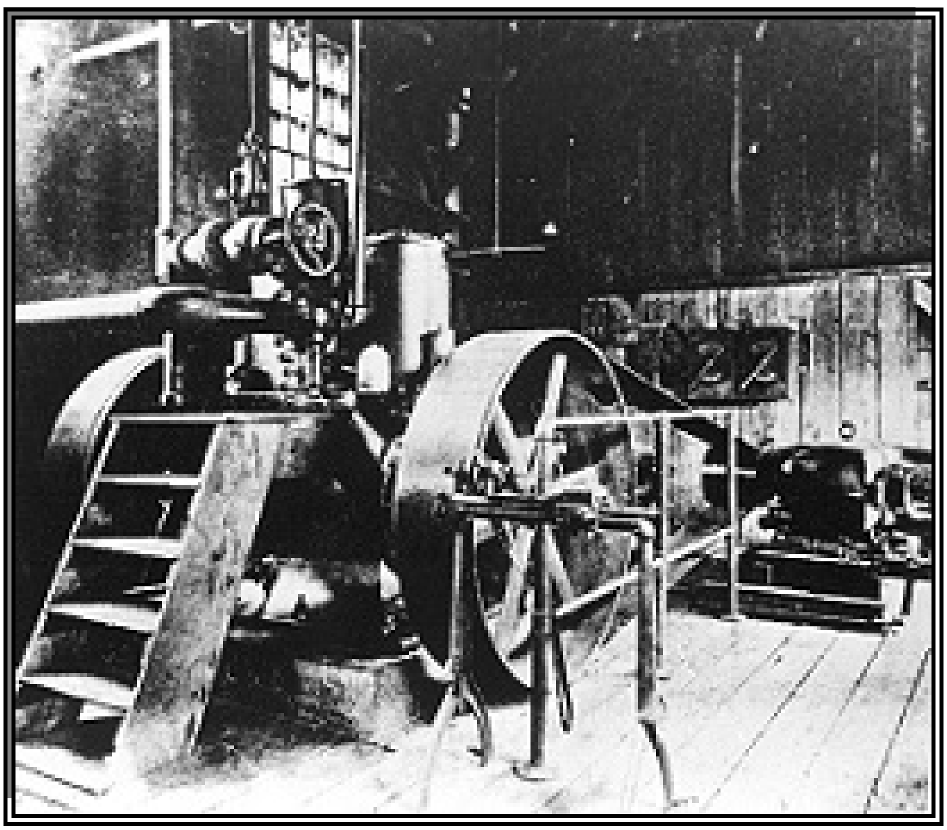
BONNEVILLE POWER ADMINISTRATION

TECHNOLOGY INNOVATION OFFICE

September 2006

TRANSMISSION TECHNOLOGY ROAD MAP



1885 Generator

At first glance one may think, "My how things have changed,"
But at second glance one may admit, "Things haven't changed much at all."

CONTRIBUTORS

This **2006 Transmission Technology Roadmap** marks the beginning, not the end, of an ongoing process to support decisions about research, development and demonstration (RD&D) investments at BPA. It is the result of synthesized input from 80 BPA staff members who are highly respected in their transmission-related specialty. The contributors, and others so inspired, are encouraged to learn more about innovative technologies and to be proactive to communicate your ideas about what-how-and-when BPA should do to successfully apply technologies that deliver BPA's mission. The future of BPA depends on you.

Transmission Operations and Planning Workshop: 12/14/05

Bloomer, Cain - DE
Doern, Terry L - TOT
Gronquist, Jim - TOT
Kochheiser, Todd W - TOS
Kosterev, Dmitry - TOM
Martin, Ken - TNTD
Mittelstadt, Bill - TOM
Olds, Peggy A - TOT
Matthews, Chuck - TOP
Oliver, Terry V - DE
Raschio, Peter - TOS
Silverstein, Brian L - TO
Sundborg, Sara - TOT
Tuck, Brian A - TOD
Wainwright, Jodie - DE
Watkins, Donald S - TO

Transmission Facilities Workshop: 2/8/06

Adolf, MayMay - TNCB
Anderson, Loren L - TNC
Andrews, Page - TNSB
Bennett, Sheila A - TNLB
Bergman, Byron R - TOM
Brown, Ken – TNLE
Burgess, James – TRS
Courts, Alan L - TN
Daume, Jon F - TNCD
Do, Thien T - T
Fleisher, Charles H - TNFB
Goldworthy, Christine - TNSD
Hildreth, Jeffrey G - TNSE
Hill, Lloyd A - T
Hoffman, Michael R - TNFD
Hofmann, Michael - TNCD
Johns, Derrol J - TNP
Kempner, Leon Jr - TNFC
Litzenberger, Wayne H - TNP
Millen, Creig B - TNT
Oliver, Terry V - DE
Pereira, Abel J - TNSF
Perez, Jared J - TNFC
Phillips, Dennis W - PFR
Pospisil, John W - TNSB
Reding, Jerry L - TNL
Riley, Michael J - TNFC
Ruff, Donald L - TNLB
Trad, Steven M - T
Tyson, Ivy L - T
Wainwright, Jodie - DE
Weintraub, Frank R - TNLB
Winters, Richard J - TF

Transmission Closeout Workshop: 8/22/06

Bennett, Sheila A - DE
Bloomer, Cain - DE
Courts, Alan - TN
Doern, Terry L - TOT
Do, Thien - T
Gronquist, Jim – TOT
Hofmann, Michael - TNCD
Johnson, Anders L – TNCD
Litzenberger, Wayne H – TNP
Olds, Peggy A - TOT
Oliver, Terry - DE
Perez, Jared J - TNFC
Phillips, Dennis W - DE
Pospisil, John W - TNSB
Radcliff, Madonna R - T
Rodd, Katie - TF
Silverstein, Brian L - TO
Wainwright, Jodie - TOM
Watkins, Donald S - TO
Weintraub, Frank R - TNLB
White, John F - TFH
Winters, Richard J - TF

Individual Interviews and Group Meetings

Anderson, James – TF
Anderson, Loren – TNC
Boman, Barry - TNSF
Brown, Ken – TNLE
Burgess, James – TRS
Carter, Lawrence – TOT
Comegyes, Gordon – TOC
Custer, Leonard – TNLB
Demory, Laura – TNTC
Doern, Terry L – TOT
Ellison, Richard - TOD
Froh, Craig – TNLE
Grill, Alan – TNLB
Gronquist, Jim – TOT
Haner, John – TOM
Hernandez, Salvador – TNSE
Ierulli, Vince – TNLB
Johnson, Anders – TNC
Keenan, Gerald –TOM
Kempner, Leon Jr - TNFC
Kochheiser, Todd W – TOS
Kohne, Kyle – TOP
Kosterev, Dmitry – TOM
Larvick, Stewart – TOM
Litzenberger, Wayne H - TNP
Martin, Ken - TNTD
Mittelstadt, Bill – TOM
Olds, Peggy A – TOT
Puyleart, Frank – TOT
Raschio, Peter – TOS
Reding, Jerry L - TNL
Rodd, Katie – TF
Rodrigues, Melvin – TOP
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Watkins, Donald S - TO
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Wientraub, Frank R. – TNLB

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EXECUTIVE SUMMARY

The 2006 Transmission Technology Roadmap represents the synthesis of expert opinion and technical knowledge of 80 BPA experts across a variety of disciplines including transmission operations, planning, facility design and maintenance. It marks the beginning of an ongoing process to support decisions about research, development and demonstration (RD&D) investments at BPA. It provides a strategic framework to guide transmission RD&D efforts based on targets and time-based milestones. It addresses the technological challenges as well as long-term needs.

