Arnold Schwarzenegger
Governor

INTEGRATING NEW AND EMERGING TECHNOLOGIES INTO THE CALIFORNIA SMART GRID INFRASTRUCTURE

A Report on a Smart Grid for California

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:
Electric Power Research Institute (EPRI)

September 2008
CEC-500-2008-047

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Commission Contract No. 500-02-014
Commission Work Authorization No. 132

Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

DISCLAIMER

Acknowledgments

This report describes research sponsored by the Electric Power Research Institute (EPRI) and the California Energy Commission.

This publication should be cited in the literature as follows:

Chuang, A., J. Hughes, M. McGranaghan, and X. Mamo., 2008. *Integrating New and Emerging Technologies into the California Smart Grid Infrastructure.* EPRI, Palo Alto, CA; California Energy Commission, Sacramento, CA. 1016535. CEC-500-2008-047.

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Integrating New and Emerging Technologies into the California Smart Grid Infrastructure is the final report under contract 500-02-014, work authorization number 132 conducted by the Electric Power Research Institute (EPRI). The information from this project contributes to PIER's Energy Systems Integration Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

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Abstract

This project determined the status of key elements of a smart grid infrastructure definition, development, and implementation; and to use this information to develop recommendations for research, development, and technology demonstrations that will accelerate smart grid deployment within California. There are varying perspectives on what constitutes a smart grid, ranging from an emphasis on infrastructure to an emphasis on new paradigm-shifting applications in the electric power industry. For example, automation of demand response and automaton of distribution operations are some applications of a smart grid. Alternatively, the smart grid can be thought of as an information pipeline that enables desired customer and utility applications using the electricity grid.

This project found that carefully designing a smart grid communications infrastructure, which collects, stores, and exchanges information cost-effectively among emerging, new, and existing grid components, is critical. A well-thought out design can enhance the feasibility and cost-effectiveness of new customer choices and uses across diverse business systems. Realization of such an information-enabled grid across the electric power industry is a major challenge, due to gaps in infrastructure, technology, and architecture development. The project describes gaps and research needs in six critical technology areas: (1) architecture and communications infrastructure, (2) renewable and distributed energy resource integration, (3) grid operations and control, (4) asset and capital efficiency, (5) customer system, and (6) workforce efficiency.

Public workshops and meetings conducted during the study were structured to enable discussion and feedback from the audience so that participants had opportunities to express individual perspectives on the California smart grid and research needs. A primary conclusion is that a unifying vision of the California smart grid shared by government, industry, utilities, and customers is needed. These could then be used as a basis for identifying research, technology development, and implementation priorities.

Keywords: Smart grid, architecture, communications infrastructure, interoperability, standards, greenhouse gas, renewable resource, energy efficiency, distributed energy resources, energy storage, advanced metering infrastructure, demand response, value capture

Executive Summary

Project in Brief

In recent years the term "smart grid" has become a popular buzzword. However, there are varying perspectives on what constitutes a smart grid, ranging from an emphasis on infrastructure to an emphasis on new paradigm-shifting applications in the electric power industry. For example, automation of demand response and automaton of distribution operations are some applications of a smart grid. Alternatively, the smart grid can be thought of as an information pipeline that enables desired applications. Adding to the variety of perspectives, more than a dozen different national groups claim to be working on smart grids. A cohesive view of the smart grid is needed. Furthermore, clarity and direction are needed to develop a comprehensive research, development, and demonstration (RD&D) plan supporting smart grid deployment in California. Critical technology areas and gaps need to be identified and linked to the potential of achieving policy-driven research priorities outlined in the *2007 Integrated Energy Policy Report.* Research priorities include: achieving targets for renewable portfolio standards, greenhouse gas emission reduction, energy efficiency, and demand response.

Project Objectives

The overall objective was to determine the status of key elements of smart grid infrastructure definition, development, and implementation and use this information to develop recommendations for research, development, and technology demonstrations that will accelerate smart grid deployment within California.

Meetings were conducted with stakeholders to examine answers to the following questions:

1) What is the current status of the smart grid?
2) What new and emerging technologies are on the horizon that impacts the smart grid of the future?
3) How can the authors avoid incompatible systems being fielded that result in costly legacy systems that must be replaced much sooner than projected?
4) How is open access, competition, and commercial growth of emerging, new and exciting technologies encouraged that provide California's ratepayers new ways to meet their energy needs while at the same time saving them money?
5) Where can government help?
6) What are the: short-, mid- and long-term smart grid infrastructure priorities for California?

Approach

The project team (California Energy Commission staff and EPRI staff) employed an iterative presentation and stakeholder feedback process to identify perspectives on what constitutes a smart grid for California. The team brought together over 100 stakeholders from electric utilities, California Public Utilities Commission staff, the California Independent System Operator, and California Energy Commission staff, as well as research organizations, end-use associations, smart metering equipment manufacturers, and other interested parties. The team held three meetings with key California agency staff and one major public workshop to foster collaborative discussion and assess understanding and research needs to spur development of a smart grid in California. More than a dozen one-on-one interviews were conducted to gather stakeholder perspectives before the public workshop.

The project team presented initial findings at each staff meeting and public workshop. To develop these initial findings, the project team employed a top-down "hierarchical" approach. By framing the big picture first, the team was able to drill down into selective technical areas in which more details were needed. This hierarchical approach supported broad coverage of smart grid topics and categorization of diverse smart grid technology areas within a unifying framework. This approach also enabled critical technology and architectural gaps to be readily identified and associated with RD&D recommendations.

Findings and Results

Stakeholder Perspectives

The staff meetings and public workshops conducted during the study were structured to enable discussion and feedback from the audience so that participants had opportunity to express individual perspectives on the California smart grid and research needs. Key perspectives gathered during these meetings included:

- Architecture is vital to integrating the different aspects of the smart grid.
- Developing a smart grid will improve renewable energy resource integration.
- A collaborative effort among all the stakeholders is needed for a smart grid vision for California.
- Demonstrations of technologies are needed to implement the vision.
- Customers can better manage their energy needs.
- Educating customers on the application benefit is needed.
- Smart grids can provide a substantial support to the achievement of the targets defined in the *2007 Integrated Energy Policy Report.*
- Customer choice is imperative as needs vary across customer classes and customers have diverse preferences.

As project interviews and meetings were conducted, it became clear that California does not yet have a unifying vision for the state's smart grid or its architecture at this time. The vision needs to be defined first by bringing stakeholders together and next steps established based on a common definition of the smart grid. Smart grid architecture should best be defined based on upon applications smart grid could support.

A Smart Grid for California

Besides stakeholder perspectives, the definition of a smart grid for California should consider smart grid drivers and barriers as well as state policy targets. In particular, a smart grid can assist the state in achieving targets for renewable portfolio standards, greenhouse gas emission reduction, energy efficiency, and demand response. These targets are summarized in Figure 1. Other considerations that impact the definition include (1) the current characteristics of the power system infrastructure in place, (2) mass technology deployments planned or projected, and (3) future orientations of state and national energy policy.

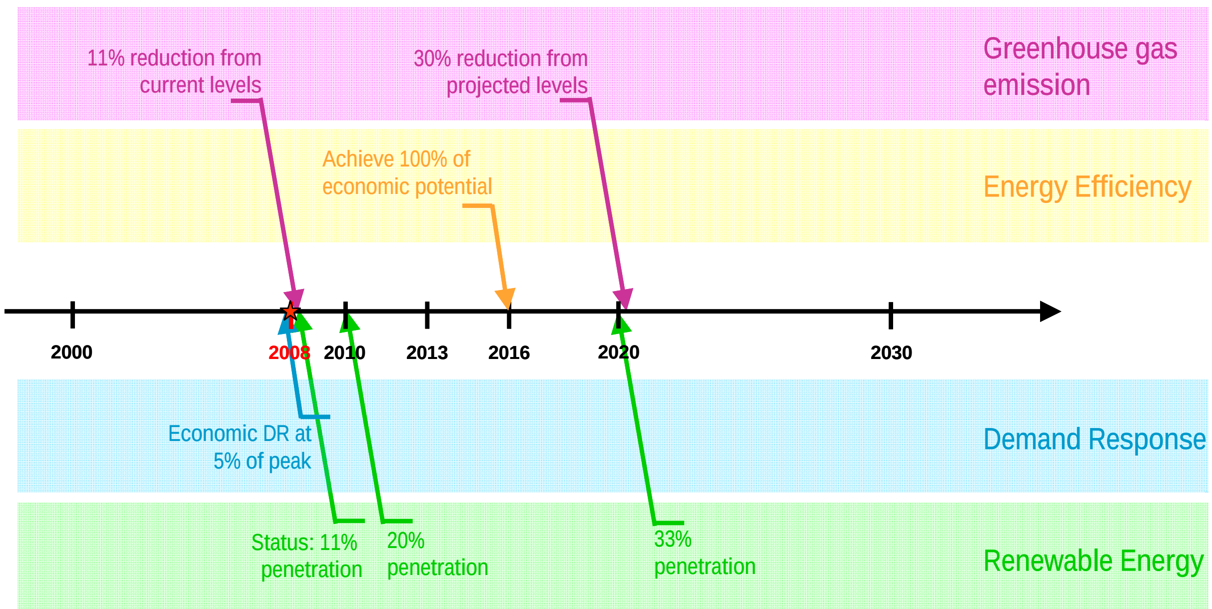

Figure 1: California Policy Targets for Renewable Energy, Demand Response, Energy Efficiency, and Greenhouse Gas Reduction.

A smart grid requires the merging of two primary infrastructures: the electrical power system and a communications infrastructure. The latter provides the foundation for implementing a variety of intelligent applications and technologies that require communication with sensors and devices in combination with methods to improve the performance of the system, allow integration of distributed energy resources (including loads through demand response), and improve the reliability and power quality of the system. Another important component of the smart grid infrastructure is the information systems that must be integrated for the intelligent applications to be used. This requires common information models and guidelines towards achieving interoperability, which enables different grid components and information systems to communicate with one another and operate in concert with each other.

Greater grid "intelligence" requires well-orchestrated use of technologies across the electric power industry, which may include a variety of equipment hardware, control algorithms, and communications networks. These smart grid components can be depicted under a unifying framework to categorize technology areas.

Categorization of Smart Grids Technology Areas

A unifying framework is developed to show the various technological components relationships that enable the smart grid. Smart grid components can be related by different technology levels and major business function. Figure 2 illustrates the framework created to depict various technical elements of the smart grid.

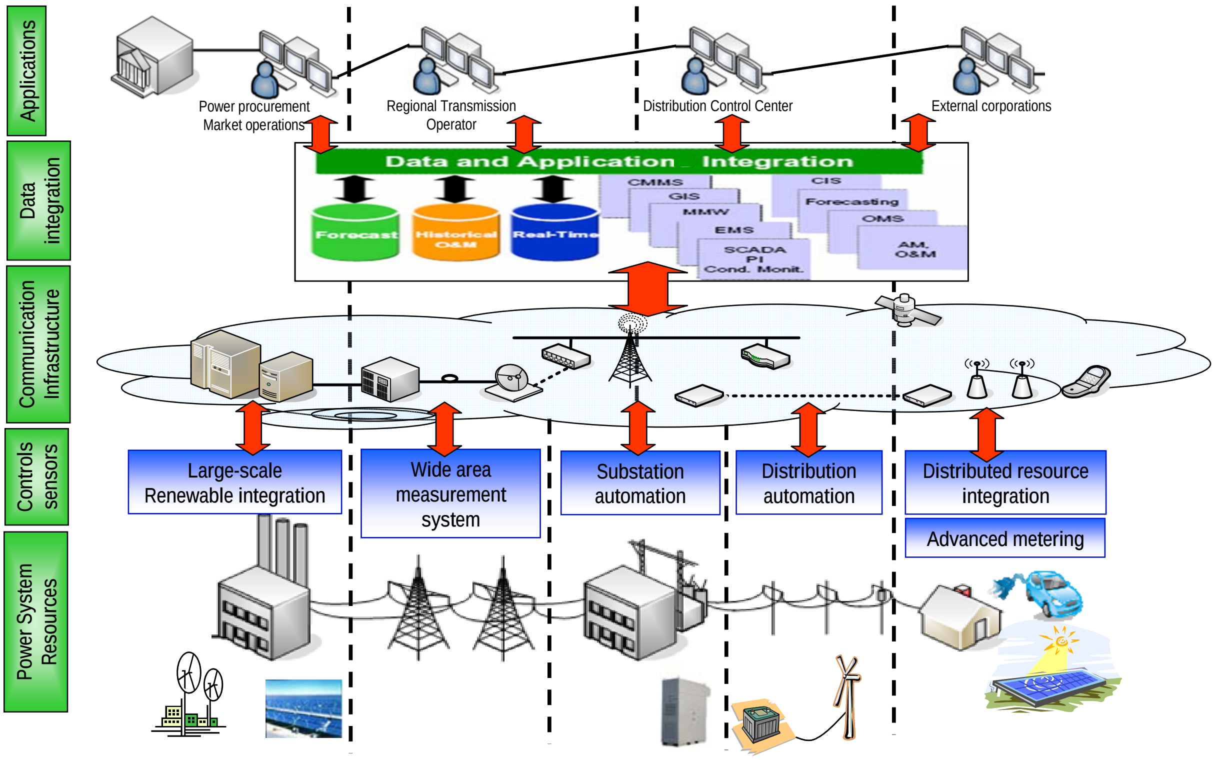

Figure 2: Depiction of technology components by hierarchical level and relevant business area provides a framework by which to identify relevant smart grid technology areas.

An Information-Centric Perspective of a Smart Grid

A "smart grid" can be described as an information-enabled grid. Information is collected through existing, new, and emerging sensing and measurement systems. The information may be used to improve efficiency, reliability, and cost-effectiveness of power system operations, planning, and maintenance. These electric power industry functions are managed through applications with human interfaces that support operator decision-making.

Information for enhancing the grid may arise from a variety of sources. For example, utility supervisory control and data acquisition systems can be augmented with advanced sensors to collect information across the grid. Advanced metering infrastructure will allow a closer view of power consumption and user profiles. Wide area measurement systems are applied to enhance a regional system operator's wide area view of real-time power system conditions. Information on distributed energy resources is also required for integrating high penetrations of distributed energy resources. This includes integration of renewable resources that are intermittent in nature. Monitoring, measuring, and, in some cases, controlling energy resources are necessary for supporting grid operations.

Careful designing of an integrated communications infrastructure applied to collect, store, and exchange information is critical. Information exchange can occur between diverse collections of decision support applications and advanced grid components. A well thought-out architecture can enhance the feasibility, cost-effectiveness, and ease of leveraging common sources of information across diverse business systems. The ability to share common sources of information across disparate systems enables new applications of the information that may be potentially very valuable. Realization of such an information-enabled grid across the electric power industry is a major challenge, due to gaps in technology and architecture.

Critical Technology Areas and Gaps

Critical technology areas for smart grid development are identified in this report under each of the following categories:

- **Architecture and Communications Infrastructure**: Develop communications architecture, standards, management and security infrastructure to support interoperability [1] of field equipment, automation, and information exchange for the smart grid.
- **Renewable and Distributed Energy Resource Integration**: Integrate and manage new sources of renewable and distributed energy supply.
- **Grid Operations and Control**: Automatically monitor, assess, and control the grid to adapt to changing conditions to meet customer reliability and power quality requirements.
- **Asset and Capital Efficiency**: Improve use of existing power system assets and new investments in hardware with better intelligence and modern technology to optimize system planning and to improve infrastructure capital efficiency.
- **Customer Systems**: Enable customers to better manage their energy consumption.
- **Workforce Efficiency**: Maximize workforce productivity, effectiveness, and safety through application of enabling tools, technologies, and training.

Recommendations

Recommendations based on stakeholder interviews, background research, and public workshop include (1) an approach to define the California smart grid architecture and requirements and (2) a summary of important development needs in each critical technology area.

[1] According to ISO/IEC 2382-01, *Information Technology Vocabulary, Fundamental Terms*, interoperability is defined as follows: *"The capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units".*)

Proposed Approach to Define the California Smart Grid Vision

The recommended method of developing requirements for the smart grid infrastructure and technologies that are part of the infrastructure is the "use case method." This is a method for describing requirements of technologies according to user interactions, and has been documented in the IEC Publicly Available Specification 62559.

It is recommended that a series of workshops be organized around different application areas to develop a prioritized set of use cases by category. These use cases would be used to derive requirements for individual technologies as well as the overall infrastructure and should coincide with stakeholder value in the applications that are being defined in order to better prioritize development efforts.

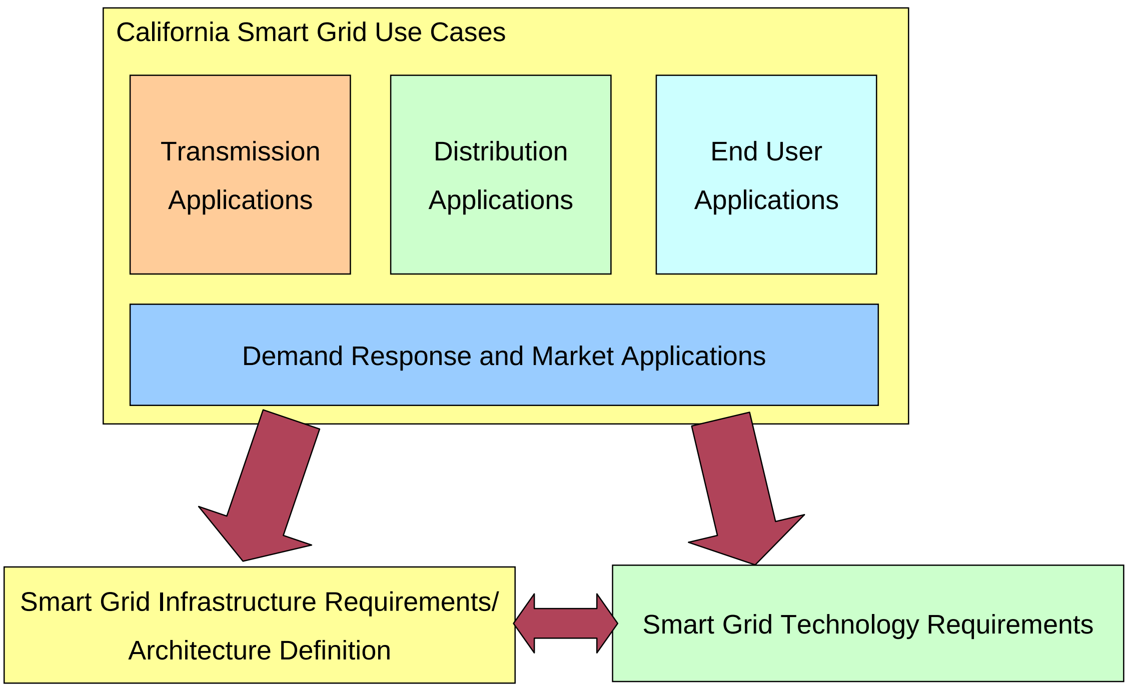

Figure 3: Developing the California smart grid use cases and using them to develop requirements for the architecture and technologies.

As technologies and applications are developed, requirements for integrating them with the smart grid infrastructure must be identified and coordinated. Integration requirements stemming from the use case process should be considered in the research and development of each critical technology and application area.

Technology Development Needs

For Architecture and Communication Infrastructure, the recommendations are:

- Characterize the strengths and weaknesses of at least the following and demonstrate the performance in real-world conditions (1) Wide Area Wireless, (2) Short Distance Wireless, (3) Powerline Media (Narrow and Broadband), (4) Fiber and Other.

- Develop and adopt new security architecture for advanced automation and customer communications to better ensure secure communications exchange and resiliency against attack. As advanced metering infrastructure becomes more prevalent as an enabling technology for demand response and integrating distributed generation and storage (including plug-in hybrid electric vehicles), the need for secure communications becomes more critical.
- Define information interfaces associated with different applications and technologies and develop these information interfaces into common standards similar to common information model Integration of information collected through advanced metering infrastructure is particularly critical in light of California's multi-billion dollar advanced metering infrastructure deployment plans.

The recommendation for renewable and distributed energy integration is to help move energy storage technologies toward maturity through their application in demonstrations. Storage technologies already exist but require wider application to drive down costs. Another recommendation is to define information models and tools for integrating the storage solutions as part of power system operations, which requires interfaces defined locally as well as hierarchically to manage the storage systems.

For Grid Operations and Control, recommendations include:

- Develop transmission applications that will support improved awareness of conditions on the grid and better integration of distributed resources.
- Develop substantially applications to: improve reliability, integrate distributed resources, improve efficiency, and manage assets better.
- Develop the information models and open source tools to make new simulation approaches possible.

For Assets and Capital Efficiency, recommendations include:

- Define an advanced monitoring infrastructure that integrates data from many different sources for advanced application development.
- Develop component research in the form of advanced equipment diagnostics and asset management as well as research into the components themselves.
- Augment or replace entirely current system planning tools with tools that can allow for smart grid design into account.

For Customer Systems, the recommendations are:

- Develop and support applications that can benefit the customer, grid operations, and distributed resource integration by leveraging the current deployment of advanced metering infrastructure (smart meters) by the utilities.
- Develop the more general case of widespread participation of consumers in capturing increased value or broader market opportunities through retail pricing and other mechanisms

- Implement customer response models in demand response infrastructure

For workforce effectiveness, the recommendation is to develop a complete set of new engineering best practices and standard processes to replace what exists, and train the workforce to support the utility industry needs as the smart grid evolves, achieves widespread implementation, and finds new applications of value to utilities and their customers.

1.0 Introduction

1.1. Background and Foundation for the Work

Since 2001 EPRI has managed a collaborative research, development and demonstration (RD&D) process that has accelerated the industry's migration towards a Smart Grid. Because of EPRI's extensive work in developing a smart grid vision and roadmap for utilities, the California Energy Commission is collaborating with EPRI to create an RD&D roadmap to spur development of California's smart grid.

1.1.1. Foundation Leveraged in This Project

In 2001, EPRI launched the Consortium for an Electric Infrastructure to support a Digital Society (CEIDS) with the objective of conducting Research, Development and Demonstrations that would lay the foundation for the power delivery infrastructure of the future. This public/private partnership pooled funding from domestic and international utilities, the California Energy Commission, the U.S. Department of Energy and high tech companies such as CISCO System. CEIDS established a vision of the power delivery system of the future as being a Smart Grid that incorporates information and communications technologies into every aspect of electric delivery – from generation to consumption – and created a technology development roadmap. In 2003, CEIDS contracted with GE to develop and industry-wide architecture for the communications networks and intelligent devices that would form the basis of the smart grid. The IntelliGrid Architecture was released in 2005 and has now been implemented by several utilities. In 2007, the IntelliGrid Architecture Methodology was published by the IEC as a Publicly Available Specification. In 2004, CEIDS contracted with ABB to develop a distributed computing architecture that would be able to effectively convert the tremendous amount of data that will be generated by the smart grid into information that can be acted upon. In 2004, CEIDS began defining the requirements for a consumer portal that would serve as the communications link between electric utilities and consumers. In 2006, Southern California Edison used the IntelliGrid Architecture and Consumer Portal results as the starting point for their $1.5 billion advanced metering infrastructure (AMI) project.

In 2006, CEIDS changed its name to IntelliGrid. The IntelliGrid program continues today to conduct research, development and demonstrations that refines the smart grid vision and builds towards an industry architecture that promotes interoperable systems. IntelliGrid coordinates its activities with other organizations that are conducting R&D related to Smart Grids such as GridWise, the Modern Grid Initiative and the European Union Smart Grid Initiative. IntelliGrid works closely with utilities that are leading the industry in implementing smart grids.

1.2. Problem Statement

In recent years the term "smart grid" has become a popular buzzword. However, varying perspectives on what a smart grid is can be cited. Perspectives range from an emphasis on infrastructure to an emphasis on new paradigm-shifting applications in the electric power industry. For example, automation of demand response and automaton of distribution operations are some cited applications of a smart grid. Alternatively, the smart grid can be thought of as the information pipeline that enables the desired applications. Adding to the variety of perspectives, well over a dozen different national groups claim to be working on smart grids. However, the vast majority are working on only a segment of the issue. A cohesive view of the smart grid is needed. Furthermore, clarity and direction are needed to develop a comprehensive RD&D plan supporting smart grid deployment in the state California. Critical technology areas and gaps need to be identified and linked to the potential of achieving policy-driven priorities for RD&D.

The project team was tasked to consider California stakeholder perspectives, existing work on smart grids, and policy-driven priorities to develop a definition for a smart grid in California. Given disparate organizational activities in this area plus a wealth of technologies that exist, a study was needed to structure a framework of thought, organize findings, and develop RD&D recommendations. Ultimately recommendations should support realization of state policy objectives.

1.3. Project Objectives

The project team was tasked to perform research and conduct meetings with stakeholders to inform the California Energy Commission on answers to the following questions:

- What is the current status of the smart grid?
- What new and emerging technologies are on the horizon that impacts the smart grid of the future?
- How can we avoid incompatible systems being fielded that result in costly legacy systems that must be replaced much sooner than projected?
- How do we help foster open access, competition and commercial growth of new and exciting technologies that provide California ratepayer new ways to meet their energy needs while at the same time saving them money?
- Where can government help and where should government stay out?
- What are the short-, mid- and long-term smart grid infrastructure priorities for California?

The overall project objective was to assess smart grid research, development, demonstrations and deployment activities to identify opportunities to:

- Integrate ongoing and future smart grid research projects to ensure a utility grid infrastructure can be developed in California that supports the necessary capabilities and technologies to meet established renewable integration goals and future system efficiency, and performance goals.
- Accelerate smart grid deployment within California through the funding of research, development, technology demonstration or policy influence.

In other words, the objectives were to assist the Energy Commission in developing a collective understanding of the status of key elements of smart grid infrastructure and technology development. The team was to leverage prior work on smart grids to inform opportunities to develop RD&D program that will spur the creation of a smart grid in California.

Furthermore, RD&D recommendations must be linked to support the following top priorities:

- Ability to increase penetration of renewable technologies on the California smart grid.
- Improve overall grid system operational reliability, availability, sustainability and maintainability.
- Improve the environmental impact of the grid on California (reducing greenhouse gases [GHG] emissions).
- Increase efficiency of the grid.
- Reduce costs of operations of the grid.

1.4. Project Funders

The project represents a collective effort between the California Energy Commission's PIER Program and EPRI's Intelligent Grid program. The rationale of co-funding the research reported in this document is to leverage the extensive body of work and personnel expertise already established within EPRI to jump start the formation of a comprehensive RD&D program on smart grids within PIER.

1.5. Report Structure

Section 1 introduces the background and objective of the project. The project team's approach to addressing the objectives are structured into tasks described in Section 2. Findings from each project task are summarized in the remaining sections of the report. Stakeholder perspectives were collected from staff meetings, an open industry workshop, and individual interviews. These findings are captured in Section 3. Collective findings characterizing a smart grid for California are summarized in Section 4. Section 5 identifies critical technology areas and gaps to be overcome in realizing a smart grid. Section 6 presents a high-level architectural framework for a smart grid, and Section 7 identifies critical infrastructure and architectural gaps. Finally, RD&D recommendations are identified and discussed in Section 8.

2.0 Project Approach

2.1. Top-Down Approach

A top-down "hierarchical" approach was followed in executing the project to achieve the stated objectives. A big-picture-to-details approach allowed drilling into selective areas where more details were needed and could be accommodated within project time constraints. This hierarchical approach enabled broad coverage of smart grid topics and categorization of diverse smart grid technology areas in a resulting framework. The framework effectively categorizes technology areas at different levels and relates them to one another and in sufficient detail to identify critical technology and architectural issues in smart grid development. The framework was applied to identify technological and architectural issues where gaps exist and require further exploration.

Given the compressed timeframe of the project from start to delivery, the general approach followed was to begin by considering existing work taking place within the categories outlined. Focus was then placed on what is applicable to California and findings processed in an integrated fashion. By leveraging prior smart grid work, such as reports by EPRI IntelliGrid as well as DOE Modern Grid Strategy, the team was able to quickly characterize critical smart grid components and areas for further research, development, and demonstration. By leveraging a team of technical experts with experience across each major business function in the electric power industry, critical technologies and architectural gaps were rapidly identified.

Major project tasks included:

1. Define what a smart grid is for California, including.
    - Categorize technology areas related to the smart grid.
    - Assess relevant government policies.
    - Assess perspectives of currently active smart grid organizations.
    - Assess perspectives of stakeholders through interviews and group meetings.
2. Identify technology and architecture gaps for the California smart grid.
3. Describe the high level architecture and architectural principles for this smart grid.
4. Recommend future RD&D activities.

2.2. Process

The processed depicted in Figure 4 was followed to collect, present, and update project findings. Presentations were developed and presented to stakeholder groups to receive feedback. Between each presentation, there was an opportunity to update the last presentation based on feedback received. This process enabled prior work and findings on smart grids to inform the next stakeholder meeting. The collection of feedback is captured in this report, along with recommendations for development of an RD&D program that will spur the creation of a smart grid in California.

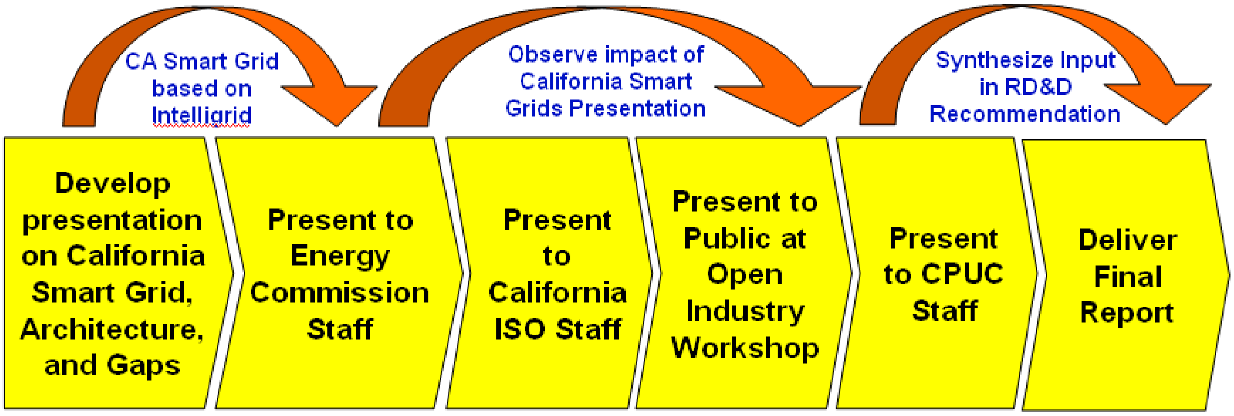

Figure 4: Process followed to define the California Smart Grid and develop RD&D recommendations.

2.3. Key Non-Technical Considerations

Besides technology and architectural considerations, various non-technical factors were identified as critical in influencing research recommendations. These non-technical considerations are discussed below.

2.3.1. Top Priorities

PIER considerations for planning new smart grid research include policy-driven priorities. Research recommendations must support the following top priorities identified by the Energy Commission:

- Ability to increase penetration of renewable technologies on the California Smart Grid.
- Improve overall grid system operational reliability, availability, sustainability and maintainability.
- Improve the environmental impact of the grid on California (reducing GHG emissions).
- Increase efficiency of the grid.
- Reduce costs of operations of the grid.

In particular, critical technologies and research recommendations identified must relate to the ability to achieve the priorities listed above.

2.3.2. Smart Grid Drivers and Barriers

Industry forces that are driving the need for smart grid development are key considerations in development of research recommendations, as are the barriers.

Drivers

The main drivers for California's Smart Grid development are detailed in Section 3 of this report. In brief these drivers include:

- Loading priority order: Stated in 2003, this strategy consists in meeting the California's energy needs first with energy efficiency and demand response; second, with renewable energy and distributed generation; and third, with clean fossil-fueled sources.
- Peak resource constraints: California's peak demand is expected to growth slightly (850 MW per year) as a consequence of the increase in cooling equipment installations due to the population's growth in dryer and warmer inland areas.
- Improve economics: The cost-effectiveness of the solutions chosen to achieve California's energy policy is a constant concern for the California Energy Commission since the last 30 years.
- Reliability concerns: providing a reliable power to the customer is one of the guiding and cross cutting principles of the California's energy policy for any generation, energy efficiency, demand response, transmission and distribution network developments.
- Environmental concerns: One of the challenges California has to deal with is to decrease the state's contribution to greenhouse gas emission (second largest in the United States) while maintaining good conditions for economy's growth.
- Enhanced innovation: California has a reputation for technology innovation and the state's energy policy is an important stimulus to increase and enhance the innovations for the benefit of the customers.

Barriers

Besides drivers, the reality of barriers in achieving California's smart grid development must be considered. These include:

- Need standards: As the California's smart grid will rely on the interaction between different components (from equipments to systems) with some already being deployed such as advanced metering infrastructure, the need for standards to allow systems interoperability and evolution is becoming more and more crucial.
- Technological barriers: New technology developments are needed to support the deployment of the smart grid in order to enhance the cost effectiveness and acceptability of the solutions that will support it such as storage, power electronics or automation.
- Automation: Very little regulatory incentives are yet available to encourage utilities in investing in smart distribution infrastructure to support flexibility including network automation.
- System operator confidence: The exchange of information between the different players is today insufficient to provide visibility on available resources, especially when it comes to the independent system operator to rely on end user load management.
- Economic justification: The deployment of the smart grid will require large investments from the different players, which need to be balanced with incoming benefits. The actual

regulatory policy induces economical uncertainties, thus constituting barriers to its development.

- Wholesale and retail disconnect: Because of the caped structure of retail prices, they are not reflecting the variations of the wholesale prices and do not encourage customers to play a more active role in the participation in the smart grid deployment.
- T&D Organization Silos: The actual organization's boundaries between transmission and distribution are not favorable to ensure trusted and coordinated operations from a smart grid system perspective.

2.3.3. Other Smart Grid Organizations and RD&D Activities

One of the initial tasks of the project was to assess and leverage work from currently active smart grid organizations. These included reports published under DOE's Modern Grid Strategy, EPRI's Intelligent Grid, Utility AMI, GridWise, government labs, the European Union Research Framework Seven, and the Galvin Electricity Initiative. Existing activities were considered in order to avoid redundancy of work already conducted elsewhere.

2.3.4. Stakeholder Perspectives

Meetings were conducted with stakeholders via one-on-one interviews as well as group meetings. These meetings were vehicles to determine answers to the following three questions with respect to each organization the project team interacted with.

