SMART GRID

Roadmap and Architecture

December 2010

California ISO
Your Link to Power

Emerging and maturing technologies will maximize the use of the transmission system, strengthen the safe and reliable operation of the grid, improve overall market efficiency and advance environmental policy objectives.

This is the vision for the California ISO Smart Grid.

The Smart Grid Roadmap and Architecture helps implement this vision by projecting a forward-looking strategy through 2020 from a technology perspective that includes advanced transmission efficiencies as well as the anticipated progress of measurement devices and automation. It offers a technical architecture based on business requirements driven from an understanding of federal and state policies and assumptions concerning the evolution of key technologies and standards. Substantial changes in federal or state policy or unexpected developments in technology, standards and other issues could alter this roadmap significantly. Because of this, the ISO considers the Roadmap a living document that will undergo frequent reviews and modifications.

The ISO thanks the Electric Power Research Institute and EnerNex Corporation for their contributions in developing this roadmap.

The Smart Grid Roadmap and Architecture may be downloaded from the ISO website at http://www.caiso.com/green/greensmartgrid.html.

The e-mail address for smart grid related comments and questions is smartgrid@caiso.com.

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Introduction

The California ISO envisions the 2020 grid of the future to be one brimming with cost-efficient, clean wind and solar energy that responds to grid operator instructions and dependably contributes to system reliability. The ISO, the power industry and manufacturers are rapidly developing the smart devices and software systems needed for grid evolution. This surge of innovation is driven by California's energy and environmental policy goals, as highlighted in Figure 1, which include procuring 33 percent of the state's retail energy needs from renewable sources by 2020, promoting energy efficiency, increasing levels of distributed generation and reducing greenhouse gas emission levels to 1990 levels.

The 2020 grid has the potential to use storage technologies to store or discharge energy that firms up the variability of renewable resources. Storage could, if developed as hoped, supply ancillary services products as well, such as regulation, which is critical in maintaining system frequency within very narrow limits. Another feature of the smart grid is the everyday use of demand response. Smart technologies are expected to make available the information residential and commercial consumers require to curtail or shift their power use to a time when prices and supply are most favorable. The absence of these technologies developing as expected could result in further reliance on conventional generation to balance renewable variable generation, which may be contrary to the goal of diversifying our generation fuels.

Figure 1: Key Smart Grid Drivers

California's modern grid will leverage existing technologies, such as synchrophasors, to perform at its peak capabilities. Up until now, synchrophasor data had been used for offline analysis, but in the smart grid rollout, it will be used for near real-time on-line monitoring and possibly control. New technologies including smart meters and smart substations will help the local distribution system, owned and operated by utilities, to match the sophistication of the high-voltage transmission system. These specialized functions, if developed, could communicate demand levels, output from distributed generation and system conditions that aid the ISO in managing a grid that is more complex than any time in history. The result would be a thriving electricity sector that is competitive and cost efficient — all to the benefit of our wholesale customers and ultimately retail consumers.

The ISO is actively pursuing initiatives that will determine system impacts and needs under different levels of renewable resources, which potentially includes hybrid and all-electric vehicles. A recently published ISO report on integrating renewable resources provides operational requirements and generation fleet capability under a 20 percent renewables portfolio mix,[1] while forthcoming studies will help characterize system conditions under a 33 percent renewables energy standard.

Given the current and anticipated challenges, it is imperative for the ISO to continue to develop the market and operations applications and devices that better monitor the real-time grid, which includes our own balancing area, our neighbors and the entire West. If successful, these new technologies and applications must have an effective, robust smart grid infrastructure to function properly.

Smart Grid Objectives

The "smart grid" is the application of technologies to all aspects of the energy transmission and delivery system that provide better monitoring, control and efficient use of the system. The ISO's goal is to enable and integrate all applicable smart technologies while operating the grid reliably, securely and efficiently, and facilitate effective, open markets that engage and empower consumers while meeting state environmental and energy policies.

To this end, the ISO will research, pilot, implement and integrate smart grid technologies that:

- Increase grid visibility, efficiency, and reliability
- Enable diverse generation including utility-scale renewable resources, demand response, storage and smaller-scale solar PV technologies to fully participate in the wholesale market
- Provide enhanced physical and cyber security.

The expected benefits from smart grid technology deployments include:

- Ability to recognize grid problems sooner and resolve them
- Efficiently use the transmission system to defer or displace costly transmission investments
- Enable consumers to react to grid conditions making them active participants in their energy use
- Leverage conventional generation and emerging technologies when possible including distributed energy resources, demand response and energy storage, to address the challenges introduced by variable renewable resources.

Building a Better Grid

The research, pilots and implementation efforts to modernize the grid provide the basis for evaluating and understanding new technologies as well as verifying the economics and work force requirements for deploying them. These efforts will require working closely with ISO stakeholders. The research and pilot efforts should accomplish a number of important objectives that contribute to smart infrastructure development:

- Provide real world experience with a new technology

[1] *Integration of Renewable Resources – Operational Requirements and Generation Fleet Capability at 20% RPS* published August 31, 2010 and available on the ISO website at http://www.caiso.com/2804/2804d036401f0.pdf.

- Help characterize the technology's benefits
- Identify what is needed to integrate the technology
- Provide the basis for conducting a cost assessment of the technology.

If the industry is to benefit from emerging technologies and capabilities they support, the efforts must extend beyond the research and pilot stage. It will be important for stakeholders to take information from the research and pilot work to develop business models and policies that bring the technology forward to implementation.

The Smart Grid Roadmap uses themes to organize and communicate the ISO technology-related efforts, which include the following:

- Advanced Forecasting
- Synchrophasors
- Advanced Applications
- Enabling Demand Response, Storage and Distributed Energy Resources
- Cyber Security.

Advanced Forecasting

The ISO determines the resources needed to serve demand based on load forecasts and ancillary service requirements forecast, in which intermittencies introduced by renewable generation pose significant challenges. Incentive-based demand response programs, significant distributed generation, the proliferation of plug-in electric vehicles and rooftop solar will also affect forecasted load. It is important for the ISO to use advanced forecasting techniques to produce the most accurate prediction of resource, load and grid conditions and status. In this way, the ISO can produce the most reliable and cost-effective scheduling and unit commitment plans.

