# Addendum to the
# Collaborative Transmission Technology Roadmap

**March 2014**

    

Bonneville Power Administration

# Enhanced PDF Functionality

Functionality of the PDF version of this document has been enhanced in the following ways:

- **Embedded Table of Contents Links:** The Table of Contents has been linked to the appropriate sections of the document.
- **Internal links embedded within the document** to facilitate navigation between sections and "Back to Table of Contents."
- **Control + F:** As always, one can navigate through the document by searching for specific words or phrases by pressing the "Control" and "F" keys simultaneously.

## Introduction

The Bonneville Power Administration (BPA) and Electric Power Research Institute led a pilot project in 2013 to create the Collaborative Transmission Technology Roadmap. They invited senior leaders from Consolidated Edison, FirstEnergy Corporation, PJM Interconnection, Tennessee Valley Authority, Xcel Energy, and the Western Area Power Administration to provide strategic guidance. Principals from these eight organizations chose five priority Technology Areas (from a list of seventeen) to structure the pilot phase of this project.[1]

While the majority of transmission system technologies of interest to BPA are included in this newly-published resource, a review of the agency's Transmission Strategy identified several important technologies that are not included. Many of these technologies are, however, identified in other agency documents.

Sections of the February 2013 agency-specific Transmission Technology Roadmap have been extracted, reformatted, and included in this addendum for the purpose of announcing these research needs as part of the BPA Technology Innovation Office's March 2014 solicitation.[2] Also included in this addendum is a sub-set of the Load Modeling roadmaps section articulating BPA-specific research needs developed outside of the Collaborative Transmission Technology Roadmap process.

## Content

The following roadmaps are included in this addendum:

1) Load Modeling
2) Power System Stability Controls
3) Outage Management
4) Congestion Management
5) Extreme Event Hardening
6) Power Flow Controls

For the five roadmaps extracted from the earlier BPA Transmission Technology Roadmap (numbers 2–6 above), descriptions of the R&D programs are included in a table immediately following the roadmaps. Where possible, roadmap content has been updated to reflect the current state of research. These roadmaps have also been reformatted from the earlier style of six "swim lanes" to the new four-swim-lane format. It should be noted that these five roadmaps have not undergone the rigorous process of peer review used to create the Collaborative Transmission Technology Roadmap, but they still contain relevant information to guide research proposals.

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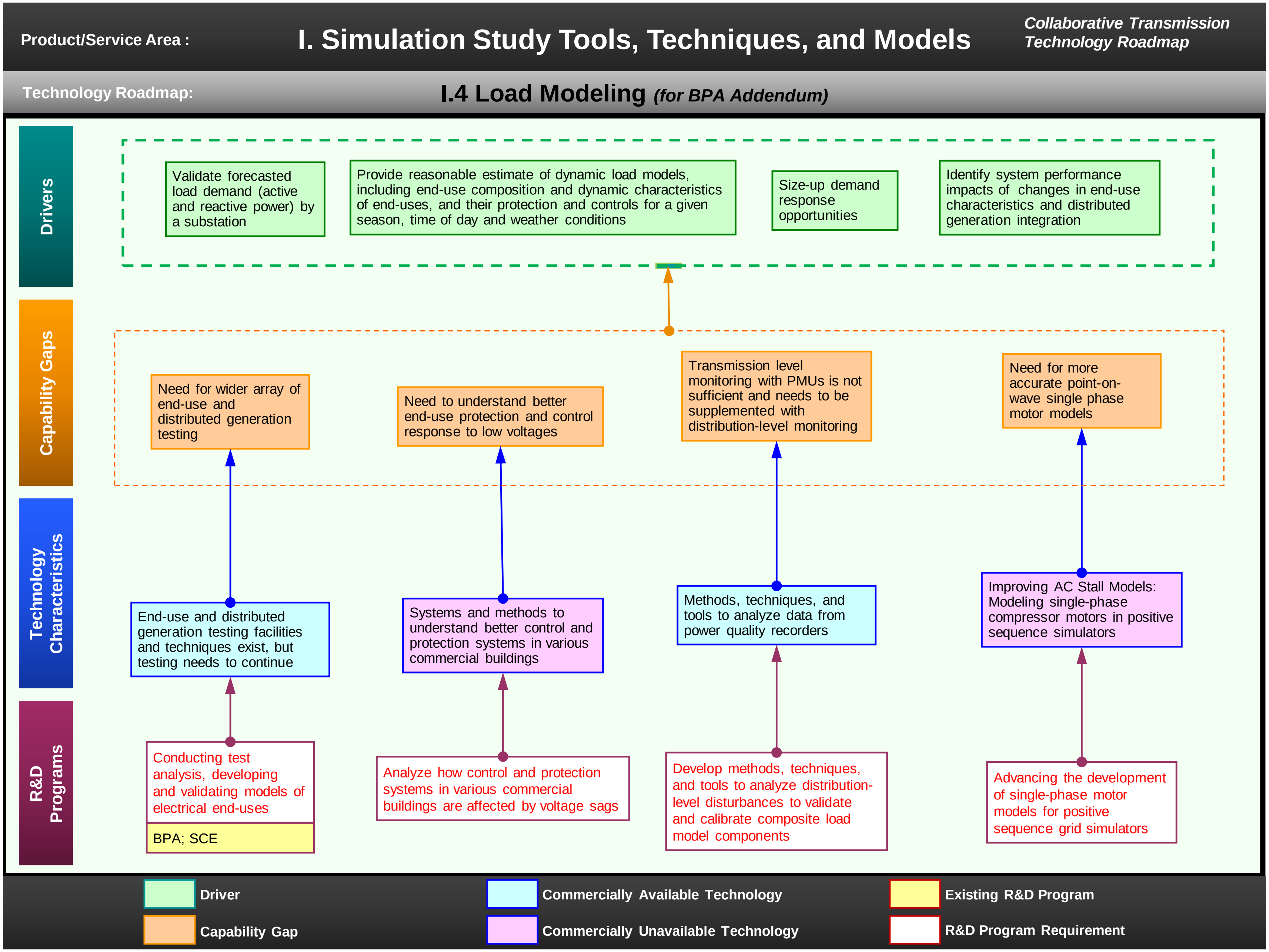
[1] See the Collaborative Transmission Technology Roadmap document for full background and content: http://www.bpa.gov/Doing%20Business/TechnologyInnovation/Documents/2014/Collaborative-Transmission-Technology-Roadmap-Jan-2014.pdf.

[2] Bonneville Power Administration, "Transmission Technology Roadmap," Feb. 2013, http://www.bpa.gov/Doing%20Business/TechnologyInnovation/Documents/2013/201303-BPA-Transmission-Roadmap-February-2013.pdf.


