Smart Grid Enabled Asset Management

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PRODUCT DESCRIPTION

Power delivery at both the transmission and distribution levels face several new challenges, including the sheer complexity that results from the introduction of new devices such as smart meters, electric and hybrid vehicles, photovoltaic arrays, and micro wind turbines. These challenges must be met while at the same time preserving the reliability and availability of the existing system. The grid is a ship that must be rebuilt at sea. This report identifies the issues that need to be addressed in achieving the goal of a transmission smart grid. It addresses the communication and computing foundations for an intelligent grid and briefly discusses how to deploy them in transmission applications.

Results and Findings

Infrastructure Asset Management is a framework for making data-driven infrastructure investment decisions so that life-cycle costs are minimized while satisfying performance, risk tolerance, budget, and other organizational goals. Performance based asset management will be a powerful tool electric utilities can use to implement and coordinate the five fundamental technologies of the Smart Grid: integrated communications, sensing and measurement, advanced control methods, and improved interfaces with decision support.

Just as the existing power delivery system was not built in a day, the smart grid will evolve over many years. The development should be based on requirements driven processes. The future power delivery system will require development of a series of requirements documents that outline future applications including security, network design, network management, data management, and interoperability.

While power delivery asset management concepts have been around for well over ten years, during much of that time decision makers have had to settle for less than idea conditions when it come to asset specific information. In most companies, the asset manager has little asset specific data or the data were expensive to obtain from the field. With the advent of the smart grid and its extensive communications infrastructure and computational capability, the asset manager will be able to determine the health and performance of specific assets and the system conditions the asset experiences.

Challenges and Objectives

One of the most significant challenges the asset manager faces today is making decisions with a limited amount of asset performance data. With the benefit of the smart grid communications backbone and the variety of equipment sensors, system operating data and other sources the asset manager will be able to significantly improve the level of equipment performance data.

Applications, Values, and Use

An intelligent, self-healing grid is one that anticipates problems and automatically reconfigures itself after an event. With these capabilities, utilities can improve reliability and optimize utilization of assets. Utility partners will realize capital cost savings from the ability to competitively procure and interoperate advanced intelligent equipment from different vendors. They also will cut life cycle costs by gaining the ability to integrate disparate systems and maintain them for the long term.

EPRI Perspective

Future EPRI work in the area of asset management should focus on two areas. The first is specific asset programs such as transformers and circuit breakers, with these components considered in light of how they must function in the context of the intelligent grid. The other area of future work will involve developing computational capabilities that can deal with the huge volumes of asset specific data and turn these data into actionable information.

Approach

The project team described the Smart Grid Conceptual Model, a set of views and descriptions that are the basis for discussing the characteristics, uses, behavior, interfaces, requirements, and standards of the Smart Grid. The team then discussed the concept of performance based asset management and defined the key elements that must be developed to evolve a robust smart power delivery architecture, including the requirements for interoperability, uniform industry standards, and open architecture. Finally, the team assessed where the industry is today in moving towards the goal of using the capabilities of the emerging smart grid to enhance asset management and what needs to be done to promote further progress.

Keywords

Smart grid
Performance based asset management
Asset management

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1 INTRODUCTION AND BACKGROUND

Electric power delivery is under pressure from several business and technical directions. In the United States, recent legislation is becoming a driving force for the industry. The Energy Independence and Security Act (EISA) of 2007 and also The American Recovery and Reinvestment Act of 2009 have mobilized significant efforts to modernize the grid. One key aspect of the ARRA is the funding of Smart Grid Demonstration Projects. These projects will significantly enable new learning about the smart grid functionality and its ultimate benefit. As the industry moves forward with plans for more renewable energy sources to meet carbon reduction strategies; power delivery at both the transmission and distribution levels face several new challenges. These challenges must be met while at the same time preserving the reliability and availability of the existing system that has been in operation for several decades.

Electric transmission systems form a critical power transport backbone and they are increasingly necessary for integration of new and more diverse power generation from a variety of sources. The intermittent operation of renewable energy sources proposed poses additional operating challenges as the sources of generation become more dependent on weather conditions. In addition transmission systems are critical infrastructure and must be protected against all forms of hostile actions both cyber as well as physical attacks. Furthermore, several new types of operation are envisioned for transmission operations including operating closer to performance limits, and engaging customers in the provision of ancillary services. All of these new operating paradigms will require the careful application of communications, networks, and embedded computing in what can be broadly described as "distributed computing" advancements in automation and information technology.

Electric distribution systems play a key role in enabling customers well being. The dependency of customers has continued to increase especially as we get more mobile and depend more on constant connectivity to the Internet for much of what we do everyday. This dependency along with new demands from a variety of new devices such as smart meters, electric and hybrid vehicles, photovoltaic arrays and micro wind turbines place a new level of complexity on our classic distribution system that is unprecedented.

All of the above lead to an even more complex asset management process. However, the complexity of the smart grid does provide the asset manager with one very powerful benefit and that is better and faster access to information about the assets. One of the most significant challenges the asset manager faces today is making decisions with a limited amount of asset performance data. With the benefit of the smart grid communications backbone and the variety of equipment sensors, system operating data and other sources the asset manager will be able to significantly improve the level of equipment performance data. Much has been written about the Smart Grid and rather than duplicate it all here please visit the EPRI Smart Grid Resource Center at http://www.smartgrid.epri.com.

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SMART GRID BACKGROUND

Smart Grid

While some may be bothered with using an undefined term such as Smart Grid, a recent publication by the U.S. Department of Energy (DOE) entitled "The Smart Grid: An Introduction"[1] elaborates with great detail in layman's terms what the Smart Grid is all about.

In terms of overall vision, the Smart Grid is:

- Intelligent – capable of sensing system overloads and rerouting power to prevent or minimize a potential outage; of working autonomously when conditions require resolution faster than humans can respond…and cooperatively in aligning the goals of utilities, consumers and regulators
- Efficient – capable of meeting increased consumer demand without adding infrastructure
- Accommodating – accepting energy from virtually any fuel source including solar and wind as easily and transparently as coal and natural gas; capable of integrating any and all better ideas and technologies – energy storage technologies, for example – as they are market-proven and ready to come online
- Motivating – enabling real-time communication between the consumer and utility so consumers can tailor their energy consumption based on individual preferences, like price and/or environmental concerns
- Opportunistic – creating new opportunities and markets by means of its ability to capitalize on plug-and-play innovation wherever and whenever appropriate
- Quality-focused – capable of delivering the power quality necessary – free of sags, spikes, disturbances and interruptions – to power our increasingly digital economy and the data centers, computers and electronics necessary to make it run
- Resilient – increasingly resistant to attack and natural disasters as it becomes more decentralized and reinforced with Smart Grid security protocols
- "Green" – slowing the advance of global climate change and offering a genuine path toward significant environmental improvement

The DOE lists five fundamental technologies that will drive the Smart Grid:

- Integrated communications, connecting components to open architecture for real-time information and control, allowing every part of the grid to both 'talk' and 'listen'
- Sensing and measurement technologies, to support faster and more accurate response such as remote monitoring, time-of-use pricing and demand-side management
- Advanced components, to apply the latest research in superconductivity, storage, power electronics and diagnostics
- Advanced control methods, to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event

- Improved interfaces and decision support, to amplify human decision-making, transforming grid operators and managers quite literally into visionaries when it come to seeing into their systems

This combination of vision with technologies will be used as a basis for the concepts and ideas put forth in the remainder of this paper. With this as background, let's take a look at some ideas for smart grid enabled asset management.