> Advanced Forecasting Vision:
>
> *Industry leader in advanced forecasting accounting for variability introduced by renewable generation and incentive based programs, minimizing forecast error for optimal unit commitment and dispatch.*

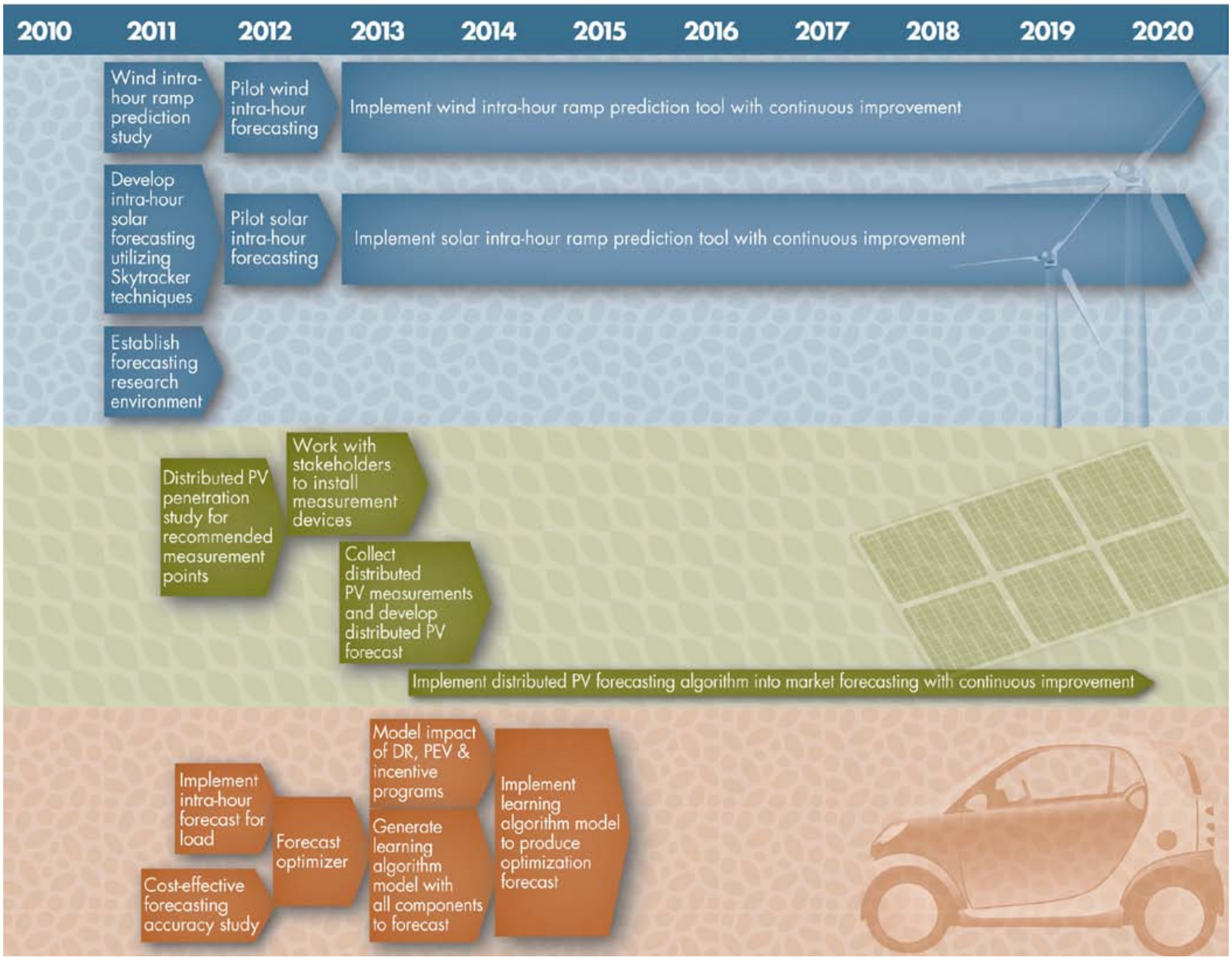
Improving forecasts for variable generation is essential. Variable generation is creating new requirements for faster ramping up and down energy. Also needed is increased procurement of regulation (energy to keep the power system in balance) and other reserves, and increased on and off, and up and down cycling of the gas generation fleet, which produces its own concerns by increasing costly maintenance needs. Improving weather data availability and accuracy, as well as renewable resources and demand response performance measures, forecasting algorithms and understanding demand response behaviors, will provide better forecasts, but they still will have some degree of worrisome error margins. This in turn should lead to more optimal unit commitment that will help account for forecast uncertainties and better use of renewable resources.

Even so, weather-measuring equipment is limited in both scale and capability. Forecasting algorithms must be enhanced to include measurements from additional devices, intra-hour ramping forecasts and upgraded models for solar thermal and photovoltaic units. ISO forecasting must take into account all types of generation on the distribution system as it becomes more prevalent. Meanwhile, how consumers interact with demand response programs and emerging new technologies and incentives is uncertain, but needs to be thoroughly understood to maintain efficient and reliable grid operations.

The ISO uses system-wide load forecasting in addition to wind and solar generation forecasts for both day-ahead and hour-ahead periods. Meteorological and meter data standards and collection are available for those participating in the ISO market.

Research, pilots and technology deployment are important components of the ISO advanced forecasting roadmap that lead to implementation of new forecasting models and techniques.

Advanced Forecasting



Synchrophasors

Having the ability to monitor grid conditions and receive automated alerts in real time is essential for ensuring reliability. System-wide and synchronized phasor measurement units take sub-second readings that provide an accurate picture of grid conditions. The ISO work in this area focuses on obtaining, displaying and storing synchrophasor data.

