Information Understanding and Interoperability for the Modern Power Grid

Ray Piasecki

Balance Energy

San Diego, CA

ray.piasecki@baesystems.com

Keywords: micro grid, information, interoperability, integration, architecture , smart grid, GWAC, CIM

Abstract

The IT infrastructure of the modern power grid will incorporate advanced network communications and data metering, cyber-security infrastructure, publish/subscribe information services and a variety of automated demand/response analytics. To achieve this vision, a complex set of IT platforms and energy management services must interact as a collaborative network, rich in the exchange of actionable information. A significant challenge will be information interoperability.

The GridWise Architecture Council (GWAC) has developed an Interoperability Context-Setting, Framework that defines eight layers of interoperability required to establish the modern grid. A few of the layer elements, such as basic hardware interfaces and network connectivity are available as commodity IT. However, there is considerable complexity in achieving interoperability in GWAC layers 3 and 4, the syntactic interoperability and semantic understanding of data.

If two or more systems are capable of communicating and exchanging data, they are exhibiting syntactic interoperability. Standardized data formats and communication protocols are fundamental to achieving syntactic information interoperability. Semantic interoperability is the ability to automatically interpret the information exchanged in a meaningfully and accurate manner. To achieve semantic interoperability, systems must share a common concept exchange model and interpret axioms in the domain of discourse. Expressing concepts and intent in the information exchange model is complex. To succeed it must be unambiguous and in machine interpretable form.

This paper presents information systems architecture, information modeling and design patterns developed to address syntactic and semantic information interoperability. Application to both the GWAC Interoperability Framework and IEC Common Information Model (CIM) are discussed. An information interoperability model will be presented and used to discuss technology concepts as well as map information system functional needs to semantic technology platforms, languages and standards.

Introduction

The power grid is in an evolutionary state. Currently , driven through legacy technologies and controlled predominantly through manual techniques. However, inside the engineering departments and pilot projects of utility companies and energy application providers the power grid is migrating towards the vision of the smart grid where sophisticated information management systems will be integrated with power generation and distribution systems and together will automate and optimize how energy is produced, distributed and consumed.

The modern power grid stands, perhaps, as the next large scale technology evolution. One can draw many similarities to the evolution of the internet as it grew from a disparate set of heterogeneous systems without any prior formal means of integration to a very large scale and open community of web servers and their data linked through a new generation of web protocols, web standards and advanced search engine technology. Another similar technology progression was the systems integration that corporations have recently achieved as they tied together their disparate employee, payroll, factory, product and customer data systems using a new generation of advanced data integration and application integration platforms.

The modern power grid vision is quite similar to these two examples of technology evolution. The modern grid must also address large scale systems integration and will require evolution of new standards specific to the energy domain. However, the power grid will also require integrating complex power and analog based elements and touches many human safety and regulatory issues that where far out of the scope of the internet or the corporate IT evolution.

The modern power grid stands as a large scale systems integration challenge with the goal of integrating both new and legacy components to become a suite of collaborative energy generation, distribution and demand management systems. A distributed and complex system that links energy management systems in homes, commercial and industrial complexes with an enterprise of energy generation and distribution choices for the purpose of optimizing the way energy is produced and consumed.

Many facets of integration and interoperability must be addressed such as; network interfaces and protocols, instantiation of power device software interfaces, new business processes and orchestration methods, regulatory processes, load management and business workflow algorithms and importantly the data all these systems must interchange and process to ascertain what is occurring across the modern power enterprise. This paper discusses technology and architecture concepts addressing information integration and interoperability, arguably, a fundamental aspect of integrating the components that will comprise the modern power grid.

1. POWER SYSTEMS INFORMATION SOURCES

Currently, most utility companies have limited capability for interoperability across the applications associated with the power generation and distribution systems. Therefore, the modern power grid vision must address integrating a fairly heterogeneous set of legacy and new energy systems applications and the variety of disparate data they produce. Figure 1 offers a conceptual view of the typical suite of components that support power grid operations and will serve as enterprise information sources. The modern grid will host a wide variety of operational applications that include;

Energy Management Systems (EMS), Distribution Management Systems (DMS) and Outage Management Systems (OMS) that monitor, control, and optimize the performance of the generation and distribution systems and capture operational and analytical data (i.e. SCADA) that represents the general state of grid operations and power system components.

Advanced metering infrastructure (AMI) that senses and captures consumption data at residential, commercial and industrial sites.

