

Multi Domain Information Architecture and Modeling for Smart Grids

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Abstract—Smart Grids are trending towards integrating Industrial Control Systems (ICS) and other domain systems for efficient operational and maintenance activities and cost savings. However, this integration poses the challenge of modeling information in a multi technology domain such that process data (e.g. voltages) and non-process data (e.g. physical access) are exchanged in an interoperable way. This paper surveys the relevant state of the art and selects Common Information Model (CIM) as standardized information model that suits the needs of such integrated systems. Based on this, we propose interoperable information architecture and methodologies to realize multi domain information modeling.

Index Terms—Data Models, Interoperability, Security, SCADA Systems, Smart Grids.

I. INTRODUCTION

Besides employing Industrial Control Systems (ICS) like Supervisory Control and Data Acquisition (SCADA), electric utilities are also employing non-ICS systems, such as physical security systems (PSS), that manage and monitor the facilities (e.g. electric substations). To add value, utilities integrate ICS and non-ICS systems thereby creating new use cases that can potentially save their operational and maintenance costs.

From a high-level system perspective, a Smart Grid information system can be considered to contain the following major building blocks [1]: (a) Smart sensing and metering technologies that provide faster and more accurate response for consumer options such as remote monitoring, time-of-use pricing, and demand-side management. (b) An integrated, standard-based, two-way communication infrastructure that provides an open architecture for real-time information and control to every end point on the grid. (c) Advanced control methods that monitor critical components, enabling rapid diagnosis, and precise responses appropriate to any event in a “self-healing” manner. (d) A software system architecture with improved interfaces, decision support, analytics, and advanced visualization that enhances human decision making, effectively transforming grid operators and managers into knowledge workers.

Throughout this paper, we use a PSS as running example for a non-ICS system. Typical major building blocks of a PSS are [7]: (a) Policies and procedures such as security goals and plans (including incident response) and their implementation.

(b) Personnel such as security guards or receptionists. (c) Access control barriers such as fences, lightning systems or signs. (d) Surveillance and alarm equipment such as motion sensors. (e) Historical records such as access logs and incident reports.

Both Smart Grid components, such as transformers or circuit breakers, and PSS components, such as fences or cameras, are modeled with their relations and data using domain specific (proprietary or standardized) information models. The information modeled in this way is then used for intra-system message exchange within the Smart Grid or the PSS respectively. As the information models are domain specific, inter-system message exchange between a Smart Grid and a PSS is not possible without further ado.

II. CHALLENGE AND USE CASE

Through the Smart Grid (SG) standardization effort, IEC has promoted protocols and information models that ease the interoperability of Smart Grid information systems such as DMS (Distribution Management Systems) or EMS (Energy Management Systems).

As utilities strive for operational efficiency, they start integrating systems from other domains which are not covered by those standards. This lack of interoperability cannot only lead to poor integration approaches, but may miss technical opportunities such as new innovative use cases. The challenge for integrators is to have any system interact with the Smart Grid information system in a unequivocal and consistent way.

To explicitly motivate the need for a multi-domain information integration, we introduce a simple use case where the integration of sensors of multiple domains can lead to operational cost savings.

A. Example Use Case: Visual Monitoring of Substation Switching Operations

For our use case, we focus on primary substations that handle high voltage lines. The future substation will be *smart* and *secure*. To prevent risks of sabotage and theft that could potentially harm the business continuity of the electrical grid, utilities need to deploy physical security monitoring systems composed of various sensors and access control systems, ranging from video cameras to smart fences. For utility

companies, there is a greater return on investment for these physical security assets if they are not only use for security purposes, but also for operations.

