Transmission Technology Assessment and Roadmapping

A Regional Exercise

Tugrul Daim, Sheila Bennet and Jisun Kim

Abstract Bonneville Power Administration (BPA) is a Federal agency marketing and transmitting electricity power to northwest area in the US. BPA invests on research, development and demonstration (RD&D) projects to create and deliver the best value for the customers. In order to identify and support the valuable RD&D projects, BPA develops technology roadmaps in several core technology areas. The transmission technology roadmap represents the synthesis of expert opinion and technical knowledge of 80 experts across a variety of disciplines in BPA including transmission operations, planning, facility design and maintenance. It marks the beginning of an ongoing process to support decisions about RD&D investments in the northwest area of US. It provides a strategic framework to guide transmission RD&D efforts based on targets and time-based milestones. It addresses the technological challenges as well as long-term needs. This paper presents the technological needs identified for the transmission business of BPA.

1 Introduction

Over the years, the Bonneville Power Administration (BPA) has been successful in responding to political, business, environmental and technological drivers of change. BPA has earned regional, national and international recognition as an

T. Daim (✉)
Portland State University, Portland, USA
e-mail: tugrul@etm.pdx.edu

S. Bennet · J. Kim
Bonneville Power Administration, Portland, USA
e-mail: sabennett@bpa.gov

J. Kim
e-mail: jxkim@bpa.gov

T. Daim et al. (eds.), *Research and Technology Management in the Electricity Industry*, Green Energy and Technology,
DOI: 10.1007/978-1-4471-5097-8_7,

innovative leader in technical breakthroughs and achievements that have saved electric consumers millions of dollars. Throughout its notable history, BPA has made significant contributions to the original development of, and incremental improvements to, a reliable high-voltage power system, energy efficiency, non-wire solutions and environmental technologies.

Now BPA is challenged to adapt to a new environment in which technology, regulation, generation resources, customer demands and power flows are much different from 20 years ago. Moving forward, BPA management chose to use roadmapping as an analysis tool to assist with decisions about how best to proceed in the next 20 years. During the roadmapping process, critical technologies were identified that best support the agency's innovation strategy. Roadmapping also identified the RD&D gaps that exist between the current and future critical technologies. This road map will assist BPA in making RD&D investment decisions and help to identify ways to leverage RD&D investments. This road map provides strategic direction about future decisions associated with transmission technologies.

Today's environment is stretching the aging transmission system to operate at power flow levels closer to voltage, thermal and stability limits. For example, from June through August 2005, the Northwest grid power flows exceeded the grid's operating transfer capability (OTC) at least 174 times [1]. As power flow congestion incidents increasingly exceed historical levels, the system operates closer to its limits more often, thus increasing the risk to system reliability and economic efficiency [1]. Although, BPA has invested more that $1 billion in new transmission construction in the last several years, relatively speaking, this is not enough to support an aging infrastructure that is continually being pushed closer and closer to its limit.

One major way to address these concerns is to place more effort in technology innovation and confirmation and to leverage resources through coordination with other organizations that share common RD&D goals. Thus, BPA has decided to ramp up RD&D expenditures to 0.5 % of gross revenues. The BPA Technology Innovation annual budget (excluding capital investments and fish and wildlife) is expected to be $12 million by 2011 [2].

The goal of future RD&D is to transform critical technologies into best practice applications. BPA developed a roadmap for the transmission technologies to support the RD&D efforts by providing a guideline to evaluate and select the RD&D projects which will fill the technical gaps. The roadmapping process identified the critical technologies that have the potential to improve system reliability, lower rates, advance environmental stewardship and provide regional accountability. These technologies are

- Real-time wide-area control, monitoring and measurement systems;
- Situational awareness and visualization tools for operations/dispatch;
- Software tools for system performance and online real-time dispatch/operations;
- Real-time automated load forecasting and generation tools;
- Power electronics, energy storage and modular substation equipment;

- Advanced maintenance and diagnostic technologies;
- Extreme event protection and facility hardening;
- High-current operating technologies and advanced conductors; and
- Non-wire solutions.

1.1 Roadmapping

As outlined by Phaal et al [3] technology roadmapping is a flexible technique which is widely used to support strategic planning. The method enables a structured and graphical means for exploring and communicating the relationships between evolving and developing markets, products and technologies over time. Many supporting methods are used to identify the market needs, existing and emerging products and technologies, and required research and development focus areas [4].

Roadmaps have been used in the government sector for policy development to promote technology development or adoption [5].

Technology Roadmaps have been used in the energy sector as well. McDowall and Eames [6] developed roadmaps for the hydrogen economy. Lee et al. [7] applied technology roadmapping process to develop a plan for technology development for the Korea Institute of Energy research. Daim and Oliver [8] reported an energy technology roadmap implementation and provided a roadmap for energy efficiency technologies. Kajikawa et al. [9] demonstrated use of other technology intelligence techniques to develop a roadmap to plan for sustainable energy development.

2 Drivers and Targets Shaping the Vision of the Future Grid

2.1 The Drivers

A key feature of BPA's approach to defining the technology innovation targets is to explicitly base them on, and link them to, BPA business drivers. During the Planning/Operation workshop held in December 2005 and the Facility workshop held in February 2006, BPA transmission experts brainstormed to identify the drivers that are moving the agency into the future. The drivers that were identified are clustered around topics that are key to BPA's strategic agenda—enhance system reliability, increase transmission capabilities and control of power flows, employ cost effective, environmentally sound energy supply and demand and maximize asset use.

