lies on substation automation and its corresponding communication (substation intra-application communication) unlike the CIM which focuses on energy management systems and control-center intra-application integration. Both standards have a basic data model but the serializations differ. A XML-serialization (Extensible Markup Language) in IEC 61850 is only needed for a small subset of objects for engineering of substations. Figure 2 shows the general modeling paradigm and the most important aspects of the standard family. The physical device is mapped onto a logical device which is represented at run-time level on an embedded device. The device has both a data model and control model to get status data from the device and set new control data for the device to act upon.

The data model which represents the physical device

is standardized in the IEC 61850 based on a strictly hierarchical system building a taxonomy. This system has a tree-like taxonomy structure and composed data types. Unlike the CIM, this model also includes functions which focus on set points for control by the SCADA (Supervisory Control and Data Acquisition) and data reports have to be implemented using queues and buffers. The data model consists of more than 100 classes (so-called Logical Nodes), 900 attributes (so-called Data Objects) and 50 base types (so-called Common Data Classes). The services make use of the data model and are defined in part -7-2. The real communication link, however, is done by instantiating the ACSI through a specific communication system mapping (SCSM). Further parts provide information for engineering time, modeling using the logical nodes and providing configuration services. Within this scope the important parts are the ACSI and the logical data model consisting of the parts 61850-7-4 and -420/410.

5 State of the Art

In this section, two existing mappings for the UA are introduced. The first mapping describes the combination of the UA and the CIM and the second mapping describes the combination of the UA and the IEC 61131-3. Both approaches provide valuable results for the suggested mapping of UA and IEC 61850.

5.1 OPC UA and IEC 61970/61968

The CIM is used within the electric utility domain for both distribution and transmission energy management systems [12], [11].

```

FUNCTION_BLOCK CTU_INT

VAR_INPUT
  CU: BOOL;
  R: BOOL;
  PV: INT;
END_VAR

VAR
  PVmax: INT := 32767;
END_VAR

VAR_OUTPUT
  Q: BOOL;
  CV: INT;
END_VAR

IF R THEN
  CV := 0;
ELSIF CU AND (CV < PVmax) THEN
  CV := CV + 1;
END_IF ;
Q := (CV >= PV);

END FUNCTION_BLOCK

```

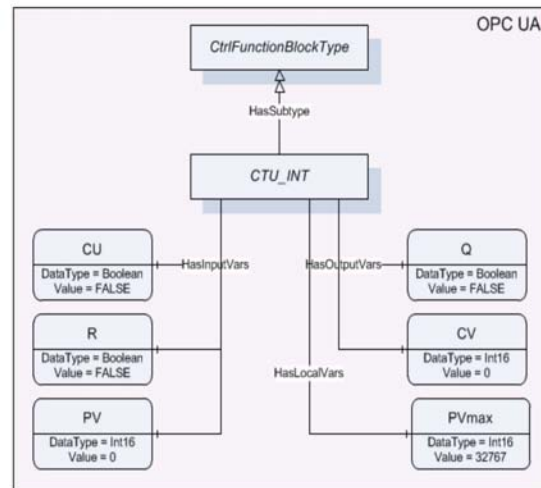
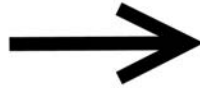


Figure 3: OPC UA and IEC 61131-3 mapping

The electronic model is developed using the UML (Unified Modeling Language) and it is published by the CIM Users Group² and the IEC. The data model includes several main packages with different functionalities. These packages include sub packages and classes with attributes and associations. This set of abstract classes, attributes and associations represents physical objects like cables and abstract objects like voltage levels. Altogether, in version 13 the model consists of 45 packages, ≈ 900 classes, ≈ 870 associations and ≈ 2650 native attributes [26].

For the mapping being the basis for the implementation, we model the abstract CIM UML classes as abstract UA *ObjectTypes*. The UA *Objects* represent the concrete instances of the abstract CIM classes. Concerning other different modeling decisions, basic design decisions have to be made. For example, in specific cases it has to be decided to model CIM attribute either as *Properties* or *Data Variables*. Furthermore, the CIM associations have to be modeled as *References*, but because of the cardinalities, a special UA *ReferenceType* has to be created. Up to this point the modeling is server independent. The next modeling steps for the server's architecture are specific. Especially the design of the *Views* is server specific and depends on the individual needs. A server can use the *Views* to give different clients or groups of clients access to parts of the model relevant to them. *Views* can also be used to deal with the concept of CIM profiles. The CIM is a very large data model and it is difficult and often not necessary to use the complete model for all purposes. To make the use of the CIM more applicable, one commonly uses profiles which include only essential classes and associations of the CIM. In most cases, utilities extend the profiles with their own specific objects for special purposes [26].