The Vision

Looking ahead 20 years, the vision established by this road map is that the increasingly complex BPA transmission system will be designed, operated and managed with real-time intelligence and control to maintain system reliability, increase transmission capacity and maximize asset use in an environmentally sound manner.

The Targets

BPA's roadmapping approach links technology innovation targets to business drivers. The business drivers are clustered around topics that are key to BPA's strategic agenda: system reliability, low rates, environmental stewardship and regional accountability. To support this vision of the future, the participants established the targets below based on customer, business, regulatory, technical and environmental drivers of change.

- Enhance the future grid's reliability, interoperability and extreme event protection for an increasingly complex system operation.
- Increase transmission transfer capabilities and power flow control.
- Use efficient, cost-effective, environmentally sound energy supply and demand.
- Maximize asset use.

To meet the targets, an intelligent grid is needed that can communicate across planning, design and operation to provide protection and control of the transmission system. This can be done with devices and processes that are interoperable, high speed, secure and reliable. Intelligent features include real-time wide-area monitoring and control with adaptive protective relaying schemes. Intelligent technologies are needed to identify and analyze temperatures, voltage and stability constraints, and dynamic system changes. They should have the capability to collect, analyze, disseminate and display large volumes of real-time data.

As the system gets increasingly more complex, reactive power and voltage support need to be maintained, as does power quality during normal conditions and disturbances. To achieve this, cost-effective control systems and power electronics are necessary. Energy storage technologies can also be used to reduce transmission stability constraints or voltage constraints.

Future technologies need to provide real-time system operation by quickly being able to generate reliable system limits that accurately reflect system operating configurations. Real-time monitoring hardware integrated with software that is capable of translating the data collected into meaningful information to support operating decisions is required. Dispatch needs additional real-time tools to reliably operate the system with increased situational awareness to alert operations/dispatch of inconsistent information and unstable conditions.

Adding to the complexity of the future grid are the simultaneous needs to increase transmission line capacity within existing corridors, provide the ability to take outages and optimize the transition of new technologies into the aging transmission system. This can be accomplished through technologies that provide high current operation and smart diagnostic/maintenance along with parallel efforts to advance substation technology and integrate new and existing equipment based on condition, life cycle, end of life identification and interoperability. The capability to model and simulate power flow scenarios with multiple contingencies is also needed.

To reduce expenses, offset construction costs and make best use of borrowing authority, nonwire solutions are needed to reduce peak load, integrate with end-user consumer systems and smooth out intermittent resources.

The Critical Technologies

The collaborative roadmapping process identified critical technologies that best support the agency’s technology innovation strategy. They are listed below.

- Real-time wide-area control, monitoring and measurement systems
- Situational awareness and visualization tools for operations/dispatch
- Software tools for system performance and online real-time dispatch/operations
- Real-time automated load forecasting and generation tools
- Communication hardware and software
- Power electronics, energy storage and advanced substations
- Advanced maintenance and diagnostic technologies
- Extreme event protection and facility hardening
- High-current operating technologies and advanced conductors
- Nonwires solutions

The RD&D gaps that exist between the current and future critical technologies were also identified. Filling these gaps has the potential to enable real-time systemwide operation, relieve congestion, reduce the frequency and duration of operational disturbances and planned outages, enhance grid stability, increase operational transfer capability (OTC), increase asset utilization, reduce peak load and harden infrastructure to detect, prevent and mitigate extreme event damage to the grid.

Technology Ranking

Power Electronics

Of all the critical technologies identified, only power electronics is used to support all four of the targets. Power electronics are at the heart of the power conversion interface and hold the potential for transforming the electric power system by allowing precise and rapid switching of electrical power. Collaborative prototype development and field test demonstrations are necessary to validate product performance and lead to cost reductions and market penetration.

Technology Risk
Using expert input gathered during the roadmapping process, the critical technologies were categorized based on high, medium or low technical risk.

- High technical risk technologies are best suited for collaborative investments and phased projects that require a highly specialized research staff, laboratories or demonstration facilitates. Examples are material science research in power electronics, energy storage, advanced cables, advanced substation equipment and facility hardening technologies.

- Medium technical risk technologies consist of prototype development and field test demonstrations that validate product performance, reduce costs and achieve market penetration. Technologies at this stage are communication equipment, power electronics, nonwire solutions, real-time measurement/monitoring hardware and advanced maintenance/diagnostic technologies. These may require a mix of BPA go-it-alone and collaborative/partnership investments.

- Low technical risk technologies are well suited for BPA to go-it-alone, if necessary, to satisfy BPA system-specific requirements and rigorous prototype testing and validation by BPA System Operations and/or Planning. Such technologies are
    - Real-time wide-area control and measurement systems;
    - A robust state estimator;
    - Real-time automated load forecasting and generation tools;
    - System performance, analysis and validation tools;
    - Automated tools and online real-time software tools for dispatch/operations;
    - Data visualization tools and displays for dispatch;
    - An improved System Earthquake Risk Assessment (SERA) program; and
    - Modeling of high-current operation of cables, connectors and hardware.

Recommended Next Step
To maintain system reliability, increase transmission capacity and maximize asset use in an environmentally sound manner, a balanced RD&D portfolio between transmission planning, operation, design and maintenance is required. A systems approach is needed to move technologies through the stages of research, development and demonstration into application within the BPA transmission grid.

Further analyses are recommended to rank and rate the critical technologies in support of future decision making. BPA experts need to engage in further discussions and provide comparative judgments about the

- competing technological goals,
- competing technological strategies and RD&D implications and
- relative rank of the critical technologies according to their contributions to fulfill the mission and achieve the targets.

A summary of the 2006 Transmission Technology Road Map Vision, Targets, Challenges, Milestones and Future Technology Applications is shown in Figure 1.

