Smart Grid Architecture Committee (SGAC) Standard Review
IEC 61850 Suite of Standards White Paper

November 2011

Standard Name	**IEC 61850 Suite of standards – Communication networks and systems for power utility automation**
Standard Number	IEC 61850
Standard Development Organization	International Electrotechnical Commission (IEC)
Priority Action Plan	None directly but many indirectly, including PAP 7, PAP 8, PAP 11, PAP 12, PAP 13, PAP 14, PAP 16, and PAP 17
URI to Specification	http://iec.ch

1. Objective of this White Paper

This SGAC document describes the IEC 61850 suite of standards as an architecture, addressing the concepts and structural components of the various IEC 61850 parts within the suite, including the different domains that are covered. The details of each of those parts will be provided in the formal SGAC reviews. This document can act as an introduction to IEC 61850, so that a more complete understanding can be achieved as each of the individual parts are reviewed.

2. Purpose and Scope of the IEC 61850 Suite of Standards

The objective of the IEC 61850 suite of standards is to provide an architecture that will meet the requirements for communications and information exchanges of field equipment.

The IEC 61850 standards cover a broad range of field equipment, including:

- Within substations
- Between substations
- Between substations and control centers
- Within hydro power plants and (currently underway) turbine power plants
- With distribution automation equipment
- With distributed energy resources, including generation and storage systems
- With electric vehicle charging systems

The structure and interrelationships of the different parts are shown in Figure 1.