An example is the monitoring of high and medium voltage switching operations at the substation. Those operations generally involve a mechanical arm that rotate by 90° to open or close a switch (disconnecter). A typical Pan-Tilt-Zoom (PTZ) security camera could be used to inspect the disconnecter equipment in case of malfunction (due to harsh weather condition, equipment age, etc.) or if the SCADA network is non-responsive. While letting the control center operator remotely visualize the disconnecter and identify root causes of failure more rapidly, more can be achieved by integrating the information processing of the camera with the Smart Grid information systems. By integrating the information systems, detections made by cameras can be directly incorporated to the HMI of the operator in an intelligent manner. By adopting video analytics, such as automatic recognition of the disconnecter status, the camera can directly send a status update to the SCADA system. Thus the integration reduces the information load on the operator while improving system reliability. In order to perform this interaction, the adoption of a standardized information model is primordial.

III. STATE OF THE ART OF INFORMATION MODELS IN SMART GRIDS

In order to promote interoperability, there is a need for different systems to agree on a common representation of information, such that each object, each entity, and their relations and interactions can be described in an unambiguous way. In software engineering, information models allow to specify such semantics for a specific domain of discourse, i.e. Smart Grid. The benefit of using a commonly agreed information model between different vendors is that they can exchange information without the need for translating the data from a vendor specific information model to another.

A. Information/Object Model Standards

There are currently three main standards that define information models related to Smart Grids: The Common Information Model (CIM, IEC61970/61968), MultiSpeak, and IEC 61850-6. We elaborate in the following sections on each of them.

1) MultiSpeak

The MultiSpeak specification (latest version 4.X) defines standardized interfaces among electric utility software applications for distribution only. NRECA started developing MultiSpeak before CIM and is the most widely applied de facto standard in North America pertaining to distribution utilities. Nearly 70 vendors are using the specification in their products and more than 600 electric cooperatives (from 15 different countries) use MultiSpeak supported products in their daily operations [4]. The MultiSpeak specification defines three components:

- Definitions of common data semantics: Data semantics is an agreement on what data needs to be

exchanged for different business processes (e.g.: outage management). It is defined as XML schema.

- Definitions of message structure: It defines the message structures to support the required data interchanges of different business processes. XML-formatted data payload is carried as part of a web services call for real time exchanges and as part of a batch file for off-line transfers.
- Definition of which messages are required to support specific business process steps: Web services method calls are linked together to accomplish each potential step in a utility business process.

MultiSpeak specification establishes interface for information flow between different software functions. A utility application can choose the MultiSpeak functions they want to support in their software application. MultiSpeak supports two communications transfer options: file based and web services (SOAP messages using HTTP over TCP/IP sockets connections). Web services is real time data transfer based (i.e no intentional time delay) while file based is batch communication based. MultiSpeak uses three different communication modes: batch communication (B), request/response (RR) communication and publish/subscribe (PS) communication.

2) CIM

The Common Information Model (CIM) allows different software applications to exchange information about the configuration and status of an electric network. It also permits the data exchanges between systems of multiple vendors.

CIM for the power sector comprises of three standards: IEC 61970, and two extensions IEC 61968, and IEC 62325. Each standard has a different domain focus, respectively transmission (61970), distribution (61968), and market (62325). These standards define among other things information models and message exchange format, which are the focus of this section. The information model is described using Unified Modeling Languages (UML) and is organized in packages. Each package contains a set of classes along with their inheritance structure, their attributes, and their associations. In order to provide a machine readable version of CIM, as well as a serialization of information modeled using CIM, IEC 61970 further specify a mapping from UML to RDF (Resource Description Framework), as well as how message should be serialized in XML (CIM XML). RDF provides a standard method for modeling information and is commonly used in web technologies.

To enhance the interoperability of subsystem, the standard defines profiles which apply for a specific application. Profiles are subsets of CIM, which generally contains a few dozen classes, whereas the whole CIM comprises more than 700 classes. IEC 61970 defines a few profiles such as “Schematic Layout Profile” or “Topology Profile”.

Currently, CIM is mainly used by EMS applications in order to exchange information about the current transmission state among distributed EMS systems. However, the potential of CIM is much higher as it can be used to describe and

exchange data about almost anything related to power systems and its management, including workforce and energy markets.