What is the Smart Grid?

The Smart Grid as defined here is based upon the descriptions found in the Energy Independence and Security Act of 2007. The term "Smart Grid" refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements – from the central and distributed generator through the high-voltage transmission network and the distribution system, to industrial users and building automation systems, to energy storage installations and to end-use consumers and their thermostats, electric vehicles, appliances and other household devices.

The Smart Grid will be characterized by a two-way flow of electricity and information to create an automated, widely distributed energy delivery network. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near-instantaneous balance of supply and demand at the device level [2].

Smart Grid Characteristics: Drivers and Opportunities

The definition of the smart grid builds on the work done in EPRI's IntelliGrid [3] program, in the Modern Grid Initiative (MGI) [4], and in the GridWise Architectural Council (GWAC) [5]. These considerable efforts have developed and articulated the vision statements, architectural principles, barriers, benefits, technologies and applications, policies, and frameworks that help define what the Smart Grid is. This section describes some of these widely accepted principle characteristics that will be the basis for the 21st Century grid we are striving to achieve.

The Smart Grid Conceptual Model

The Smart Grid Conceptual Model is a set of views (diagrams) and descriptions that are the basis for discussing the characteristics, uses, behavior, interfaces, requirements and standards of the Smart Grid. This does not represent the final *architecture* of the Smart Grid; rather it is a tool for describing, discussing, and developing that architecture. The conceptual model provides a context for analysis of interoperation and standards, both for the rest of this document, and for the development of the architectures of the Smart Grid. The top level of the conceptual model is shown in Figure 2-1.

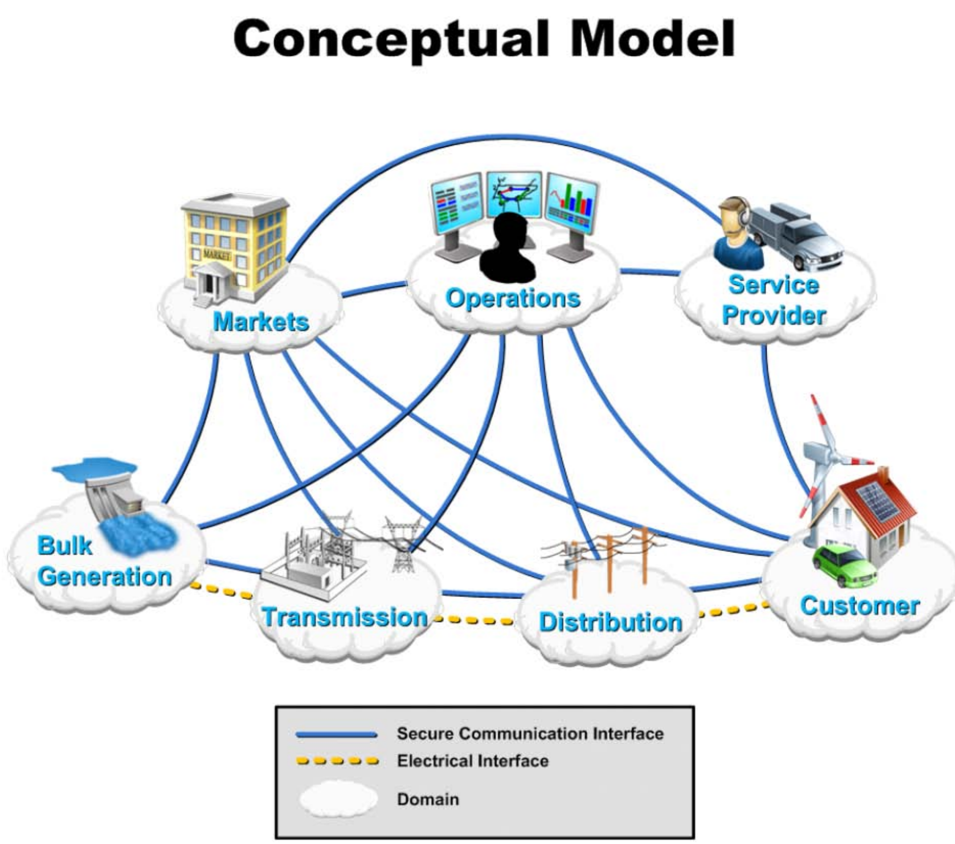

Figure 2-1
Smart grid conceptual model – top level

The conceptual model consists of several *domains*, each of which contains many *applications* and *actors* that are connected by *associations,* which have *interfaces* at each end*:*

- **Actors** may be devices, computer systems or software programs and/or the organizations that own them. Actors have the capability to make decisions and exchange information with other actors through interfaces.
- **Applications** are the tasks performed by the actors within the domains. Some applications are performed by a single actor, others by several actors working together.
- **Domains** group actors to discover the commonalities that will define the interfaces. In general, actors in the same domain have similar objectives. Communications within the same domain may have similar characteristics and requirements. Domains may contain other domains.
- **Associations** are logical connections between actors that establish bilateral relationships. At each end of an association is an interface to an actor.
- **Interfaces** show either electrical connections or communications connections. In Figure 2-1, the electrical interfaces are shown as yellow lines and the communications interfaces are shown in blue. Each of these interfaces may be bi-directional. Communications interfaces represent an information exchange between two domains and the actors within; they do not represent physical connections. They represent logical connections in the smart grid information network interconnecting various domains (as shown in Figure 2-1).

Further details about the Smart Grid can be found in the References section of this report.

Investigating further the smart grid conceptual model shown above, one can see that the majority of the asset management function is contained within three areas. These are the Operations, Transmission and Distribution. In the next section we will examine more deeply the Operations domain and relate it to the asset management function.