2.1.1 Enhance System Reliability

The BPA and related Pacific Northwest grid infrastructure are facing an increasingly complex operating environment. There has been a steady increase in the volume of complex transactions that directly affect operations, dispatch, scheduling and outage coordination. For example, from June through August 2005, power flows exceeded the flowgate OTC on the Northwest grid at least 174 times. In each of those occasions, BPA operators successfully responded within 20–30 min to bring the system back within OTC limits, meeting the new and mandatory Western Electricity Coordinating Council reliability criteria. But, this type of occurrence has been steadily increasing, causing power flow congestion incidents to exceed historical levels. The more often the system operates outside OTC limits, the greater is the risk to system reliability and economic efficiency. This disconcerting trend of increasing network congestion is forcing dispatchers to more frequently react in real time, or "emergency mode," to bring power flows within operational standards [10].

Currently, dispatchers lack tools, processes and data to predict congestion 1–5 min ahead of time, which significantly reduces their ability to deal with multiple contingencies that could occur in real time. As the 1996 Northwest power outage and the 2003 East Coast blackout forcibly demonstrated, multiple events on a system can occur at lightning speed, leaving dispatchers with little or no time to react [10].

BPA currently employs specialized measurement equipment, a wide-area measurement system (WAMS), to monitor dynamic changes on the system such as voltage, current, frequency, and real and reactive power. The ability to successfully operate in this increasingly complex environment will depend on the ability to collect, distil and disseminate vastly larger amounts of data. The challenge has been to fully use all the information available in the measured data to support real-time situational awareness and analyzes to keep the system stable, safe and reliable. Also, currently there is a lack of analytical capabilities for real-time operational decision making based on relieving thermal, voltage and stability constraints. The complexity of the power system and its dynamic network means that matching measured data to theoretical models is necessary to predict power flows 1–5 min ahead of time. To support this, it is necessary to model a large number of statistically likely contingent conditions and operating scenarios within a time frame that must be significantly shorter than present capabilities allow.

Also, BPA anticipates a future increase of local, decentralized, small-generation interconnections that will have an impact on future load composition changes. With this future increase of wind, renewable and distributed generation, there is a need for "quick and stable" integration of these energy sources into the grid. Accomplishing this while avoiding stressing the grid is a very complex task.

2.1.2 Increase Transmission Capabilities and Control of Power Flows

The grid's ability to transfer power is restricted by thermal flow limits on individual transmission lines and transformers, limits on acceptable bus voltage stability requirements and the North American Electric Reliability Council reliability requirements. Also, BPA has implemented Federal Energy Regulatory Commission Order 888 and subsequent revisions. A number of merchant generators has been connected to the BPA transmission network in the past 5 years. These new regulations, open access rules and market conditions have affected how BPA manages power flows and, as a consequence, have expanded the need for some transmission facilities. At the same time, BPA is experiencing increasing parallel path issues with other interconnected transmission systems, and our ability to manage flows on critical paths is becoming inadequate.

Yet, BPA's investment in transmission facilities is limited by the agency's borrowing authority and by customer pressure to control costs and keep rates as low as possible. The public also has a negative view toward building new transmission lines, particularly in urban and suburban areas that have the greatest load growth. As a result, BPA is driven to maximize the power transfer capability of the grid within existing corridors in order to increase revenues and reduce costs.

Scheduled outages for maintenance inherently conflict with the need to maximize the power transfer capability to increase revenues. As such, needed scheduled outages are increasingly harder to obtain, and the outage durations are shrinking, being "packed" into short windows of opportunity in spring and summer. This further increases the complexity of system operation and results in an inefficient use of existing transmission capacity as well as in our inability to react in a timely manner to create automated OTCs and address real-time system outages/changes.

Also, as BPA anticipates a future increase of local, decentralized and small generation interconnections, the system's robustness will be challenged to quickly integrate intermittent resources and manage changing load compositions (increased Pacific Northwest air conditioning use, for example).

2.1.3 Employ Cost Effective, Environmentally Sound Energy Supply and Demand

The demand for additional transmission service is growing at the same time public resistance to building new lines is increasing. A related issue is the increased difficulty in siting new transmission lines due to environmental and land use restrictions. Yet the system is currently operated at or near capacity. In order to increase transfer capability, BPA needs to meet future transmission demand with "low risk/high return" solutions such as intermittent generation, demand response and non wire solutions.

The integration of wind's intermittent generation further challenges system reliability and scheduled capacity. Wind power production varies widely and periods of strong production do not always match up with periods of peak electricity consumption. Wind resource integration presents technical challenges with regard to regulation, load following and oscillation damping. Yet, wind power is a proven renewable electricity source and is the fastest-growing renewable power in the Pacific Northwest. Since 2005, over 900 MW of wind power have been completed or are under construction, and another 600 MW or more is expected over the next 2 years. Wind power currently supplies about 3 % of the region's electricity. Project developers have asked for integration services and facilities to add over 3,000 additional MW of wind power in the region.

Demand response is a new resource to the region, appearing for the first time in the Northwest Power and Conservation Council's 2004 power plan. The Council estimates the resource at about 1,600 MW and targeted 400 MW for development within the plan period. Demand response is a change in customer electricity demand corresponding to a change in the cost of serving that demand. It can be accomplished through pricing or incentive mechanisms. Several technologies are being used to facilitate demand response efforts including smart thermostats, load control devices and third-party aggregators. Additional efforts are under way to control load response during system disturbances. WECC observed periods of prolonged voltage depression that were linked to the dynamic behavior of residential air conditioners. With larger penetration of air conditioning load in the Pacific Northwest, this issue becomes more relevant to BPA and other Pacific Northwest utilities.