Geographic Information Systems (GIS) that manage data which represents topological and geospatial information about grid components and their state.

Customer Information Systems (CIS) and other **Back Office** and **Front Office systems** that collect and manage customer information and account data as well as maintain project, planning and engineering data used by the power provider and utility organizations.

Asset Management Systems that monitor installation locations and other attributes, device configuration, equipment performance, inspection and maintenance history and pending work orders as well as measurements and controls of Smart Grid devices.

Demand Response Systems (DR) will serve to automate enterprise level grid operations and perform functions that provide rapid and un-attended automation of curtailment based on price or grid integrity, automate load control, automate failure response, facilitate e-commerce like dynamic pricing and perform control over distributed power generation and storage systems.

IT Infrastructure will be a critical part of the modern power grid and will provide enterprise wide network management and security services to enable reliable and assured information operations.

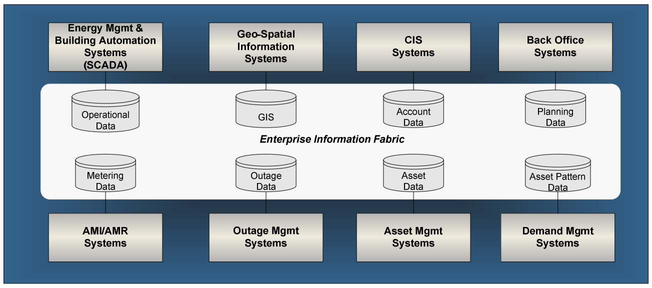

Figure 1 Power Systems Information Sources

Information Collection

From the description of power systems components it is recognized that data collection and persistence will exist at many levels across the modern power enterprise. To perform the automated demand response and control functions envisioned for the smart grid the distributed suite of power systems components will need to collaboratively publish and process information. It is clear that in addition to the wide array of network and interface level of interoperability issues that must be addressed there also exists a complex integration and interoperability need at the information level. To operate as an integrated enterprise the enterprise suite of power systems components need a common vocabulary to interchange data structures and will require advanced information processing operations to facilitate interpreting and understanding what the distributed and disparate data represents.

2. INFORMATION INTEROPERABILITY

The GridWise Architecture Council (GWAC) was formed by the U.S. Department of Energy (DOE) to promote and enable interoperability among the many entities that will interact within the electric power system. The GWAC developed an Interoperability Context-Setting Framework, shown in Figure 2, as a means to define interoperability areas that need to be addressed to achieve the vision of the modern power grid. The GWAC framework describes eight categories of system interoperability that range from low level network and system connectivity, up through data interchange, business process interoperability and at the highest level of application interoperability defines elements of regulatory and economic policy integration.

The GWAC interoperability categories 3 and 4 relate specifically to data and call out two levels of information interoperability; Syntactic and Semantic interoperability respectively. The GWAC model defines syntactic interoperability as the capability for systems to exchange and understand common data structures. The GWAC model defines semantic interoperability as the capability for systems to understand concepts in the data they exchange. Achieving this level of interoperability is complex and requires application of supporting architectural design constructs, information modeling technologies and information management services.

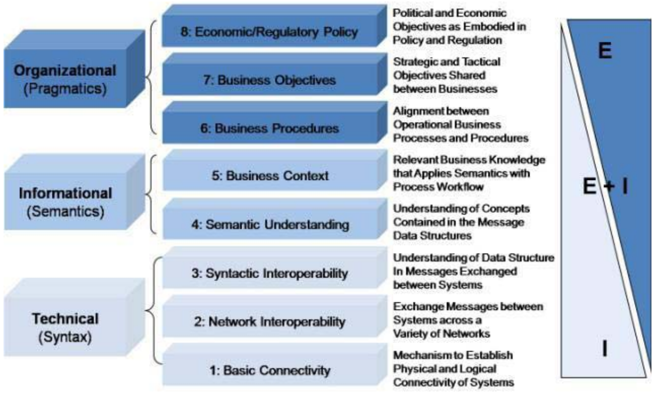

Figure 2 GWAC Interoperability Framework

Through our Microgrid research, Balance Energy has explored technology to address information understanding in support of achieving GWAC level 3 and 4 interoperability. Balance developed an Information Understanding Reference Model (IUM) that represents the content expressiveness (i.e. semantic strength) of various information representation technologies and architectural techniques. The IUM serves as a reference model to help architects understand the different levels of content expression that can be achieved when designing and integrating information systems.