Operations Domain

Actors in the Operations domain are responsible for the smooth operation of the power system. Today, the majority of these functions are the responsibility of a regulated utility. The smart grid will enable more of them to be outsourced to service providers; others may evolve over time. No matter how the Service Provider and Markets domains evolve, there will still be basic functions needed for planning and operating the service delivery points of a "wires" company. In transmission operations, Energy Management Systems (EMS) are used to analyze and operate the transmission power system reliably and efficiently, while in distribution operations, similar Distribution Management Systems (DMS) are used for analyzing and operating the distribution system.

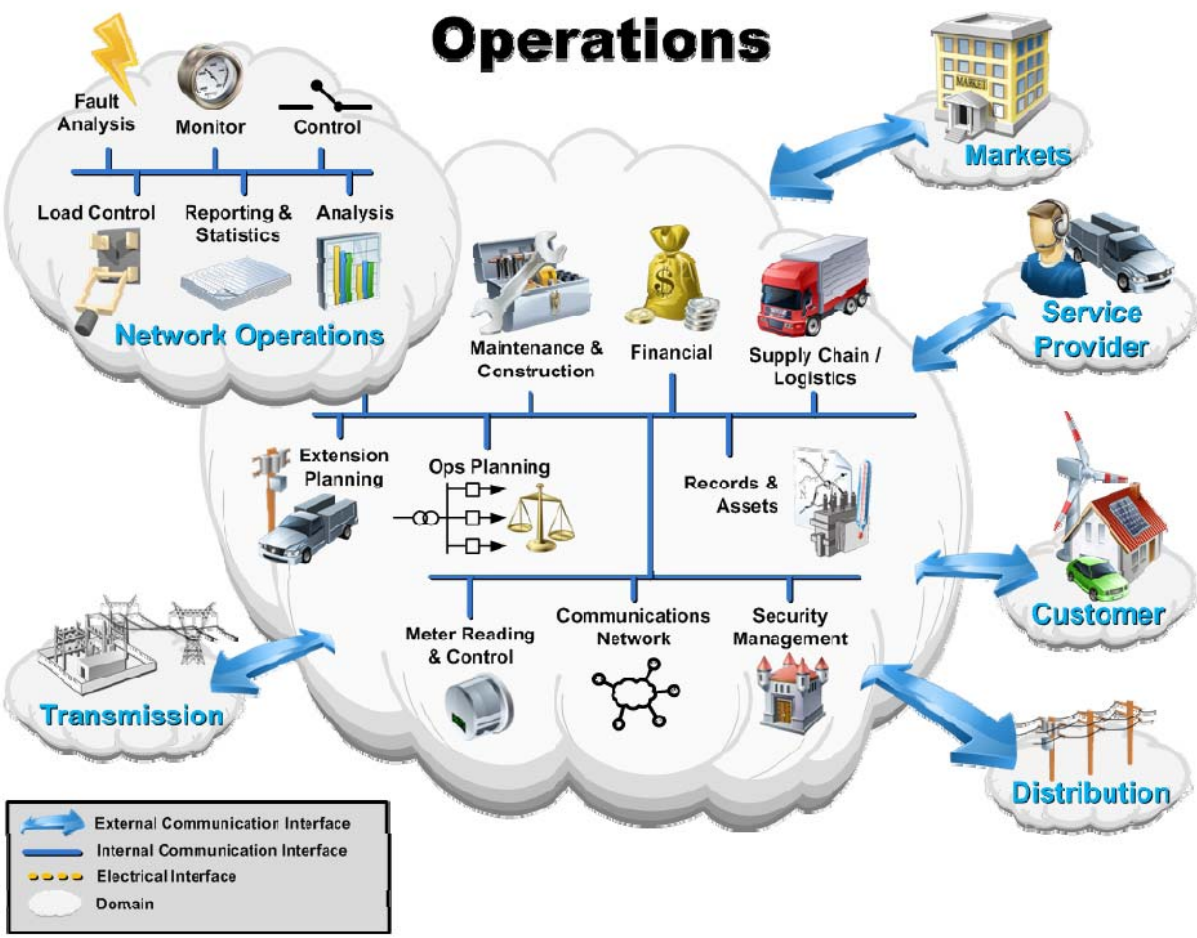

Figure 2-2
Overview of the operations domain

Representative applications within the Operations domain are described in Table 2-1. These applications are derived from the IEC 61968-1 Interface Reference Model (IRM) for this domain [2].

Table 2-1
Typical applications in the operations domain

Application	Description
Network Operations	The Network Operations domain (actually a sub-domain) within Operations includes the applications:
Monitoring	Network Operation Monitoring actors supervise network topology, connectivity and loading conditions, including breaker and switch states, and control equipment status. They locate customer telephone complaints and field crews.
Control	Network control is coordinated by actors in this domain, although they may only supervise wide area, substation, and local automatic or manual control.
Fault Management	Fault Management actors enhance the speed at which faults can be located, identified, and sectionalized and service can be restored. They provide information for customers, coordinate with workforce dispatch and compile information for statistics.
Analysis	Operation Feedback Analysis actors compare records taken from real-time operation related with information on network incidents, connectivity and loading to optimize periodic maintenance.
Reporting and Stats	Operational Statistics and Reporting actors archive on-line data and to perform feedback analysis about system efficiency and reliability.
Calculations	Real-time Network Calculations actors (not shown) provide system operators with the ability to assess the reliability and security of the power system.
Training	Dispatcher Training actors provide facilities for dispatchers that simulate the actual system they will be using. (not shown on diagram).
Records and Assets	The Records and Asset Management actors track and report on the substation and network equipment inventory, provide geospatial data and geographic displays, maintain records on non-electrical assets, and perform asset investment planning.
Operational Planning	Operational Planning and Optimization actors perform simulation of network operations, schedule switching actions, dispatch repair crews, inform affected customers, and schedule the importing of power. They keep the cost of imported power low through peak generation, switching, load shedding or demand response.
Maintenance and Construction	Maintenance and Construction actors coordinate inspection, cleaning and adjustment of equipment, organize construction and design, dispatch and schedule maintenance and construction work, capture records gathered by field personnel and permit them to view necessary information to perform their tasks.
Extension Planning	Network Extension planning actors develop long term plans for power system reliability, monitor the cost, performance and schedule of construction, and define projects to extend the network such as new lines, feeders or switchgear.
Customer Support	Customer Support actors help customers to purchase, provision, install and troubleshoot power system services, and relay and record customer trouble reports.