Product/Service Area :
I. Simulation Study Tools, Techniques, and Models
Collaborative Transmission Technology Roadmap
Technology Roadmap:
I.4 Load Modeling (for BPA Addendum)
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Validate forecasted load demand (active and reactive power) by a substation
Provide reasonable estimate of dynamic load models, including end-use composition and dynamic characteristics of end-uses, and their protection and controls for a given season, time of day and weather conditions
Size-up demand response opportunities
Identify system performance impacts of changes in end-use characteristics and distributed generation integration
Need for wider array of end-use and distributed generation testing
Need to understand better end-use protection and control response to low voltages
Transmission level monitoring with PMUs is not sufficient and needs to be supplemented with distribution-level monitoring
Need for more accurate point-on-wave single phase motor models
End-use and distributed generation testing facilities and techniques exist, but testing needs to continue
Systems and methods to understand better control and protection systems in various commercial buildings
Methods, techniques, and tools to analyze data from power quality recorders
Improving AC Stall Models: Modeling single-phase compressor motors in positive sequence simulators
Conducting test analysis, developing and validating models of electrical end-uses
BPA; SCE
Analyze how control and protection systems in various commercial buildings are affected by voltage sags
Develop methods, techniques, and tools to analyze distribution-level disturbances to validate and calibrate composite load model components
Advancing the development of single-phase motor models for positive sequence grid simulators
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program
R&D Program Requirement

# R&D Program Summaries

**Conducting test analysis, developing and validating models of electrical end-uses. Southern California Edison has premier facilities for testing a wide variety of electrical end-uses and distributed generation.** BPA has previously done the end-use testing in other BPA labs. BPA is now constructing its dedicated end-use testing facility, including a large chamber with controlled temperature. BPA and SCE plan to continue testing a wide range of electrical end-uses, including additional tests on air-conditioners (3-phase commercial units, high efficiency electronically connected units), heat-pumps (including variable refrigerant flow units), various types of fans, consumer electronics, lighting, power electronic drives, and solar PV inverters.

BPA is seeking an on-going collaboration with local universities in conducting test analysis, developing and validating models of electrical end-uses.

**Existing research:** BPA and Southern California Edison.

**Key research questions:**

1. Questions not yet specified.

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**Analyze how control and protection systems in various commercial buildings are affected by voltage sags.** Assumptions on end-use control and protection are essential for load modeling. WECC and DOE funded initial work on understanding how various end-uses are impacted by voltage sags and their duration. There is a need to build upon this work (see John Kueck, "Voltage Influence on Typical Protection and Controls for Motors, Power Electronics, and Other Common Loads," WECC report, http://www.wecc.biz/committees/StandingCommittees/PCC/TSS/MVWG /02282011/Lists/Minutes/1/WECC%20report%20draft1%20w%20comm%201.docx).

**Existing research:** None identified.

**Key research questions:**

1. Research must include particular buildings: groceries (e.g. Safeway, Whole Foods), box retailers (e.g. Target, Ross), shopping malls (Westfield), restaurants (e.g. Applebee's, Olive Garden), office building in an office park, office building in downtown area, etc.
2. The project needs to include field visits to various types of buildings and interviews of building operators.

**Develop methods, techniques, and tools to analyze distribution-level disturbances to validate and calibrate composite load model components.** Southern California Edison with support from the DOE CERTS program installed a number of power quality recorders in its distribution systems [12]. The program has been a huge success. A large number of events were recorded since the start of the program, many being FIDVR. The data is available for analysis through CERTS. The data is essential for validating and tuning single-phase air-conditioner models, for both positive sequence and transient.

BPA is developing a plan to install a number of similar power quality recorders devices in the Pacific Northwest. The installation will include distribution substations and customer locations. Data will be available for analysis and model validation similarly to SCE data. The power quality recorders will record:

- Point-on-wave data during a fault – 5 cycles before, 30 cycles after
- RMS quantities at 1 sample per second for 30 seconds past fault
- continuous 5-minute recordings of load voltage, frequency, active, and reactive power.

**Existing research:** None identified.

**Key research questions:**

1. The available recordings are taken on the customer side (240 or480 voltage) of a distribution transformer, and include point-on-wave voltage and current waveforms before and after a fault. The validation models must include EMTP-level models of corresponding residential and commercial customers, and their positive sequence equivalent models.

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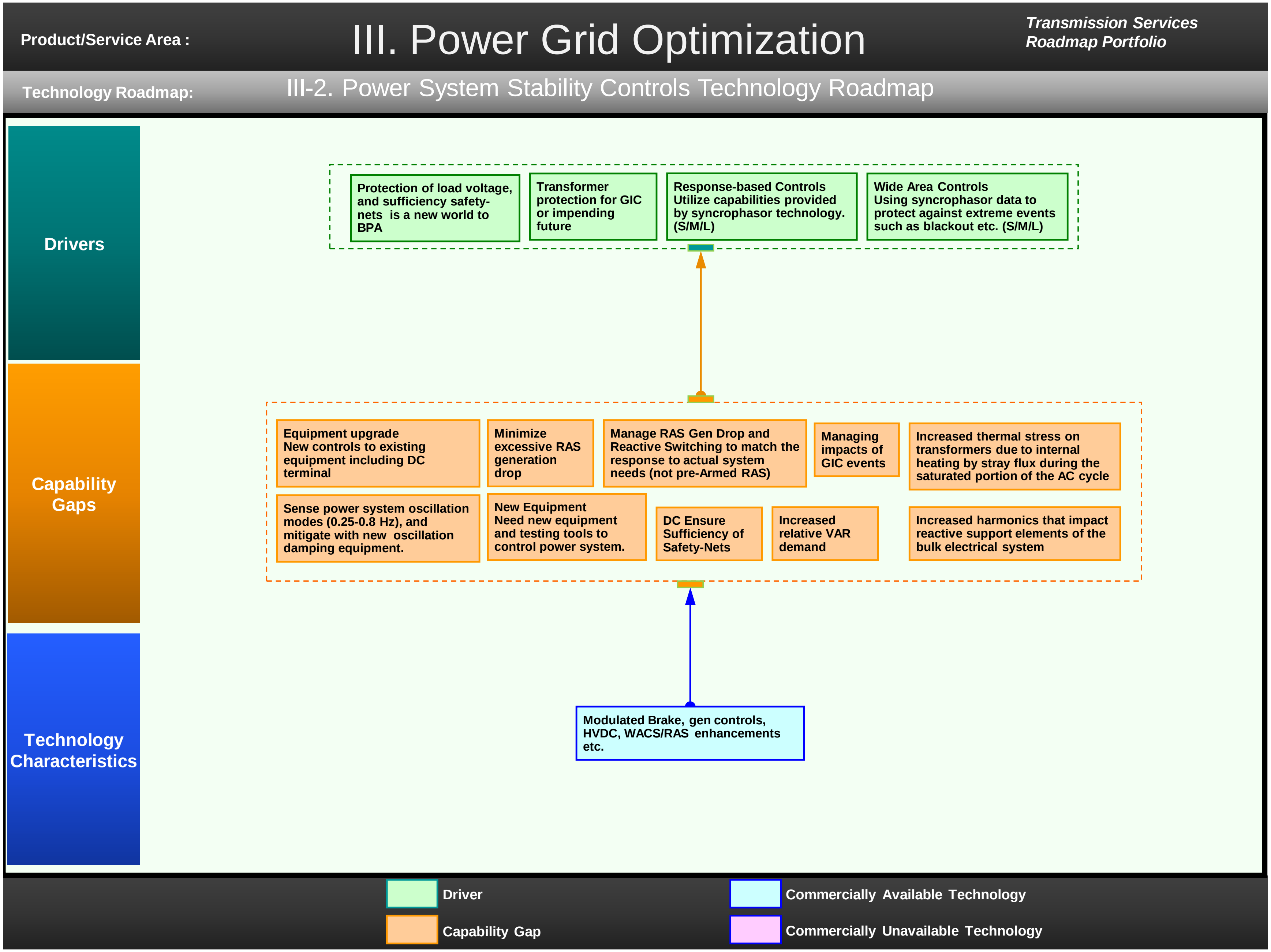
**Advancing the development of single-phase motor models for positive sequence grid simulators.** Single-phase compressor motors in residential air-conditioners and heat-pumps tend to stall quickly during voltage sags. SCE, BPA and EPRI tested 27 residential air-conditioners. General air-conditioner characteristics are understood. However, the effects of point-on-wave and of part of the compression cycle when a fault is applied need further investigation. Point-on-wave single phase motor models have been available for decades. Our challenge is to model single-phase compressor motors in positive sequence simulators. BPA expects MATLAB code to be delivered for point-on wave and positive sequence models developed under this project.