- What is the participant's understanding of what a smart grid is?
- What research or effort is the participant's organization involved with that is smart grid related?
- What research does the participant think that Energy Commission should do to support smart grids?

Well over a dozen interviews were conducted with individuals across utilities (investor-owned as well as municipal-owned), end-user associations (representing the interest of manufacturers, building owners, and their residential employees), and research organizations. Staff meetings were held with key organizations including the California Independent System Operator, California Energy Commission, and California Public Utilities Commission. Finally, a public workshop open to the industry was held in Palo Alto to provide an opportunity for the general public to provide perspectives and feedback.

3.0 Stakeholder Perspectives

This section summarizes lessons learned from stakeholder interviews, onsite staff meetings, and an open industry workshop conducted with the groups identified below.

3.1. Meetings and Workshop Findings

The staff meetings and public workshop conducted during the study were structured to enable discussion and feedback from the audience so that participants had opportunity to express individual perspectives on the California smart grid and research needs.

The following questions were posed as objectives in the meeting announcements:

(1) What is the current status of the smart grid?

(2) What new and emerging technologies are on the horizon that affects the smart grid of the future?

(3) How to avoid incompatible systems being fielded that result in costly legacy systems that must be replaced much sooner than projected?

(4) How to help foster open access, competition and commercial growth of new and exciting technologies that provide California ratepayer new ways to meet their energy needs while at the same time saving them money?

(5) Where can government help? Where should government stay out?

(6) What is the short-, mid- and long-term smart grid infrastructure priorities for California?

Each meeting began with a presentation by the project team to describe initial findings. Key takeways are summarized below.

Key findings from each meeting are summarized below, with further details contained in the Appendix of this report.

3.1.1.1. *Energy Commission Staff Meeting*

Architecture is key to integrate the different aspects of the Smart Grid

The smart grid will be an integration of different "sub-smart grid" (transmission, distribution, end use) with specific interactions to handle at different levels with end use (buildings), smart or zero energy communities, and bulk power. To deal with this integration aspect, there is a need to develop a robust infrastructure that will be able to evolve and incorporate the changes in the interactions with the grid. As an example, advanced metering infrastructure (AMI) deployment will support end-use and community integration. AMI will also support standardization efforts at the appropriate level (state, nation, international), which are needed to help enhance the maturity of the underlying technologies and with a special emphasis on security.

The Smart Grid will provide local greenhouse gas emission levels to consumers

The smart grid could provide real time data to consumers to let them know what their carbon footprint is and encourage them to reduce it. A competitive neighborhood carbon footprint comparison program could be set up. The data made available by the Smart Grid could also identify carbon footprint versus greenhouse gas emission reduction and energy efficiency impacts at a local level.

Renewable energy sources will drive Smart Grid developments

The smart grid will have to integrate a broad range of distributed energy sources including small renewables (for example, solar photovoltaic on rooftops). These resources will drive smart grid development because they will be out of the control of network system operators. This situation may be problematic to maintaining grid reliability. More accurate forecasts and more intelligence in the operation of these intermittent distributed resources are thus needed to attenuate their effects.

3.1.2. California ISO Staff Meeting

The grid will become smart thanks to new information use

A smart grid can be described as an information-enabled grid. Information is collected through existing, new and emerging sensing and measurement systems. The information may be used to improve efficiency, reliability, and cost-effectiveness of power system operations, planning, and maintenance. These electric power industry functions are managed through human interfaces providing decision support. Information for enhancing the grid may arise from a variety of sources.

Architecture is vital to enabling information sharing across business areas

A well-thought out architecture can enhance the feasibility, cost effectiveness, and ease of leveraging common sources of information across diverse business systems to enable new value-added applications of the information. Realization of such an information-enabled grid across the electric power industry is a major challenge, primarily due to lack of standard protocols and methods to achieve integrated communications across traditional business units. Legacy systems, non-standard methods, and a wealth of communication protocols in use today abound. These challenges impact realization of a Smart Grid in California.

Improving customer service is the ultimate goal of a smart grid

The smart grid ultimate goal should be to improve the customer service (duration and frequency of events). One way to achieve it is to set a goal to restore the complete bulk system in 2 hours to limit the impact on the customer and assess the technologies that can enable its realization. The associated cost of service can thus vary but the customer should have the choice and depending on their needs some may be ready to pay more for better quality of service.

3.1.3. Open Industry Workshop

A smart grid vision is needed for California, which will require a collaborative effort

A necessary step in the definition of the overall architecture to support the California smart grid is development of a common vision. As smart grid deployment impact is very broad for the society (for example, can minimize the impact of blackouts, reduce wood fires due to power lines, contribute strongly to achieve the state's AB 32 targets), the state legislature, state commissions, as well as industry, and other organizations need to be involved in a broad collaborative effort to address this aspect.

On-going deployments need to be taken into account

Efforts are already on track to set up and deploy some key elements of the smart grid such as AMI or distribution automation. They need to be taken into consideration when it comes to define architecture or new features in order to integrate them as smoothly as possible and find consensus.

Demonstration of technologies are needed to implement the vision

Demonstrations of key pieces that need to be emphasized to develop the smart grid (1 to 3 years) are also needed in addition to the Smart Grid vision definition. These should include the assessment of storage options for California (Sodium-Sulfide (NaS) batteries, flywheels, flow batteries and compressed air storage), automated demand response systems, transmission systems (FACTS), control and wide area measurement systems and smarter power components.

3.1.4. CPUC Staff Meeting

The smart grid will allow customers to meet their energy needs and save money

The objective of "foster open access, competition and commercial growth of new and exciting technologies that provide California ratepayer new ways to meet their energy needs while at the same time saving them money" is very important for CPUC and should support the areas where government can help.

Customer perception of smart grid benefits is variable

A difference needs to be made between big consumers that are well aware of related smart grid issues (because of the amount of their power bill) and residential consumers who want more choice: the "one size fits all" does not apply in this case. A behavioral change is needed to make the residential consumers play a more active role in the system. The benefits these consumers can get from smart grid deployment should be highlighted and advertised.

An education process is needed

The need for defining a vision for a California smart grid is clear and the next step will be to build this vision as a consensus between the different players (IOUs, California ISO, CPUC, industry) in a 9 to 12 months timeframe (a specific attention should be made on the efforts going on regarding the amounts invested in AMI deployments). A workshop on smart grid could be organized to provide guidance and technical issues to move forward. The idea is to enable creativity coming from different organizations but come to a shared system (and not many different ones). CPUC is favorable to this and it might be a good way to facilitate the definition of standards.

3.2. Stakeholder Interviews

Interviews were conducted with individual stakeholder organizations such as utilities, end-user associations, and research institutions to determine individual perspectives on the following:

- What a smart grid is.
- What research or effort the organization is involved with that is smart grid related.
- What research the Energy Commission should do to support smart grids.

Lessons learned are summarized below. Utility perspectives are included, as well as that of end-use associations and research organizations.

3.2.1. Utilities

Smart grids can provide a substantial support to the achievement of the targets defined in the California Energy Policy

- This can involve integration of demand-side and renewable resources.
- "Storage will be the key to integrating intermittent resources in high penetration."
- Field deployments needed to "move from conceptual to pilot to see if ideas would really work or not."
- Microgrid demonstration projects to validate technologies and identify grid issues.
- PHEV demonstrations.

Data integration, controls, and decision support are also important

- "Given existing infrastructure, how to interface with legacy equipment, how to develop open interface system, and then how to take all that data and make decisions."
- "Machine to machine speed and decision making to prevent catastrophic failures."
- "If don't have a lot of devices to control then having the communication network is not all that useful."

Wide Area Measurement Systems are needed

- "Could have avoided the northeast blackout with widespread phasor measurement unit (PMU) deployment."

Security issues need to be addressed

- "The number one critical area of concern."

3.2.2. End-User Associations

A smart grid will facilitate demand response, an area of end-use customer interest

- "Interested in how smart grid could facilitate demand response (DR)," so customers can gain benefit from responding.
- Standardize protocols for payment methods and market participation protocols are needed.

- "Without automation difficult to expect participation DR program."

A smart grid will facilitate distributed generation interconnection, another area of end-use customer interest

- "Interested in how smart grid could facilitate DR," so customers can gain independent validation of cost of service results, to lower interconnection charges that currently make the interconnection of DG prohibitive.
- Smart grid will provide data potentially available to both utility and regulator to look at the cost and benefits of DG along the distribution system.
- Need more plug-and-play interconnections.

Economic analysis is a key area of research needed

- "Interested in how smart grid could facilitate Demand Response," so customers can gain economic benefit.
- What is it going to cost to integrate renewable resources since need other resources when wind doesn't blow?
- Develop cost/benefit and measurement of value of onsite generation in the load pockets. Does it avoid local congestion and line losses and if so how will customers capture value for investing in DG?
- "Need to fund research to look at different workable economic models. Make sure there is a marrying of a sound economics with whatever RD&D you have."
- Smart grid can provide the data to do cost/benefit analysis.

Electric service reliability can be enhanced by a smart grid

- A smart grid informs how the utility can manage the grid to better forestall an outage.
- A smart grid is also about how and where to install pieces of smart grid that will provide overall reliability benefit to the system but also utility cost savings over time, through management of the distribution system.

3.2.3. Research Organizations

Microgrid research is a critical area of need and demonstrations are underway

The study of microgrids can provide a means of achieving greater penetration of small scale distributed generation and renewable energy.

Development of requirements is a critical initial step of research required

A repository of generic requirements is needed and once developed can be shared with other utilities.

Development of architectural methods and tools are needed

- Assessing existing infrastructure and planning what should be retained, renovated, removed, or developed new, as in "urban planning" but of the electric power system.
- Optimal distribution of intelligence.
- Allocating technical performance throughout components of architecture.

3.2.4. Perspectives on Electric Service Reliability

Customer choice is imperative as needs vary across customer classes and customers have diverse preferences

- "Research should not be looking at a one size fits all for customers. Needs to be a flexible solution."
- "Reliability is totally key to manufacturing"
- Can match quality of power and reliability to the requirements of the end uses by controlling power quality and reliability (PQR) locally rather than centrally.
- Economic assessment is needed as "cost and benefits of having deviations in power quality and reliability is under researched area."

4.0 A Smart Grid for California

4.1. Smart Grid Vision and Characteristics

This section summarizes results of the project task to define characteristics and other defining aspects of a California Smart Grid. The findings are based on government policy at both state and federal level, as well as currently active smart grid organizations.

4.1.1. California Energy Policy

*The 2007 Integrated Energy Policy Report (*IEPR)[2] provides an integrated assessment of the major energy trends and issues facing the California's electricity, natural gas, and transportation fuel sectors. The IEPR is the overall guiding document on energy policy. The Energy Action Plan II [2](2008 update) is a document intended to capture recent changes in the policy landscape and describe intended activities to accomplish those policies. As a reminder, the original Energy Action Plan defined for the first time a "loading order" to address California's future energy needs. The "loading order" established that the state, in meeting its energy needs, would invest first in energy efficiency and demand-side resources, followed by renewable resources, and only then in clean conventional electricity supply.

These reports were used as sources to identify and extract the major targets associated to the California Energy Policy regarding the electricity sector. This analysis will be used as a guidance to identify the specificity of the California Smart Grid and the way it can contribute to achieve these energy goals through the development and deployment of adapted technologies.

Climate change

Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), T*he California Global Warming Solutions Act of 2006*, mandates that California reduce its greenhouse gas emissions to 1990 levels by 2020. This is an aggressive goal that represents approximately an 11 percent reduction from current emissions levels and nearly a 30 percent reduction from projected business-as-usual levels in 2020. The Governor's Executive Order S-3-05 underscores that long-term commitment, establishing a goal of 80 percent below 1990 levels by 2050.

Energy Efficiency

Assembly Bill 2021 (Levine, Chapter 734, Statutes of 2006) requires the Energy Commission, in consultation with the CPUC and the publicly owned utilities, to produce a statewide estimate for investor-owned and publicly owned utilities of "all potentially achievable cost-effective electricity and natural gas efficiency savings and establish statewide annual targets for energy efficiency savings and demand reduction over 10 years." The Energy Commission concluded that the statewide targets should be set to achieve all of the state's cost-effective energy

[2] California Energy Commission. 2007. 2007 Integrated Energy Policy Report. CEC-100-2007-008-CMF

efficiency. The CPUC supports this goal and has described a course of action focused on programs under its and the Energy Commission's authority to pursue it.

The CPUC and the Energy Commission envision "big, bold" programmatic initiatives within the overall statewide strategic plan designed to achieve zero-net-energy homes by 2020 and zero-net-energy commercial buildings by 2030.

Demand Response

The first Energy Action Plan set a goal of five-percent of peak demand to come from price response from consumers by 2007. Results are nowhere near that goal and must reinvigorate our efforts in this area.

The Energy Commission has opened a proceeding to examine how its legislative authority to adopt load management standards for the state can be used to accelerate our pace of demand response. In addition to being able to integrate technology and tariff innovations, the Energy Commission's standards would be applicable to publicly owned utilities.

Renewable energy

Senate Bill 1078 (Sher, Chapter 516, Statutes of 2002) introduced a Renewables Portfolio Standard (RPS) with the goal of increasing the portion of electricity derived from renewable resources and sold to retail customers to 20 percent by 2017. Initially designed to address California's growing dependence on natural gas for electricity generation and encourage long-term power purchase contracts, the RPS is also an important means for meeting the state's AB 32 greenhouse gas emission reduction goals. Senate Bill 1250 (Perata, Chapter 512, Statutes of 2006) accelerated the 20 percent goal to 2010. The Governor, the Energy Commission, and the CPUC have endorsed an enhanced target of 33 percent renewable by 2020.

Currently, about 11 percent of the state's electricity is from renewable energy sources such as solar, wind, and biomass.

The Executive Order S-06-06 of April 2006 sets a target for biomass to comprise 20 percent of the state's Renewables Portfolio Standard for 2010 and 2020. In addition, the order states that California shall produce a minimum of 20 percent of its biofuels within the state by 2010, 40 percent by 2020, and 75 percent by 2050.

Through the Million Solar Roofs Program, California has set a goal to create 3,000 megawatts of new, solar-produced electricity by 2017. The California Public Utilities Commission, through its California Solar Initiative, provides incentives over the next decade for existing residential homes and existing and new commercial, industrial, and agricultural properties. The California Energy Commission manages a 10-year, $400 million program to encourage solar in new home construction through its New Solar Homes Partnership. The overall goal is to help build a self-sustaining photovoltaic, solar electricity market.

Distribution systems

Electric distribution systems throughout California still mainly use designs, technologies, and strategies that were designed to meet the needs of mid-20th century customers. These large and complex systems have historically provided reliable electric power to millions of customers throughout the state; however, aging infrastructure coupled with modern demands is starting to erode this capability. About 90 percent of all customer interruptions and outages are caused by distribution problems.

California's commitment to distributed renewable energy, combined heat and power, and demand response requires a change in the design of these distribution systems to accommodate the integration of these new resources. Ideally, an automated 21st century distribution grid would allow operators to manage the grid in real time, provide for rapid two-way information exchange between utilities and customers, and provide a seamless integration of the full spectrum of 21st century technologies

The Energy Commission supports the development of a modern electric distribution system to incorporate new resources and recommends in the IEPR that the state:

- Integrate distribution planning with other resource procurement processes to support the use of new low-carbon resources and applications — renewable energy, demand response, efficient combined heat and power, distributed generation, energy storage, advanced metering infrastructure, and plug-in hybrid electric vehicles.
- Provide financial incentives for utilities to meet goals related to performance, achievement of designated goals, service reliability, and customer assistance to achieve greater efficiency of electricity use.

These targets and recommendations derived from the California Energy Policy provide a solid basis to define criteria to assess the contribution of Smart Grid technologies in supporting the achievement of these goals:

- Ability to increase penetration of renewable technologies on the California Smart Grid.
- Improve overall grid system operational reliability, availability, sustainability and maintainability.
- Improve the environmental impact of the grid on California (reducing GHG emissions).
- Increase efficiency of the grid.
- Reduce costs of operations of the grid.

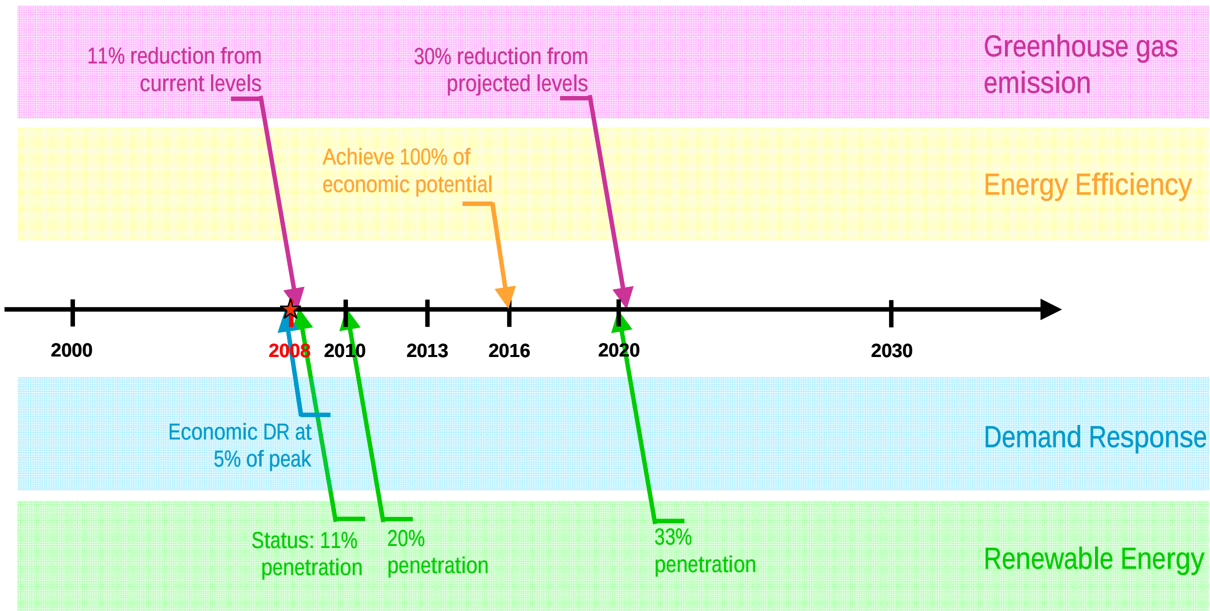

Figure 5: California Policy Targets for Renewable Energy, Demand Response, Energy Efficiency, and Greenhouse Gas reduction.

4.1.2. Energy Independence and Security Act (EISA) of 2007 and DOE Activities

The objective of the Energy Independence and Security Act[3], signed by the end of 2007, is to move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase the efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the federal government, and for other purposes.

Title XIII of this Act is specifically addressing issues related to smart grid defined as the support for the modernization of the electricity transmission and distribution system to maintain a reliable and secure electricity infrastructure that can meet future demand growth. In order to achieve the smart grid each of the following characteristics needs to be addressed (Section 1301):

1. Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.
2. Dynamic optimization of grid operations and resources, with full cyber-security.
3. Deployment and integration of distributed resources and generation, including renewable resources.

[3] Energy Independence and Security Act of 2007

4. Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.
5. Deployment of ''smart'' technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.
6. Integration of ''smart'' appliances and consumer devices.
7. Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.
8. Provision to consumers of timely information and control options.
9. Development of standards for communication and interoperability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.
10. Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

Under Title XIII, seven other sections address issues related to smart grid implementation.

4.1.3. European Union Framework Program Seven (FP 7)

The smart grid's vision is about a bold program of research, development, and demonstration that charts a course towards an electricity supply network that effectively and efficiently meets Europe's future needs. Europe's electricity networks must be:

- Flexible: Fulfilling customers' needs whilst responding to the changes and challenges ahead.
- Accessible: Granting connection access to all network users, particularly for renewable power sources and high efficiency local generation with zero or low carbon emissions.
- Reliable: Assuring and improving security and quality of supply, consistent with the demands of the digital age with resilience to hazards and uncertainties.
- Economic: Providing best value through innovation, efficient energy management and "level playing field" competition and regulation.

Key elements of the vision include:

- Creating a toolbox of proven technical solutions that can be deployed rapidly and cost-effectively, enabling existing grids to accept power injections from all energy resources.
- Harmonizing regulatory and commercial frameworks in Europe to facilitate cross-border trading of both power and grid services, ensuring that they will accommodate a wide range of operating situations.
- Establishing shared technical standards and protocols that will ensure open access, enabling the deployment of equipment from any chosen manufacturer.
- Developing information, computing and telecommunication systems that enable businesses to utilize innovative service arrangements to improve their efficiency and enhance their services to customers.

- Ensuring the successful interfacing of new and old designs of grid equipment to ensure interoperability of automation and control arrangements.

A key principle that has been applied in developing the Framework Program 7 Strategic Research Agenda[4] is that the grid user should be at the centre of the developments. Only with an accurate assessment of the requirements of the user can the electricity market develop effectively, whether the user is large (industrial) or small (residential). Active user participation should not limit itself to being part of the retail or commodity market, but to really participate in the demand for new services: real time pricing, active demand side participation schemes, distributed generation. Putting the user in the centre will also stimulate the decision makers in administration and regulation to assess the social need for the research developments.

4.1.4. EPRI IntelliGrid and Advanced Distribution Automation Programs

The IntelliGrid vision is: "A new electric power delivery infrastructure that integrates advances in communications, computing, and electronics to meet the energy needs of the future."

The vision was developed by stakeholders who identified the important benefits of the system of the future and then identified the capabilities needed to provide those benefits. The importance of reaching consensus with stakeholders on the vision is that there is support by stakeholders to make investments that are aligned with the vision. Society benefits most when everyone invests in concert with the vision.

In addition to the IntelliGrid program, the Advanced Distribution Automation (ADA™) program is developing the technical foundation for the distribution system of the future. ADA™ is a concept for a fully controllable and flexible distribution system that exchanges both energy and information between participants and system components. The result is a highly automated, responsive, and resilient distribution system that delivers benefits to a broad range of participants.

The main characteristics associated to this vision to achieve the smart grid are:

- Self-healing and adaptive
- Interactive with consumers and markets
- Optimized to make best use of resources and equipment
- Predictive rather than just reacting to emergencies
- Distributed across geographical and organizational boundaries
- Integrated, merging monitoring, control, protection, maintenance, EMS, DMS, marketing, and IT
- More secure from attack

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[4] European Commission, EUR 22580 – Strategic Research Agenda for Europe's Electricity Networks of the Future

4.1.5. Modern Grid Strategy

The U.S. Department of Energy (DOE) established the *Modern Grid Strategy* in 2005 through its Office of Electricity Delivery and Energy Reliability (OE) and National Energy Technology Laboratory (NETL).

The Modern Grid Strategy vision is: "To revolutionize the electric system by integrating 21st century technology to achieve seamless generation, delivery, and end-use that benefits the nation."

This vision statement[5] is defined through characteristics describing the features of the grid in terms of its functionality rather than in terms of specific technologies that may ultimately be needed:

- First, it will heal itself.
- Second, it will motivate consumers to be an active grid participant and will include them in grid operations.
- Third, the Modern Grid will resist attack.
- Fourth, the Modern Grid will provide the level of power quality desired by 21st century users.
- Fifth, the Modern Grid will accommodate all generation and storage options.
- Sixth, the Modern Grid will enable markets to flourish.
- Finally, the Modern Grid will optimize its assets and operate more efficiently.

The Modern Grid Initiative is creating a shared national vision of a modern grid's principal characteristics and key technology areas. The initiative is analyzing performance and technology gaps, developing a national concept of the modern grid, encouraging industry consensus and coordinating regional technology integration projects.

4.1.6. Other Organizations

The EPRI report[6] delivers information and profiles for use in distinguishing results of wide-ranging research on smart grids and for identifying collaborative opportunities. Benefits of this knowledge include increased coordination among R&D programs, reduced research costs through collaboration, and more widespread application of findings among vendors and utilities. The report highlights the commonalities and differences of the following programs: IntelliGrid, The Modern Grid Strategy, smart grid activities at DOE-OE (including GridWise), Advanced Grid Applications Consortium, Power Systems Engineering Research Center,

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[5] The NETL Modern Grid Initiative, A VISION FORTHE MODERN GRID, March 2007

[6] *2008 Update of the Profiling and Mapping of Intelligent Grid R&D Programs*. EPRI, Palo Alto, CA and EDF R&D, Clamart, France: 2008

Consortium for Electric Reliability Technology Solutions, California Energy Commission—Public Interest Energy Research, New York State Energy Research and Development Authority European Union Framework Programs, Galvin Electricity Initiative, SINTEF (Norway), CEATI International (Canada) and KEPRI (Korea).

4.1.7. Summary Findings

The analysis of the characterization efforts to define what a generic smart grid might be undertaken by different organizations reveal a good consistency among the results. The general concept is commonly shared and if the wording might differ from time to time a simple mapping exercise allows interconnecting each of the characteristics identified.

This generic definition needs to be used as a basis to illustrate the ideal smart grid. When it comes to apply this concept to a specific case such as the state of California, (1) the current characteristics of the power system infrastructure in place and (2) the future orientations of the energy policy shall be taken into account to define a California Smart Grid vision.

4.2. Examples of Applications Enabled by a Smart Grid

A smart grid enables innovative applications, some of which are well-advanced beyond existing power system operating paradigms. This section provides examples of innovative applications that a smart grid can support, to better depict the behavior of smart grids beyond the characteristics described in the previous section. Such applications represent advancements that a smart grid can offer, such as new operating paradigms and higher levels of responsiveness and customer choice.

As part of the electricity supply chain, residential customers interact with latest price, load control, and environmental signals sent to inform electricity consumption

Residential customers are commonly considered as "passive loads" from the power system planners' and operators' perspectives. Static load profiles are used to represent them. Profiling loads is important in forecasting system load and market prices. Transmission and distribution network operators also model loads to size or select the appropriate power system assets.

The smart grid can cause a paradigm shift by enabling residential customers to become active in the electricity supply chain, as "active loads" with dynamic characteristics. This evolution can be achieved through information exchanged with residential customer systems. Latest information on greenhouse gas emission levels and generation mix composition can inform customers of the impact of their end-use (at least on the margin). Household appliances and other end-use devices may receive latest price signals to influence programmable thermostats settings and other end-use options. In this smart grid enabling paradigm, residential customers will have the opportunity to play an interactive role in the electricity supply chain by modifying their energy uses based on signals received for coordination purposes. Local distributed generation such as photovoltaic-generated electricity (PV) or storage capabilities like plug-in-hybrid electric vehicles (PHEV) could be leveraged.

Development of low cost equipment and communications technologies may facilitate widespread customer interactiveness. Delivering pricing and other information signals to end-use devices in a very low cost, ubiquitous, and interoperable manner could have significant benefit and result in an exponential increase in deployment of grid-friendly devices. Technologies that support this paradigm-shifting application of the smart grid include:

- Low-cost, wireless transceivers and common information models that are easily embedded in commodity products without interfering with their core design or function.
- Low cost, distributed computing technology that can manage a fleet of commodity devices to optimize system performance based on a common objective function. Objectives may include minimization of overall energy use, shift of peak demand, minimization of peak demand, and minimization of one or more environmental metrics such as carbon dioxide (CO_2), sulfur oxide (SO), or nitrogen oxide (NO_2), emission levels.

An active distribution management system senses outages and automatically forestalls them

Traditional distribution system design and operation models are based on assumption of one-way power flow. The traditional paradigm is that energy is provided from generation plants to end users through transmission and distribution networks. Power system assets are generally designed and sized accordingly, along with associated voltage and protection plans to ensure reliability and safety for the entire system. However, about 90 percent of all customer interruptions and outages in the United States including California are caused by distribution problems. When an outage occurs it is often the customer who first alerts the utility of the issue. That is, trouble calls are initiated by customers and outages are discovered and resolved as they are reported.

The deployment of renewable energy resources, demand response, and energy efficiency solutions at the distribution or end use levels must change traditional methods of designing, operating and protecting the distribution network. Making power systems smarter will require more sophisticated management and control systems than have been in use in the past. In particular, smart devices like advanced sensors and relays deployed along the distribution system will assist active distribution management. Control systems can strategically determine use of these smart devices to predict and forestall outages by reconfiguring the grid, thereby improving distribution system operations. Such application of smart grid technologies is one of those enabled by active distribution management systems and enables enhanced awareness of latest grid conditions and predictive decision-making.

Under this paradigm, smart grid infrastructure may be applied for substation asset management, distribution feeder asset management, distribution feeder load versus DG balance awareness, advanced distribution automation, and microgrid management. In general, active distribution management systems include:

- Distribution monitoring system with capabilities to sense active equipment state information, voltage, current, power factor, power quality, and other parameters throughout the distribution system.
- Data processing capabilities to manage large amounts of real-time data coming from the monitoring systems.
- Simulation tools that perform state estimation and support control algorithms in determining dispatch actions that are needed.
- Control systems including control algorithms to coordinate operation of active components in real-time distribution management.

A more detailed description of the concept of active distribution management is provided in Section 5 of this report.

4.3. Categorization of Smart Grid Technology Areas

4.3.1. Multidisciplinary Nature of the Smart Grid

The power grid of today was primarily built upon the disciplines surrounding power engineering with some assistance from other disciplines. The smart grid will require a more complete interdisciplinary approach to adequately describe. The power system and information technology, as well as communication infrastructure and architectural components must be included in the picture. Architecture includes the distributed computing infrastructure that requires systems engineering as well as communications, software engineering, data management, network management, architecture development and other related disciplines that are evolving. Thus, a high level description of a smart grid is the merging of two infrastructures, composed of the electric power infrastructure and a communications infrastructure that enables and intelligent grid.

4.3.2. Technology Categories of the Smart Grid

If the grid is going to be smart, it will use a well orchestrated combination of a wide variety of equipment hardware, control algorithms and communications networks. These smart grid components can be related by different technology levels and major business function. Both utility business and technical perspectives together assist an understanding of how the elements come together and what is needed to enable the smart grid. Figure 6 depicts a structured method by which to identify the various technical elements of the smart grid.

The smart grid is comprised of various levels of technology ranging from power delivery infrastructure (that is, physical assets and energy resources), plus sensors and control devices, to communication infrastructure that gathers data from sensors and measurement systems. The information is used to determine the state of the power system and transform its operation, maintenance, and planning using knowledge derivable from a rich set of collected data. This transformation depicts a grid enabled to be operated, planned, and maintained more intelligently through development and deployment of key technologies that enable these characteristics.

As depicted in Figure 6, traditional business areas include generation, transmission, distribution and external operations applicable to enhancing customer service. Different classes of technologies and applications are typically found within each business unit at each hierarchical level. The following hierarchy is used to characterize technologies at different levels, as depicted in Figure 6.

- **Power system resources**: This level designates the traditional physical assets that constitute the power system (cables, transformers, lines, meters) as well as the resources connected to it (wind farms, PV installations, CHP systems, storage, PHEV).
- **Controls and sensors**: This level designates the equipment and materials installed on the power system that allow and facilitate the control or the measurement of the different assets.
- **Communication infrastructure**: This level designates the combination of the systems needed to support the two-way exchange of information with the controls and sensors level. It is constituted of the physical infrastructure and the associated protocols.
- **Data integration**: This level designates the information technology systems needed to store the data provided through the communication infrastructure layer and allow their use by the relevant applications to transform it into information. Interoperability between systems is a critical issue at this level for applications to leverage the data collected and extract maximum value.
- **Applications**: This level designates the business processes supported by human interfaces providing decision support. Information collected at the data integration level is used by business process-supporting applications to improve efficiency, reliability, and cost effectiveness of power system operations, planning, and maintenance.

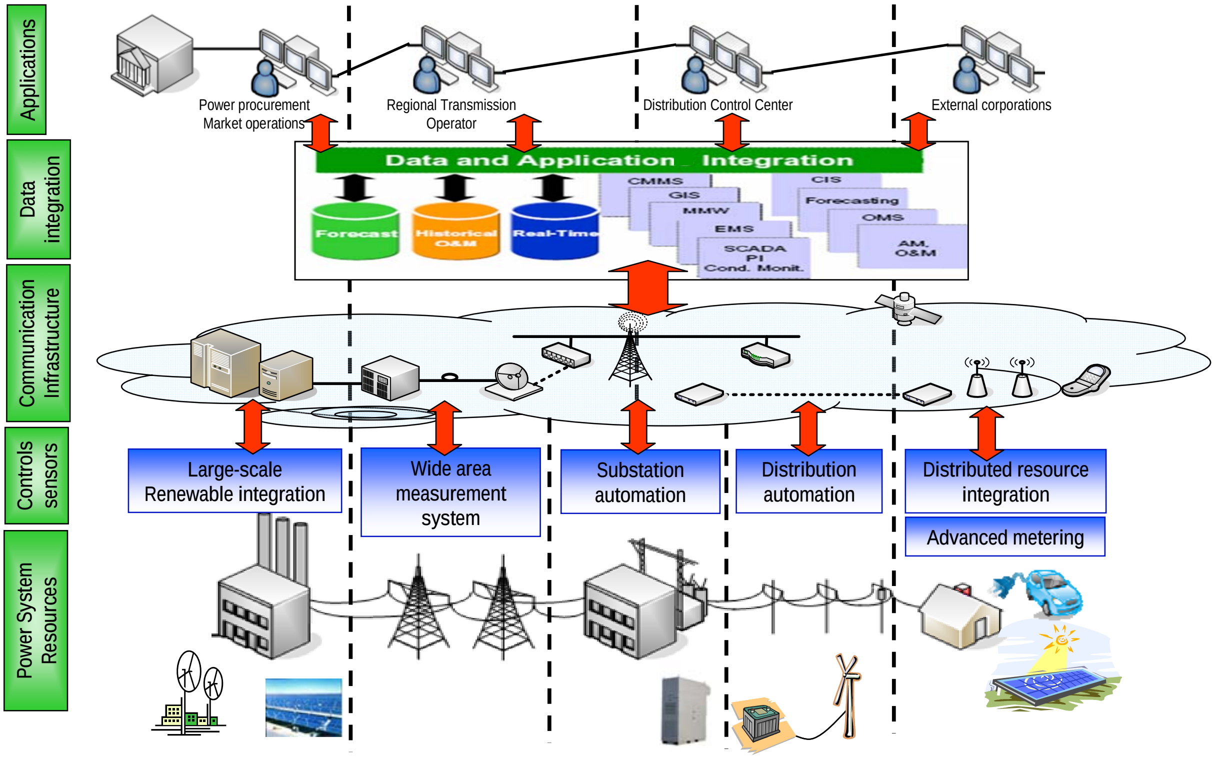

Figure 6: Depiction of technology components by hierarchical level and relevant business area provides a framework by which to identify relevant smart grid technology areas.