The various levels diagrammed in IUM describe information modeling technologies and architectural techniques that enable systems to expressively exchange data and ultimately understand the concepts in the data being exchanged. In the IUM hierarchy, the lowest tier of information representation is raw data and lacks formal content expression (i.e. weak semantics). As the semantic hierarchy rises raw data is tagged with metadata and becomes a sophisticated information structure offering richer content expression that leads to more effective search and active discovery mechanisms. At the very top of the hierarchy, data is expressed with formal ontological modeling techniques and carries very rich context expression that provides mechanisms for information understanding and enables interpretation and reasoning.

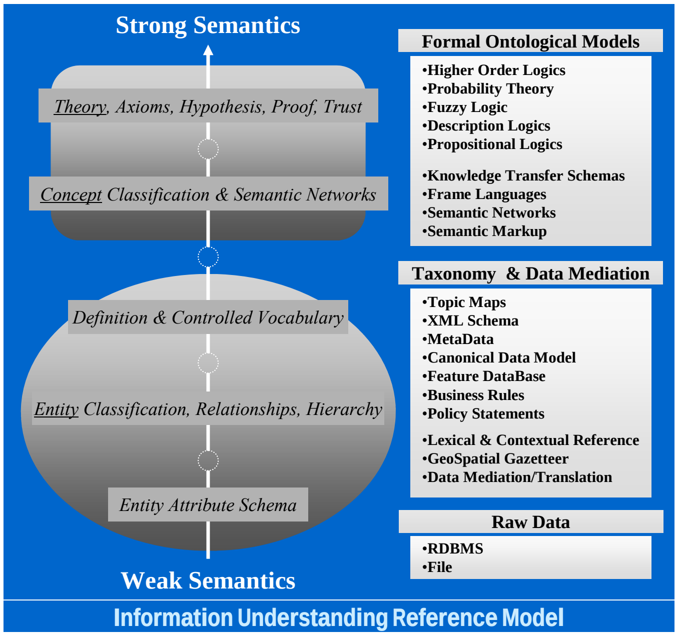

Figure 3 Information Understanding Reference Model

The IUM hierarchy highlights the fact that various levels of information expressiveness exist within the GWAC semantic and syntactic layers. The IUM offers insight into how applications can markup and model data to be more semantically and syntactically expressive. The different levels of content modeling described in the IUM hierarchy can be leveraged to address specific areas of information interoperability and ensure a richer degree of information integration and interoperability in the modern power grid.

There are two significant information understanding techniques described in IUM and each must be planned for to achieve information interoperability. First, the “Taxonomy and Data Mediation” approach, bounded by the circle in the IUM diagram. This circle in IUM bounds the facets of syntactic interoperability and correspondingly maps to layer 3 of the GWAC. The Taxonomy notion (i.e. metadata model) addresses techniques used to define the composition and content of data structures and enables software systems to share a common syntax, vocabulary and common methods of information translation. A Common Information Model (CIM) is being derived by the International Electrotechnical Commission (IEC) and the smart grid community. The CIM is an example of a controlled vocabulary used for common data interchange. In formal information modeling terms the CIM is a taxonomic model and falls at the taxonomy level shown in the IUM. Note from the IUM that in addition to establishing a CIM a complete solution must also address Data Mediation such as policy based information translation and supporting lexical references and gazetteer services to achieve full GWAC level 3 syntactic interoperability.

The second technique applied to information understanding is “Formal Ontological Models” and is bounded by the rounded rectangle in IUM. This tier of IUM diagrams how systems can express the concepts, intent and beliefs held in data. Developing semantic models to describe concepts and intent in a domain requires sophisticated algorithmic constructs and highly expressive semantic representation languages that enable machine inference and reasoning. A variety of algorithmic techniques are typically incorporated into semantic representation languages such as Set Theory and Bayesian Statistics. This area of IUM maps to GWAC level 4 , semantic interoperability. The IUM gives some examples of semantic representation models and algorithmic techniques used to express the concepts and meaning held in data.

It is important to analyze and derive a holistic design plan for the information tagging and semantic markup during the enterprise architecture and system integration design activities. Designing a common enterprise data model as an independent activity only addresses half of the integration need, policy based data mediation, data reference services and semantic representation languages are important supporting elements to the data model design. This holistic approach enables the enterprise data models to be considered as an element of the overall information management fabric and fosters an integrated and low risk information management plan.