BPA has included demand response in its non wire solutions initiative because reducing peak electricity use on a radial part of the transmission system can delay or obviate the need to build additional transmission facilities, thereby saving the region costs and reducing the risk of underutilizing new facilities.

2.1.4 Maximize Asset Use

BPA is implementing new risk, standardization and asset management practices to systemize equipment selection, maintenance and replacement. But, as each day passes, the aging transmission infrastructure becomes older and older, causing a gradual erosion of system capabilities and health. Because of minimal investment, the aging infrastructure is being challenged with increased power flows through existing transmission corridors, as BPA is driven to maximize the power transfer capability of the grid to increase revenues and reduce costs.

As the transmission infrastructure ages, it will need more planned outages for maintenance and repair even though scheduled outages for maintenance conflict with maximum asset use. While current maintenance techniques do not allow maintenance to be performed during certain system loading conditions, live-line maintenance techniques and tools would allow BPA to respond as in-service time requirements increase. However, Oregon and Washington law and the International Brotherhood of Electrical Workers Union restrict hot-line bare-handing techniques in part of BPA's service territory.

Incrementally integrating new technology with existing equipment presents coordination challenges for communication systems and equipment life cycles. Existing equipment is operated and maintained with information technologies that lag way behind other progressive digital and electronic industries. The ability to monitor the service life or condition of equipment becomes necessary as a means of extending equipment life and optimizing performance.

Also, in the near future BPA will experience a deficit in knowledge and skills as many of the older transmission experts retire. This anticipated vacuum of expertise cannot be compensated for with unrealistic expectations of quick technology fixes in materials, equipment and processes. Maximizing the use of BPA's physical infrastructure assets can only be achieved with highly trained and skilled transmission planning, operation, design, construction and maintenance experts.

2.1.5 Target Needs and Technology Features

To meet Target 1:
Enhance future grid reliability, interoperability and extreme event protection for increasingly complex system operation, an intelligent grid architecture is needed that can communicate across planning, design and operation to provide protection and control of the transmission system by assessing power flows, risk, emergency management and economics. This must be done with system wide communication processes that include software and hardware that are interoperable, high speed, secure and reliable. The features of an intelligent architecture include

- Real-time wide-area monitoring and control with adaptive protective relaying schemes;
- Analysis capabilities to identify thermal, voltage and stability constraints and dynamic changes on the system;
- Capability to model and simulate power flow scenarios with multiple contingencies; and
- Capabilities to collect, analyze, disseminate and display large volumes of real-time data.

The future grid needs to be able to perform online real-time analysis and to identify reliability risks for dispatch/operations within 0–30 min using automated tools. Future technologies will address real-time system outages/changes by being able to quickly generate reliable system limits that accurately reflect system operating configurations and create automated operational transfer capabilities (OTCs). Automated generation of OTCs for critical paths such as the I-5 corridor, where limits are entirely thermal, would increase OTCs by hundreds of MW, at times.

Dispatch needs better tools to reliably operate the system, especially during periods of high system stress, multiple planned and/or unplanned outages and high risk conditions associated with an extreme event (for example, storms, forest fires and earthquakes). Dispatch also needs better situational awareness tools that provide wide area overviews in a visual and graphic format to allow for more robust system analyzes and to alert operations/dispatch to inconsistent information and unstable conditions. Wide area control and measurements systems with enhanced features such as strategically placed phasor measurement units, direct data exchange with all WECC utilities and improved linkage into the emergency management system will increase BPA's real-time capabilities.

Real-time interoperable monitoring and measuring hardware integrated with interoperable software able to translate and convert the data collected into meaningful information to support operating decisions is required. Software engineering is required for data-base management and advanced computational and decision-support tools along with visualization and human/machine interface technologies. Exploration and prototyping is needed for new automatic control schemes that complement and enhance the control capabilities of human operators. It is essential for the ultimate acceptance of these technologies that development efforts take place in field settings with active engagement of transmission system operators and support staff.

To enhance grid reliability as the system gets increasingly more complex, reactive power and voltage support need to be maintained along with power quality during normal conditions and during disturbances. To achieve this, cost-effective control systems and power electronics are necessary for

- Reactive power and auto dispatch of remedial action,
- Smooth integration of intermittent and distributed energy generation and
- Energy storage technologies to reduce transmission stability constraints or voltage constraints.

Adding to the complexity of the future grid is the need to increase transmission line capacity within existing corridors and to take outages. To do this, BPA needs to implement high-current technologies that can reinforce 230 kV paths to support 500 kV grid operation and outages. Other options include the innovative use of existing technologies and alternating current to direct current line conversions.

As BPA moves into the future, it must quickly optimize the transition of new technologies into the aging transmission system. The agency needs technologies that support the integration of new and existing equipment based on condition, life cycle, end of life identification and interoperability. Smart diagnostic and maintenance technologies for transmission lines, substations and rights-of-way will provide increased reliability and reduce outages.