4.4. Information-Centric Perspective on a Smart Grid

A smart grid can be described as an information-enabled grid. Information is collected through existing, new and emerging sensing and measurement systems. The information may be used to improve efficiency, reliability, and cost effectiveness of power system operations, planning, and maintenance. These electric power industry functions are managed through human interfaces providing decision support.

Information for enhancing the grid may arise from a variety of sources. For example, utility supervisory control and data acquisition (SCADA) systems can be augmented with advanced sensors to collect information across the grid. Advanced metering infrastructure will provide a rich view to end-use consumption measurements. Wide area measurement systems are applied to enhance a regional system operator's wide area view of real-time power system conditions. Information on distributed energy resources (DER) is also required for integrating high penetrations of DER. This includes integration of renewable resources that are intermittent in nature. Monitoring, measuring, and in some cases controlling resources are necessary for supporting grid operations.

Careful architecting of the integrated communications infrastructure applied to collect, store, and exchange information is critical. Information exchange can occur between diverse collections of decision support applications and advanced grid components. A well-thought-out architecture can enhance the feasibility, cost effectiveness, and ease of leveraging common sources of information across diverse business systems to enable new value-added applications of the information. Realization of such an information-enabled grid across the electric power industry is a major challenge, due to gaps in technology and architecture. An example of a technology gap is the need for a cost-effective storage solution for effective integration of renewable energy resources, particularly intermittent resources. Architecture gaps include lack of standard protocols and methods to achieve integrated communications across traditional business units. Legacy systems, non-standard methods, and a wealth of communication protocols in use today abound. These challenges impact realization of a smart grid in California and are further described in Chapters 5 and 7 of this report.

5.0 Critical Technology Areas and Gaps

Critical technology areas involved in smart grid development are identified in Figure 7. The areas are defined as:

- **Architecture and communications infrastructure**: Develop communications architecture, standards, and management and security infrastructure to support interoperable field equipment, automation, and information exchange for the smart grid.
- **Renewable and distributed energy resource (DER) integration**: Integrate and manage new sources of renewable and distributed energy supply.
- **Grid operations and control**: Automatically monitor, assess, and control the grid to adapt to changing conditions to meet customer reliability and power quality requirements.
- **Asset and capital efficiency**: Improve capital efficiency using better intelligence and technology to optimize system planning and to improve asset throughput.
- **Customer system**: Enable customers to become "active" participants in the energy supply chain to better manage energy consumption.
- **Workforce efficiency**: Maximize workforce productivity, effectiveness, and safety through application of enabling tools, technologies, and training.

This section discusses critical technologies within each of the identified areas as well as associated gaps given the state of the art and current industry practice.

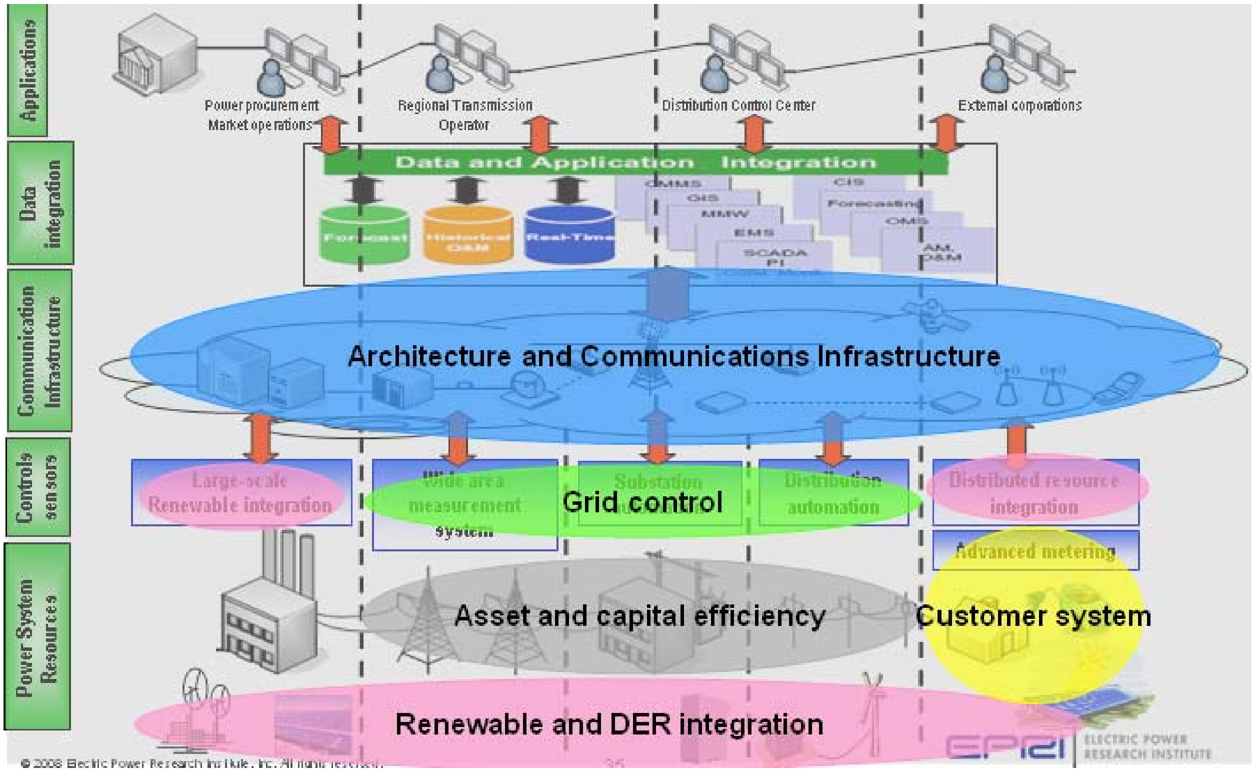

Figure 7: Critical technology areas are represented by the bubbles overlaid atop a common framework depicting smart grid technology components.

5.1. Architecture and Communications Infrastructure

The importance of architectural development for the ultimate support of the California Smart Grid is heavily driven by the operational complexities that the state power grid operators face in implementing the vision of California's future power and energy system. Additional generation from intermittent renewable sources of all sizes combined with newer operating paradigms of dynamic customer systems integration as well as integration of electric vehicle technology will drive the system to new levels of complexity. The management of this complexity is a necessary element to meeting California goals and is at the heart of the need for development of architecture. Among other activities, architecture includes documenting and managing the communications and distributed computing systems necessary to support a smart grid.

5.1.1. Architecture Defined

Architecture is defined as:

- **Architecture:** The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time*.

This definition is adopted by the Department of Defense and it is based on an IEEE Standard. There are other definitions but this is broad enough to encompass the California Smart Grid. It is important to note that Architecture takes the high level perspective to define how the various elements are to be brought together to meet the business, regulatory and technical objectives of the smart grid for California. The perspective of architecture encompasses all levels of operation from ISO/RTO operations to communications within customer premise and end-use equipment.

Architecture development provides a structured way to develop, document, design, implement and manage systems over their lifecycles. The disciplines surrounding architecture development are related to the fields of systems engineering. Systems engineering represents a set of disciplines directed toward applying a sufficient level of rigor to ensure the designs of intelligent systems meet their intended goals.

The level of sophistication necessary to implement the smart grid as correctly as possible is not trivial. The road too many of the technologies that California now seeks to implement for customer communications, for example, is strewn with many failed efforts, unsuccessful pilots and almost no success in achieving applications in areas such as dynamic customer systems integration.

The scope of California "Smart Grid" Architecture ranges from ISO/RTO operations through the integration of end-use equipment within customer premises as shown in Figure 8.

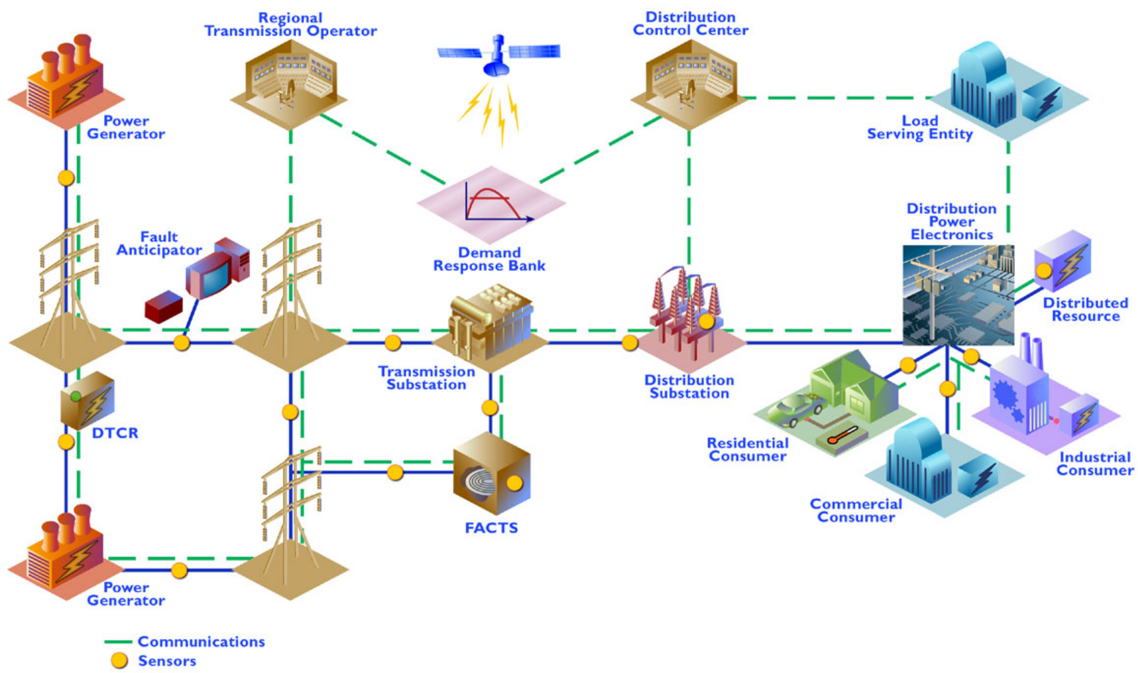

Figure 8: Illustration of the end-to-end scope of smart grid architecture.

5.1.2. Importance of Architectural Considerations

Architecture development is at the heart of a smart grid infrastructure for California. Its development is on a critical path since it can address many of the issues that have held back the vision of fully integrated systems.

Architecture is defined as: "The structure of components, their relationships, and the principles and guidelines governing their design and evolution over time*. This definition based on an Institute of Electrical and Electronics Engineers, Inc. (IEEE) standard and adopted by the Department of Defense indicates that the challenges facing California are not unique but shared by many industries and organizations preparing for the future. The importance of architecture is partially described in responses to the following questions posed by the Energy Commission for this project. The answers in this section are supplemented by subsequent chapters for additional detail.

- What is the current status of the smart grid?

The grid that is in place in California today is substantially "smart" having benefited from decades of power engineering expertise. The systems put into place already execute a variety of sophisticated system operations and protection functions. In addition it should be noted that what is now termed "smart grid" has been under development by the California utilities and the industry for many years. Much of the integration has been done through incremental applications of technology and fitting them into system operations as well as possible. Many of these are custom engineered integrations; work a rounds, and proprietary systems. The smart grid will include many incremental enhancements to the existing California electric power infrastructure. That said, the state desires to shift gears and fully integrate dispersed systems including visions of integrating dynamic new customer systems applications, improved system automation and control as well as the projected siting of significantly more renewable resources. This compels California to develop a smart grid architecture since the state needs to move from one off and custom integration to mass scaling. While there is significant technology that already exists and can be adopted from other industries there is also some missing technology that needs to be further developed both within the power industry and externally.

It is not just component technology that is need but also the tools and methods by which the smart grid will be brought together. It is important to have the necessary communications and integration infrastructure specified, designed and implemented in a well managed way. If a rigorous approach is not taken in developing the infrastructure the state could face risks from premature obsolescence of technology, security intrusions, and risks introduced by the communications systems put into place. These systems are complex and must be engineered using the latest methods for systems engineering and architecture. These methods are also on pathways to maturity as well.

The full vision of all the possible applications from what is implied by the phrase "smart grid" is several years away. However, California can take definite steps to assist and accelerate the key technologies to enable the priority functions and visions to happen sooner.

- What new and emerging technologies are on the horizon that impacts the smart grid of the future?

The sections below highlight the results of several years of EPRI and Industry research. The treatment is not exhaustive; rather it has been focused to the areas that are of highest priority as indicated by the Energy Commission. Remember that it is not just the new and emerging technologies but how they can be integrated into existing systems already in operation that need to remain in operation.

- How can the state avoid incompatible systems being fielded that result in costly legacy systems that must be replaced much sooner than projected?

The "new and emerging technologies" are coming from several industries including but not limited to: communications, computing, networking, software, building automation, power electronics and end-use equipment development to name a few. The challenge is one of correctly evaluating the emerging technologies against the backdrop of "smart grid" requirements and appropriately adopting and integrating the available technologies into an architecture.

In addition the technical disciplines involved in the smart grid development similarly cut across several industries including but not limited to: power systems engineering, building automation and controls, telecommunications engineering, embedded computing, data and communications networking, information technology as well as software engineering. The multi-discipline nature of smart grids also drives the need to use the latest in systems engineering to provide the necessary rigor to the technical processes that develop the system requirements, as well as those used to specify, document, design, implement, and manage systems over their lifecycles.

- How can the state help foster open access, competition and commercial growth of new and exciting technologies that provide the California ratepayer new ways to meet their energy needs while at the same time saving them money?

Open access, competition and commercial is enabled through the careful development of an open systems based architecture that enables interoperability between all the smart grid participants as well as enabling a flourishing marketplace for many vendors from industries as varied as advanced utility field equipment to building automation, distributed generation and storage as well as customer end use equipment including vehicles. Open systems enables the smart grid to happen sooner because the open interfaces are well defined and support integration of components and software applications in key areas. Without this infrastructure the industry will not move forward on any significant level.

- Where can government help?

Government can assist the process in ways similar to EPRI by doing focused work in key areas and topics that are necessary for infrastructure development. The results can be contributed to the relevant standards development organizations and/or industry user groups to develop into formal standards and user implementation agreements to assist and accelerate the standards. The government helps in a significant way but still lets the key processes work. In addition the development of projects that apply the standards and then in turn can be the basis for government procurements will also provide both the direction and the incentive for vendors to build to the open architecture. Once again this can accelerate acceptance. Government also has a role in overseeing the development and implementation of appropriate policies in areas such as systems management and security so that the public trust in the systems deployed will maintain credibility and remain appropriately secure.

- Where should government stay out?

Government should avoid implementing proprietary systems that do not contribute to the development of open systems-based technologies. The government should also operate at a level of policies and let free market forces work out actual system designs.

- What are the short-, mid- and long-term smart grid infrastructure priorities for California?

Short-range priorities include the development of an open architecture for integration of renewable resources and storage as well as augmenting the automation, protection and well managed operation of the overall California power system to effectively integrate this technology at any level of the system. Short range priorities are also critical for working out the remaining technical and integration issues surrounding customer communications and metering technologies. This urgency is driven by the present timeline the California utilities have in place.

Midrange priorities include migrating to state-level infrastructures for integrating legacy utility systems into an overall state infrastructure at appropriate interfaces between system operators at the California ISO, Western Electricity Coordinating Council (WECC) as well as the utilities and third-party generators and service providers. This will take a considerable time to migrate.

5.2. Renewable and Distributed Energy Integration

Renewable and distributed energy integration are top priorities for PIER-sponsored smart grid RD&D. This section describes critical technology areas for integrating and managing new sources of renewable energy and distributed energy resources.

5.2.1. Interconnection and Measurement and Verification

Interconnection standards, or the lack of effective and reasonable interconnection standards, have done much to inhibit the introduction of new technologies on the nation’s grid. Just the topic of “net metering” is met with high resistance by the utilities because of the lack of effective standards that protect both the utility and the independent power producer, which can be an intermediate size generation source or a residential power source.

The functional operation known as "islanding" is also met with high resistance because of multiple barriers involving distribution system safety, power flow control, especially for large systems, back loading the grid, intentional islanding to solve blackout conditions, and many others that are designed to protect both the power system and revenue flows of the utilities.

Many of these restrictions are imposed at the discretion of the individual utilities and not by a common code or standard designed to protect the interest of all the parties involved. The CPUC and other regulatory bodies need to define the real limitations that are to be imposed on these interconnection issues through the development of reasonable codes and standards.

5.2.2. Storage

Current State-of-the-Art

During the past two decades, developments of advanced energy storage technologies and associated power electronics components and systems have made substantial progress and are nearing commercial realization. As little as 10 years ago, conventional wisdom considered the use of utility-scale energy storage devices, with the exception of pumped hydro, to be cost-prohibitive. Current developments indicate that large scale, high technology energy storage systems, on the order of 10s to 100s of MWh are now poised to enter the utility inventory. These new systems have the capability of providing high power, on the order of 1 to 10 MW, for reasonably long periods of up to six to eight hours. Both energy storage system and high power device development have contributed significantly to this new era. These present-day developments are summarized in the discussion in 5.2.2 and 5.2.3.

Energy Storage Technologies

Energy storage systems can be categorized into two areas that they are designed to support: energy or power. Because of the nature of the electrochemical process associated with energy storage, an energy storage device is typically designed to produce high power for short periods of time, or medium to low power for long periods of time. It is possible to design a storage system to perform both functions, but the penalties in efficiency and life expectancy are great; consequently, designers generally work toward only one primary goal, power or energy.

Power Systems

Power systems provide short bursts power of up to 15 minutes in duration to support applications such as UPS, spinning reserve, area regulation, VAR compensation, and power quality. Lead-acid battery systems have played a role in each of these applications; however, a typically short life expectancy for this technology as well as reliability issues have resulted in limited deployment in support of super critical applications only. New technologies have been developed to supplant the lead-acid battery in these applications. Reliability has become the key word for the introduction of these energy storage technologies. These technologies are now emerging as viably economical and highly reliable.

- Flywheel Energy Storage Systems (FESS): Several utility-scale systems have been developed and deployed in Europe; however, only small scale systems on the order of 5 to 100 kW have been deployed in the United States. Current developments of utility-scale FESS are underway with plant designs of up to 20 MW completed. This system consists of a modular approach using FESS components of 100 kW for up to 15 minutes. Utility-scale applications such as spinning reserve and area regulation, which require short discharge periods at high power for less than one second up to 15 minutes, are ideal applications for this energy storage technology.

- Super Capacitor Systems: Because of the initial cost and relatively little experience, only one utility scale system is currently in existence, a 450 kW, 30-second system has been very recently commissioned and is currently in demonstration. Super capacitor systems can cycle tens of thousands of times, at high rates of charge and discharge, with little effect on life expectancy for the system. In power applications where short bursts of power of sub-second to several seconds duration, in and out of the storage system are important, this energy storage component has the advantage of high efficiency, fast response, and long life expectancy in a heavy cycling operational environment. Applications such as VAR compensation, power quality, line stability, and ride-through are ideal for this type of energy storage system.

Energy Systems

Energy systems are required for peak shaving, load leveling, renewable dispatch, micro-grid power management, and other applications where long-term storage is needed. Several new technologies that can store up to 100s of MWh of energy are currently available and are nearing commercialization in the United States.

- Zinc Bromine (ZnBr) Battery. This is an intermediate sized energy storage system in the range of 500 kWh to 5 MWh, aimed at intermittent to daily cycling applications. In the standby mode, this battery has a very low self-discharge rate allowing it to stand idle for very long periods, at some intermediate state-of-charge, without a substantial loss of charge or high maintenance activity. Because of the modularity approach to system design, power/energy combinations can be custom integrated to fit the application. Mobility is also a consideration for the implementation of this technology. Applications such as peak shaving and substation upgrade deferral are ideal for this technology. The ability to deploy or relocate to critical sites on short notice are also key advantages to this type of energy storage system.
- Vanadium Redox (VRB) Battery. This is an intermediate to large energy storage system designed for intermittent to daily cycling applications. Much the same at the ZnBr technology with the primary difference being that the system is not mobile or modular, the current design decouples the energy storage capacity from the power capacity by employing bladder-type electrolyte storage that can be sized to meet the energy storage requirement for a specific application. Power levels can be independently determined based on the needs of the specific application. Consequently, the VRB storage system can be customized to meet the needs of the customer without substantial variations in the basic design of the system. Applications such as peak shaving, load leveling, substation and transmission line upgrade deferral, UPS, and renewable energy dispatch are ideal candidates for this energy storage technology.

- Sodium Sulfur (NaS) Battery. This energy storage technology is fully commercialized in Japan where it is used for applications ranging from wind stabilization to peak shaving. Several applications are now being supported in the United States: a peak-shaving application with daily discharges on a routine basis, and a transmission line upgrade deferral in a mountainous region in the eastern part of the United States. The NaS system has an excellent self-discharge capability and experiences only minimal losses during standby operations. However, this technology is best applied in an application where it is to be cycled daily as it is necessary to keep the battery cells above 300 degrees Celsius in order to keep the electrolyte molten. Temperature management is quite easily achieved if the system is cycled daily as the temperature is self-maintained during discharge operations. If daily discharges are not implemented, the system must be kept at temperature by external heating which leads to a reduction in efficiency. This energy storage technology is ideal for cycling applications requiring high power and energy storage periods of up to eight hours. Applications such as daily peak-shaving, load leveling, renewable energy daily dispatch, and line stabilization are prime candidates for this technology.
- Compressed Air Energy Storage (CAES). An emerging energy storage technology is now receiving more attention than previously as higher levels of storage are being identified for wind generation stabilization and dispatch. Most wind farms are located far from their loads which lead to several problems, one of which is transmission system overload. When a wind farm is operating at near capacity, transmission systems are loaded typically beyond their rated capacity ultimately leading to the curtailment of power from the wind farm to protect the transmission system. Another problem exists when the wind farm is generating more power than is required by the load. In both of these cases, energy is lost as generation is curtailed to maintain line integrity. CAES systems, strategically located, could store energy that is generated during under-load/over-capacity periods and then dispatched when the power can be moved to the load. The obvious benefit is that the wind becomes dispatchable and reliable and wind energy is not wasted by curtailing generation.

Barriers to Energy Storage Application Acceptance

Although utility scale energy storage systems are quickly maturing, many barriers exist for their acceptance by the utilities. The paradigm of machinery generated power persists and the use of rotating machinery is always the first choice when disbursed generation is needed. Even if the power is needed for peaking support, the gas turbine or diesel generator, with all their emissions problems, is always the system designer’s first choice. It has been tested and widely demonstrated in Japan and Europe that stored energy is ideal for peak shaving. In the United States, the use of pumped hydro, where it is feasible to locate the systems, replaces several hundreds of MWs of peaking generators. The concept is acceptable only because the prime mover is a turbine, hardware totally acceptable to today’s power systems designers.

Other mass storage applications using compressed air energy storage (CAES) are currently under consideration or design in the United States but they are being held up in several ways including permitting, not-in-my-back-yard concerns, funding, and issues dealing with interfaces with the local utilities resulting in long delays in getting projects underway. Educating the utilities and the public is essential to remove these barriers, many of which are based on sheer ignorance and not on a viable factual situation.

Regulatory and interconnection barriers are often the primary reason that projects cannot get started. Much of the time, delays in acquiring permits are sufficient to dissuade the backers of energy storage projects from continuing to attempt to get permits for large scale projects. Projects over 10 MW have no standards to help persuade the utilities to grant permits for large scale energy storage projects.

Many times, it is extremely difficult to find willing customers or utilities that are interested in trying a new technology, even if its success will immediately lead to avoided costs or more reliable service or both. The unwillingness generally is due to the conservative nature of utilities not willing to try something new or the perceived risk to customers that productivity may be jeopardized.

Top priorities

The most effective, near-term activity that should be supported by the Energy Commission is the sponsorship of demonstration projects involving emerging energy storage technologies at locations throughout the state of California. Funds expended in the sponsoring of these demonstrations will greatly enhance the deployment of these effective and efficient energy storage systems to broad use, both in and out of the state. That, in turn, can be expected to bring new industry and jobs to the state to support the deployment. The major return on this investment will be seen in the ultimate realization of the California Smart Grid that will bring substantial benefits to both the California utilities and its citizens.

5.2.3. Power Electronics

During the past 10 years, progress in the development of new power electronics devices have resulted in dramatic increases in voltage and current capacities for several solid state power electronic components. The advanced Integrated Gate Bipolar Transistor (IGBT) and the Emitter Turn-off Thyrystor (ETO) solid-state power conversion components are making major advances in bringing a viable utility scale solid state switching device to the power electronics industry. Voltages in the range of 5000 VDC and currents in the range of 1500 Amps DC are now being realized in the integration of these new technologies in inverters and power conditioning systems. The primary barrier to the commercialism of these devices is the reluctance of the utilities to try something new and different; they are locked in to the gate turn-off (GTO) device for DC to AC conversion as it is well understood although the GTO cannot match the power quality and power levels of the new devices.

There are currently no utility scale, high power, off-the-shelf invertors and power converters on the market. As applications are defined that require energy storage in their implementation, power conversion devices and controls are designed from the ground up on a case-by-case basis. In addition, there is little desire to develop standardized components among the system integrators involved in bringing new energy storage applications on-line. Consequently, costs are almost prohibitive as there is no other way to bring an energy storage system on-line except to pay for the complete design, testing, and integration of custom components for each energy storage application. Even the energy storage manufacturers have not made inroads in the development of power electronics and control systems dedicated to their own energy storage system as most delivered systems are one-of-a-kind with little or no opportunity to mass produce the electronics necessary for their device. The most important near-term development that needs to be realized in power electronics and controls is to motivate the system integrators to begin packaging their systems in a turn-key manner so that costs for their systems can be driven down to more reasonable levels.

A major gap which will inhibit the wide deployment of PV in California is the lack of codes and standards that are effective in removing the hurdles brought about by lack of effective interconnection standards that cover the full range of power systems that will employ PV technology. Efforts should be supported by the Energy Commission, much in the same way that the DOE sponsored the development of the IEEE 1547 standard portfolio.

An effort is currently underway at the National Renewable Laboratory (NREL), sponsored by the Energy Commission, to develop a modular power converter/controller for renewable applications, primarily photovoltaics. The expected outcome is a cost effective, performance effective power converter/controller designed around a common topology that will be scalable to the various power levels from residential to utility scale applications. Contracts for the design of this modular power converter/controller system are currently being placed by NREL. The development and integration of a cost effective, efficient, and reliable power converter to the California grid should be one of the top priorities of the Energy Commission's Smart Grid Project as it will substantially increase the penetration of PV power on the grid by bringing the cost of PV systems down, and bringing PV system efficiency up.

5.2.4. Renewable Integration in Grid and Market Operations

One of the main needs for the California Smart Grid is to increase penetration of renewable technologies in very reliable manner to meet the goals to improve environmental impact of the grid on California. Wind generation is a renewable energy resource that may pose an adverse effect on system balance due to its intermittent and rapidly fluctuating power characteristics and the limited ability to accurately forecast and schedule the amount of energy produced. System imbalance causes frequency problems. Most generation units have installed automatic generation control (AGC) to control system frequency by automatically adjusting generation output to meet load fluctuations. Existing AGC functions may not be adequate for accommodating system balance requirements and need to be re-examined in the context of rapid fluctuations from intermittent resources, particularly in systems with large amounts of wind power connected to the transmission system.

Consequently, advances are needed in AGC practice and algorithms to integrate within bulk system operations the high penetrations of renewable resources mandated by California's Renewable Portfolio Standard. In particular, required advances in algorithms for reliable wind integration include:

- An advanced short-term (one to three hours ahead) low-cost regional wind generation forecasting tool to be used by Control Area Operator and Scheduling Coordinators for more accurate and economical supplemental energy scheduling, Load following, real-time dispatch and Automatic Generation control.
- Advanced real-time system impact study algorithm development for operators to quickly study the impact of Wind, DER integration data for AGC.
- AGC simulation tool in study mode to address the wind integration impacts for ACE and frequency calculations.

5.3. Grid Operations and Control

The critical technology areas for Grid Operations and Control include the following areas:

- Wide Area Measurement System
- Substation Automation and Transmission System
- Distribution Automation and Managed Islanding
- Smart metering for augmenting distribution operations

A mapping of the impact of each of these critical technology areas to the policy drivers is shown in the following grid. Each of the critical technology areas for Grid Operation and Control support multiple policy objectives as can be observed.

Grid Operations and Control	Energy Efficiency	Reliability and Security	Economics	Environment	
				Reduce GHG	Increase Renewable Penetration
Wide Area Measurements - PMUs	X	X	X	X	X
Substation Automation / Transmission System		X	X	X	X
Active Distribution Management and Control	X	X	X	X	X
Smart Metering for Augmenting Distribution Ops	X	X	X	X	X

Figure 9: Critical grid operations and control technologies.

A more detailed description and review of the critical Grid Operations and Control technologies is discussed in the following subsections:

5.3.1. Wide Area Measurement System

A wide area measurement system (WAMS) gathers real-time phasor measurements across broad geographical areas to provide a wide area view of real-time grid conditions. WAMS has been gradually implemented across parts of the western United States in recent years. This system integrates information collected from data gathering devices such as phasor data concentrators (PDCs) and real-time phasor measurement units (PMUs) for detailed power grid monitoring and stability control. Data is collected across broad geographical areas atop a communications network that links field devices to central station WAMS applications.

Phasor Measurement Units

The most prominent key technology that supports a wide area measurement system is synchrophasor measurement unit (PMU) and a communications network that supports bandwidth requirements. The typical standard in use today is IEEE C37.118. *IEEE C37.118 Standard for Synchrophasors for Power Systems* defines measuring methods using synchronized satellite time clocks to determine in real-time voltage, current, and their phase angles at any location in the transmission grid and compare it to any other point on the grid. PMUs provide exact state measurements of the grid status, versus calculated state estimation currently used. Changes over time can be used to determine the current operational health of the grid. System operators can be use synchrophasor measurements to:

- Provide early warning of potential system instability.
- Monitor damping of inter-area modes, and take corrective actions when necessary.
- Increase system loading while maintaining adequate stability margins.
- Improve operator response to system contingencies such as overload conditions, transmission outages, or generator shutdown.
- Advance system knowledge with correlated event reporting and real-time system visualization.
- Promote system wide data exchange with a standardized synchrophasor data format.
- Validate planning studies to improve system load balance and station optimization.

At a national level this area is being heavily promoted through the North American SynchroPhasor Initiative a joint effort sponsored by the Department of Energy and the North American Electric Reliability Corporation. The wide area measurement capability of synchrophasors enhances the operational efficiency of the grid by providing better visibility of grid operations and more reliable grid state measurement through enhanced state estimation capability. This improved visibility provides system operators a more reliable view of system transfer and stability margins and therefore allows for optimal use of all grid resources.

The key technology gaps that exist today in wide deployment of synchrophasors is the lack of a secure wide area communications network to transmit the data, management protocols that enable subscription to the data, and security measures to keep this infrastructure secure. These and other issues are being addressed by the North American SynchroPhasor Initiative. The full deployment will simultaneously support priorities to improve reliability while allowing the system to fully optimize transfer of power from large renewable resources, supporting the state's RPS goals and reducing greenhouse gases.

While this technology may provide unique benefits to California and other western states that have very long transmission lines and large power transfers, the support for this effort at the North American level provides interested parties a more effective solution to coordinating the exchange of large blocks of renewable generation from sources to large load centers, along with improving system reliability by adopting advanced WAMS applications.

Phasor Data Concentrators

A phasor data concentrator (PDC) gathers files that are recorded by PMUs at the measurement site and correlates files from different sites using the recorded time stamps. PDCs use the same IEEE C37.118 data format standard to communicate the data from PMUs to PDCs. Using the precision of phasor measurements, data concentrators facilitate system and event analysis. Hence, the PDC is the center of a measurement system in which data from various PMUs or other PDCs is aggregated and fed to various software applications. The PDC correlates phasor data by sample number and time-tag, effectively creating a system wide set of measurements that is time-synchronized. In addition, PDCs typically evaluate and report on the quality of the data, forming a data stream that it buffers and feeds to defined applications. PDCs also typically monitor the overall data gathering network and incorporate a client interface. PDC systems have proven particularly valuable in disturbance analysis, providing quick and easy access to information used to support system operations and rapid response. Thus PDCs are another key field-level device technology critical for maintaining reliable grid operations. These devices are ideal for measurement-based controls, since the measurements are gathered at high speed and offer a high level of accuracy.

WAMS Applications

Key to WAMS success is the need to deploy high-speed wide area communications required to scan PMU/PDC data. A number of successful deployments for local Volt/VAR control for long distance transmission of renewable resources have been effectively demonstrated using PMUs in a WAMS scheme. Additional advanced algorithms need to be developed for use of PDU/PDC measurement data in SCADA/EMS systems.

- Advanced state estimator
- Advanced disturbance monitoring
- Power systems instability prediction algorithms
- Dynamic power system modeling tools
- Adaptive relying
- Under-voltage load-shedding schemes
- Wide-area control voltage/VAR resource optimization

5.3.2. Substation Automation and Transmission System

In the area of substation automation, one of the key enabling technologies is provided through implementation of IEC 61850. This standard and the supporting hardware built to the standard are getting significant traction in the utility industry. While the benefits of this international standard are many, the reduction in physical wiring provided by its messaging protocol and the implementation of logical control through software are significant to substation automation.

Many challenges still exist to effectively manage substations built to this standard. Vendors are still developing a device description and configuration model that is necessary to effectively describe all the devices in the substation.

The North American Reliability Corp. (NERC) Critical Infrastructure Protection (CIP) standards pose significant financial impacts for non-compliance and as a result have slowed down the substation automation implementations due to concerns with wide area communications security. This is a prudent step on the part of utilities but one that needs careful attention to make sure it does not become permanent.

At the transmission level, high speed communications infrastructure needed to support transmission system protection or automation such as special protection schemes or remedial action schemes are difficult to reliably implement.

Ultimately, all substation devices that have microprocessor based control will need to be connected to a communications network. This will enable advanced control algorithms to be developed and deployed within the smart grid. However, the tools needed to manage these network connected devices are lacking as well as the standards needed to implement the tools. Technology used in other areas can be used as a starting point but much work is still needed in this area. This effort will bring with it a significant set of security measures. Effective implementation of these tools may require hardware upgrades and should be thoroughly evaluated before any significant rollout is deployed.