3. INFORMATION INTEROPERABILITY ARCHITECTURE PATTERNS

Balance Energy has applied various information interoperability patterns during the course of developing architectures for information integration projects. Several are presented here as examples of integration methods to address information interoperability at GWAC level 3 (syntactic interoperability) and GWAC level 4 (semantic interoperability) .

Syntactic Solutions

Canonical Data Model : Application of an enterprise wide data schema that is used as a common data interchange model for all components in a system. The canonical model defines a common taxonomy for interchanging data. Data types, their attributes and their hierarchy are all typically defined. The canonical model offers a mechanism to avoid the N^2 problem that occurs when applications in a system must maintain translation to every other existing schema in a system. With the canonical model all systems only need to convert from their native schema to the canonical data model. The IEC-61970 Common Information Model (CIM) is an example of a canonical data model.

Policy Based Information Mediation: A repository of rules and underlying data translation methods created to define flexible, rule-based mapping between data elements in a system. The policy based mediation offers a mechanism to make data interchange programmable and extensible versus developing hard coded data mapping software.

Lexical Reference: A set of software services and underlying vocabulary database used as a reference to lookup the accepted meaning of words or data types when translating or interpreting data.

Semantic Solutions

Decision Trees: A decision tree is a decision support model that uses a tree-like graph of decisions and the possible set of consequences or outcomes. Semantic data translations can be expressed in the tree graph by providing logic driven paths that are transversed and mapped to derive a selected data translation. One benefit of a tree graph is that it can offer sophisticated mechanisms of ontology merging through linking graphs from other systems for the purpose of correlating the meaning of concepts in different systems. The ontology translation is a mechanism to perform dynamic, machine based information understanding when exchanging data between systems with disparate data models. This type of capability is required to achieve GWAC level 4 interoperability – understanding and interchange of concepts in different systems. A popular semantic representation language for building this type of semantic graph is the RDF/XML W3C standard.

Enterprise Knowledge Base: A Knowledge Base persists a formal ontological model for a specific domain of discourse. A knowledge base is significantly more expressive then syntactic metadata tagging. It incorporates techniques such as predicate logic or sophisticated semantic representation languages with embedded algorithms that enable machine understanding, learning and inference. A popular semantic representation language for building ontology’s is the OWL W3C standard.

Information Provenance and Pedigree Models: This is a technique to provide traceability and understanding of the heritage of data as it is exchanged across an enterprise. Incorporates a provenance family-tree ontological model with supporting query over ancestor or descendant resources and data systems. Provenance information helps data consumers understand and trust data and also enables a variety of useful analysis tools. Provenance information is frequently used to enable systems to reconstitute corrupted data (whether due to malicious attack or error) and allows authorized users to propagate warnings to downstream process and derived data resources. Provenance information can provide a useful record of which resources are used most often or support critical mission activities. System analysts can use this information to identify resources that should be made highly available or require greater protection against cyber attack. Additionally, the provenance family tree can aid discovery, by giving users information about related resources or other data derived from the same ancestors. When a grid outage has occurred, outage management systems can use Provenance and Pedigree information to reconstitute data sets and track points of server failure or data corruption.

Knowledge Portal, Wiki and Communities of Interest (COI) : Includes use of a web portal or semantic wiki with sophisticated natural language query, semantic search and knowledge authoring tools, community forums, etc.. Fosters the development of large scale, enterprise-wide user communities and social networking paradigms that allow users to search and access data from other similar communities of interest as well as link together knowledge bases from related communities to build broader social networks. As the smart grid vision proceeds forward users will ultimately seek to form communities of interest within and across neighborhoods (i.e. residential home owners with smart thermostats). The COI forums will share tips and experiences on how to better understand and optimize home energy systems. Fostering network communities is quite popular in the internet and computer industry as it helps to reduce the overall costs associated with tech support resources. It is quite common for the depth and quality of information available on community forums to far exceed the quality of live tech support or information contained in product manuals.

4. INFORMATION INTEGRATION USE CASE : MICROGRIDS

Energy policies are promoting and rewarding energy efficiency. This is motivating a nationwide desire to increase the application of renewable energy resources, distributed generation (DG) and supporting energy storage devices. DG installations and particularly variable, renewable energy sources are envisioned to be a key component of the modern power grid. Successful application of distributed generation requires an enterprise level, system perspective which views generation and associated loads as an integrated and autonomous subsystem or a “Microgrid”. Research and federally funded pilot projects have demonstrated that distributed generation operating within a Micro grid is a viable energy efficiency option and has the potential to greatly improve our energy generation and reliability issues.

