Bonneville Power Administration

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TRANSMISSION TECHNOLOGY ROADMAP

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Introduction

Throughout its history, 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 innovative leader in technology breakthroughs and achievements that have saved electricity consumers in its territory millions of dollars. BPA has contributed greatly to the overall development of, and incremental improvements to high-voltage power system in the Pacific Northwest, energy efficiency programs that support regional and national goals, non-wire solutions and environmental technologies.

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 technology roadmaps provides 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 & 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.

Key Challenge Areas

A. Transmission Planning and Operational Challenges

Power system modeling

Development and use of common system models – The inconsistent system models from planning through operations. Another challenge is due to the Insufficient Power System Models. Current models are insufficient to simulate power flow scenarios with multiple contingencies that include intermittent and variable generation.

Transmission Operations

Situational awareness & visualization tools – Inability to monitor system dynamics conditions in real-time.

Power Grid Optimization

Power flow controls – BPA needs to increase capacity of the transmission system without extensive capital investment.
Power system stability controls – Utilization of the synchrophasor technology can be improved by leveraging wide area and response based controls.

Transmission scheduling

Shorter duration scheduling – There are four major challenges in short duration scheduling of transmission scheduling: forecasting transmission flows in near-term, sub-hour scheduling, integration of ancillary energy markets, difficulty in accommodating variability in demand and supply, and potential formation of region-wide energy imbalance market.
Outage management – Increased pressure to replace equipment ‗Hot‘ (without an outage), and Increased difficulty to take outages on power system equipment and lines because of insufficient capacity and increasing demand.
Congestion management – BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources

B. New Technology Integration Challenges

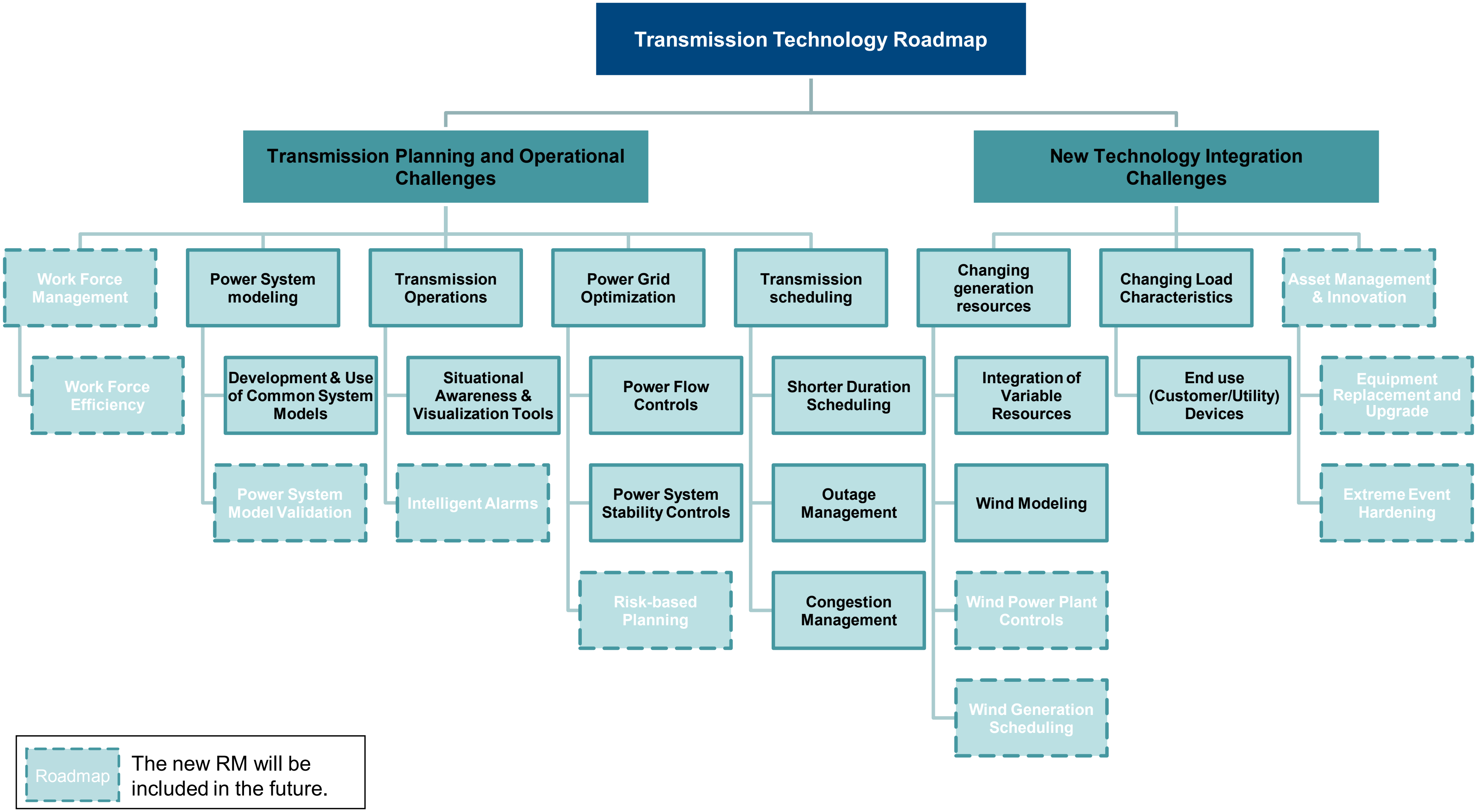
Changing generation resources

Integration of variable resources – As large amounts of variable generation such as wind are added to the energy mix in the Pacific Northwest, increasing amounts of flexible dispatchable resources are required to integrate them.
Wind modeling – The current wind models cause problems with system planning. Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support.

Changing Load Characteristics

The changing characteristics of end-use devices is another critical business challenge for the BPA transmission system.

Transmission Technology Roadmap Structure



- Transmission Technology Roadmap
  - Transmission Planning and Operational Challenges
    - Work Force Management
      - Work Force Efficiency
    - Power System modeling
      - Development & Use of Common System Models
      - Power System Model Validation
    - Transmission Operations
      - Situational Awareness & Visualization Tools
      - Intelligent Alarms
    - Power Grid Optimization
      - Power Flow Controls
      - Power System Stability Controls
      - Risk-based Planning
    - Transmission scheduling
      - Shorter Duration Scheduling
      - Outage Management
      - Congestion Management
  - New Technology Integration Challenges
    - Changing generation resources
      - Integration of Variable Resources
      - Wind Modeling
      - Wind Power Plant Controls
      - Wind Generation Scheduling
    - Changing Load Characteristics
      - End use (Customer/Utility) Devices
    - Asset Management & Innovation
      - Equipment Replacement and Upgrade
      - Extreme Event Hardening

The new RM will be included in the future.

Proposed Updates for Next Version

Additional Technology Roadmaps

A. Transmission Planning Operational Challenges

Work Force Management

- Work Force Efficiency

Power System Modeling

- Power System Model Validation

Transmission Operations

- Intelligent Alarms

Power Grid Optimization

- Risk-based Planning

B. New Technology Integration Challenges

Changing Generation Resources

- Wind Power Plant Controls
- Wind Generation Scheduling

Assets Management & Innovation

- Equipment Replacement & Upgrades
- Extreme Event Hardening Technologies

I. Power System Modeling

Development and Use of Common System Models Roadmap

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 analyses 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 & 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:

Analysis / 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 & 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?

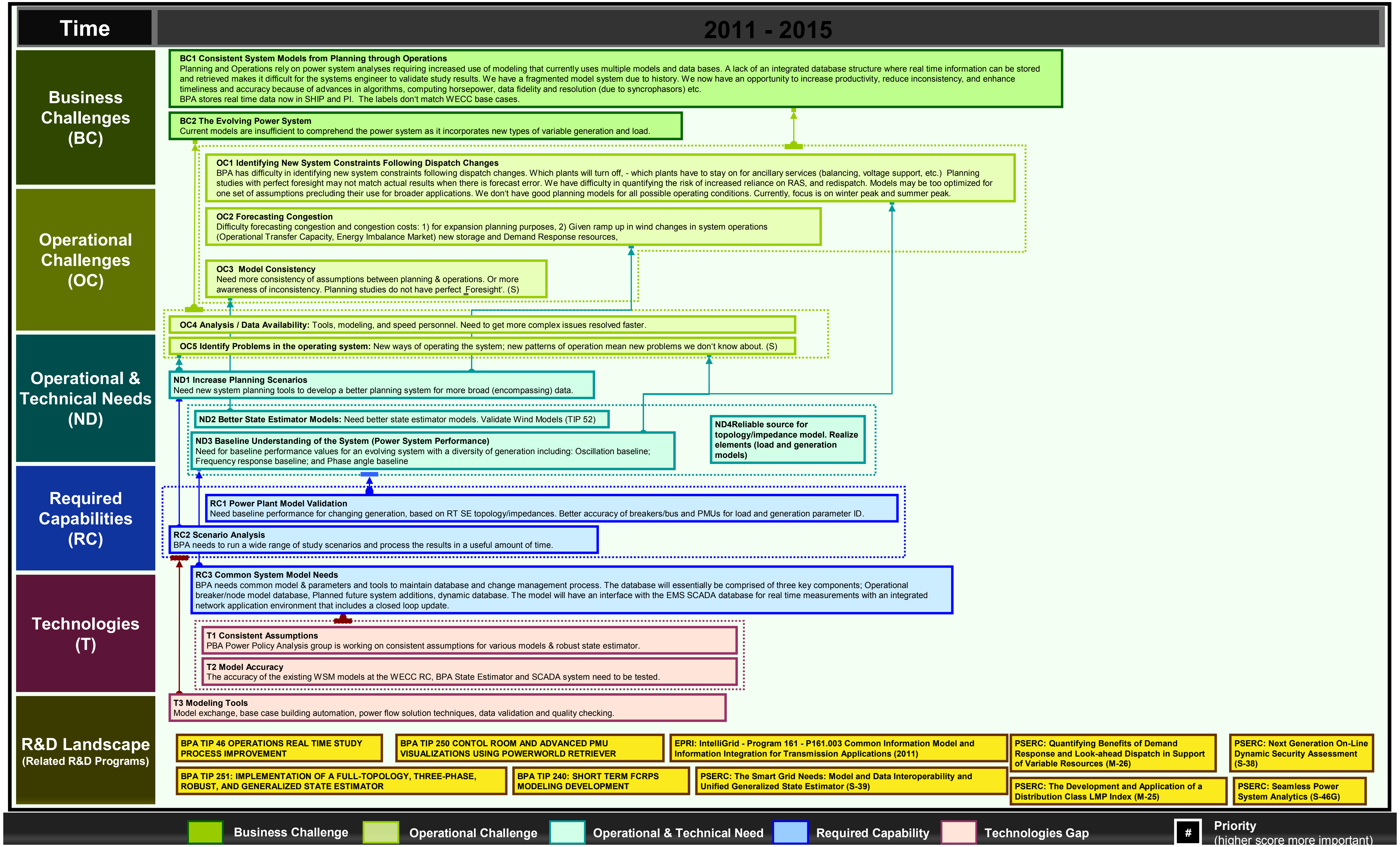
Business and Technological Challenges which are covered by commercialized technologies and products, however demonstration or confirmation studies may be required.

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.

BPA Transmission Technology Roadmap

Development and Use of Common System Models Technology Roadmap

Technical Area: Power System Modeling



Time | **2011 - 2015**

Business Challenges (BC)

BC1 Consistent System Models from Planning through Operations
Planning and Operations rely on power system analyses requiring increased use of modeling that currently uses multiple models and data bases. A lack of an integrated database structure where real time information can be stored and retrieved makes it difficult for the systems engineer to validate study results. We have a fragmented model system due to history. We now have an opportunity to increase productivity, reduce inconsistency, and enhance timeliness and accuracy because of advances in algorithms, computing horsepower, data fidelity and resolution (due to syncrophasors) etc.
BPA stores real time data now in SHIP and PI. The labels don't match WECC base cases.

BC2 The Evolving Power System
Current models are insufficient to comprehend the power system as it incorporates new types of variable generation and load.

Operational Challenges (OC)

OC1 Identifying New System Constraints Following Dispatch Changes
BPA has difficulty in identifying new system constraints following dispatch changes. Which plants will turn off, - which plants have to stay on for ancillary services (balancing, voltage support, etc.) 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.

OC2 Forecasting Congestion
Difficulty forecasting congestion and congestion costs: 1) for expansion planning purposes, 2) Given ramp up in wind changes in system operations (Operational Transfer Capacity, Energy Imbalance Market) new storage and Demand Response resources,

OC3 Model Consistency
Need more consistency of assumptions between planning & operations. Or more awareness of inconsistency. Planning studies do not have perfect ‚Foresight'. (S)

OC4 Analysis / Data Availability: Tools, modeling, and speed personnel. Need to get more complex issues resolved faster.

OC5 Identify Problems in the operating system: New ways of operating the system; new patterns of operation mean new problems we don't know about. (S)

Operational & Technical Needs (ND)

ND1 Increase Planning Scenarios
Need new system planning tools to develop a better planning system for more broad (encompassing) data.

ND2 Better State Estimator Models: Need better state estimator models. Validate Wind Models (TIP 52)

ND3 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

ND4Reliable source for topology/impedance model. Realize elements (load and generation models)

Required Capabilities (RC)

RC1 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.

RC2 Scenario Analysis
BPA needs to run a wide range of study scenarios and process the results in a useful amount of time.

RC3 Common System Model Needs
BPA needs common model & parameters and tools to maintain database and change 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.

Technologies (T)

T1 Consistent Assumptions
PBA Power Policy Analysis group is working on consistent assumptions for various models & robust state estimator.

T2 Model Accuracy
The accuracy of the existing WSM models at the WECC RC, BPA State Estimator and SCADA system need to be tested.

T3 Modeling Tools
Model exchange, base case building automation, power flow solution techniques, data validation and quality checking.

R&D Landscape (Related R&D Programs)

- BPA TIP 46 OPERATIONS REAL TIME STUDY PROCESS IMPROVEMENT
- BPA TIP 250 CONTOL ROOM AND ADVANCED PMU VISUALIZATIONS USING POWERWORLD RETRIEVER
- EPRI: IntelliGrid - Program 161 - P161.003 Common Information Model and Information Integration for Transmission Applications (2011)
- PSERC: Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)
- PSERC: Next Generation On-Line Dynamic Security Assessment (S-38)
- BPA TIP 251: IMPLEMENTATION OF A FULL-TOPOLOGY, THREE-PHASE, ROBUST, AND GENERALIZED STATE ESTIMATOR
- BPA TIP 240: SHORT TERM FCRPS MODELING DEVELOPMENT
- PSERC: The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)
- PSERC: The Development and Application of a Distribution Class LMP Index (M-25)
- PSERC: Seamless Power System Analytics (S-46G)

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap **#** Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & 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.**
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.

BPA Challenge	Lead Research Organization	Project Title & 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.	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!**

BPA Challenge	Lead Research Organization	Project Title & 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 Univ., 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.
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 Univ. 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.**

BPA Challenge	Lead Research Organization	Project Title & 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.
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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..

BPA Challenge	Lead Research Organization	Project Title & 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.	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.**
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 analyses 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.**
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.**

BPA Challenge	Lead Research Organization	Project Title & 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.	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

II Transmission Operations

Situational Awareness & Visualization Tools Roadmap

Business and Technology Challenges

One of the critical challenges in Transmission Monitoring & Control Systems, is in the area of Situational Awareness & Visualization Tools. The problem is the **Inability to monitor system dynamics and conditions in real-time**. This creates the following operational challenges:

Decision making and Support Tools

- Too much data – the information important for decision making and support is not readily available to system operators. We need a better focus on what you need to know and when you need it

Operational Tools/ Processes too slow for Operations

- Both power flow studies and RAS arming is operated by manual processes

Translating Analysis into Operating Solutions

- There are a lot more entities involved in coordinating decisions, data, in real time.