> Synchrophasor Vision:
>
> *Fully implemented phasor measurement network for the ISO and inter-connected regional entities supporting grid visualization, situational awareness, phasor-based control actions and operator decision support.*

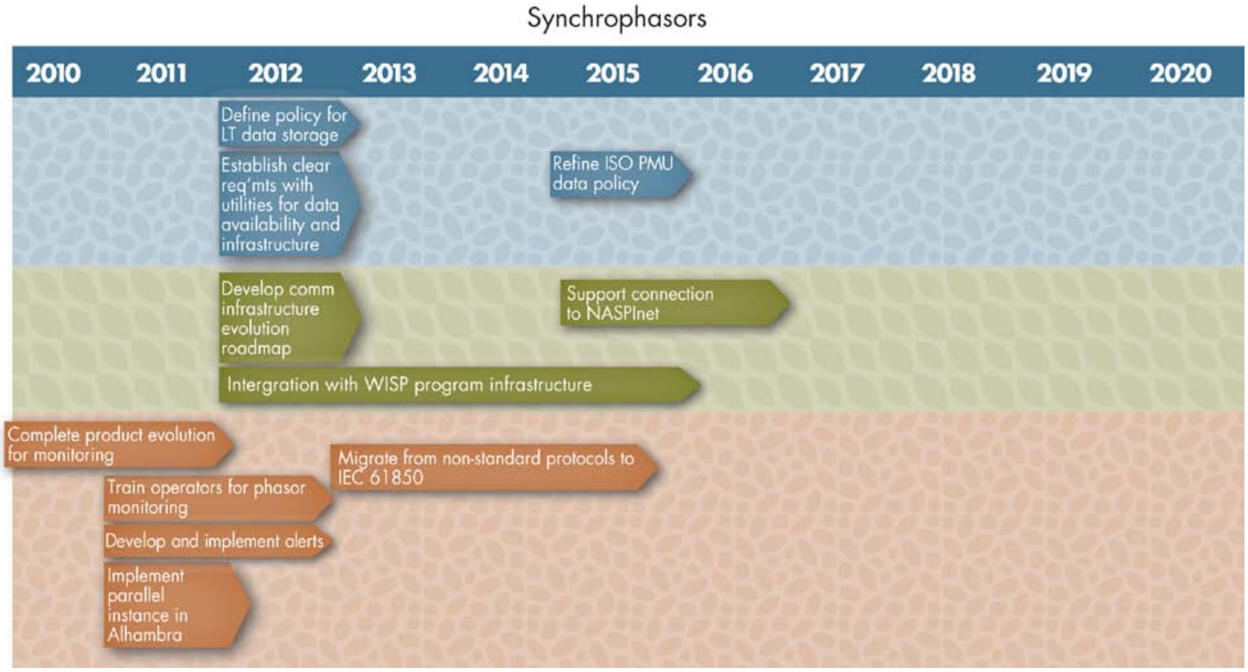
Deployment of synchrophasor technology is accelerating under recent U.S. Department of Energy initiatives. Most relevant to the ISO, the Western Electricity Coordinating Council's *Western Interconnection Synchrophasor Project (WISP)* will almost triple the now deployed phasor measurement units to over 300. The project will also develop common software suites that improve situation awareness, system-wide modeling, performance analysis and wide-area monitoring and controls.

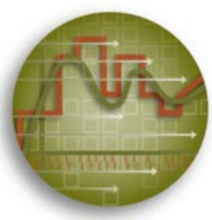
Among the challenges related to using synchrophasor technology is the communications infrastructure, which lacks the bandwidth to handle the data traffic produced by the smart devices, needs enhanced security and must maintain a high degree of reliability if the data is used for control decisions. Another major challenge is the lack of available applications that assimilate and provide meaningful, understandable visual displays of the extensive data produced by the smart devices to the operators.

Phasor units measure voltage and electric current physical characteristics. This data can be used to assess and maintain system stability following a destabilizing event within and outside the ISO footprint, which includes alerting system operators to take action within seconds of a system event. This capability reduces the likelihood of an event causing widespread grid instability.

Phasor data is also useful in calibrating the models of generation resources, energy storage resources and system loads for use in transmission planning programs and operations analysis, such as dynamic stability and voltage stability assessment. The technology may have a role in determining dynamic system ratings and allow for more reliable deliveries of energy, especially from remote renewable generation locations to load centers. The ISO currently uses phasor data on a real-time basis for basic monitoring and on a post-mortem basis to understand the cause and impact of system disturbances.

Data from 57 phasor devices stream at a rate of 30 scans per second collecting more than three gigabytes of data per day. The ISO will begin to receive data from other phasor locations in the Western Electricity Coordinating Council area in the next six months that will further enhance visibility to grid conditions. Critical to the synchrophasor roadmap is implementing a robust, standards-based communication infrastructure and monitoring and alert capabilities, as outlined below.





Advanced Grid Applications

> Advanced Grid Applications Vision:
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> *Industry leader in advanced grid monitoring, wide area control and decision support applications providing grid transparency, efficiency and reliability.*

The ISO relies on advanced grid applications to monitor grid conditions, recognize possible sources of instability and provide prices and control signals to system resources. This information is used in tandem with economic models to solve reliability problems in the most cost-effective way. These applications need to evolve into more forward-looking and pro-active systems, rather than only reacting to real-time conditions in order to truly enhance grid operations.

Integrating phasor data as well as other measurements made possible by smart grid technology can enhance a number of applications used today for managing the grid. Advanced applications for monitoring, dynamic (on the fly) assessments of grid conditions and automated controls are slowly emerging. Because the technology and communication infrastructure for synchrophasors is only now being implemented, developing applications to use this data is lagging. Also, inserting more inputs into modeling algorithms adds significant complexity on top of an already complicated system.

Increased variable generation on the grid is expected to bring challenges in terms of decreased system inertia,[2] which reduces the margins to maintain stability. Phasor data availability may lead to algorithms to measure this effect in real time and provide needed feedback that can be used to take preventive measures, such as scheduling additional conventional generation or sending signals to fly wheels or demand response applications.