3) SCL

IEC 61850-7 is one of the core standards of IEC for the SG standardization. The scope of the object model is for the substation automation only, and thus does not cover transmission or distribution semantics as the previous models. Parts 61850-7-3 and 61850-7-4 define the object model that describes the primary equipment and secondary equipment of the substation. Part 61850-7-2 defines the communications services, which permits to query or send commands to the devices. Part 61850-6 finally defines an XML language called SCL (Substation Configuration Language) and 4 file formats for describing the configuration of substation equipment and IEDs configurations. The most interesting of those files is the Substation Configuration Description (SCD) file, which describes the complete substation configuration, including single line diagrams, communication network, and IEDs configurations.

To summarize, IEC-61850 provides a language that describes substation automation in a comprehensive way. It is a core standard of Smart Grids, and there is a trend that IEC 61850 will gain market share in the incoming years. As both CIM and IEC 61850 model substation automation, it is on the roadmap of CIM to harmonize with IEC 61850, such as conversions between the two models become unequivocal [1].

B. Mapping between Different Models

1) Mapping between IEC 61850 and CIM

Both CIM and SCL from IEC 61850 can model the substation equipment as depicted on Figure 1. IEC TC 57 has currently on their roadmap to harmonize both standards such that the mapping between the two information models can be done more easily.

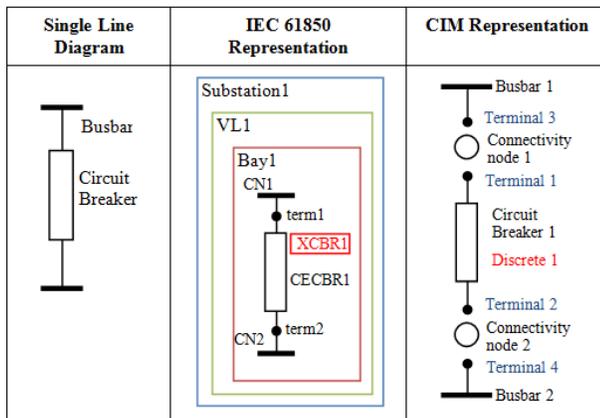


Figure 1: Substation representation under IEC 61850 and CIM [3]

For now, there exist semi-automated approaches to create converters between IEC 61850 and CIM models such as reported in [8].

2) Mapping between MultiSpeak and CIM

Message headers can be readily mapped between MultiSpeak and IEC 61968 but mapping of message content

between the two is more complex. A direct translation between CIM and MultiSpeak can be achieved using style sheets and readily available tools [5]. A collection of stylistic rules (like layout) is called style sheet (e.g. XSL). A custom style sheet can be used to map the objects and attributes of MultiSpeak to their corresponding classes and fields in CIM. However, this does not guarantee completely compatible semantics, but an IEC working group (WG14) is active in producing mapping guidelines between the MultiSpeak Version 4.0, IEC 61970 Version 13 and IEC 61968 Version 10 [5]. They are currently developing two set of standards: IEC 61968-14-1-3 to 14-1-10 (Proposed IEC Standards to Map IEC61968 and MultiSpeak Standards) and IEC 61968-14-2-3 to 14-2-10 (Proposed IEC Standards to Create a CIM Profile to Implement MultiSpeak Functionality) [6].

IV. ANALYSIS AND DATA MODEL SELECTION

In this section we have analyzed the state of the art information models (see Section III), identified its gaps and selected an information model for our information architecture based on specific evaluation criteria.

A. Gaps in Existing Standards

Table 1 shows gaps in the different models. We look at the relevance of the standards by capturing the domain of discourse and markets covered by the standard. Furthermore, we evaluate technical implementation of the protocols such as technologies currently use to transport and represent the models.