Vision

In 20 years, the increasingly complex BPA transmission system will be designed, installed, operated and maintained with real time intelligence and control to maintain system reliability, increase transmission capacity and maximize asset use in an environmentally sound manner

Targets

- Enhance future grid reliability, interoperability & extreme event protection
- Increase transmission transfer capabilities & control of power flows
- Use efficient, cost-effective, environmentally sound energy supply & demand
- Maximize asset use

Challenges

- Intelligent grid that communicates across planning, design, operation, protection & control of the transmission system
- Capability to perform online, real time analysis for dispatch/operations
- Power system modeling & simulation of multiple contingencies to assess power flows, risk, emergency management & economics
- Provide reactive/voltage support & maintain power quality
- Increase transmission line capacity within existing corridors
- Application of technologies that reduce expenses & offset construction costs
- Optimize the transition of new technologies into aging transmission system
- Effective Integration of distributed energy, intermittent resources & WECC utilities

Milestones

Near Term (0-5 years)

- Develop accurate forecasts of generation & load models
- Improve & expand base case power flow capabilities
- Improve & expand dynamic simulation capabilities
- Integration of SERA program output into Power Flow Program
- Assess river-xing tower liquefaction vulnerability
- Planning tools to review FACTS option for new projects
- Employ digital infrastructure of wireless & fiber optic communication technologies to support measurements & automation
- Install relay controls with programming & logic that are interoperable with other equipment
- Understand energy storage applications best for BPA
- Meet industry standards for high temperature operation of substation and line equipment
- Use advanced inspection & prevention tools for maintenance
- Understand hot line/substation industry practices impact on BPA's business/legal case

Mid Term (5-10 years)

- Develop robust state estimation through integrated planning & operation capability
- Develop operational on line performance & assessment tools
- Develop visualization tools & systems for dispatch
- Develop tools for modeling, diagnosis, containment, mitigation & restoration of extreme events
- Reinforce critical substation components to withstand earthquake ground motions
- Acquire high current operation analysis capabilities
- Reinforce 230kV to support 500kV grid operations
- Field tests and demos of power electronics, energy storage and HVDC to demonstrate reliability & lower costs.
- Real time monitoring & diagnostic of cables & substations
- Integrate new substation & line equipment with existing equipment to maximize interoperability & life cycles
- Greater use of Non-Wires Solutions
- Implement hotline maintenance policy/procedures system wide

Long Term (10-20 years)

- Acquire real time situational awareness & real time contingency analysis capability by monitoring & control of system wide operations
- Develop the capability for scenario & probabilistic planning & load forecasting for multiple constraints, distributed resources, demand response & non-wires
- Use of a common communication architecture that facilitates interoperability system wide
- Deploy real time automated system wide data measuring, collection, monitoring, visual display, processing & analysis to support planning, operations, dispatch & maintenance
- Use cost-effective advanced high current capacity cables
- Development of power electronic & energy storage standards & guidelines for system application
- Utilize modular designs for substations & lines to manage failures & rapid restoration
- Design, build & demonstrate a "smart" prototype substation

Future Technology Applications

- Response Based Real Time Wide Area Control Systems
- Robust State Estimation
- Enhanced Wide Area Measurement Systems
- Software Tools for System Performance & Online Real Time Analysis
- Real Time Automated Load Forecasting & Generation Tools
- Advanced Conductors
- Power Electronics
- Advanced Substations
- Hot Line & Substation Tools & Procedures
- Automated Tools for Dispatch & Operation
- Extreme Event Modeling & Facility Hardening Technologies
- Communication Technologies
- Data Visualization Tools for Dispatch
- Real-time Monitoring System Wide
- High Current Operating Technologies
- Energy Storage
- Non-Wires Solutions
- Advanced Maintenance & Diagnostic Technologies

INTRODUCTION

Over the years, the Bonneville Power Administration (BPA) has been successful in responding to political, business, environmental and technological drivers of change. BPA has earned regional, national and international recognition as an innovative leader in technical breakthroughs and achievements that have saved electric consumers millions of dollars. Throughout its notable history, BPA has made significant contributions to the original development of, and incremental improvements to, a reliable high-voltage power system, energy efficiency, nonwire solutions and environmental technologies.

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

Today's environment is stretching the aging transmission system to operate at power flow levels closer to voltage, thermal and stability limits. For example, from June through August 2005, the Northwest grid power flows exceeded the grid's operating transfer capability (OTC) at least 174 times. [Challenge for the Northwest, April 2006, p. 3] As power flow congestion incidents increasingly exceed historical levels, the system operates closer to its limits more often, thus increasing the risk to system reliability and economic efficiency. [Challenge for the Northwest, April 2006, p. 3] Although, BPA has invested more that $1 billion in *new* transmission construction in the last several years, relatively speaking, this is not enough to support an aging infrastructure that is continually being pushed closer and closer to its limit.

One major way to address these concerns is to place more effort in technology innovation and confirmation and to leverage resources through coordination with other organizations that share common RD&D goals. Thus, BPA has decided to ramp up RD&D expenditures to 0.5 percent of gross revenues. The BPA Technology Innovation annual budget (excluding capital investments and fish and wildlife) is expected to be $12 million by 2011. [Technology Innovation Summary, July 2005, p. 1]

The goal of future RD&D is to transform critical technologies into best practice applications. The roadmapping process identified the critical technologies that have the potential to improve system reliability, lower rates, advance environmental stewardship and provide regional accountability. These technologies are

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

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

ROAD MAP SCOPE

The road map marks the beginning of the technology innovation/confirmation strategy effort rather than the end. During the next 20 years, the effort will require continued support, commitment and refinement from BPA experts and regional/national transmission technology experts. During the last nine months, the roadmapping process facilitated group collaboration and interaction among the BPA transmission experts through participation in workshops, individual interviews and group meetings to identify

- change drivers,
- future technologies,
- gaps between existing and future technologies and
- challenges to implementing these new technologies.

The resulting road map represents the integration of the thoughts and technical knowledge of BPA experts across a variety of disciplines, including operations, planning, substation design, line design and maintenance. This road map articulates BPA's transmission technology confirmation/innovation strategy. It provides a strategic framework for guiding transmission RD&D efforts based on targets and time-based milestones. It addresses the technological challenges as well as long-term needs. This transmission technology road map reflects a common view about

- the drivers of change that are shaping the vision of BPA's future,
- the critical technologies that will have the greatest potential to support the agency's strategic future plan and mission deliverables,
- the future technology goals and how to achieve them,
- the gaps that exist between existing technologies and the critical future technologies identified and
- near-, mid- and long-term milestones needed to accomplish future technology applications.

ROADMAP PURPOSES

The purposes of this road map are to

- show the relationship between technologies and strategic targets,
- assist in transmission technology planning and coordination,
- assist in making the appropriate technology investment decisions and leverage those investments,
- make sure the right capabilities are in place at the right time to achieve future targets and
- serve as a communication and decision tool for BPA staff and senior management.

THE ROADMAP AND BPA's STRATEGIC PLAN (2007-2011)

Bonneville Power Administration
BPA's current mission is to

- provide an adequate, efficient, economical and reliable power supply;
- deliver to our customer's electric transmission of federal and non-federal power that could be generated from decentralized and/or centralized locations;
- provide interregional interconnections;
- maintain system reliability and stability; and
- mitigate the Federal Columbia River Power System's impacts on fish and wildlife.