Substation automation can significantly enhance reliability and efficiency of grid operations through better operator visibility of grid constraints. Furthermore, operations may be enhanced through control algorithms enhancing renewable integration and operational reliability.

5.3.3. Active Distribution Management and Control

Active distribution management and control utilizes the integration of intelligent electronic devices (IEDs) with distribution supervisory control and data acquisition systems (SCADA) to provide rapid reconfiguration of discrete devices such as switches, capacitor banks, reactor banks, and tap changing transformers. It also provides the basis for enabling managed islanding modes of operation. Objectives of active distribution management and control are to improve reliability and power quality by maintaining bus voltages across the system within specified voltage and power quality limits and responding to disturbances on the distribution system in order to minimize customer out-of-service time.

Figure 10 illustrates the overall concept of active distribution management and control.

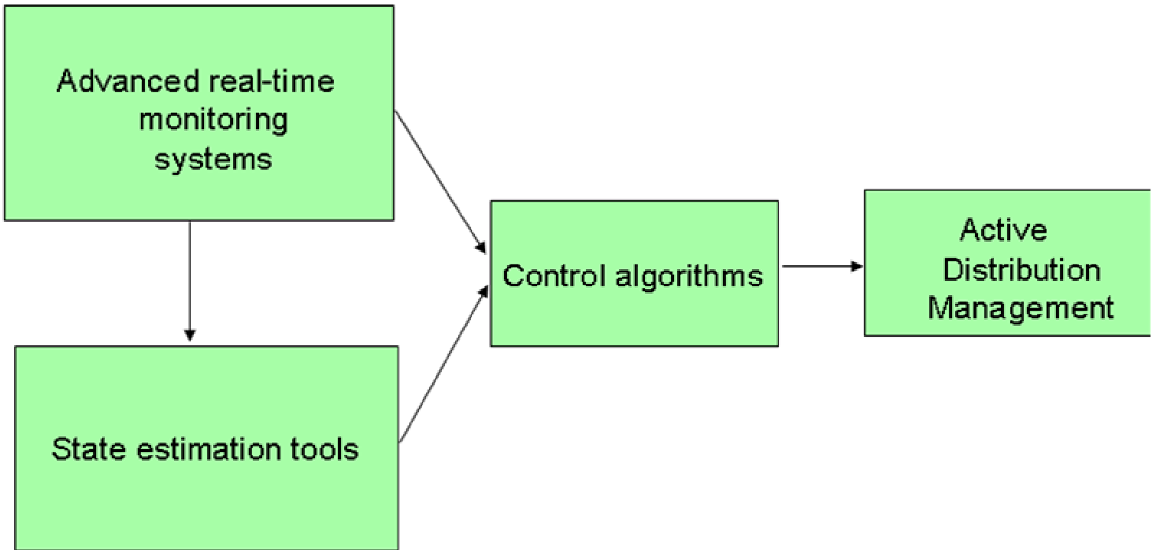

Figure 10: Conceptual block diagram of active distribution management and control system.

The following description elaborates on the nature of active distribution management and control systems and their development needs.

Real-time monitoring system requirements: Active distribution management will require distributed monitoring that can provide information about continually changing conditions in real time to distribution management systems. The monitoring system must provide feedback on control actions as well as on normal variations in system conditions. Monitoring of all active components, either directly or indirectly, is necessary for coordinated interoperability with the rest of the distribution system components. Active components include capacitor banks, switchgear, regulators, DER, AMI, and any other non-passive components. Work is needed to examine the requirements for developing real-time monitoring systems, including use of active components as monitoring system sensors. The active components can contribute to the overall monitoring of the distribution system in that some of them have status information on voltage, current, power factor, climatic conditions and other parameters at their sites that can be use to support strategic operations. Hence, in addition to other functions that they perform, the active components act as nodes in a larger real-time monitoring system to support distribution operations. This reduces the number of dedicated monitoring sensors needed in the monitoring system and saves money. However, low-cost sensors also need to be developed for inclusion in monitoring systems at nodes where use of active components for monitoring is not an option.

Communication interface and information models: To achieve interoperability in the distribution system environment with many active distribution components, it must be easy to connect active components to a common, standardized communication infrastructure. Hence, all active components and monitoring sensors need standardized information models (also called object models), that enable easy integration to the communication infrastructure and avoid the need to custom engineer a communication system for every case. The information models can be embedded in the communication interfaces of specific equipment types, or in some cases, they can be embedded at a SCADA or local control level with direct ties to the equipment they represent. The information modeling and standardization needed for active management and control systems need to be aggressively supported by smart grid stakeholders in California and elsewhere. The principal body of communication architecture standards for real-time operations that is under development is IEC 61850. In another section the scope and development status of IEC 61850 are described. As noted therein, the California smart grid program should have plans for utility migration to IEC 61850 over the long term.

Data processing requirements: The distributed control of smart distribution devices and the rest of the distribution system will require that the large amount of data coming from the monitoring system be processed to determine what is happening in the distribution system and what control actions are needed. Hence, an adaptable data processing capability is needed to filter out key event information and support the control system in taking actions according to predetermined algorithms. The requirements for development of widely applicable data processing systems for active distribution management and control must be determined via assessment, specification, and evaluation of pilot data processing systems in actual distribution systems.

Simulation tool requirements: Active distribution management and control will require advanced analysis tools for planning and design, as well as state estimation tools to support the control system. It is possible that similar platforms can form the foundation of both types of simulation tools. This is the basic principle of a "common information model (CIM)," which is under development as IEC 61970. Advanced simulation tools should be developed and evaluated, and guidelines for simulation needs in the planning and design stages (For example: benefits assessment and technical design evaluations) should be developed. This work should be coordinated closely with EPRI work on fast simulation and modeling and with the advanced Grid-D simulation platform development led by the Pacific Northwest National Laboratory. In addition, the applicability of these tools to real time simulation needs should be evaluated, and the requirements for integration of monitoring information into the real time system simulations should be developed.

Algorithm requirements: The algorithms execute active management and control based on information coming from the monitoring and state estimation tools. Algorithms will be continually improved based on available information and tools. The important need is to provide the flexibility to plug in new algorithms as they are developed based on overall information models and integration guidelines. The requirements for developing and integrating control algorithms into active distribution management and control systems should be determined.

In controlling smart grids, it is anticipated that the active distribution management systems will be developed that are hierarchical in nature. They will use individual smart device control algorithms, such as the algorithms for control of individual capacitor banks, switchgear, or distributed generators. These algorithms are mainly for tasking the devices to provide their specific functions and will be fairly generic for any specific type of device. There will be local controllers for specific circuits or groups of circuits. This level of control will manage assemblages of smart devices of several types in the circuits governed. The algorithms at this level will not be generic and will need some adaptability to the specific circuit in each case, because no two circuits will have exactly the same characteristics and assemblage of smart devices. These algorithms will be designed to select circuit and device dispatch actions in response to data coming in real time from the monitoring systems and the state estimation tools. There may also be a higher level of supervisory control, such as at the substations, which would also require algorithms that are tailored to the specific case. The individual device control algorithms should be relatively easy to develop and may already be supplied by vendors with some equipment types. The higher level control algorithms will be more difficult to develop, and little has been done yet in this area. The California Smart Grid program should include activities on the development of real-time monitoring systems, state estimation tools, and control algorithms.

Technology requirements: The needs for new equipment technologies to meet the requirements of active distribution management and control systems should be examined. The effectiveness of existing technology approaches should be examined to determine the strengths and weaknesses of the technology used and the needs for new technology development.

Software requirements: The needs for new software to meet the requirements of active distribution management and control systems should be examined. The effectiveness of existing software approaches should be examined to determine the strengths and weaknesses of the software used and the needs for new technology development.

Compatibility with emerging concepts in distributed controls for smart distribution systems: Distributed control for future distribution systems is a topic with a high level of interest. Management of active components should be considered in the efforts underway to develop distributed control. The vision is to have a local controller for a circuit or group of circuits that can manage the local system that is coordinated with more central control for handling broader system operations. The local control must be able to handle all the strategic uses of DER, such as emergency power, peak shifting, VAR support, intentional islanding of circuits, and others, at differing DER penetration levels. And, it must coordinate this control with the strategic use of other active components and demand management. New work in California should be aligned with work on distributed control that is underway elsewhere. In particular, it is desired to develop local control devices that are widely adaptable in distribution circuits. No two circuits are the same. Alignment should be sought with active distribution system management work at EPRI, DOE, in the Galvin Initiative, in private industry, and elsewhere.

Packaged system options: Packaging should be evaluated and the requirements for packaging future active distribution management and control systems should be determined. Packaging is not a reference to physical enclosures. It means the appropriate component and software configurations and whether an all-in-one product is desired or individual components and software should be available. That is, which is preferable and why?

Field trials and demonstrations: The constructs of active distribution management and control systems (as described above) should be defined in terms of specifications for systems. California utilities should engage in a coordinated program of field trials of complete active distribution management and control systems or of major constructs and should share experiences with the aim of moving the industry toward best practices for active distribution system management and control.

5.3.4. Smart Metering for Augmenting Distribution Operations

Distribution operations can be improved greatly by integrating AMI data streams with a distribution network management system. A distribution circuit map overlaid on top of a geographical information system (GIS) with real-time data feed from an AMI enabled customer information system is critical to implementing a smart grid.

Key technologies that support smart metering for augmenting distribution operations and management include:

- Real-time metering of customer load and outage status to distribution operations.
- Real-time metering of customer distributed energy resources including renewable generation is required for field personnel safety.
- Advanced DER interconnect devices that can interface with distribution hierarchical control and protection systems.
- Real-time messaging of customer load information between AMI and workforce field display information systems that includes customer account and usage info.
- Advanced smart meters with power quality analysis, detection, and event notification that predict and mitigate impending faults.
- Auto identification of outage location and outage type down to individual circuit device.

A distribution network management system (NMS) is an emerging cornerstone of a smart grid implementation and incorporates all functionality of an outage management system (OMS) and a distribution management system (DMS). Its capabilities include switch order management and operation, work resource planning, along with network planning, analysis, simulation, and optimization. It handles SCADA functions along with maintaining current network topology as designed and as operated. It has to identify customer outages and interface with external systems such as CIS – customer information systems, EMS - energy management systems on the bulk power supply side, WMS - workforce management systems, emerging AMI – advanced metering infrastructure systems, and GIS - geographical information systems. The system has to have the ability to archive critical operational data. The system can be operated more efficiently by constantly evaluating feeder and circuit loading and adjusting voltage and VAR support in real time to lower distribution system losses.

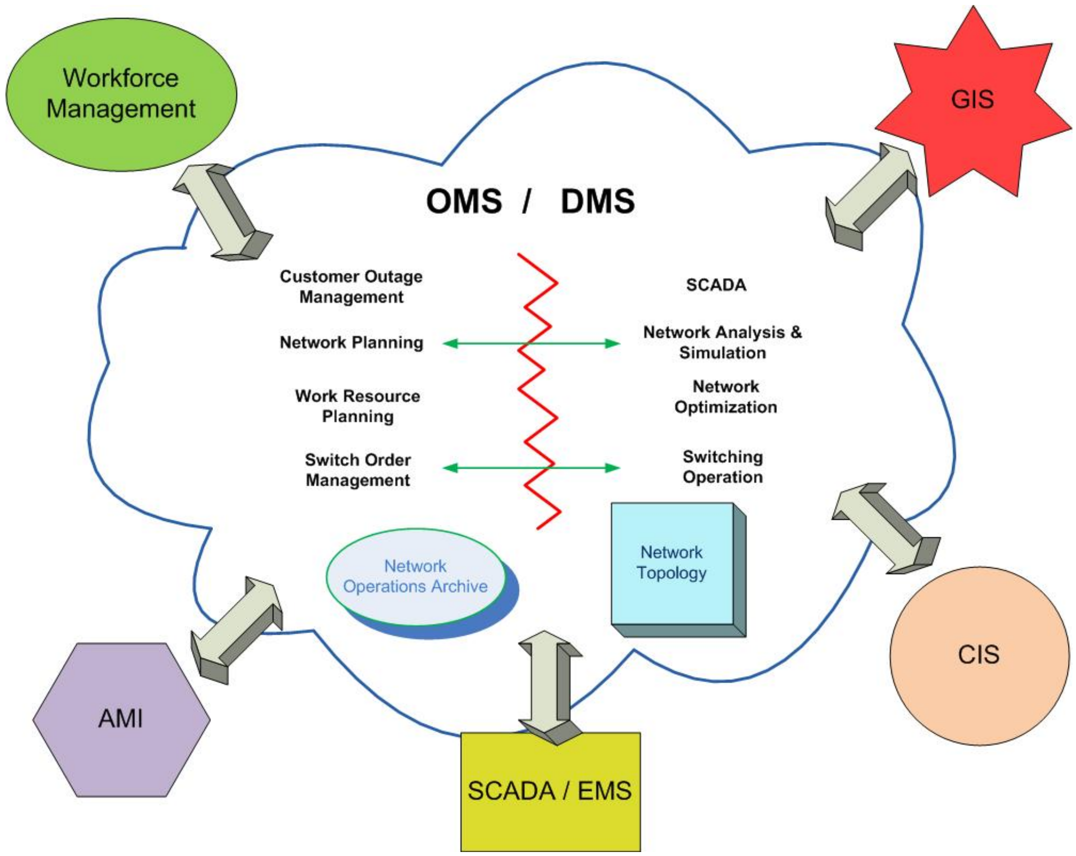

Figure 11: The distribution NMS.

The distribution NMS will provide the following benefits:

- Reduce CAIDI/SAIDI customer outage statistics.
- Optimize field work crew management by sending the correct team with the correct equipment to fix an outage.
- Improve major storm outage restoration times.
- Identify assets and equipment that are under or over utilized.
- Maintain constant communication with customer on state of outage and time to repair. Identify location of renewables on distribution feeders, protecting worker safety and alarming unsafe operations.
- Allow for fault identification in real-time, isolate and restore non-affected customers.
- Identify high value customers and prioritize restorations.

5.3.5. Grid Operations and Control: Critical Technology Gaps

The following list discusses gaps that new research, standards development or field experimentation is needed for smart grid deployment:

Gap Action	Gap
Field Demo	Managed distributed energy resources (DERs) on line or at customer
Standards	Distribution field device protocol standards TCP/IP/IEC61850
Field Demo	Field device operation with open standards broadband wireless communication
Research	Advanced fault detection, isolation, circuit reconfiguration, and restoration
Research	Advanced real-time distribution state estimator
Field Demo	Optimized distribution line energy loss algorithm with integrated volt/VAR
Field Demo	Real-time metering of DERs to field personnel information displays
Research	Advanced DER interconnection
Research	Smart meter-sensor fault predictor
Research	PMU exchange and security protocols
Research	Advanced WAMS applications for grid control
Field Demo	Area-wide PMU deployment, data collection and WAMS user applications
Field Demo	Substation field device multi-vendor interoperability testing TCP/IP/ IEC16850

5.4. Asset and Capital Efficiency

Asset and capital efficiency refers to optimizing system planning and improve throughput. This is another key area requiring advancement in smart grid development. Discussion of this critical technology area and identification of gaps ensue.

5.4.1. "Urban planning" tools for power grid

The urban planning concept comes from a discussion paper[7]. The most relevant points related in this section were extracted from this document.

"One of the Smart Grid challenge resides in the way to deal with 'perpetual systems' that can be replaced completely many times but part-by-part along their lifespan, like Air Traffic Control systems, IT banking systems. Furthermore, adding to complexity, the general trend is to interconnect enterprise information systems with operation systems. As in those examples we are looking to dramatically increase the systems value, by adding intelligence and communication on top of well known mainly material subsystems and components of traditional infrastructures. This usually makes the complexity exploding in many cases beyond current feasibility limits. Due to the immaterial and conceptual new orientation, it happens very often that manageable boundaries are crossed without even realizing it. There are Architecture challenges, but furthermore "Urban Planning" challenges: a city lives 24/7 with old parts, new parts, parts under maintenance or construction.

The current infrastructures won't be removed and completely replaced at once. What can be done: replacement of existing equipments, replacement of more global parts of infrastructures (line, substation….), addition of new equipments, and addition of new parts of infrastructure? One may think that an ideal "target situation" is when all the infrastructures will have been

[7] "From "seeds" to a naturally grown Power Delivery infrastructure", R. Schomberg, EDF, 2004

replaced through a progressive process. It could take an indefinite time to come close to such a theoretical "target situation", and it would certainly not be optimal trying to pursue 100% of such a goal.

In fact it appears non feasible to describe all R&D projects and all the engineering projects that will bridge from now to an impossible to define "target situation". The target is moving, because as we move forward we get better understanding on what to do in the five coming sliding years, the societal and regulatory constraints will evolve, and new technology can suggest new solutions as new (functional) needs can set goals to define new technologies. So today it appears non realistic to define a concrete target, and defining new elementary bricks would be an extreme challenge."

The California Smart Grid will have to deal with this "urban planning" challenge while achieving its AB 32 targets. As stated in the IERP, the main issues are (1) to address the interconnection of renewable and distributed generation and (2) to take into account the impact of energy efficiency and demand response in the system planning tools. The current fleets of system planning tools (For example: short circuit, load flow, feeder design, capacity planning protection design) are woefully inadequate to design smart grid systems incorporating the operating concepts and technologies of the smart grid. All of these tools must be augmented or replaced entirely with tools that can take these designs into account.

Enabling these features will allow planning grid investments to be channeled into appropriate technologies and equipment that will lead to the development of a modern and smart network. Utilities will be spending billions of dollars over the next 10 years rebuilding and expanding their distribution systems. It is essential that this massive capital flow be directed to where it can be most effective.

In addition, the moving targets and regulatory or societal constraints will continue to evolve and these aspects need to be included in the asset management processes as possible risks. To achieve this new methods (risk based asset management) are needed to provide a good decision support basis to the future investment options taking into account all the uncertainties discussed in this section.

5.4.2. Condition-Based Monitoring

A major issue for distribution systems mentioned in [1] is related to the age of the existing underground cable system. Customer preference for underground cables is so high that the California Public Utilities Commission (CPUC) authorizes utilities to replace portions of overhead cable in areas of their service territory with underground cable every year.

Throughout the 1970s and 1980s, utilities installed increasing amounts of underground cable, much of which is approaching the end of its design life. It will therefore have to be replaced in the near future to avoid failures. But in most cases the replacement cycle is not adequate enough and reliability impact is foreseen to increase in the next 5 to 10 years.

The IEPR also highlights existing technology gaps to deal with this problem by determining which lines are at greatest risk of failing and replace them first, since some older underground cables are still capable of performing reliably for some years into the future. An inexpensive and reliable diagnostic technique that can accurately determine the condition and remaining life of underground cables does not currently exist.

More precisely, the technology gaps associated with the condition based monitoring are at two different levels:

- Models and data: Modeling the end of life of equipment by taking into account the specific characteristics of equipment is necessary to be able to make predictive analysis on equipment failures and help prioritize the investments. Reliable data are critical to build and validate these models because the physical ageing or failures mechanisms are difficult to assess theoretically. Associated to this aspect is the data model issue which could provide interoperability and make data available to other systems thus enabling an easier framework for data collection and sharing.
- Sensors: Aging mechanisms of power systems asset are often the combination of different types of phenomenon such as mechanical, chemical or thermal degradation. If each of those has its own influence, some have a more direct contribution to the ageing mechanism depending on the equipment considered. Actual sensor technology can only monitor some of this criteria and more technology research is needed in this area to provide a complete set of sensors that will enable a complete assessment of the state of power system equipment. Another issue to consider is the communication capability of the sensors: as moving to more miniaturized sizes to facilitate the integration on the asset to monitor, the question of the communication interface becomes critical especially in constrained environment such as substations. Examples of wireless mesh technology applied to substation sensors exists (EPRI – TVA) but further research is also needed in this area to develop commercial products.

5.5. Customer Systems

Customer systems involve critical technologies that enable customers to become active in the electricity supply chain. The critical technology areas under customer systems include the following:

- Smart metering
- Customer gateway
- Home area network
- Communicating thermostat
- Plug-in hybrid vehicle
- Value capture

A mapping of the impact of each of these critical technology areas to the policy drivers is shown in the following grid. Each of the critical technology areas for customer system supports multiple policy objectives.

Customer Systems	Energy Efficiency	Reliability and Security	Economics	Environment	
				Reduce GHG	Increase Renewable Penetration
Smart Metering	X	X	X	X	
Home Area Networks	X		X	X	
Programmable Controllable Thermostats	X	X	X	X	
Plug-in Hybrid Electric Vehicles		X		X	
Advanced Electrical Rate Products	X	X	X	X	X

Figure 12: Customer Systems

5.5.1. Smart Metering, Customer Gateways, Home Area Network, and Communicating Thermostat

Smart metering combined with customer internetworking gateways and mature in-building communications are critical elements of the dynamic consumer applications envisioned as part of the smart grid. Smart metering along with associated real-time two-way communication technology and enterprise information systems is an enabling technology. Smart metering allows the utility to implement advanced customer Time-of-Use rate structures such as real-time pricing (RTP) or critical peak pricing (CPP).

Customer communications infrastructure includes the development of a customer internetworking gateways to the home area network. Additional functionality can then be extended by both the utility and the customer to implement real-time energy displays, control loads, and implement demand response based upon external system signals that notify customers of economic or system reliability price signals. These signals will be used to curtail lower priority end uses, activate setbacks with communicating thermostats, and coordinate other activities that customers manage using home energy management systems.

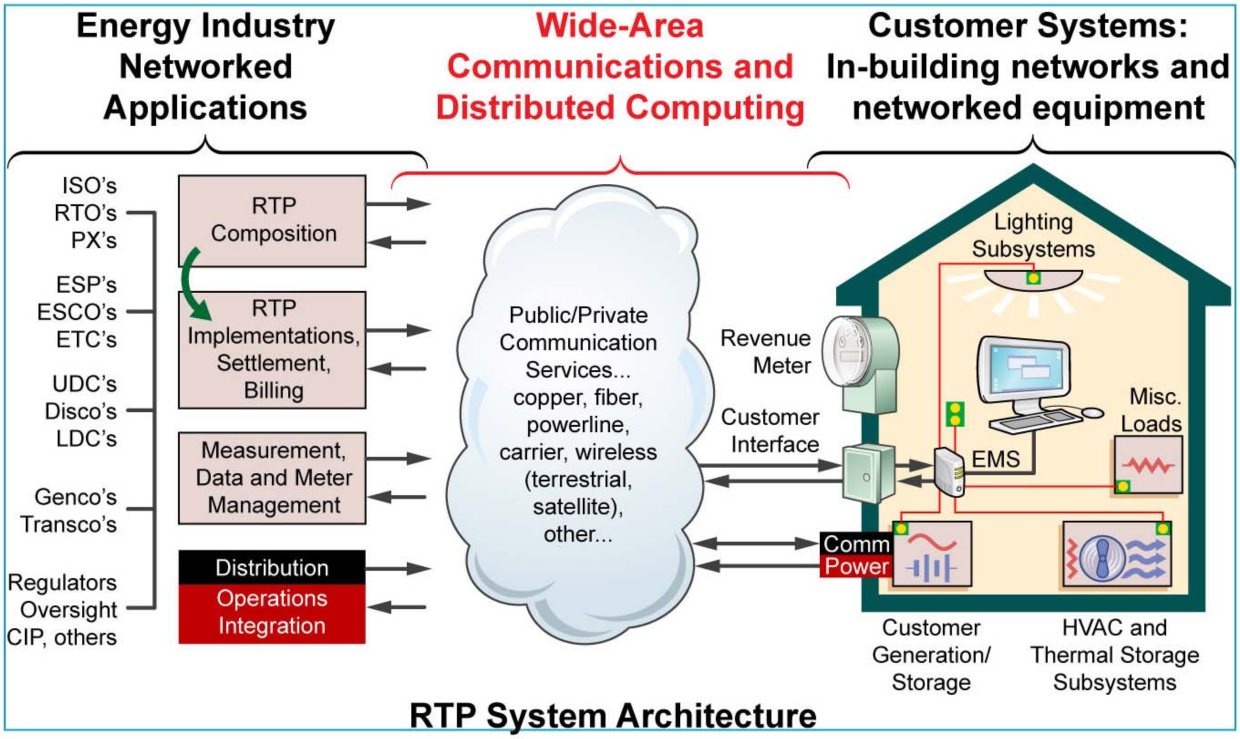

Figure 13: Customer system architecture.

A consumer internetworking gateway based on an open flexible architecture, would facilitate the implementation of new services such as demand response, real time pricing, outage detection, remote connect/disconnect, support to distribution operations, PQ monitoring and improved customer information. In addition, consumer portals will support new information-based solutions that improve the efficiency, comfort and safety of businesses, buildings and homes and integrate with power delivery system applications.

Key technologies that support these efforts for advanced distribution network management include:

- Smart meters based upon open standards
  - Integrated secure two-way broadband communication
- Home area networks based upon open standards
  - In-home energy displays
  - Remote load controllers
- Programmable controllable thermostats
- Smart-home energy management system
- Smart home advanced energy optimization algorithms
- Web portal for customer access to real-time account billing and usage

5.5.2. Plug-in hybrid electric vehicle

A plug-in hybrid electric vehicle (PHEV) is essentially a hybrid electric vehicle similar to those on the road today with a large battery pack which can be recharged from the electricity grid. This means that a PHEV has the regenerative braking and engine efficiency improvements of an HEV, plus the ability to use electricity as an alternative fuel. The combination of efficiency and fuel switching should make PHEVs and other electric drive vehicles an important part of California's transportation future. In the near term, even moderate volumes of electric drive vehicles will not overburden California's electricity grid; however, it is important to introduce infrastructure changes as early as possible to ensure that as vehicle sales volume and energy use grows this additional load can be managed as part of the Smart Grid.

Various government agencies in California are currently defining how PHEVs will be integrated into the state transportation plan. AB1493 requires automakers to reduce vehicle CO2 emissions beyond the levels required to meet future Federal fuel economy standards. Portions of this law are currently in litigation, so it is unclear when and how this requirement will affect the vehicle fleet. However, this requirement combined with the proposed addition of PHEVs to the California Air Resources Board (ARB) Zero-Emissions Vehicle mandate make it likely that PHEVs will be an important part of the future vehicle fleet. Once these vehicles are available, the treatment of electricity as an alternative fuel will be important. AB1007 directs the State of California to increase use of alternative vehicle fuels to reduce petroleum use and greenhouse gas (GHG) emissions, but without increasing air pollution, water pollution, or other substances known to damage human health. Executive Order S-01-07 further directs California to adopt a Low-Carbon Fuel Standard, which creates a tradable credit system in which the average fuel-fuel cycle carbon intensity of all automotive fuels would be reduced by 10%. Each of these regulations is still in process, so the outlooks for PHEVs and electricity as a transportation fuel are still fluid; however the overall potential for electric transportation is unambiguous: analysis by EPRI and the National Resources Defense Council demonstrates that increased use electric drive vehicles would result in modest air quality improvements and substantial reductions in GHG emissions.

In the near term PHEVs will not represent a substantial load, but given the nature of the automotive. Based on automaker announcements and historical trends for advanced technologies, vehicle sales will start at the end of 2010, and by the end of 2011 should reach a sales rate of about 30, 000 vehicles per year in California. With a peak load of 2 kW and an average load much lower than this, increased load from vehicles will be much lower than natural load growth during the first few years. However, around 2 million vehicles are sold per year in California and vehicle design cycles are around 5 years, so vehicle load growth could increase substantially in California during the time frame of this study, especially if current trends in petroleum fuel prices continue. EPRI estimates based on an optimistic supply-side projection of vehicle penetration that the peak power of unmanaged PHEVs could approach 1 GW in California in 2020, with continued rapid growth after that. Managing vehicle load would become critical to grid stability in this timeframe.

Plug-in hybrid electric vehicles present a unique opportunity for load management. A PHEV can use a gasoline or diesel engine to provide motive power, so vehicles do not have to fully charge in a particular day. Since most passenger vehicles are parked for much more time than they are driving, there is significant potential to defer charging during times when the grid is stressed. Additionally, in the long term vehicle chargers could be designed to provide power back to the home or even back to the grid, significantly improving reliability and decreasing the variability of load. This flexibility would have to be weighed against the potential for consumer and automotive industry complaint: electricity would have to be perceived to be a reliable fuel source, but intelligent use of PHEVs as part of the smart grid could provide the same potential for load reduction as thermostat control programs with significantly less customer resistance.

5.5.3. Value Capture

The ability of customers to capture value from onsite installations of resources such as demand response, distributed generation, and renewable energy is necessary in order to realize high penetrations of distributed resources targeted by the state. A major challenge lies in the development of workable economic models to sustain such penetrations. A customer-driven perspective on economics is therefore vital to addressing the value capture challenge.

Utility rates and other retail contracts dictate the pricing structure by which customers pay for electricity and are incentivized to provide valuable services for grid support. Services include demand response, stand-by generation, and other valuable services including green power. The ability of customers to capture value through provision of such services originating from the demand-side, however, is limited by retail rate structures that are today largely disconnected from wholesale market conditions. Therefore, a gap persists in the reconciliation of wholesale and retail electricity products with sound economics. Development of sound economics is needed to compel customer solutions that enable integration of wholesale and retail electricity markets.

Enhanced value capture for end-use customers can be achieved by structuring customer opportunities and retail pricing so that choices in investments focus on customers' greatest pains and improve upon value capture under status quo. Innovative rate structures supported by enabling technologies can provide a menu of options that better meet customer needs. This critical gap is a crucial step on the track of achieving the high penetrations of distributed energy resources, demand response, and renewable energy targeted in state policy.

5.5.4. Summary of Critical Technology Gaps for Customer Systems

The following list identifies gaps that new research, standards development, or demonstrations can bridge in smart grid deployment.

Gap Type: Gap

- Standards: Smart meters and two-way communication links.
- Demo: Smart meters and two-way communication links.
- Develop: Customer Internetworking gateways.
- Standards: Home area networks.
- Demo: Home area networks and devices for displays, controllers.

- Standards: Programmable controllable thermostat.
- Research: Smart home advanced energy optimization algorithms.
- Demo: Customer energy account Web portal application.
- Research: PHEV real time pricing tariffs.
- Standards: PHEV electrical and communication standards.
- Demo: PHEV vehicle-to-grid support of peak loads.
- Research: PHEV impact on grid operations (need for hierarchical controls).

5.6. Workforce Effectiveness

Smart grid implementation in California involves utilization of technologies that could improve the overall effectiveness of the workforce. However, grid operations today is still very labor centric and also very hands on, requiring manual actions. While SCADA is very prevalent in the industry, it provides a limited view of system state and operates in a command and control mode. In a smart grid, system state is greatly enhanced through the vast deployment of meters and controllers throughout the system. The autonomous operation of these disperse controllers will relieve the operator of mundane tasks and allow time to deal with broader system issues.

Tomorrow's smart grid workforce will need to be trained to handle such technologies at a much high caliber than today. Planning, operations, as well as maintenance functions could be impacted by availability of tomorrow's smart grid technologies to the extent of requiring refinement or redefinition of current business processes. For example, development of new work practices may be required to ensure operational safely of field technicians. This is of particular concern in a smart grid with high penetration of distributed energy resources, including renewable sources. Operators and field crew will require training to utilize new processes and field support equipment that improve their awareness of the implications of their actions and that of customers in a broader smart grid context.

Today, physical copper wires typically connect field devices with network equipment and their configuration are easily identified on one-line diagrams or through visual inspection. In contrast, information exchanged across a smart grid communications infrastructure, transported over physical media such as Ethernet or fiber networks, are not as easily depicted. Thus, the inter relationship of field devices may not be readily apparent visually nor on drawings, but require computer based tools. The training necessary to effectively use these new tools will take time to develop and require information technology as well as power system technical backgrounds than typically expected today.

6.0 High-Level Architecture Framework

This task defines the key high level architecture framework issues for a smart grid for California. It is important to note that both the technology as well as the approach to develop the smart grid are independently evolving and carry important relationships and dependencies. The task will use a top down approach similar to other major initiatives that have been developed by EPRI, government and other industries.

6.1. Guiding Principles:

Guiding principles includes key drivers, stakeholders, policy sources, success factors, performance, metrics, and other policy related characteristics of a future smart grid for California.

6.2. Key Architectural Drivers

The following attributes have been put forward by industry groups working toward the vision of smart grids. Documents that contribute to this section include: IntelliGrid, public documents, GridWise architecture, Modern Grid Initiative, Galvin Initiative, , and Government infrastructure-related documentation including Department of Defense Architectural Framework and documents from federal and state CIO offices.

6.2.1. Drivers for Smart Grid Implementation

- Reliability.
- Security.
- Economy.
- Efficiency and productivity.
- Environment.
- Safety.
- Robustness.
- Extensibility.
- Manageability.

6.2.2. Performance Under Various Operating Conditions

The following performance indices can apply to both the power delivery infrastructure as well as the supporting communications infrastructure. The smart grid must be able to effectively operate under the following system conditions

- Normal operations.
- Optimization.
- Emergency response.

- Threat and attack resistance.
- System restoration.
- Future extensibility.

6.2.3. Stakeholders, Processes, and Policy Sources

High-level architecture viewpoints must take into account the roles and impact of all major stakeholders. A stakeholder is any organization or individual that can influence, use, or is impacted by the smart grid. The development of the smart grid must recognize the roles of various stakeholder groups in all aspects of smart grid development, from requirements to life-cycle management. The recommendations for California development of the smart grid will include the appropriate engagement of stakeholder communities in the development of all aspects of the infrastructure from development of requirements to life-cycle management of the smart grid technologies.

6.2.4. Consistent Policy Implementation

The smart grid needs to enable the consistent implementation and management of industry policies. These policies for operation of the communications and distributed computing infrastructure often cut across jurisdictions and must support emerging laws related to issues such as privacy, business practices and national security. These policies will play important roles in defining requirements for smart grid infrastructure and future operations. High level sources of policies that can drive technical requirements for smart grid infrastructure include those developed under regulatory agencies and related organizations such as the North American Electric Reliability Council and other stakeholders that can influence infrastructure requirements and operations.

6.2.5. High-Level Architecture Development and Frameworks

High level architecture development includes the topics of technical issues surrounding complex architecture as well as understanding the relationships California may have with other developing architectures. This section briefly touches on these topics.