Table 2-1
Typical applications in the operations domain (continued)

Application	Description
Meter Reading and Control	Meter Reading and Control actors perform a variety of functions on the metering system including data collection, disconnect/reconnect, outage management, prepayment point of sale, power quality and reliability monitoring, meter maintenance and asset management, meter data management including validation, estimation and editing (VEE), customer billing, and load management, including load analysis and control, demand response, and risk management.
Supply Chain and Logistics	Supply Chain and Logistics actors manage the processes for acquiring necessary supplies; tracking acquired and ordered supplies; and allocating them.
Financial	Financial actors measure performance across the whole organization, including the evaluation of investments in capital projects, maintenance, or operations. They track risk, benefits, costs and impact on levels of service.
Communications Network	The planning, operations and maintenance of all communications network asset that are required to support Operations.
Security Management	The management of security policies, distribution and maintenance of security credentials, and centralized authentication and authorization as appropriate.
Premises	Information regarding the location of a service. This set of functions includes: Address management; Right of ways, easements, grants; and Real estate management.
Human Resources	Human Resources actors manage personnel information and activities including safety, training, benefits, performance, review, compensation, recruiting and expenses.
Business Planning and Reporting	These actors perform strategic business modeling, manpower planning, reporting, account management, and both assess and report on risk, performance and business impact.
Stakeholder Planning and Management	These actors perform track and manage the needs and concerns of various utility stakeholders by monitoring customer input, regulators, service standards, and legal proceedings.

Monitoring of assets within the smart grid will be more cost effective and beneficial than previously since the required infrastructure will be in place to support the smart grid functions broadly and not just for equipment monitoring. Sensing and measurement technologies are a key enabler of the Smart Grid. They are envisioned as being able to support faster and more accurate response to functions such as remote monitoring, time-of-use pricing and demand-side management. Precise intelligence of the parameters required and their current and forecast values can be used to determine the limitations that various power delivery elements impose on any given situation. This added intelligence should provide greater clarity and improved decisions.

3
PERFORMANCE BASED ASSET MANAGEMENT

Asset management is a business approach designed to align the management of asset-related spending to corporate goals. The objective is to make all infrastructure-related decisions according to a single set of stakeholder-driven criteria. The goal is to identify a set of spending decisions capable of delivering the greatest stakeholder value from the investment dollars available.

Infrastructure Asset Management

Infrastructure Asset Management is a framework for making data-driven infrastructure investment decisions so that life-cycle costs are minimized while satisfying performance, risk tolerance, budget, and other organizational goals.

This definition, with its focus on cost minimization, is equally applicable to for-profit utilities, government-owned utilities, and customer-owned utilities.

Utilities have to work within a budget. Typically, a utility will have a set of capital and non-capital budgets and may have to spread work over a multi-year period to keep within these budgets. Closely related to budgets is the use of craft labor. There are only a fixed number of employees to do the work, often requiring work to be spread out over time. A company can contract labor to outside sources, but this also may be limited and may have different cost structures.

The above definition of infrastructure asset management makes sense from a regulatory perspective. Regulators expect utilities to provide adequate levels of service to customers for the lowest possible rates. The goals of infrastructure asset management are identical. Regulators also expect spending decisions to be backed up by good data and sound analysis so that budget and performance projections have a high level of confidence. Asset management also has this expectation of rigor based on asset-level data.

Many utilities have applied the concepts of asset management to targeted aspects of their business. Examples include the following: equipment inspection and maintenance programs, computerized maintenance management systems, equipment condition monitoring, equipment utilization, risk reviews for cancelled projects, and software that prioritizes spending requests. These are all useful initiatives that can benefit from the concepts of asset management. However, they do not in themselves constitute asset management. Rather, they should be considered potential aspects of an overall corporate asset management framework. Asset management is a broad concept and, by definition, must consider all spending related to utility infrastructure assets.

Stated simply, asset management is a corporate strategy that seeks to balance performance, cost, and risk. Achieving this balance requires alignment of corporate goals, management decisions, and technical decisions. It also requires the corporate culture, business processes, and information systems capable of making rigorous and consistent spending decisions based on asset-level data. The result is a multi-year infra-structure investment plan that maximizes shareholder value while meeting all performance, cost, resource, and risk constraints.

The definition of infrastructure asset management represents an optimization problem subject to a set of constraints. At first glance, there is a single and clear objective: to minimize life-cycle cost. However, the ability of a utility to minimize life-cycle cost is constrained by performance targets and risk exposure. A higher level of performance requires higher cost. A lower level of risk (reducing the probability of negative events and/or the consequence of these events) also requires higher cost. Therefore, inherent to asset management are the tradeoffs between cost, performance, and risk. These tradeoffs must ultimately be aligned with overall corporate objectives set by senior management. With these points in mind, the goals of asset management become the following:

Goals of Infrastructure Asset Management

- Balance cost, performance, and risk
- Align spending decisions with corporate objectives
- Base spending decisions on asset-level data

Of these three goals, the last one benefits the most from the smart grid since the ability to capture and transmit asset level data becomes a simplistic task. Pursuing an asset management strategy is time consuming, a lot of effort, and disruptive for a period of time. For these reasons, it is fair to inquire as to the benefits of asset management. There are many, but the principal benefits of asset management for power delivery companies include the following:

Principal Benefits of Asset Management

- Ability to lower budgets with the least impact to performance
- Ability to improve performance in a demonstrated least-cost manner
- Auditable justification for all asset spending decisions
- Ability to address multi-year issues such as aging infrastructure
- Ability to coordinate capital, operational, and maintenance spending
- Ability to coordinate capacity and reliability spending
- Ability to coordinate spending across programs
- Ability to coordinate spending across operational divisions
- Improved ability to proactively manage risk
- Ability to justify asset spending decisions to regulators
- Improved investor confidence and senior management confidence

Although the term “asset management” is used throughout this document, a restricted meaning of “asset” is intended. In accounting, an asset is a valuable resource acquired at a measurable cost. In addition to “real stuff,” this also includes financial assets and intangible assets such as purchased intellectual property and goodwill. In many business situations, other items are casually called assets, such as employees, reputation, and others. For the rest of this document, “asset” refers specifically to infrastructure equipment and systems that directly support infrastructure equipment. It is understood that an effective asset management system must consider human issues and must coordinate with other aspects of overall corporate strategy. However, the asset management guidelines provided in this document are intended for power delivery physical infrastructure assets, and may not be applicable to other types of assets.

The Power Delivery Asset Management Model

In previous work at EPRI, the Power Delivery Asset Management (PDAM) model was defined. This model illustrates the interfaces among the various components and shows the required inputs and expected outputs. The model helps to better define the important PDAM processes and was used in subsequent work to identify data and analytical tool requirements for individual elements and processes.