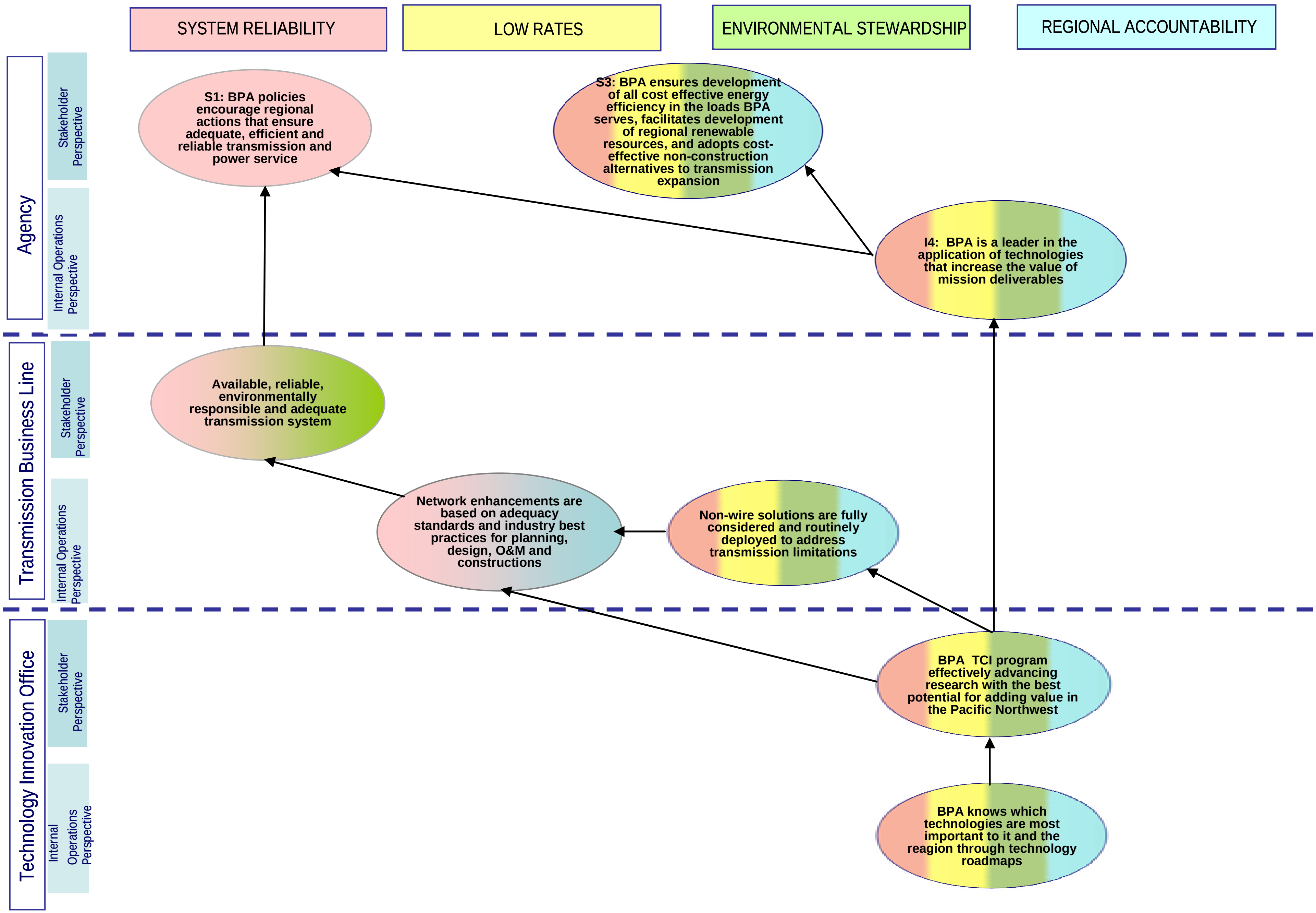
To accomplish this mission, BPA policies encourage regional actions that ensure adequate, efficient and reliable transmission and power service. Also, BPA works to develop cost-effective energy efficiency in the loads BPA serves, facilitate the development of regional renewable resources and adopt cost-effective nonconstruction alternatives to transmission expansion. The agency strategic plan calls out that ***BPA is a leader in the application of technologies that increase the value of mission deliverables.***

Transmission Services
Transmission Services' strategic objective is to make transmission system network ***enhancements based on adequacy standards and industry best practices*** for planning, design, operation, maintenance and construction that will provide an available, reliable, environmentally responsible and adequate transmission system. Nonwire solutions are fully considered and routinely deployed to address transmission limitations.

Technology Innovation Office
The mission of the Technology Innovation Office is to lead and partner in regional and national efforts to modernize the electric grid and to ***advance technologies to best-practice applications*** that have the potential to improve reliability, energy efficiency, system efficiency and security. The Office was created in June 2005 to guide the development and management of how BPA researches, develops, demonstrates, confirms and deploys new technology to meet BPA's central goals of system reliability, low rates, environmental stewardship and regional accountability.

The strategic plan relationship between the agency, Transmission Services and the Technology Innovative Office is illustrated in Figure 2: Technology Roadmapping and BPA's Strategic Plan (2007-2011).

Figure 2: Technology Roadmapping & BPA's Strategic Plan (2007-2011)



DRIVERS AND TARGETS SHAPING THE VISION OF THE FUTURE GRID

The Drivers

A key feature of BPA's approach to defining the technology innovation targets is to explicitly base them on, and link them to, BPA business drivers. During the Planning/Operation workshop held in December 2005 and the Facility workshop held in February 2006, BPA transmission experts brainstormed to identify the drivers that are moving the agency into the future. Refer to the Planning and Operations Transmission Roadmapping Workshop Products in Appendix 1 and the Transmission Facilities Roadmapping Workshop Products in Appendix 2. The drivers that were identified are clustered around topics that are key to BPA's strategic agenda – enhance system reliability, increase transmission capabilities and control of power flows, employ cost effective, environmentally sound energy supply and demand and maximize asset use.

<u>Enhance System Reliability</u>

The BPA and related Pacific Northwest grid infrastructure are facing an increasingly complex operating environment. There has been a steady increase in the volume of complex transactions that directly affect operations, dispatch, scheduling and outage coordination. For example, from June through August 2005, power flows exceeded the flowgate operational transfer capability (OTC) on the Northwest grid at least 174 times. In each of those occasions, BPA operators successfully responded within 20 to 30 minutes to bring the system back within OTC limits, meeting the new and mandatory Western Electricity Coordinating Council reliability criteria. But, this type of occurrence has been steadily increasing, causing power flow congestion incidents to exceed historical levels. The more often the system operates outside OTC limits, the greater is the risk to system reliability and economic efficiency. This disconcerting trend of increasing network congestion is forcing dispatchers to more frequently react in real time, or "emergency mode," to bring power flows within operational standards. [Challenge for the Northwest, April 2006, p. 3].