6.2.6. Technical Issues and State of High Level Architecture Disciplines

The smart grid will need to employ the concepts of high level architecture and frameworks. It should be noted that the technical disciplines behind the development of architectures and frameworks is a work in progress. The underlying disciplines of systems engineering and complex systems engineering are also not fully mature. In simple terms there is no universally agreed upon way to specify, model, document and manage architectures on the scale and scope implied by the smart grid. However, there is a large body of prior work that can be adopted.

6.2.7. Industry Specific Architecture Framework Development

Industry-specific architecture development has been taking place within EPRI initiatives such as the utility communications architecture work from the 1990s as well as the integrated energy and communications systems architecture project (2004) that is the basis for IntelliGrid architecture. It should be noted that these program areas resulted in contributions to standards development organizations (SDO), including the IEEE under Standards Coordinating

Committee (SCC) 36 and contributions to International Electro-technical Commission (IEC) TC 57. The contributions to these SDO's has resulted in the work becoming developed into industry level standards that are now resulting in real products in the marketplace from major vendors. Architecture development is continuing under the TC 57 Committee. In addition the IEEE has recently formed a smart grid coordination committee. Other industry initiatives related to industry architecture include the GridWise Architecture and Modern Grid Initiative.

6.2.8. Relationship of California to other developing Architectures

California will also need to understand how state-level architecture will need to integrate with other developing architectures such as from federal departments and Department of Defense that have operations in California. The integration between the California Smart Grid architecture and other state offices such as the state Chief Information Officer should also be investigated.

6.3. Distributed Computing Infrastructure

The infrastructure necessary to support the smart grid encompasses more than just physical communications media such as wireless, powerline, or other message transports. More accurately described as "distributed computing", the infrastructure in simplified form includes: physical communications media, the networking technology and the "language" that is used to integrate smart grid equipment. An illustration of this simplified form in shown in Figure 14.

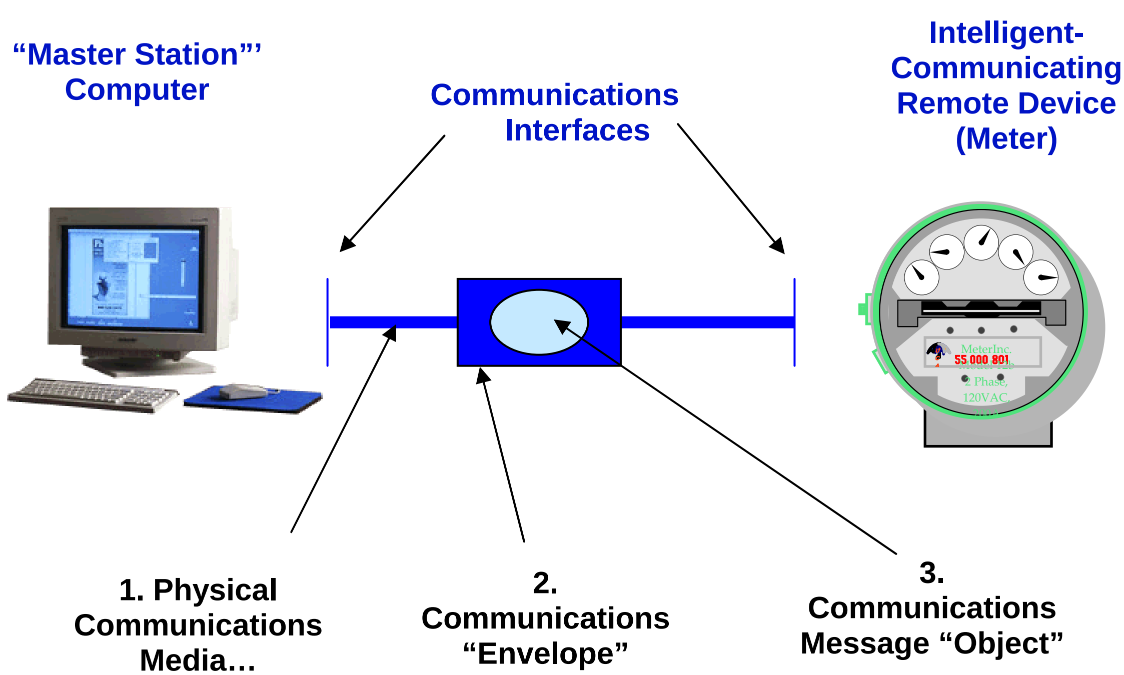

Figure 14: Elements of distributed computing

The layering of technology enables the architecture to standardize on key elements and still be flexible to technology such as communications physical media.   This is illustrated in Figure 15.

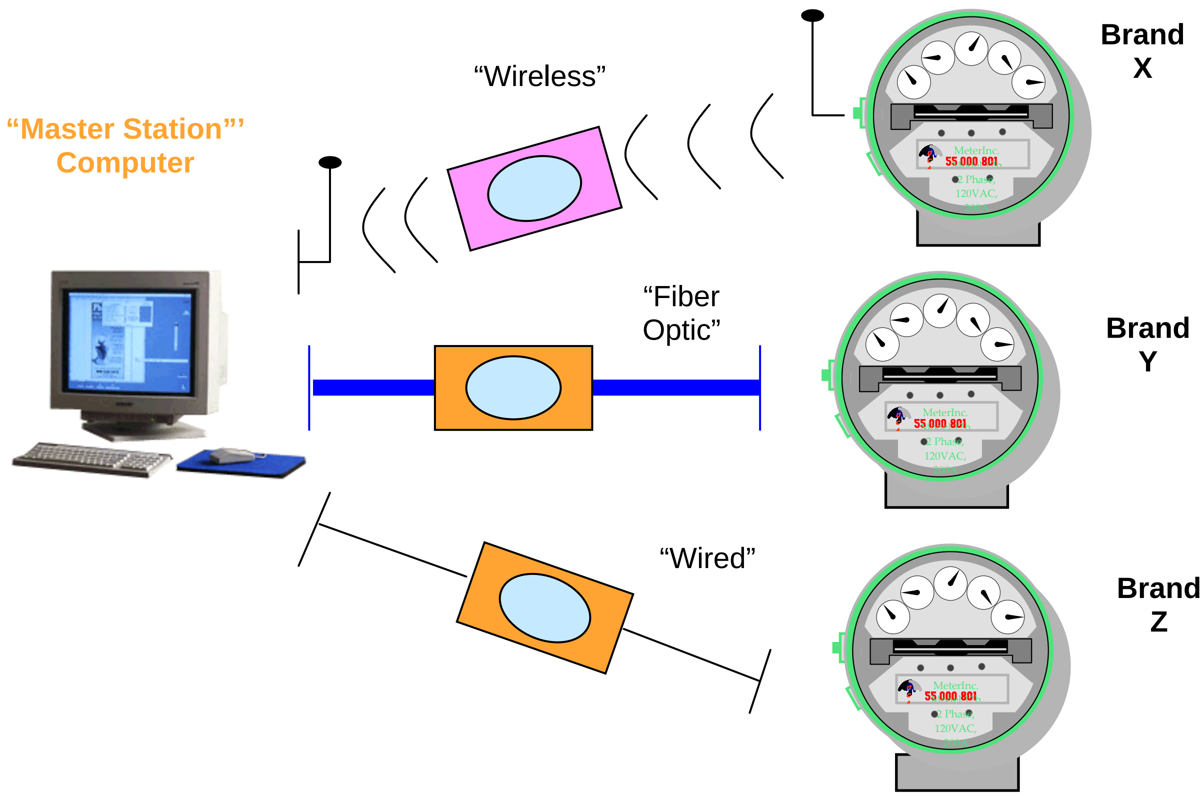

Figure 15: Recommendation: Develop Designs That Make Use of Layered Communications

The concept of layering communications enables choice of communications media to match cost, performance, management and security to the applications.   This will be necessary because the smart grid will require integration of diverse communications technology into an overall infrastructure.   One size of physical communications media does not fit all smart grid applications.

The diversity in networks and communications media poses additional architectural challenges in implementing consistency in management and security policies over massively scaled systems. Figure 16 below illustrates this challenge in a very simplified way.

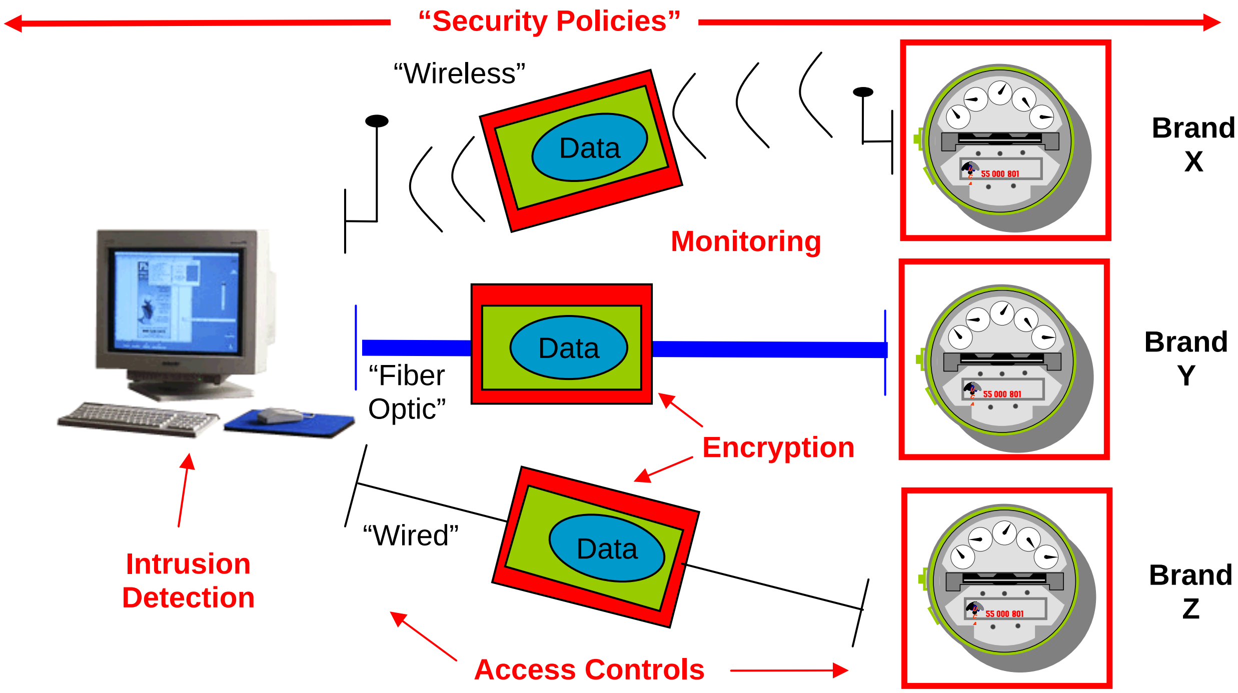

Figure 16: Recommendation: Develop Requirements and Technology to Enable Consistent Security Policies Implementation

6.3.1. Open Standards

The main drivers for open standards in the development and adoption of California Smart Grid technology is graphically depicted below in Figure 17.

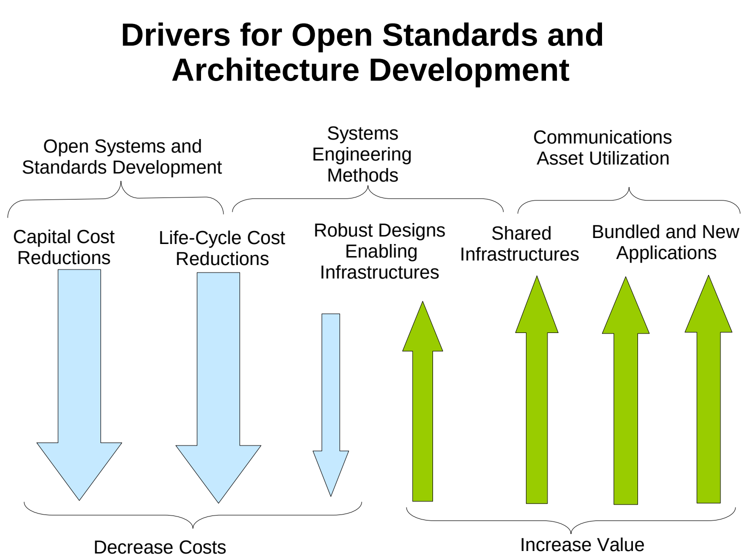

Figure 17: Drivers for Open Standards and Architecture Development

The infrastructure technology of California's smart grid is already partly developed by the organizations shown in Figure 8. It should be noted that for California's priority applications, significant work from several of these organizations can now be put to use. It should be noted however, that the standards and technical agreements from these organizations only represent the building blocks of an architecture design. An infrastructure design for California would encompass a selected set of standards and additionally define ways to effectively integrate the standards into a smart grid architecture. The work and processes in defining this architecture are discussed in the next section.

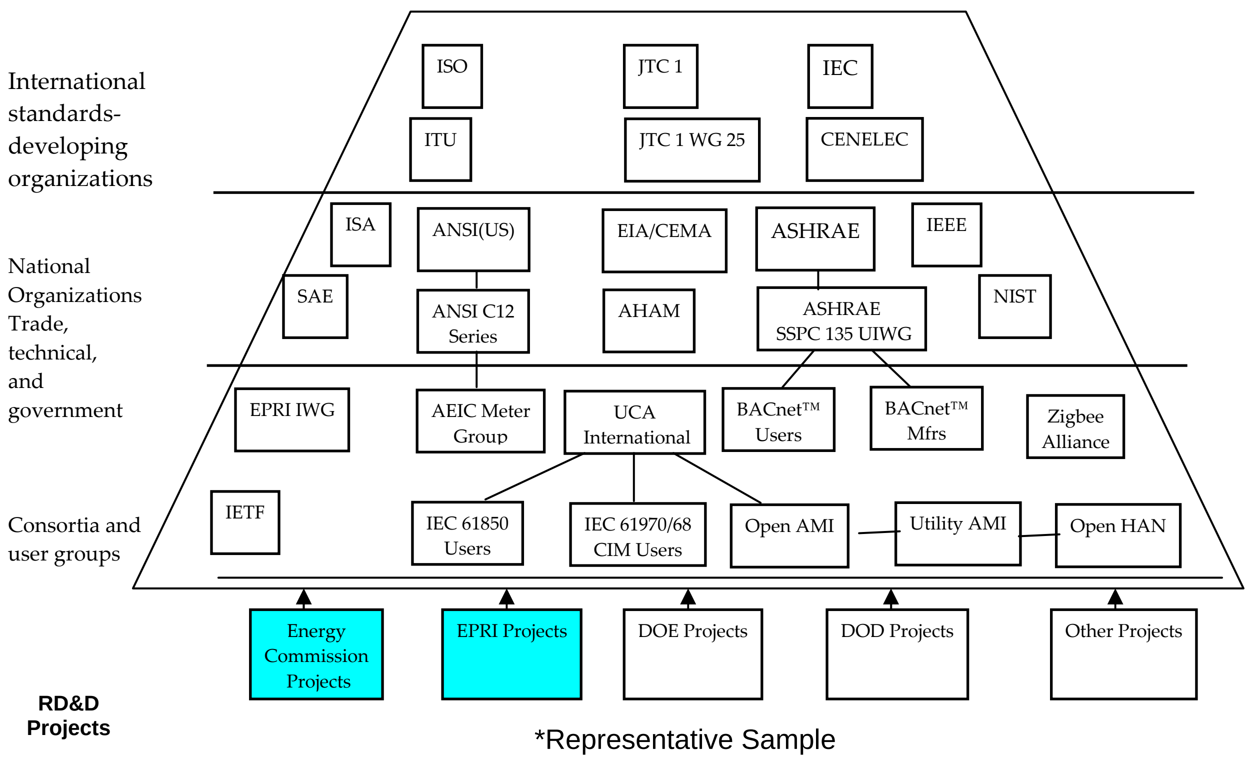

Figure 18: Key Standards Organizations Involved in the Development of "Smart Grid" Infrastructure

6.3.2. The Three Legged Stool of Interoperability

Interoperable systems and equipment requires a combination of the three elements of the three legged stool shown in Figure 9.

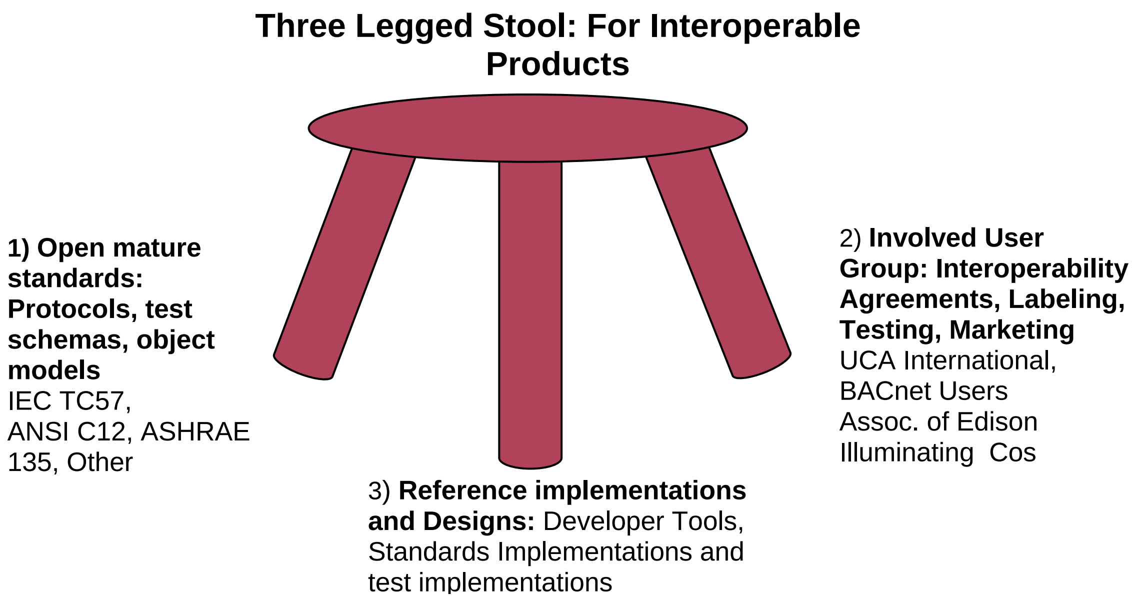

Figure 19: Three Necessary Ingredients for Successful Interoperable Systems Development

6.3.3. Ideal Architecture Characteristics

Ideally a mature architecture exhibits the following characteristics:

- Uses consistent policies across operating domains.
- Integrates a wide variety of networks.
- Integrates a wide variety of physical media.
- Enables interoperability among intelligent equipment.
- Uses a carefully integrated set of standards from different industries.
- Standards are supported by effective user groups.
- Industry requirements are shared across the industry.
- Interoperable equipment is available across the industry.
- Conformance and interoperability testing widely adopted.
- Standardized notation and models widely used to specify and manage systems.
- Systems engineering and architecture development methods are mature and widely used.

6.3.4. Architecture Development Processes

In addition to the content elements of the system architecture highlighted above, the development of a California infrastructure should follow the latest in systems engineering methods. It is important to note that systems engineering and architecture development methods are also seeking to mature. This section covers some of the gaps in development processes and recommends some steps to address them.

6.3.5. Define Consistent Policies for Smart Grid Supporting Infrastructure

Current gaps in processes are recognized as the need for a consistent set of industry policies for both the anticipated operation of the smart grid as well as those policies relevant to the management of the supporting distributed computing architecture. Policies are developing within some key communities such as the North American Electric Reliability Council that carry implications for the reliability of bulk power operations and supporting communications infrastructure. Policies for operation of the dc architecture arise from within system operator communities such as the California utilities, California Independent System Operator and the state Chief Information Officer. Privacy laws, Sarbanes Oxley, and other sources of policy could also influence the operation of the California Smart Grid since operations are anticipated to integrate customer operations into grid operations. It should be noted that policies for integration of federal buildings within the state may be subject to policies under federal agencies such as the General Accounting Office or the Department of Defense.

6.3.6. Systems Engineering

Systems engineering is a methodical approach to developing complex systems like the California Smart Grid. Systems engineering processes have been used in both EPRI projects like the IntelliGrid architecture and are now being used by utilities and user groups working toward smart grid requirements development. A full treatment of systems engineering methods is beyond the scope of this report but a few of the key elements are discussed below. Interested readers should find several resources on the topic that is now covered in several universities' curricula. The methods used by the original EPRI architecture project were developed into an IEC publicly available specification under Technical Committee Eight. This document is available from the IEC.

6.3.7. Define Requirements

Defining system requirements will be critical to developing the California Smart Grid. A current architectural gap is the fact that there are no state-level requirements for the development of a smart grid. Requirements development engages key stakeholders in the process of defining system functions and performance. Requirements are generally categorized into functional and non-functional. Functional requirements describe what the systems or applications do for the end-users. Non-functional requirements are those requirements that cover the performance, security and system administration functions that support the correct execution of the functional requirements. Both of these requirements are necessary to achieve a full requirements specification.

6.3.8. Define Models

Defining models of system structure are an important to document and ultimately specify and manage complex systems. Models are tools that are used to integrate and evaluate requirements and to develop specifications for how the systems will be brought together. Models are necessary tools for technology transfer across the many developers and vendor communities that will be putting components together. Presently the state does not have a model of overall smart grid interactions between the key stakeholders. This is particularly important for massively scaled systems such as revenue metering and customer communications. Standardized modeling languages and computer based tools assist in these processes. It should be noted that there are modeling approaches for both distributed computing and information technology systems as well as models that are developed for power systems integration and operation. Both of these have a place in the California Smart Grid as it becomes more established.

6.3.9. Develop Example Designs and Implementations

Equipment as well as the supporting standards and infrastructure are not complete without designs and implementations that are used to put the infrastructure to test. Designs based on the key open standards lead to implementations on the bench top at first. These implementations are necessary to flesh out issues and ambiguities in the standards and for user and vendor communities to converge on key common elements of the designs. Finally implementations are necessary to fully test the robustness of the designs and to test them for achieving management and security goals. Designs and implementations of open standards can also make use of "open source" approaches that enable a stable core of functions but let the vendor/implementer community work out issues and how they may differentiate products but still adhere to minimum integration and interoperability requirements with the balance of the system. Figure20 below generically illustrates these processes from requirements to commercial systems. Each step in this development pathway also contributes to the maturity of the standards and the user implementation agreements necessary to achieve interoperable systems and mature standards.

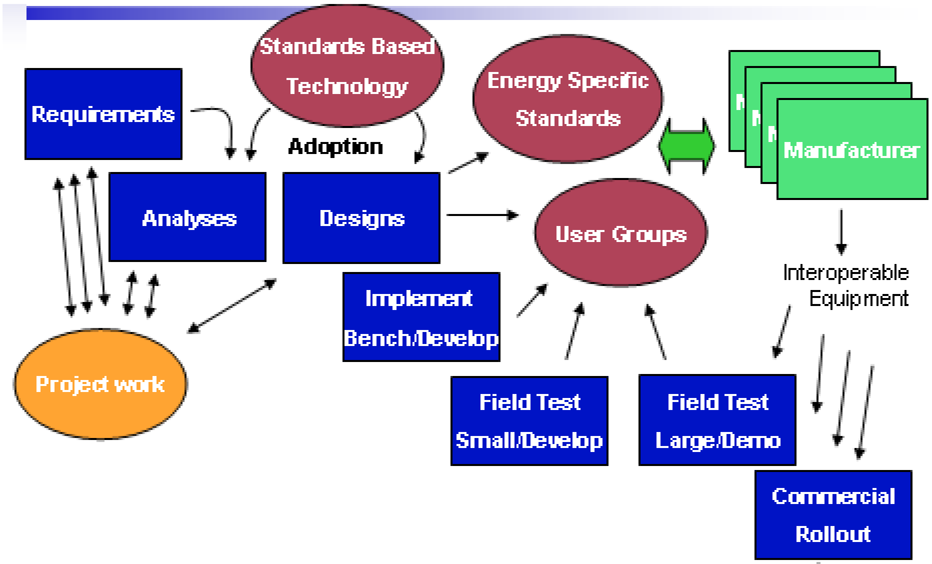

Figure 20: Recommended Processes: Applications and Infrastructure Development Occurs in Parallel

7.0 Critical Infrastructure and Architectural Gaps

7.1. Architecture Gaps

The ideal state of Architecture development as listed above in Architecture description does not yet exist for most of the envisioned California smart grid. This is not to say that there haven't been substantial bodies of good work that can be used. There has been substantial good work within utilities as well as within the standards and user group communities. However, the industry is at the point where the component elements of an overall architecture need to be brought together. The key elements of this architecture need to be developed now to assist California in achieving it's near, medium and long-term goals.

There are several gaps in an industry-level architecture that ideally would be available for California use. Some of the identified architecture level gaps are listed below:

- There does not exist a complete state-level architecture for integrating smart grid operations across key stakeholders and systems operators.
- Policies for systems management and cyber security need to be further developed and consistently applied across public infrastructures.
- Network and systems management infrastructures need to be further specified, evaluated, developed, and adopted.
- Security architecture needs to be developed/adopted for advanced automation and customer communications.
- Physical media communications options need to be better understood for California-specific smart grid requirements, both functional and non-functional.
- Initial implementations and reference designs for smart grid applications need to be developed, implemented, and tested.
- Networking technology infrastructure options need to be better understood in terms of their ability to support California Smart Grid requirements.
- Robust Network Designs need to be evaluated, Developed, Implemented, and Tested
- Requirements and reference designs for advanced automation and customer communications need to be fleshed out for California-specific functions:
    - Distributed energy resource (generation and storage) integration at all levels of operation hierarchy
    - Advanced T&D automation
    - Customer communications and metering
    - In-building equipment integration for energy functions

- Battery-electric vehicle and plug-in hybrid electric vehicle integration for advanced operations
- Common application level communication objects need to be developed for key applications that cut across traditional operations.
- Robust and truly interoperable smart grid equipment needs to be made available, enabled through a combination of mature open standards and a mature marketplace that supports multiple vendor communities.

The topic of key system components for the California architecture will be presented hierarchically. Technology categories include two major categories of key system component technologies: 1) content and 2) methods. It is important to note that there are critical technologies in each of these major areas. The smart grid needs an appropriate blend of technologies from both of these major categories. Briefly stated the content represents the components and the methods are the technologies that bring them together and enables them to be managed over their lifecycle.

It should be noted that the concepts of content and methods are not orthogonal. The functions, capabilities and characteristics of the component technologies are not independent from the methods and tools used to define smart grid systems. The technology cannot and should not be developed in a vacuum independent of stakeholder input.

Each of these major categories is described in the sections below:

7.2. Smart Grid Methods and Tools

This section introduces some of the technical methods and tools for how the smart grid needs to be brought together for California. It is important to note that the methods and processes by which the smart grid comes together are just as important as the “content” technologies that make up the necessary components. The California smart grid development must recognize that the development of the smart grid is a journey that will take time to fully implement all the envisioned applications and to manage them on a continuing basis for their lifetimes. This section briefly outlines the major methods and tools.

This section identifies the major methods for defining, designing, implementing and life-cycle managing a smart grid for California. The methods and tools are necessary to develop in parallel with the necessary components for the smart grid. The systems have become so complex that advanced methods are required to specify, document, design and manage them over their lifecycle. The smart grid cannot be implemented without these advanced methods in systems engineering and architecture design and without further development of “methods and tools” technology in critical areas.

7.2.1. California and Industry-Level Architecture Development

One of the critical areas of development of the smart grid is the overall systems integration approach. This topic is critical to component development in that it defines the techniques by which massively scaled, interoperable, secure, and well-managed infrastructures become developed. The necessary high-level viewpoint and set of methods to integrate systems on the scale necessary is known as architecture development. Architecture development methods and tools are necessary to be able to effectively integrate systems at appropriate levels and at an industry level.

Industry Level Architecture is important to integrating operations among ISOs/RTOs as well as organizations such as WSCC that cross state lines. Industry architecture is also important at the end-use end of the smart grid infrastructure to ensure that products made available from national and internationally recognized product vendors have the ability to interoperate not only between similar product lines but across different industries. Industry architecture development also plays a key role in consistent management and security policy implementation and enforcement that are likely to come from a number of federal sources of policy identified above.

7.2.2. California State Architecture Development

California government is a large end-user stakeholder in its own right and integration of utility operations with state buildings will need to follow California policies in areas such as management and security. The California State CIO is developing infrastructure documentation for integrating state offices and business practices.

7.2.3. Infrastructure for the California Smart Grid

This section is a description of infrastructure development for the California Smart Grid will contain particular end use and application development priorities. These priorities, articulated in the reference documents will drive particular emphasis in technical development and R&D infrastructure work. The following section expands upon California specific smart grid issues and their relationship to the overall industry infrastructure development.

7.2.4. Energy Commission-Specific Identified California Technology Areas

It is clear that California has urgency to implement applications of the smart grid that enable specific technologies and functions to be integrated into the overall operation of the California energy infrastructure. The following list of priorities will drive the balance of the recommended work and smart grid development discussion.

Ability to increase penetration of renewable technologies on the California Smart Grid

Infrastructure for distributed computing is at the core of effectively managing a growing installed base of distributed energy generation and storage technologies. Standardization of both the power system requirements as well as the distributed computing infrastructure is necessary to lower the barriers to increased penetration of renewable systems. This integration however, must be combined with effective use of open standards infrastructures for utility operations as well including transmission, substation, distribution and customer operations.

Improve overall grid system operational reliability, availability, sustainability, and maintainability

Standardized infrastructures for integrating intelligent equipment and enabling advanced monitoring and control algorithms are central to the future operations of the grid. In particular, standards and architecture that cut across traditional field operation lines are important elements of this strategy. In addition, the ability to effectively integrate "real-time" field operations with information technology environments are also important to advance the next generation of enterprise and industry-level applications.

Improve the environmental impact of the grid on California

Smart grid infrastructure can enable a variety of applications to limit environmental impacts including but not limited to extending new operating paradigms to obtain the most from existing power and energy infrastructure. Transmission systems may be operated more optimally under all conditions if the correct data and information is put to use in advanced monitoring and control algorithms. Architecture, if correctly implemented, also enables the effective integration of intermittent renewable resources as well as new operating paradigms with energy storage.

Increase efficiency of the grid

Grid efficiency improvements are also enabled with a well architected infrastructure that provides a more complete and accurate representation of real time operations. This vision is one of moving from grid "state estimation" to grid "monitoring," so that optimal power flows and efficiency improvements can be implemented

Reduce costs of operations of the grid

Several applications related to operation cost containment are related to the development of standardized infrastructures. Robustly designed networks and intelligent equipment applications can enable self-diagnostics in field equipment, performance-based management and other applications associated with maintenance management. Infrastructure also enables new applications that effectively make use of available resources built into field equipment.

7.2.5. California Building and Appliance Standards

California has been on the leading edge of both building and appliance performance standards since the 1970s. The infrastructure for the smart grid can enable an entirely new generation of energy performance enhancing capabilities for buildings as well as appliances and end-use equipment. Most notably the ability to cost effectively monitor and control formerly disparate systems within buildings opens opportunity to manage building energy performance over the life cycle based on empirical data. The ability to integrate communications with advanced end-use appliances and equipment opens opportunity to more effectively manage end-use loads including capabilities such as monitoring, trending, diagnosis and repair assistance.

7.3. State of Enabling Infrastructure

This section provides an assessment of the state of the technology development necessary for the California Smart Grid. This task will categorize technologies for high-level evaluation within their general context. It should be noted that there are multiple interrelated dimensions to smart grid technology. To understand each of the technology areas and their respective levels of development, it is necessary to understand the technology from different viewpoints.

Each viewpoint is developed from a different technical perspective. The state of technology development will include supporting activities underway to develop the needed technologies.

7.3.1. Component Technology "Content" Assessments and Views

This section discusses the state of development of the specific technologies necessary to implement California priority applications

7.3.2. Smart Grid Power Engineering Applications and "Intelligence" Development Status

Smart grid applications include the monitoring and control functions that are necessary to execute the advanced automation functions and capabilities outlined in California's priority areas. It is important to note that smart grid functions and capabilities will be initially defined by these applications. These will be distributed applications and the major monitoring and control algorithms that will be used to orchestrate the operations of the smart grid. The next four major categories outlined below are subordinate to the requirements defined by these applications.

- Advancement of DER Control and Protection within Transmission and Distribution Systems to Support Significant Penetration of DER and Demand Response Resources.
- Effective Integration of DER, DR, and EE Resources from Customers.
- Improved Performance of Power System Operations.
- Other.

7.3.3. Advanced Power Engineering Equipment and Control Algorithm Development

This section highlights the development status of advanced field equipment development specific to California application priorities. These include the missing components, local algorithms and infrastructures necessary to address key applications identified above.

Advancement of DER Control and Protection Within Transmission and Distribution

The development of the hierarchical control and systems integration algorithms need to be developed from an overall systems operation perspective. This includes supporting system protection as well as a variety of automation applications that must be developed under the anticipated penetration of intermittent renewable resources across the state. These developments should be approached from a combined systems engineering and power engineering perspective. Requirements and use cases can lead to modeling of both the power infrastructure as well as the supporting distributed computing infrastructure.

Effective Integration of DER, DR, and EE Resources from Customers

The development of T&D operations algorithms for managing significant demand response and energy efficiency applications in addition to customer siting generation and storage also needs to be developed. Since the California Smart Grid anticipates these additional dynamic capabilities these control and management algorithms need to be developed now. Of course, this will need to be accompanied by the distributed computing infrastructures discussed below to enable this to happen at the customer level.

1. ISO/RTO-level equipment.
2. Central generation equipment development.
3. Transmission equipment development.
4. Substation equipment development.
5. Sub-transmission equipment development.
6. Distribution equipment development.
7. Metering and customer communications equipment development.
8. In-building equipment development.
9. EV and PHEV development.
10. Federated services equipment development.

This section can also discuss the development of specific communications related topics that are related to components. Examples are the state of standardized object and device models available for specific equipment

7.3.4. Distributed Computing Infrastructure Development

This section is an assessment of the state of the distributed computing infrastructures necessary to support both the advanced equipment and the higher level power operations applications presented earlier in this section. The distributed computing infrastructure is subordinate to the technical requirements coming from the combination of the intelligence and the next generation of field equipment.

Distributed computing is a term that encompasses all the communications elements necessary to implement the applications, whether these are in "real-time" environments or in information systems. Distributed computing includes all the layers of the OSI Basic Reference Model stack necessary to support the applications. The status of distributed technology is discussed in the following sections.