To meet Target 2:
Increase transmission transfer capabilities and control of power flows, an intelligent grid architecture is needed that can communicate across planning, design and operation and perform power system modeling to provide increase transmission and control of power flow. This must be done with system wide communication processes that include software and hardware that are interoperable, high speed, secure and reliable. The features of an intelligent architecture include,

- modeling and simulation of multiple contingencies to asses power flows and economics;
- power system modeling to support real-time OTC that is based on accurate forecasts of generation and load models;
- improved and expanded base case power flow capabilities that include automation tools to move from snap shot to real time;
- accurate, quality WECC base case data;
- offline case studies with captured real-time phase measurement unit data synchronized with the supervisory control and data acquisition (SCADA) system; and
- real-time monitoring hardware with software able to translate and convert the data collected into meaningful information to support design, planning and operating decisions.

The need to increase transmission line capacity and availability within existing corridors while also providing the ability to take outages can be accomplished with technologies that are able to

- provide real-time OTC,
- to operate at high current and high temperatures,
- to upgrade lines and/or upgrade voltages,
- to make use of innovate applications of existing technologies (A list of Innovative Applications of Existing Technologies is presented in Appendix 3),
- to reinforce 230 kV paths to support 500 kV grid operation and outages and
- to convert AC lines to DC.

The need for effective interconnection between BPA and WECC utilities can be achieved with technology that provides cost effective control systems for reactive power, auto dispatch of remedial action and high voltage DC transmission.

The need for effective integration of distributed energy and intermittent resources can be accomplished by scenario planning that accommodates a variety of generation resources such as renewable and distributed energy, demand response and non-wire solutions. Also it requires technologies that are capable to reduce peak load, integrate with end-user consumer systems and smooth out intermittent resources. To do this, cost effective control systems for reactive power, demand response and intermittent and distributed energy are required.

To meet Target 3:
Employ efficient, cost-effective, environmentally sound energy supply and demand, an effective integration of distributed energy and intermittent resources is required. This can be accomplished by scenario and probabilistic planning using real-time automated load forecasting and generation tools that can accommodate a variety of resources such as renewable and distributed energy, demand response and non-wire solutions.

Technologies with the ability to reduce peak load, integrate with end-user consumer systems and smooth out intermittent resources are also required. To do this, energy storage combined with cost effective control systems for demand response and intermittent and distributed energy are required.

The need for enabling technologies that reduce expenses and offset construction costs while making the best use of borrowing authority can be satisfied with non-wire solutions that reduce peak loads and have the capability to integrate end-use consumer systems into the grid.

To meet Target 4:
Maximize asset use, there is a need to increase transmission line capacity and availability within existing corridors and to increase the ability to take outages by increasing the real-time operational transfer capacity (OTC). Future technologies will address real-time system outages/changes by being able to quickly generate reliable system limits that accurately reflect system operating configurations.

The need to increase transmission line capacity and availability within existing corridors while also providing the ability to take outages can be accomplished with technologies that operate at high current and/or high temperatures, make use of innovate applications of existing technologies and reinforce 230 kV paths to support 500 kV grid operation and outages.

There is a need for enabling technologies that reduce expenses, offset construction costs, make best use of borrowing authority and optimize the transition of new technologies into the aging transmission system. This requires technologies that are capable to reduce peak load, integrate with end-user consumer systems and smooth out intermittent resources. Technologies are needed with features that support the integration of new and existing equipment based on condition, life cycle, end of life identification and interoperability. Smart diagnostic and maintenance technologies for transmission lines, advanced substations and right-of-ways will provide increased reliability and reduce outages.

To maximize asset use the system needs reactive power and voltage support. Also, it must be able to maintain power quality during normal conditions and disturbances. To achieve this, cost effective control systems and power electronics are necessary for,

- Reactive power and auto dispatch of remedial action, and
- Smooth integration of intermittent and distributed energy generation.

Continued improvement is needed in sensors to be better able to monitor various parameters of conductors, transformers, and other components in order to fully use their capacities. To support this information measurement and management systems for collecting, analyzing, displaying and disseminating large volume of real-time data are needed. Real-time monitoring hardware with software capable to translate and convert the data collected into meaningful information to support design, planning and operating decisions is required.

In addition, live-line maintenance techniques and tools are needed as in-service time requirements increase. At some point, certain lines cannot be taken out of service for maintenance, and maintenance cannot be performed during certain

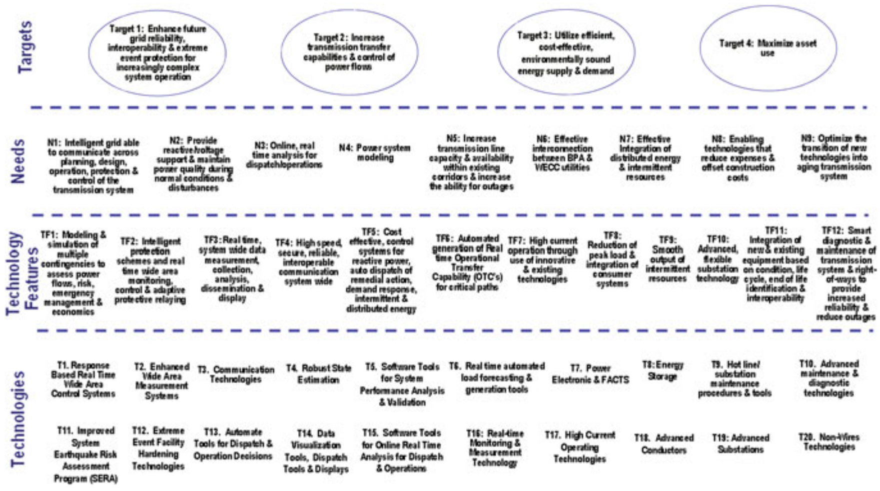


Fig. 1 Transmission technology roadmap—targets, needs, technology features and technologies

system loading conditions. Software tools are needed to help prioritize maintenance schedules and activities.