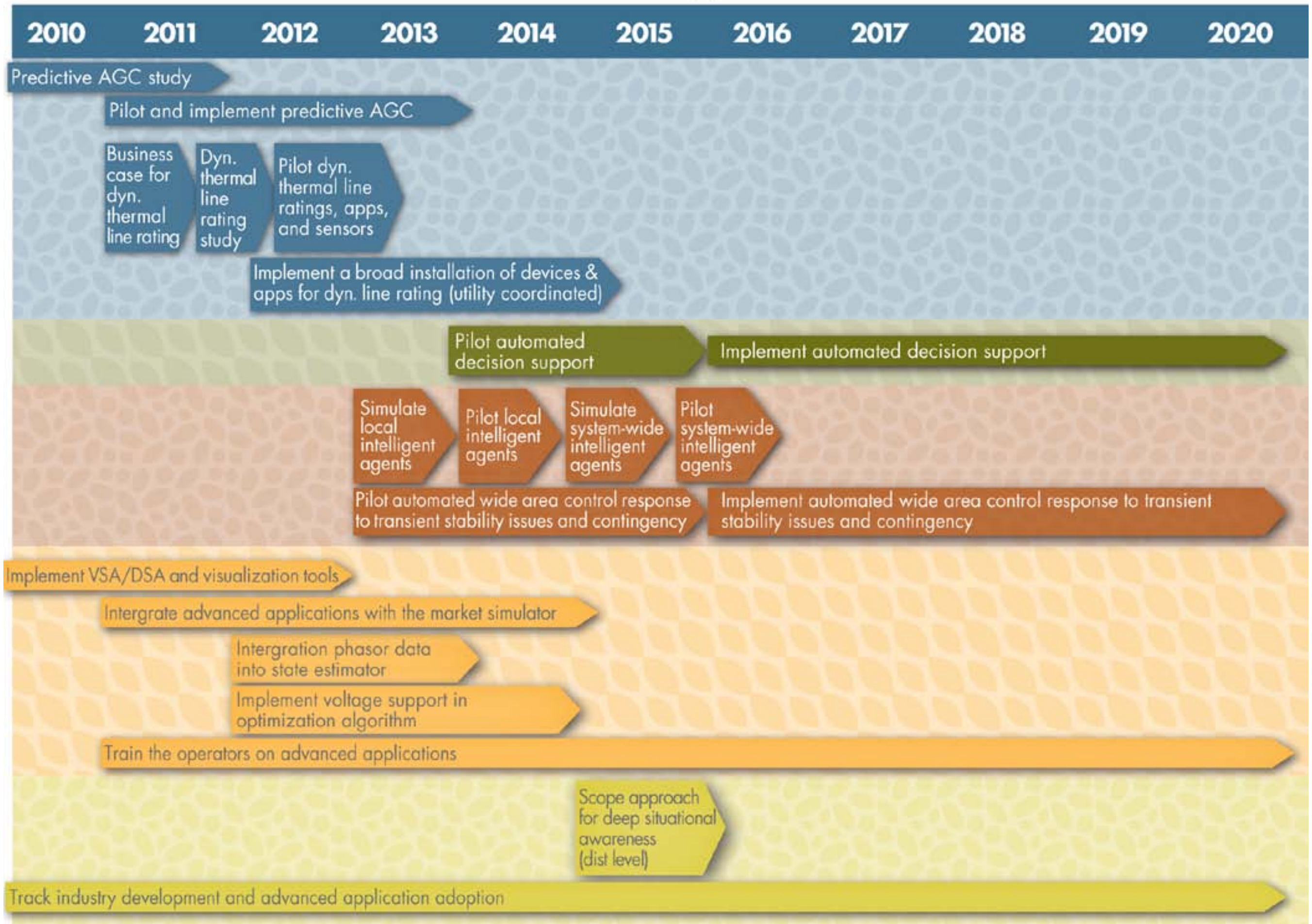
The ISO has a suite of market and power flow systems and tools that determines the best use of available resources based on economics and reliability. The tools include an energy management system, a modeling system that estimates the status of the statewide grid, system event analysis, voltage assessment, automatic economic unit commitment and dispatch for the real time and day ahead markets, a load-forecasting tool, and plant outage scheduler. Under development is a voltage stability analysis application that calculates voltages at

[2] System inertia is the ability of a power system to oppose changes in frequency.

different locations on the system to determine those near limits and sends alerts to grid operators. Integrating this functionality into the market systems will enable the ISO to commit units based on the voltage information.

The applications roadmap includes activities to advance as much as possible, monitoring capabilities, the systems and algorithms to determine the best use of the grid, including dynamic thermal line ratings, and automated adaptive generation control that uses demand, storage and other system resources response forecasts. The roadmap also calls for investigating and implementing automated decision-making and control systems. However, unforeseen problems may prevent some technologies from coming to market, which contributes to the complexity in upgrading the grid and, at least, maintaining current levels of reliability.

Advanced Grid Applications



Enabling Demand Response, Storage and Distributed Energy Resources

Among the highest priorities for the ISO is to identify the viable smart grid technologies that will aid in understanding what is happening on the grid and support active participation in California's wholesale energy market. Demand response needs are driving infrastructure needs, which includes smart devices and control systems that can collect data, present it to the power user and then relay their decisions back to the utilities or third party aggregators (also called curtailment service providers). The enabling technologies include but are not limited to:

> Enabling Demand Response, Storage, and Distributed Energy Resources Vision:
>
> *Deployed infrastructure built on national business and interface standards that provide the flexibility to support demand response, advanced storage and distributed energy resource applications.*

- Building Automation Systems — the software and hardware needed to monitor and control the mechanical, heat and cooling, and lighting systems in buildings that can also interface with smart grid technologies.
- Home Area Networks — similar to smart building technologies, except for the home where devices communicate with the smart grid to receive and present energy use and costs, as well as enable energy users to reduce or shift their use and communicate those decisions to the load-serving entities.