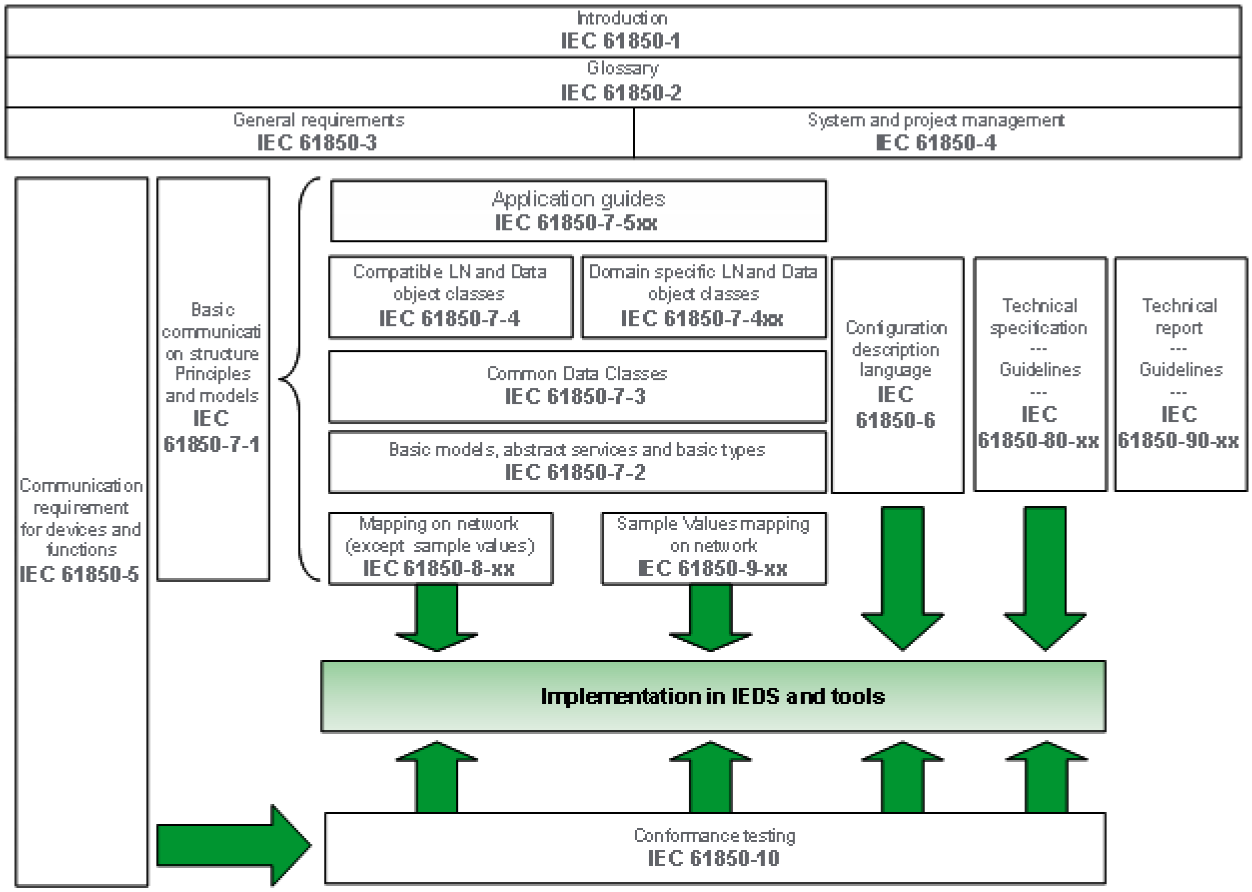

Figure 1: IEC 61850 Interrelationship of parts

3. IEC 61850 Architectural Concepts

The IEC 61850 suite of standards defines a layered communication architecture for power system automation, focused on managing intelligent systems connected with the power system. IEC 61850 as an advanced automation standard is designed to work in distributed computing environments that include those operating in "real-time" where the information exchanges must occur within tightly defined time frames, including less than 4 milliseconds, 10s of milliseconds, seconds, and longer.

This IEC 61850 communication architecture consists of standards that define abstract semantic object models of classes (representing hierarchical information models) and syntactic services, such that these object models are independent of specific protocol stacks, implementations, and operating systems. The IEC 61850 architecture also includes standards that define the mapping of these abstract object models and services to actual protocol stacks, such as the Manufacturing Message Specification (MMS), GOOSE messaging, web services (being updated), and (as a work in progress) DNP3. Additional IEC 61850 technical reports provide guidelines and descriptions on design, implementation, and testing of systems that use the IEC 61850 modeling and mapping standards.

From an architectural modeling perspective, the IEC 61850 suite of standards covers a number of the GWAC stack layers (see Figure 2), including:

- Layer 5: Business context

- Layer 4: Data object semantic models
- Layer 3: Syntactic messaging services
- Layer 2: Networking layers
- Layer 1: Basic connectivity (connection performance requirements)