Figure 1 shows a summary of the Transmission Technology Road map Targets, Needs, Technology Features and Technologies.

2.2 *Technology Roadmapping*

The assessment completed the first round was followed by graphical representation of the technology needs and available technologies, when the next time the technology roadmap was updated. The following is an extract from that to demonstrate the process:

The technology roadmaps provide clarity on:

1. Key business challenges (environmental/global, market, policy and regulatory, and technology innovation) affecting the Federal Columbia River Power System (FCRPS);
2. Operational challenges created by the identified business challenges;
3. Technological needs that address the challenges;
4. Gaps in existing R&D programs designed to address identified technology needs; and
5. BPA's priorities in regard to the treatment of R&D gaps.

The Transmission Technology Roadmap specifically addresses challenges facing BPA's high voltage transmission system and its interactions with generation sources and the distribution systems of it customers. The challenges are grouped in the following major areas:

A. Transmission Planning Operational Challenges

I. Power System Modeling

(1) Development And Use Of Common System Models

II Transmission Operations

(2) Situational Awareness and Visualization Tools

III Power Grid Optimization

(3) Power Flow Controls
(4) Power System Stability Control

IV Transmission Scheduling

(5) Shorter Duration Scheduling
(6) Outage Management
(7) Congestion Management

B. New Technology Integration Challenges

V Changing Generation Resources

(8) Integration Of Variable Resources
(9) Wind Modeling

VI Changing Load Characteristics

(10) End Use (Customer/Utility) Devices.

The aim of BPA's Technology Innovation program is to provide the impetus to transform R&D into best practice applications. The roadmapping process identifies critical technologies that have the potential to improve system reliability, lower rates, advance environmental stewardship and provide regional accountability. This extract is taken from the introduction of the roadmap. We will present one of 10 areas studied in this roadmap. Section 2.3 below is an extract and provided as a demonstration of roadmap implementation.

2.3 Development and Use of Common System Models Roadmap

2.3.1 Business and Technology Challenges

A critical challenge for BPA's transmission modeling systems is the inconsistency of system models from power generation through transmission planning to transmission scheduling and operations. Currently, power system analyzes use multiple models and data bases that are not integrated. A common architecture is needed that can communicate across planning, design and operation to perform power system modeling that increases transmission capacity and control of power flow. It should include improved and expanded base case power flow capabilities with automation tools that move from snap shots to real time. It should include accurate, quality WECC base case data with proper labels.

This impacts several areas creating the following operational challenges:

Identifying New System Constraints Following Dispatch Changes

- Current models do not identify new system constraints following dispatch changes. They do not indicate which plants to turn off and which plants must stay on to provide ancillary services.
- Planning studies with perfect foresight may not match actual results when there is forecast error.
- We have difficulty in quantifying the risk of increased reliance on RAS, and redispatch.
- Models may be too optimized for one set of assumptions precluding their use for broader applications.
- We don't have good planning models for all possible operating conditions. Currently, focus is on winter peak and summer peak.

Forecasting Congestion

- Difficulty in forecasting congestion and congestion costs for expansion planning purposes
- Given ramp up in wind changes in system operations (Operational Transfer Capacity, Energy Imbalance Market) new storage and Demand Response resources.

Model Consistency

- Need more consistency of assumptions between planning and operations or more awareness of inconsistency. Planning studies do not have perfect 'Foresight'.

Another challenge due to the **insufficiency of power system models**—Current models do not simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.

This results in the following operational challenges:

Availability/Data Availability

- Real-time interoperable monitoring and measuring hardware integrated with interoperable software is needed to translate and convert the data collected into meaningful information to support operating decisions and to get increasingly complex issues resolved faster.

Adapting to a Changing Power System

- Effective integration of new generation and changing load patterns requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions. Exploration and prototyping is needed for new automatic control schemes that complement and enhance the control capabilities of human operators.

The operational and technical needs to respond to the challenges include:

Increase Planning Scenarios

- Need new system planning tools to develop a better planning system for more broad (encompassing) data.

Better State Estimator Models

- Need better state estimator models. Validate Wind Models

Baseline Understanding of the System (Power System Performance)

- Need for baseline performance values for an evolving system with a diversity of generation including: Oscillation baseline; Frequency response baseline; and Phase angle baseline

Reliable source for topology/impedance model realizing elements such as load and generation models

The required capabilities to satisfy the needs are:

Power Plant Model Validation

- Need baseline performance for changing generation, based on RT SE topology/ impedances. Better accuracy of breakers/bus and PMUs for load and generation parameter ID.

Scenario Analysis

- BPA needs to run a wide range of study scenarios and process the results in a useful amount of time.

Common System Model

BPA needs common model data structures and parameters with tools to maintain the database and change the management process. The database will essentially be comprised of three key components; Operational breaker/node model database, Planned future system additions, dynamic database. The model will have an interface with the EMS SCADA database for real time measurements with an integrated network application environment that includes a closed loop update.