Figure 21 below illustrates the Open Systems Interconnect Basic Reference Model (BRM). The BRM is based on industry standards and is used to discuss the development of technologies used for distributed computing and network communications. The discussion of technologies for the smart grid infrastructure use this as a framework to discuss key areas of component development ranging from physical communications media (layers 1, 2) up through application level communications (Layer 7 and above). This model also forms the basis of the architectural concept of layering communications. Figure 21 also depicts some of the issues with the various technologies at key layers of the BRM. It should be noted that one of the proposed strategies is a collapsing of the seven layers of this model into a simpler operating paradigm. At this point, however, the OSI BRM is still a useful technology categorization tool.

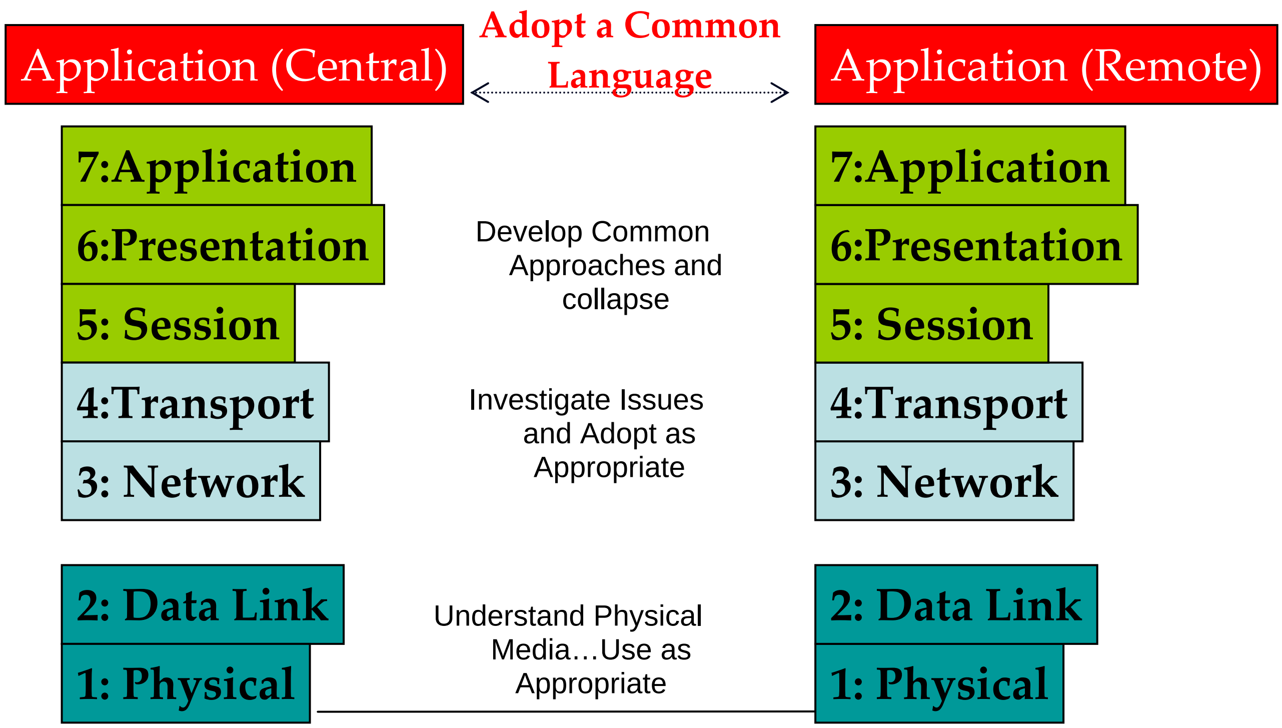

Figure 21: Architecture Strategies

7.3.5. Physical Communications Media (Layers 1, 2)

Physical Communications Media is specified in layers one and two of the OSI Basic Reference Model. Physical media is now and will always be under constant development. The strategy for the smart grid is to apply the concept of "layered communications" to make use of the existing and new physical media technologies as they become available and are able to meet smart grid requirements. For integration and interoperability, the industry needs to standardize on a common language(s) at the application layer and above, and develop strategies to make use of existing, emerging, and future physical communications media. Assessments of existing and emerging technologies in this area can support the local decision making process in the appropriate use of candidate technologies.

7.3.6. Wireless

Wireless technology will be important to employ in the execution of the smart grid. Several candidate technologies are available for both wide area and local (short distance) wireless. There are gaps in fully understanding the strengths and weaknesses of the candidate technologies, and this is an area that can benefit from closer study by experts in these fields. EPRI has done some initial analyses on leading candidate wireless technologies and this can be built upon. EPRI's assessment of Wireless Technologies for Advanced Automation has evaluated five leading wide area technologies against the backdrop of IntelliGrid Architecture requirements. Of specific note is the potential for utilities to come together to specify the use of the 700MHz "Block D" frequencies that are now proposed for "public safety" and other important commercial uses. These frequencies could enable the development of true private wireless networks that would be licensed. These frequencies have particularly good characteristics for use in T&D operations and customer communications and should be further investigated for technical merits as well as with the possibility of being supported by several utilities.

Zigbee based on IEEE 802.15.4 is targeted for short distance and may be appropriate for in-building communications. It is unlicensed however and could be subject to interference as wireless products proliferate and or if mitigation measures are not robust enough. It should be further investigated for appropriateness for utility requirements.

7.3.7. Power Line Carrier

Power line carrier technologies that exist and are now emerging also need to be evaluated against the backdrop of advanced automation and customer communications requirements for the smart grid. Candidate technologies include both narrow and broadband power line communications. Evaluations should include not only performance and ability to meet applications requirements but should also include a more complete understanding of interference issues associated from both human as well as natural activities. Power line communications can be sensitive to interference from noise that can come from both terrestrial and extraterrestrial natural events. Power line communications is a promising candidate for integrating equipment within buildings as well as integration of in-building and external networks. The smart grid implementers should have as complete an evaluation on the strengths and weaknesses of PLC technologies to make informed local decisions on its use. Emphasis should be placed on PLC communications based on open standards to the extent possible to allow a breadth of design choices as appropriate.

7.3.8. Wired

Physical media assessments should also be conducted for several candidate wired and fiber technologies that can be used to support some of the smart grid infrastructure. This media represents a broad class of communications that can be used for both wide area as well as in-building communications. Standards based wired media such as IEEE 802.2 (Ethernet) is already in use as part of the ASHRAE BACnet building automation standard. Evaluations should emphasize open standards development for flexibility in marketplace offerings.

7.3.9. Networking (Layers 3, 4)

Networking layers are a critical part of a wide area communications infrastructure. These layers establish the rules for addressing equipment, navigating data packets over networks as well as supporting other services necessary for smart grid communications. These layers include network and transport, layers 3 and 4 respectively, in the middle of the OSI BRM. These layers are currently in a state of flux and this does not help the establishment of infrastructure for networking within the smart grid. The most famous and widely used routing protocol Internet Protocol Version 4 (IPv4) has been in use since the 1970's and has some well known architectural issues such as address exhaustion. Internet Protocol Version 6 (IPv6) has been under development for over a decade. IPv6 is intended to overcome some of the well known weaknesses within IPv4 but the process has resulted in a myriad of proposed changes. IPv6 in its current form is now supported by over one hundred documents and specifications according to a recent report release by the National Institute of Standards and Technology (NIST). Implementations of IPv6 may involve any one of several of these documents in composing a given "profile" for standardized networking. This result is a myriad of possible profiles that may not integrate. The "parts count" on the number of elements that need to be agreed upon presents a challenge for the industry. There are also some remaining issues that are still largely unresolved, with the infrastructure in the middle of the networking stack including but not limited to functions such as multi-homing, quality of service management, mobility and security. These functions will be needed in the ultimate deployment of an architecture the scale and scope of the smart grid. These issues represent architectural gaps in the ultimate development of a smart grid networking and distributed communications infrastructure over wide area communications networks. Researchers studying "patterns" within networking infrastructure have suggested a new networking where the traditional layers of the OSI Basic Reference Model can be simplified and collapsed down even for wide area networking. Understanding these issues as well as their potential solutions requires research in networking technology. Recommendations include identifying key requirements and functions that need to be supported by smart grid communications and working toward approaches and strategies to resolve these issues.

7.3.10. Integration of Networks With Applications (Layers 5 ,6, 7)

Layers 5, 6, and 7 are concerned with communications between applications and networking infrastructures. While historically distinct layers were defined many of the newer technologies are seeing some convergence or collapse of these. A few key technologies here include ASN.1, ACSE, XML/XML Schema, and those associated with management and security at these layers.

7.3.11. Common Language for applications (Layer "8"plus)

Key Application Level Language Development for California Priorities includes those covered in the following sections. Applications layer communications development is a key architecture issue that can be effectively addressed by focused R&D work. A critical set of emerging standards for the California smart grid is underdevelopment at the International Electro-technical Commission (IEC) the status of these are briefly discussed below.

Overview of IEC 61850 Standards Series

Under its Technical Committee (TC) 57, IEC is developing normative standards (the 61850 series) to support open-systems-based communications for electric power systems. These standards will allow easy assimilation of components into an interoperable communication system to support smart grid operations by standardizing the object models and the protocols involved. The use of international standards will eliminate the need to do custom engineering of the communication system in every instance and use a "plug and work" process instead. The end result is more cost-effective and rapid development of the communications systems for smart grids. The California smart grid program should include a plan for migration to this body of standards.

The development of standards under TC-57 is performed by working groups (WG). The 61850 series of standards is aimed at the communication needs for real-time operations of smart power systems. TC-57 also manages other related standards work, including work on standards for power system business enterprise (WG-14) and standards for information security (WG-15). Overall coordination is the responsibility of WG-19.

Object models (information models of equipment) in the 61850 series are broken down into a structure of logical nodes. An object model can be thought of as the building and the logical nodes as its bricks. This approach is by intentional design. The intent is to be able to reuse the logical nodes wherever possible as the modeling of more device types is added to the 61850 series. This approach achieves efficiency in adding new device models and consistency in naming model attributes throughout the entire series.

The portion of IEC 61850 for substations has been completed by WG-10 and released. Major vendors are now offering substation equipment that conforms to 61850. Utilities worldwide are increasingly specifying 61850 for substations, and substations providers are installing turnkey 61850 substations. This standard is the lynch pin for an expanding series that will addresses interoperability of the entire power system. Maintenance and updates for the substation standard are being performed by WG-10.

The substation portion of IEC 61850 consists of the following parts detailed in separate documents

- IEC61850-1: Introduction and overview.
- IEC61850-2: Glossary.
- IEC61850-3: General requirements.
- IEC61850-4: System and project management.
- IEC61850-5: Communication requirements for functions and device models.
- IEC61850-6: Configuration description language for communication in electrical substations related to intelligent electronic devices.
- IEC61850-7: Basic communication structure for substation and feeder equipment.
- IEC61850-8 and 9: Specific communication service mapping (SCSM).
- IEC61850-10: Conformance testing.

Other documents in the series and their status are shown below:

- IEC 61850-7-410 -- Hydroelectric Power Plants - Communication for monitoring and control. (Published). Was developed by WG-18.

- IEC 61850-7-420 -- Communications systems for Distributed Energy Resources (DER) - Logical nodes (Draft). Under development by WG-17. In IEC terminology, DER denotes distributed generation and storage.
- IEC 62445
  - IEC 62445-1 -- Use of IEC 61850 for the communication between substations. (New Work).
  - IEC 62445-2 -- Use of IEC 61850 for the communication between control centers and substations (New Work).
  - IEC 62445-3 -- Mapping of IEC 61850 based Common Data Classes (CDC's), information addressing, services onto IEC 60870-5-104/101 (New Work).
- IEC 61400-25 -- IEC61850 Adaptation for Wind Turbines (Parts have been published and other parts are work in progress).

The wind power standards are applicable to both central and distributed wind power.

In WG-17, the draft of the logical nodes for DER has been approved in Committee Draft voting and upon completion of editorial work will be submitted soon for voting as a first draft international standard (FDIS). This document includes the logical nodes for four DER types:

- Photovoltaic power systems.
- Fuel cell power plants.
- Reciprocating engine generator systems.
- Combined heat and power systems.

Due to modularity of photovoltaic systems and fuel cell power plants, the object models for them could be applicable to central as well as distributed power plants using these technologies.

WG-17 is being expanded to develop the object models for distribution feeder and network equipment, such as switchgear, capacitor banks, and reclosers. This will involve extensions and adaptations from the substation work and reuse of logical nodes from the substation and DER work wherever possible. WG-17 will also maintain the DER standards and add other DER types, as necessary domain information becomes available.

Distributed Energy Resource Integration Standards

Overview of IEEE 1547 Standards for Distributed Resource Interconnection and Integration

The 1547 series of standards is being developed under IEEE Standards Coordinating Committee 21. The original standard IEEE 1547™ (2003) was released in 2003. It broadly addresses interconnection by providing a normative standard for an interconnection system (IS) for interconnecting distributed resources (DR) with electric power systems. The 1547 series uses "DR" to denote distributed generation and storage. The original 1547™ standard presents the minimum requirements that an IS must meet. The standard does not limit the approach an IS supplier might take to meet the requirements in any way. The standard was developed during the period 1999 to 2003 by a working group of several hundred members. This standard is now five years old and is currently being balloted for reaffirmation, per IEEE requirements.

The US Federal Energy Policy Act of 2005 calls for state commissions to consider certain standards for electric utilities. Per Section 1254: "Interconnection services shall be offered based upon the standard developed by the Institute of Electrical and Electronics Engineers: IEEE Standard 1547 for Interconnecting Distributed Resources with Electric Power Systems, as they may be amended from time to time."

Additional documents to expand on the original 1547™ are being or have been prepared. These include the following:

- 1547.1™ (2005): Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.

- P1547.2: Draft Application Guide for IEEE 1547™ Standard for Interconnecting Distributed Resources with Electric Power Systems.

- 1547.3™ (2007): Guide for Monitoring, Information Exchange and Control of DR Interconnected with Electric Power Systems.

- P1547.4: Draft Guide for Design, Operation, and Integration of DR Island Systems with Electric Power Systems.

- P1547.5: Draft Technical Guidelines for Interconnection of Electric Power Sources Greater Than 10 MVA to the Power Transmission Grid.

- P1547.6: Draft Recommended Practice for Interconnecting Distributed Resources with Electric Power System Distribution Secondary Networks.

Those standards with a trademark symbol have been released by IEEE. Those with a "P" in front of the number are still in preparation. The documents 1547.1™ and 1547.3™ have been completed and have been released by IEEE. P1547.2 is just now reaching the ballot process. Others are still under development.

1547.1™ is a standard for conformance testing to aid in determining if a specific IS meets the original 1547™. P1547.2 will be an application guide to support users in applying the original 1547™.

1547.3™ is guide for monitoring, information exchange, and control of DR in electric power systems. The original 1547™ had one very brief paragraph on normative requirements for communication with DR. The purpose of 1547.3™ is to provide a guide which not only supports the user in meeting the minimum normative communications requirements of 1547™, but also provides guidance on how to set up more sophisticated monitoring, information exchange, and control, which go beyond the minimum requirements. 1547.3™ contains basic "how-to" guidance on information modeling, business processes, and preparation of use cases relative to DR. It does not contain normative standards for these items.

Normative standards for information models or "object models" are being developed by the International Technical Commission (IEC), as discussed in another section. As is explained there, it is the goal of the IEC standards to have normative object models that are internally consistent for the whole power system to facilitate interoperability of all active components in the system, including but not limited to the DR.

The 1547 series should be considered a growing body of tools, some of which are available now, to aid in integrating DR into the mix of resources in smart grids, in California and elsewhere. Collectively, these tools will help increase the value of DR in smart grid operations. California used the original 1547™ is it Rule 21. California should continue to adopt the IEEE 1547 series as part of its smart grid development plan.

Customer Communications and Metering Infrastructure

Metering and customer communications is a substantial portion of the smart grid that needs infrastructure development. Significant work has been done but now needs to be brought together and evaluated prior to major commitments. The following is a synopsis of the major areas of architecture related to dynamic customer integration with the California Smart Grid.

Metering standards are substantially developed under the ANSI C12 series however, implementation agreements and example implementations are necessary to work through the design issues and implementation details necessary for secure, well managed and interoperable systems.

Customer internetworking gateways are also necessary to be able to forward pricing and control information to customer owned networks and energy management and end use equipment. Standardized application level objects need to build upon prior work related to IEC 61850 and UCA communications that were used to develop contributions to the ASHRAE BACnet committee and support the ASHRAE RP 1011 Project. Control and Real Time Pricing and other objects for Utility/Energy Service Provider to Customer need to be finalized in example designs and implementations.

"Recommended approaches to standardize on utility/energy service provider to customer communications make use of the application level communications that was developed for the ASHRAE RP1011 project. The communication "objects" developed for sending price signals and controls was based on an approach that is now adopted as part of the International Standard IEC 61850 part 6. The standard uses a rich hierarchy as a way to structure data and device models and applies an extensible markup language XML schema to structure the communications "objects". This approach is now being used for configuring advanced field equipment for Transmission and Distribution automation communications as well as integration of DER equipment communications. The approach is flexible enough to support a variety of device models and supports both data as well as control functions. Standardizing on this approach can greatly assist the industry in converging on a consistent application level language for communications with customer systems. The semantics of standard customer communication objects in IEC 61850 formats can also be integrated or harmonized with IEC 61968 objects for use in a Service Oriented Architecture environment. As an application level language it is independent of underlying network and 61850 formats can also be integrated or harmonized with IEC 61968 objects for use in a Service Oriented Architecture environment. As an application level language it is independent of underlying network and physical communications media used to transport the messages. It is critical for the industry to settle on consistent semantics and syntax of application level communications to have an anchor point for interoperable systems and equipment."

In addition, liaisons and common object development for in-building communications with key standards communities such as Society of Automotive Engineers (electric and plug-in hybrid vehicles), Association of Home Appliance Manufacturers, and American Society of Heating Refrigeration and Air Conditioning Engineers need to be integrated into an industry level common applications language. Other Standards organizations should be integrated as well into a common language for in-building systems to the extent that this can become established.

The industry is substantially fragmented in infrastructure development but some of the leading candidate technologies can accommodate much of the work of others and this can be illustrated with some focused work on example designs and implementations which could be developed into Reference implementations through cooperative work with the industry. This cooperation can be augmented through work with the UCA International User groups, AEIC Metering Group, ASHRAE BACnet Utility Working Group and AHAM to name a few. In addition, the use of Open Source for key communications software development can augment direct technical participation in use and appropriate extensions of the standards.

7.3.12. Systems and Network Management

Systems and network management include all of the functions to maintain communication networks and connected intelligent equipment. This category of technologies includes the open standards based infrastructures necessary to implement management functions such as the following: fault management, accounting management, performance management, configuration management and security management. This area of work is a current gap in the development of an open systems based infrastructure for wide area communications of the type required by advanced T&D automation as well as customer communications.

Some of the requirements for future systems network and systems management have been put forward in various Standards communities as well as in the UCA International Users Group notably Utility AMI use cases. These use cases can benefit from additional work to flesh out a full set of requirements as well as developing the industry model to capture the requirements in standardized forms.

In addition the technology surrounding the middle of the OSI BRM for networks is not mature enough for straightforward adoption by the power industry. The Internet Protocol for instance is supported by more than one hundred documents and specifications under the IETF. In a report released earlier this year the National Institute for Standards and Technology (NIST) has expressed concerns with adopting this technology for Federal Government use. Transmission Control Protocol and Internet Protocols are both experiencing an unsettling amount of turmoil that makes adoption of IETF based standards a significant challenge. Several technical issues are unresolved including but not limited to: multi-homing, quality of service, addressing and security.

Since the power industry generally takes the path of assessing and appropriately adopting technology these areas is of significant concern in large scale network development.

A full complement of security requirements and technology assessments are also necessary for large scale networks for both T&D as well as customer communications.

8.0 Recommendations

The objectives of the public workshop, staff meetings, and interviews with different stakeholders were to answer important questions regarding the implementation of a smart grid in California. Key findings resulting from stakeholder feedback are summarized in Section 3 as well as the Appendices of this report. This section summarizes important conclusions and recommendations based on a combination of background research and stakeholder feedback. In particular, this section proposes an approach to defining the California Smart Grid vision. The section also summarizes key RD&D needs associated with each of the identified critical technology areas discussed in Section 5. That is, recommendations are identified for each of the critical technology areas below.

- Architecture and communications infrastructure.
- Renewable and distributed energy resource (DER) integration.
- Grid operations and control.
- Asset and capital efficiency.
- Customer system.
- Workforce efficiency.

8.1. Proposed Approach to Define the California Smart Grid Vision

One of the first goals of the project was to define the California Smart Grid and a high-level architecture framework, which could then be used as a basis for identifying research, technology development, and implementation priorities towards achieving the smart grid. As the interviews and meetings were conducted, it became clear that California does not yet have a unifying *vision* for the California smart grid or its architecture at this time. A key conclusion is summarized below.

The smart grid architecture should be defined based on the requirements and characteristics of the applications that the smart grid infrastructure will support.

This conclusion represents one of the first steps for ongoing research.

8.1.1. Applications at Different Levels

The smart grid infrastructure must enable intelligent applications at all levels of the grid. Desired applications must be first understood in order to develop the requirements for the overall smart grid infrastructure. An approach is to focus on applications that have high intrinsic value but presently have low net value due to the high cost or unavailability of required technology, operating cost of that technology, or reliability of the technology. Figure 22: depicts examples of applications. The infrastructure that enables such applications includes two basic components.

1. The communications infrastructure.

2. Information systems for data integration.

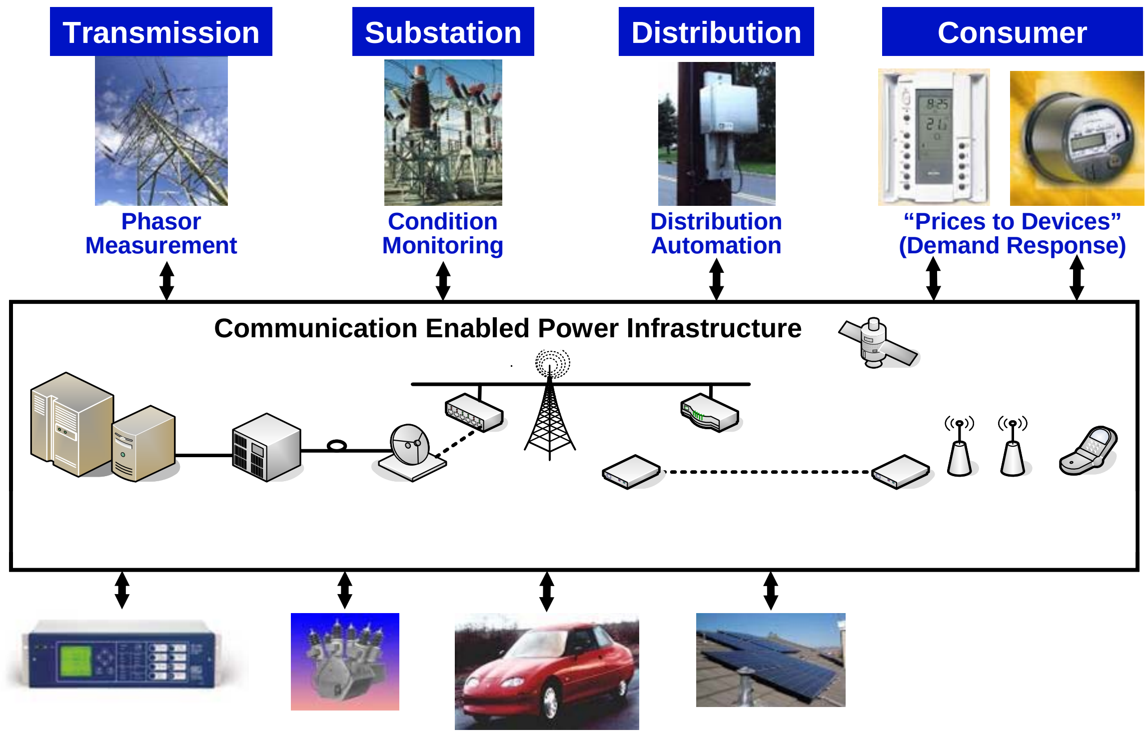

Figure 22: The smart grid infrastructure (communications infrastructure and information systems) will enable advanced applications at all levels of the system.

8.1.2. Use Case Process

A proven method for developing the requirements of the smart grid infrastructure and associated technologies is the "use case method". This method has been defined as part of the IEC Publicly Available Specification 62559[8]. Figure 233 provides an overview illustration of the methodology.

[8] *IntelliGrid Methodology for Developing Requirements for Energy Systems*, IEC Publicly Available Specification 62559

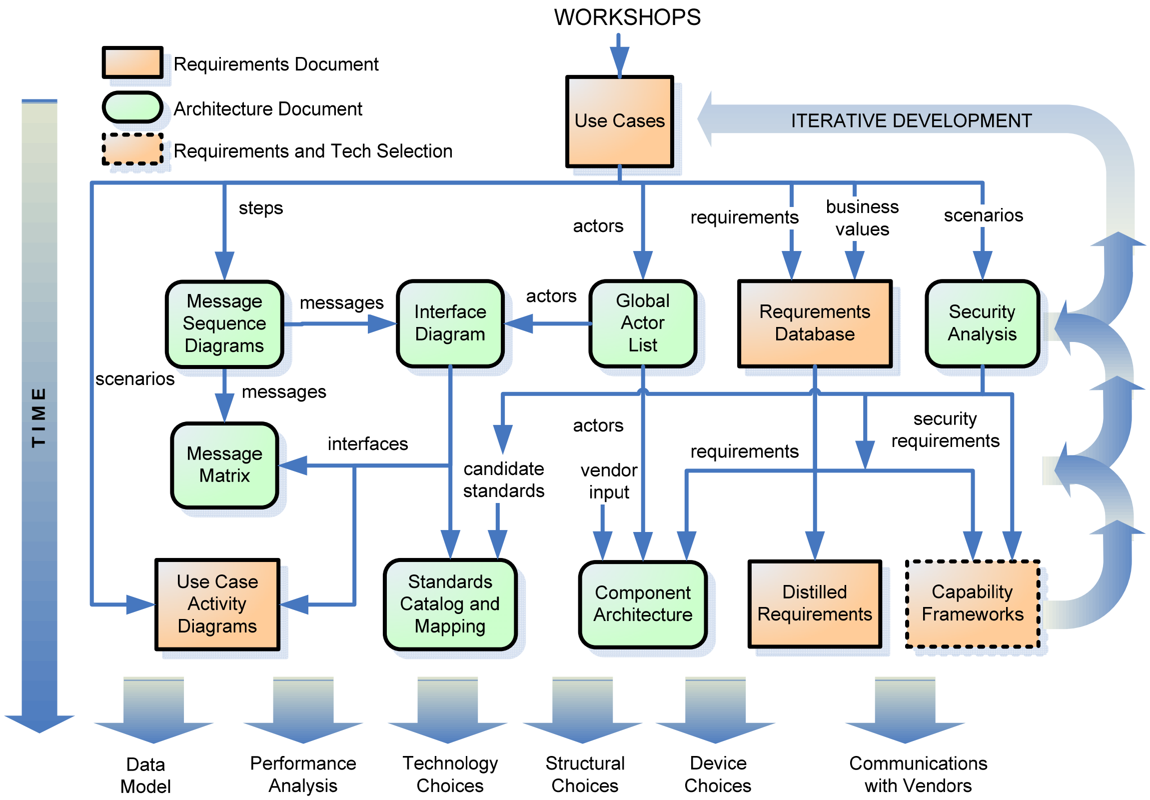

Figure 23: The methodology for developing requirements and technology choices for the smart grid – the "use case" approach.

An important recommendation from the public workshop was to develop and establish a set of California smart grid use cases with full stakeholder participation. The uses cases could then be used to derive a foundation of smart grid infrastructure requirements and technology requirements.

8.1.3. Developing the California Smart Grid Use Cases

The California Smart Grid use cases will define key applications of the smart grid. Collectively these applications define the requirements for individual technologies that comprise the smart grid and the requirements for the overall infrastructure. Aspects of California Smart Grid needs that warrant development of use cases and requirements at a statewide level include:

- Applications like demand response cut across all of the individual utilities, California ISO, and other market players.
- The renewable portfolio standard in California creates a need for applications that integrate renewable generation technologies at all levels of the grid.
- Assuring the reliability of the smart grid with increased use of renewables and distributed resources requires an understanding of these technologies and their integration requirements.

- Advanced Metering implementations in California will provide the infrastructure for many applications that have not yet been defined. Some effort to understand these applications is needed to assure that the AMI infrastructure will be able to support them in the future.
- An aging infrastructure and a continued push to move the distribution infrastructure underground creates needs for sensors and intelligent applications that will optimize the use of existing assets and maintenance of these assets.

It is recommended that a set of workshops be organized around different application areas to develop a prioritized set of use cases in each category. These use cases would then be used to derive requirements for the individual technologies, or actors, as well as the overall infrastructure.

Individual utilities and even the Energy Commission have already been working on use cases for different elements of the smart grid. (For example, the Energy Commission has been developing distribution technology use cases and SCE has developed an initial set of advanced metering use cases). These efforts provide an excellent starting point for the development of a statewide set of use cases and requirements for the smart grid.

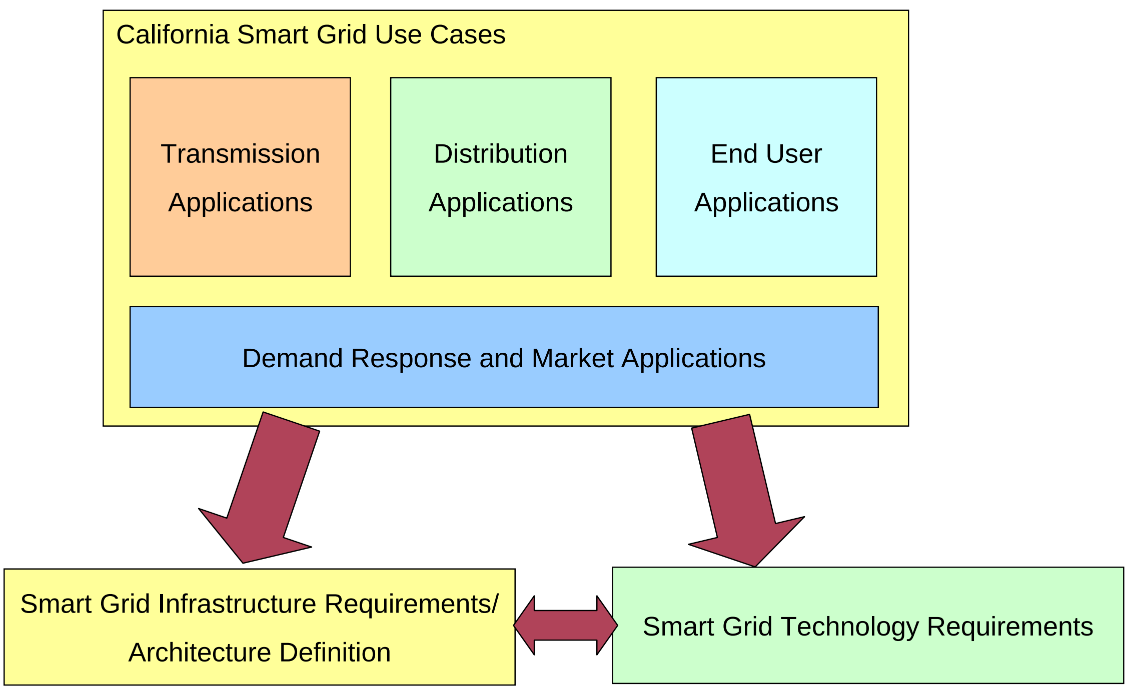

Figure 24: Development of California Smart Grid use cases feeds into development of requirements for smart grid architecture and technologies.

8.1.4. Industry Coordination

The development of a smart grid is not only a California initiative but is a national and international priority as well. The *Energy Independence Act of 2007* defines the need for a smart grid and international initiatives like the European Smart Grids effort have similar objectives. It is universally realized that a smart grid is needed to achieve our objectives for reliability, increased efficiency, renewable integration, and complete integration of distributed resources with energy markets.

Therefore, it is critical that the development of a library of smart grid use cases and associated requirements in California be coordinated with the overall industry.

One possible method of accomplishing this is through the IEEE Intelligent Grid Standards Coordinating Committee. This group can maintain the industry repository of use cases, infrastructure requirements, and technology requirements. This will bring together use case efforts that are under way at many other utilities, national initiatives, and international efforts along with the California initiative.

This coordination is necessary to make sure that a common set of requirements are eventually agreed on so that economies of scale and common applications can be realized as part of the smart grids around the world. The California effort will recognize the unique aspects of the California infrastructure and objectives while making California a leader in defining the overall industry needs.

8.1.5. Incorporating Value Assessments

During the use case process, it will also be important to identify stakeholder value in the applications that are being defined. This is a critical element in validating the requirements for the application.

8.1.6. Prioritizing Technology and Application Development for the Smart Grid

The use case process will provide requirements for the smart grid infrastructure and for the individual technologies that will become part of the smart grid. The PIER research programs are already working on many of these technologies and applications. As technologies and applications are developed, requirements for integrating them with the smart grid infrastructure must be identified and coordinated. As these requirements come out of the use case process, they should be incorporated into the various technology and application research and development process.

Some priorities for this coordination are identified here and specific needs for development with respect to the smart grid integration are identified.

Priorities for technologies and applications are based on the following criteria:

- Ability to increase penetration of renewable technologies on the California Smart Grid.
- Improve overall grid system operational reliability, availability, sustainability and maintainability.
- Improve the environmental impact of the grid on California.

- Increase efficiency of the grid.
- Reduce costs of operations of the grid.

8.2. Architecture and Communication Infrastructure

8.2.1. Communication Network Options for Different Applications

A good understanding of physical communication technology alternatives with strengths and weaknesses defined as a function of different applications is needed so that smart grid implementers can make informed decisions. The smart grid applications should in general be independent of the physical communication technology but the requirements developed in the use cases for bandwidth, security, response time, etc. may point to specific alternatives.

Research should characterize the strengths and weaknesses of at least the following and demonstrate the performance in real world conditions:

- Wide area wireless.
- Short distance wireless.
- Power line media (narrow and broadband).
- Fiber and other.