For the technical implementation an addin for

SparxSystems Ltd Enterprise Architect (EA)³ was developed. The EA is used to maintain the CIM UML model. The addin is called CIMbaT (CIM based Transformation) and beside the XML based UA Address Space mapping it also realizes a WSML (Web Service Modeling Language) ontology mapping for semantic web services. UA engineers can make several design decisions before the mapping starts. This is necessary because in some cases more than one solution is reasonable. After the mapping is created and the Address Space is generated another tool e.g. OPC UA Address Space Model Designer⁴ can be used to instantiate the Address Space for specific server models.

5.2 OPC UA and IEC 61131-3

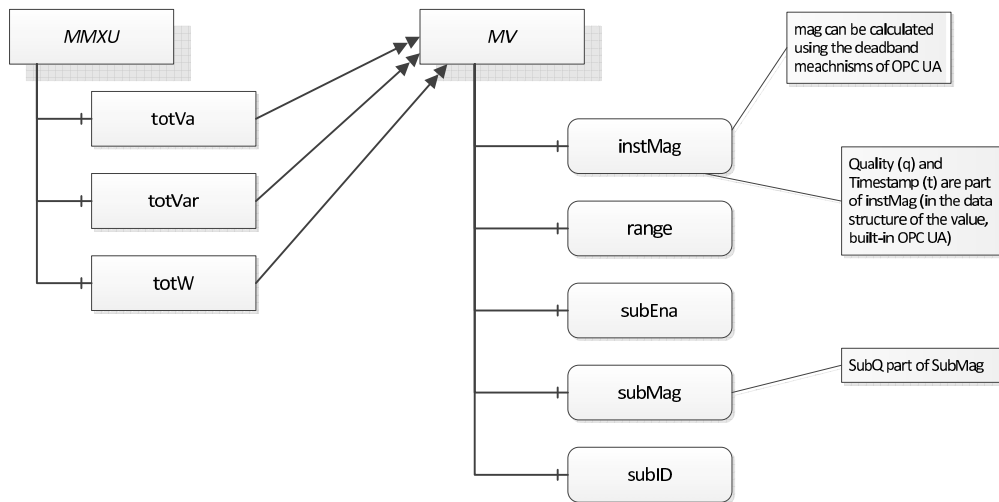
In a joint effort the OPC Foundation and PLCopen developed an OPC UA based information model for IEC 61131-3 languages [5]. IEC 61131-3 standardizes programming languages for industrial automation and defines the common elements of the programming languages. The software model defines different resources with tasks and programs running in those tasks. Programs can be constructed out of function blocks.

The standardized mapping of those concepts to an OPC UA information model is defined in [19]. The main purpose of the first version of the mapping is supporting the observation and operation of PLC (Programmable Logic Controller) programs. This includes reading and monitoring function block parameters and program variables as well as writing them. By using the type information rapid engineering is supported. For example, a user interface can be developed for a specific PLC program defined in IEC 61131-3. This user interface can be deployed to any PLC running this program without the need to reconfigure the user interface other than connecting to the representation of the program in the OPC UA server.

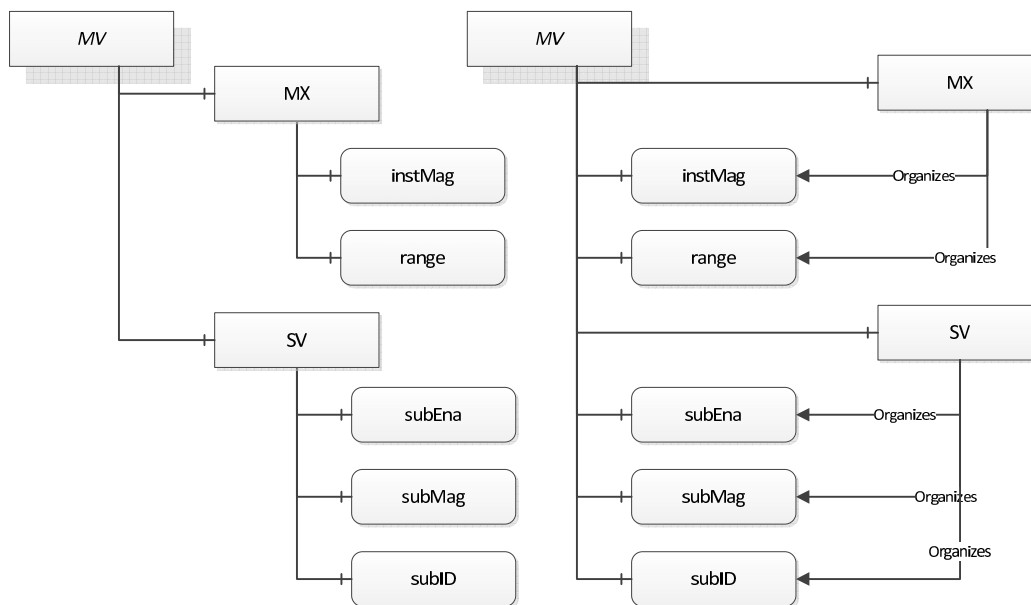
²<http://cimug.ucaiug.org/default.aspx>

³<http://www.sparxsystems.com/>

⁴<http://www.commsvr.com/UAModelDesigner/Index.aspx>



Mapping Option (a) without considering Functional Constraints (FC)