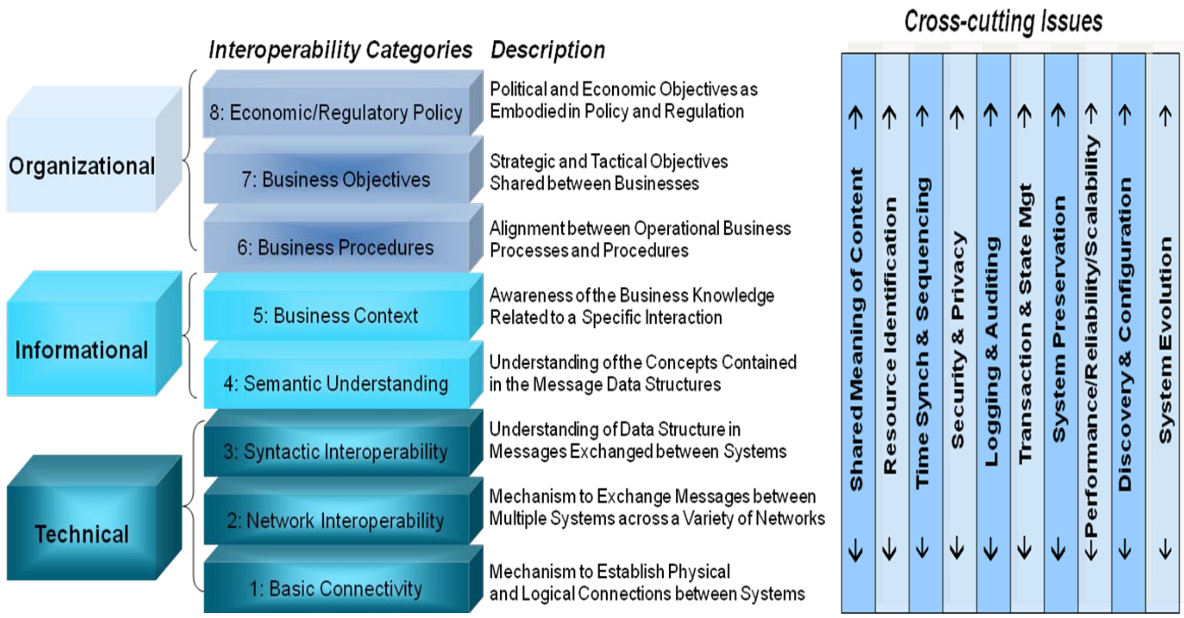

Figure 2: GridWise Architecture Council Stack (GWAC Stack)

These layers allow mixing and matching so that different performance and configuration requirements can be met, as shown in Figure 3 which compares the scope of different communication standards to the GWAC Stack.

