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Information Services for Smart Grids

ABSTRACT

Interconnected and integrated electrical power systems, by their very dynamic nature are complex. These multifaceted systems are subject to a host of challenges-aging infrastructure, generation availability near load centers, transmission expansion to meet growing demands, distributed resources, dynamic reactive compensation, congestion management, grid ownership vs. system operation, reliability coordination, supply and cost of natural resources for generation, etc. Other types of challenges facing the industry today include balancing between resource adequacy, reliability, economics, environmental constraints, and other public purpose objectives to optimize transmission and distribution resources to meet the needs of the end users. The goal is to provide a vision for a comprehensive and systematic approach to meeting the grid management challenges through new information services. These services will have as the heart of their data streams a sensor web enablement that will make the grid a part of the semantic web.

Keywords: *Protection and Control, Ontology, Information Semantics, Sensor Web*

1. Introduction

Since it is not possible to completely prevent blackouts, then effective and fast power system restoration is necessary to minimize the impact of major disturbances. This requires rapid decision in a data rich, but information limited environment. The streams of data from a variety of sensors do not provide system operators with the necessary information to act on in the timeframes necessary to minimize the impact of a disturbance. Even if there are fast models that can convert the data into information, the system operator must deal with the challenge of not having a full understanding of the context of the information and, therefore, the information content cannot be used with any high degree of confidence. Some of the key elements for response in smart grids are:

- Well-defined procedures that require overall coordination within the affected area, as well as with the neighboring grids.
- Reliable and efficient software tools to aid operators and area coordinators in executing dynamic control procedures and in making the right decisions.
- Control solutions reducing the overload and instability risks during recovery.

Today's technology allows improved processes and smart systems to aid in decision-making to minimize impacts of outages (spatially and temporally). Standard operating procedures, based on pre-defined system conditions and operating parameters, can be provided via a set of power system information services. For example, rapid restoration or minimizations of outages by selected islanding are options for consideration in minimizing the consequences of an outage to a user.

Information services are focused on providing the right information at the right moment to the right decision maker. High-level operational information services (i.e., actionable intelligence) are often needed along with supportive sensor data or trends to provide context. The information services required by grid operators could vary from scenario development to estimates of socio-economic impacts of failures to quantitative statistics, trends and forecasts. These services also must be available in a geospatial context and at various temporal scales to support the needs of system operators, planners, and regulatory agencies. Information services must be characterized by a strong integration of grid data with ancillary data and information, and this will require a knowledge based approach for capturing the best practices of utilities and regulators. The complexity of these information services will require a network of partners who will contribute to the production of the services. To facilitate these services it will be incumbent upon the power research community to develop tools to facilitate operational data acquisition and handling in interoperable formats and to create information products through a coordinated process chain. The successful conversion of power sensor data into actionable intelligence will require the integration of power system expertise in modeling, data management and service delivery to describe the state of the grid and to predict responses to actual and potential change.

2. Information Semantics

Information semantics is an innovative approach for handling complex systems. This approach can be used to accomplish knowledge discovery and to provide decision support to grid operators by focusing on making machines more closely interact at human conceptual levels. These software tools are based on semantics and ontologies that use web-addressable sensors, World Wide Web Consortium (W3C) standards, such as the Ontology Web Language (OWL), and standardized markup languages (e.g., sensorML).Information semantics provides meanings for systems, data, documents, agents and spans ontologies, knowledge representations, semantic web, natural language processing, and knowledge management.

Figure 1 represents the overall data flow from measurements (power flow, voltage) to actionable intelligence (open breaker x) on the grid via the Semantic Web. The Semantic Web makes the meaning of information accessible not only to humans, but also to machines. A specific instance of the Semantic Web is a sensor web enablement (SWE) that makes sensors addressable over the web and provides an extensive monitoring and sensing system that contributes timely, comprehensive, continuous, and multi-mode observations for the grid. SWE facilitates flexible data discovery, access, tasking and providing alerts based on open standards. The semantic web is an extension of the current web in which information is given well defined meaning, better enabling computers and people to work in cooperation. Ontology is a knowledge representation scheme that provides the glue to hold everything together and defines the terms used to describe as well as represent an area of knowledge. It defines the vocabulary and the meaning of the vocabulary in context. This discussion will focus on results from a sensor web enablement project for power sensors and how these are used as the basis for information services for the system operator.