Currently, dispatchers lack tools, processes and data to predict congestion 1-5 minutes ahead of time, which significantly reduces their ability to deal with multiple contingencies that could occur in real time. As the 1996 Northwest power outage and the 2003 East Coast blackout forcibly demonstrated, multiple events on a system can occur at lightning speed, leaving dispatchers with little or no time to react. [Challenge for the Northwest, April 2006, p. 3]

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

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

Increase Transmission Capabilities and Control of Power Flows

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

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

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

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

Employ cost effective, environmentally sound energy supply and demand

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

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

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

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

Maximize Asset Use

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

As the transmission infrastructure ages, it will need more planned outages for maintenance and repair even though scheduled outages for maintenance conflict with maximum asset use. While current maintenance techniques do not allow maintenance to be performed during certain system loading conditions, live-line maintenance techniques and tools would allow BPA to respond as in-service time requirements increase.

However, Oregon and Washington law and the International Brotherhood of Electrical Workers Union restrict hot-line bare-handing techniques in part of BPA's service territory.

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

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

The Targets

Given the preceding drivers of change, the following targets were established to develop a vision of the future BPA transmission system. Also, the targets are used to determine which critical future technologies will best support the agency's strategic flight plan.

Target 1: Enhance future grid reliability, interoperability and extreme event protection for increasingly complex system operation

Target 2: Increase transmission transfer capabilities and control of power flows

Target 3: Employ efficient, cost-effective, environmentally sound energy supply and demand

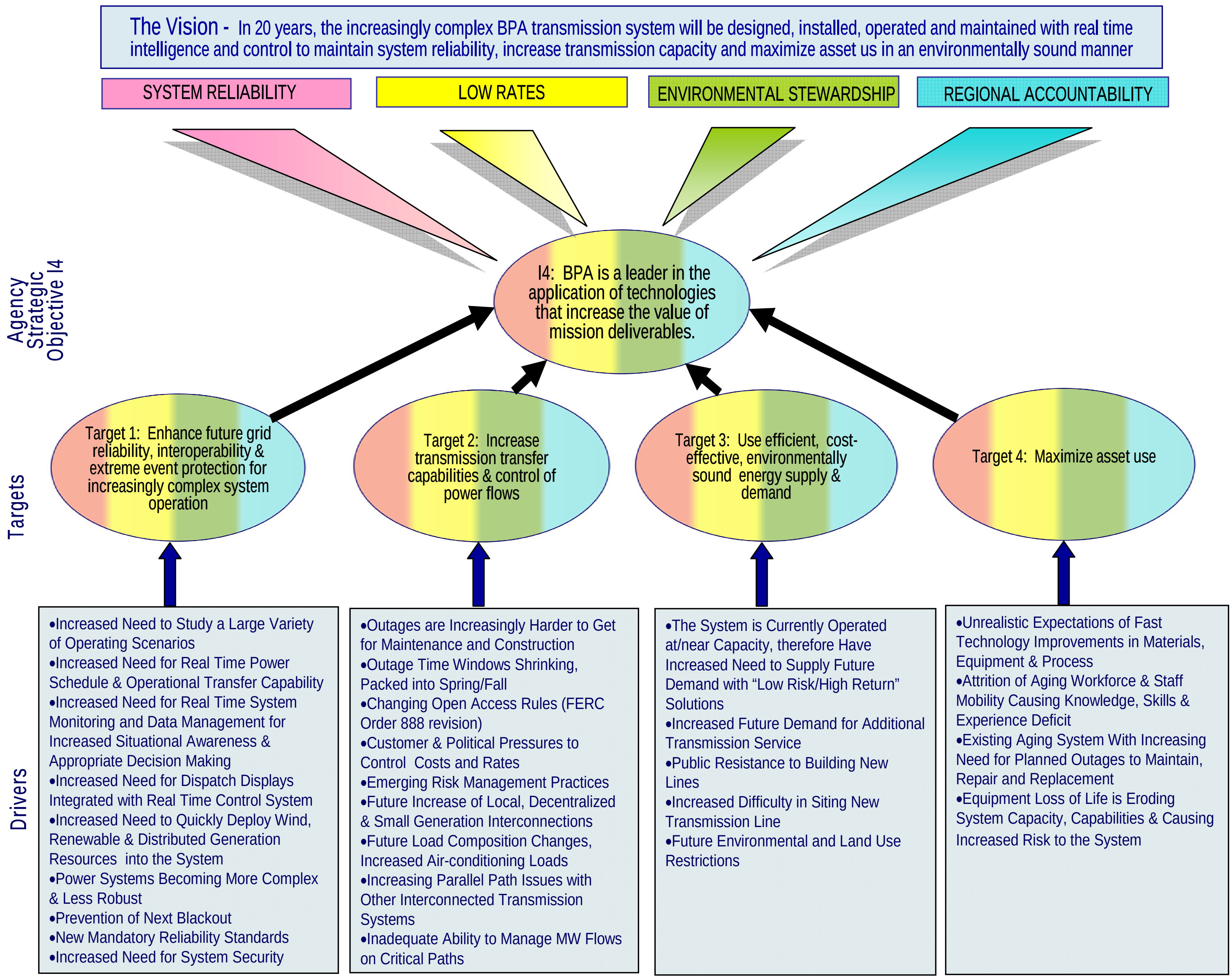
Target 4: Maximize asset use

The Vision

In 20 years, the increasingly complex BPA transmission system will be designed, installed, operated and managed with real-time intelligence and control to maintain system reliability, increase transmission capacity and maximize asset use in an environmentally sound manner.

A summary of the transmission technology road map drivers, targets, objectives and vision is presented in Figure 3.