Situational Awareness

- Not yet sufficient for identifying the unexpected - Lack of tools that are optimized and forward looking or that can respond to changes based on situation.

System Alarms

- BPA has had Phase angle alarms since 1997. Need to avoid nuisance alarms. Alarms are good for one BPA transmission path. Difficult to set a phase angle limit that is valid for changing generation patterns/ conditions and unplanned outages.

To address these challenges the following are needed:

Visualization

- Decision support needs to include visualization, manage system alarms, provide training for dispatchers.

Situational Awareness

- Measurement-Based Alarms - For evolving events. Synchrophasor enabled. Types needed: Oscillation detection (mode meter); Voltage stability (generator voltage control tool); effective phase angle alarm and data mining tool.

Specific capabilities required are:
Situation Identification within 5 Seconds, Provide Appropriate Guidance Based on Situation, Provide applicable DSO related information, Better processing to get information out of data.

R&D Gaps

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

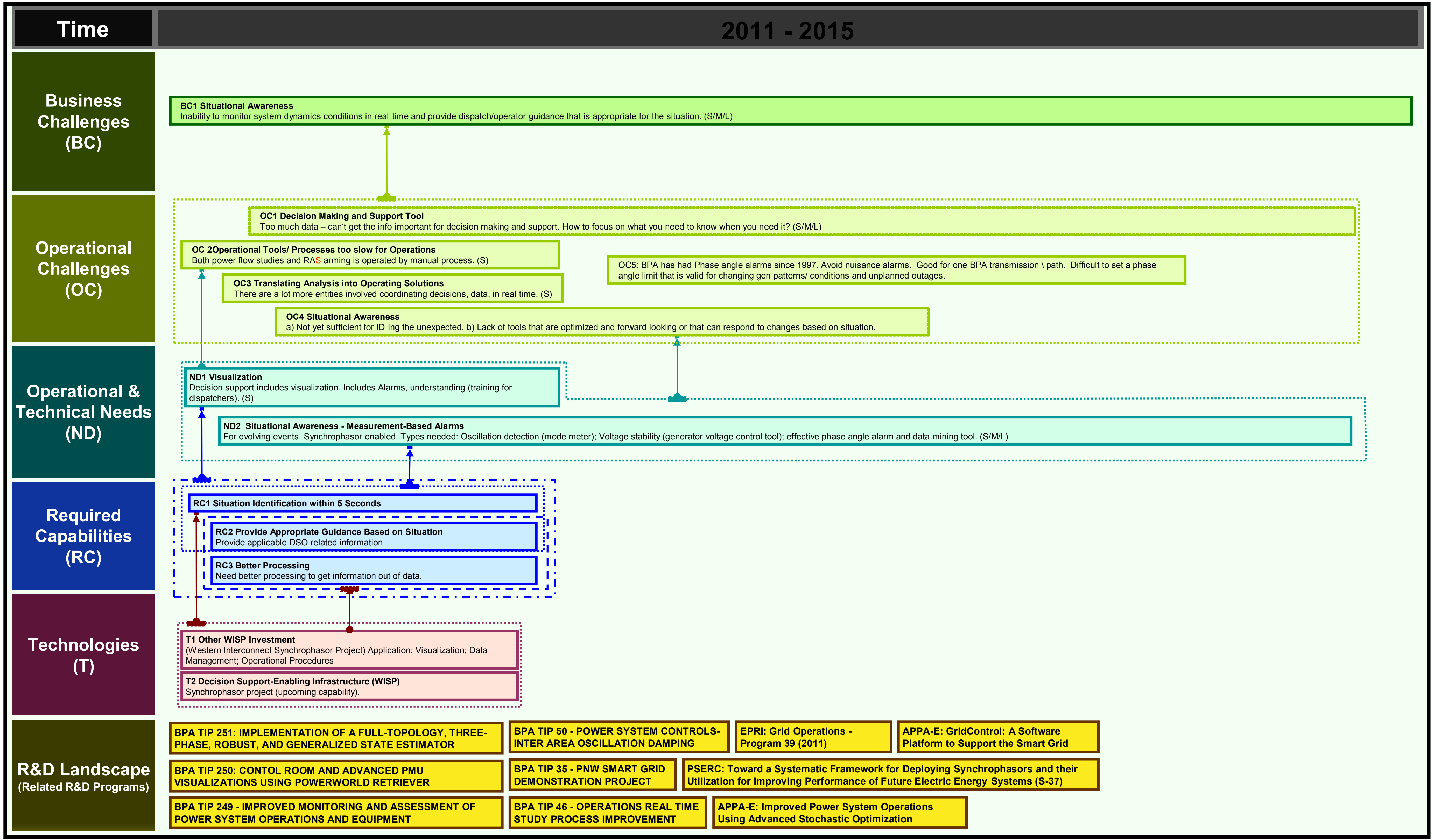
1. Translating Analysis into Operating Actions/Mitigations
2. Capability to Identify unusual states (through data mining)
3. Managing visualization (coordination and prioritization)

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

1. Decision making and Support Tools
2. Operational Tools/ Processes too slow for Operations
3. Situational Awareness
4. System Alarms
5. Visualization

Situational Awareness & Visualization Tools Technology Roadmap

Technical Area: Transmission Operations



Time 2011 - 2015

Business Challenges (BC)

BC1 Situational Awareness
Inability to monitor system dynamics conditions in real-time and provide dispatch/operator guidance that is appropriate for the situation. (S/M/L)

Operational Challenges (OC)

OC1 Decision Making and Support Tool
Too much data – can't get the info important for decision making and support. How to focus on what you need to know when you need it? (S/M/L)

OC 2Operational Tools/ Processes too slow for Operations
Both power flow studies and RAS arming is operated by manual process. (S)

OC3 Translating Analysis into Operating Solutions
There are a lot more entities involved coordinating decisions, data, in real time. (S)

OC5: BPA has had Phase angle alarms since 1997. Avoid nuisance alarms. Good for one BPA transmission \ path. Difficult to set a phase angle limit that is valid for changing gen patterns/ conditions and unplanned outages.

OC4 Situational Awareness
a) Not yet sufficient for ID-ing the unexpected. b) Lack of tools that are optimized and forward looking or that can respond to changes based on situation.

Operational & Technical Needs (ND)

ND1 Visualization
Decision support includes visualization. Includes Alarms, understanding (training for dispatchers). (S)

ND2 Situational Awareness - Measurement-Based Alarms
For evolving events. Synchrophasor enabled. Types needed: Oscillation detection (mode meter); Voltage stability (generator voltage control tool); effective phase angle alarm and data mining tool. (S/M/L)

Required Capabilities (RC)

RC1 Situation Identification within 5 Seconds

RC2 Provide Appropriate Guidance Based on Situation
Provide applicable DSO related information

RC3 Better Processing
Need better processing to get information out of data.

Technologies (T)

T1 Other WISP Investment
(Western Interconnect Synchrophasor Project) Application; Visualization; Data Management; Operational Procedures

T2 Decision Support-Enabling Infrastructure (WISP)
Synchrophasor project (upcoming capability).

R&D Landscape
(Related R&D Programs)

- BPA TIP 251: IMPLEMENTATION OF A FULL-TOPOLOGY, THREE-PHASE, ROBUST, AND GENERALIZED STATE ESTIMATOR
- BPA TIP 50 - POWER SYSTEM CONTROLS-INTER AREA OSCILLATION DAMPING
- EPRI: Grid Operations - Program 39 (2011)
- APPA-E: GridControl: A Software Platform to Support the Smart Grid
- BPA TIP 250: CONTOL ROOM AND ADVANCED PMU VISUALIZATIONS USING POWERWORLD RETRIEVER
- BPA TIP 35 - PNW SMART GRID DEMONSTRATION PROJECT
- PSERC: Toward a Systematic Framework for Deploying Synchrophasors and their Utilization for Improving Performance of Future Electric Energy Systems (S-37)
- BPA TIP 249 - IMPROVED MONITORING AND ASSESSMENT OF POWER SYSTEM OPERATIONS AND EQUIPMENT
- BPA TIP 46 - OPERATIONS REAL TIME STUDY PROCESS IMPROVEMENT
- APPA-E: Improved Power System Operations Using Advanced Stochastic Optimization

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap # Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
Oscillation detection; Voltage stability (generator voltage control tool); effective phase angle alarm and data mining tool.	Project Leader: Dmitry Kosterev Org: TPP	**TIP 50 - POWER SYSTEM CONTROLS- INTER AREA OSCILLATION DAMPING** This project will research devices and control schemes that can greatly improve damping of inter-area power oscillations. The primary focus is on North-South power oscillations, affecting California - Oregon Intertie. The secondary focus is on East - West oscillations affecting Montana imports into Pacific Northwest. The project methods are the Assessment of Grid Component Capabilities and Investigation of Wide Area Control Configurations.
Inability to monitor system dynamics conditions in real-time	Project Leader: Lee Hall Org: PES	**TIP 35 - PNW SMART GRID DEMONSTRATION PROJECT** The project expands upon the region‘s experience in the 2006 DOE-funded Pacific Northwest GridWise™ Demonstration Project on the Olympic Peninsula, which successfully tested demand response concepts and technologies. BPA‘s role is to coordinate with Battelle and participating utilities to develop a smart grid business case based on data from utilities, customers and project vendors to inform a cost benefit analysis. Lead public outreach and communication with governments (states, Northwest delegation, Tribes, others), non-partner utilities, educational institutions, energy and regulatory organizations (WECC, NERC, NWPCC, NWPPA, etc.), the general public and other regional demonstration projects. Support research and infrastructure design as well as integrating BPA data streams to the system. Integrate BPA operating units for policy and standards development, resource planning, wind integration, and coordination with DR programs.
Inability to monitor system dynamics conditions in real-time	Project Leader: Scott Lissit Org: TEP	**TIP 249 - IMPROVED MONITORING AND ASSESSMENT OF POWER SYSTEM OPERATIONS AND EQUIPMENT** This project demonstrates a cost effective monitoring solution delivering accurate, reliable information – supporting a wide range of predictive analyses and fault detection – enabling improvements in the data employed for applications from phasor measurement to asset maintenance to providing the information necessary to the effective application of power electronics, helping to improve service delivery, asset longevity and productivity. Using optical sensors developed by the United States Navy and licensed by SSC, the monitoring solution delivers continuous, highly accurate measurements of temperature, pressure, current, voltage and material strain.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Inability to monitor system dynamics conditions in real-time	Project Leader: Brian Tuck Org: TOT	**TIP 46 - OPERATIONS REAL TIME STUDY PROCESS IMPROVEMENT** This project uses the innovative Operations Study Process Improvement environment to investigate options to reduce unnecessary risks and curtailments by accurately modeling near term system conditions for Operations study engineers following an unplanned outage or during extreme operating conditions. The study automation system will be designed to assist BPA Systems Operations engineers to calculate a reliable system Operating Limit (SOL) for real time operation of BPA's critical transmission paths such as the California Oregon Intertie (COI). The system will be built around PowerWorld's Simulator power flow that is used daily for off-line studies.
Inability to monitor system dynamics conditions in real-time	Project Leader: Ross Pies Org: ST	**250 - CONTOL ROOM AND ADVANCED PMU VISUALIZATIONS USING POWERWORLD RETRIEVER** This project will use a previously created full topology power system model to implement a new series of power system visualizations in PowerWorld Simulator and Retriever for use in the BPA control center. These visualizations will be for use on BPA's large video wallboard and smaller desktop displays, and scripts will be written to automatically update the displays following system maintenance. Automated building of substation diagrams will also be added to the PowerWorld products. In addition, new tools will be added to PowerWorld's visualization environment to handle phase measurement unit (PMU) data, including trending and real-time contouring of this data. These new tools will be available to both the planning and operations staff of BPA for off line or real time analysis.
Decision making and support tools, translating analysis into operating solutions, situational awareness	EPRI	**Grid Operations - Program 39 (2011)** Having good information based on real-time data, as well as decision-making support and an in-depth understanding of the complexity of the grid, is essential when operating the grid. Today, utilization of transmission assets has reached a level requiring decisions to be made quickly to avoid possible reliability events. Grid Operations research is addressing these needs by improving real-time situational awareness, wide-area protection, and the capabilities to manage the grid through extreme events as well as to restore the system in the event of an outage.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Operational tools/ processes too slow for Operations - Both power flow studies and RAS arming is operated by manual processes	PSERC Project Leader: Dr. Marija Ilic Carnegie Mellon University; milic@ece.cmu.edu	**Toward a Systematic Framework for Deploying Synchrophasors and their Utilization for Improving Performance of Future Electric Energy Systems (S-37)** This project addresses the difficult problem of critical measurements and control strategies for managing today's and future electric energy systems according to pre-specified technical and economic criteria. A systematic model-based framework will be introduced for determining measurement and control priorities on a given system, so that the most limiting technical problems are managed according to their severity and importance. While the answers to these problems are system specific, the framework provides an approach to identifying critical measurements and control actions for any given system of interest.
Decision making and support tools	ARPA-E Sandia National Laboratory	**Improved Power System Operations Using Advanced Stochastic Optimization** Market management systems (MMSs) are used to securely and optimally determine which energy resources should be used to service energy demand. Increased penetration of renewable energy resources increases the uncertainty of operating and market conditions, complicating decision making. Sandia National Laboratory will collaborate with Iowa State University, the University of California at Davis, Alstom Grid, and ISO New England to create probability-based decision-making software for MMSs that can account for the increased uncertainty while retaining overall grid reliability and market stability.
Operational tools/ processes too slow for Operations - Both power flow studies and RAS arming is operated by manual processes	ARPA-E Cornell University	**GridControl: A Software Platform to Support the Smart Grid** Cornell University will create software that will reduce the time and difficulties required to prototype and demonstrate new smart-grid control methods. The project will enable cloud computing capabilities that are more responsive, secure, and accurate for grid control.

III. Power Grid Optimization

Power Flow Controls Roadmap

Business and Technology Challenges

A critical challenge in Transmission Monitoring & Cont rol Systems is **Transmission System Capacity** – we need to increase capacity of the transmission system without extensive capital investment. This creates multiple operational challenges:

Network Capacity Limitations

- A network increases reliability at the cost of capacity underutilization and inefficiency. In a transmission grid, capacity is limited by the lowest-capacity segment. Electricity follows a —path of least resistance" (lowest impedance), so the first line to reach its thermal capacity limits the capacity of the entire system, even though a majority of the lines of the system may be significantly below their limit.

Voltage Stability

- Increased application of variable energy resources balanced within-hour by remote conventional resources adds additional variation to power flows and voltage support capabilities.

These challenges result in the following operational and technical needs:

Control Power Flows

- Having the ability to explicitly control power flow could enable accessing this unused capacity to relieve congestion, relieve outage constraints and improve system security as an alternative to new transmission lines

Voltage Controls

- Major load service paths that are voltage stability limited may require additional devices that control voltage variability.

Required capabilities to fulfill the needs are:

Power Flow System Components for Grid Optimization

- Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed. Much longer long term assessment and evaluation of interactions.

Automated Controls

- Automated controls must be able to handle sudden events (unplanned outages) or unexpected operating conditions in ways that don‘t disturb the rest of the system.