A Microgrid is a localized, scalable, and sustainable power grid consisting of an aggregation of electrical and thermal loads and corresponding energy generation sources capable of operating independent of the larger grid. Microgrid components include; distributed energy resources (including demand management, storage, and generation), control and management, secure network and communications infrastructure, and assured information management. When renewable energy resources are included, they usually are of the form of wind power, solar, hydro, geothermal, waste-to-energy, and combined heat and power systems.

Microgrids perform dynamic control over energy sources enabling autonomous and automatic, self healing operations. During normal or peak loading or at times of power grid failure the Microgrid can operate independently from the larger grid and isolate its generation nodes and loads from the disturbance without affecting the larger grid’s integrity. Independent Microgrid operation can offer higher reliability and cost efficiency than that provided by traditional grid control.

The Microgrid is both an energy market consumer and provider of electrical power. Microgrids interoperate with existing power systems, information systems, and network infrastructure. The Microgrid may take the several forms, such as a utility metropolitan area, a shopping center, industrial park, college campus or a small energy efficient community.

A technical complexity for Microgrids is enterprise level data sensing, monitoring and control of the distributed components. Microgrid operations will need to support complex system functions such as; new energy sources being added to the Microgrid without modification of existing components, dynamic and automatic orchestration of DG sources, autonomous and self healing operations, connect to or isolate from the transmission grid in a seamless fashion and manage reactive and active power according to the changing need of the loads.

The Microgrid operations described are quite dynamic and address low level control of many Microgrid components. New and legacy components will comprise the Microgrid and the grid enterprise will be operating as a distributed and collaborative suite of control, generation, distribution and load nodes. The most fundamental Microgrid operations will require a common data exchange vocabulary to enable the distributed components to share control and status data as well as provide a mechanism for new sources to publish source, load and power capabilities. Advanced demand management and price aggregation workflow operations will require enterprise-wide information exchange and interpretation methods. Control operations like dynamic decisions to island the grid or orchestrate distributed generation will require real-time monitoring and complex information analytics. Adding new components and integrating legacy systems will require adding data translation and interoperability services. As described in the GWAC Framework and NIST Smart Grid conceptual models, information interpretation and interoperability will be a significant and necessary element of modern power grid operations.

5. CONCLUSIONS

Information management concepts and syntactic and semantic technologies have progressed in parallel with the recent computer systems and IT evolution. Architectural techniques now exist to enable information understanding and inference that previously were only attempted in university and industry research lab experiments. Semantic technology has evolved to be well understood and practiced. Computer, network and information persistence technologies have evolved and are currently positioned to enable high performance computation and orchestration of the types of sophisticated software systems required to perform machine based information interchange and understanding. It can be concluded that the GWAC vision of enterprise information understanding is reasonable and in-line with current IT technology. Through experienced application of the types of information understanding patterns discussed in this paper and through supporting enterprise architecture design the modern power grid and broad smart grid vision can be addressed and fostered to stand as a major participant in the next significant technology evolution.

6. REFERENCES

Reference List

1. GridWise Architecture Council Interoperability Context-Setting Framework (v1.1) Document. March 2008

2. IEC 61970-301 Common Information Model (CIM)

3. Web Ontology Language:http://www.w3.org/2004/OWL/

Biography

Mr. Ray Piasecki is an Engineering Fellow and the Chief Architect at Balance Energy, a BAE Systems initiative in San Diego CA. As Chief Architect, Mr. Piasecki directs the architecture development and software design of Smart Grid, MicroGrid and Energy Systems applications developed at Balance Energy. For the last 28 years, Mr. Piasecki has led both advanced research and application development projects in the field of distributed information systems , knowledge management systems and distributed control applications for enterprise level and embedded real-time applications. Mr. Piasecki has been a speaker at many industry technology conferences and has also participated in several industry consortia and standards committees, such as OSF, OMG, IEEE and Enterprise Java , that have worked to develop standards and technology concepts in the field of information management, information semantics and distributed systems architectural frameworks. Mr. Piasecki holds an MSEE and BSEE from San Diego State University. Mr. Piasecki is a participant in the NIST, OpenSG, and IEEE standards working groups on Smart Grid topics.