R&D Gaps

Business and Technological Challenges which are not addressed by existing R&D programs:

1. Forecasting Congestion
2. Modeling HILF (high impact low frequency), geomagnetic disturbance/geomagnetically induced currency (GMD/GIC)

3. Transformer models to evaluate the Impact of GIC for the generation of harmonics increased VAR consumption and thermal stress on transformers

Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

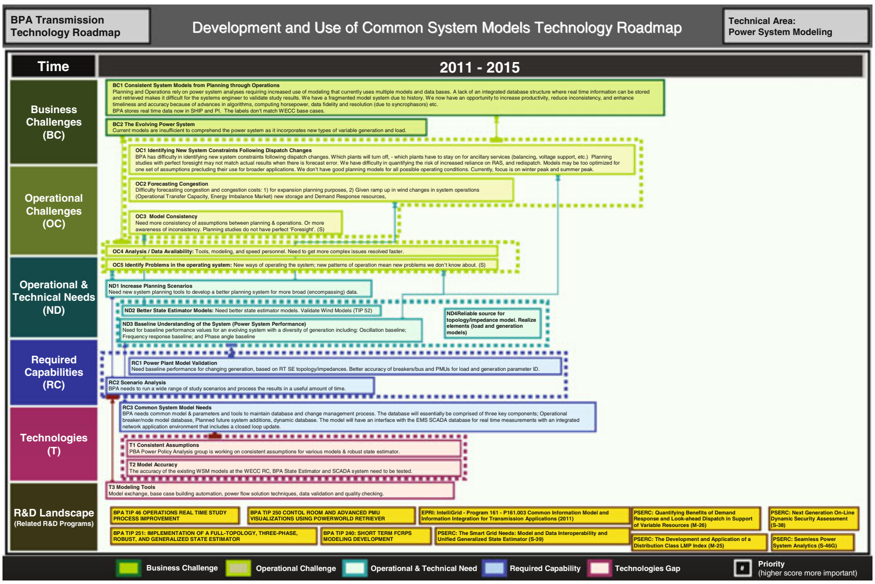
1. Model Consistency
2. Analysis/Data Availability
3. Adapting to a Changing Power System

- There are a number of Locational Marginal Pricing (LMP) methodologies currently practiced by all the Independent System Operators (ISO), Regional Transmission Organizations (RTO) and Energy Imbalance Market (EIM) operators. What is different between the current practices/methodologies for LMP and those for existing R&D projects?

Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required.

1. Insufficiency of power system models: Current BPA models do not sufficiently simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.
   - Almost all Energy Management Software (EMS) vendors already have state estimators that can do the above. The need is to verify if they are sufficient for BPA purposes.
2. Need to identify new system constraints following dispatch changes.

The following sections include the roadmap and descriptions of the R&D programs identified.



Related Internal and External Projects

BPA challenge	Lead research organization	Project title and project description
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	PSERC Project Leader: Mladen Kezunovic Texas A&M University, kezunov@ece.tamu.edu,	*The Smart Grid Needs*: *Model and Data Interoperability and Unified Generalized State Estimator* (*S-39*) Future Smart Grid applications such as Unified Generalized State Estimation, Intelligent Alarm Processing, and Optimized Fault Location, can benefit from the smart grid integration across data and models but the problem of data and model interoperability hinders the implementation. As an example, two difficult and interrelated problems in state estimation, ability to detect topology errors, and implementation complexity due to the two-model (node/breaker and bus/branch) architecture, will be much easier to solve if data and model interoperability are resolved. This project will identify the interoperability issues and will illustrate novel ways of their resolution in the future so that both legacy solutions, as well as future smart grid applications can utilize the same data and models but use them in a manner consistent with the application requirements and aims *REVIEW*: *A number of collaborative efforts for model interoperability testing has been done at EPRI level*

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	EPRI	*IntelliGrid - Program 161 - P161.003 Common Information Model and Information Integration for Transmission Applications (2011)* Robust and highly integrated communications and distributed computing infrastructures will be needed to create a smart grid. These infrastructures need to be interoperable across vendor equipment and throughout the enterprise. Achieving the necessary level of interoperability requires the development and industry adoption of a tightly coupled suite of standards. The Common Information Model (CIM) provides a common language for integrating applications across the enterprise and is a foundation standard for smart grids. IEC 61850, Distributed Network Protocol (DNP), and the Internet Protocol (IP) also are key standards. Significant work has been done on these standards, but a substantial amount of work is needed This project develops requirements and use cases for advanced transmission operations. These requirements serve as the basis for data and device models for emerging standards as well as for contributions to standards activities within key industry organizations such as IEC, IEEE, NIST and others

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions	PSERC Project Leader: Le Xie Texas A&M, Lxie@mail.ece.tamu.edu, 979-845-7563	*Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)* The objective of this project is to conduct a first-of-its-kind empirical study on the benefits of combining look-ahead dynamic dispatch with price responsive demands for integration of variable energy resources. Based on substation level demand response data and site-specific wind generation data from ERCOT, this project will develop algorithms and a case study to quantify (1) the price elasticity of demand for typical users, and (2) the economic benefit of look-ahead dispatch with price responsive loads. To our knowledge, this is the first study to estimate demand response at the customer level for a U.S. regional system operator. Moreover, we will combine the look-ahead dispatch with the price responsive demand to quantify the system-wide benefits

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation	EPRI [*Satisfies the challenge 50 %*]	**1. Existing Commercial Solutions** CIM, proposed in the late 90′s A formal method to define power system data using formal database models EMS vendors have created converters to the CIM model from their proprietary models, but little development of CIM-native applications have occurred in the industry CIM has been only partially adopted. There are ongoing users groups for CIM interoperability and development Interoperability is currently limited to various vendors solving small power flow cases A problem with CIM is that is very verbose, and the equivalent of planning cases requires Gbytes A second problem is that is defined at the abstract level **2. Ongoing Research** CIM, EPRI is investigating the possibility to propose a canonical data format such as CIM. However, changes are needed to: Resolve the issue of large size of power flow cases CIM is an abstract model as opposed to a physical model. It is not suited for compliance because its implementation is left to the developer **3. Research Needs** A common, flexible data format for power systems is needed in the industry. CIM could be a good starting point, but clear model adoption roadmap, compliance mechanisms, and a vast array of applications supported must be set upfront. Organizational and cooperation mechanisms must be in place so adoption of the model does not take decades *REVIEW*: *CIM supposes to be a common format and power system models can be exchanged at ease, but non of the EMS vendor CIM versions can be exchanged at this point, regardless of relentless industry efforts. This is questionable in terms of practicality*!