System Expansion & Optimization

- Optimization of the existing system, increase in number of lines & interconnections by about 10%. Control power flow and Optimize RAS

Related technology is power flow control/flexible alternating current transmission system (FACTS) devices. HVDC (back to back or AC to DC conversion, voltage source conversion) phase shifting, impedance changing technologies

R&D Gaps

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

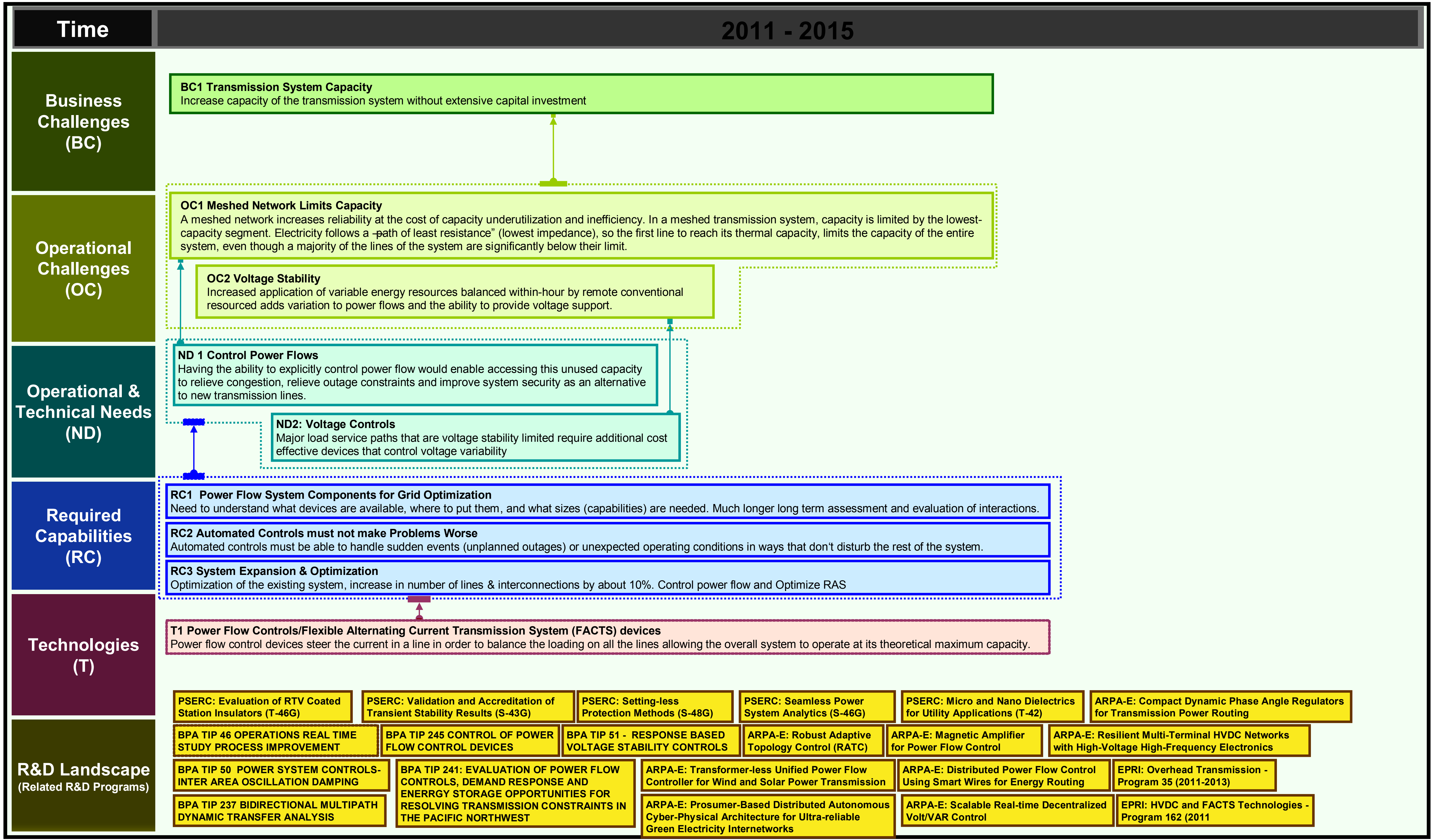
1. Network Capacity Limitations
2. System Expansion & Optimization
3. Automated Controls
4. Response based controls

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

1. Control Power Flows
2. Power Flow System Components for Grid Optimization
3. Voltage Stability
4. Voltage Controls

Power Flow Controls Technology Roadmap

Technical Area:
Power Grid Optimization



Time	2011 - 2015
Business Challenges (BC)	**BC1 Transmission System Capacity** Increase capacity of the transmission system without extensive capital investment
Operational Challenges (OC)	**OC1 Meshed Network Limits Capacity** A meshed network increases reliability at the cost of capacity underutilization and inefficiency. In a meshed transmission system, capacity is limited by the lowest-capacity segment. Electricity follows a ―path of least resistance” (lowest impedance), so the first line to reach its thermal capacity, limits the capacity of the entire system, even though a majority of the lines of the system are significantly below their limit. **OC2 Voltage Stability** Increased application of variable energy resources balanced within-hour by remote conventional resourced adds variation to power flows and the ability to provide voltage support.
Operational & Technical Needs (ND)	**ND 1 Control Power Flows** Having the ability to explicitly control power flow would enable accessing this unused capacity to relieve congestion, relieve outage constraints and improve system security as an alternative to new transmission lines. **ND2: Voltage Controls** Major load service paths that are voltage stability limited require additional cost effective devices that control voltage variability
Required Capabilities (RC)	**RC1 Power Flow System Components for Grid Optimization** Need to understand what devices are available, where to put them, and what sizes (capabilities) are needed. Much longer long term assessment and evaluation of interactions. **RC2 Automated Controls must not make Problems Worse** Automated controls must be able to handle sudden events (unplanned outages) or unexpected operating conditions in ways that don't disturb the rest of the system. **RC3 System Expansion & Optimization** Optimization of the existing system, increase in number of lines & interconnections by about 10%. Control power flow and Optimize RAS
Technologies (T)	**T1 Power Flow Controls/Flexible Alternating Current Transmission System (FACTS) devices** Power flow control devices steer the current in a line in order to balance the loading on all the lines allowing the overall system to operate at its theoretical maximum capacity.
R&D Landscape (Related R&D Programs)	PSERC: Evaluation of RTV Coated Station Insulators (T-46G) PSERC: Validation and Accreditation of Transient Stability Results (S-43G) PSERC: Setting-less Protection Methods (S-48G) PSERC: Seamless Power System Analytics (S-46G) PSERC: Micro and Nano Dielectrics for Utility Applications (T-42) ARPA-E: Compact Dynamic Phase Angle Regulators for Transmission Power Routing BPA TIP 46 OPERATIONS REAL TIME STUDY PROCESS IMPROVEMENT BPA TIP 245 CONTROL OF POWER FLOW CONTROL DEVICES BPA TIP 51 - RESPONSE BASED VOLTAGE STABILITY CONTROLS ARPA-E: Robust Adaptive Topology Control (RATC) ARPA-E: Magnetic Amplifier for Power Flow Control ARPA-E: Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency Electronics BPA TIP 50 POWER SYSTEM CONTROLS-INTER AREA OSCILLATION DAMPING BPA TIP 241: EVALUATION OF POWER FLOW CONTROLS, DEMAND RESPONSE AND ENERRGY STORAGE OPPORTUNITIES FOR RESOLVING TRANSMISSION CONSTRAINTS IN THE PACIFIC NORTHWEST ARPA-E: Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission ARPA-E: Distributed Power Flow Control Using Smart Wires for Energy Routing EPRI: Overhead Transmission - Program 35 (2011-2013) BPA TIP 237 BIDIRECTIONAL MULTIPATH DYNAMIC TRANSFER ANALYSIS ARPA-E: Prosumer-Based Distributed Autonomous Cyber-Physical Architecture for Ultra-reliable Green Electricity Internetworks ARPA-E: Scalable Real-time Decentralized Volt/VAR Control EPRI: HVDC and FACTS Technologies - Program 162 (2011

🟩 Business Challenge 🟩 Operational Challenge ▢ Operational & Technical Need 🟦 Required Capability ▢ Technologies Gap # Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
Increased application of variable energy resources balanced within-hour by remote conventional resources adds additional variation to power flows and voltage support capabilities.	Project Leader: Dmitry Kosterev Org: TPP	**TIP 51 - RESPONSE BASED VOLTAGE STABILITY CONTROLS** This project researches all three types of controls (primary, secondary, emergency) will be considered. Primary Voltage control - Response-based controls for fast reactive switching of 500-kV shunt capacitor banks in Portland / Salem area. Coordination reactive resources in Southern Oregon / Northern California area. Secondary Voltage Controls - Reactive power management to optimize voltage profile and to maximize reactive margins. Emergency voltage controls - Low voltage shedding.
Need to increase capacity of the transmission system without extensive capital investment	Project Leader: Travis Togo Org: PGSP	**TIP 241 - EVALUATION OF POWER FLOW CONTROLS, DEMAND RESPONSE AND ENERRGY STORAGE OPPORTUNITIES FOR RESOLVING TRANSMISSION CONSTRAINTS IN THE PACIFIC NORTHWEST** The proposed project will 1) Develop the framework and methodology for evaluating powerflow control and load control options in the transmission planning process – i.e. expanding the toolbox of the transmission planners to include applicable non-wire solutions, 2) Test the methodology to size up powerflow control and load control options for a) Portland metro area, b) Seattle / Northern Intertie, c) Export capability out of Pacific Northwest, 3) Study feasibility of various powerflow control and load control options, and 4) Evaluate control strategies.
Power Flow System Components for Grid Optimization - Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed.	Project Leader: Paul Ferron Org: TPP	**TIP 245 - CONTROL OF POWER FLOW CONTROL DEVICES** The objective of this project is to investigate the effectiveness of power flow control devices such as FACTS devices with regards to congestion management and improving the usage of the existing transmission system. This will allow providing a more flexible system and pushing more power through the existing lines. We will derive the schemes to determine the optimal settings of the power flow control devices taking into account the varying power injections from intermittent and variable generation resources such as wind and solar generation.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Major load service paths that are voltage stability limited may require additional devices that control voltage variability.	Project Leader: Dmitry Kosterev Org: TPP	**TIP 51 - RESPONSE BASED VOLTAGE STABILITY CONTROLS** This project researches all three types of controls (primary, secondary, emergency) will be considered. Primary Voltage control - Response-based controls for fast reactive switching of 500-kV shunt capacitor banks in Portland / Salem area. Coordination reactive resources in Southern Oregon / Northern California area. Secondary Voltage Controls - Reactive power management to optimize voltage profile and to maximize reactive margins. Emergency voltage controls - Low voltage shedding.
Control power flows	ARPA-E Texas Engineering Experiment Station	**Robust Adaptive Topology Control (RATC)** Historically, the electric grid was designed to be passive, causing electric power to flow along the path of least resistance. The Texas Engineering Experiment Station team will develop a new system that allows real-time, automated control over the transmission lines that make up the electric power grid. This new system would create a more robust, reliable electric grid, and reduce the risk of future blackouts, potentially saving billions of dollars a year.
Control power flows	ARPA-E Michigan State University	**Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission** Michigan State will develop a unified power flow controller (UPFC) that will have enormous technological and economic impacts on controlling the routing of energy through existing power lines. The UPFC will incorporate an innovative circuitry configuration that eliminates the transformer, an extremely large and heavy component, from the system. As a result, it will be light weight, efficient, reliable, low cost, and well suited for fast and distributed power flow control of wind and solar power.
Control power flows	ARPA-E Oak Ridge National Laboratory	**Magnetic Amplifier for Power Flow Control** Complete control of power flow in the grid is prohibitively expensive, which has led to sub-optimal, partial control. Oak Ridge National Laboratory will develop a magnetic based valve-like device for full power flow control. The controller will be inherently reliable and cost-effective, making it amenable for widespread distributed power flow control. The benefits are far-reaching, including full utilization of power system assets, increased reliability and efficiency, and more effective use of renewable resources.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Control power flows	ARPA-E Georgia Tech Research Corporation	**Prosumer-Based Distributed Autonomous Cyber-Physical Architecture for Ultra-reliable Green Electricity Internetworks** Georgia Tech will develop and demonstrate an internet-like, autonomous control architecture for the electric power grid. The architecture has distributed intelligence, autonomously coordinating control within a network that includes energy production units, storage units, and consumers (homes, buildings, microgrids, utility systems). It will reduce constraints on grid control and enable massive penetration of distributed energy resources (primarily wind and solar power) and storage devices (such as batteries).
Control power flows	ARPA-E Smart Wire Grid, Inc	**Distributed Power Flow Control Using Smart Wires for Energy Routing** Over 660,000 miles of transmission line exist within the continental United States with roughly 33% of these lines experiencing significant congestion. This congestion exists while, on average, only 45-60% of the total transmission line capacity is utilized. A team led by startup company Smart Wire Grid will develop a solution for controlling power flow in the transmission grid to better take advantage of the unused capacity. The power controller will be a ―smart wire” that incorporates advanced control software, sensors, and communications technologies.
Power flow system components for grid optimization	ARPA-E California Institute of Technology	**Scalable Real-time Decentralized Volt/VAR Control** Caltech will develop scalable, real-time, decentralized methods for power control to achieve system-wide efficiency, stability, reliability, and power quality in the presence of uncertain renewable generation. The distributed control architecture will allow each of the end nodes to effectively manage their own power, while at the same time optimizing overall power flow within the grid. This will enable an interconnected system with millions of active energy applications, such as distributed wind and solar power units.
Power flow system components for grid optimization	ARPA-E General Electric Company-Global Research	**Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency Electronics** Some advanced transmission technologies require expensive power conversion stations to interface with the grid. GE Global Research will collaborate with North Carolina State University (NCSU) and Rensselaer Polytechnic Institute (RPI) to develop a prototype transmission technology that incorporates an advanced semiconductor material, silicon carbide. This prototype will operate at a high voltage level appropriate for the grid. It will decrease the cost and complexity of advanced transmission systems as well as improve efficiency.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Increase capacity of the transmission system without extensive capital investment	EPRI	**Overhead Transmission - Program 35 (2011-2013)** Transmission companies face issues such as improving safety and reliability, as well as cutting operations and maintenance (O&M) costs. They are also seeking ways to increase transmission capacity without making large capital investments. Reducing capital expenditures for new and refurbished equipment is another priority. This EPRI research program is designed to address the research needs of transmission asset owners. The program includes projects focused on specific components (e.g., insulators, compression connectors and crossarms) as well as projects focused on issues (e.g., lightning and grounding, live working, and transmission capacity). The program delivers a blend of short-term tools such as software, reference guides and field guides, together with longer-term research such as component aging tests and the development of sensors for monitoring line components and performance.
Control power flows	EPRI	**HVDC and FACTS Technologies - Program 162 (2011** The power industry is faced with the difficulty of acquiring rights-of-way for new transmission lines, the need to improve the reliability of the power grid, and the challenge of integrating renewable power sources into power systems. High-voltage direct current (HVDC) and flexible ac transmission system (FACTS) technologies offer some effective schemes to meet these demands. Applying HVDC technologies within an existing ac system is an option that can increase the transmission capacity of the existing power system. HVDC technologies can also be applied to the power system to improve system reliability. HVDC may provide solutions in integrating renewable power sources such as wind and solar energy into a power system. FACTS is an effective means of managing power flows. Both HVDC converters and FACTS share some common technologies. This program offers a comprehensive portfolio of HVDC and FACTS research, consisting of two HVDC project sets and one FACTS project set. Participants can apply program research to existing and future power systems, and better understand the options of using these technologies when evaluating these systems.
Power flow system components for grid optimization - Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed.	PSERC Project Leader: Ravi S. Gorur Arizona State Univ., ravi.gorur@asu.edu, 480-965-4894	**Evaluation of RTV Coated Station Insulators (T-46G)** Evaluate and quantify the performance of RTV-coated porcelain insulators when compared with uncoated porcelain and composite insulators.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Power flow system components for grid optimization	PSERC Project Leader: Tom Overbye Univ. IL/Urbana, overbye@illinois.edu, 217-333-4463)	**Validation and Accreditation of Transient Stability Results (S-43G)** Determination of the transient stability properties of a power system for a set of contingencies is of vital importance. However, it is widely known in the industry that different transient stability packages can give substantially different results for seemingly identical models. The goal of this project is to develop validation and accreditation methodologies for transient stability packages with a focus on the Western Electricity Coordinating Council (WECC) system models. Different commercial transient stability packages will be utilized for testing and comparisons.
Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed	PSERC Project Leader: A. P. Sakis Meliopoulos Georgia Institute of Technology sakis.m@gatech.edu, 404-894-2926)	**Setting-less Protection Methods (S-48G)** The capabilities of protective relays have increased dramatically as higher and higher end microprocessors are used in modern numerical relays. At the same time the complexity has increased primarily because numerical relays are set to mimic the traditional electromechanical counterparts. We propose to examine approaches that will lead to setting-less protection schemes. Several approaches will be examined: (a) adaptive relaying, (b) component state estimation approach, (c) substation based protection, and pattern recognition based approach. Each approach will be evaluated with the following criteria: (a) feasibility, (b) dependability, (c) security, (d) reliability, and (e) speed of protection. It is expected that these approaches will lead to true setting-less protection schemes.
Power Flow System Components for Grid Optimization, Automated controls, System Expansion & Optimization	PSERC Project Leader: James McCalley Iowa State Univ. 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.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Power flow system components for grid optimization - Need to understand what devices are available, what are their operating characteristics, where to put them, and what sizes (capabilities) are needed.	PSERC Project Leader: Ravi S. Gorur Arizona State University, ravi.gorur@asu.edu	**Micro and Nano Dielectrics for Utility Applications (T-42)** New materials made from polymers and porcelain containing micron to nanometer (nm) size ingredients are being used for various utility applications like insulators, bushings, instrument transformers, etc. They promise significant improvement over other materials in key metrics like dielectric strength, resistance to corona (or partial discharges), etc. The underlying mechanisms and the failure modes are not well understood. We will learn more about the dielectric behavior through experiments, modeling and computation of internal electric fields. The results are useful for condition assessment of existing products and identification of superior material formulations for use in equipment that is more compact, performs better and lasts longer than present technology.
Control power flows	ARPA-E Varentec, Inc.	**Compact Dynamic Phase Angle Regulators for Transmission Power Routing** Varentec will develop a compact, low-cost solution for controlling power flow on transmission networks. The technology will enhance grid operations through improved asset utilization and by dramatically reducing the number of transmission lines that have to be built to meet increased renewable energy penetration. Finally, the ability to affordably and dynamically control power flow will open up new competitive energy markets which were not possible under the current regulatory structure and technology base.