Figure 3: TRANSMISSION TECHNOLOGY ROADMAP
DRIVERS ➔ TARGETS ➔ OBJECTIVE ➔ VISION



TARGET NEEDS AND TECHNOLOGY FEATURES

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

The features of an intelligent architecture include

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

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

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

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

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

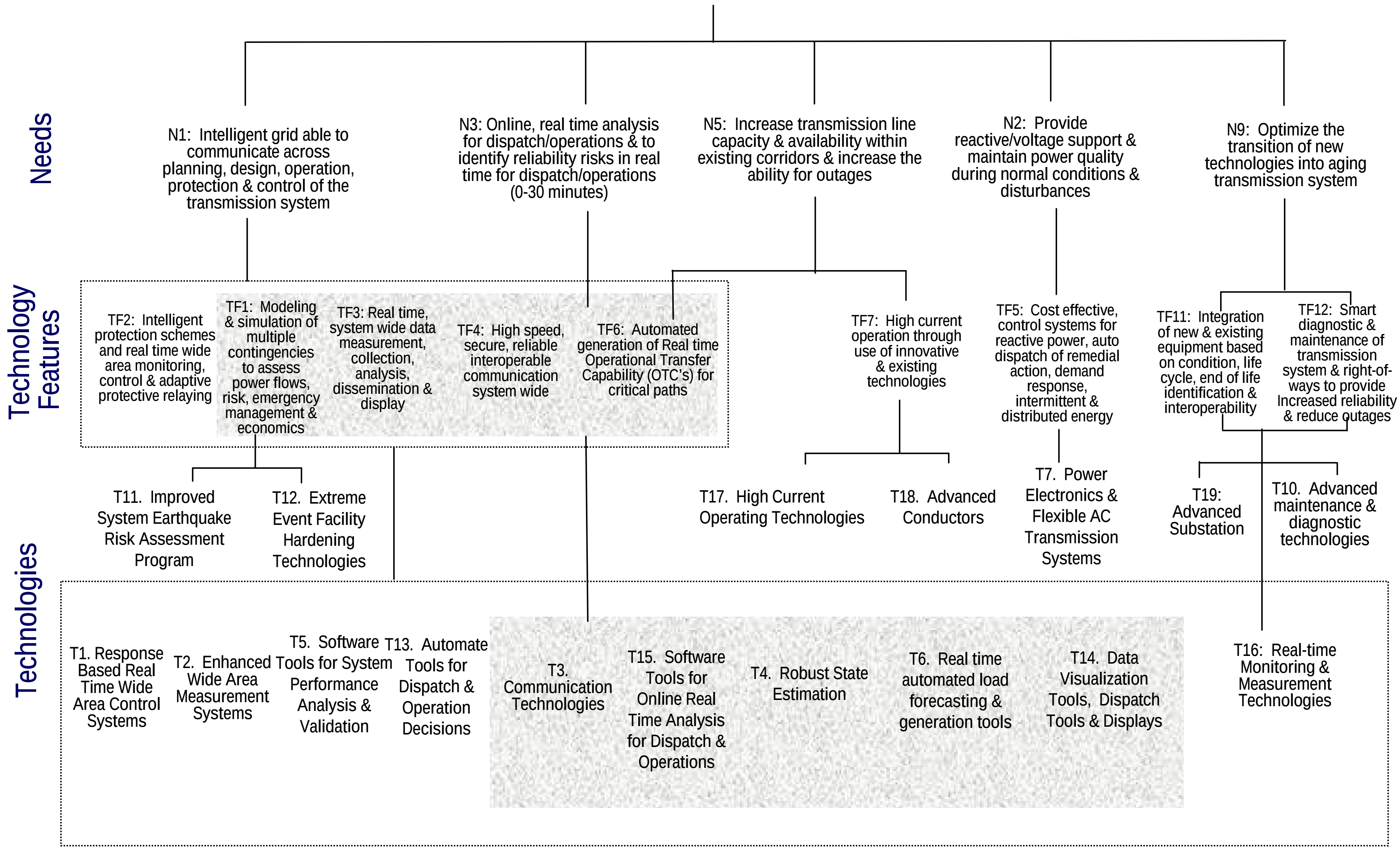
- Reactive power and auto dispatch of remedial action,
- Smooth integration of intermittent and distributed energy generation and
- Energy storage technologies to reduce transmission stability constraints or voltage constraints.

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

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

Figure 4 shows the relationships between needs, technology features and technologies to achieve Target 1.

Figure 4: TARGET 1 - Enhance future grid reliability, interoperability & extreme event protection for increasingly complex system operation



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

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

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

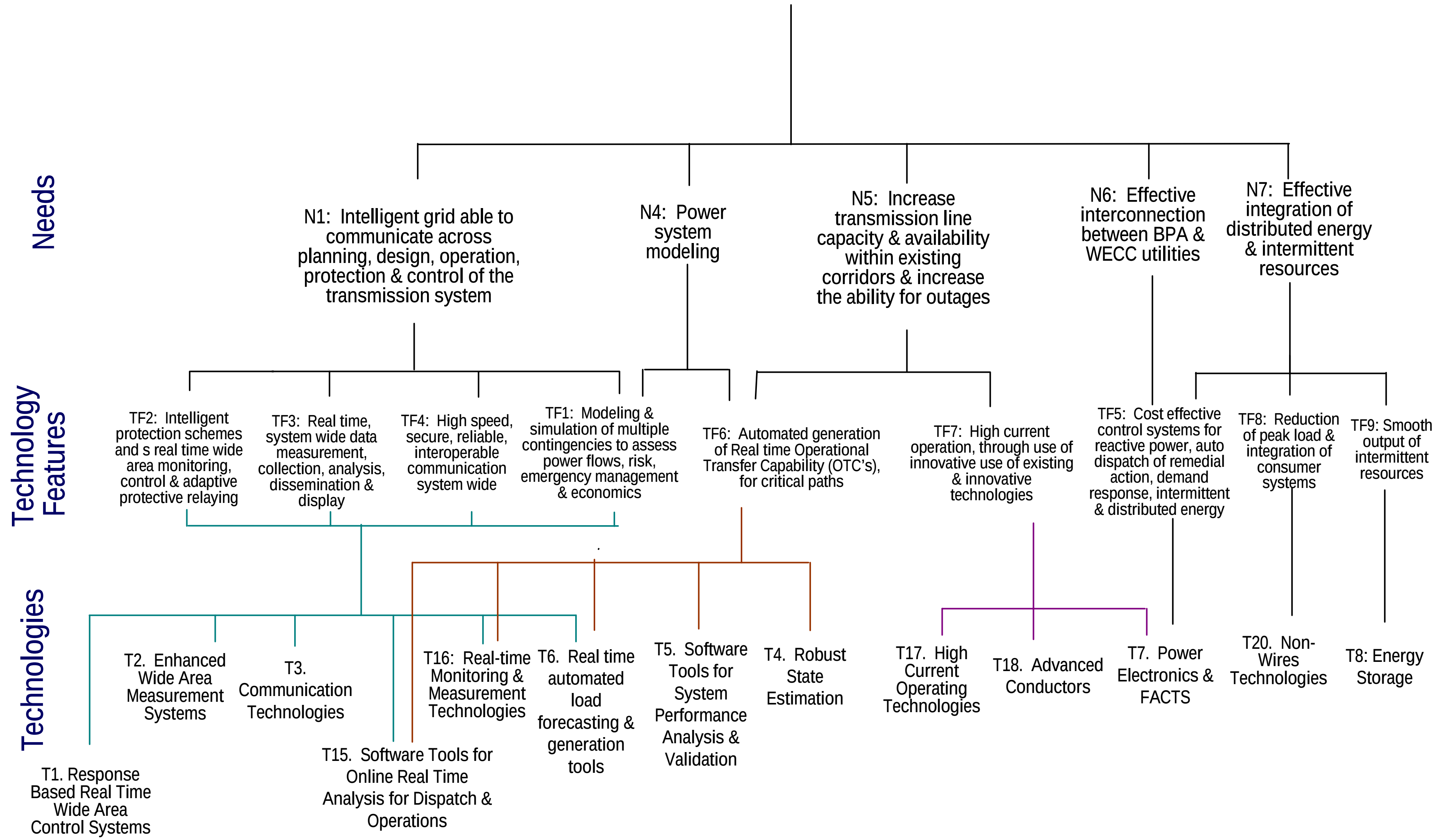
- provide real-time OTC,
- to operate at high current and high temperatures,
- to upgrade lines and/or uprate voltages,
- to make use of innovate applications of existing technologies (A list of Innovative Applications of Existing Technologies is presented in Appendix 3).
- to reinforce 230-kV paths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

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

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

Figure 5 shows the relationships between needs, technology features and technologies to achieve Target 2.