**Existing research:** None identified.

**Key research questions:**

1. How the air-conditioner stalling affected by point-on-wave when a fault is applied? How air-conditioner stalling is affected by a part of compression cycle when a fault is applied (reciprocating and scroll compressors)?
2. What are the key sensitivity parameters and how to quantify them in a positive sequence model, including the following: point on wave when a fault is applied, position of compressor crankshaft, compressor type, and ambient temperature?
3. How accurate can we expect a positive sequence model to represent responses of a single-phase compressors to a fault?
4. How to equivalence the behavior of multiple single phase motors along distribution feeders in a positive sequence equivalent models?
5. What is the expected level of modeling accuracy that can be achieved with model equivalencing with respect to voltage sags?


Product/Service Area :
III. Power Grid Optimization
Transmission Services Roadmap Portfolio
Technology Roadmap:
III-2. Power System Stability Controls Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
Protection of load voltage, and sufficiency safety-nets is a new world to BPA
Transformer protection for GIC or impending future
Response-based Controls Utilize capabilities provided by syncrophasor technology. (S/M/L)
Wide Area Controls Using syncrophasor data to protect against extreme events such as blackout etc. (S/M/L)
Equipment upgrade New controls to existing equipment including DC terminal
Minimize excessive RAS generation drop
Manage RAS Gen Drop and Reactive Switching to match the response to actual system needs (not pre-Armed RAS)
Managing impacts of GIC events
Increased thermal stress on transformers due to internal heating by stray flux during the saturated portion of the AC cycle
Sense power system oscillation modes (0.25-0.8 Hz), and mitigate with new oscillation damping equipment.
New Equipment Need new equipment and testing tools to control power system.
DC Ensure Sufficiency of Safety-Nets
Increased relative VAR demand
Increased harmonics that impact reactive support elements of the bulk electrical system
Modulated Brake, gen controls, HVDC, WACS/RAS enhancements etc.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology

Product/Service Area : **III. Power Grid Optimization**

*Transmission Services Roadmap Portfolio*

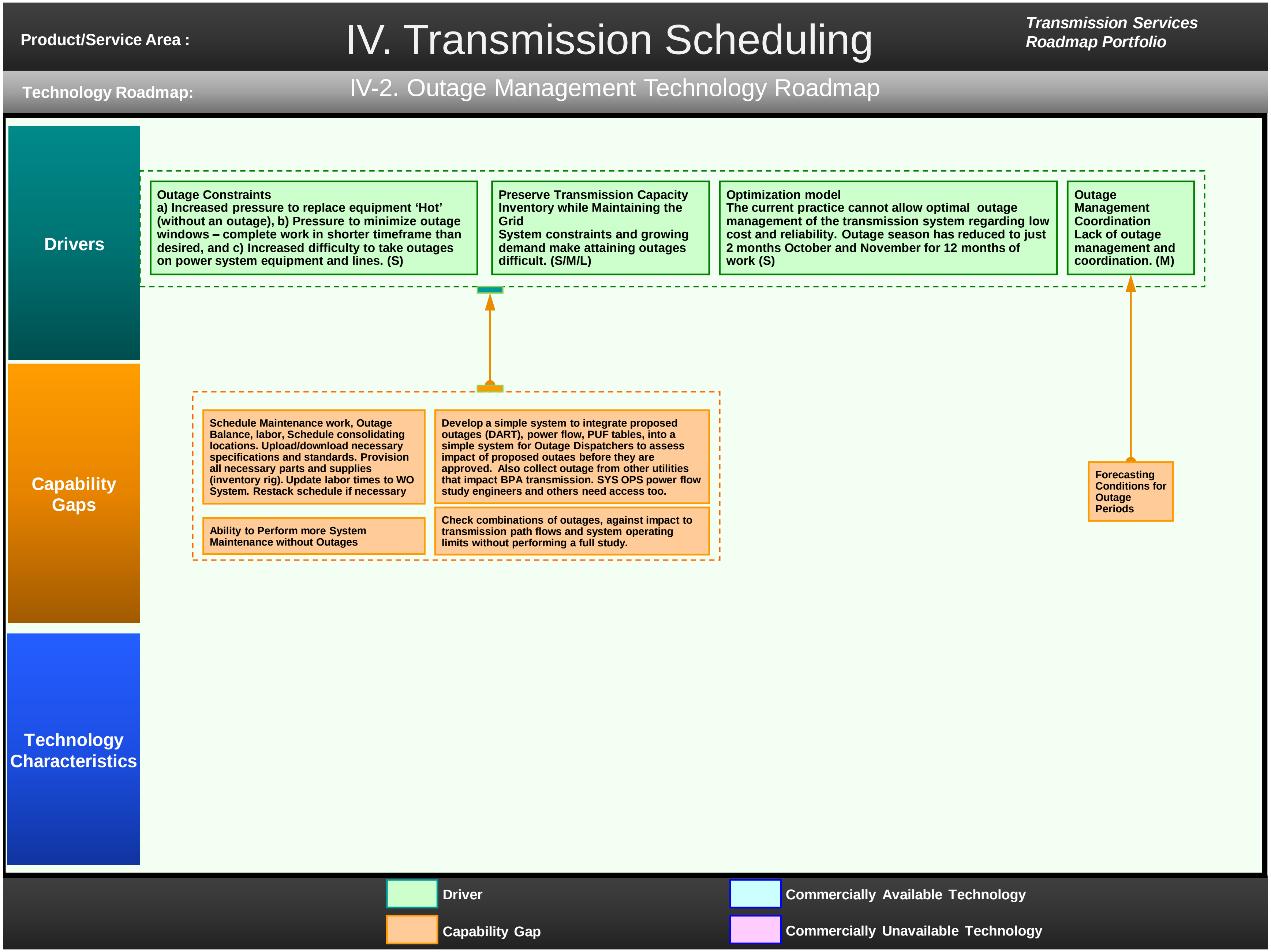
Technology Roadmap: **III-2. Power System Stability Controls Technology Roadmap**