Power System Stability Controls

Business and Technology Challenges

One of the critical challenges in Transmission Monitoring & Control Systems, is **Managing System Disturbances**. Utilization of synchrophasor technology can be improved by leveraging wide area and response based controls. Also, the electric system can be protected against extreme events by using Synchrophasor data.

Specific operational challenges include:
Protection of load voltage, and ensure sufficiency of safety-nets.
Transformer protection against GIC

Operation and technical needs related to the challenges include:
Ensure Sufficiency of Safety-Nets

- Safety Nets are protective schemes designed to localize disturbances and the uncontrolled loss of generation, transmission and interruption of customer electric service. They are needed to minimize and reduce the severity of low probability, unforeseen events to prevent cascading.

Managing impacts of GIC events (Geomagnetically Induced Current)

- GIC events are caused by half cycle saturation of the transformer core due to the DC offset from GIC
- GIC transformer protection strategy
- GIC Reactive control strategy

The following are specific technology capabilities needed:
Manage RAS-initiated responses to system disturbances such as Generation Drop and Reactive Switching to match the actual system needs (not the pre-Armed RAS conditions)
Minimize excessive RAS generation drop
Sense power system oscillation modes (0.25-0.8 Hz), and mitigate with new oscillation damping equipment

- Modulated Brake, generation controls, HVDC, WACS/RAS enhancements etc.

Technologies capable of dealing with GIC events should be able to manage:

- Increased relative VAR demand
- Increased harmonics that impact reactive support elements of the bulk electrical system (SVC, capacitor banks, and filter groups).
- Increased thermal stress on transformers due to internal heating by stray flux during the saturated portion of the AC cycle.

R&D Gaps

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

1. Manage RAS-initiated responses to system disturbances
2. Minimize excessive RAS generation drop
3. Transformer protection for GIC or impending future
4. GIC Reactive control strategy
5. Impact of GIC Harmonics on FACTS, HVDC controls, protective relays

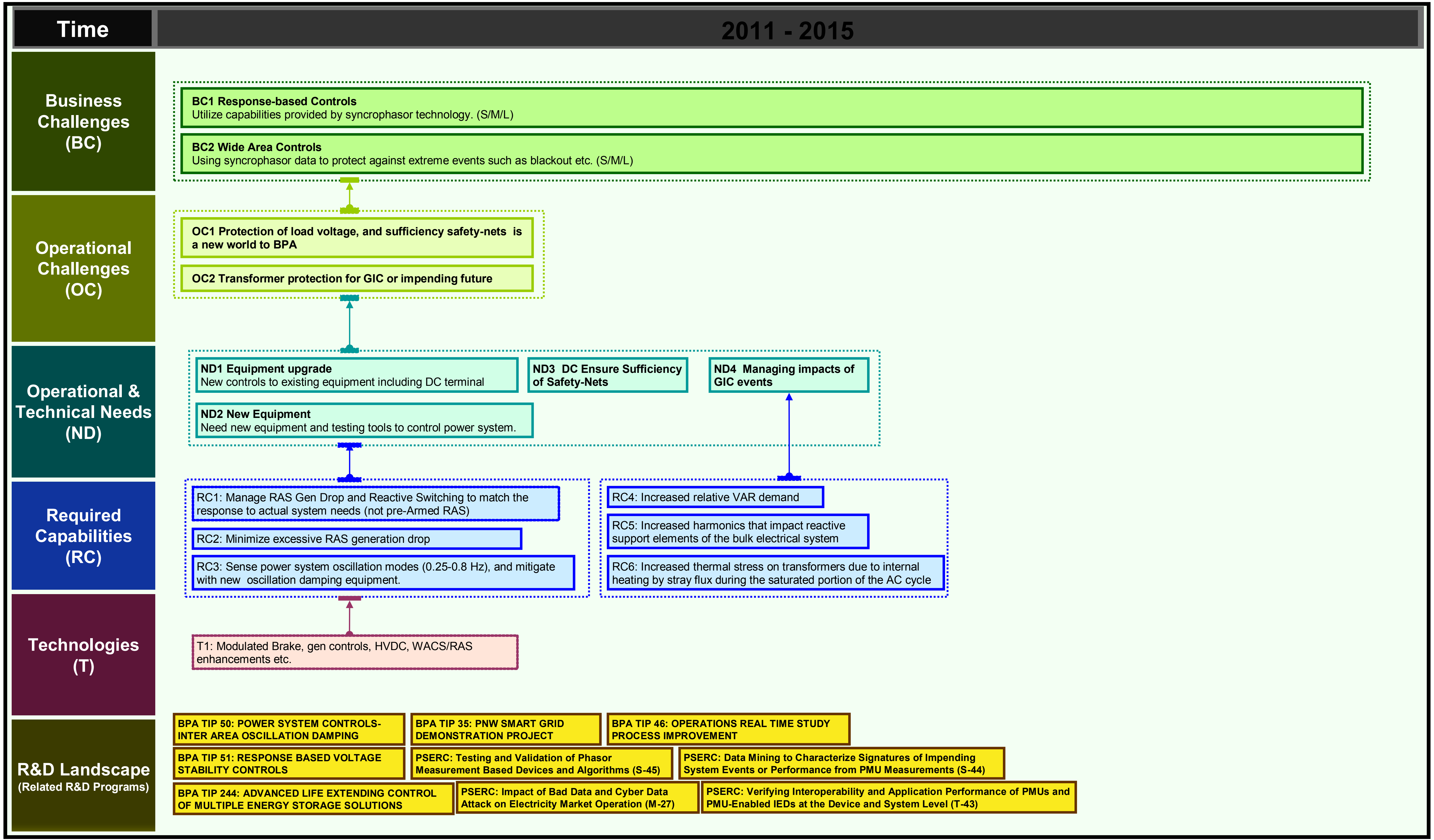
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Protection of load voltage
2. Ensure Sufficiency of Safety-Nets
3. Managing impacts of GIC events
4. Sense power system oscillation modes, and mitigate with new oscillation damping equipment

BPA Transmission Technology Roadmap

Power System Stability Controls Technology Roadmap

Technical Area: Power Grid Optimization



Time — **2011 - 2015**

Business Challenges (BC)

BC1 Response-based Controls
Utilize capabilities provided by syncrophasor technology. (S/M/L)

BC2 Wide Area Controls
Using syncrophasor data to protect against extreme events such as blackout etc. (S/M/L)

Operational Challenges (OC)

OC1 Protection of load voltage, and sufficiency safety-nets is a new world to BPA

OC2 Transformer protection for GIC or impending future

Operational & Technical Needs (ND)

ND1 Equipment upgrade
New controls to existing equipment including DC terminal

ND3 DC Ensure Sufficiency of Safety-Nets

ND4 Managing impacts of GIC events

ND2 New Equipment
Need new equipment and testing tools to control power system.

Required Capabilities (RC)

RC1: Manage RAS Gen Drop and Reactive Switching to match the response to actual system needs (not pre-Armed RAS)

RC2: Minimize excessive RAS generation drop

RC3: Sense power system oscillation modes (0.25-0.8 Hz), and mitigate with new oscillation damping equipment.

RC4: Increased relative VAR demand

RC5: Increased harmonics that impact reactive support elements of the bulk electrical system

RC6: Increased thermal stress on transformers due to internal heating by stray flux during the saturated portion of the AC cycle

Technologies (T)

T1: Modulated Brake, gen controls, HVDC, WACS/RAS enhancements etc.

R&D Landscape (Related R&D Programs)

- BPA TIP 50: POWER SYSTEM CONTROLS-INTER AREA OSCILLATION DAMPING
- BPA TIP 35: PNW SMART GRID DEMONSTRATION PROJECT
- BPA TIP 46: OPERATIONS REAL TIME STUDY PROCESS IMPROVEMENT
- BPA TIP 51: RESPONSE BASED VOLTAGE STABILITY CONTROLS
- PSERC: Testing and Validation of Phasor Measurement Based Devices and Algorithms (S-45)
- PSERC: Data Mining to Characterize Signatures of Impending System Events or Performance from PMU Measurements (S-44)
- BPA TIP 244: ADVANCED LIFE EXTENDING CONTROL OF MULTIPLE ENERGY STORAGE SOLUTIONS
- PSERC: Impact of Bad Data and Cyber Data Attack on Electricity Market Operation (M-27)
- PSERC: Verifying Interoperability and Application Performance of PMUs and PMU-Enabled IEDs at the Device and System Level (T-43)

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap # Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
Oscillation detection; Voltage stability (generator voltage control tool); effective phase angle alarm and data mining tool.	Project Leader: Dmitry Kosterev Org: TPP	**TIP 50 - POWER SYSTEM CONTROLS- INTER AREA OSCILLATION DAMPING** This project will research devices and control schemes that can greatly improve damping of inter-area power oscillations. The primary focus is on North-South power oscillations, affecting California - Oregon Intertie. The secondary focus is on East - West oscillations affecting Montana imports into Pacific Northwest. The project methods are the Assessment of Grid Component Capabilities and Investigation of Wide Area Control Configurations.
Utilization of the synchrophasor technology can be improved by leveraging wide area and response based controls	Project Leader: Lee Hall Org: PES	**TIP 35 - PNW SMART GRID DEMONSTRATION PROJECT** The project expands upon the region's experience in the 2006 DOE-funded Pacific Northwest GridWise™ Demonstration Project on the Olympic Peninsula, which successfully tested demand response concepts and technologies. BPA's role is to coordinate with Battelle and participating utilities to develop a smart grid business case based on data from utilities, customers and project vendors to inform a cost benefit analysis. Lead public outreach and communication with governments (states, Northwest delegation, Tribes, others), non-partner utilities, educational institutions, energy and regulatory organizations (WECC, NERC, NWPCC, NWPPA, etc.), the general public and other regional demonstration projects. Support research and infrastructure design as well as integrating BPA data streams to the system. Integrate BPA operating units for policy and standards development, resource planning, wind integration, and coordination with DR programs.
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future	Project Leader: Brian Tuck Org: TOT	**TIP 46 - OPERATIONS REAL TIME STUDY PROCESS IMPROVEMENT** This project uses the innovative Operations Study Process Improvement environment to investigate options to reduce unnecessary risks and curtailments by accurately modeling near term system conditions for Operations study engineers following an unplanned outage or during extreme operating conditions. The study automation system will be designed to assist BPA Systems Operations engineers to calculate a reliable system Operating Limit (SOL) for real time operation of BPA's critical transmission paths such as the California Oregon Intertie (COI). The system will be built around PowerWorld's Simulator power flow that is used daily for off-line studies.
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future	PSERC Project Leader: Lang Tong Cornell Univ. ltong@ece.cornell.edu 607-255-3900	**Impact of Bad Data and Cyber Data Attack on Electricity Market Operation (M-27)** This project investigates impacts of bad or malicious data on economic dispatch. Specifically, the project studies changes in price and economic dispatch due to state estimation errors caused by meter malfunction, topological errors, and maliciously injected data by adversaries. The research develops ways of detecting bad/malicious data and investigates worst case attack strategies by adversaries with different access capabilities.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future using the synchrophasor technology	PSERC Project Leader: Anurag K Srivastava Washington State University asrivast@eecs.wsu.edu	**Testing and Validation of Phasor Measurement Based Devices and Algorithms (S-45)** The electric power system is moving towards the Smart Grid (SG) development for improved reliable, secure and economic operation. Implementation of such a system requires enhanced testing and validation of smart grid technologies as well as development of new approaches to fully utilize the capabilities of these technologies. This project is focused on testing and validation of phasor based applications, testing of devices using existing real time hardware-in-the-loop digital simulation testbed, and development of new applications of phasor data. Specifically, testing of PMU based voltage stability and state estimation algorithms will be performed in real time; a new protection approach will be developed and demonstrated for dynamic protection of transformers and it will be compared to conventional protection schemes. Comparative testing and analysis of PMU, PDC, and historians will be performed using existing and enhanced testbed.
Protection of load voltage, and sufficiency safety-nets and transformer protection for GIC or impending future using the synchrophasor technology	PSERC Project Leader: Vijay Vittal Arizona State, vijay.vittal@asu.edu, 480-965-1879	**Data Mining to Characterize Signatures of Impending System Events or Performance from PMU Measurements (S-44)** This project applies data mining techniques to characterize signatures of impending system events or performance from PMU measurements. The project will evaluate available data mining tools and analyze the ability of these tools to characterize signatures of impending systems events or detrimental system behavior. The use of PMU measurements from multiple locations will also be considered. The performance of the data mining tools will be verified by comparing the results obtained for measurements corresponding to know events on the system.
Utilization of the synchrophasor technology	PSERC Project Leader: Mladen Kezunovic Texas A&M University, kezunov@ee.tamu.edu 979-845-7509	**Verifying Interoperability and Application Performance of PMUs and PMU-Enabled IEDs at the Device and System Level (T-43)** As a result of the American Recovery and Reinvestment Act (ARRA) funding and other unrelated infrastructure investment plans in the utility business it is expected that the number of installed Phasor Measurement Units (PMUs) and PMU-enabled Intelligent Electronic Devices (IEDs) will dramatically increase. New applications using synchronized data will become an important part of the overall power system operation. The risk of using such elaborate high precision measurement infrastructure requires appropriate testing for interoperability and application performance at both the device and system level to ensure accuracy and consistency across multiple IED types, as well as future scalability and upgradeability, hence avoiding the costly infrastructure becoming a stranded asset.