One purpose of constructing this conceptual model is to illustrate the functional boundaries and data exchanges among the various processes. This model will be helpful in describing the interfaces between the various Smart Grid components and PDAM. Figure 3-1 below is a simplified version of the original one published in Guidelines for Power Delivery Asset Management [6].

In this model, there are a number of interactions defined. Many of these interactions are routinely handled today with existing business systems such as work management, budgeting, accounting and procurement. However, there a few processes that will be significantly enhanced through the installation of the Smart Grid. These are:

- D7 – Asset/Service Performance
- D8 – Asset Information and Inventory
- P1 – Monitor Assets and Performance
- P3 – Evaluate Asset Condition and System Performance
- P12 – Monitor Implementation

Each of these is highlight in yellow in Figure 3.1 and will be described in further detail below and identify how the Smart Grid benefits each of them. The entire model with all of the process descriptions can be found in reference [6].

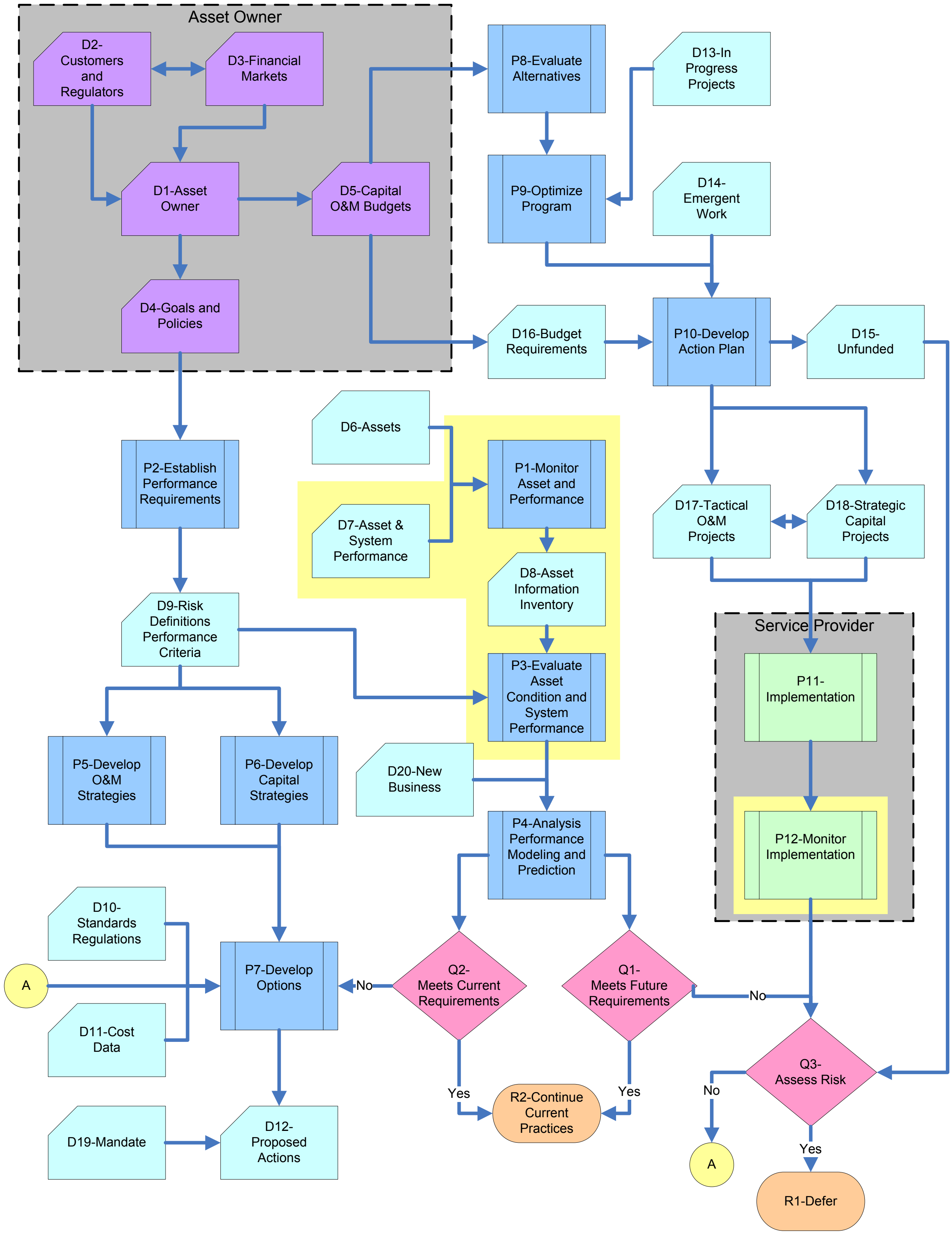

Figure 3-1
Second level generic power delivery asset management model

Model Process Definitions

D7 – Asset/Service Performance

Asset and Service System Performance represents the final output of all the processes of the organization. These terms are used in the broadest sense, and there are two distinct but related aspects to asset/service performance. The organization's Assets are used to provide services to customers – end user service levels, often referred to as system performance in power delivery – and these can be measured by various metrics. Examples for power delivery include SAIFI, SAIDI, and energy-not-delivered and these are developed in the Evaluate Asset Condition and System Performance process. In addition, individual assets or groups of assets are expected to perform at certain levels, which may or may not affect end user service levels. Examples here include equipment failure rates, return on investment, and maintenance costs. The service levels provided with the assets directly impact customers and are directly influenced by Asset condition and operating procedures.

D8 – Asset Information and Inventory

Asset Information and Inventory includes a collection of databases that hold complete, current, and accurate information on system performance, asset condition and performance metrics, failure and replacement histories, asset location, age, specifications, and costs. An Asset's Performance can only be accurately established in the total context of its use. Therefore, data on operations and maintenance histories and costs, as well as the asset's importance or criticality to system performance measures should also be recorded.

P1 – Monitor Assets and Performance

Monitor Assets and Performance is the process of collecting data that reflects Asset and System Performance and condition. There are multiple processes, both manual and automated, used to monitor and measure both end user service levels and the performance of individual components, assets, or groups of assets. Inspections, testing, on-line monitors and trouble call tallies are examples of these monitoring processes. The outputs of these monitoring processes are stored in various databases, the Asset Information Inventory, throughout the organization for analysis, direct reporting, and subsequent use in other processes. Only data that has an identifiable use in a subsequent process should be collected. The adequacy (timeliness, precision, etc.) of the data outputs of this process should be corrected by feedback from all subsequent processes that make use of the data (not shown).