Use of these physical systems for wide area network implementation also needs to be better understood with standard designs that are implemented and tested with security requirements and methods documented.

8.2.2. Network Management and Security for Smart Grid Applications

Network and Systems Management Infrastructures need to be further specified, evaluated and adopted/developed:

- IPv4/IPv6 Profiles for advanced automation and customer communications.
- Remote upgrade of firmware.

New security architecture needs to be developed/adopted for advanced a=automation and customer Communications:

- Hardening.
- Authentication, key management.
- Integrity, confidentiality, encryption.
- Managing residual risk.
- Intrusion detection.
- Survivable networks.
- Forensics.

8.2.3. Information Integration

There is a tremendous need for definition of information interfaces associated with different applications and technologies and then bringing these information interfaces to common standards such as the common information model (CIM). This will be a major focus of requirements definition from the use cases but beyond the requirements is actual definition of the information models and standardizing these models.

Information integration is critical in at least the following areas and should be a major area of focus where California efforts can contribute to the entire industry:

- Distributed energy resource integration.
- Advanced T&D automation.
- Customer communications and metering.
- In-building equipment integration for energy functions.
- EV/PHEV integration for advanced operations.

The information integration occurs at two levels and it works best if these are harmonized:

1. The equipment interface level. Object models at the actual communications interface level need to be defined and implemented as part of the communications and data management infrastructure. This has traditionally been the role of standards like IEC 61850 and the extension of these concepts to distribution, distributed resources, and the consumer interface needs to be developed.
2. The information systems interface level. This defines the information models for sharing of information across on information bus or the equivalent. These information models are typically incorporated into the common information model (CIM) but this is far from complete for distribution applications, distributed resources, and consumer applications such as AMI.

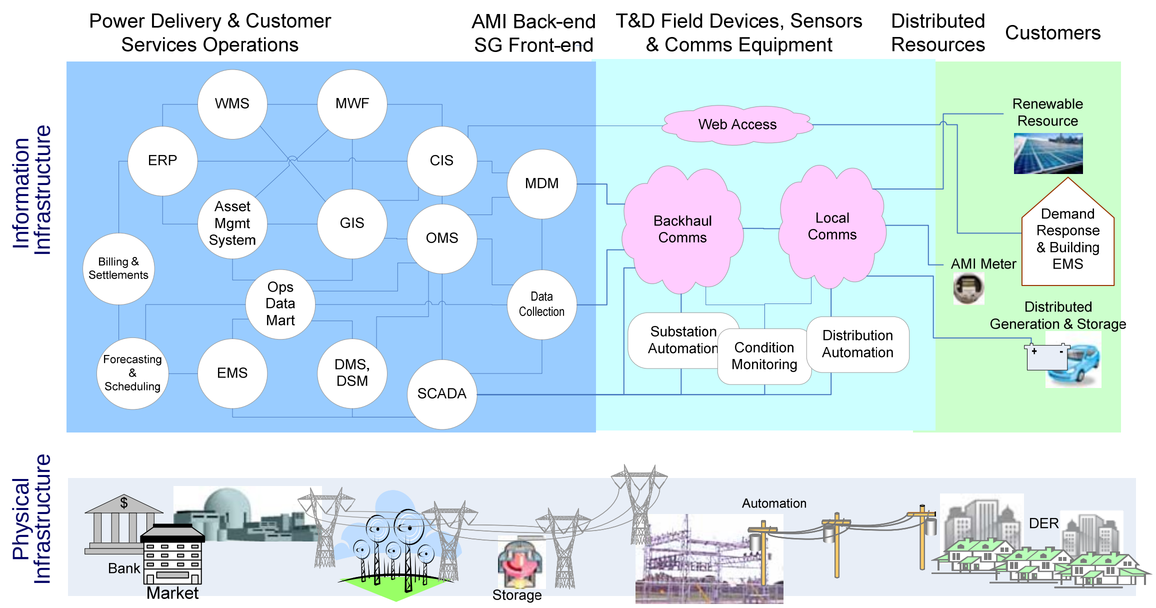

Figure 25: Example of information management interfaces that need to be defined at different levels (courtesy of KEMA).

8.2.4. Information Integration for Advanced Metering Infrastructure

Information integration is critical at all levels as indicated in the previous section. Information integration issues for advanced metering integration are particularly critical as the rollout of these systems is imminent in California.

Common information models for the meter interface need to be developed and standardized so that they can be the basis of integration with many smart applications at the enterprise level. The integration is likely to occur at the meter data management system level but the information models affect the requirements all the way down to the meter interface.

The architecture should also a accommodate integration of information from legacy metering systems as illustrated below.

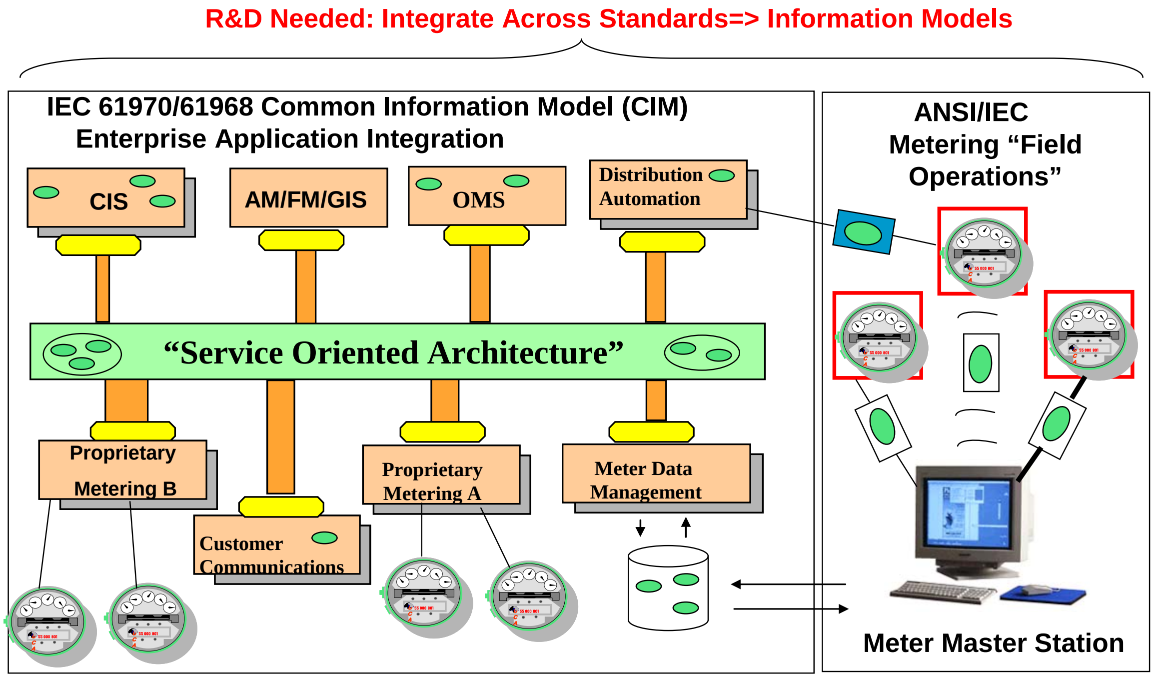

Figure 26: Illustration of integration of information from advanced metering with enterprise applications.

8.2.5. Integration of Legacy Systems

Of course, there are many smart applications already deployed – automation, equipment diagnostics, etc.

Research should develop methods for providing information gateways so that these applications can be integrated with overall architecture.

Build on work under way in distribution program.

8.3. Renewable and Distributed Energy Integration

8.3.1. Integration of Photovoltaic Systems with Local, and Neighborhood Energy Storage

There is an initiative to deploy 1 million PV systems in California. PV in general is gaining favor as rising energy prices, falling costs of PV enabling materials and supporting technologies, and the climbing societal value of green technologies combine to make these systems cost effective. If these systems can be combined with locally networked energy storage technology, the resulting energy capture can be maximized and overall system efficiency significantly increased. Technologies that support this concept include:

- Standardized information models and communication protocols to facilitate sharing operational status, capacity, demand patterns, and other parameters between PV systems, energy storage systems (including dedicated storage systems as well as PHEV), and distributed computing technology capable of optimizing the efficiency of the overall system.

- Distributed control, computation, and optimization algorithms to support the above.

Enhanced residential and distribution system protection technologies, operating, and design practices that facilitate multi-directional energy flows on the distribution system and within the home.

8.3.2. Widespread Energy Storage Demonstrations, and Integration With System Operation

Many different energy storage technologies are available for integration with system operation to support higher penetration levels of renewables, demand reduction, etc. The biggest need for these technologies is to move them towards maturity through more widespread application (demonstrations) and to provide the information models and tools for integrating the storage solutions as part of system operations at both the local and system levels.

8.4. Grid Operations and Control

8.4.1. Transmission Operations Applications for the Smart Grid

There are both short term and long term development needs for transmission applications that will support improved awareness of conditions on the grid and better integration of distributed resources, including demand response.

Some short term needs include:

- Wide area measurement and control applications that enable a wider view of system operations.
- System protection applications that account for major penetration of distributed energy resources (DER), storage and demand response (DR).
- Phasor measurement infrastructure development and applications.
- Information integration using CIM for simpler implementation of advanced applications.
- Planning tools expansion to include DER and DR as a resource.

This is consistent with developments currently under way that include continued studies of higher levels of renewable integration, operational tools to support the integration, new regulatory rules and tariff changes, market product assessments, and changes to generator interconnection and planning processes.

Longer term needs include:

- Develop applications that enable managed islands and microgrid operations integrated with DER and DR.

The following figure from California ISO illustrates the needs for effective integration of renewables with the overall grid operation:

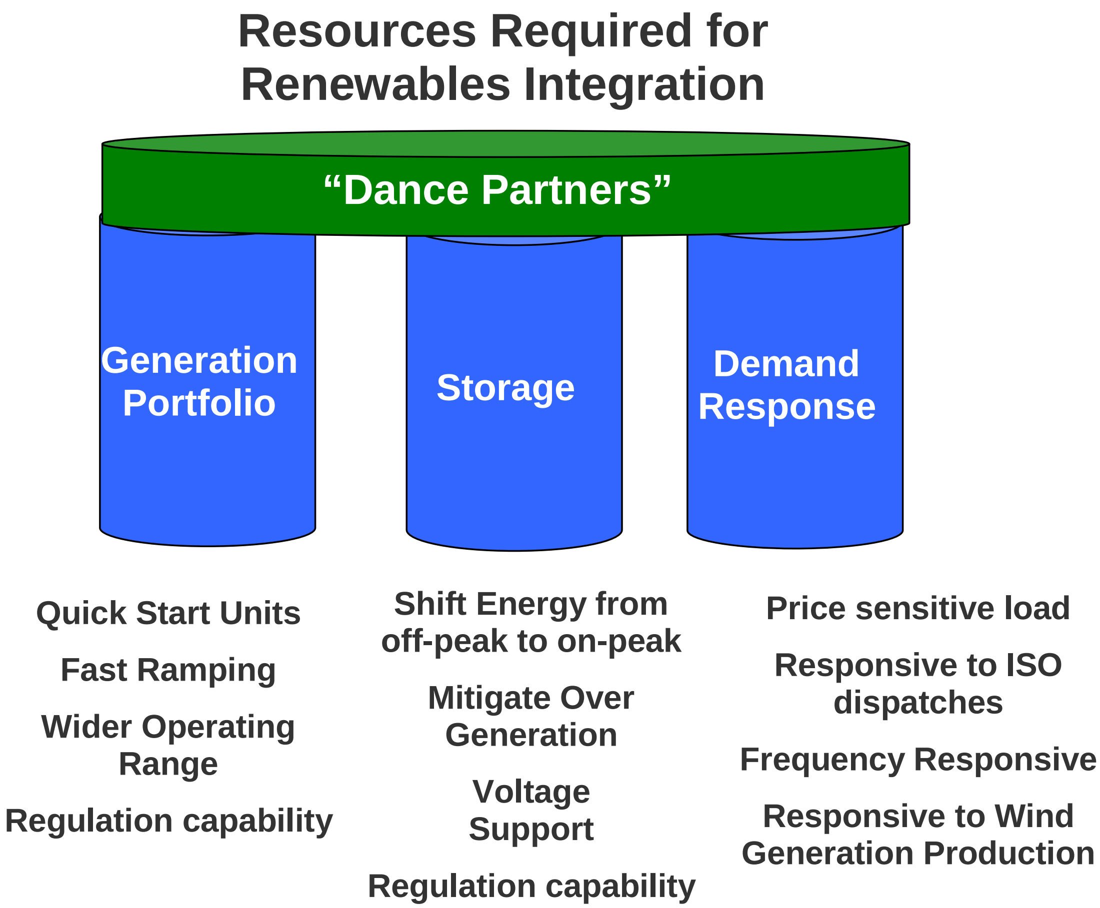

Figure 27: Summary of requirements for integrating renewables with grid operation (courtesy of California ISO).

8.4.2. Distribution Operations Applications for the Smart Grid

The distribution operations stand to benefit the most from development of the smart grid. There are tremendous opportunities to improve reliability, integrate distributed resources, improve efficiency, manage assets better, etc.

In order to achieve the benefits of these applications, substantial development is required and there is a real opportunity for public funding to provide a base for this development.

Some short term needs include:

- Develop advanced distribution automation applications requirements that lead to device and object models based on IEC 61850.
- Integration of device information models with CIM for systems level integration.

- Develop advanced distribution automation applications that take into account significant penetration of DER, storage and demand response on the system.

Longer term development needs include:

- New distribution simulation approaches that take into account full integration of AMI information (both planning and real time applications).
- Develop applications that use this infrastructure to optimize losses, voltage control, integration of renewables and DR.
- Develop applications that more effectively coordinate overall system protection with generation protection.
- Develop application requirements for managed islanding.

8.4.3. Foundation for Distribution System Simulation Tools

The development of the smart grid communication infrastructure and advanced metering provides the opportunity for parallel advancements in the simulation of distribution systems. These simulation tools will have both real time and planning applications (working off of common information systems).

- Fault location.
- Outage management.
- Optimize efficiency, voltage control, VAR management, power quality.
- Demand control at the distribution level (optimize investment).
- Support system reconfiguration – reliability improvement.
- Asset management support (accurate loading information, operations information).
- Support integration of distributed resources.

Research effort s can help develop the information models and open source tools to make these new simulation approaches possible. This research would coordinate with other efforts like GridLab-D at the national level.

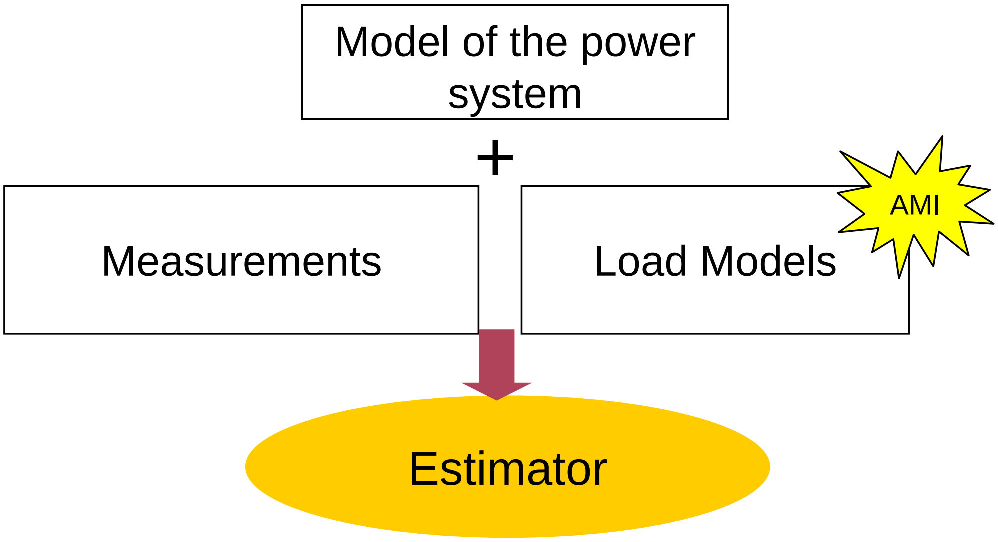

Figure 28: Concept of advanced distribution system simulation approaches that incorporate detailed load models and distribution representations to improve distribution system performance.

8.4.4. Integration of Managed Islanding

This term implies major changes in the way substations, distribution systems, and residential electric systems are designed, operated, and protected. It involves managing a very complex system of systems integration problem involving large numbers of devices and requiring continuous optimization and control among several object functions whose priorities change dynamically. Technologies that support this concept include:

- Dynamic optimization algorithms that can rapidly shift between optimizing for energy efficiency, environmental impact, and load profile shaping and safety during abnormal operating conditions.
- Immunizing energy production and storage power electronic interfaces (e.g. PV controllers) from power quality disturbances (e.g. voltage sags) that knock them offline when they are most needed to transition into islanded operation.
- Power electronic devices that can island / isolate portions of the system at distribution and residential voltage levels without the need for mechanical switching.

Dynamic system protection that utilizes communications and advanced sensing to tract system topology and capacity in real-time thus enabling fast clearing of faults in dynamic environments (i.e. shifting energy flow directions, changing short circuit capacities, changing availability of storage and energy production capacity).

Asset and Capital Efficiency

8.4.5. Equipment Diagnostics and Utility Asset Management Applications

This will be one of the most important application areas of the smart grid in the future.

Information integration needs to incorporate information from advanced sensors and equipment diagnostics applications with overall information systems research should facilitate development of these advanced applications by defining the standard information interfaces.

There is a need for definition of an advanced monitoring infrastructure that integrates data from many different sources for advanced application development.

Research should demonstrate and evaluate example applications that use advanced sensor and monitoring information to improve management of infrastructure.

Important applications that need to be developed, supported with information models, and demonstrated:

- Equipment diagnostics and asset management.
- Fault location and analysis.
- Detection of high impedance faults (fire risk).
- Protection system performance analysis (for example, with distributed resources).
- Improved efficiency, voltage management.

8.4.6. Advanced Sensors

In general, sensors are best coupled with specific applications in mind. However, as multiple applications are being run simultaneously that have similar data needs, the ability to tap into a common sensor network on a distribution system and neighborhood begins to have high value. These applications might include substation asset management, distribution feeder asset management, distribution feeder load/distributed generation balance awareness, advanced distribution automation, microgrid management. Technologies that support this concept include:

- Low cost sensors that can be easily applied (for example, glued onto a disconnect, clamped onto a line with a hot stick, stuck on a wall or pole) that embed standardized RF mesh technology that create robust ad-hoc sensor networks and utilize other advanced technologies such as parasitic powering and non-contact sensing.
- Low cost sensor network nodes and node managers that augment a sensor network by enhancing range and providing autonomous, distributed, or centralized network monitoring and management.

8.4.7. Component Research for Smart Grid Interfaces

Component research can take the form of advanced equipment diagnostics and asset management as well as research into the components themselves.

- Advanced diagnostics for lifetime assessment of components.
- Advanced diagnostics to detect incipient failures.

Important components that become part of the smart grid:

- Superconducting cables and systems.
- Solid state fault current limiters.
- Power electronics for power system – SVC, FACTS, HVDC.
- Intelligent universal transformers.
- Solid-state switchgears (distribution and microgrids).
- Advanced monitoring, including phasor measurement units.

8.4.8. Smart Grid Planning Tools

The current fleet of system planning tools (for example, short circuit, load flow, feeder design, capacity planning, and protection design) are woefully inadequate to design smart grid systems incorporating the operating concepts and technologies described above. All of these tools must be augmented or replaced entirely with tools that can take smart grid design into account.

8.5. Customer Systems

8.5.1. Price, load control, and environmental control signals to residential energy consuming devices

Consumer devices are generally commodity devices that have low profit margins. Manufacturers therefore are reluctant to implement automation unless there is a clear value story and/or consumer demand. This includes thermostats, window mount air conditioners, water heaters, washers, and dryers. Developing very low cost technologies that can facilitate delivering pricing information to these devices in a very low cost, ubiquitous, and interoperable manner would have significant benefit and result in an exponential increase in deployment. Technologies that support this category include:

- Low cost, wireless transceivers supporting common information models that are easily embedded in commodity products without interfering with their core design or function.
- Low cost, distributed computing technology that can manage a fleet of commodity devices to optimize system performance based on a common objective function (for example, minimize overall energy use, shift peak energy use, minimize peak energy use, minimize one or more environmental metrics such as CO_2, SO, NO_2).

It is possible that the system architecture will point towards a gateway that is the main interface to the customer facility for managing the response to price signals but this gateway will still have to talk to individual smart appliances to achieve the control.

8.5.2. Customer Communications and Metering Applications Development

Advanced metering infrastructure will support a plethora of applications that can benefit the customer, grid operations (like advanced distribution operations applications described above), and distributed resource integration. There are fundamental development needs to support these applications (some of these were mentioned above but are reinforced here):

- Identify/define a consistent set of systems management policies applicable to customer communications.
- Develop a common set of requirements for customer communications applications, network and systems management and security.
- Develop designs (reference designs) for customer communication internetworking gateways and master stations for supporting DR and energy efficiency.
- Develop a common application level language for customer communications.
    - Utility/ESP to customer first.
    - In-building second.

8.5.3. Infrastructure for Integrating Demand Response and Distributed Resources

There has been substantial work on the integration of demand response with system operations, such as the complete architecture developed by LBNL for the Auto-DR system (see figure below). This work provides an excellent foundation, including important aspects of information mode requirements. However, substantial research is needed for the more general case of widespread participation of consumer participation in the market through price signals and other mechanisms. A concept of a “distributed resource availability and control system” has been proposed. A significant amount of research is needed on both the architecture and the functionality of such a system. This will then provide the foundation for actual implementations in California.

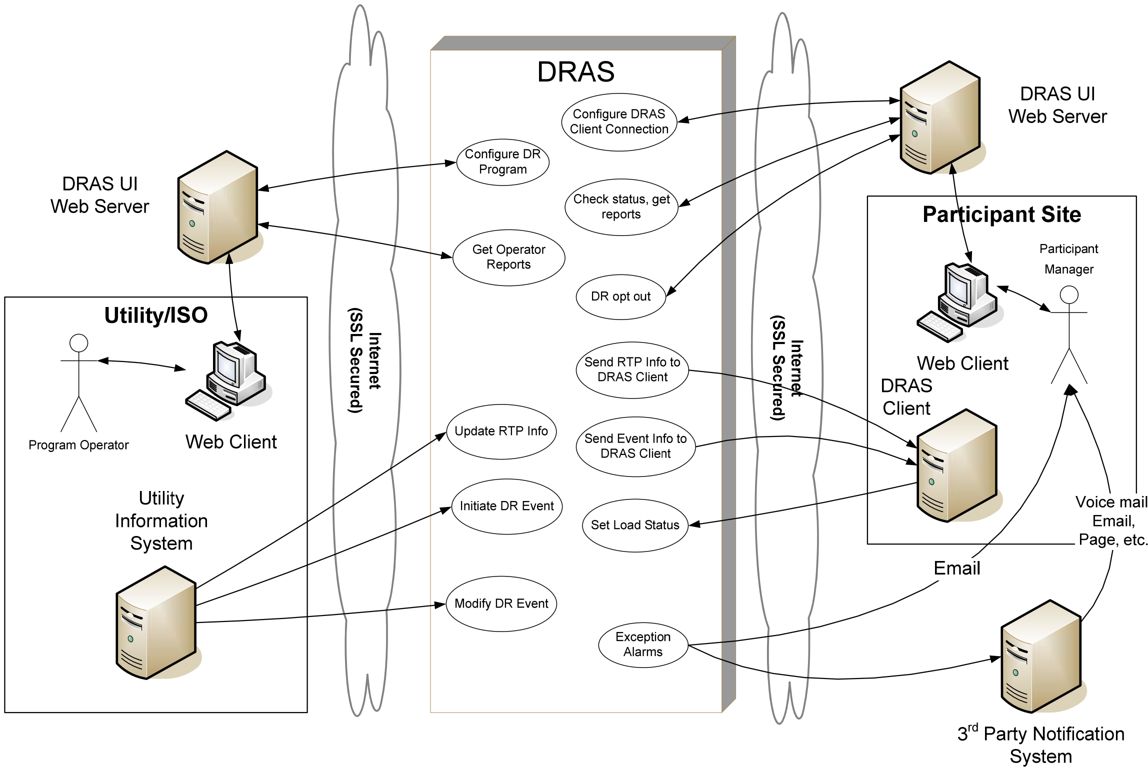

Figure 29: Demand Response Automation Server Event Architecture (LBNL Auto-DR System)

Advanced metering infrastructure will support a plethora of applications that can benefit the customer, grid operations (like advanced distribution operations applications described above), and distributed resource integration. There are fundamental development needs to support

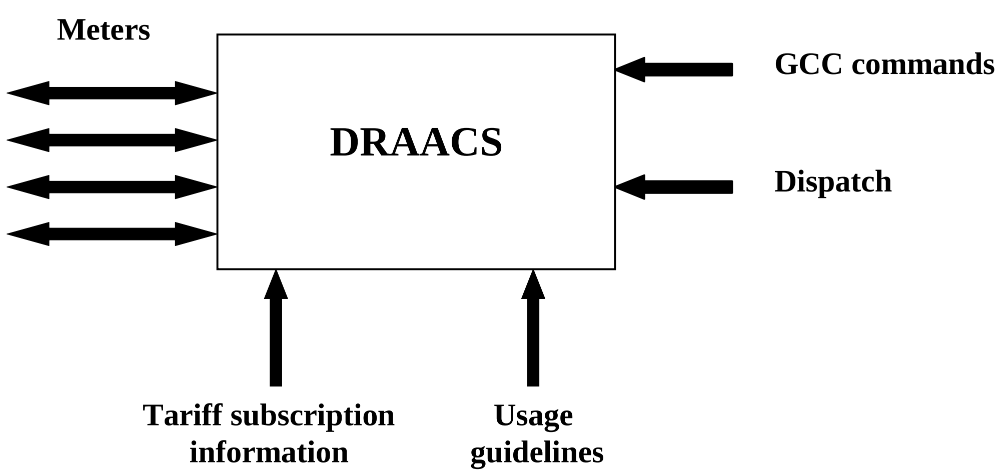

Figure 30: Once concept for a distributed resource availability and control system

8.5.4. Modeling and Implementing Customer Response Models in the Demand Response Infrastructure

This will be a key research area ongoing.

Significant work has been done but customer response will change as the technology improves (less involvement of the customer with real time decision making).

Need to understand in order to integrate demand response and customer systems with overall operation of the system at the ISO level and for planning future system expansion (Reliability Issue).

8.6. Workforce Effectiveness

8.6.1. Smart Grid Design Guidelines and Standards

As smart grid operational concepts evolve, technologies permit, and tools become available, the classic distribution engineer's shelf of distribution design and construction practices and standards will quickly become obsolete and be relegated to a museum of 20th electric power engineering. In order for the smart grid to evolve, achieve widespread implementation, and provide consistent and ongoing value, a complete new set of engineering best practices and standards must be developed to replace what we have now. Needs for such standards have already been evidenced. In early attempts by large developers to create sustainable communities that integrate renewable distributed generation, microgrids, and dynamic energy efficiency into their designs, roadblocks have quickly appeared due to the lack of standards to support the design and installation of the underlying electrical infrastructure necessary to create such a community. In many cases, the concepts are directly prohibited by existing outdated distribution design and construction standards and practices.

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10.0 Glossary

The following table lists acronyms found in the report and provides some expanded definitions.

AB	ASSEMBLY BILL. A STATE LAW PASSED BY THE LEGISLATURE.
ABB	ASEA BROWN BOVERI. A GLOBAL COMPANY PROVIDING POWER AND AUTOMATION TECHNOLOGIES TO UTILITY AND INDUSTRIAL CUSTOMERS.
AC	ALTERNATING CURRENT. AN ELECTRICAL CURRENT WHOSE MAGNITUDE AND DIRECTION VARY CYCLICALLY, AS IN A SINE WAVE OR OTHER WAVEFORM, FOR MORE EFFICIENT TRANSMISSION OF ELECTRIC ENERGY.
ACE	AREA CONTROL ERROR
ACSE	ASSOCIATION CONTROL SERVICE ELEMENT. AN OSI METHOD FOR ESTABLISHING A CALL BETWEEN TWO APPLICATION PROGRAMS AND PERFORMING IDENTIFY AND CONTEXT CHECKS OF APPLICATION ENTITIES.
AEIC	ASSOCIATION OF EDISON ILLUMINATING COMPANIES. AN ELECTRIC POWER INDUSTRY ASSOCIATION THAT ENCOURAGES RESEARCH AND TECHNICAL INFORMATION EXCHANGE THROUGH COMMITTEES STAFFED WITH EXPERTS FROM MEMBER COMPANIES.
AGC	AUTOMATIC GENERATION CONTROL
AHAM	ASSOCIATION OF HOME APPLIANCE MANUFACTURERS. A TRADE ASSOCIATION BASED IN THE U.S. CONSISTING OF THE HOME APPLIANCE MANUFACTURERS.
AMI	ADVANCED METERING INFRASTRUCTURE
ANSI	AMERICAN NATIONAL STANDARDS INSTITUTE
ASHRAE	AMERICAN SOCIETY OF HEATING, REFRIGERATION AND AIR CONDITIONING ENGINEERS. AN INTERNATIONAL ORGANIZATION WITH THE "MISSION OF ADVANCING HEATING, VENTILATION, AIR CONDITIONING AND REFRIGERATION TO SERVE HUMANITY AND PROMOTE A SUSTAINABLE WORLD THROUGH RESEARCH, STANDARDS WRITING, PUBLISHING AND CONTINUING EDUCATION." (SOURCE: HTTP://WWW.ASHRAE.ORG/ABOUTUS)
ASN.1	ABSTRACT SYNTAX NOTATION ONE. "A FORMAL LANGUAGE FOR ABSTRACTLY DESCRIBING MESSAGES TO BE EXCHANGED AMONG AN EXTENSIVE RANGE OF APPLICATIONS INVOLVING THE INTERNET, INTELLIGENT NETWORK, CELLULAR PHONES,

	GROUND-TO-AIR COMMUNICATIONS, ELECTRONIC COMMERCE, SECURE ELECTRONIC SERVICES, INTERACTIVE TELEVISION, INTELLIGENT TRANSPORTATION SYSTEMS, VOICE OVER IP AND OTHERS." (SOURCE: HTTP://ASN1.ELIBEL.TM.FR)
AUTODR	AUTOMATED DEMAND RESPONSE. DEMAND RESPONSE ENABLED THROUGH AUTOMATION AND COMMUNICATIONS WITH CUSTOMER END-USE EQUIPMENT.
CAES	COMPRESSED AIR ENERGY STORAGE
CAIDI	CUSTOMER AVERAGE INTERRUPTION DURATION INDEX. A RELIABILITY INDEX COMMONLY USED IN THE ELECTRIC POWER INDUSTRY INDICATING THE AVERAGE OUTAGE DURATION EXPERIENCED BY CUSTOMERS, OR AVERAGE RESTORATION TIME.
CAISO	CALIFORNIA INDEPENDENT SYSTEM OPERATOR. THE REGIONAL TRANSMISSION AND MARKET SYSTEM OPERATOR OF THE STATE OF CALIFORNIA.
CARB	CALIFORNIA AIR RESOURCES BOARD. AN ORGANIZATION WITH THE OBJECTIVE "TO PROMOTE AND PROTECT PUBLIC HEALTH, WELFARE AND ECOLOGICAL RESOURCES THROUGH THE EFFECTIVE AND EFFICIENT REDUCTION OF AIR POLLUTANTS WHILE RECOGNIZING AND CONSIDERING THE EFFECTS ON THE ECONOMY OF THE STATE." (SOURCE: HTTP://WWW.ARB.CA.GOV/HTML/MISSION.HTM)
CDC	COMMON DATA CLASSES
CEATI	CEATI INTERNATIONAL IS AN ASSOCIATION THAT "BRINGS ELECTRICAL UTILITY INDUSTRY PROFESSIONALS TOGETHER, THROUGH FOCUSED INTEREST GROUPS AND COLLABORATIVE PROJECTS, TO IDENTIFY AND ADDRESS TECHNICAL ISSUES THAT ARE CRITICAL TO THEIR ORGANIZATIONS." (SOURCE: HTTP://WWW.CEATECH.CA)
CEC	CALIFORNIA ENERGY COMMISSION
CHP	COMBINED HEAT AND POWER. REFERS TO A SYSTEM IN WHICH HEAT AND ELECTRICITY ARE GENERATED SIMULTANEOUSLY, WITH THE THERMAL ENERGY USED FOR END-USE REQUIREMENTS SUCH AS WATER HEATING, PROCESS HEATING, OR COOLING.
CIM	COMMON INFORMATION MODEL. A STANDARD DEVELOPED IN THE ELECTRIC POWER INDUSTRY THAT HAS BEEN OFFICIALLY ADOPTED BY THE IEC AND IS AIMED AT ENABLING

	APPLICATION SOFTWARE TO EXCHANGE INFORMATION ABOUT THE CONFIGURATION AND STATUS OF AN ELECTRICAL NETWORK.
CPP	CRITICAL PEAK PRICING. A VARIANT OF TIME-BASED ELECTRICITY RATES. THE CRITICAL PEAK PERIOD IS CHARACTERIZED BY A SIGNIFICANTLY HIGHER PRICE THAT IS INVOKED FOR ONLY A FEW HOURS OR DAYS A YEAR DURING THE MOST EXTREME PEAK DEMAND PERIODS.
CPUC	CALIFORNIA PUBLIC UTILITIES COMMISSION
DER	DISTRIBUTED ENERGY RESOURCES. ELECTRIC ENERGY SOURCES DISPERSED IN NATURE THAT TYPICALLY INCLUDE DISTRIBUTED GENERATION AND STORAGE AND MAY BE INTERCONNECTED WITH THE POWER SYSTEM AT TRANSMISSION OR DISTRIBUTION LEVEL VOLTAGES.
DG	DISTRIBUTED GENERATION. ACTIVE ENERGY SOURCES DISPERSED IN NATURE, SUCH AS A MICROTURBINE, DIESEL BACKUP GENERATOR, OR OTHER STANDBY GENERATION THAT MAY BE INTERCONNECTED WITH THE POWER SYSTEM AT TRANSMISSION OR DISTRIBUTION LEVEL VOLTAGES.
DMS	DISTRIBUTION MANAGEMENT SYSTEM. A CONTROL SYSTEM TO MANAGE DISTRIBUTION POWER OPERATIONS THROUGH A COMBINATION OF COMMUNICATIONS WITH FIELD EQUIPMENT AND HIERARCHICAL CONTROL ALGORITHMS.
DOE	U.S. DEPARTMENT OF ENERGY
DR	DEMAND RESPONSE. A DYNAMIC CHANGE IN ELECTRIC LOAD REGARDED AS A VALUABLE SERVICE TO A SYSTEM OPERATOR, SUCH AS CUSTOMER RESPONSE TO PRICES, NOTIFICATIONS, CONTROLS, OR OTHER SIGNALS DESIGNED TO COORDINATE CHANGES IN ELECTRIC POWER DEMAND.
EMS	ENERGY MANAGEMENT SYSTEMS. 1) A CENTRALIZED COMMUNICATION AND CONTROL SYSTEM FOR THE MANAGEMENT OF POWER DELIVERY OPERATIONS OR 2) A SYSTEM FOR MONITORING AND CONTROLLING END-USE EQUIPMENT WITHIN A BUILDING.
EPRI	ELECTRIC POWER RESEARCH INSTITUTE.
ETO	EMITTER TURN-OFF THYRISTOR
FACTS	FLEXIBLE AC TRANSMISSION SYSTEMS. A POWER ELECTRONIC BASED SYSTEM AND OTHER STATIC EQUIPMENT THAT PROVIDE CONTROL OF ONE OR MORE AC TRANSMISSION