IV. Transmission Scheduling

Shorter Duration Scheduling Roadmap

Business and Technology Challenges

There are four major challenges in short duration scheduling of transmission:
1) Forecasting transmission flows in near-term, 2) Sub-hour scheduling and integration of ancillary energy markets, 3) Difficulty in accommodating variability in demand and supply, and 4) Potential formation of region-wide energy imbalance market

Transmission network flows are currently not calculated or predicted, even in one hour in the future. This leaves dispatch in a vulnerable situation, often waiting until the ramp is over to see how things settle out. Also, BPA is moving to ½ hour scheduling. Proposed energy imbalance markets will present challenges to integrating operationally into BPA if they move to 15 or 10 min. markets. Another critical challenge is current scheduling and dispatch systems have **difficulty in accommodating variability in demand and supply**. Finally, WECC and regional entities are considering formation of an energy imbalance market that would change BPA system operations and require interface with a new independent market.

Specific challenges include **integration of dispatch, transmission scheduling & hydro scheduling**. Closer coordination with scheduling, hydro power operations and transmission dispatch would provide better understanding of power system impacts of each others demands and solutions. Additionally, the system is currently designed for dispatchable resources, but is required to balance increasing amounts of intermittent resources. **The current system cannot be scheduled in an open, flexible, and continuous way.**

Therefore, an **accurate understanding of the sustainable capacity and energy of within–the-hour resources** is needed. The understanding would include: how resources are modeled and at what time scale? What are the requirements for monitoring performance, dispatch protocols and extreme events confidence? There is also a need for understanding and **acceptance of VGM (Variable Generation Mitigation)** and **systems and protocols** that support open, flexible, and continuous scheduling.

The following are specific capabilities needed:
Forecast of VGM Events
- Curtail projects only when needed to minimize outage duration.

Continuously variable start/stop time, scheduling interval, ramp rates at any time

R&D Gaps

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

1. Systems and protocols that support open, flexible, and continuous scheduling
2. Forecast of VGM Events
3. Continuously variable start/stop time, scheduling interval, ramp rates at any time

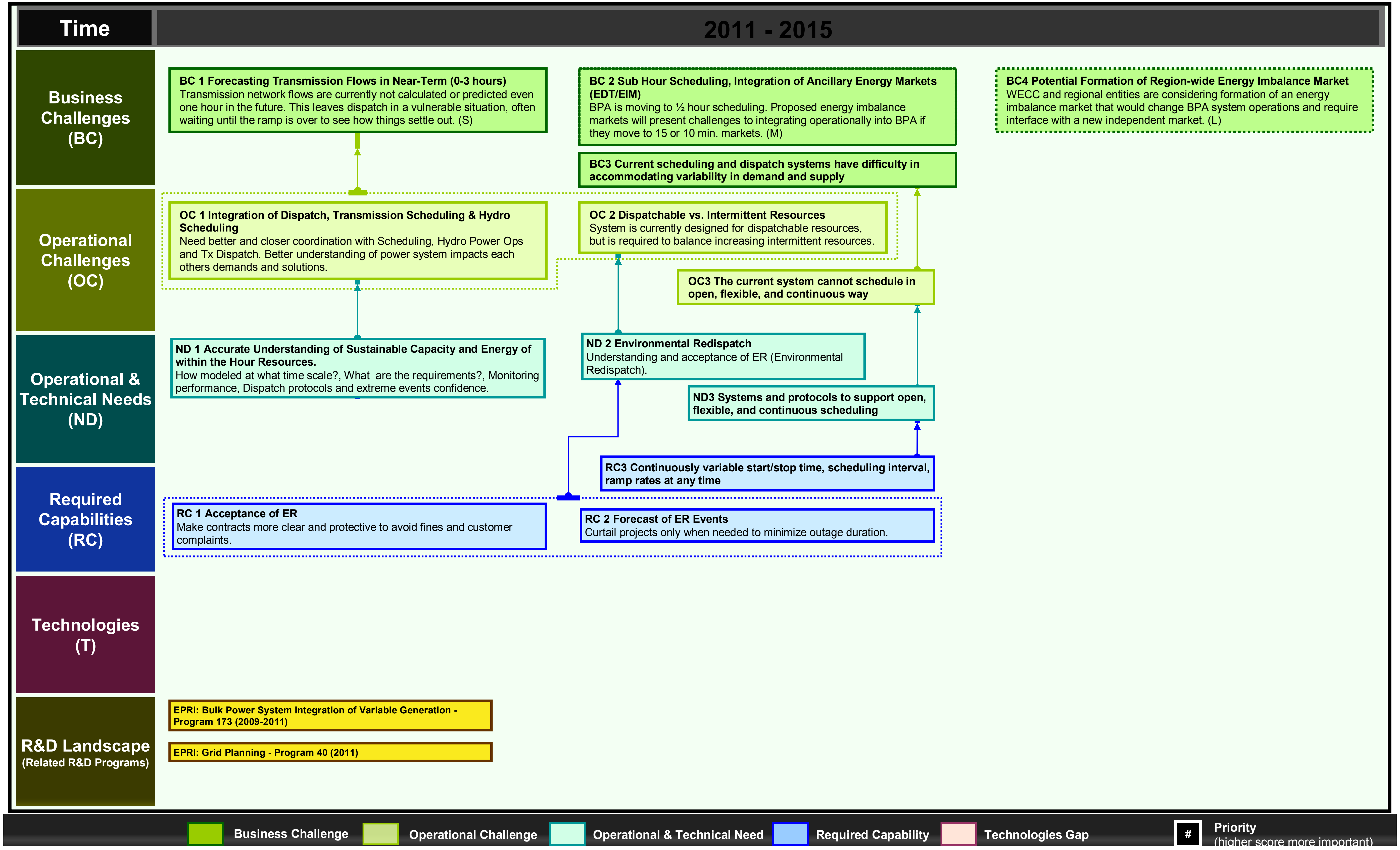
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Accurate understanding of the sustainable capacity and energy of within–the-hour resources
2. Difficulty in accommodating variability in demand and supply
3. The current system cannot be scheduled in an open, flexible, and continuous way

BPA Transmission Technology Roadmap

Shorter Duration Scheduling Technology Roadmap

Technical Area: Transmission Scheduling



Time | **2011 - 2015**

Business Challenges (BC)

BC 1 Forecasting Transmission Flows in Near-Term (0-3 hours)
Transmission network flows are currently not calculated or predicted even one hour in the future. This leaves dispatch in a vulnerable situation, often waiting until the ramp is over to see how things settle out. (S)

BC 2 Sub Hour Scheduling, Integration of Ancillary Energy Markets (EDT/EIM)
BPA is moving to ½ hour scheduling. Proposed energy imbalance markets will present challenges to integrating operationally into BPA if they move to 15 or 10 min. markets. (M)

BC3 Current scheduling and dispatch systems have difficulty in accommodating variability in demand and supply

BC4 Potential Formation of Region-wide Energy Imbalance Market
WECC and regional entities are considering formation of an energy imbalance market that would change BPA system operations and require interface with a new independent market. (L)

Operational Challenges (OC)

OC 1 Integration of Dispatch, Transmission Scheduling & Hydro Scheduling
Need better and closer coordination with Scheduling, Hydro Power Ops and Tx Dispatch. Better understanding of power system impacts each others demands and solutions.

OC 2 Dispatchable vs. Intermittent Resources
System is currently designed for dispatchable resources, but is required to balance increasing intermittent resources.

OC3 The current system cannot schedule in open, flexible, and continuous way

Operational & Technical Needs (ND)

ND 1 Accurate Understanding of Sustainable Capacity and Energy of within the Hour Resources.
How modeled at what time scale?, What are the requirements?, Monitoring performance, Dispatch protocols and extreme events confidence.

ND 2 Environmental Redispatch
Understanding and acceptance of ER (Environmental Redispatch).

ND3 Systems and protocols to support open, flexible, and continuous scheduling

Required Capabilities (RC)

RC3 Continuously variable start/stop time, scheduling interval, ramp rates at any time

RC 1 Acceptance of ER
Make contracts more clear and protective to avoid fines and customer complaints.

RC 2 Forecast of ER Events
Curtail projects only when needed to minimize outage duration.

Technologies (T)

R&D Landscape (Related R&D Programs)

EPRI: Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)

EPRI: Grid Planning - Program 40 (2011)

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap # Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
difficulty in accommodating variability in demand and supply, and potential formation of region-wide energy imbalance market	EPRI	**Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)** EPRI research and development in the area of bulk power system integration of variable generation and controllable load will produce knowledge and tools that will help system operators and planners: - Understand the impacts of variable generation and controllable load on system reliability - Control variable generation and controllable load to minimize operational risks - Design robust transmission systems to integrate variable generation and controllable load - Develop system and industry standards that ensure efficient and reliable operation. P173.003 Grid Performance and Modeling of Variable Generation and Evolving Power System Resources P173.005 Operator Tools for Scheduling, Reserve Determination, and Frequency Control with Variable Generation P173.006 Advanced Planning Tools to Study the Impact of Variable Generation and Controllable Loads P173.007 Evaluation of Potential Bulk System Reliability Impacts of Distributed Resources and Potential Mitigating Strategies
The current system cannot schedule in open, flexible, and continuous way for increasing amounts of intermittent resources	EPRI	**Grid Planning - Program 40 (2011)** Utilities, transmission companies, and ISOs/RTOs need to plan for future demand growth and provide transmission services for changing generation portfolios. The challenge of meeting reliability requirements with the addition of variable generation and allowing demand response as a capacity resource may necessitate transmission planning to reassess planning objectives. Planning for peak load scenarios may not be sufficient. Evaluation of additional scenarios such as low load and shoulder load, as well as intermittent availability of variable resources, may also be required. Variable resources have two other characteristics that need to be addressed in planning: uncertainty, and a regional nature beyond the traditional utility boundaries. A second focus of this program is to identify and develop solutions and decision-support tools for planners to deal with specific technology gaps to improve overall planning activities. Some projects within the Grid Planning program use phasor measurement to verify models—the foundation for all simulation and analysis efforts—and move traditionally offline analysis tasks closer to online real-time analysis.

Outage Management Roadmap

Business and Technology Challenges

Another critical challenge in Transmission Scheduling is **Outage Management**. System constraints and growing demand make attaining outages difficult. The current outage management system is not well coordinated. The critical challenge is to maintain and improve the physical grid while delivering the transmission services and capacity that our customers need.

Specific challenges include**:**

Increased pressure to replace equipment 'Hot' (without an outage)

Increased difficulty to take outages on power system equipment and lines

- Insufficient capacity and increasing demand reduces planned outage windows

Optimal outage management

- The current practices do not allow optimal outage management of the transmission system in terms of low cost and reliability. Outage season has been reduced to just 2 months, October and November to accomplish 12 months of work.

Therefore, a work management system is needed that will schedule maintenance work, outage balance, labor, and consolidate locations. The system should upload and download specifications and standards, provision all necessary parts and supplies (inventory rig), update labor times to work order system, and restack the schedule if necessary.

Additional needs include: an outage management coordination system to **integrate proposed outages (DART), power flow, PUF tables, into a simple tool for Outage Dispatchers to assess impact of proposed outages before they are approved**. It should also collect outage information from other utilities that impact BPA transmission. SYS OPS power flow study engineers and others need access too. We also need the ability to perform more system maintenance without outages.

A required capability would be the ability to **check combinations of outages, against impact to transmission path flows and system operating limits without performing a full study**.

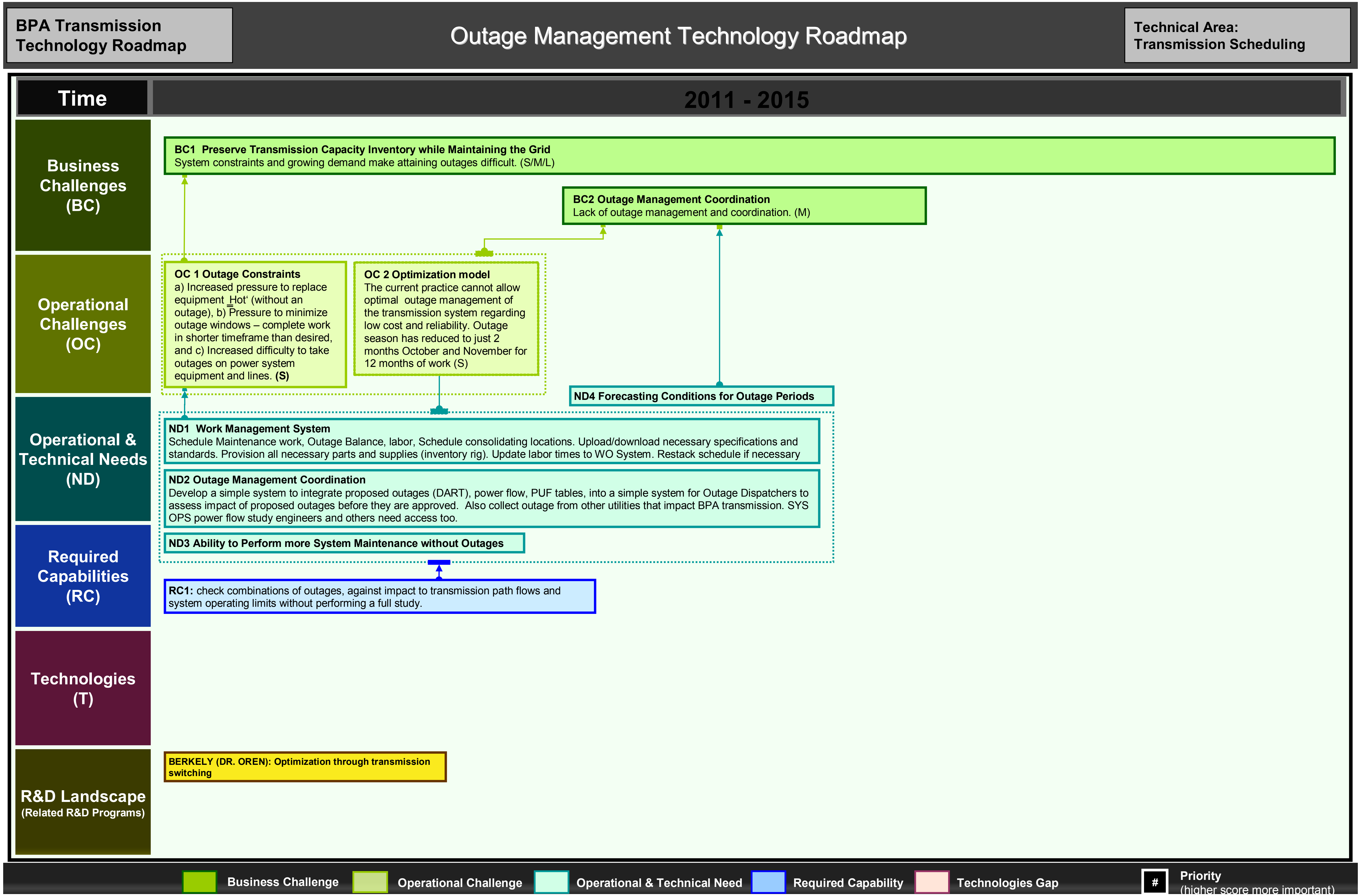
R&D Gaps

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

1. Integrate proposed outages (DART), power flow, PUF tables, into a simple tool for Outage Dispatchers to assess impact of proposed outages
2. Optimal outage management

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

1. Increased difficulty in taking outages on power system equipment and lines



BPA Transmission Technology Roadmap

Outage Management Technology Roadmap

Technical Area: Transmission Scheduling

Time — **2011 - 2015**

Business Challenges (BC)

BC1 Preserve Transmission Capacity Inventory while Maintaining the Grid
System constraints and growing demand make attaining outages difficult. (S/M/L)

BC2 Outage Management Coordination
Lack of outage management and coordination. (M)

Operational Challenges (OC)

OC 1 Outage Constraints
a) Increased pressure to replace equipment ‗Hot' (without an outage), b) Pressure to minimize outage windows – complete work in shorter timeframe than desired, and c) Increased difficulty to take outages on power system equipment and lines. **(S)**

OC 2 Optimization model
The current practice cannot allow optimal outage management of the transmission system regarding low cost and reliability. Outage season has reduced to just 2 months October and November for 12 months of work (S)

Operational & Technical Needs (ND)

ND4 Forecasting Conditions for Outage Periods

ND1 Work Management System
Schedule Maintenance work, Outage Balance, labor, Schedule consolidating locations. Upload/download necessary specifications and standards. Provision all necessary parts and supplies (inventory rig). Update labor times to WO System. Restack schedule if necessary

ND2 Outage Management Coordination
Develop a simple system to integrate proposed outages (DART), power flow, PUF tables, into a simple system for Outage Dispatchers to assess impact of proposed outages before they are approved. Also collect outage from other utilities that impact BPA transmission. SYS OPS power flow study engineers and others need access too.