B. Information Model Evaluation Criteria

We select the information model for exchanging information between PSS and SCADA based on the following criteria:

- The information model should make the PSS interoperable with SCADA systems from different vendors. This maximizes the return on investment for the solution development.
- For future expansions, the information model should allow a seamless integration of the PSS with various maintenance and energy utility applications (e.g. SCADA, DMS, and EMS).

C. Information Model Selection

Applying the criteria defined in Section IV.B to the information models summarized in Table 1, we recommend CIM (IEC 61970/61968) as the preferred information model standard to be used to exchange data between PSS and SCADA applications for the following reasons:

- Market penetration: A large number of electric utilities in US and UK are using applications that support “CIM for power systems” [2]. NERC sponsorship of CIM as standard for exchanging operational power system models between control areas and security coordinators has encouraged this mass adoption in North America. The adoption in Europe is driven by Transmission System Operators (TSO) who is currently adopting the standards to

exchange information about the state of the transmission grid.

- CIM not only models substation automation like SCL, but the whole power transmission and distribution infrastructure.
- CIM makes it simple to realize data exchange with SCADA and also with other electric utility applications like DMS and EMS [2].
- It is foreseen that IEC will harmonize CIM with the object model of IEC 61850 in the future (IEC TC57 WG19). At the same time the trend is that the usage of IEC 61850 (core standard of Smart Grid) will increase worldwide.

V. INFORMATION ARCHITECTURE

This section proposes an interoperable information architecture for integrating multiple domain systems in Smart Grid.

A. Data Exchange with CIM Compliant Systems

Figure 2 shows the Policy, Personnel, Equipment and Records components of a PSS as introduced in Section I and a Message Bus component that stands exemplarily for any kind of intra-PSS communication system.

In order to exchange data with Smart Grid applications which support CIM, such as a SCADA application, our CIM module provides the following subcomponents: a CIM Mapper, a CIM Parser/Constructor and a Middleware component. While the former two deal with information layer specific CIM tasks, the latter deals with the communication layer which might be using CIM based or any other suitable protocol such as Open Platform Communications (OPC) or others.

The CIM mapper sub component comprises of the CIM information model, PSS model, mapping table and mapping engine. The PSS model is a proprietary model whose format varies as per the vendors. The mapper table is a static lookup table that holds entries of the CIM elements and its corresponding PSS elements. In runtime when the CIM module receives the CIM information the mapping engine selects the equivalent PSS representation and sends it to the PSS message bus.

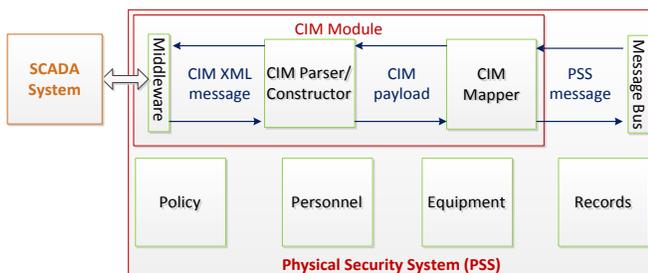


Figure 2: PSS CIM Module

a) SCADA to PSS

The CIM XML message from the SCADA system is received by the PSS system via the Middleware of the CIM

module. It is then parsed by the CIM Parser/Constructor and the CIM payload is extracted and sent to the CIM mapper. The mapping engine (of CIM mapper) accesses the mapping table (of CIM mapper) to identify the corresponding PSS representations for each of the SCADA data within the CIM payload. Thus the CIM Mapper converts this CIM payload information into the PSS information model and forwards it as PSS message to the PSS Message Bus. The PSS message can be in XML or any other format as defined by the vendor.

b) PSS to SCADA

The CIM Mapper receives the PSS message from the PSS Message Bus and converts it into CIM payload. The CIM Parser/Constructor then embeds it into a CIM XML message and communicates it via the Middleware to the SCADA system.