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Analysis and data availability, Adapting to a changing power system	PSERC Project Leader: Vijay Vittal Arizona State University, vijay.vittal@asu.edu	*Next Generation On-Line Dynamic Security Assessment (S-38)* This project addresses five elemental aspects of analysis for the enhanced performance of on-line dynamic security assessment. These five elemental components includes; a) A systematic process to determine the right-sized dynamic equivalent for the phenomenon to be analyzed, b) Employing risk based analysis to select multi-element contingencies, c) Increased processing efficiency in decision-tree training, d) Using efficient trajectory sensitivity methods to evaluate stability for changing system conditions, and e) Efficient determination of the appropriate level of preventive and/or corrective control action to steer the system away from the boundary of insecurity *REVIEW*: *This project is on its own merit and not related to the Common Power System Model*
Requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions	PSERC Project Leader: Gerald T. Heydt Arizona State University., heydt@asu.edu	*The Development and Application of a Distribution Class LMP Index (M-25)* This project focuses on the development and application of a distribution engineering analog of Locational Marginal Prices (LMPs). It is proposed to develop and apply a distribution LMP (D-LMP), which is used for energy and power flow management in networked distribution systems as well as pricing. The D-LMP will be designed to encourage the implementation of renewable resources in distribution systems in a cost effective way. The D-LMP signal may be used for control strategies such as management of distributed energy storage operation

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	PSERC Project Leader: James McCalley Iowa State University. jdm@iastate.edu, 515-294-4844	*Seamless Power System Analytics (S-46G)* The current approach to power system analysis has developed over the last 3–4 decades in a piecemeal approach where the various applications run separately using their own system models and formats. Although these tools have improved, the programs are still built upon core technology and software architectures from decades ago, each developed for its own unique purpose rather than an integrated approach that builds upon state-of-the-art algorithms, hardware, and modern day methods for data management across a shared environment. These limitations need to be overcome by modern analytical tools that can support modernization of the electricity industry. This project will identify design requirements to transition to a new systems analysis platform that encapsulates a comprehensive power system model with seamless analytics. Design requirements are organized as: (a) types of organizations and analysis needs of each; (b) computing applications associated with each analysis need; (c) basic functions comprising each computing application; (d) algorithm/hardware combinations associated with each function; (e) software architecture designs to facilitate seamless and computationally efficient power system analysis *REVIEW*: *Too general and broad base. Need to be more specific to power system applications, software and database*

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	PSERC Project Leader: Mladen Kezunovic Texas A&M University, kezunov@ece.tamu.edu,	*The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)* Future Smart Grid applications such as Unified Generalized State Estimation, Intelligent Alarm Processing, and Optimized Fault Location, can benefit from the smart grid integration across data and models but the problem of data and model interoperability hinders the implementation. As an example, two difficult and interrelated problems in state estimation, ability to detect topology errors, and implementation complexity due to the two-model (node/breaker and bus/branch) architecture, will be much easier to solve if data and model interoperability are resolved. This project will identify the interoperability issues and will illustrate novel ways of their resolution in the future so that both legacy solutions, as well as future smart grid applications can utilize the same data and models but use them in a manner consistent with the application requirements and aims.

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Inconsistent System Models from Planning through Operations, Models may be too optimized for one set of assumptions precluding their use for broader applications	EPRI	*IntelliGrid - Program 161 - P161.003 Common Information Model and Information Integration for Transmission Applications (2011*) Robust and highly integrated communications and distributed computing infrastructures will be needed to create a smart grid. These infrastructures need to be interoperable across vendor equipment and throughout the enterprise. Achieving the necessary level of interoperability requires the development and industry adoption of a tightly coupled suite of standards. The Common Information Model (CIM) provides a common language for integrating applications across the enterprise and is a foundation standard for smart grids. IEC 61850, Distributed Network Protocol (DNP), and the Internet Protocol (IP) also are key standards. Significant work has been done on these standards, but a substantial amount of work is needed This project develops requirements and use cases for advanced transmission operations. These requirements serve as the basis for data and device models for emerging standards as well as for contributions to standards activities within key industry organizations such as IEC, IEEE, NIST and others