ND3 Ability to Perform more System Maintenance without Outages

Required Capabilities (RC)

RC1: check combinations of outages, against impact to transmission path flows and system operating limits without performing a full study.

Technologies (T)

R&D Landscape (Related R&D Programs)

BERKELY (DR. OREN): Optimization through transmission switching

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap **#** Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
Increased pressure to replace equipment ‗Hot' (without an outage), and increased difficulty to take outages on power system equipment and lines because of insufficient capacity and increasing demand.	University of California, Berkeley (Dr. Shmuel Oren)	**1. Ongoing Research** Optimization through transmission switching Ref: Hedman, Kory W., Richard P. O'Neill, Emily Bartholomew Fisher, and Shmuel S. **Oren**, "Optimal Transmission Switching - Sensitivity Analysis and Extensions," IEEE Transactions on Power Systems , Vol. 23, No. 3, (2008) pp 1469-1479. Hedman, Kory W., Richard O'Neill, Emily Bartholomew Fisher, and Shmuel S. **Oren**, "Optimal Transmission Switching with Contingency Analysis", IEEE Transactions on Power Systems , Vol. 24, No. 3, (2009) pp 1577-1586.

Congestion Management Roadmap

Business and Technology Challenges

Congestion management is another critical challenge in transmission scheduling. Generally, the challenge is to reduce congestion by increasing capacity of the transmission system without extensive capital investment.

A specific challenge for BPA has been **difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes** given the increases in wind generation, changes in system operating limits, a potential Energy Imbalance Market, and possible new energy storage and demand response resources. Also, increasing transmission congestion on the FCRTS requires system operations to become proactive in identifying and managing congestion.

To address those challenges we need to: **Provide alternatives to curtailment**; **use power flow controls on critical circuits to manage congestion; develop day-ahead and hour-ahead forecasting of congestion**; and **develop the ability to assess path capacity in near time or real time**. Additionally, it is estimated that the daily average capacity grid utilization rates are typically only 40% to 60% of theoretical capacity. Some of this unused capacity could be recovered through peak shifting.

Capabilities needed to meet those challenges include:

- Improved tools for running studies in real-time, including static and dynamic security assessment.
- Better forecasting tools for load, generation, and line temperatures. A supporting technology would be line temperature monitoring that could indicate line capacity utilization and help determine which lines can be taken out for maintenance work and load optimization.
- New power electronic devices that would enable dispatchers to control power flows more directly.
- Demand response: Peak shifting would require transactive signals to enable devices to increase electricity use during low demand periods and decrease electricity use in high demand periods.

R&D Gaps

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

1. Develop the ability to assess/forecast path capacity/congestion in near time or real time
2. Ability to make available all real time transmission capacity

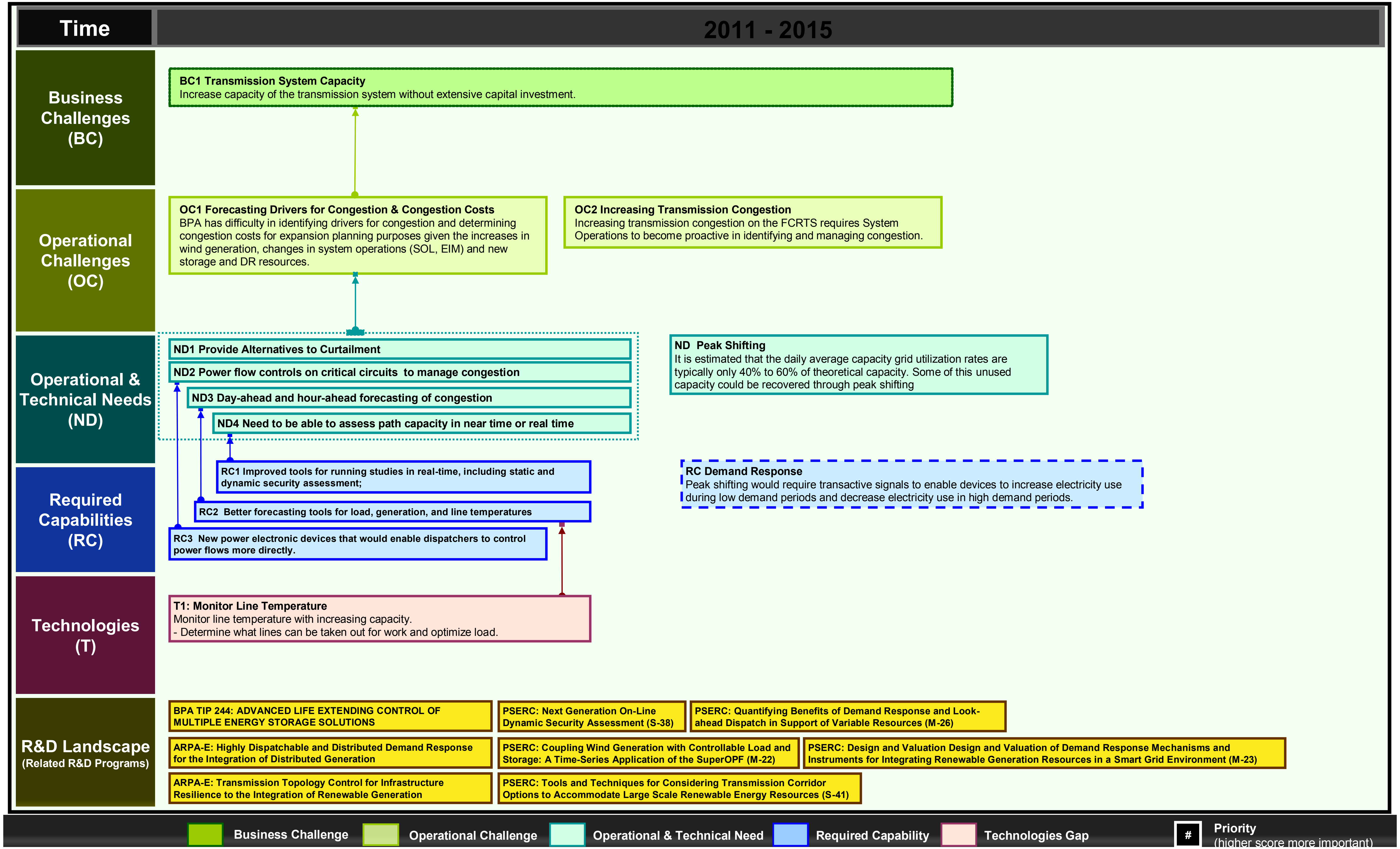
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Power flow controls on critical circuits to manage congestion
2. Improved tools for running studies in real-time, including static and dynamic security assessment
3. Better forecasting tools for load, generation, and line temperatures.
4. New power electronic devices that would enable dispatchers to control power flows more directly.
5. Demand response

BPA Transmission Technology Roadmap

Congestion Management Technology Roadmap

Technical Area: Transmission Scheduling



Time

2011 - 2015

Business Challenges (BC)

BC1 Transmission System Capacity
Increase capacity of the transmission system without extensive capital investment.

Operational Challenges (OC)

OC1 Forecasting Drivers for Congestion & Congestion Costs
BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources.

OC2 Increasing Transmission Congestion
Increasing transmission congestion on the FCRTS requires System Operations to become proactive in identifying and managing congestion.

Operational & Technical Needs (ND)

ND1 Provide Alternatives to Curtailment

ND2 Power flow controls on critical circuits to manage congestion

ND3 Day-ahead and hour-ahead forecasting of congestion

ND4 Need to be able to assess path capacity in near time or real time

ND Peak Shifting
It is estimated that the daily average capacity grid utilization rates are typically only 40% to 60% of theoretical capacity. Some of this unused capacity could be recovered through peak shifting

Required Capabilities (RC)

RC1 Improved tools for running studies in real-time, including static and dynamic security assessment;

RC2 Better forecasting tools for load, generation, and line temperatures

RC3 New power electronic devices that would enable dispatchers to control power flows more directly.

RC Demand Response
Peak shifting would require transactive signals to enable devices to increase electricity use during low demand periods and decrease electricity use in high demand periods.

Technologies (T)

T1: Monitor Line Temperature
Monitor line temperature with increasing capacity.
- Determine what lines can be taken out for work and optimize load.

R&D Landscape (Related R&D Programs)

BPA TIP 244: ADVANCED LIFE EXTENDING CONTROL OF MULTIPLE ENERGY STORAGE SOLUTIONS

PSERC: Next Generation On-Line Dynamic Security Assessment (S-38)

PSERC: Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)

ARPA-E: Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation

PSERC: Coupling Wind Generation with Controllable Load and Storage: A Time-Series Application of the SuperOPF (M-22)

PSERC: Design and Valuation Design and Valuation of Demand Response Mechanisms and Instruments for Integrating Renewable Generation Resources in a Smart Grid Environment (M-23)

ARPA-E: Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation

PSERC: Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources (S-41)

🟩 Business Challenge
🟩 Operational Challenge
🟦 Operational & Technical Need
🟦 Required Capability
🟥 Technologies Gap
Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources.	Project Leader: Stephen White Org: SR	**TIP 244 - ADVANCED LIFE EXTENDING CONTROL OF MULTIPLE ENERGY STORAGE SOLUTIONS** This project includes advanced ―life extending control” and coordination of multiple energy storage solutions to maximize cost effective energy production, reduce dependency and strain on the hydro-power system by buffering from variable renewables, reduce spinning reserve and peak load problems, increase transmission capacity and help stabilize power quality disturbances.
BPA has difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given DR resource	ARPA-E AutoGrid, Inc.	**Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation** AutoGrid, Inc., in conjunction with Lawrence Berkeley National Lab and Columbia University, will design and demonstrate a highly distributed Demand Response Optimization and Management System for Real-Time (DROMS-RT). The project will enable ―personalized” price signals to be sent to millions of customers in extremely short timeframes. This will allow customers to reduce their demand when the grid is congested. DROMS-RT is expected to provide a 90% reduction in the cost of operating demand response programs in the United States.
Improved tools for running studies in real-time, including static and dynamic security assessment	ARPA-E Charles River Associates	**Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation** Charles River Associates will develop decision support technology that will improve the efficiency of the electrical grid by implementing appropriate short term changes of transmission line status, i.e., by controlling the configuration of the transmission grid. The changes will relieve transmission congestion, as well as provide additional tools and controls to operators to manage uncertainty, thus enabling higher levels of renewable generation.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Need Improved tools for running studies in real-time, including static and dynamic security assessment	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.
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources	PSERC Project Leader: Tim Mount Cornell University, tdm2@cornell.edu	**Coupling Wind Generation with Controllable Load and Storage: A Time-Series Application of the SuperOPF (M-22)** The objective of this project is to evaluate the effects of using controllable load and storage to offset the effects of intermittent wind generation on overall system performance and on the operating costs and revenues for different loads and generators. This task will be accomplished by enhancing the current capabilities of the SuperOPF developed at Cornell to model sequential time periods that capture the effects of daily load cycles and the ability to shift load among time periods**.**
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation	PSERC Project Leader: Vijay Vittal Arizona State University, vijay.vittal@asu.edu	**Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources (S-41)** The project develops assessment tools and techniques for considering transmission corridor options to accommodate high levels of penetration of renewable energy resources.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources	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..
Difficulty in identifying drivers for congestion and determining congestion costs for expansion planning purposes given the increases in wind generation, changes in system operations (SOL, EIM) and new storage and DR resources	PSERC Project Leader: Shi-Jie Deng Georgia Institute of Technology, deng@isye.gatech.edu	**Design and Valuation Design and Valuation of Demand Response Mechanisms and Instruments for Integrating Renewable Generation Resources in a Smart Grid Environment (M-23)** We propose to investigate alternative contractual based approaches to the design and valuation of demand response (DR) mechanisms and instruments aimed at addressing the ancillary service (AS) challenges associated with integrating an increasing quantity of intermittent renewable generation resources into a power grid. For our investigation, we will develop a methodology for simulating systems with integrated renewable and DR resources over longer periods. The methodology will be effectively used to study how different DR mechanisms and financial instruments can facilitate the integration of DR programs into ISO markets and provide the much needed AS support to the intermittent renewable generation.

V. Changing Generation Resources

Integration of Variable Resources Roadmap

Business and Technology Challenges

Integration of the variable resources in BPA‘s balancing area presents challenges to the Federal Columbia River Power System (FCRPS). As large amounts of variable generation such as wind are added to the energy mix in the Pacific Northwest, increasing amounts of flexible dispatchable resources are required to integrate them. The FCRPS is a large flexible resource that is limited by ‗higher order‘ hydro obligations such as fish protection constraints, navigation, irrigation, and recreation. These limitations reduce the system‘s balancing resources and present challenges to scheduling, voltage stability, frequency control and response, and contribute to transmission constraints. We are thus limited in providing all the ancillary services expected of a balancing authority (BA).

Specific operational challenges include provisioning sufficient balancing reserves through the FCRPS or developing other types of reserves than those currently available; increased wear & tear due to increase operations of power control breakers to switch capacitor banks for voltage control; changes to path flows impacting voltage, voltage stability and system oscillation. These challenges add to transmission constraints and present additional demands to RAS (Remedial Action Schemes) arming.

The required operational and technical needs include frequency response controls; voltage controls; manage variability of renewable generation; increased balancing reserve capacity; reducing balancing reserve requirement; new or better ways to control voltage changes due to variable power flow

Therefore, required technical capabilities to respond to the challenges include:

Digital emulation of governor response of standard generators

Analytical model

- Modeling capability analyzing how energy storage can impact BPA balancing reserves and the current power & transmission system

Advanced Dispatch Tools

- Dispatch tools should provide situational awareness of wind ramps, consider reserve requirements, and include operator training.