P3 – Evaluate Asset Condition and System Performance

The Evaluate Asset Condition and System Performance process takes inputs from the Monitor Assets and Performance process and either directly or with added calculations compares them with desired levels from Risk Definitions and Performance Criteria. Gaps or anomalies in performance levels may be identified here. Additional input comes from the Asset Information Inventory, to put the monitoring data in context. The major output is a series of values that reflect the condition assessment of the system, groups of assets, individual assets, or asset components. Examples are outage numbers and durations, number of equipment failures, and cost totals for a specific number and kind of task. This process addresses directly measured performance metrics and values with the objective of determining current asset condition or performance level.

Evaluations of asset and system performance provide factual and quantitative information on the performance of the Assets in meeting established Performance Requirements and information to predict their ability to meet these requirements in the future. Performance monitoring forms the basis for management of an asset throughout its life. It facilitates adjustments to the various outputs of subsequent processes, ensuring that program performance goals are met and providing indications where changes are required. Effective asset condition assessment in relation to its service performance is needed to understand the deterioration that leads to reduced asset performance in the future. Evaluations of system performance also may be conducted externally (e.g., Customer perceptions of the quality of infrastructure condition, or Regulator assessment of the provision of services), and these are valid inputs for analysis as well.

P12 – Monitor Implementation

The Monitor Implementation process monitors the work done to implement the approved actions. At one level, it is a check on the service provider, but it is also important to the larger asset management focus. It includes tracking of actual delivery costs as measured against expected costs. This information can be used to improve understanding of the true costs of various activities so that this information can be used to enhance future resource allocation decisions in Proposed Actions and in a few cases may necessitate review of proposed actions. Similarly, schedules are also monitored. Problems in implementation may necessitate changes in the Develop Action Plan process.

4
BUILDING THE SMART GRID

Just as the existing power delivery system was not built in a day, the smart grid will evolve over many years. It will be created through the incremental deployment and integration of various intelligent systems that meet specific business and regulatory drivers. Each owner will have different starting points, business drivers, implementation paths and deployment rates. Therefore, the interfaces between owners and between systems and business areas within a single owner must seamlessly interact with each other. This is the often touted “plug and work” mantra. Achieving this level of seamless integration is the benefit of open standards.

Requirements Driven Processes

The future transmission system will require development of a series of requirements documents that outline future applications. The IntelliGrid template is currently the recommended starting place for eliciting requirements for future systems. The requirements process and the template are described in an IEC Publicly Available Specification (PAS) and it is available from the EPRI IntelliGrid website http://intelligrid.epri.com . One should also consider the very recent work published in the NIST Framework and Roadmap for Smart Grid Interoperability Standards Release 1.0 (Draft) [7] Requirements development must include both functional and non-functional requirements that include systems management and security.

Build the Right Foundation

Designing and building the right foundation in any project is a critical first step. Without a solid foundation, everything that follows will be a futile effort. The design of any transmission line begins with design criteria. Engineers determine what critical physical elements are applicable to their situation. Design questions such as do I need to consider ice loading, hurricane force winds, seismic or other events? Thorough review of these design criteria have led to the physically robust power delivery system we have today.

Similarly, during the design phase of the transmission smart grid, engineers need to consider some fundamental items to assure ourselves that the critical design parameters are considered. Some of these critical key elements are:

- Security (physical and cyber)
- Network design
- Management
- Data Management
- Interoperability

The challenge posed by these elements that are different than the environmental ones considered during the physical build out is they are not static. While global warming may be impacting our environment and therefore the weather conditions we are experiencing, they are quite slow moving when compared to the technological improvements made in the areas listed above. Since all of the items are man made they are all subject to design improvements. These design improvements will, over time, require system upgrades that are more frequent than what is currently accepted in the electric utility industry.

Security methods that are considered effective today become ineffective in short order. The constant attack by hackers (both “good” and “bad”) put increasing pressure on the security system developers to stay one step ahead. This constant cycle of improving security means that systems need to be designed with the inherent flexibility to be upgraded on a regular basis.

Similarly, new network technology and management schemes will drive system upgrades on a regular interval, probably less frequent than the security upgrades but frequent none the less. The last two items are probably the most stable. Data management and interoperability are somewhat dependent items and since standards tend to be developed in a relatively slow moving process, the frequency of upgrade should be less.

So the design of infrastructure and applications for the smart grid will have its own set of unique asset management challenges that will be very different from what the industry has previously seen and much work needs to be done to design and test the concepts on a large scale.

Smart Power Delivery Architecture

There are three key elements that provide for robust smart power delivery architecture. They are:

- Interoperability
- Industry Standards
- Open Architecture

Interoperability is the ability of software and hardware on different machines from different vendors to share data. It is a critically important requirement, when implementing EMS applications developed by different vendors. With properly established standards and implementation of those standards, the concept of “plug and work” is possible. While the concept is desired, actual achievement will be a challenge in the early stages of the smart grid but to have it as an overarching goal should be continued. The complexity of the systems involved may test this concept but it should be achievable within the various modules or components that make up the overall system. In the future, imagine a protective relay gets physically installed in a substation and when initially powered up looks for the network connection and then goes through a series of self checks, reaches out to a master device that in turn provides the relay with its configuration and setting. Once configured, the relay would then execute a series of tests and if successful establish itself as an in-service device and begin serving its role in the smart grid.

The above level of “plug and work” does not happen with out a very comprehensive set of industry standards. Through industry standards the level of interoperability described above is possible since the standards provide for the firm description of requirements that compliance to a standard requires. The standards also provide for smooth transitions from one version to the next and in many cases provide ample transition time for overlap of interoperability between versions thereby lowering the risk of obsolescence.

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SMART GRID ENABLED ASSET MANAGEMENT

The use of more sophisticated control algorithms and technologies such as expert systems, inference engines, knowledge bases and other advanced processing approaches have been studied for over twenty years. In trying to move forward with these ideas in power delivery systems, the field has typically run into implementation challenges due to the high cost of communications systems. There were no cost effective mechanisms established to effectively integrate field equipment to enable the widespread use of advanced control algorithms. With the emergence of next generation open standards for communications that are being encouraged with the new smart grid deployments companies should capitalize on the opportunity and leverage the lower cost options now available.

Situation Analysis: Where are we today?

Today's transmission systems have a fair amount of intelligence. The most sophisticated probably being the energy management system (EMS) with its automatic generator control (AGC). Within these system a variety of advanced applications such as state estimation, contingency analysis, voltage stability and other applications are run on a regular basis. However, as these network models continue to get larger and larger with more detailed models, computation time has become problematic even the in CPU speed and other technical gains in computing. Also, the typical 2-4 second data scan rates when combined with the computational time are in some cases too long in providing actionable information.