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Requires changes to scenario planning that accommodates a variety of resources such as renewable and distributed energy, demand response and non-wire solutions	PSERC Project Leader: Le Xie Texas A&M, Lxie@mail.ece.tamu.edu 979-845-7563	*Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)* The objective of this project is to conduct a first-of-its-kind empirical study on the benefits of combining look-ahead dynamic dispatch with price responsive demands for integration of variable energy resources. Based on substation level demand response data and site-specific wind generation data from ERCOT, this project will develop algorithms and a case study to quantify (1) the price elasticity of demand for typical users, and (2) the economic benefit of look-ahead dispatch with price responsive loads. To our knowledge, this is the first study to estimate demand response at the customer level for a U.S. regional system operator Moreover, we will combine the look-ahead dispatch with the price responsive demand to quantify the system-wide benefits
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation	Georgia Institute of Technology (Dr. Santiago Grijalva) [*Satisfies the challenge 30 %*]	**1. Ongoing Research** Ongoing research on the unified data model and framework with applications to generalized state estimation Further testing of performance of the unified framework for various applications including operations and planning compatibility at the N-k contingency analysis level **2. Research Needs** Industry-wide utilization of the unified operations and planning framework Methods to test interoperability of unified models Utility/ISO planning directly with node-breakers models Implications of potential abandonment of bus/branch models Widespread creation of WECC or Eastern Interconnection models at the node-breaker level *REVIEW: Others EPRI, WECC WSM, PowerWorld, etc. have done what stated in the proposal*

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Insufficient Power System Models—Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation	Project Leader: Thong Trinh Org: TS [*Satisfies the challenge 80-100 %*]	BPA EXP 16 Development of a Common Power System Model and Database Increasing reliance on power system analyzes for the operation and planning of the power system has led to modeling being elevated to a critical function for both planning and operations. Models are supporting a variety of enterprise functions, and better model exchanges are needed. Today, the need for model consolidation and sharing is on everyone's mind. The necessity for: better operating tools, increased transfer capability, accurate real-time load forecasts, validation of power system dynamics, and smart grid will all carry this trend further This project proposes the development of a centralized database that includes closed loop update and maintenance processes, and integrated network applications. The database will essentially be comprised of three key components: Operational breaker/node model; Planned future system additions; Dynamic database. The model will have an interface with the EMS SCADA database for real time measurements with an integrated network application environment with closed loop *REVIEW*: *This is a practical approach that deals with real practical needs*

(continued)

(continued)

BPA challenge	Lead research organization	Project title and project description
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation	Siemens	**1. Existing Commercial Solutions** Siemens has created a product capable of mapping models between their EMS system and their PSSE models. Effectively the model is a case converter from the EMS to centralized database to PSSE. However, because fundamentally the planning cases loses information of the switching devices, it is not possible to "go bacK" from the planning model to the operations model. System has been deployed successfully at various control centers, ERCTO, etc *REVIEW*: *First sentence is not entirely truth. MOD (Model On Demand) still not capable of completely doing as stated. This is to solely benefit Siemen PSSE product*
Inconsistent System Models from Planning through Operations. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation	Texas A&M (Dr. Mladen Kezunovic) [*Satisfies the challenge 5 %]*	**1. Ongoing Research** Ongoing research on data model compatibility between fault detection and operational models

3 Conclusions

Technology roadmaps are created to support research and development (R&D) plans that meet the strategic goals of industries and organizations with research needs. BPA's technology roadmaps are essentially a snapshot of current perspectives to inform a research agenda that will help BPA adapt to a new environment in which technology, regulation, generation resources, customer demands, and power flows are changing dramatically. The roadmapping process of BPA identifies critical technologies that have the potential to improve system reliability, lower rates, advance environmental stewardship, and provide regional accountability.

References

1. BPA (2006) Challenge for the Northwest: protecting and managing an increasingly congested transmission system (No. DOE/BP-3705). Bonneville Power Administration, Portland
2. BPA (2005) Technology innovation summary. Technology Innovation Office, Bonneville Power Administration, Portland
3. Phaal R, Farrukh CJP, Probert DR (2004) Technology roadmapping—A planning framework for evolution and revolution. Technol Forecast Soc Chang. 71(1–2):5–26 Roadmapping: from sustainable to disruptive technologies. ISSN 0040-1625, doi: 10.1016/S0040-1625(03)00072-6
4. Fenwick D, Daim TU, Gerdsri N (2009) Value driven technology road mapping (VTRM) process integrating decision making and marketing tools: case of internet security technologies. Technol Forecast Soc Chang 76(8):1055–1077
5. Kajikawa Y, Usui O, Hakata K, Yasunaga Y, Matsushima K (2008) Structure of knowledge in the science and technology roadmaps. Technol Forecast Soc Chang 75(1):1–11. ISSN 0040-1625, doi: 10.1016/j.techfore.2007.02.011
6. McDowall W, Eames M (2006) Forecasts, scenarios, visions, backcasts and roadmaps to the hydrogen economy: a review of the hydrogen futures literature. Energy Policy 34(11):1236–1250 Hydrogen. ISSN 0301-4215, doi: 10.1016/j.enpol.2005.12.006
7. Lee S, Mogi G, Kim J (2009) Energy technology roadmap for the next 10 years: the case of Korea. Energy Policy 37(2):588–596
8. Daim TU, Oliver T (2008) Implementing technology roadmap process in the energy services sector: a case study of a government agency. Technol Forecast Soc Chang 75(5):687–720. ISSN 0040-1625, doi: 10.1016/j.techfore.2007.04.006
9. Kajikawa Y, Yoshikawa J, Takeda Y, Matsushima K (2008) Tracking emerging technologies in energy research: toward a roadmap for sustainable energy. Technol Forecast Soc Chang 75(6):771–782. ISSN 0040-1625, doi: 10.1016/j.techfore.2007.05.005
10. Challenge for the Northwest: Protecting and managing an increasingly congested transmission system (2006) White Paper, Bonneville Power Administration, Portland, DOE/BP-3705