Increase dynamic transfer capability

- More robust PCB (power circuit breaker)
- Capability to accomplish higher duty cycles

R&D Gaps

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

1. Governor control, voltage control and accommodation in the power system due to dynamic power schedules

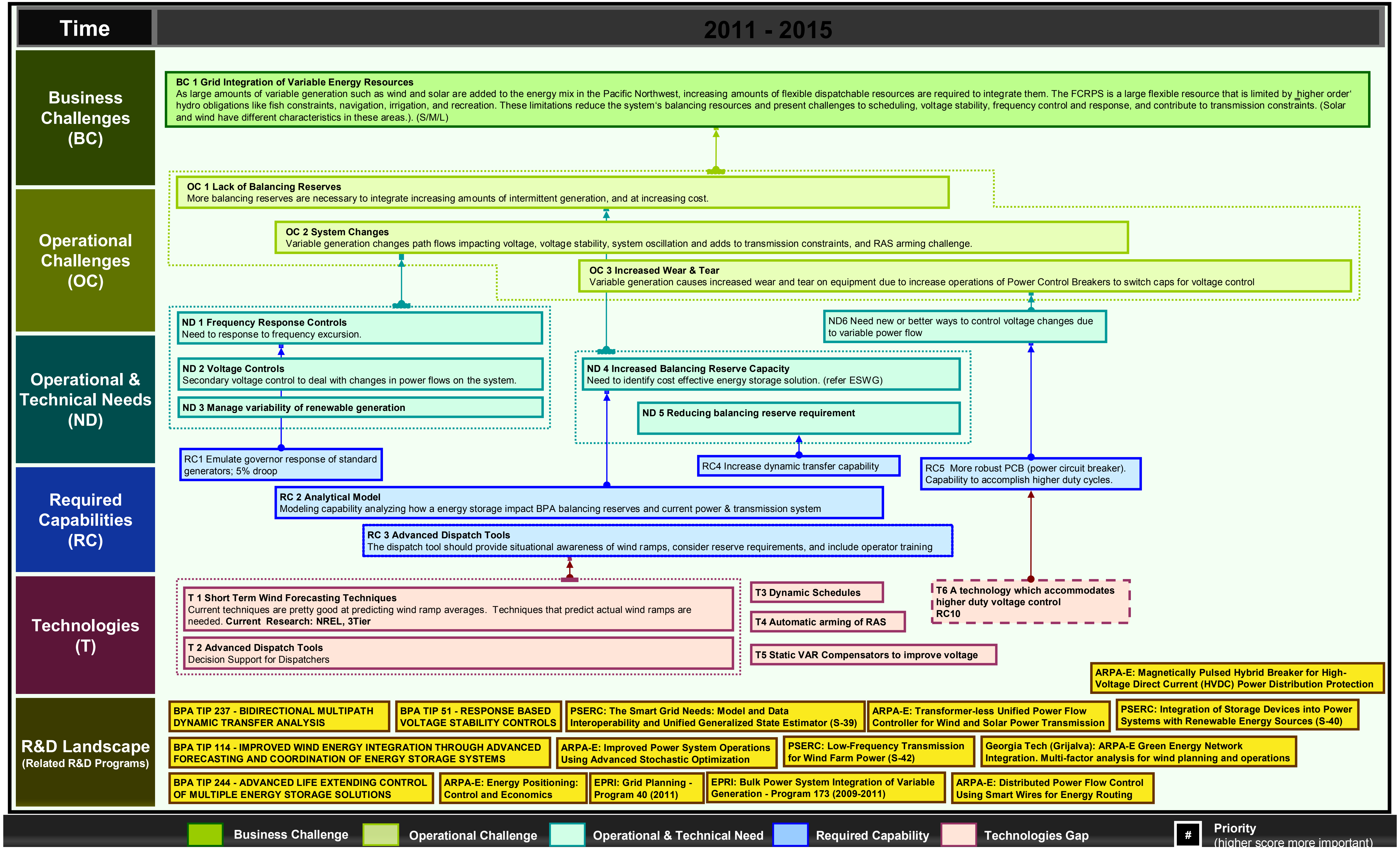
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. Modeling capability analyzing how energy storage impact BPA balancing reserves
2. Advanced Dispatch Tools
3. Increase dynamic transfer capability
4. More robust PCB (power circuit breaker) to accommodate dynamic transfers

BPA Transmission Technology Roadmap

Integration of Variable Resources Technology Roadmap

Technical Area: Changing Generation Resources



Time | **2011 - 2015**

Business Challenges (BC)

BC 1 Grid Integration of Variable Energy Resources
As large amounts of variable generation such as wind and solar are added to the energy mix in the Pacific Northwest, increasing amounts of flexible dispatchable resources are required to integrate them. The FCRPS is a large flexible resource that is limited by ‗higher order‘ hydro obligations like fish constraints, navigation, irrigation, and recreation. These limitations reduce the system‘s balancing resources and present challenges to scheduling, voltage stability, frequency control and response, and contribute to transmission constraints. (Solar and wind have different characteristics in these areas.). (S/M/L)

Operational Challenges (OC)

OC 1 Lack of Balancing Reserves
More balancing reserves are necessary to integrate increasing amounts of intermittent generation, and at increasing cost.

OC 2 System Changes
Variable generation changes path flows impacting voltage, voltage stability, system oscillation and adds to transmission constraints, and RAS arming challenge.

OC 3 Increased Wear & Tear
Variable generation causes increased wear and tear on equipment due to increase operations of Power Control Breakers to switch caps for voltage control

Operational & Technical Needs (ND)

ND 1 Frequency Response Controls
Need to response to frequency excursion.

ND 2 Voltage Controls
Secondary voltage control to deal with changes in power flows on the system.

ND 3 Manage variability of renewable generation

ND 4 Increased Balancing Reserve Capacity
Need to identify cost effective energy storage solution. (refer ESWG)

ND 5 Reducing balancing reserve requirement

ND6 Need new or better ways to control voltage changes due to variable power flow

Required Capabilities (RC)

RC1 Emulate governor response of standard generators; 5% droop

RC 2 Analytical Model
Modeling capability analyzing how a energy storage impact BPA balancing reserves and current power & transmission system

RC 3 Advanced Dispatch Tools
The dispatch tool should provide situational awareness of wind ramps, consider reserve requirements, and include operator training

RC4 Increase dynamic transfer capability

RC5 More robust PCB (power circuit breaker). Capability to accomplish higher duty cycles.

Technologies (T)

T 1 Short Term Wind Forecasting Techniques
Current techniques are pretty good at predicting wind ramp averages. Techniques that predict actual wind ramps are needed. **Current Research: NREL, 3Tier**

T 2 Advanced Dispatch Tools
Decision Support for Dispatchers

T3 Dynamic Schedules

T4 Automatic arming of RAS

T5 Static VAR Compensators to improve voltage

T6 A technology which accommodates higher duty voltage control RC10

R&D Landscape (Related R&D Programs)

- ARPA-E: Magnetically Pulsed Hybrid Breaker for High-Voltage Direct Current (HVDC) Power Distribution Protection
- BPA TIP 237 - BIDIRECTIONAL MULTIPATH DYNAMIC TRANSFER ANALYSIS
- BPA TIP 51 - RESPONSE BASED VOLTAGE STABILITY CONTROLS
- PSERC: The Smart Grid Needs: Model and Data Interoperability and Unified Generalized State Estimator (S-39)
- ARPA-E: Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission
- PSERC: Integration of Storage Devices into Power Systems with Renewable Energy Sources (S-40)
- BPA TIP 114 - IMPROVED WIND ENERGY INTEGRATION THROUGH ADVANCED FORECASTING AND COORDINATION OF ENERGY STORAGE SYSTEMS
- ARPA-E: Improved Power System Operations Using Advanced Stochastic Optimization
- PSERC: Low-Frequency Transmission for Wind Farm Power (S-42)
- Georgia Tech (Grijalva): ARPA-E Green Energy Network Integration. Multi-factor analysis for wind planning and operations
- BPA TIP 244 - ADVANCED LIFE EXTENDING CONTROL OF MULTIPLE ENERGY STORAGE SOLUTIONS
- ARPA-E: Energy Positioning: Control and Economics
- EPRI: Grid Planning - Program 40 (2011)
- EPRI: Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)
- ARPA-E: Distributed Power Flow Control Using Smart Wires for Energy Routing

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap # Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
Lack of balancing reserves - increasing amounts of flexible dispatchable resources are required to integrate renewable energy	Project Leader: Brian Tuck Org: TOT	**TIP 237 - BIDIRECTIONAL MULTIPATH DYNAMIC TRANSFER ANALYSIS** This project is intended to improve the new dynamic transfer methodology for integrating large amounts of intermittent energy sources. This project will evaluate improvements to the methodology, implement prototype tools to study wind integration models (such as the NREL / 3 TIER Western Wind and Solar Integration Study mesoscale model) using the new methodology, and identify approaches to compute additional costs incurred by BPA transmission when accommodating dynamic transfer across the FCRTS.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	Project Leader: Mike Hulse Org: TESM	**TIP 114 - IMPROVED WIND ENERGY INTEGRATION THROUGH ADVANCED FORECASTING AND COORDINATION OF ENERGY STORAGE SYSTEMS** This research seeks to enable more effective use of energy storage to minimize scheduling uncertainty, increase load leveling capabilities and reduce reserve requirements. This advanced research includes comprehensive simulations and experimental lab-grid implementation that models renewable installations, traditional generation sources, energy storage technologies, power electronic converter control, and representative loads.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	Project Leader: Stephen White Org: SR	**TIP 244 - ADVANCED LIFE EXTENDING CONTROL OF MULTIPLE ENERGY STORAGE SOLUTIONS** This project includes advanced ―life extending control” and coordination of multiple energy storage solutions to maximize cost effective energy production, reduce dependency and strain on the hydro-power system by buffering from variable renewables, reduce spinning reserve and peak load problems, increase transmission capacity and help stabilize power quality disturbances.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	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.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	ARPA-E Sandia National Laboratory	**Improved Power System Operations Using Advanced Stochastic Optimization** Market management systems (MMSs) are used to securely and optimally determine which energy resources should be used to service energy demand. Increased penetration of renewable energy resources increases the uncertainty of operating and market conditions, complicating decision making. Sandia National Laboratory will collaborate with Iowa State University, the University of California at Davis, Alstom Grid, and ISO New England to create probability-based decision-making software for MMSs that can account for the increased uncertainty while retaining overall grid reliability and market stability.
Analytical model - modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	ARPA-E University of Washington	**Energy Positioning: Control and Economics** The University of Washington will develop control technologies for energy management. The technology will intelligently decide if excess energy from renewable energy sources should be consumed or directed to storage facilities. If directed to a storage facility, the control technology will also decide to route the energy to a location that is best positioned for later use. The coordinated control of well-positioned and properly sized storage facilities and demand response will facilitate the large-scale integration of renewable generation, significantly reduce the need for transmission expansion, and improve system reliability.
Variable generation increases wear & tear due to increase operations of power control breakers to switch caps for voltage control	ARPA-E Michigan State University	**Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission** Michigan State will develop a unified power flow controller (UPFC) that will have enormous technological and economic impacts on controlling the routing of energy through existing power lines. The UPFC will incorporate an innovative circuitry configuration that eliminates the transformer, an extremely large and heavy component, from the system. As a result, it will be light weight, efficient, reliable, low cost, and well suited for fast and distributed power flow control of wind and solar power.
Variable generation also changes path flows impacting voltage, voltage stability and system oscillation	Project Leader: Dmitry Kosterev Org: TPP	**TIP 51 - RESPONSE BASED VOLTAGE STABILITY CONTROLS** This project researches all three types of controls (primary, secondary, emergency) will be considered. Primary Voltage control - Response-based controls for fast reactive switching of 500-kV shunt capacitor banks in Portland / Salem area. Coordination reactive resources in Southern Oregon / Northern California area. Secondary Voltage Controls - Reactive power management to optimize voltage profile and to maximize reactive margins. Emergency voltage controls - Low voltage shedding.

BPA Challenge	Lead Research Organization	Project Title & Project Description
Variable generation also changes path flows impacting voltage, voltage stability and system oscillation	PSERC Project Leader: A.P. Sakis Meliopoulos Georgia Institute of Technology, sakis.m@gatech.edu	**Low-Frequency Transmission for Wind Farm Power (S-42)** The project's goal is to evaluate alternative transmission systems from remote wind farms to the main grid using low-frequency AC technology. Low frequency means a frequency lower than nominal frequency. To minimize costs cyclo-converter technology will be utilized resulting in systems of 20/16.66 Hz (for 60/50Hz systems respectively). The technical and economic performance of low-frequency AC transmission technology will be compared to HVDC transmission (including HVDC Light) and conventional AC transmission.
Increasing amounts of flexible dispatchable resources are required to integrate them	EPRI	**Grid Planning - Program 40 (2011)** Utilities, transmission companies, and ISOs/RTOs need to plan for future demand growth and provide transmission services for changing generation portfolios. The challenge of meeting reliability requirements with the addition of variable generation and allowing demand response as a capacity resource may necessitate transmission planning to reassess planning objectives. Planning for peak load scenarios may not be sufficient. Evaluation of additional scenarios such as low load and shoulder load, as well as intermittent availability of variable resources, may also be required. Variable resources have two other characteristics that need to be addressed in planning: uncertainty, and a regional nature beyond the traditional utility boundaries. A second focus of this program is to identify and develop solutions and decision-support tools for planners to deal with specific technology gaps to improve overall planning activities. Some projects within the Grid Planning program use phasor measurement to verify models—the foundation for all simulation and analysis efforts—and move traditionally offline analysis tasks closer to online real-time analysis.
Increasing amounts of flexible dispatchable resources are required to integrate them	EPRI	**Bulk Power System Integration of Variable Generation - Program 173 (2009-2011)** EPRI research and development in the area of bulk power system integration of variable generation and controllable load will produce knowledge and tools that will help system operators and planners: - Understand the impacts of variable generation and controllable load on system reliability - Control variable generation and controllable load to minimize operational risks - Design robust transmission systems to integrate variable generation and controllable load - Develop system and industry standards that ensure efficient and reliable operation. P173.003 Grid Performance and Modeling of Variable Generation and Evolving Power System Resources P173.005 Operator Tools for Scheduling, Reserve Determination, and Frequency Control with Variable Generation P173.006 Advanced Planning Tools to Study the Impact of Variable Generation and Controllable Loads P173.007 Evaluation of Potential Bulk System Reliability Impacts of Distributed Resources and Potential Mitigating Strategies

BPA Challenge	Lead Research Organization	Project Title & Project Description
Increasing amounts of flexible dispatchable resources are required to integrate renewables.	Georgia Institute of Technology (Dr. Santiago Grijalva)	**1. Ongoing Research** ARPA-E Green Energy Network Integration, major project proposing a control architecture to achieve 40% penetration of renewable energy. Components are the distributed architecture and the autonomous distributed stochastic optimization Multi-factor analysis for wind planning and operations. - There are many factors involved in comprehensive planning. Requires other types of tools including GIS, multi-factor spatial-temporal methods **2. Research Needs** Top down vision and electricity policy for emerging technologies and method
Increase dynamic transfer capability	ARPA-E Smart Wire Grid, Inc	**Distributed Power Flow Control Using Smart Wires for Energy Routing** Over 660,000 miles of transmission line exist within the continental United States with roughly 33% of these lines experiencing significant congestion. This congestion exists while, on average, only 45-60% of the total transmission line capacity is utilized. A team led by startup company Smart Wire Grid will develop a solution for controlling power flow in the transmission grid to better take advantage of the unused capacity. The power controller will be a ―smart wire" that incorporates advanced control software, sensors, and communications technologies.
Modeling capability analyzing how an energy storage impact BPA balancing reserves and current power & transmission system	PSERC Project Leader: George Gross University of Illinois, Urbana, gross@illinois.edu	**Integration of Storage Devices into Power Systems with Renewable Energy Sources (S-40)** The recent advances in the state of the art of storage technology have led to wider deployment of storage technologies. This project will develop models and a simulation methodology for analyzing the effects of storage integration on transmission constrained electricity markets over longer-term periods. Our goal is to assess the use of storage as a system resource that provides the flexibility to mitigate the effects of variable renewable energy sources, improves the overall system reliability, and has the ability to provide energy- and capacity-based ancillary services. The methodology can be implemented into practical tools to quantify the system variable effects
More robust PCB (power circuit breaker)	ARPA-E General Atomics	**Magnetically Pulsed Hybrid Breaker for High-Voltage Direct Current (HVDC) Power Distribution Protection** General Atomics will develop a low loss, high reliability power routing technology that operates about 10 times faster than conventional technology. This technology will be a key enabler of advanced transmission networks, which will play a vital role in linking remotely located renewable energy sources like offshore wind farms and solar energy fields to consumers in urban centers.