Besides the EMS system, there is other information available to the operator. Some of these are dynamic line ratings, synchrophasor data and variety of condition monitoring information. The majority of this information tends to reside outside the EMS and may not be well integrated into the overall situational awareness capabilities in the control center.

As you can see, there is a fair amount of information available to the system operator however; much of the data is stuck in the control center and not readily available to the rest of the enterprise. To make this data available to the broader enterprise some utilities have installed data historians that allow asset managers access. This is not a trivial task and in most cases requires significant administration effort to translate coded point tags into understandable point tags. For example, point tags in an EMS may be something like "ELM345B1VA" which represents "Elmhurst 345Kv Bus 1 A Phase Voltage". This may not seem like a big task but when tens of thousands of points are involved this accounts for a significant task and as the system changes with field asset upgrades there is constant maintenance.

What does the Smart Grid Offer?

The recent "Report to NIST on the Smart Grid Interoperability Standards Roadmap" provides extensive references to a number of standards that are suggested to be used as the foundation for the smart grid. Most if not all of these standards are design to have interoperability and self description as key elements of their make up. The interoperability feature minimizes the work effort to interface applications and data between domains. The self description feature further minimizes the labor component by automatically describing a given data element. It also eliminates many of the human errors associated with typing and labeling data points since the labels get derived from predefined objects.

Sensors and Actuators

The role of sensors and actuators in the smart grid is one of the fundamental elements required for successful operation of the grid. It is through these devices that the actual power system's reaction to various inputs and outputs is measured. As in classic control systems, it is through sensors that vital information about a variety of conditions is received. The sensors convert voltage, current, phase angle, position status and other data into manageable signals that are either analog or digital in nature.

Today, these sensor signals are usually sent to a centralized operations center for a geographic region. At the operations center various control computers process this sensor data into information and control signals. Some of the information is routed to displays in the control center for system operator to use in their constant monitoring and management of the grid. The information is also routed to generators to provide the continuous balancing of load and generation and other automatic functions. The system is also capable of responding to manual inputs from system operators for manual actions such as energizing and de-energizing lines for maintenance.

In the power delivery smart grid, sensors will increase in both type and quantity. In fact over the last 10-15 years or so, a number of new commercially produced sensors have been introduced by suppliers. These have included transformer monitors, circuit breaker monitors, infrared cameras and others. Also, EPRI has been very active in the development and commercialization of a whole host of sensors for not only typical substation assets but also for transmission lines. Sensors like the corona camera, sag-o-meter, partial discharge, acoustic and many more. While all of these sensors provide useful information to the utility operators and managers, they have all suffered from wide adoption for the same reason, the lack of wide area, high bandwidth communications out to the field assets. As a result, many of these remote sensors have had to rely upon make shift approaches to gather the field data from the sensor and typically the data was only available to a limited set of personnel within the utility enterprise.

One prevalent sensor at every utility is the microprocessor relay. There are over 500,000 microprocessor relays installed in North America, based on one manufactures sales figures. This would include both transmission and distribution but regardless of the split, this is a large penetration of a single vendor's device. Taking into consideration the other suppliers and there is significant penetration of these relays. Each of these relays contains within it a significant number of data values that go beyond what is necessary for protection. Included in many of these devices are digital fault records, sequence of event recorders, calculation of I^2t which is a measure of thermal energy associated with current flow, synchrophasor measurement and a very large quantity of other measured and calculated values including analog values such as voltages, currents and digital values like circuit breaker contacts "a" and "b" closure time. Once again due to the limited bandwidth out to the field assets, this valuable information remains in the relay and is seldom if ever used by the operations or asset management staffs. If one were able to routinely gather this type of data, some very simple analytic processes could be setup by the maintenance staff. By accumulating the I^2t value for each circuit breaker over time you could develop an algorithm to trigger maintenance of the breaker at a prescribed value that would be indicative of contact wearing beyond an acceptable value. Also, by monitoring the contact timing values one could identify breakers that operated slowly and once again perform maintenance. The maintenance task would probably be as simple as lubricate and exercise the breaker. Without this knowledge, the task may become replace failed breaker since the slow opening caused excessive arcing and heating.

The influx of sensors into the electric utility marketplace has been extensive. The capability of the installed microprocessor based relays is also extensive. The limitation to fully utilizing this data for both operations and management has been limited bandwidth connecting the field assets to the utility enterprise.

An actuator is either an electrical or electromechanical device that responds to the output signal provided by the control system. In the electric utility enterprise actuators are fairly limited. They include classic items such as circuit breakers, phase shifting transformers, and special protection schemes (or remedial action schemes). Some modern actuators are high voltage direct current controls (HVDC) and flexible AC transmission systems (FACTS). There are other actuators related to generation control that will not be cover in this report.

Using IEC 61850 for Condition Based Maintenance

Condition Based Maintenance is an area that would benefit by the adoption of the IEC 61850 standard, and the monitoring resources it offers.

Today the majority of equipment maintenance in power delivery systems is carried out by either corrective or preventive maintenance. Corrective maintenance lets the component or system run until breakdown or fault before maintenance action is considered. For this reason corrective maintenance is also known as run-to-failure maintenance. In contrast, preventive maintenance is carried out at predetermined intervals according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item [8]. This is done by repair or component exchange in preset intervals. Preventive maintenance is sometimes called planned, or time based maintenance.

It has been shown that these traditional maintenance techniques, corrective and preventive, are very costly and inefficient. To try to maintain the correct equipment at the right time, predictive maintenance techniques were introduced. In predictive maintenance, the maintenance intervals are decided according to the condition of the equipment rather than time in service or number of operations. Predictive maintenance is also known as Condition Based Maintenance (CBM). CBM relies on monitoring selected parameters of the equipment in a manner that the ongoing condition can be continuously or periodically assessed and maintenance is initiated based on the present needs of the equipment condition [9]. The main purpose of CBM is to eliminate or minimize breakdowns and prolong the preventive maintenance intervals. As a result, an increase in equipment availability is achieved, and then power availability and quality is increased too.

One of the key concepts behind performance based asset management is to optimize maintenance. Maintenance is frequently one of the biggest controllable expenditures in a company [10]. For that reason, the introduction of the condition based maintenance concept in power delivery substations and elsewhere in the system will allow electric power companies to optimize their maintenance and operation costs, while at the same time that will increase the quality and continuity of the electrical supply due to an increase in the efficiency of devices.