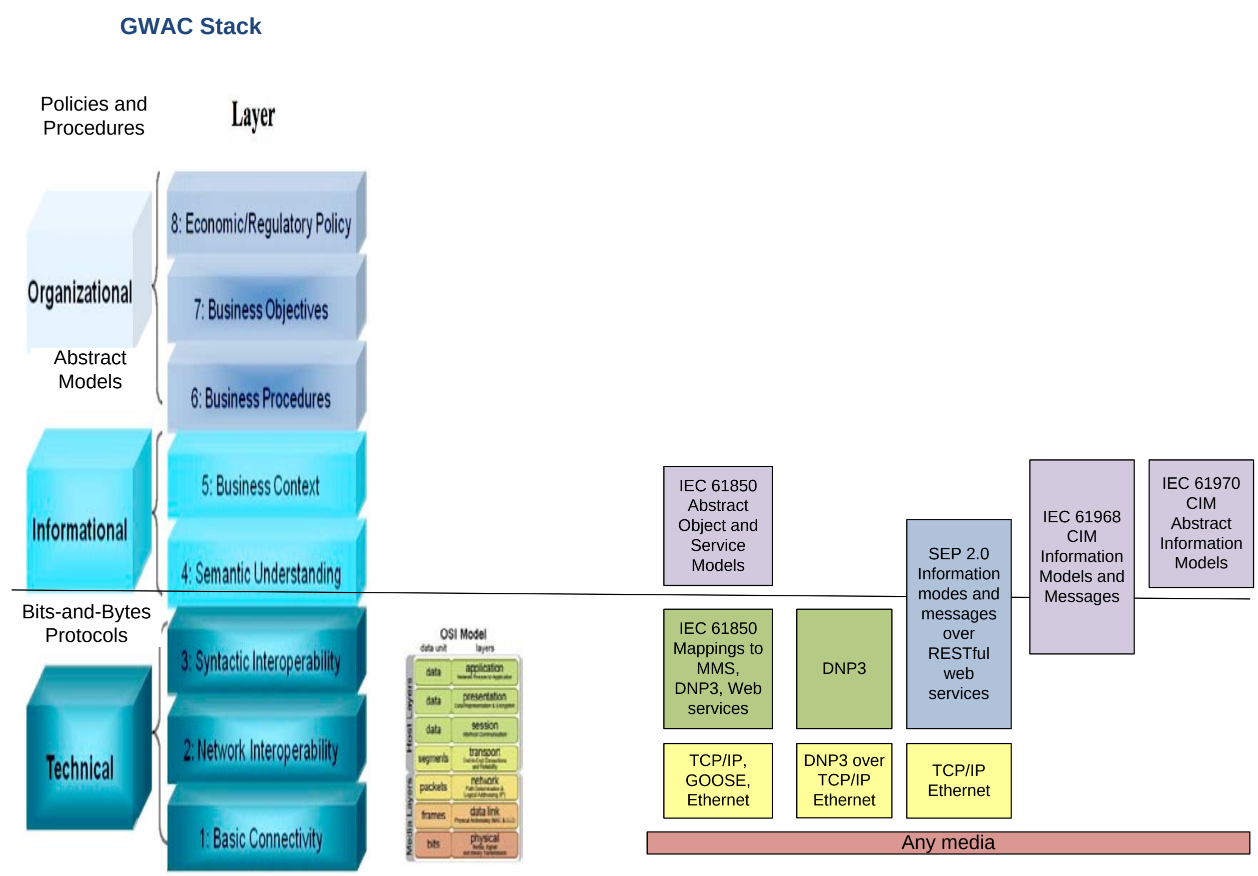

Figure 3: Comparison of IEC 61850 components to other standards in the context of the GWAC Stack

A simple diagram showing the breadth of IEC 61850 and comparison to CIM is shown in Figure 4.

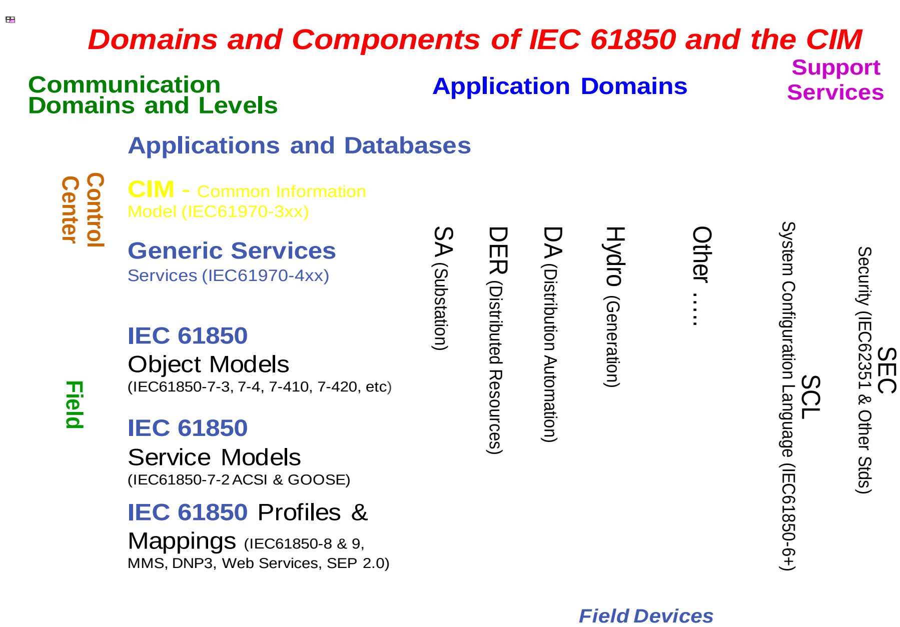

Figure 4: Domains and components of IEC 61850 and CIM

4. Key Parts of IEC 61850 Suite of Standards

The goal of the IEC 61850 suite of standards is to provide interoperability for the information exchanges between the Intelligent Electronic Devices (IEDs), controllers, and systems used in power system automation. The standards were first developed for substation automation, but are increasingly being implemented in other domains, such as phasor measurement units, Distributed Energy Resources (DER) generation and storage, electric vehicle chargers, wind power plants, and hydro power plants.