**R&D Programs**

| | |
| --- | --- |
| R&D 34 - Power system controls- inter area oscillation damping | BPA TIP 50: (TRL-9) |
| R&D 50 - PNW Smart Grid Demonstration Project | BPA TIP 35: (TRL-8) |
| R&D 6 - Operations Real Time Study Process Improvement | BPA TIP 46: (TRL-8) |
| R&D 51 - Verifying Interoperability and Application Performance of PMUs and PMU-Enabled IEDs at the Device and System Level (T-43) | PSERC |
| R&D 52 - New remedial action scheme (RAS) research work to avoid cascading caused by intermittent output of renewable energy resources (TRL-3) | BPA TIP 275 |
| R&D 53 - Testing and Validation of Phasor Measurement Based Devices and Algorithms (S-45) | PSERC |
| R&D 30 - Response based voltage stability controls | BPA TIP 51: (TRL-9) |
| R&D 54 - Data Mining to Characterize Signatures of Impending System Events or Performance from PMU Measurements (S-44) | PSERC |
| R&D 55 - Wide Area Damping Control Proof-of-Concept Demonstration (TRL-6) | BPA TIP 289 - |
| R&D 56 - Real Time PMU-Based Stability Monitoring (S-50) | PSERC |
| R&D 57 - Advanced life extending control of multiple energy storage solutions | BPA TIP 244: (TIP-4) |
| R&D 58 - Impact of Bad Data and Cyber Data Attack on Electricity Market Operation (M-27) | PSERC |

Existing R&D Program or Project

R&D Program Requirement


Product/Service Area :
IV. Transmission Scheduling
Transmission Services Roadmap Portfolio
Technology Roadmap:
IV-2. Outage Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
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)
Preserve Transmission Capacity Inventory while Maintaining the Grid System constraints and growing demand make attaining outages difficult. (S/M/L)
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)
Outage Management Coordination Lack of outage management and coordination. (M)
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
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 outaes 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.
Ability to Perform more System Maintenance without Outages
Check combinations of outages, against impact to transmission path flows and system operating limits without performing a full study.
Forecasting Conditions for Outage Periods
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology

Product/Service Area : **IV. Transmission Scheduling**

*Transmission Services Roadmap Portfolio*

Technology Roadmap: IV-2. Outage Management Technology Roadmap

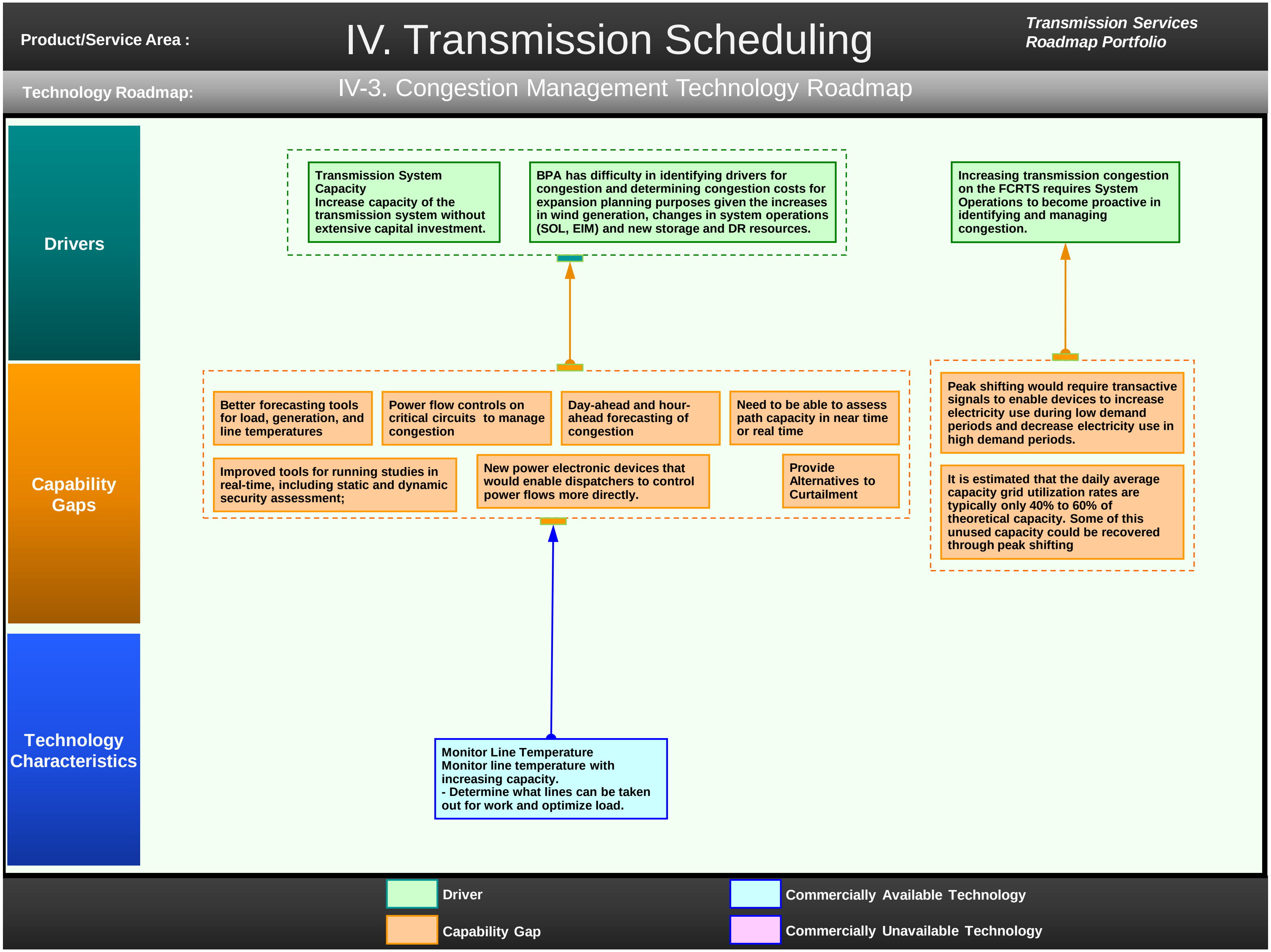
**R&D Programs**

R&D 67 - Optimization through transmission switching

BERKELY (DR. OREN):

Existing R&D Program or Project

R&D Program Requirement


Product/Service Area :
IV. Transmission Scheduling
Transmission Services Roadmap Portfolio
Technology Roadmap:
IV-3. Congestion Management Technology Roadmap
Drivers
Capability Gaps
Technology Characteristics
Transmission System Capacity
Increase capacity of the transmission system without extensive capital investment.
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.
Increasing transmission congestion on the FCRTS requires System Operations to become proactive in identifying and managing congestion.
Better forecasting tools for load, generation, and line temperatures
Power flow controls on critical circuits to manage congestion
Day-ahead and hour-ahead forecasting of congestion
Need to be able to assess path capacity in near time or real time
Improved tools for running studies in real-time, including static and dynamic security assessment;
New power electronic devices that would enable dispatchers to control power flows more directly.
Provide Alternatives to Curtailment
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.
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
Monitor Line Temperature
Monitor line temperature with increasing capacity.
- Determine what lines can be taken out for work and optimize load.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology

Product/Service Area : 

# IV. Transmission Scheduling

*Transmission Services Roadmap Portfolio*

Technology Roadmap:

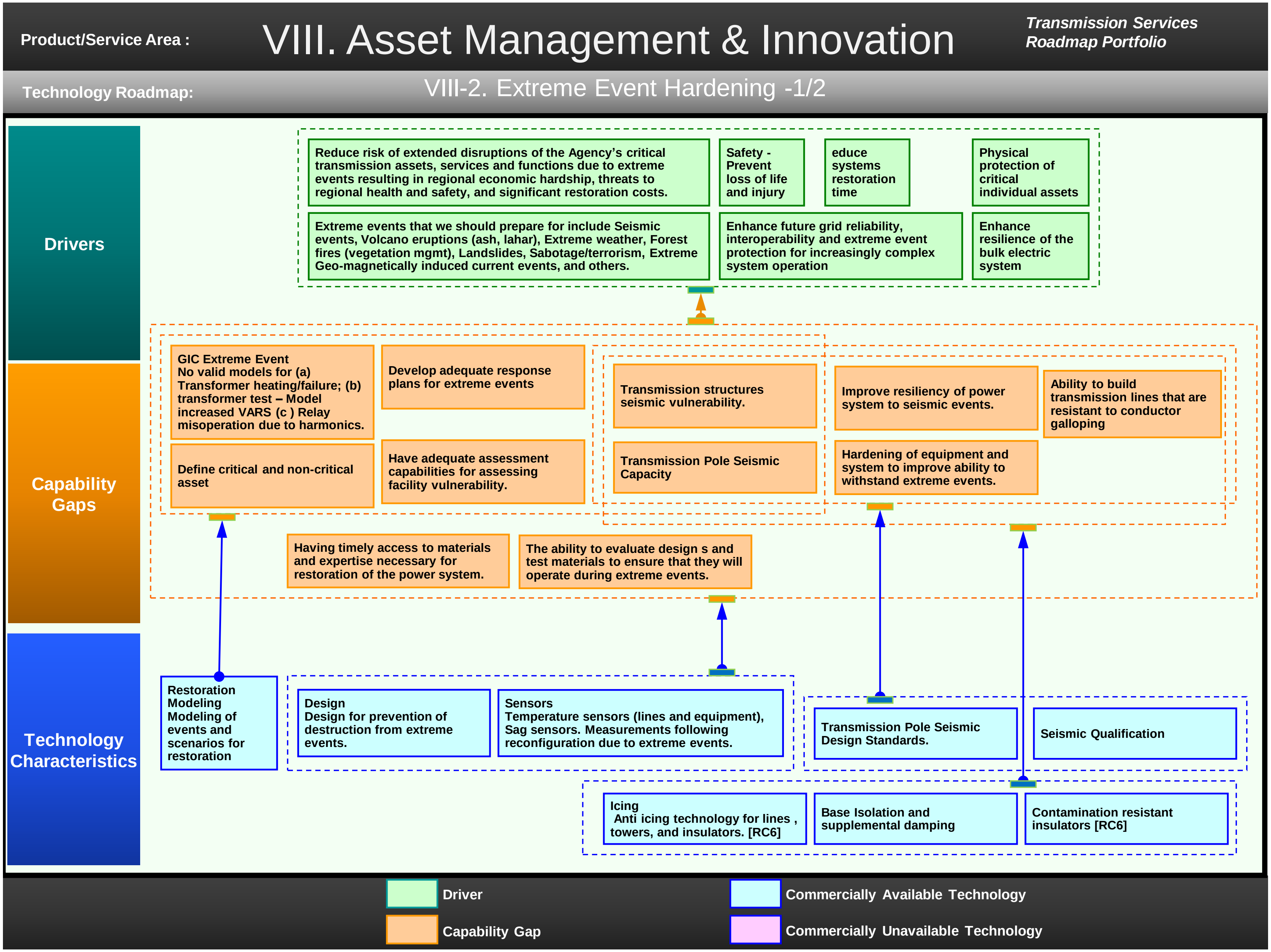
## IV-3. Congestion Management Technology Roadmap

**R&D Programs**

| R&D Program | Existing R&D Program or Project |
| --- | --- |
| R&D 46 - Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation | ARPA-E |
| R&D 9 - Next Generation On-Line Dynamic Security Assessment | PSERC: (S-38) |
| R&D 68 - Coupling Wind Generation with Controllable Load and Storage: A Time-Series Application of the SuperOPF | PSERC: (M-22) |
| R&D 69 - Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources | PSERC: (S-41) |
| R&D 70 - Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation | ARPA-E: |
| R&D 57 - Advanced life extending control of multiple energy storage solutions | BPA TIP 244: (TIP-4) |
| R&D 3 - Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources | PSERC: (M-26) |
| R&D 71 - Design and Valuation Design and Valuation of Demand Response Mechanisms and Instruments for Integrating Renewable Generation Resources in a Smart Grid Environment | PSERC: (M-23) |

Existing R&D Program or Project

R&D Program Requirement



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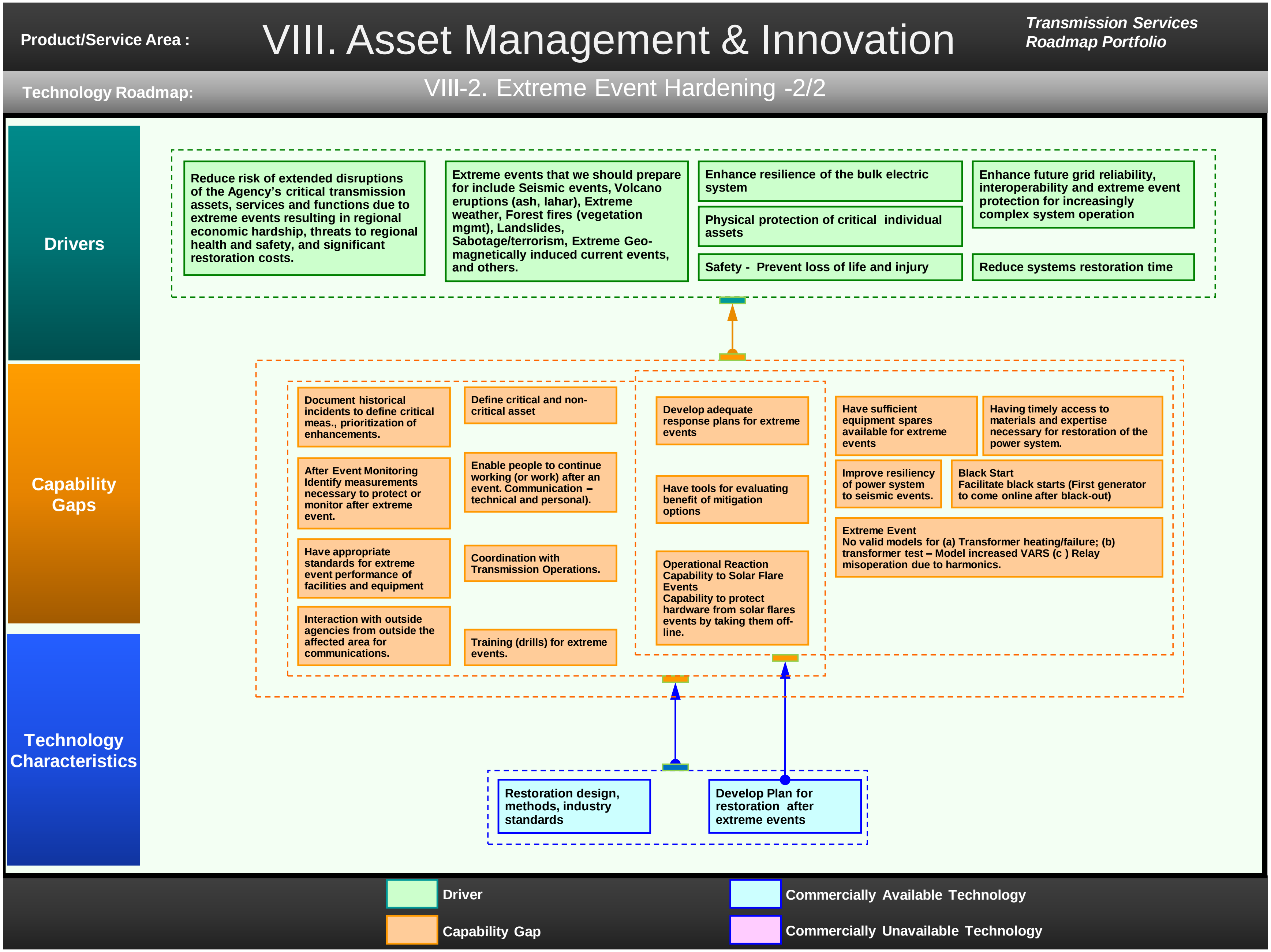