If the technologies develop as hoped, power users will also be able to receive real-time prices or indicators of grid conditions that aids their decision-making processes. For instance, if the grid is under stress, consumers could elect to configure devices that automatically respond to these indicators to shift or curtail use even before wholesale prices rise or system events occur. This is one reason, along with price-responsiveness, why the ISO needs to better understand how consumers use demand response capabilities so that we can predict responsive behaviors that will affect forecasts and energy resource unit commitments.

Among the challenges to overcome:

- Enhancing current market models, which are based on operational characteristics of conventional generation (natural gas, nuclear, hydro) that do not accommodate the full participation of demand-side resources
- Determining minimum monitoring and telemetry requirements to enable more cost-effective participation for many small aggregated demand resources
- Maturing standards such as OpenADR[3] to enable demand response.

Besides conducting the research and analysis to form the market theories that aids industry understanding of how demand response should work under real conditions, the ISO will pursue pilots and demonstration projects that help prove or disprove expectations.

Smart grid technologies focused on consumers holds the promise of providing visibility of their real-time use, the current condition of the grid and their energy costs. With this information, consumers can make choices about how to adjust their energy usage manually by turning down or off the air conditioner, etc., or automatically by setting thresholds managed by smart grid technologies. Direct consumer grid interaction and impact is possible, but only if a host of other challenges are overcome, including closing the gap between the wholesale market and retail prices, communication standards, data confidentiality and network security.

[3] OpenADR, developed by Lawrence Berkeley National Laboratory, is a set of rules that specify how building and facility managers can implement automated demand response in the energy management systems.

The ISO is also stepping up its activities to understand and prove how storage technologies will play a role within the advancement of the smart grid. Among those activities are:

- Better understanding how different types of storage behave (flywheels, batteries, etc.)
- How they fit into grid operations
- Understanding how storage technologies can efficiently and effectively provide regulation energy and operating reserves
- Understanding how storage technologies can efficiently and effectively shift energy deliveries from off-peak periods to peak loads
- Understanding how storage facilities can co-locate with renewable resources to assist in more efficient use of transmission capacity.

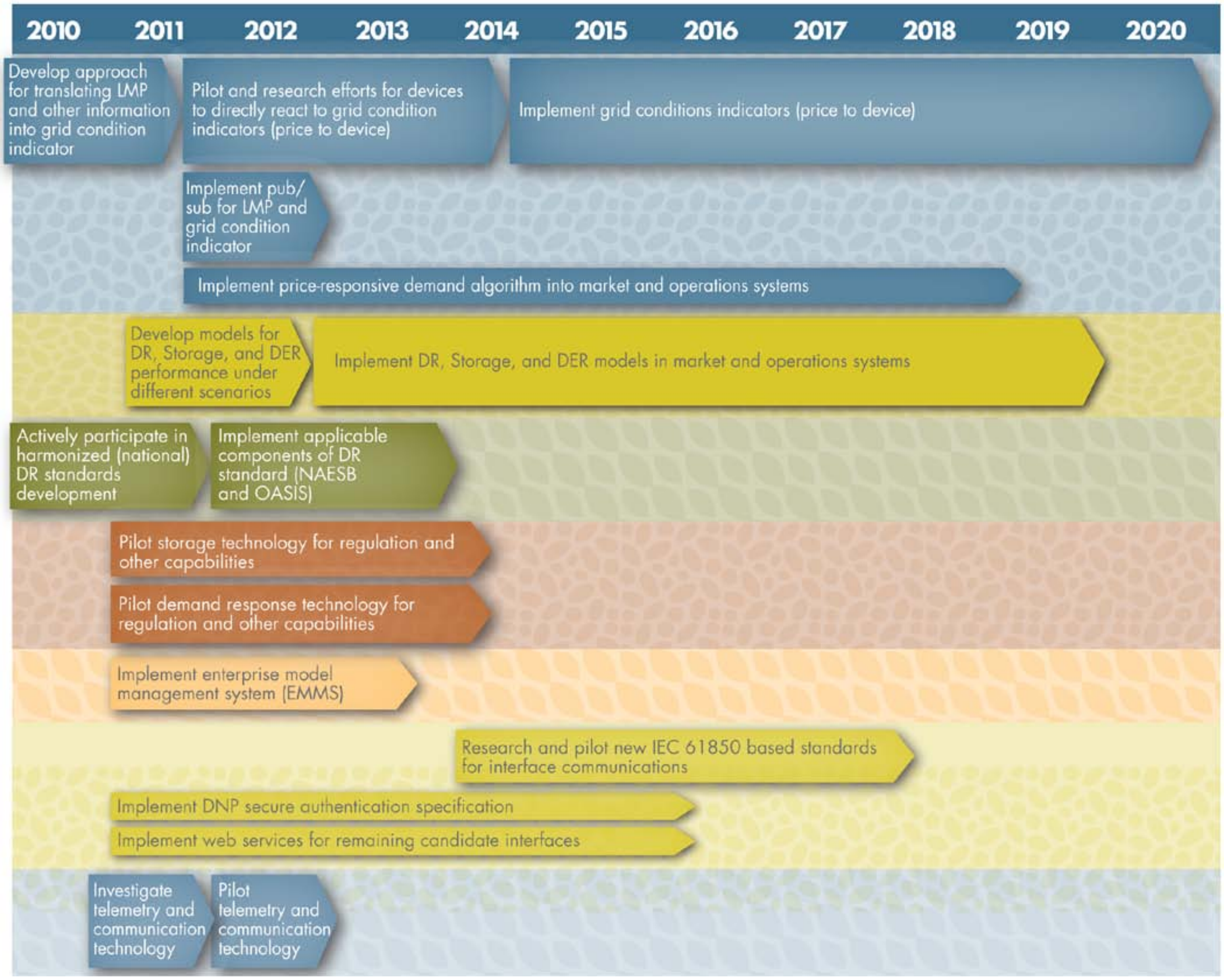
Identifying and creating standards that technologies must meet becomes increasingly important and difficult as expanding ramping capabilities, ensuring the type of plants that follow demand up and down are available and other requirements for reliably managing the grid increase. Should the ability be realized to use different types of demand-side resources during high-renewable production and favorable grid conditions, and reduce during unfavorable conditions; could reduce the need — and cost — for building new generation and in some cases, new transmission lines. Currently, the ISO has market mechanisms and products (such as proxy demand resource that allows aggregators access to the wholesale market) supporting the increased participation of storage, demand response and distributed energy resources and enjoy comparable treatment as generating resources; however, no model exists that allows these resources to participate fully. Meanwhile, Western Electricity Coordinating Council rules are evolving, albeit slowly, to allow participation in spinning reserve and regulation markets. [4]

The ISO is actively participating in wholesale smart grid standards development efforts led by National Institute of Standards and Technology (NIST) through the North American Energy Standards Board (NAESB) and the ISO/RTO Council (IRC). The ISO is also closely involved with demand response policies being considered at the California Energy Commission and smart grid proceedings at the California Public Utilities Commission.