- The primary IEC 61850 standards for **substations** are IEC 61850-5, 6, 7-2, 7-3, 7-4, 8-1, 9-1, & 10, although parts 7-3 and 7-4 are now the basic object models referenced by other parts. 8-1 is the mapping to MMS which is also used by other devices.
- The primary IEC 61850 standard for **hydro power plant** object models is IEC 61850-7-410.
- The IEC 61850 standards for **distributed energy resources (DER)** cover generation and storage systems typically interconnected to the distribution or subtransmission circuits. DER systems include diesel generation as well as renewable generation such as photovoltaic systems, fuel cells, combined heat and power, and battery storage. The primary Parts for DER are IEC 61850-7-420 and 90-7 with additional parts under development.
- IEC 61850 standards for **wind power** are being implemented as IEC 61400-25-2 & 25-4.
- Cybersecurity for IEC 61850 is provided by IEC 62351

5. IEC 61850 Architecture of Multiple Layers

The IEC 61850 architecture covers multiple layers, but separates them into different parts that are coordinated to form a complete communications architecture. This approach allows flexibility to meet different architectural requirements and expandability to include new functions and new types of systems.

The IEC architecture does provide appropriate functionality for these various layers. Additional effort is being made to ensure these layers are well coordinated and capable of being expanded without major backward compatibility concerns.

In brief, the IEC 61850 architectural components are illustrated in Figure 7 and consist of:

- **IEC 61850 abstract object models (nouns):** IEC 61850 standardizes an extensible set of the data objects that might need to be communicated for various kinds of devices. Every data object has a unique name so that it can be "understood" when received in a message. Data objects can be added with little difficulty to cover any kind of technical or business process innovation. These data objects are organized into logical groupings called Logical Devices (LD) and Logical Nodes (LNs) and their exchange formats are specified by standardized Common Data Classes (CDCs) and common attributes which are constructed of standard data types such as integers, floating point, Boolean, etc. The CDCs are characterized by type such as status, setting, measurement, and control, while most include at least the data value, a timestamp, and a quality code. Strict naming rules must be followed for the data object names to ensure they are both unique and understandable by both servers and clients. These data objects, currently defined on "paper", are in the process of being converted to UML class models.

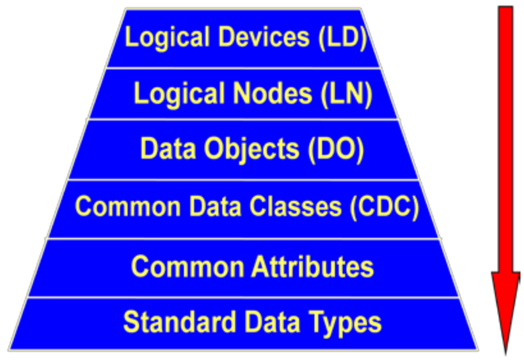

Figure 5: Hierarchy of the IEC 61850 abstract object model

- **IEC 61850 abstract services model (verbs):** The IEC 61850 standard includes many different types of abstract services, including:
  - Real-time data access and retrieval
  - Device control
  - Reporting by exception
  - Event logging
  - Publish/subscribe
  - Self-description of devices (device data dictionary)
  - Data typing and discovery of data types
  - File transfer

  The real-time data access is further refined into specific services that allow access not only to the individual values, but also to the metadata structures and sets of data, including GetDataDirectory, GetDataValues, SetDataValues, GetDataSetValues, SetDataSetValues, CreateDataSet, etc. In addition, there are a number of ways of initiating the services, including "on request", "report by exception", "report periodically".

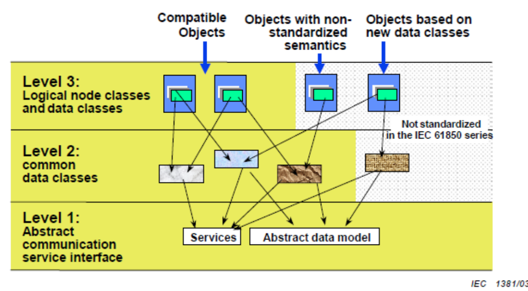

Figure 6: IEC 61850 logical nodes, common data classes, and services

- **Dynamic creation of Data Sets for messaging.** Data objects using these services can be combined in Data Sets. A Data Set is a collection of data objects that can be defined at configuration time or even during communications. Unlike some other standards, the actual messages are ***not*** standardized – only the method is standardized for creating the messages (CreateDataSet) and providing the client with the definition of those created messages (GetDataSetDirectory). DataSets can be pre-installed for convenience, but since their content is not standardized, they do not limit the new types of data and combinations of data that could be exchanged. This concept is critical to the flexibility and expandability of the IEC 61850 standards as new requirements are identified over time.