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Product/Service Area :

# VIII. Asset Management & Innovation

*Transmission Services Roadmap Portfolio*

Technology Roadmap:

## VIII-2. Extreme Event Hardening (1&2)

**R&D Programs**

| | |
| --- | --- |
| R&D 72 - Seismic Studies of Substation Equipment – 2011 | BPA TIP 25a - EPRI TC (TRL-5) |
| R&D 42 - Overhead Transmission - Program 35 (2011-2013) | EPRI |
| R&D 123 - Conductor/Connector Sensor | EPRI |
| R&D 124 - High-Voltage Power Transformer Base Isolation Technology & Implementation | BPA TIP 156 (TIP-5) |

R&D 125 - 500 kv disconnect switch with grounding switch, qualification at 1.0g event.

R&D 126 - Seismic affects of rigid and flexible bus on cable terminations

Existing R&D Program or Project

R&D Program Requirement

Product/Service Area : **III. Power Grid Optimization**

*Transmission Services Roadmap Portfolio*

Technology Roadmap: **III-1. Power Flow Controls Technology Roadmap**

| | Hardware | Modeling | Control |
|---|---|---|---|

**Drivers**

D1: A meshed network increases reliability at the cost of capacity underutilization and inefficiency. 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.

D2: Increased application of variable energy resources balanced within-hour by remote conventional resourced adds variation to power flows and the require additional voltage support.

**Capability Gaps**

CG1: Need to have the ability to explicitly control power flow. This would enable accessing this unused capacity to relieve congestion, relieve outage constraints and improve system security as an alternative to new transmission lines.

CG2: 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.

CG3: Develop specifications to compare the performance of power flow control devices.

CG4: Need the ability to model power flow control devices accurately for both planning and operational control purposes.

CG5: Need to verify that existing power flow control models accurately predict the behavior of devices installed in the grid.

CG6: 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.

CG7: Major load service paths that are voltage stability limited require additional cost effective devices that control voltage variability

**Technology Characteristics**

HVDC – High voltage DC, back-to-back converters in particular can be used to control network flows.

Line Impedance Control – Devices which control the impedance of a given path.

Phase Shifting Transformers

Landscape analysis of commercial and near-commercial Power Flow Controls/Flexible Alternating Current Transmission System (FACTS) devices.

Pilot field test of a power flow control device to demonstrate feasibility and benefits.

Collect data and information on actual performance, costs and operating experience of power flow control products.

Demonstrate through planning studies the ability to cost effectively use power flow control devices to accommodate a variety of generation resources such as renewable and distributed energy.

Driver | Commercially Available Technology

Capability Gap | Commercially Unavailable Technology

Product/Service Area :

# III. Power Grid Optimization

*Transmission Services Roadmap Portfolio*

Technology Roadmap:

## III-1. Power Flow Controls Technology Roadmap

**R&D Programs**

| R&D Program Requirement | Existing R&D Program or Project |
|---|---|
| R&D 44 - Compact Dynamic Phase Angle Regulators for Transmission Power Routing | ARPA-E |
| R&D 30 - Response based voltage stability controls | BPA TIP 51 - (TRL-9) |
| R&D 45 - Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency | ARPA-E |
| R&D 32 - Magnetic Amplifier for Power Flow Control | ARPA-E |
| R&D 33 - Transmission Power Flow Controls for Bulk Grid Optimization | BPA TIP 282 - (TIP-6) |
| R&D 34 - Power system controls- inter area oscillation damping | BPA TIP 50 (TRL-9) |
| R&D 35 - Distributed Power Flow Control Using Smart Wires for Energy Routing | ARPA-E |
| R&D 36 - Transformer-less Unified Power Flow Controller for Wind and Solar Power | ARPA-E |
| R&D 37 - Scalable Real-time Decentralized Volt/VAR Control | ARPA-E |
| R&D 38 - HVDC and FACTS Technologies | EPRI: Program 162 (2011) |
| R&D 39 - Control of power flow control devices | BPA TIP 245 (TIP-4) |
| R&D 48 - Evaluation of power flow controls, demand response and energy storage opportunities for resolving transmission constraints in the pacific northwest | BPA TIP 241: (TIP-7) |

Existing R&D Program or Project

R&D Program Requirement

# R&D Program Descriptions

| R&D Program Code | Lead Research Organization | Project Title & Project Description |
|---|---|---|
| **R&D 3** | PSERC PL: Le Xie (Texas A&M University) | **Quantifying Benefits of Demand Response and Look-ahead Dispatch in Support of Variable Resources (M-26)**<br>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. |
| **R&D 6** | BPA PL: Brian Tuck | **TIP 46 - operations real time study process improvement**<br>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.<br>Key Results/Conclusions<br>-Implemented distributed processing to use multiple CPUs to speed up system operating limit studies by up to 1000%.<br>-Improved the software efficiency of the automated system operating limit studies adding an additional 600% speed improvement.<br>-State estimator and custom software automatically generate 100 cases a day.<br>-State estimator based studies use real measurements for more accurate system studies.<br>-Implemented a power circuit breaker oriented power flow model to find hidden problems.<br>-Cost savings during unplanned line outage events impacting the northern intertie path (±$665K) and west of Cascades north path (±$793K). |
| **R&D 9** | PSERC PL: Vijay Vittal Arizona (State University) | **Next Generation On-Line Dynamic Security Assessment (S-38)**<br>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.<br>**REVIEW: This project is on its own merit and not related to the Common Power System Model.** |



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# R&D Program Descriptions

| R&D Program Code | Lead Research Organization | Project Title & Project Description |
|---|---|---|
| **R&D 30** | BPA PL:<br>Dmitry Kosterev | **TIP 51 - Response Based Voltage Stability Controls**<br>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.<br>Key Results/Conclusions:<br>-A combination of model-based stability assessment, measurement based tools and response-based Remedial Action Scheme (RAS) are needed to address voltage stability limits.<br>-Operational tools: Several measurement-based tools have been researched and are currently in the prototype phase.<br>-Response-based RAS: Wide-area control system is under the development. WACS will be deployed under the synchro-phasor capital program. California-Oregon Intertie reactive coordination studies are in progress.<br>-Wind power plant voltage controls: Voltage control requirements are developed. Secondary voltage control studies are planned.<br>-Load-Induced voltage instability: Load models are developed by WECC. BPA did significant amount of equipment testing, model development and data preparation. Studies indicate that the Portland metro may be at risk of voltage instability due to air-conditioner stalling. The project supports the development of regulatory framework which will have huge impact on the capital investment needs.<br>-Analysis tools: Tools for analysis of wind power plant voltage controls.<br>-Time-sequence power flow: Time-sequence powerflow capabilities in Power World and PSLF; also, the time sequence for studying the impact of wind ramp events on system voltage stability. |
| **R&D 32** | ARPA-E<br>Oak Ridge National Laboratory | **Magnetic Amplifier for Power Flow Control**<br>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. |