Figure 5: TARGET 2 - Increase transmission transfer capabilities & control of power flows



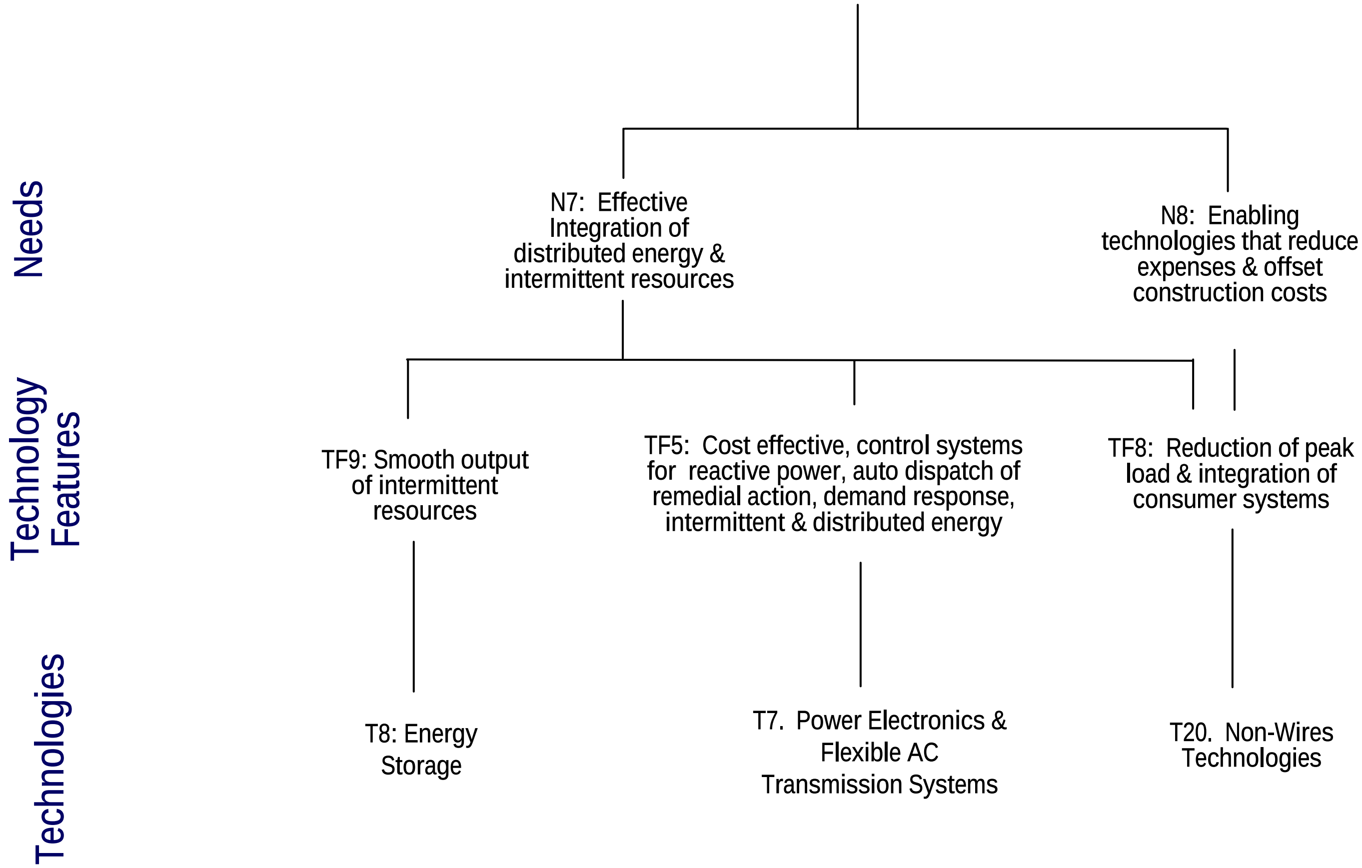
To meet *Target 3: Employ efficient, cost-effective, environmentally sound energy supply and demand,* an effective integration of distributed energy and intermittent resources is required. This can be accomplished by scenario and probabilistic planning using real-time automated load forecasting and generation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

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

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

Figure 6 shows the relationships between needs, technology features and technologies to achieve Target 3.

Figure 6: TARGET 3 - Utilize efficient, cost effective, environmentally sound energy supply & demand



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

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

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

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

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

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

In addition, live-line maintenance techniques and tools are needed as in-service time requirements increase. At some point, certain lines cannot be taken out of service for maintenance, and maintenance cannot be performed during certain system loading conditions. Software tools are needed to help prioritize maintenance schedules and activities.
Figure 7 shows the relationships between needs, technology features and technologies to achieve Target 4.
Figure 8 shows a summary of the Transmission Technology Road Map Targets, Needs, Technology Features and Technologies.