- **Mappings to different communication stacks and protocols**. The abstract services model was designed to be mapped to a variety of communications protocols. The first mapping is to the Manufacturing Message Specification (MMS) ISO/IEC 9506 which can run over TCP/IP, MMS mapped into high speed GOOSE protocol, MMS over Ethernet. Additional mappings have been made to web services, OPC/UA, and more recently to DNP3 (IEEE 1815.1 / IEC 61850-80-5) and partially to SEP 2.0.
- **Separation of abstract components from "bits and bytes" protocols.** A fundamental architectural concept is the necessity for separating the abstract objects and services from the mappings to different communication protocols. This fundamental concept provides IEC 61850 the flexibility to meet many different performance and configuration requirements, and allows it to expand to new domains, respond to new performance scenarios, and take advantage of new protocols as these are developed.
- **Interoperability of data objects and messages**. Since different data objects within different messages with different performance requirements are needed by different implementations, it is not practical to standardize messages. Therefore, IEC 61850 developed concepts and services that can be used to "discover" what data objects that a server can provide, to "create" new messages of combinations of these data objects, and to tell the server to start sending these new messages (report by exception, periodically, on request, etc.). Therefore, a client can "discover" all data objects in a server via the IEC 61850 services, and can combine groups of data objects into DataSets that can be sent together via other IEC 61850 services.
- **System configuration language (SCL)**. Since logical devices can have many different configurations and include different logical nodes with only the necessary subset of data objects within the logical nodes, the IEC 61850 has a system configuration language that provides the standardized approach to configuring systems. Many tools have been developed to implement this SCL capability.