B. Data Exchange with CIM Non-Compliant Systems

For a utility which has not adopted an integration framework based on CIM, two alternatives exist to integrate a PSS with the utility's system. In case CIM is already implemented in the PSS, then implement an intermediate mapper that translates the utility's information model to CIM e.g. as discussed for SCL and MultiSpeak in Section III.B. Alternatively, implement an adapter converting the utility's information model directly to the PSS information model.

The intermediate mapper solution has several advantages over the adapter solution as follows: First, the mapper can be reused by the utility provided that it is implemented as a reusable, stand-alone component. Second, the mapper may have already been implemented by a third party and could be bought. Third, from an architecture perspective, it cleanly separates the model from the control, thus respecting the widely adopted model-view-controller pattern.

VI. CIM MODULE REALIZATION

In order to realize our CIM module the exchanged multi domain data should be modeled in an interoperable way, and the message exchange format as well as the system interface should be defined.

A. Multi Domain Information Modeling Methodology

The methodology to generate CIM Information model is proposed in this subsection. The PSS model can be generated via a method analogous to that of our CIM Information model.

Traditionally CIM is used for modeling only single, Smart Grid domain information as presented in [11] and [2]. In Figure 3 we propose a methodology for generating the CIM Information model element of the CIM mapper subcomponent (see CIM module in Figure 2), by extending this single domain to a multi domain modeling methodology. As per our method CIM is not only used to model smart grid application data but also models flexibly other domain data (e.g.: PSS data like physical access info), to generate a CIM XML RDF schema which can be seamlessly exchanged between different electric utilities and enables interoperable system. The most common and accepted tools (open source and commercial) in the CIM community that support the integration of CIM into Smart Grid applications include CIMBench, CIMTool,

CIMSpy, Enterprise Architect (EA), CIM EA, and CIMDesk [11].

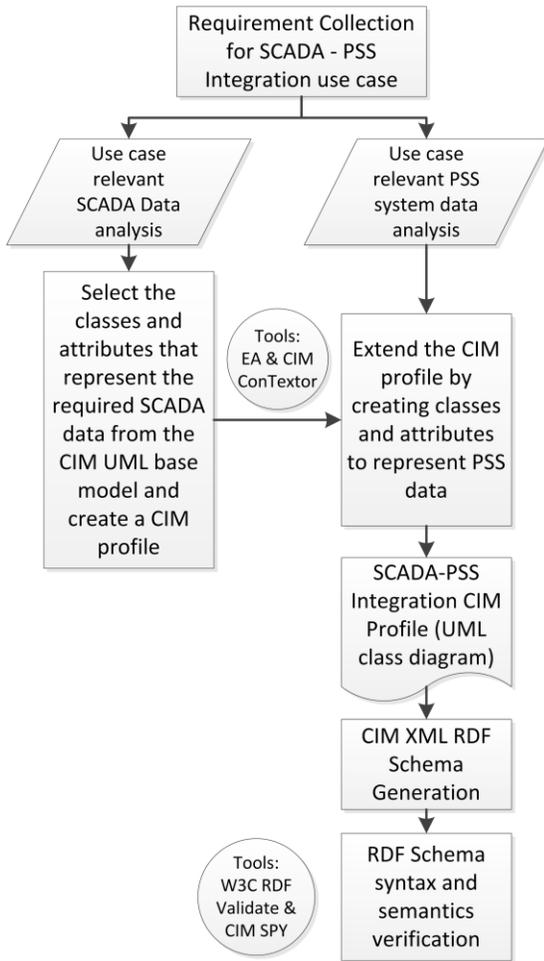


Figure 3: Information Modeling Methodology

B. Standardized Message Exchange and Interface

CIM standard not only defines the information modeling methods but also defines the message exchange format as well as the interfaces for inter application message exchange. The following methodology is proposed for a) PSS to realize CIM standardized message exchange with ICS system, b) aid defining an interface between PSS and SCADA