	SYSTEM PARAMETERS TO ENHANCE CONTROLLABILITY AND INCREASE POWER TRANSFER CAPABILITY.
FDIS	FIRST DRAFT INTERNATIONAL STANDARD
FESS	FLYWHEEL ENERGY STORAGE SYSTEMS
GHG	GREEN HOUSE GAS. A GAS WHEN IN HIGH CONCENTRATIONS IN THE ATMOSPHERE CONTRIBUTES TO THE GREENHOUSE EFFECT AND GLOBAL WARMING.
GTO	GATE TURN-OFF THYRISTOR. A TYPE OF THYRISTOR WITH FULLY CONTROLLABLE SWITCHES WHICH CAN BE TURNED ON AND OFF BY THE GATE LEAD.
HVDC	HIGH VOLTAGE DIRECT CURRENT
IEC	THE INTERNATIONAL ELECTRO-TECHNICAL COMMISSION. THIS ORGANIZATION PREPARES AND PUBLISHES INTERNATIONAL STANDARDS FOR ALL ELECTRICAL, ELECTRONIC AND RELATED TECHNOLOGIES.
IED	INTELLIGENT ELECTRONIC DEVICES
IEEE	INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS. A PROFESSIONAL ENGINEERING ASSOCIATION FOR ELECTRICAL, ELECTRONIC, AND OTHER ENGINEERS.
IEPR	INTEGRATED ENERGY POLICY REPORT. A 2007 REPORT THAT PROVIDES AN INTEGRATED ASSESSMENT OF THE MAJOR ENERGY TRENDS AND ISSUES FACING THE CALIFORNIA'S ELECTRICITY, NATURAL GAS, AND TRANSPORTATION FUEL SECTORS, AND PROVIDES GUIDANCE ON STATE ENERGY POLICY.
IETF	INTERNET ENGINEERING TASK FORCE (IETF). AN OPEN INTERNATIONAL COMMUNITY OF NETWORK DESIGNERS, OPERATORS, VENDORS, AND RESEARCHERS THAT CONDUCTS TECHNICAL WORK THROUGH WORKING GROUPS TO ADDRESS THE EVOLUTION OF THE INTERNET ARCHITECTURE AND THE SMOOTH OPERATION OF THE INTERNET.
IGBT	INTEGRATED GATE BIPOLAR TRANSISTOR. A THREE-TERMINAL POWER SEMICONDUCTOR DEVICE WITH HIGH EFFICIENCY AND FAST SWITCHING CAPABILITIES.
IP	INTERNET PROTOCOL
IPV4	INTERNET PROTOCOL VERSION 4
IPV6	INTERNET PROTOCOL VERSION 6
IS	INTERCONNECTION SYSTEM

ISO	INDEPENDENT SYSTEM OPERATOR. A REGIONAL SYSTEM OPERATOR RESPONSIBLE FOR THE RELIABLE OPERATION OF THE BULK ELECTRIC TRANSMISSION SYSTEM IN ITS FERC-APPROVED GEOGRAPHIC TERRITORY.
KW	KILOWATT. A UNIT OF MEASUREMENT OF POWER EQUAL TO 1000 WATTS.
LBNL	LAWRENCE BERKELEY NATIONAL LABS. A NATIONAL LAB THAT "CONDUCTS UNCLASSIFIED RESEARCH ACROSS A WIDE RANGE OF SCIENTIFIC DISCIPLINES WITH KEY EFFORTS IN FUNDAMENTAL STUDIES OF THE UNIVERSE; QUANTITATIVE BIOLOGY; NANOSCIENCE; NEW ENERGY SYSTEMS AND ENVIRONMENTAL SOLUTIONS; AND THE USE OF INTEGRATED COMPUTING AS A TOOL FOR DISCOVERY." (SOURCE: HTTP://WWW.LBL.GOV/LBL-PID/LBL-OVERVIEW.HTML)
MRTU	MARKET REDESIGN TECHNOLOGY UPGRADE
MVA	MEGAVOLT AMPERE
MW	MEGAWATT
NAS	SODIUM SULFUR BATTERY
NETL	NATIONAL ENERGY TECHNOLOGY LABORATORY. A NATIONAL LABORATORY THAT "IMPLEMENTS RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAMS TO RESOLVE THE ENVIRONMENTAL, SUPPLY, AND RELIABILITY CONSTRAINTS OF PRODUCING AND USING FOSSIL RESOURCES." (SOURCE: HTTP://WWW.NETL.DOE.GOV/ABOUT/MISSION.HTML)
NIST	NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY. A FEDERAL INSTITUTE WITH THE OBJECTIVE OF PROMOTING "U.S. INNOVATION AND INDUSTRIAL COMPETITIVENESS BY ADVANCING MEASUREMENT SCIENCE, STANDARDS, AND TECHNOLOGY IN WAYS THAT ENHANCE ECONOMIC SECURITY AND IMPROVE OUR QUALITY OF LIFE." (SOURCE: HTTP://WWW.NIST.GOV/PUBLIC_AFFAIRS/NIST_MISSION.HTM)
NMS	NETWORK MANAGEMENT SYSTEM. A SYSTEM TO MANAGE COMMUNICATIONS NETWORKS.
NREL	NATIONAL RENEWABLE ENERGY LABORATORY. A NATIONAL LABORATORY WITH RESEARCH AND TECHNOLOGY DEVELOPMENT AREAS THAT "SPAN FROM UNDERSTANDING RENEWABLE RESOURCES FOR ENERGY, TO THE CONVERSION

	OF THESE RESOURCES TO RENEWABLE ELECTRICITY AND FUELS, AND ULTIMATELY TO THE USE OF RENEWABLE ELECTRICITY AND FUELS IN HOMES, COMMERCIAL BUILDINGS, AND VEHICLES.” (SOURCE: HTTP://WWW.NREL.GOV/OVERVIEW/)
OE	OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY. AN OFFICE OF THE U.S. DEPARTMENT OF ENERGY WITH THE OBJECTIVE OF ENSURING THE NATION’S “ENERGY DELIVERY SYSTEM IS SECURE, RESILIENT AND RELIABLE.” (SOURCE: HTTP://WWW.OE.ENERGY.GOV/ABOUT.HTM)
OSI	OPEN SYSTEMS INTERCONNECTION. AN INITIATIVE THAT DEVELOPED THE OSI BASIC REFERENCE MODEL.
OSI BRM	OPEN SYSTEMS INTERCONNECTION BASIC REFERENCE MODEL. ALSO KNOWN AS THE OSI SEVEN LAYER MODEL, THIS IS AN ABSTRACT DESCRIPTION FOR COMMUNICATIONS AND COMPUTER NETWORK PROTOCOL DESIGN. IT IS COMPRISED OF SEVEN LAYERS WITH EACH LAYER REPRESENTING FUNCTIONS PROVIDING SERVICES TO THE LAYER ABOVE AND RECEIVING SERVICES FROM THE LAYER BELOW.
PCT	PROGRAMMABLE COMMUNICATING THERMOSTAT
PDC	PHASOR DATA CONCENTRATORS
PIER	PUBLIC INTEREST ENERGY RESEARCH
PHEV	PLUG-IN HYBRID ELECTRIC VEHICLES
PMU	PHASOR MEASUREMENT UNIT
PQ	POWER QUALITY. A BROAD TERM USED TO DESCRIBE THE MEASUREMENT OF ELECTRICAL POWER PERFORMANCE. VARIATIONS IN VOLTAGE, FREQUENCY, WAVE SHAPE (HARMONICS) AND OTHER ASPECTS OF POWER MAY MAKE THE POWER DELIVERED TO EQUIPMENT LESS THAN IDEAL, CREATING COMPATIBILITY PROBLEMS. ELECTRONIC EQUIPMENT MAY BE ESPECIALLY SENSITIVE TO POWER QUALITY PROBLEMS.
PV	PHOTOVOLTAIC
RD&D	RESEARCH, DEVELOPMENT, AND DEMONSTRATION
RPS	RENEWABLE PORTFOLIO STANDARD
RTO	REGIONAL TRANSMISSION ORGANIZATION. A REGIONAL SYSTEM OPERATOR RESPONSIBLE FOR THE RELIABLE OPERATION OF THE BULK ELECTRIC TRANSMISSION SYSTEM IN ITS FERC-APPROVED GEOGRAPHIC TERRITORY.

SCADA	SUPERVISORY CONTROL AND DATA ACQUISITION
SCC	STANDARDS COORDINATING COMMITTEE
SDO	STANDARDS DEVELOPMENT ORGANIZATION
SINTEF	THE SINTEF GROUP IS THE LARGEST INDEPENDENT RESEARCH ORGANIZATION IN SCANDINAVIA. IT CONDUCTS RESEARCH AND DEVELOPMENT ON BEHALF OF NORWEGIAN AND OVERSEAS COMPANIES.
SIS	SYSTEM IMPACT STUDY
SVC	STATIC VAR COMPENSATOR. AN ELECTRICAL DEVICE PROVIDING FAST-ACTING REACTIVE POWER COMPENSATION ON HIGH VOLTAGE ELECTRIC TRANSMISSION NETWORKS AS PART OF A FLEXIBLE AC TRANSMISSION SYSTEM.
T&D	TRANSMISSION AND DISTRIBUTION. THE POWER DELIVERY SYSTEM OR BUSINESS AREA.
TC	TECHNICAL COMMITTEE
TCP	TRANSMISSION CONTROL PROTOCOL
UCA	UCA INTERNATIONAL USERS GROUP. A NONPROFIT CORPORATION COMPRISED OF UTILITIES AND SUPPLIERS THAT FUNCTIONS AS AN INTERNATIONAL USERS GROUP AND PROMOTES THE INTEGRATION AND INTEROPERABILITY OF ELECTRIC, GAS, AND WATER UTILITY SYSTEMS THROUGH USE OF INTERNATIONAL STANDARDS-BASED TECHNOLOGY.
UPS	UNIVERSAL POWER SUPPLY
VAR	VOLT-AMPERE REACTIVE. A UNIT OF REACTIVE POWER. FOR A TWO-WIRE CIRCUIT, THE PRODUCT OF THE VOLTAGE TIMES THE CURRENT TIMES THE SINE OF THE ANGULAR PHASE DIFFERENCE BY WHICH THE VOLTAGE LEADS OR LAGS THE CURRENT. VARS AND WATTS COMBINE IN A QUADRATURE RELATIONSHIP TO FORM VOLT-AMPERES.
VRB	VANADIUM REDOX BATTERY
WAMS	WIDE AREA MEASUREMENT SYSTEM
WECC	WESTERN ELECTRICITY COORDINATING COUNCIL. A REGIONAL FORUM THAT PROMOTES ELECTRIC SERVICE RELIABILITY IN THE WESTERN UNITED STATES AND WESTERN CANADA.
WG	WORKING GROUP. A SUBGROUP OF A LARGER COMMUNITY THAT TYPICALLY CONDUCTS TECHNICAL WORK SURROUNDING A GIVEN TOPIC.
XML	EXTENSIBLE MARKUP LANGUAGE. A SPECIFICATION FOR

	CREATING CUSTOM MARKUP LANGUAGES TO FACILITATE THE SHARING OF STRUCTURED DATA ACROSS DISPARATE INFORMATION SYSTEMS OVER THE INTERNET.
ZNBR	ZINC BROMINE BATTERY

Appendix A

1st Meeting (Initial Presentation to Energy Commission Staff on February 28, 2008 in Sacramento, California)

(1) The smart grid is not the issue by itself; it should support the accomplishment of the target defined by California's energy policy.

The requirements are very important compared to the technologies which purpose is only to provide an answer to given specifications.

The smart grid will be an integration of different sub-smart grid components (transmission, distribution, and end use) with specific interactions to deal with depending on the considered interface:

- End use: buildings and smart grid.
- Smart or zero-energy communities (bill optimization) and smart grid.
- Bulk power (more energy for more usage) and smart grid.

(2) PHEV will connect the vehicle to the home and the utility will be the back-up. In this scenario lot of interaction will be needed between the PHEV and the smart grid (hours and time of charge).

PHEV is an interesting development but the infrastructure to support its deployment will not be needed in a three to five year time frame and the changes induced will not impact on a short term the structure of the network.

One emerging technology area could be refrigeration: how much refrigeration improvement and control can impact the efficiency and the greenhouse gas footprint.

(3) The use of the power grid as a communication network was not possible because of the competition it will have induced with telecommunication companies but the idea could remain valuable for providing a communication media for the utilities needs. The smart grid should provide a good distribution of communication features for the benefit of the end user and the power supplier.

There is a need to develop a robust infrastructure to handle the changes that are and will occur on the grid.

The communication infrastructure can be compared to the human nervous system: there is a need for a common basis for operation (like TCP/IP for internet).

(4) The end users want a smart house not just for electricity. The models need to be expanded in order to share the same communication media between different usages.

There is a trend for the customer to go off the grid (self generation capabilities, PHEV) but what is the economical development associated?

The smart grid could provide real time data to consumers to let them know their carbon footprint and encourage them to reduce it for instance through a competitive neighbor carbon footprint comparison program. It could also identify carbon footprint versus GHG emission reduction or versus energy efficiency at a local level.

(6) Advanced metering infrastructure deployment has a high priority in providing support to the achievement California's energy policy targets because it enables demand response.

Standardization is also very important to help enhance the maturity of the technologies that will support AMI or DER integration. There is a need to define at which level the standards should be defined (California, USA, international) and to coordinate with IEC.

Security is an issue that needs to be constantly managed and strengthened (redundancy, traceability, damages analysis, recovery options) to enable the end user privacy protection

An assessment on the way DER integration will change the grid needs to be done because solar PV can be installed on every roof. Forecasting is very important because renewable will drive the grid because out of the control of the utility operation staff. More accurate forecasts will enable the reliability of the grid and of the equipments. More intelligence is needed on the way renewable are operated and managed

Appendix B

2nd Meeting (Presentation to California ISO on March 11, 2008 in Folsom, California)

(1) The smart grid is defined with attributes and not with behaviors (like a product) and the associated risk is to lose the essence of it. Differences also exist between the smart grid characteristics and business objectives: the ultimate goal should be to improve the customer service. For instance setting a goal of 2 hours for restoring the complete bulk system and assessing the technologies that will enable its realization is another way to address the question.

The grid will become smart thanks to the information not the technology. A well informed infrastructure means a well informed system: transmission (PMU, WAMS), distribution and end use (when to use the loads). The concept behind the Smart Grid is to get more information and to make a better use of it.

(2) PMU and WAMS will enable the smart grid.

(3) Architecture is a key issue (on the contrary of technologies) to provide the right information to support decision for grid management.

The challenges with the architecture requirements are to make an open system with full security and a performing system at low cost.

The more control options the California ISO can have (centralized systems) the better it will be for the entire system, but the objective of the smart grid is not to develop a system to control directly the loads or resources.

(4) The smart grid should be able to provide support for the resource adequacy by giving quick information to respond more accurately with the well adapted means to any issue for the benefit of the whole system.

(5) Energy Commission should write a *Smart Grid 101* with a California ISO review for legislation issues in order to educate other players (information coming from the smart grid can help the California ISO to improve its control).

Energy Commission should organize a meeting (1 to 1.5 hours) to present to the commissioners what the smart grid is and help them understand that implementing this vision is not as easy as vendors can tell.

(6) Regarding distributed generation, there are differences between the people that have the control on these equipment and those who are maintaining them and this might impact the efficient operation of such systems in correlation with the smart grid.

For renewable, the first step is to make the business case, then address the question on how to bring more renewable to the grid to meet the RPS targets. One main issue is the correlation with the grid reliability.

Security is a large area of research that needs to be explored further and it has a very high priority in the objective of creating a robust architecture.

Appendix C

3rd Meeting (Open Industry Workshop on March 13, 2008 in Palo Alto, California)

(1) Beyond the smart grid definition there is a need for there is a need for skilled people (workforce effectiveness): this issue impacts any implementation, maintenance of any system.

The system operation area (not necessary grid control or asset management) needs also to be mentioned and addressed in the smart grid definition and status.

There is a missing step relative to the definition of the overall architecture to support the smart grid: the "big picture" needs to be defined.

(2) Some improvements are needed on the dynamic models used for wind turbines integration: today there a models for each type of turbine but tomorrow more detailed models should be made available thanks to the PMU measurements.

Storage options for California are NaS batteries, flywheels, flow batteries and compressed air storage. Experimentations of such systems are on track.

The automated demand response is a very promising technology to help achieve the targets. Such systems can work on real time (client – server architecture) and could be implemented with real time pricing (no pilots for such tariffs are planned in California). The question of the integration with the home automation needs to be addressed (compatibility with PCT).

The management of the quantity of data that will be made available by the smart grid is an important issue which needs to be addressed.

The emphasis for smart grid is demand side management but it should also address transmission systems (FACTS). There is a need to expand the thinking on control systems and research on wide area measurement systems.

The research on power components need also to be expanded to support control and monitoring because the existing assets are old and they will need to be replaced by smarter ones.

(3) On demand side, the problems will be solved because there are many players addressing the issue but on the transmission side, the scope of the IT infrastructure is now broad and there is a need to define clearly the architecture. There is also a need to work on a cross cutting basis to identify and provide margins at different levels.

A new group was set up in IEEE (Intelligent Grid sub-committee) with the objective of providing use cases and requirements repository for smart grid technology. This group will become a standard coordination committee soon and will address the development of interconnection standards.

The common information model (CIM) should not be too prescriptive because it may create some difficulties regarding the flexibility of the model. Multi-speak is more mature and widespread in the United States and it should be acknowledged that CIM needs to be integrated with it.

(4) Smart grids are important to minimize the impact of (1) blackouts (history of blackouts in California) (2) wood fires due to power lines, and to speed up (3) the development of smart grid including the customers and solar energy program to meet the state's Assembly Bill 32 (AB 32) goals: metering is not enough to achieve these goals: the system needs to be Smart Grids ready. More generally there is a need for the industry to move faster on technology improvements to enable meeting the AB 32 goals.

Regarding the synergies between gas and electricity, an integrated approach is needed and will be developed.

(5) A different approach as technology assessment and evaluation emerges: (1) Pick up a date in the future to define when the smart grid will be there (2020) and where we are from now (use cases needs to be done) (2) define demonstrations, key pieces that need to be emphasized to develop the smart grid (1 to 3 years).

(6) The Energy Commission should look at opportunities for integrating legacy systems: addressing the issues and providing some transitioning path. This issue is under consideration and Energy Commission has an ongoing project on legacy interoperability.

Regarding AMI deployments, the objective is to figure out what capabilities are available now and will be in the future. The PIER perspective is to integrate new features as smoothly as possible and find a consensus. No theoretical specification on the remote upgrade of the firmware of sensors exists yet and there is a need to define a standard interface to allow this feature. All three California IOUs AMI projects include remote firmware upgrade and two-way communication.

Security is an important issue: UCA International AMI-SEC and Utility-SEC working groups are focusing on security issues and this might be a good opportunity for collaboration. DOE has already done some extensive work on this topic and a coordination effort is needed. A MOU was signed between EPRI and DOE for research coordination. NIST also has done substantial work in security.

Appendix D

4th Meeting (Presentation to CPUC on March 14, 2008 in San Francisco, CA)

(3) There is a divergence in the activities related to PCT and home area network (HAN) on the communication modules (RDS versus ZigBee). A clarification is needed on that matter between the players involved.

(4) The objective of "foster open access, competition and commercial growth of new and exciting technologies that provide California ratepayer new ways to meet their energy needs while at the same time saving them money" is very important for CPUC and should support areas where government can help.

Consumer can get lots of benefits from the smart grid implementation and these needs to be highlighted and provided to the consumers (marketing people to help).

(5) To start the EPRI contract, some policy perspectives were given by Energy Commission in order to come to some technology demonstrations. But during the process the need to define a vision for a California Smart Grid raised and the next step will be to build this vision as a consensus between the different players (IOUs, California ISO, CPUC, industry) in a 9 – 12 months timeframe (a specific attention should be made on the efforts going on regarding the amounts invested in AMI deployments). Legislature is looking for help in this area and a partnership with all the involved players could be a good way to provide answers

A workshop on smart grid could be organized to provide guidance and technical issues to move forward. The idea is to enable creativity coming from different organizations but come to a shared system (and not many different ones). CPUC is favorable to this and it might be a good way to facilitate the definition of standards.

The conclusion of the EPRI contract could be the starting point for the launch of this definition process and education process. There are different places to address this matter such as California ISO working groups, white papers or PIER research and the right one need to be defined.

Appendix E

Background on CEC-Sponsored Energy Storage Projects

Energy Commission/DOE PIER Program Energy Storage Initiative

In 2004, the Energy Commission and the DOE entered into a joint initiative agreement to sponsor up to five energy storage demonstration projects that would employ emerging energy storage technologies that did not use lead-acid battery technology. In addition, projects that exclusively demonstrated power quality projects were not allowed to bid into the project. The project was also in search of currently viable advanced energy storage technologies that were near commercialization. As a result of the RFQ, fourteen bids were submitted for consideration, of which only 3 met the criteria for applications of interest and commercial maturity. This result suggests that utility scale energy storage technologies had not yet reached a stage that they were ready to support application on a utility scale as many of them were still in a RD&D status and not ready to become economically viable. The initiative was very successful in identifying the energy storage technologies that existed for utility scale applications. This initiative ultimately led to new far-reaching energy storage projects in California and other parts of the country.

Projects

Three projects were selected by the PIER Program to demonstrate utility scale, commercially viable, advanced energy storage technologies. These projects included:

- A flywheel project for a trackside "muni" railroad application to provide peak shaving to control costs associated with peak- loading and, in addition, to provide storage for regenerative braking power presently wasted in resistive load usage when power could not be returned to the track.
- A super capacitor project to provide stability to a wind powered micro grid in addition to providing ride-through power while generators were being started to support a power failure at a water treatment plant.
- A flow battery project to provide peak power to defer substation upgrade for annually experienced, infrequent substation overload problems.

In Progress

Projects that are in progress and in the planning stage are described below:

- Flywheel Muni Railroad Trackside Project: The Muni Trackside Railroad Project was a 450 kW, 112.5 kWh flywheel system connected to the power rail to recover regenerative braking power as a train arrives at a station, temporarily store the energy in the flywheel, and then return the energy to the power system when the train accelerates out of the station. The importance of this project to the State was great as many electric rail systems are currently in use throughout the state. Although this project was selected to be demonstrated under the Energy Commission/DOE PIER Program Energy Storage Initiative, the bidder withdrew prior to Energy Commission placement of a contract.

- Another project was selected to replace the trackside which involved a 100 kW, 15 minute flywheel that was to demonstrate the viability of a flywheel for area (frequency) regulation. A flywheel can react to the California ISO ACE (area control signal) much faster than conventional area regulation systems; the value of high speed ACE tracking was acknowledged by the California ISO to be at least two times greater value than conventional regulation systems. Consequently a much lower power output would be needed to perform the required regulation function. The project, installed and demonstrated at the PG&E DUIT Facility in San Ramon, concluded successfully with system availability in excess of 90% demonstrated. The system also demonstrated that the ACE signal could be followed and reacted to in less than four seconds, much faster than the regulatory requirement of several minutes.
- Wind Stabilization and Power Interruption Ride-through Project: The wind stabilization and ride-through project consists of a 450 kW, 30 second super capacitor system that provides voltage regulation support for a 950 kW wind turbine system that supports a typical 1.3 MW peak load. The purpose of the wind system is to reduce demand, and consequent demand charges, from the utility. In addition to the stabilization support, the system provides up to 30 seconds of ride-through power during which time back-up generators can be brought on-line to support the water treatment plant critical loads. The primary purpose of this demonstration was to show the functionality of energy storage in wind stabilization applications as well as to demonstrate a multi-functional energy storage system. The project is scheduled for commissioning in the first quarter of 2008 and is schedule to operate in the demonstration mode for a period of 1 year.
- Substation Upgrade Deferral Project: A modular, transportable 2 MW, 2 MWh Zinc-Bromine flow battery was proposed for the purpose of supporting short-term substation overloads that ultimately lead to a transformer replacement and a subsequent substation upgrade. Deferral of a substation upgrade has several promising economic benefits that include the potential avoidance of stranded assets and the economic gains made by deferring the cost investment of the upgrade itself. An additional benefit of using a transportable energy storage device was also to be demonstrated as the ZnBr battery is mounted on a trailer in 500 kW/500 kWh modules that allow the relocation of the system to be performed cost effectively to support multiple summer peaking and winter peaking substation locations. Although the project has been plagued with delays due to design and engineering problems, the value of the technology in the proposed application is such that the PIER Program Office plans to continue to support the

development and deployment of this technology through providing demonstration opportunities beyond the end of the current contract period scheduled to end in 2008.

In Planning

The high value of energy storage in utility scale applications has long been acknowledged by the PIER Program. To support this position, the PIER Program has developed several new programs to demonstrate viable energy storage devices and systems in California. Four energy storage system demonstrations are currently under consideration or in active planning as described in the following paragraphs.

- SMUD Light Rail Trackside Energy Recycle Feasibility Demonstration: The Sacramento light rail system, RT, is currently impacting local customers during high peak load periods by introducing sags and overvoltage transients on the substations that supply the light rail system. SMUD has determined that a substantial substation upgrade will be required to restore stability to the system during peak train activity periods, typically during morning and evening rush hours. A system consisting of a 1 MW, 30 second super capacitor storage device is proposed to provide a permanent solution to the transient problems. A preliminary study has shown the system to be economically viable with a reasonably short payback time and a long life expectancy for the electrical energy storage system. The project is anticipated to be commissioned during 2009 at a site that has been selected in the SMUD grid.
- Telecom peak shaving and uninterruptible power supply system: A telecommunications switching and relay site has been identified in the SMUD grid that continuously pays premium power prices because of demand charges for only rare peak power consumption periods. A 20 kW, 180 kWh Vanadium Redox Flow Battery System is planned for the telecom site and is sponsored by the Energy Commission PIER Program, SMUD, and the Telecom Company. The system will provide up to four hours of peak shaving during peak loading hours while holding five hours of battery power in reserve for UPS support. Because of the reliability issues in lead-acid battery technologies, lead-acid batteries are not viable for this type of usage because of the life-shortening that is experienced when cycling lead-acid batteries as is needed by this telecom application. The value of this technology in reducing peak demands on the utility grid while guaranteeing telecom availability is of high value to the California grid.
- Wind Stabilization and Transmission System Upgrade Deferral: It is well known to California utilities that the wind generation systems in California have a negative effect on stability in their power grids. Storage has long been considered a viable technology that can mitigate the destabilizing effects of wind generation on the grid. Because of the lack of maturity and the un-tried condition of the currently available, large-scale energy storage systems, utilities have been unwilling to try these new emerging technologies in their systems. There is now available multi-megawatt, multi-megawatt hour energy storage systems capable of mitigating the transients commonly seen in wind farm generation systems and, at the same time, provide peak load following to minimize

overloads on long transmission systems. Sodium-Sulfur (NaS) battery systems developed in Japan have proven their cycling and high power capabilities at many sites in Japan. There are also two sites in the United States that are using the NaS technology in their systems, one for transmission upgrade deferral and one for daily peak shaving. PG&E has teamed with the Energy Commission to demonstrate this technology on the California grid. During 2008, an 8 MW/64 MWh system is planned to be purchased and installed by PG&E to demonstrate wind stabilization and transmission system upgrade deferral on their grid.

- Area (frequency) Regulation Ancillary Services: Planning with the California ISO and the Energy Commission is underway to provide a mechanism that will lead to a California ISO contract for 20 MW of area regulation using the flywheel regulation system recently demonstrated at the PG&E DUIT Facility during the Energy Commission /DOE Energy Storage Initiative. It is speculated that 20 MW of flywheel regulation may be able to replace up to 200 MW of conventional regulation systems; it is also accepted by the California ISO that a 20 MW system will displace at least 40 MW of conventional regulation. A 20 MW system has been designed and the hardware developed to perform this ancillary service. It is anticipated that other ancillary services may also be supported by this same system as operational strategies and energy dispatch are better understood in the operational environment. The value of this technology is apparent in that its deployment will free up resources currently committed to regulation activity and allow those resources to be dispatched when needed and not have to be held in reserve for regulation service.

Appendix F

Open Industry Workshop Attendees

Approximately 100 individuals participated in the March 13th public workshop on the California Smart Grid. In-person attendees are listed in Table 1 and webcast participants are listed in Table 2. Presentations from the workshop are included as an attachment to this report.

Table 1: Open Industry Workshop Attendee List

First Name	Last Name	Company
Art	Altman	Electric Power Research Institute (EPRI)
Thomas	Bialek	San Diego Gas & Electric Co.
Michael	Buckner	Panasonic R&D Company of America
Michael	Burns	ITRON, Inc.
Edward	Cazalet	MegaWatt Storage Farms
Seung Tae	Cha	KEPRI
Edward	Chan	Utility Consulting International
Angela	Chuang	Electric Power Research Institute (EPRI)
Jeffrey	Crowe	Electric Power Research Institute (EPRI)
Doug	Dorr	Electric Power Research Institute (EPRI)
Robert	Earle	The Brattle Group
Ashley	Eldredge	Electric Power Research Institute (EPRI)
Robert	Entriken	Electric Power Research Institute (EPRI)
Robert	Ewald	Applied Materials
Frank	Goodman	Electric Power Research Institute (EPRI)
Michael	Gravely	California Energy Commission
Erich	Gunther	EnerNex Corporation
Christina	Haslund	ITRON, Inc.
Joseph	Hughes	Electric Power Research Institute (EPRI)
Erfan	Ibrahim	Electric Power Research Institute (EPRI)
Damian	Inglin	Echelon Corporation
Ali	Ipakchi	KEMA, Inc.
Matthew	Johnson	Gaia Power Technologies
Nam Joon	Jung	KEPRI
Patrick	Koch	Current Technologies
Bill	Kramer	NREL National Renewable Energy Laboratory
Kenneth	Lau	Pacific Gas & Electric Co.
Geoffrey	Lee	NASA
Fiona	Ma	CA State Assembly
Faramarz	Maghsoodlou	KEMA, Inc.
Xavier	Mamo	EDF Electricite de France
Nokhum	Markushevich	Utility Consulting International
Mark	McGranaghan	Electric Power Research Institute (EPRI)
Ben	Mehta	Energy Connect
Jerry	Melcher	EnerNex Corporation
David	Michel	California Energy Commission
Khosrow	Moslehi	ABB Network Management

Paul	Myrda	Electric Power Research Institute (EPRI)
Mary	Piette	Lawrence Berkeley Laboratory
Alonso	Rodriguez	SC Power Systems
George	Rodriguez	Southern California Edison Co.
Chet	Sandberg	Altairnano
Susan	Schoenung	Longitude 122 West, Inc.
Richard	Schomberg	EDF Electricite de France
Omar	Siddiqui	Electric Power Research Institute (EPRI)
William	Steeley	Electric Power Research Institute (EPRI)
Kai	Sun	Electric Power Research Institute (EPRI)
Bernard	Tatera	Pacific Gas & Electric Co.
Daniel	Taub	Applied Materials
Maria	Veloso Koenig	Sacramento Municipal Util. Dist.
Jin	Yi	Applied Materials
James	Zahoudanis	Current Group Technologies
Guorui	Zhang	EPRI

Table 2: Webcast Participant List

Name	Company
Alan Spangler	Blue Sky Modern Energy
Ali Morabbi	LADWP
April Mulqueen	California PUC
Ashley Eldredge	EPRI
Behnam Danai	OATI
Bill Roberts	Economic Sciences Corp
Bill Smith	Promethean Energy Solutions
Boyko Aladjov	Electro Energy Inc.
Brian P. Pugliese	KEMA
Bruce Hamer	R. W. Beck
Charles Smith	California Energy Commission
Christopher Villarreal	California Public Utilities Commission
Daniel Borneo	Sandia
dave Nichols	Rolls-Royce Fuel Cell Systems(US)
David Flamm	SRI International
David Hawkins	California ISO
David Torrey	Advanced Energy Conversion
Dean Mizumura	Hawaiian Electric Company, Inc.
Elsa Olivetti	MIT
Farrokh Rahimi	OATI
Garth Corey	Sandia National Laboratories
James Foster	NYSERDA
Jamie Patterson	Ca Energy Commission
Janos Rajda	SatCon Power Systems
Jerry Casarella	PSEG
Jerry Gibson	AESC
John Del Monaco	PSE&G
Jon VanDonkelaar	Edison Materials Technology Center
Kerry Roach	TVA
Larry Colton	Echelon

lon house	water and energy consulting
Margaret Miller	California ISO
Martin Burns	Hypertek, Inc.
Matthew L. Lazarewicz	Beacon Power Corp.
Mike Gravely	CEC
Paul Wang	E2RG
Peter Evans	New Power Technologies
Sharon	eMeter Corporation
Shih-Min Hsu	Southern Company Transmission
Stephen Frantz	Sacramento Municipal Utility District
Tenley Dalstrom	Energetics
Walt Johnson	California ISO
Walter Levesque	Plexus Research
William Owens	Nilar, Inc.
Witold Bik	S&C Electric