Wind Modeling Roadmap

Business and Technology Challenges

The current wind models cause problems with system planning. Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support. Within hour/next hour reserve management of wind resources and inadvertent interchange with Pacific NW and California load areas needs to be modeled appropriately. Short term wind forecast improvement is needed to accurately forecast reserve requirements and congestion to optimally manage reserves of the Big 10 Columbia/Snake River Dams in real time (Big 10). Balancing authorities cannot control power flows (ex. large solar intermittency in CA demands reserves from Pacific NW on an unscheduled basis). Inadvertent interchange consumes some transmission capacity.

More specific operational challenges are:

Within Hour/Next Hour Reserve Management of Wind (Schedule Error)

- Short term wind forecast improvement is needed to accurately forecast reserve requirements and congestion to optimally distribute reserves to the Big 10 in real time.

Inadvertent Interchange with PNW and California Load Areas

- Balancing Authorities can‘t control power flows (ex. Large solar intermittency in CA demands reserves from PNW on an unscheduled basis). Inadvertent Interchange consumes some transmission capacity.

These challenges require following addition capabilities: **power plant model validation**, **improved system modeling** and **data sharing (data management)**, and **understanding characteristics of wind generators**. These remedies will give BPA an appropriate wind and solar monitoring system which demonstrates accurate performance expectations from 0 to 60 min.

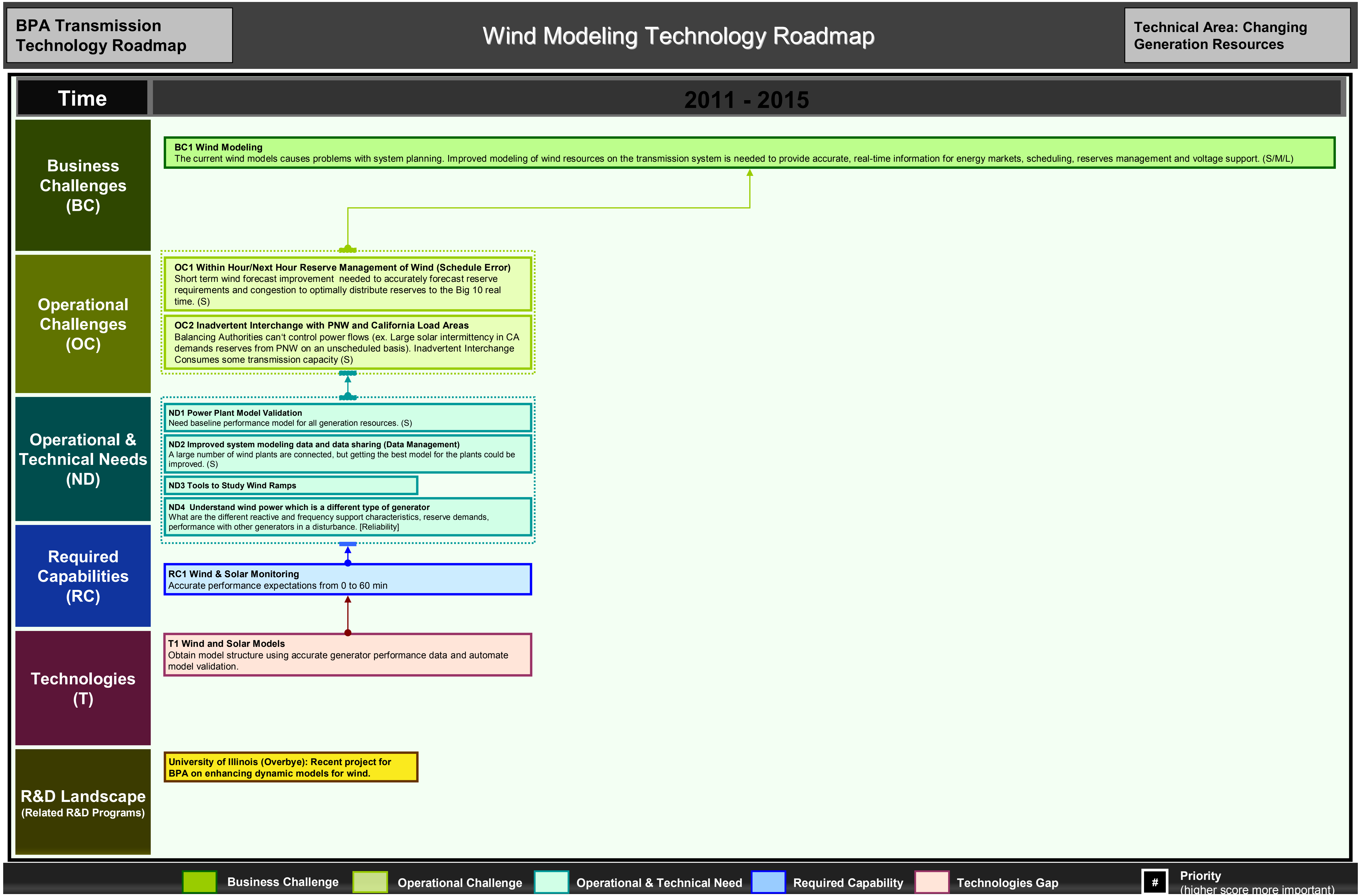
R&D Gaps

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

1. Power plant model validation
2. Improved system modeling and data sharing (data management)

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

1. Within Hour/Next Hour Reserve Management of Wind
2. Inadvertent Interchange with PNW and California Load Areas
3. Understanding of the wind generator characteristics



BPA Transmission Technology Roadmap

Wind Modeling Technology Roadmap

Technical Area: Changing Generation Resources

Time | **2011 - 2015**

Business Challenges (BC)

BC1 Wind Modeling
The current wind models causes problems with system planning. Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support. (S/M/L)

Operational Challenges (OC)

OC1 Within Hour/Next Hour Reserve Management of Wind (Schedule Error)
Short term wind forecast improvement needed to accurately forecast reserve requirements and congestion to optimally distribute reserves to the Big 10 real time. (S)

OC2 Inadvertent Interchange with PNW and California Load Areas
Balancing Authorities can't control power flows (ex. Large solar intermittency in CA demands reserves from PNW on an unscheduled basis). Inadvertent Interchange Consumes some transmission capacity (S)

Operational & Technical Needs (ND)

ND1 Power Plant Model Validation
Need baseline performance model for all generation resources. (S)

ND2 Improved system modeling data and data sharing (Data Management)
A large number of wind plants are connected, but getting the best model for the plants could be improved. (S)

ND3 Tools to Study Wind Ramps

ND4 Understand wind power which is a different type of generator
What are the different reactive and frequency support characteristics, reserve demands, performance with other generators in a disturbance. [Reliability]

Required Capabilities (RC)

RC1 Wind & Solar Monitoring
Accurate performance expectations from 0 to 60 min

Technologies (T)

T1 Wind and Solar Models
Obtain model structure using accurate generator performance data and automate model validation.

R&D Landscape (Related R&D Programs)

University of Illinois (Overbye): Recent project for BPA on enhancing dynamic models for wind.

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap # Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
Improved modeling of wind resources on the transmission system is needed to provide accurate, real-time information for energy markets, scheduling, reserves management and voltage support	University of Illinois (Dr. Thomas Overbye)	**1. Ongoing Research** Recent project for BPA on enhancing dynamic models for wind. **2. Research Needs** Sensitivity of operationa, planning and market outcomes on model accuracy. - Model Validation Methods - Modeling/Simulation compliance and certification methods

VI. Changing Load Characteristics

End Use (customer/utility) Devices Roadmap

Business and Technology Challenges

Changing characteristics of end-use devices are another critical business challenge for the BPA transmission system.

New products also need to include designs that support grid flexibility. Otherwise, we may face transmission voltage recovery delayed events such as those caused by stalled air-conditioner compressors. Multiple fault induced delayed voltage recovery events occurred in Southern California Edison‘s desert regions during the peak air-conditioning period including a major incident which affected a 1000 square mile area in Riverside County.

Therefore, BPA needs **base-testing for load composition through new lab testing facilities**. The facilities are needed for automatic load control devices.

R&D Gaps

*Business and Technological Challenges which may be addressed by **collaboration** with others*

1. Base-testing for load composition through new lab testing facilities

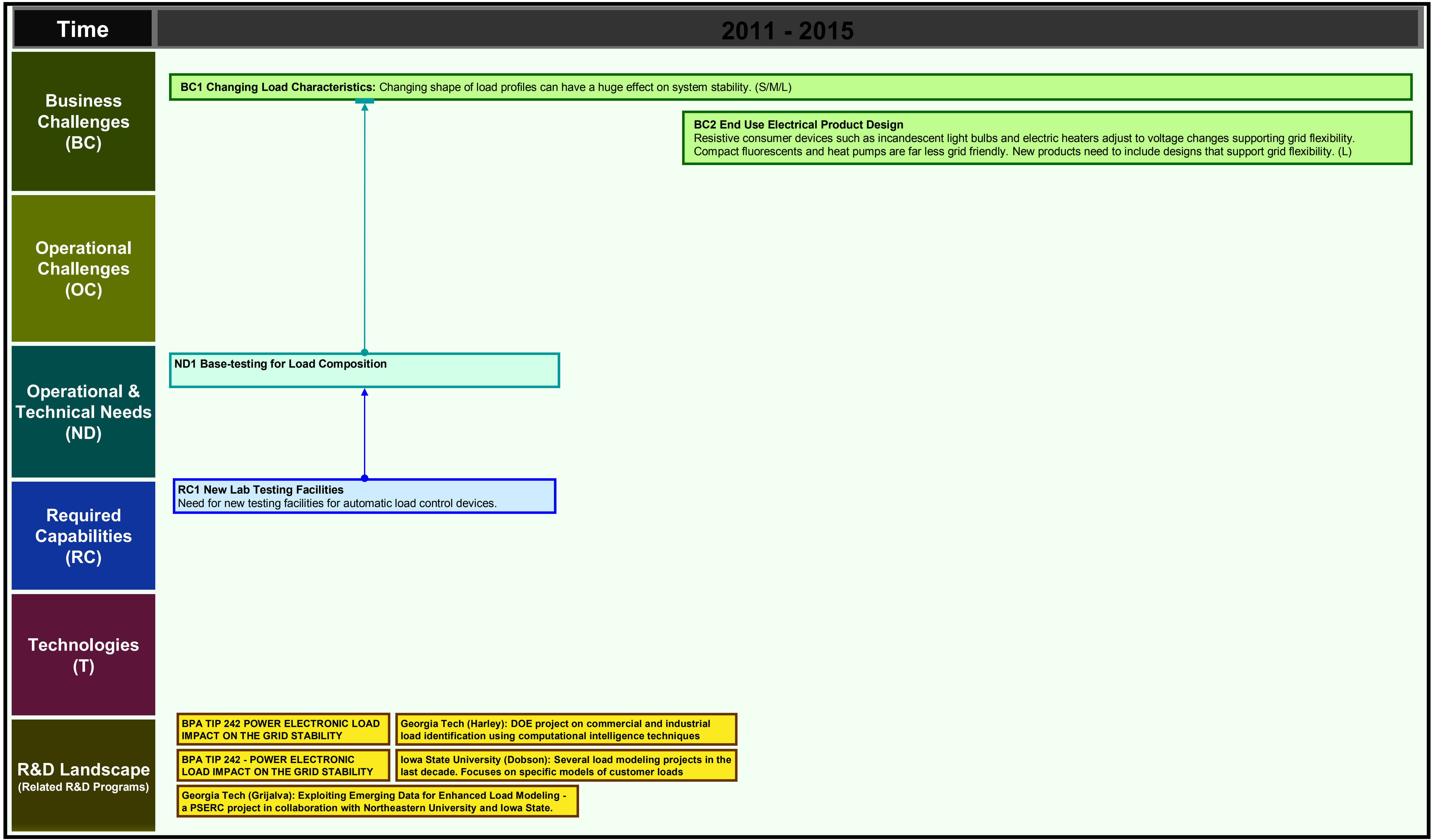
Business and Technological Challenges which are covered partially by existing R&D programs but still require further research and development:

1. New products also need to include designs that support grid flexibility

BPA Transmission Technology Roadmap

End Use (Customer/Utility) Devices Technology Roadmap

Technical Area: Changing Load Characteristics



BC1 Changing Load Characteristics: Changing shape of load profiles can have a huge effect on system stability. (S/M/L)

BC2 End Use Electrical Product Design
Resistive consumer devices such as incandescent light bulbs and electric heaters adjust to voltage changes supporting grid flexibility. Compact fluorescents and heat pumps are far less grid friendly. New products need to include designs that support grid flexibility. (L)

ND1 Base-testing for Load Composition

RC1 New Lab Testing Facilities
Need for new testing facilities for automatic load control devices.

BPA TIP 242 POWER ELECTRONIC LOAD IMPACT ON THE GRID STABILITY

Georgia Tech (Harley): DOE project on commercial and industrial load identification using computational intelligence techniques

BPA TIP 242 - POWER ELECTRONIC LOAD IMPACT ON THE GRID STABILITY

Iowa State University (Dobson): Several load modeling projects in the last decade. Focuses on specific models of customer loads

Georgia Tech (Grijalva): Exploiting Emerging Data for Enhanced Load Modeling - a PSERC project in collaboration with Northeastern University and Iowa State.

🟩 Business Challenge 🟩 Operational Challenge 🟦 Operational & Technical Need 🟦 Required Capability 🟥 Technologies Gap # Priority (higher score more important)

Related Internal and External Projects

BPA Challenge	Lead Research Organization	Project Title & Project Description
Changing characteristics of end-use device is another critical business challenge for the BPA transmission system.	Iowa State University (Ian Dobson)	**1. Ongoing Research** Several load modeling projects in the last decade. Focuses on specific models of customer loads.
Changing characteristics of end-use device is another critical business challenge for the BPA transmission system.	Georgia Institute of Technology (Dr. Santiago Grijalva)	**1. Ongoing Research** Exploiting Emerging Data for Enhanced Load Modeling - a PSERC project in collaboration with Northeastern University and Iowa State. - Project includes three levels: a) Dynamic state estimator and dynamic load identification for transmission, b) data mining aspects for demand response using smart meters, and c) non-intrusive dynamic load identification **2. Research Needs** - Data acquisition in the next 2-3 years will 4 orders of magnitude the present volume. There has been little research on "what can be done with the emerging data" (PMU, IEDs, smart meters) - Very limited expertise on databases within the power community and long learning curve for CS community regarding power needs - very limited number of hybrid CS/power researchers - Research on this area is very promising. Several National Labs are interested in partnering in this area.
Changing characteristics of end-use device is another critical business challenge for the BPA transmission system.	Georgia Institute of Technology (Dr. Ronald G. Harley)	**1. Ongoing Research** DOE project on commercial and industrial load identification using computational intelligence techniques

BPA Challenge	Lead Research Organization	Project Title & Project Description
New products also need to include designs that support grid flexibility. Otherwise, we may face transmission voltage recovery delayed events such as those caused by stalled air-conditioner compressors.	Project Leader: Steve Yang Org: TECM	**TIP 242 - POWER ELECTRONIC LOAD IMPACT ON THE GRID STABILITY** The project will evaluate the impact of power electronic loads on the power system stability, specifically dynamic voltage stability, damping of power oscillations, frequency controls. The project will look at a wide spectrum of power electronic loads, including Variable Frequency Drives, consumer electronics, LED lighting, and Electric Vehicle Chargers. The project will help simulate, test and evaluate designs that can make these electronic loads be friendly with respect to electrical power grid. The project will provide technical input to a much larger DOE and NERC efforts in addressing the power system stability impact due to increasing penetration of power electronic loads, raising the awareness of the grid effects of electronic loads among the equipment manufacturers, and to support the development of the grid-friendly end-use standards.