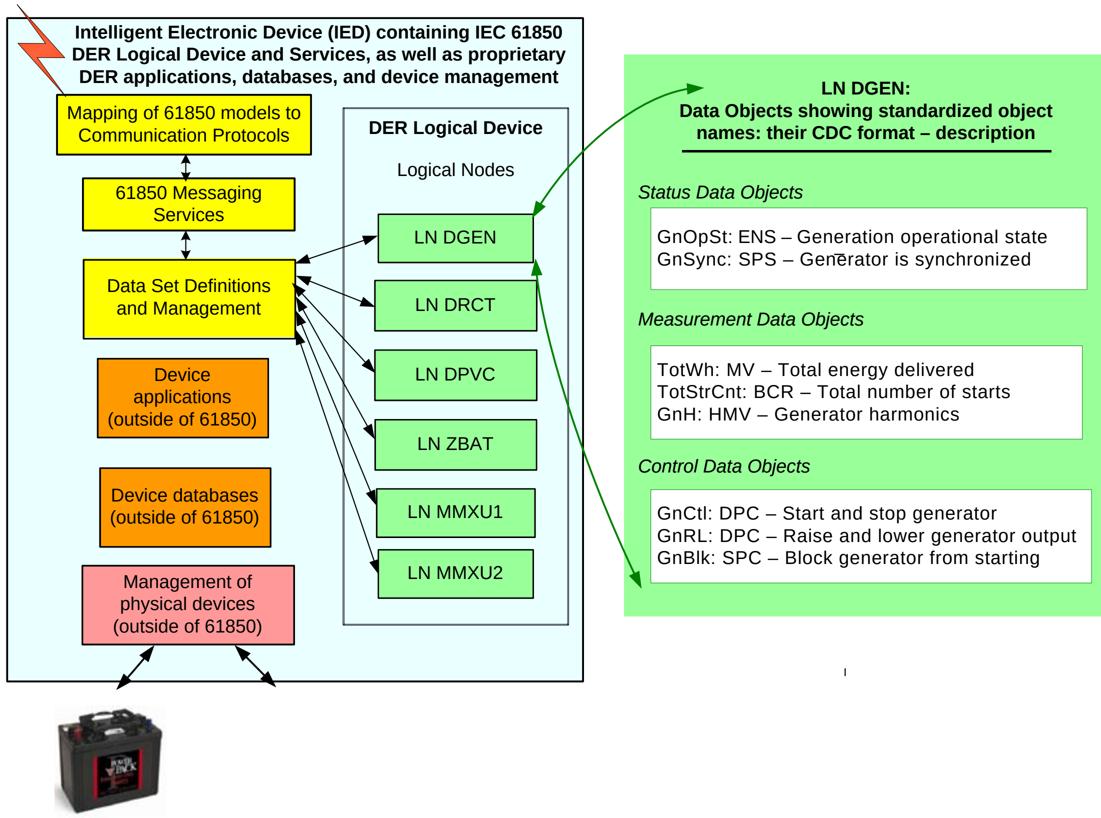

Figure 7: Example of IEC 61850 Architectural Components

6. IEC 61850 Extendibility and Future-Proofing

The IEC 61850 architecture is very flexible and extensible, and multiple IEC TC57 working groups are currently very active developing additional IEC 61850 parts to address new requirements, such as those needed in the Smart Grid for additional substation automation functions, condition monitoring, inverter-based renewable energy, distribution automation, new types of DER generation and storage devices, electric vehicles, wind power, hydro and turbine power plants, etc.

The IEC 61850 models are currently being translated into UML models so that they will be available electronically and will ensure more consistency as extensions to the existing models are created. The UML models are planned to be available through the UCA International Users Group, and will be the source for all IEC 61850 object model standards.

In addition, IEC 61860 has developed the System Configuration Language (SCL) (IEC 61850-6) that provides the standardized methods for implementing new configurations.

The IEC 61850 architecture does not limit options for innovation in the future since it is constantly evolving to address new requirements as they are discovered.

7. Migration Path from Legacy Protocols to IEC 61850

A number of protocols are still in use in many of the domains covered by IEC 61850, including DNP3, ModBus, and many other legacy protocols. Migration paths are being developed through the development of standards for mapping to these older protocols. For instance, a standard is being developed to translate between IEC 61850 and DNP3 (IEEE 1815.1 / IEC 61850-80-5).

In addition, new work is being started to update and improve the existing IEC 61850 mappings to web services. These updates will support the implementation of IEC 61850 communications in XML-based environments, including SEP 2.0. With the object models being converted into UML models, this mapping to modern technology will help ensure consistency and will simplify electronic access.

8. NIST / SGIP Priority Action Plans (PAPs) Related to IEC 61850

The IEC 61850 architecture is not directly associated with any specific PAP, but some parts are related to the efforts of some PAPs. These include:

- IEC 61850-7-420 and IEC 61850-90-7 (Distributed Energy Resources) are associated with PAP 7, PAP 8, and PAP 17
- IEC 61400-25 (wind power version of IEC 61850) is associated with PAP 16
- IEC 61850-90-5 (PMU time synchronization) is associated with PAP 13
- IEC 61850-90-8 (under development) is associated with PAP 11
- IEC 61850-80-5 (mapping between DNP3 and IEC 61850) is associated with PAP 12
- IEEE C37.239-2010 (Comfede - IEC 61850 number not yet assigned) is associated with PAP 14

9. Cross PAP Issues for IEC 61850

Many discussions on the different aspects of IEC 61850 have taken place within PAPs and within the IEC working groups. The relation across PAPs has been discussed and broadly mapped to the GWAC Stack by an SGAC Working Group. The SGAC has also gathered a large library of use-cases and requirements that have gone into the development of the conceptual model. However, discussions of the explicit details of the integration of the standards mentioned above that are derivatives of IEC 61850 have not taken place within the SGAC. There is awareness that these cross PAP integrations are needed and this is indicated on the Cross PAP TWiki page.