Condition monitoring is a major component of predictive maintenance. With the appearance of IEC 61850 series, condition monitoring and other monitoring tools become easier to implement in automation substation systems. It defines among its information models several items that help to determine the condition of substation equipment. For example, the logical node used for modeling circuit breakers (XCBR) includes the sum of switched amperes (SumSwARs) and one operation counter (OpCnt) as some of their data attributes. The sum of switched amperes in a circuit breaker, also known as I^2t, and the number of switching operations are some of the key monitoring parameters to know the circuit breaker condition. In a similar way, several logical nodes include key data attributes needed to know the condition of power transformers.

Examples of logical nodes used to monitor transformer condition are:

- YPTR: includes the winding hotspot temperature.
- YLTC: includes key attributes to monitor the tap changer condition.
- ZBSH: provides properties and supervision of bushings as used for power transformers.
- SARC: includes attributes for monitoring and diagnostics for arcs.
- SPDC: includes attributes for monitoring and diagnostics for partial discharges.
- SIML: supervises liquid insulation medium such as oil used in transformers and tap changers, including attributes like relative saturation of moisture (H_2O), insulation liquid temperature (Tmp) and measurement of hydrogen concentration (H_2).

As described in [11], in the future all these nodes will be extended and included in logical node group S, specially dedicated to sensors and monitoring. Other logical nodes also useful for condition monitoring are described in section IV that belong to metering and measurement logical node group M, such as MMXU, MMXN, MMTR, MSTA, MHAI or MHAN [12].

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CONCLUSION

In terms of overall vision, smart grid enabled asset management will be a powerful tool for electric utility companies in many ways. Of the five fundamental technologies that the DOE lists will drive the Smart Grid; integrated communications, sensing and measurement, advanced control methods and improved interfaces with decision support.

Using the Smart Grid Conceptual Models, which is a set of views (diagrams) and descriptions that are the basis for discussing the characteristics, uses, behavior, interfaces, requirements and standards of the Smart Grid, one can postulate different mechanisms by which the smart grid enable asset management process may be enhanced. By investigating further the smart grid conceptual model shown previously, one can see that the majority of the asset management function is contained within three areas. These are the Operations, Transmission and Distribution areas. Each of these domains will benefit significantly from the smart grid since monitoring of assets within the smart grid will be more cost effective and beneficial than previously since the required infrastructure will be in place to support the smart grid functions broadly and not just for equipment monitoring. Sensing and measurement technologies are a key enabler of the smart grid.

Performance Based Asset Management

Asset management is a business approach designed to align the management of asset-related spending to corporate goals. Infrastructure Asset Management is a framework for making data-driven infrastructure investment decisions so that life-cycle costs are minimized while satisfying performance, risk tolerance, budget, and other organizational goals.

Stated simply, asset management is a corporate strategy that seeks to balance performance, cost, and risk. It also requires the corporate culture, business processes, and information systems capable of making rigorous and consistent spending decisions based on asset-level data. A higher level of performance requires higher cost.

Some portions of the power delivery asset management model benefits more from the smart grid than others. These portions are D7 – Asset/Service Performance, D8 – Asset Information and Inventory, P1 – Monitor Assets and Performance, P3 – Evaluate Asset Condition and System Performance, P12 – Monitor Implementation.

Building the Smart Grid

Just as the existing power delivery system was not built in a day, the smart grid will evolve over many years. The development should be based on requirements driven processes.

The future power delivery system will require development of a series of requirements documents that outline future applications such as: security (physical and cyber), network design, network management, data management and interoperability. From an architecture aspect there are three key elements that enable robustness, they are: interoperability, industry standards and open architecture.

Smart Grid Enabled Asset Management

The "Report to NIST on the Smart Grid Interoperability Standards Roadmap" provides extensive references to a number of standards that are suggested to be used as the foundation for the smart grid. The interoperability feature minimizes the work effort to interface applications and data between domains. The role of sensors and actuators in the smart grid is one of the fundamental elements required for successful operation of the grid. In the power delivery smart grid, sensors will increase in both type and quantity.

Developing the proper foundation elements including security and leveraging industry standards to ensure interoperability between systems and devices helps to keep costs reasonable over the long term. Finally, involve the information systems organization into the process all along the way.

While power delivery asset management concepts have been around for well over ten years, during much of that time decision makers have had to settle for less than idea conditions when it come to asset specific information. In most companies, the asset manager has little asset specific data or the data was expensive to obtain from the field. With the advent of the smart grid and its extensive communications infrastructure and computational capability, the asset manager will be able to very specifically determine the health and performance of specific assets and the system conditions the asset experiences. Through this report one can envision a much higher caliber asset management process and also a much more automated one. Once the smart grid starts to get deployed at electric utility companies, the asset manager will be one of the primary benefactors and the performance level of the organization will take a significant step up in analytical capability and understanding asset performance.

Final Thoughts

Future EPRI work in this area should take place in two areas. The first should be in the specific asset specific programs such as transformers, circuit breakers, etc. These asset specific programs should analyze the data sources available to them and look for ways to tap into these sources for more comprehensive measures. For example, in the transformer area besides the routine information such as loading and dissolved gas analysis, one can now take into account the basis for the loading. In the smart grid world, a transformer expert would know the cause of the overload and frequency and other parameters to take into account.

The other area of future work will need to be in enhancing the computational capabilities to deal with the large volumes of asset specific data and developing algorithms to adequately interpret the data and turn it into actionable information.

7 REFERENCES

Previous EPRI published work involving future smart grid systems operations was completed recently. This work was in the area of transmission and protection applications along with existing open standards.

The intent behind this work was to identify key technical infrastructure issues that need to be addressed through a combination of standards development, consortia support, and focused technical project work. Critical elements of the needed open systems-based infrastructures remain to be resolved before the vision of next-generation automation systems can be realized.

This work will not be repeated in this report but can be found in the following reports: 2, 3 and 7.

[1] U.S. Department of Energy (DOE) entitled "The Smart Grid: An Introduction".

[2] Report to NIST on the Smart Grid Interoperability Standards Roadmap (Contract No. SB1341-09-CN-0031—Deliverable 10) Post Comment Period Version Document, National Institute of Standards and Technology under the terms of Contract No. SB1341-09-CN-0031. http://www.nist.gov/smartgrid/Report%20to%20NISTlAugust10%20(2).pdf.

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[9] User guide for the application of monitoring and diagnostic techniques for switching equipment for rated voltages of 72.5 kV and above. Cigré. 2000.

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[11] Karlheinz Schwarz, "IEC 61850 also outside the substation for the whole electrical power system", 15th Power Systems Computation Conference PSCC, Session 13, Paper 6. 2005.

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