# R&D Program Descriptions

| R&D Program Code | Lead Research Organization | Project Title & Project Description |
|---|---|---|
| **R&D 33** | BPA<br>2012-2014 | **TIP 282 - Transmission Power Flow Controls for Bulk Grid Optimization**<br>The project will test the hypotheses that a well planed transmission upgrade adding power flow control to the main grid can provide an increase to operating transfer capability (OTC) and total transfer capability (TTC), while maintaining or increasing reliability and operating flexibility, at a better benefit/cost ratio than a new line build addressing the same constraints. The final goal is to provide a list of projects that have tested results and are available for Transmission Planning to move into the Planning Process, as determined appropriate.<br>Deliverables:<br>§At the end of stage 1 a white paper on modern power flow control applications will be provided. The white paper will summarize the applications, costs, life cycle, operations, maintenance, and first hand utility experiences with the different devices used to control power flow across transmission systems.<br>§In stage 1 power flow studies will be evaluate the performance of power flow control solutions on the BPA system.<br>§In stage 2 a more detailed set of studies will consider the impacts to system stability and control of the solutions identified.<br>§In phase 3 the work moves into a development effort. A feasibility analysis of the most promising projects identified from phase 1 and phase 2 will be performed.<br>§For any software enhancements pursued, documentation of the improvement and a presentation will be prepared for the transmission study staff at BPA. The goal of this deliverable will be to ensure this enhancement is well communicated to the staff that will benefit from its development. |
| **R&D 34** | BPA PL:<br>Dmitry<br>Kosterev | **TIP 50 - Power system controls- inter area oscillation damping**<br>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.<br>Deliverables:<br>§System-Level Oscillation Damping Controls<br>§Supply-Side Oscillation Damping Controls<br>§Demand Side Solutions<br>§Ambient and Event Based Mode Monitoring |
| **R&D 35** | ARPA-E<br>Smart Wire<br>Grid, Inc | **Distributed Power Flow Control Using Smart Wires for Energy Routing**<br>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. |
| **R&D 36** | ARPA-E<br>Michigan State<br>University | **Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission**<br>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. |


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| **R&D 37** | ARPA-E California Institute of Technology | **Scalable Real-time Decentralized Volt/VAR Control**<br>Caltech is developing a distributed automation system that allows distributed generators—solar panels, wind farms, thermal co-generation systems—to effectively manage their own power. To date, the main stumbling block for distributed automation systems has been the inability to develop software that can handle more than 100,000 distributed generators and be implemented in real time. Caltech's software could allow millions of generators to self-manage through local sensing, computation, and communication. Taken together, localized algorithms can support certain global objectives, such as maintaining the balance of energy supply and demand, regulating voltage and frequency, and minimizing cost. An automated, grid-wide power control system would ease the integration of renewable energy sources like solar power into the grid by quickly transmitting power when it is created, eliminating the energy loss associated with the lack of renewable energy storage capacity of the grid. |
| **R&D 38** | EPRI | **HVDC and FACTS Technologies - Program 162 (2011)**<br>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.<br>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. |
| **R&D 39** | BPA PL: Paul Ferron 2011 - 2012 | **TIP 245 - Control of Power Flow Control Devices**<br>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.<br>Key Results/Conclusions:<br>§White Paper, approximately10 pages, documenting test system used, justification for objective function and description of method used for sensitivity analysis.<br>§Interim Report, approximately 15 pages. Description of decentralized control methodology including simulation results comparing achieved results with results of Optimal Power Flow.<br>§Final Report, approximately 50 pages. Detailed report on project tasks carried out, results of system studies and conclusions on effectiveness of power flow control devices in the proposed application.<br>§Simulation code software including detailed comments.<br>§Presentation of accomplished work including explanation of simulation code. |

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| **R&D 42** | EPRI | **Overhead Transmission - Program 35 (2011-2013)**<br>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. |
| **R&D 44** | ARPA-E<br>Varentec, Inc. | **Compact Dynamic Phase Angle Regulators for Transmission Power Routing**<br>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. |
| **R&D 45** | ARPA-E<br>General Electric Company-Global Research | **Resilient Multi-Terminal HVDC Networks with High-Voltage High-Frequency Electronics**<br>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. |
| **R&D 46** | ARPA-E<br>Charles River Associates International, Inc. (CRA) | **Transmission Topology Control for Infrastructure Resilience to the Integration of Renewable Generation**<br>The CRA team is developing control technology to help grid operators more actively manage power flows and integrate renewables by optimally turning on and off entire power lines in coordination with traditional control of generation and load resources. The control technology being developed would provide grid operators with tools to help manage transmission congestion by identifying the facilities whose on/off status must change to lower generation costs, increase utilization of renewable resources and improve system reliability. The technology is based on fast optimization algorithms for the near to real-time change in the on/off status of transmission facilities and their software implementation. |
| **R&D 48** | BPA PL:<br>Travis Togo | **TIP 241 - Evaluation of Power Flow Controls, Demand Response And Energy Storage Opportunities For Resolving Transmission Constraints in the Pacific Northwest**<br>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.<br>Key Results/Conclusions:<br>§Methodology Draft, Regulatory Framework Assessment<br>§System impact studies for power flow controls<br>§Feasibility assessment<br>§Control Simulations<br>§Final Methodology, Study and Business Case Guidelines |

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| R&D Program Code | Lead Research Organization | Project Title & Project Description |
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| **R&D 50** | BPA PL:<br>Lee Hall | **TIP 35 - PNW smart grid demonstration project**<br>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. |
| **R&D 51** | PSERC PL<br>Mladen Kezunovic (Texas A&M University) | **Verifying Interoperability and Application Performance of PMUs and PMU-Enabled IEDs at the Device and System Level (T-43)**<br>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. |
| **R&D 52** | Hitachi America, Ltd. | **TIP 275 - New remedial action scheme (RAS) research work to avoid cascading caused by intermittent output of renewable energy resources**<br>The objective of this project is to develop feasible new remedial action schemes (RAS) using synchrophasors and on-line contingency analysis will be studied. Concept of desired RAS is identified.<br>Deliverables:<br>§Syncrophasor data analysis - Issue list and simulation research plan.<br>§Simulation research - Transient stability study for each case<br>§Developing concept of desired RAS - Final report. |