Mapping Option (b) considering FC

Mapping Option (c) considering FC

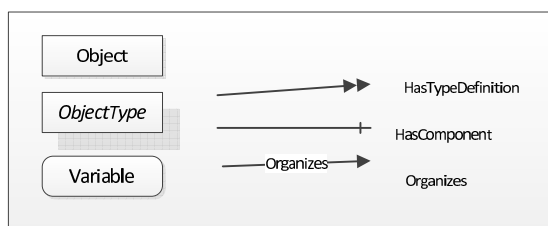


Figure 4: Extract from the mapping of MMXU and MV on UA

An example of the mapping is shown in figure 3. The definition of the function block CTU.INT realizing a counter is shown on the left hand. It is mapped to an OPC UA ObjectType inheriting from the generic CtlFunctionBlockType defined in [19] shown on the right hand. The variables of the function block are mapped to OPC UA variables and the data types of the variables are mapped to the OPC UA DataTypes as defined in [19].

6 Mapping OPC UA and IEC 61850

Due to the fact that the IEC 61850 includes not only a simple data model but also functions, the mapping cannot be done in exactly the same way as for the CIM which is only a data model. There are different ways how 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 times-

tamp should be mapped as all other attributes or handled specifically using the OPC UA mechanisms. Furthermore the Functional Constraints (FC) defined for attributes in IEC 61850 could be made available in OPC UA or not using different modeling alternatives. In this section one possibility for the mapping is introduced making specific use of OPC UA mechanisms and showing alternatives for the mapping of FCs.

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 [10]. The CDC MV represents measured values [9]. Because of limited space, 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 Functional Constraints (FC). FC shall indicate the services that are allowed to be operated on a specific attribute [8]. 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 4 shows three ways of how MV could be realized, one without considering the FC (a) and two ways describing how FC could be realized as organizational groupings. Option (b) defines a mapping where the FC are always visible and option (c) a mapping where FC can be considered or not. The last option is similar to the modeling of parameters for devices as defined in [20].

For the mapping the following decision were made:

- **LN Classes** as defined in IEC 61850-7-x are generally mapped onto UA *ObjectTypes*.
- **LNodeTypes** [7] are generally mapped onto UA *ObjectTypes* subtyping the LN Class.
- **LN** are generally mapped onto UA *Objects* as instances of LNodeTypes.
- **CDC** are also generally mapped onto UA *ObjectTypes*.
- **LN Data** as the attributes of LN are mapped onto UA *Objects*.
- **CDC DataAttribute** as the attributes of CDC are mapped onto UA *Variable*.
- **CDC DataAttribute Type** are the types of the CDC attributes and mainly mapped onto existing UA standard *DataTypes* like Integer, Float and String.

- **FC:** are mapped onto UA *Objects*.

To structure the objects three standard UA *ReferenceTypes* 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 optional grouping by FC.
- **Organizes** could be used as an alternative in the case that the CDC attributes are grouped by FC.
- **HasTypeDefinition** connects the LN attributes with the according CDC.

The mapping shows that it is easily possible to expose the IEC 61850 model in OPC UA. By providing the LN Class and the LNodeTypes in the 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 graphical elements for the MMXU.

7 Future Work

In the scope of future work, we mainly see the application and standardization of the OPC Address Space model mappings for the individual communication mappings of the aforementioned IEC TC 57 standards for the smart grid. As this process in the standardization bodies unfolds, a lot of lessons learned for the vendors of equipment will come up, proving the usefulness of a common communication technology mapping in the smart grid. One important item to achieve this is to check all the smart grid standards for applicability of the OPC UA technology. For the two most dominant ones, this paper has already shown the applicability. As this work progresses, Address Space models and mappings will be made available to the community to use OPC UA server with CIM data at distribution and transmission level as well as mappings for the IEC 61850 ACSI, mainly mapping the data model and the corresponding services to the OPC UA. This works need to be addressed by IEC working groups, recommended from the view of the contributing authors is the IEC TC 57 WG 19 on long term harmonization.

8 Summary

Within this contribution, we have outlined the possible application of the IEC 61850 data and object models alongside the upcoming IEC 62541 OPC UA. We discussed the importance of the IEC 61850 for the future smart grid automation and have discussed the meaningful separation of the data and object model from the actual communications mapping through the so called ACSI. One way to implement the ACSI has been demonstrated through an example using the OPC UA. As a future work item, we have shown the importance of also mapping the CIM to the OPC UA, but from a different perspective,

namely the WebService OPC UA XML interface. This makes for an easy common communications technology for the two main smart grid standards unambiguously accepted in the community. A common communication technology would make for easier implementation and integration of the nowadays separated parts from ICT and automation in the IEC TC 57 SIA.

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