3. Timing Issues Related to Services

Figure 2 shows the timing of events in the electric power grid and the reaction times commonly available for either an automated or operator intervention. At one end of the spectrum are the actions taken by the power system protection equipment to take an automated response based on measured quantities (e.g., frequency, current). At the other end of the spectrum, the operator controls the system in a steady state mode using data acquired from a host of sensors via a SCADA system. Actions may be automated or are more often made based upon an operator's visual interpretation of the data presented through a variety of meters and display devices.

In steady state operations, an operator normally has adequate time to consider the data, consult text based help guides, or seek another operator's opinion before having to make a decision. In between these two ends of the spectrum is a time in which an operator may have to make a decision based simply on heuristics or past ex-

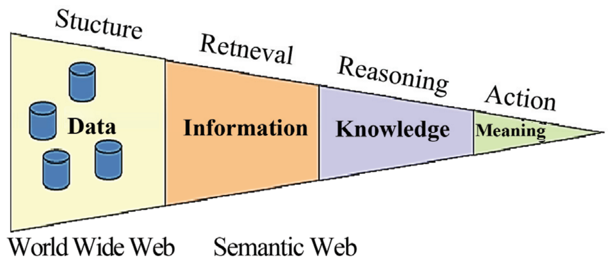

Figure 1. Process model to change data to action

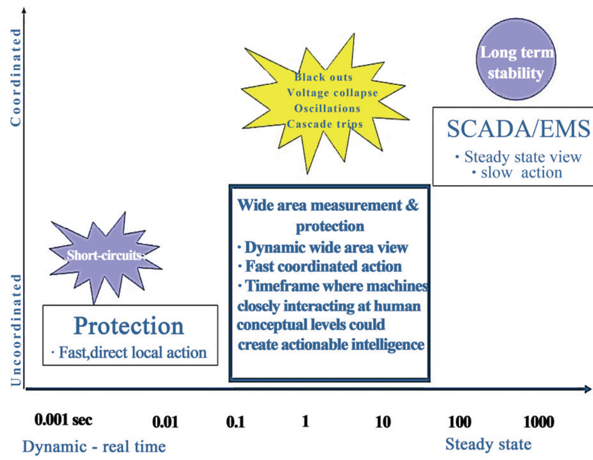

Figure 2. Critical timing and reaction times for power grid operations

periences.Obviously, these actions often may not result in the best consequence. This is the critical time period in which immediate actions must be made by an operator to prevent wide area collapses of the grid.

To ensure the secure and stable operation of the power system across the temporal spectrum, it is required to develop and apply new decision support tools that provide actionable intelligence in the required timeframe. In the aspects of secure and stable control, we need to think of an *automatic pilot* power system concept, representing a trend to improve Energy Management Systems (Figure 3).

In other aspects, such as emergency control, restoration control and etc., multiple services are required to be harmoniously interconnected into a multi-agent system to perform calculations, analyses, and be able to create actionable intelligence to support auto-pilot operation.

4. Information Semantics and Ontology Applications in Power System of the Future

The present power system operation environment is primarily composed of many distributed tools and compo nents. The interfaces of the various components must be so standardized to work in a "plug and play" concept similar to the hardware used in the substation automation. For modeling and tools, there are two major tasks;