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| R&D Program Code | Lead Research Organization | Project Title & Project Description |
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| **R&D 53** | PSERC PL: Anurag K Srivastava (Washington State University) | **Testing and Validation of Phasor Measurement Based Devices and Algorithms (S-45)**<br>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. |
| **R&D 54** | PSERC PL Vijay Vittal (Arizona State) | **Data Mining to Characterize Signatures of Impending System Events or Performance from PMU Measurements (S-44)**<br>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. |
| **R&D 55** | Sandia National Laboratories | **TIP 289 - Wide Area Damping Control Proof-of-Concept Demonstration**<br>Recent efforts by the Bonneville Power Administration (BPA) have identified control schemes that can mitigate inter-area power oscillations through increased damping. This project includes the frequency sensor specifications, the communications link specifications, actuation device specifications, and the design of the high level supervisory control system that monitors system damping and identifies potential failures of the damping control system and takes autonomous corrective action. The goal of this research and development effort is to perform a proof-of-concept demonstration of a wide area damping controller system.<br>Deliverables:<br>§Sandia will furnish prototype frequency sensor devices (e.g. PMU's with updated firmware) to be deployed in the BPA fiber network. These devices will become BPA property upon conclusion of the contract.<br>§Sandia will furnish a damping control node consisting of an energy storage device, power electronics, a computer control system, and a supervisory control system to be installed at the Ross Complex Energy Storage Test Facility. This hardware will become BPA property upon conclusion of the contract.<br>§Sandia and Montana Tech will provide BPA with all software developed under this effort. This includes analysis code developed for PSLF or MATLAB, as well as all control code that runs on the local or supervisory control nodes.<br>§Sandia will provide BPA electronic copies of all reports, workshop briefings, conference papers, journal papers, test plans, drawings, and test data developed under this effort. |

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| **R&D 56** | PSERC | **Real Time PMU-Based Stability Monitoring (S-50)**<br>We propose new algorithms for real time stability monitoring in a control center environment. Two distinct but complementary methods are proposed for PMU-based stability monitoring: (a) waveform analysis to extract the “trending” information of system dynamics embedded in Lyapunov exponents – Is the system approaching instability?, and (b) a real time stability analysis based on energy functions for a faulted system – Will the system remain stable following the fault?. The combination of these approaches will provide a comprehensive and predictive stability monitoring system that help to avoid cascading failures and maximize system reliability. |
| **R&D 57** | BPA PL:<br>Stephen White | **TIP 244 - Advanced Life Extending Control of Multiple Energy Storage Solutions**<br>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.<br>Key Results/Conclusions:<br>The OSU WESRF in-lab grid, established through BPA funding, significantly benefits controller development while enabling hardware verification. The in-lab grid features an emulated wind farm, energy storage systems (supercapacitors, flow cell battery, and pumped hydro), traditional hydro generation resources, and local loads. These models show the promise of significant contributions to life extending control (LEC) algorithms that can integrate RDI models and dispatch resources, including energy storage resources, in a manner that would optimize hydro performance and overall system economics. It was also demonstrated that transmission congestion can be alleviated by adding energy storage devices and demand response loads to key locations on the grid. |
| **R&D 58** | PSERC PL:<br>Lang Tong<br>(Cornell University) | **Impact of Bad Data and Cyber Data Attack on Electricity Market Operation (M-27)**<br>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. |

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| R&D Program Code | Lead Research Organization | Project Title & Project Description |
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| **R&D 67** | University of California, Berkeley PL: Shmuel Oren | **Optimization through transmission switching**<br><br>Ref:<br>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.<br>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. |
| **R&D 68** | PSERC PL: Tim Mount (Cornell University) | **Coupling Wind Generation with Controllable Load and Storage: A Time-Series Application of the SuperOPF (M-22)**<br>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. |
| **R&D 69** | PSERC PL: Vijay Vittal (Arizona State University) | **Tools and Techniques for Considering Transmission Corridor Options to Accommodate Large Scale Renewable Energy Resources (S-41)**<br>The project develops assessment tools and techniques for considering transmission corridor options to accommodate high levels of penetration of renewable energy resources. |

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| **R&D 70** | ARPA-E<br>AutoGrid, Inc. | **Highly Dispatchable and Distributed Demand Response for the Integration of Distributed Generation**<br>AutoGrid, in conjunction with Lawrence Berkeley National Laboratory and Columbia University, will design and demonstrate automated control software that helps manage real-time demand for energy across the electric grid. Known as the Demand Response Optimization and Management System - Real-Time (DROMS-RT), the software will enable personalized price signals to be sent to millions of customers in extremely short timeframes—incentivizing them to alter their electricity use in response to grid conditions. This will help grid operators better manage unpredictable demand and supply fluctuations in short time-scales —making the power generation process more efficient and cost effective for both suppliers and consumers. DROMS-RT is expected to provide a 90% reduction in the cost of operating demand response and dynamic pricing programs in the U.S. |
| **R&D 71** | PSERC PL:<br>Shi-Jie Deng<br>(Georgia Institute of Technology) | **Design and Valuation Design and Valuation of Demand Response Mechanisms and Instruments for Integrating Renewable Generation Resources in a Smart Grid Environment (M-23)**<br>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. |
| **R&D 72** | EPRI PI:<br>Dr. Ashel Schiff<br>BPA PM: Leon Kempner Jr.<br>2009 - 2012 | **TIP 25a - EPRI TC: Seismic Studies of Substation Equipment**<br>EPRI will select the item(s) of equipment that is (are) to be tested for each year. EPRI establishes equipment support structure specifications and vibration test requirements, electrical equipment specifications, and test specifications. EPRI will select a vibration testing facility (and electrical testing laboratory, if required) to perform tests and EPRI draws a contract for laboratory services. The manufacturer and the testing laboratory prepare qualification documentation for the equipment that is qualified following IEEE 693 requirements<br>Key Results/Conclusions:<br>- Acceptance Criteria for Qualifying Hollow-Core Composites<br>- Qualifying Components with Complex Geometry, Non-Linear Response, or Non-Measureable Failure Modes<br>- Sine Beat Test Procedure<br>- Table Impulse to Excite Equipment on Shake Table<br>- New Procedure for Qualifying Transformer-Bushing Systems<br>- Orientation of Equipment Modes of Vibration can cause Under- or Over-Testing<br>- Curve Fitting to estimate Damping and Frequency in the Time Domain |

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| R&D Program Code | Lead Research Organization | Project Title & Project Description |
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| **R&D 123** | EPRI | **Conductor/Connector Sensor**<br>This project is developing and demonstrating low-cost RF sensors to assess conductors and compression connectors on overhead transmission lines. The sensors measure the following parameters: Temperature, Current, Three axes of inclination, Vibration in three axes (see the project summary for the Vibration Sensor Suite) |
| **R&D 124** | MCEER PI:<br>Dr. A. Reinhorn<br>BPA PM:<br>Leon Kempner<br>2010 - 2012 | **TIP 156: High-Voltage Power Transformer Base Isolation Technology & Implementation**<br>This project demonstrated that exiting base isolation technology can be designed to protect high voltage transformers. A simplified design procedure was develop for design of high voltage transmission applications<br>Research results have been shared with the IEEE 693 Seismic Design Standard and presentations made to numerous utilities.<br>Demonstration project has been developed for implementation of a base isolation design on two of BPA's high voltage transformers<br>Key Results/Conclusions:<br>-Implementation of design procedures and tools that enable evaluation and further use of protective technologies<br>-Identify limitations of base isolation systems, which require innovative solutions<br>-Identify utilities to participate in implementing base isolation of transformers and other equipment<br>-Identify equipment and sites; select base isolation solution from the methods researched<br>-Design and implement a protective solution including equipment, connectors to first conductor support, in-situ<br>-Develop plans for instrumentation and monitoring of demonstration installation(s)<br>-Provide guidance to BPA engineers with design or selection of off-the-shelf solutions (instrumentation, protection, and monitoring)<br>-Provide guidance for monitoring and processing of demonstration installation(s) |
| **R&D 125** | | **500 kv disconnect switch with grounding switch, qualification at 1.0g event.** |
| **R&D 126** | | **Seismic affects of rigid and flexible bus on cable terminations** |