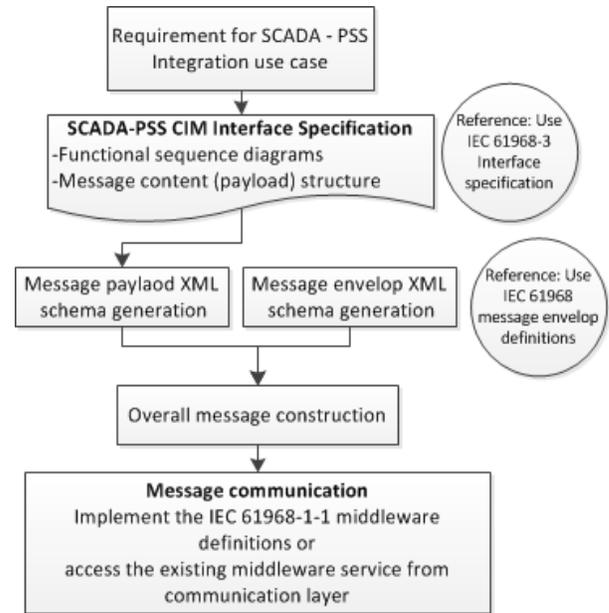


Figure 4: Standardized CIM XML message exchange and interface methodology

VII. RELATED WORK

PHYSBITS [12] is a vendor-independent framework integrating PSS and IT security (ITS) supporting enterprise risk management. An interesting aspect of PHYSBITS is that it comes with a data model to exchange data between PSS and ITS, but exchange with ICS is not yet supported.

The work presented in [15] describes a method to provide CIM clients access to classes and metadata that are outside its namespace by introducing an association class and a mapping file. Their work focuses on mapping existing namespaces, but does not consider incorporating new data domains.

In [14] the authors describe a way to extend CIM models and make them more flexible without requiring changes to existing/current implementations. They add the concept of multiple inheritance associations to CIM, which is not sufficient for support multi domain modeling needs like process and non-process data representation

In [13] the authors investigate data interchanging and functional duties of life-cycle assets management (LCAM) in Smart Grid and propose a corresponding CIM-based data

TABLE I. GAPS IN EXISTING STANDARDS

	CIM (electricity)	MultiSpeak	IEC 61850
Utility domain	Extensive coverage of the Smart Grid domain. Gaps in dynamics and weather data	Only covers distribution	Covers essentially substation automation
Markets focus	International, but existing products have limited support	Only predominant in USA	International, market penetration is slow due to long lifetime of substations
Data transfer	Transport independent.	SOAP messages using HTTP, TCPI/IP	Communication defined in IEC 61850 is aimed at substation automation only.
Multi-Domain Extension	CIM does not support PSS; but its model can be extended	MultiSpeak model does not support PSS; but can be extended.	Considerable extension of the object model needed to support PSS

integration framework. A limitation of their work is that their data model does not integrate with the one of the substation.

In [16] the patent seems to cover modeling video data using CIM, but the available English version of the document has not been translated in an understandable manner.

VIII. CONCLUSION AND FUTURE WORK

The current Smart Grid standardization efforts do not address interoperability of information systems that are unrelated to Smart Grid operations. We have introduced an exemplary use case namely the visual monitoring of substation switching operations where the integration of multiple sensors from SCADA (operational domain) and PSS systems (non-operational security domain) can lead to cost saving.

Based on our state of the art Smart Grid information model analysis and evaluation criteria we have selected CIM. We have proposed based on this information model an interoperable information architecture for integrating multiple domain systems in Smart Grid. This architecture enables seamless data exchange of non-operational domain systems (like PSS) with both CIM compliant as well as CIM non-compliant operational domain systems (like SCADA). The current single domain data modeling realization procedure is extended by us to propose a multi domain information modeling methodology, which can enable developers to flexibly implement as well as extend the information architecture. A procedure to develop SCADA and PSS system interface specification is also presented.

As part of future work we intend to develop a SCADA-PSS CIM profile using our multi domain data modeling methodology.

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