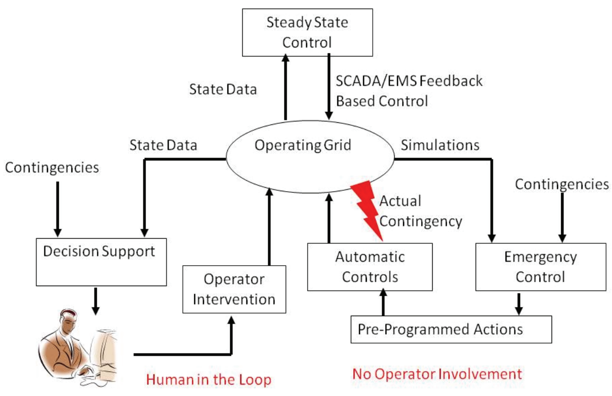

Figure 3. Steady state, transient state and dynamic state representations of control on the grid

namely data sharing amongst applications, and integration of functions of various tools. Data sharing streamlines the process of validation and requires a common data format for exchanging data amongst applications.

Today, each application uses a different format or different system topology and level of details based on different applications. For example, short circuit programs use intermediate busses to reflect physical construction of line and tower geometry. Data exchange amongst different applications such as (Power Flow to EMS), and short circuit to power flow is paramount. Likewise, data exchange between similar applications from different power companies using different manufacturer products (e.g.: Planning, Operation, Transient, and short circuit program) is vital. Semantic heterogeneity is a major detriment to exchange of data among the various services necessary for auto-pilot.

The next large scale task (that should start today) is to integrate the functions of the individual services so that they can perform more complicated functions. To realize the harmonious interconnection of these information services, we must start from the data and information level, and work in three aspects:

1) Standardization of the data model. This effort is addressed by IEC 61970 standard. The standard addresses requirements for transmitting information among EMS software or different EMS products. EPRI also has focused on the data standardization related with EMS applications.

2) Sharing of clear and precise data and information among software. This approach leads to higher working efficiency and expansibility.

3) Standardize the semantics (terminology) and develop taxonomies for ontology drives decision support tools for the electric grid.

4.1 Semantics Driven Knowledge Discovery

Knowledge discovery (features, complex relationships, and hypotheses that describe potentially interesting regularities) from large heterogeneous networks of observtions and information products generated from modeling efforts are essential for protection and control of the electric grid. Domain specific knowledge building is required before it can be discovered and shared. Data from various sources (e.g. PMUs, SCADA, etc.) are transformed into information at different application domain data analysis centers (research centers, universities, etc.) and eventually into actionable intelligence. However, to achieve this, middleware is required that provides tools to browse and access the data resources for resolving heterogeneity problems.

Middleware, by its most general definition, is any programming that serves to "glue together" or mediate between separate and often already existing programs. This layer is introduced in systems to hide the heterogeneity of the underlying components or applications and provide uniform access to their functions. In short, middleware facilitates interoperability by hiding low-level access and providing standard services. To provide the services necessary for an electric grid decision support system middleware will need to be developed that provides functionalities for ontology management, storage, query, and inference services. It will also need to be designed to enable resource discovery and to create semantic metadata. Such an ontology middleware system serves as a flexible and extendable platform for knowledge management solutions.

Domain specific knowledge building is achieved through ontological modeling that provides functionalities for capturing knowledge. Ontology is "a shared, formal conceptualization of a domain" [1]. The ontology middleware system serves as a flexible and extendable platform for knowledge management solutions, Figure 4. The middleware also serves to hide the ontology sources from domain specific application clients.

The seamless access to real time or near real time sensor data is constrained by varying characteristics (physical/logical) of the sensor networks. This results in:

- Data sets stemming from the same data-source with unequal updating periods.
- Data sets represented in the same data-model, but acquired by different operators.
- Data sets which are stored in similar, but not identical data-models.
- Data sets from heterogeneous sources (across geographical boundaries), which differ in data-modeling, scale, thematic content, contexts, meaning, etc.