The enabling demand response, storage and distributed energy resources roadmap includes pilots to better understand technology capabilities, expectations for continued participation in national standards development efforts, and developing and piloting approaches for reflecting grid conditions that can be directly sent to smart grid devices.

[4] Spinning reserves is standby generation capacity that is capable of responding and producing energy within 10 minutes and able to run for at least 2 hours. Regulation is energy needed to maintain transmission system frequency.

Enabling Demand Response, Storage and Distributed Energy Resources



Cyber Security

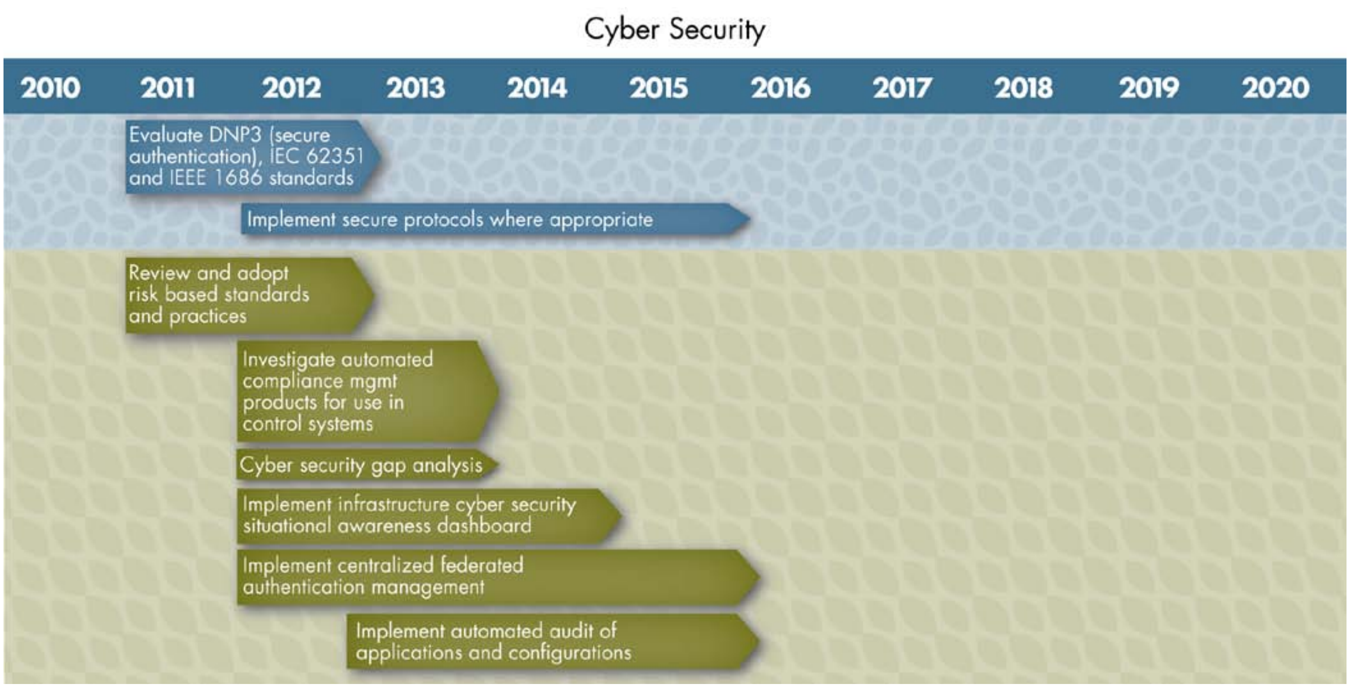
Cyber security becomes a priority concern as additional technologies connect to grid systems and provide more real-time data as well as two-way communications. The need exists to assess risks and vulnerabilities all along the communications chain from data sources to consumers, much of which is outside ISO control. There is little doubt that situations will emerge that require new security controls and monitoring to ensure that grid monitoring, operations and control systems are not compromised.

> Cyber Security Vision:
>
> *Standards compliant cyber security policy and resulting infrastructure that automatically identifies, visualizes and resolves threats and vulnerabilities.*

A number of national forums are addressing security concerns. One is the National Institute of Standards and Technology that recently released *NISTIR 7628, Guidelines for Smart Grid Cyber Security*. This is a three-part document covering smart grid from a high-level functional requirements standpoint.

Among the challenges associated with cyber security is tailoring policies for power system monitoring and control applications, which are complex and industry and application specific. Implementing, maintaining, monitoring and improving information security so it is consistent with the organizational requirements and process are also issues to address.

The roadmap for cyber security addresses the evaluation and implementation of secure and standard protocols where applicable. It also calls for creating centralized security management and auditing as well as a situational awareness dashboard.



Architecture

The ISO architecture vision is to allow each network service (software designed to do a specific job) to operate individually but share information with other services all through a base system called service oriented architecture (a collection of services that make up a network system). To address issues identified during this roadmap effort requires building on the ISO's recent Market Redesign and Technology Upgrade implementation and its foundation to accommodate robust and flexible system architecture.

As shown in Figure 2, the ISO will develop new systems while existing systems will undergo significant change in the next 10 years to support smart grid implementation efforts. Even systems not directly involved with smart grid support will likely be impacted by the changes, adding to concern about avoiding unintended consequences.