In addition, there is work taking place within IEC TC57 Working Group 19 to harmonize IEC 61850 with IEC 61970/61968 standards where this harmonization is needed to support applications that cross into information technology environments. This harmonization has taken place and been accepted at the abstract modeling levels and the UML models of both 61850 and CIM are using the same tools and approach.

However, the modeling concepts used in CIM and 61850 are different enough that direct mapping between the two standards is not really feasible – and may not be necessary since most cross-CIM-61850 interactions will necessarily require gateways and applications to combine and manage the 61850 field data before transferring it to the CIM-based control center applications, while the CIM-based applications will need methods to convert their power system assessments into specific settings and control commands to 61850 field devices.

10. IEC 61850 Use Cases

The IEC 61850 suite of standards does include a few use cases to help describe functions, but in most cases these use cases are externally developed and not explicitly part of the IEC 61850 standards. It should be noted that the development of IEC 61850 came from a rich set of requirements for substation operations that were not directly articulated in use-case formats. The standard uses a robust hierarchical object model that can be extended as necessary to meet emerging requirements from advanced applications.

Several new use cases and associated requirements are anticipated from the developing areas noted above. Most notably advanced distribution automation, wide area measurement and control, and distributed energy resource integration. Also on the horizon would include managed (intentional) islanding that includes integrating with the work coming from IEEE 1547 suite of standards.

11. IEC 61850 Coverage in the SGAC Conceptual Architecture

Use cases associated with the IEC 61850 architecture are mostly covered in the Conceptual Architecture at a high level. Working Drafts of these Requirements are located on the following link: *http://collaborate.nist.gov/twiki-sggrid/bin/view/SmartGrid/SGIPConceptualArchitectureDevelopmentSGAC#Working_drafts_of_the_Conceptual*.

These requirements were drawn from prior industry work and additional efforts taking place within focused efforts of the SGAC Conceptual Architecture Working Groups.

12. IEC 61850 Terminology

The terminology is relatively clearly written and mostly consistent through the IEC 61850 suite of standards. Part 2 is a glossary of terms. That said, the IEC 61850 architecture does require some understanding of how the various parts work together.

13. UML Models of IEC 61850

The IEC 61850 models are currently being translated into UML models so that they will be available electronically and will ensure more consistency as extensions to the existing models are created. The UML models are planned to be available through the UCA International Users Group, and will be the source for all IEC 61850 object model standards.

14. Transition to IEC 61850

The mappings to multiple protocols, including legacy protocols, will assist during transitions from these other protocols to full use of the IEC 61850 architecture. Some of these mappings are taking place today in PAP 12 for IEEE 1815.1 (DNP3) and in PAP 13 for IEEE C37.118 (IEC 61850-90-5). EPRI has also sponsored the mapping to SEP 2.0, while some utilities have mapped IEC 61850 to ModBus. The IEC is updating the mapping of IEC 61850 to web services. Other work includes harmonization with CIM Standards under IEC TC57 Working Group 19.

15. Maturity of IEC 61850

Different parts of the IEC 61850 suite of standards are at different levels, with some parts very mature with well established conformance and interoperability tests and beginning to be widely implemented. Other parts are newer and, although they may be being implemented, there is expectation that some updates and modifications will be necessary to these parts.

16. SGAC Summary Comments

The IEC 61850 architecture is well designed for its domain of advanced automation. It has seen widespread use in substations particularly in Europe, though it is spreading to South America and Asian communities. The newer domains of distributed energy resources are being particularly rapidly implemented in Europe.

Uptake of the standard has been slower in the US. Beyond substations, it is now anticipated to support advanced field operations and functions from the efforts noted above. Its robust object model is anticipated to support many of the real-time and field equipment applications now anticipated for the smart grid. Through harmonization with the Common Information Model standards and others designed for Service Oriented Architectures, it can provide a powerful way to integrate field operations with back office environments.