The resolution of such conflicts depends on the reconciliation of both syntactic and semantic heterogeneities in the data. Syntactic standardization (interoperability) has long been proposed and a number of metadata standards (Federal Geospatial Data Committee, International Standards Organization, etc.) have been developed world-w-

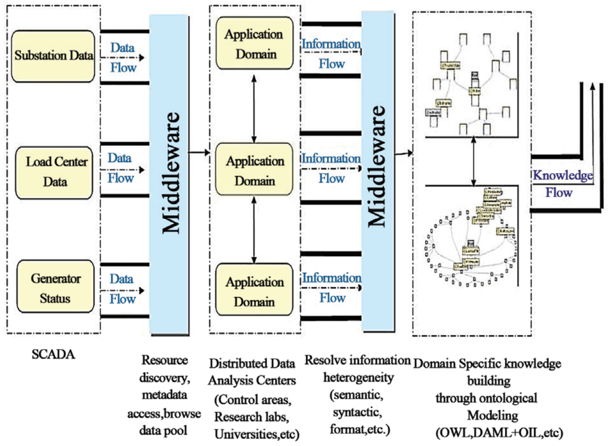

Figure 4. Ontology and information semantics in power system applications

ide during the last decade, which are now widely accepted as the standardized models for both data and metadata. Each of these standards originated in one particular community and was quickly adopted in a variety of domains. Although the metadata standards support to a large extent the interoperability of the data, a problem that is still not completely solved is diversity (heterogeneity) in the process of converting this data into information and actionable intelligence. In general, the data heterogeneity problems can be divided into three categories [2].

- Syntactic heterogeneity is caused by different logical models (e.g. relational vs. object oriented) or due to different geometric representations (raster vs. vector).
- Schematic heterogeneity occurs because of different conceptual data models (e.g. objects in one database considered as properties in another, different generalization hierarchies).
- Semantic heterogeneity raises most serious information integration problems. It occurs because of the differences in meaning, interpretation or usage of the same or related data.

One approach to the problem domain is by modeling the semantics of the data, instead of just relying on the syntactic and structural representations. Our proposed approach is distinguished from other existing approaches in the following manner:

- Heterogeneous sensor data sets integrated through ontology based approaches and intelligent reasoning over the acquired knowledge base that enables access to content instead of just keyword based searches.
- Use of real or near real time data derived from sensor networks (e.g., SCADA).
- Semantics and content-based data extraction and integration from a host of sensors (sensor web).
- Involve industry and expert groups to propose and evolve a Power and Control Semantic Metadata Standard (Figure 5), which we envision would be developed as a layer on top of the existing syntactic metadata standard.

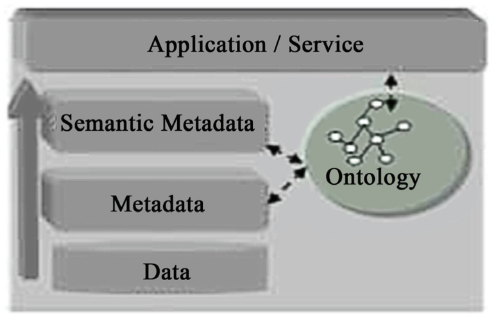

Figure 5. Application services require metadata interpretable through ontologies for resource discovery

The importance of resolving semantic differences has recently gained wide attention resulting in the next generation semantic web efforts, which is largely due to the progress in techniques to model, capture, represent and reason about semantics; gradual progress in attention from data to information, and increasingly towards knowledge acquisition and management.

Semantic interoperability requires resolving various context-dependant incompatibilities. The context refers to the knowledge that is required to reason about the system for the purpose of answering a specific query [2]. Therefore, it is important to provide contextual knowledge of the protection and control domain applications in order to ensure semantic interoperability. Each information source serves as a context for the interpretation of the information contained therein. This view implies that an information entity can only be completely understood within its context and we need to find ways to preserve the contextual information in the translation process.

Assuming that ontologies are used to capture the context of the information entities, then as we move from one context to another there is a requirement to integrate ontologies. A hybrid ontology approach consisting of a global shared ontology that encompasses all the local application level ontologies for a domain of interest (e.g., protection) is proposed. Recent studies [3] have suggested the advantages of this approach to be:

- New sources can be added easily without the need of modification.
- Supports acquisition and evolution of ontology.