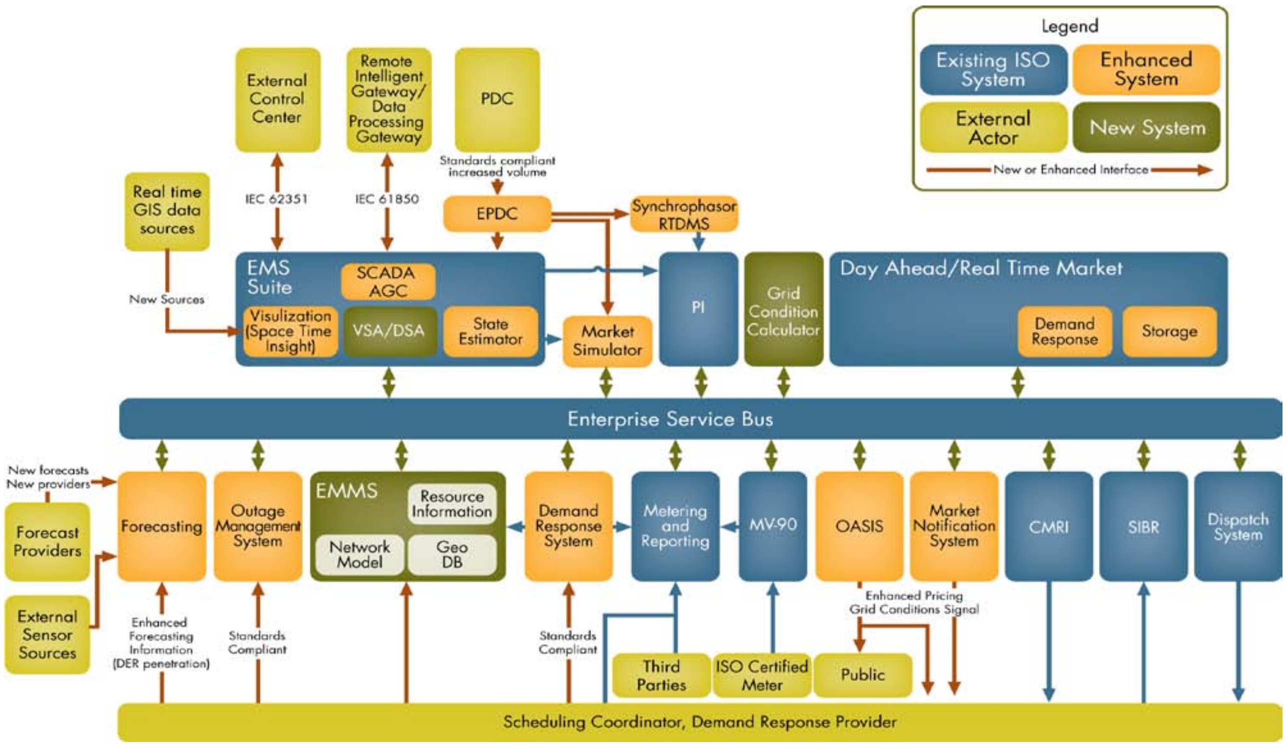


Figure 2: Draft ISO architecture as impacted by smart grid changes

One key architectural component is a centrally managed network model. The Enterprise Model Management System (EMMS) the ISO plans to implement will centralize the functions of several current ISO services and significantly reduce the time between network model builds. This model and data management system will reduce the time it takes for new resources to register in the ISO markets, which is a significant improvement over the current process given the larger numbers of resources expected to seek participation under demand response and storage integration programs. The model and data management system will also enable the ISO to carry out grid, transmission and system event analysis using time-based models that reflect point-in-time grid conditions. This essential feature contributes to the security of a more complex and rapidly changing grid.

To support a "price to device concept" that reflects grid conditions, the ISO will explore creating a grid condition indicator that will require a new system capability via the grid condition calculator. The indicator will act as a signal once published for public consumption through a public website and, possibly, a new Internet subscription service that could be directly consumed by end user devices.

As mentioned in the advanced application section, the expected increases in wind and solar generation will significantly change the behavioral characteristics of the grid, which in many cases are still unknown. It will become increasingly important to analyze the dynamic and voltage stability of the grid and prepare responses to potential problems. To provide this new level of analysis, the ISO will incorporate dynamic and voltage stability analysis applications.

Systems Interface Architecture

The interface diagram shown in Figure 3 shows the data and information communication infrastructure, of which some exists today and the rest to be implemented by 2020. The ISO will use well-defined, self-contained and secure interfaces and web services, to communicate data and orchestrate business processes, which will continue to evolve as services expand. In some cases where the amount of data is too big to relay across the system, we will continue to use a secure file transfer protocol (FTP) server. Secure FTP will also be used for exchanging the network models with other entities. Such Secure FTP activities will likely be managed with web services. The flexible service oriented architecture will allow entities to subscribe to new ISO services that send them prices, system conditions and other messages as appropriate.

The ISO, along with the rest of the entities in the Western Electricity Coordinating Council region, will move toward standard national and international web services for phasor data, telemetry and other interactions.[5] The common information model (CIM) is an international standard that provides a common vocabulary and definitions for the electric power industry. At every opportunity, the ISO seeks to use the CIM as a basis for standards development — and encourages others to do the same.