Understanding of the complex interrelationships within the electrical power system necessitates the exploration of strategies for innovative acquisition, integration, and data exploitation technologies for fully interchangeable, timely, and accurate data analysis and creation of actionable intelligence. Sharing of the generated datasets, information, and results, between geographically distributed organizations often proves to be challenging. This is due to the complicated steps involved in data discovery

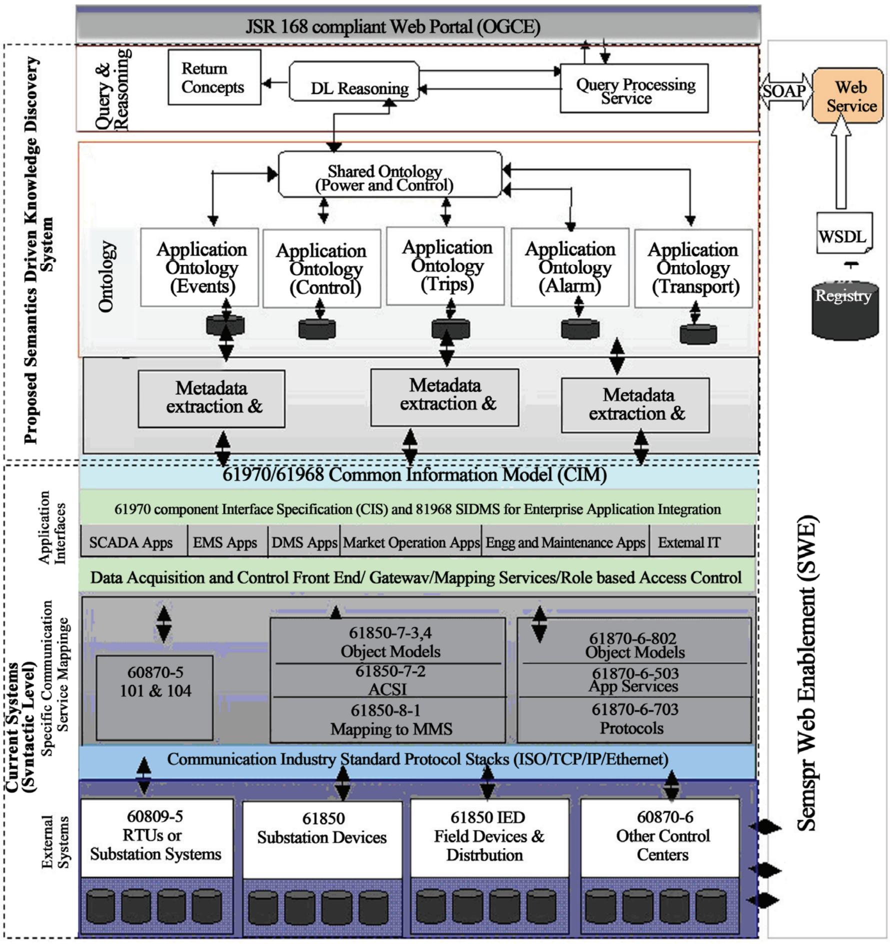

Figure 6. Architecture of the power grid sensors integration through semantics enabled middleware

and conversion that result from the problems of syntactic, structural, and semantic heterogeneity in the datasets. The syntactic heterogeneity problems have been addressed to some extent by the standardization of metadata as advocated by multiple organizations. However, the lack of sufficient description of the meaning of the data along with a context may lead to the misinterpretation of data by users who are not involved in the original data acquisition process. Thus, semantic reconciliation is necessary to guarantee meaningful data sharing. Figure 6 shows a high level visualization of the layered architecture for electric grid protection and control utilizing a sensor web enablement approach.

5. Conclusions

Some of the concepts suggested in this paper about utilizing information semantics and integrating data from a myriad of sensors will be required to maintain social and environmental obligations for the electric utility industry. The protection and control will be instrumental to achieve the reliability, efficiency, and financial aspects of the 21st century grid.

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