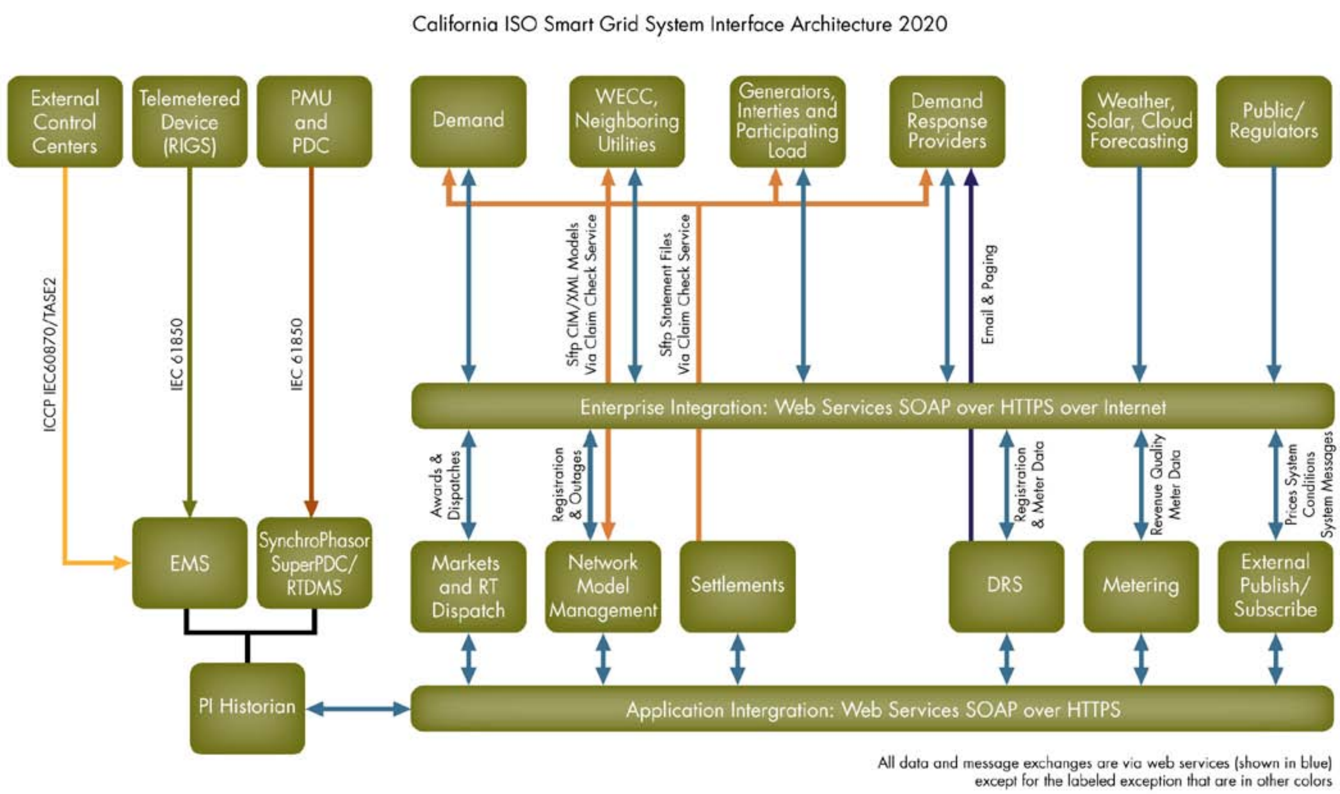


Figure 3: California ISO system interface diagram guided by standards

[5] For phasor data, the ISO currently uses a proprietary protocol and will implement the emerging standard IEC 61850. Note that IEEE C37.118 is the current standard and will likely be an interim step. The ISO currently uses DNP3 for telemetry exchange and will likely implement secure DNP3 with the end-state being the emerging IEC 61850 standard for telemetry.

The ISO will evaluate options that lower technical barriers to entry into the wholesale markets. E-mail and paging systems may be used for messaging when they can meet security, response times and delivery assurance benchmarks, especially in the demand response system. The Internet will continue to be used as a less costly alternative to the Energy Exchange Network, the ISO's secure communications system.

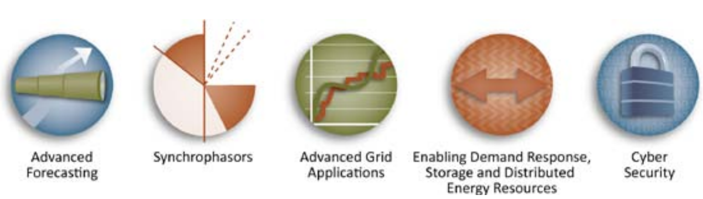
The ISO will continue working with other agencies and organizations in creating new smart grid standards. That includes remaining involved with the National Institute of Standards and Technology created Smart Grid Interoperability Panel (SGIP) and its series of Priority Action Plans that begin the process to standard business practices and interface specifications

Summary

The Smart Grid Roadmap and Architecture lays out a path and technical vision for the discovery and deployment of smart grid technologies beneficial to the ISO, its stakeholders and California consumers. This strategy will evolve with changing federal and state priorities and policies. It will also experience modifications as we gain more understanding of the potential uses and benefits of new technologies and as advanced applications mature and are proven.

Acronyms

AGC	Automatic Generator Control
CMRI (ISO Application)	CAISO Market Results Interface
DNP	Distributed Network Protocol
DR	Demand Response
DRS	Demand Response System
DSA	Decision Support Applications
EMMS	Enterprise Model Management System
EMS	Energy Management System
EPDC	Enterprise Phasor Data Concentrator
GIS	Geographic Information System
HTTPS	Hypertext Transfer Protocol Secure
IEC 61850	International Electrotechnical Commission
LMP	Locational Marginal Pricing
NAESB	North American Energy Standards Board
NASPI	North American SynchroPhasor Initiative
OASIS	Organization for the Advancement of Structured Information Society
OASIS (ISO Application)	(California ISO) Open Access Same-Time Information System
OpenADR	Open Automated Demand Response
PDC	(Synchro) Phasor Data Concentrators
PEV	Plug In Electric Vehicles
PMU	(Synchro) Phasor Measurement Unit
PV	Photovoltaic
RIG	Remote Intelligent Gateway
RTDMS	Real Time Dynamics Monitoring System
SCADA	Supervisory Control and Data Acquisition
SIBR (ISO Application)	Scheduling Infrastructure Business Rules
SOAP	Simple Object Access Protocol
VSA	Voltage Stability Analysis
WECC	Western Electricity Coordinating Council
WISP	Western Interconnection Synchrophasor Project



Watch for these easy reference icons in future Smart Grid reports, papers and associated documents.