Figure 7: TARGET 4 - Maximize Asset Use

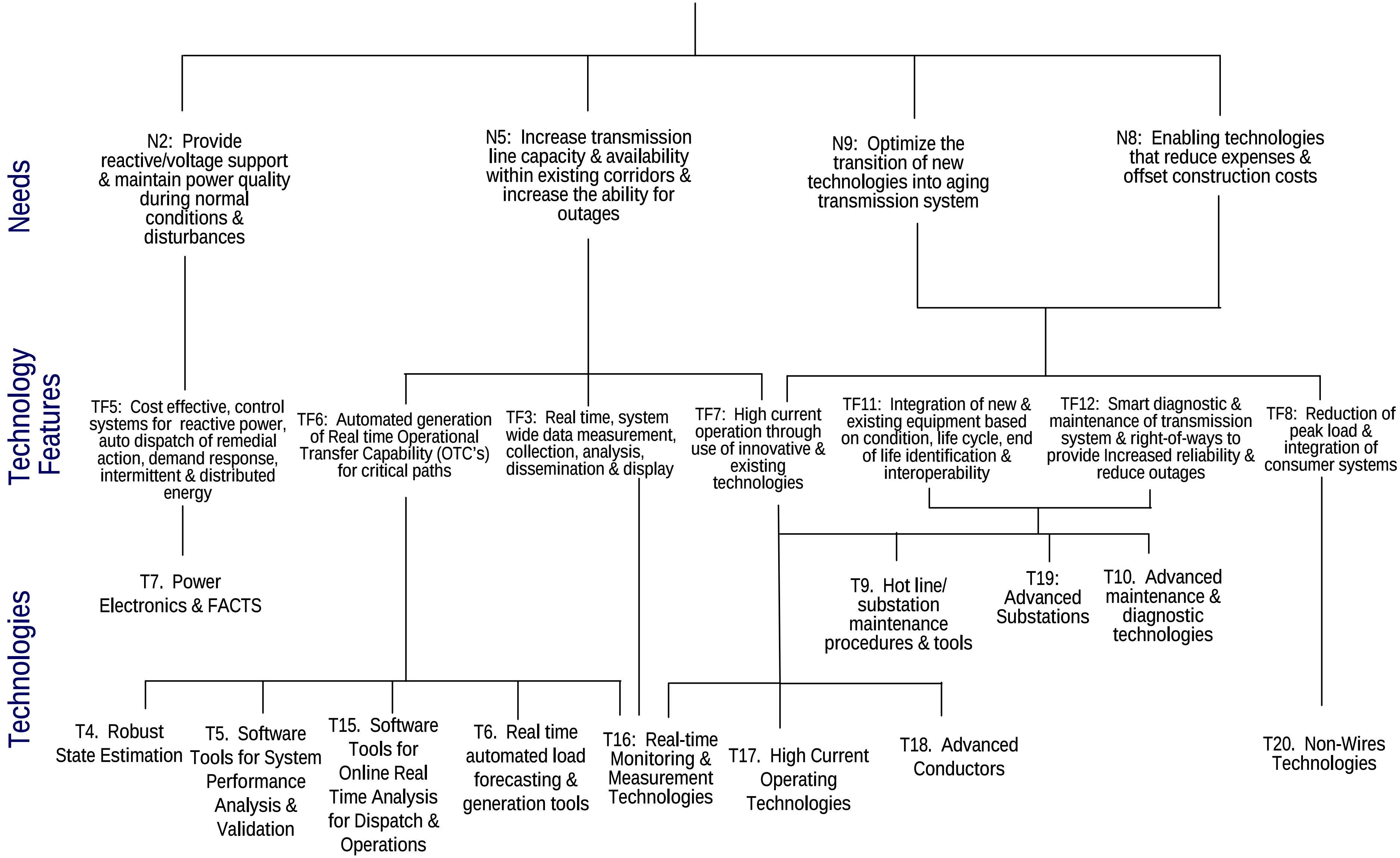


Figure 8: TRANSMISSION TECHNOLOGY ROADMAP

TARGETS, NEEDS, TECHNOLOGY FEATURES & TECHNOLOGIES

Targets

- Target 1: Enhance future grid reliability, interoperability & extreme event protection for increasingly complex system operation
- Target 2: Increase transmission transfer capabilities & control of power flows
- Target 3: Utilize efficient, cost-effective, environmentally sound energy supply & demand
- Target 4: Maximize asset use

Needs

- N1: Intelligent grid able to communicate across planning, design, operation, protection & control of the transmission system
- N2: Provide reactive/voltage support & maintain power quality during normal conditions & disturbances
- N3: Online, real time analysis for dispatch/operations
- N4: Power system modeling
- N5: Increase transmission line capacity & availability within existing corridors & increase the ability for outages
- N6: Effective interconnection between BPA & WECC utilities
- N7: Effective Integration of distributed energy & intermittent resources
- N8: Enabling technologies that reduce expenses & offset construction costs
- N9: Optimize the transition of new technologies into aging transmission system

Technology Features

- TF1: Modeling & simulation of multiple contingencies to assess power flows, risk, emergency management & economics
- TF2: Intelligent protection schemes and real time wide area monitoring, control & adaptive protective relaying
- TF3: Real time, system wide data measurement, collection, analysis, dissemination & display
- TF4: High speed, secure, reliable, interoperable communication system wide
- TF5: Cost effective, control systems for reactive power, auto dispatch of remedial action, demand response, intermittent & distributed energy
- TF6: Automated generation of Real time Operational Transfer Capability (OTC's) for critical paths
- TF7: High current operation through use of innovative & existing technologies
- TF8: Reduction of peak load & integration of consumer systems
- TF9: Smooth output of intermittent resources
- TF10: Advanced, flexible substation technology
- TF11: Integration of new & existing equipment based on condition, life cycle, end of life identification & interoperability
- TF12: Smart diagnostic & maintenance of transmission system & right-of-ways to provide increased reliability & reduce outages

Technologies

- T1. Response Based Real Time Wide Area Control Systems
- T2. Enhanced Wide Area Measurement Systems
- T3. Communication Technologies
- T4. Robust State Estimation
- T5. Software Tools for System Performance Analysis & Validation
- T6. Real time automated load forecasting & generation tools
- T7. Power Electronic & FACTS
- T8: Energy Storage
- T9. Hot line/ substation maintenance procedures & tools
- T10. Advanced maintenance & diagnostic technologies
- T11. Improved System Earthquake Risk Assessment Program (SERA)
- T12. Extreme Event Facility Hardening Technologies
- T13. Automate Tools for Dispatch & Operation Decisions
- T14. Data Visualization Tools, Dispatch Tools & Displays
- T15. Software Tools for Online Real Time Analysis for Dispatch & Operations
- T16: Real-time Monitoring & Measurement Technology
- T17. High Current Operating Technologies
- T18. Advanced Conductors
- T19: Advanced Substations
- T20. Non-Wires Technologies

LIST OF CRITICAL TECHNOLOGIES

The roadmapping collaborative process identified critical technologies that have the potential to enable real-time systemwide operation, relieve congestion, reduce peak load, reduce frequency and duration of operational disturbances and planned outages, enhance grid stability, increase OTC, increase asset utilization and harden infrastructure to detect, prevent, and mitigate extreme events to the grid. These technologies are listed below.

T1: Response-based real-time wide-area control systems
T2: Enhanced wide-area measurement systems
T3: Communication technologies
T4: Robust state estimator
T5: Software tools for system performance
T6: Real-time automated load forecasting and generation tools
T7: Power electronics
T8: Energy storage
T9: Hot-line and substation maintenance
T10: Advanced maintenance and diagnostic technologies
T11: Improved system earthquake risk assessment (SERA) program
T12: Extreme event facility hardening technologies
T13: Automated tools for dispatch/operations
T14: Data visualization tools and displays for dispatch
T15: Software tools for online real-time dispatch/operations
T16: Real-time and measurement and monitoring technologies
T17: High current operating technologies
T18: Advanced conductors
T19: Advanced substations
T20: Nonwire solutions

CRITICAL TECHNOLOGIES – DESCRIPTION and CHALLENGES

T1: Response-Based Real-Time Wide-Area Control Systems (WACS)

Description

Research is needed to create algorithms that can detect and protect the system from power, frequency and voltage swings. Rigorous study and testing of a response-based real-time wide-area control system (WACS) would consist of algorithms, software, phasor measurement unit (PMU) data, phasor data concentrator (PDC), secure communication network, real-time process controller and reactive power devices. Extensive work is needed to study and quantify the potential benefits of the control actions taken by WACS. Control algorithms will be developed and thoroughly tested to ensure that WACS operates when it is supposed to and does not harm the system. WACS implementation is dependant on high quality and reliable phasor measurement unit data so a parallel effort is needed to design a phasor measurement unit and phasor data concentrator infrastructure engineered to remedial action scheme (RAS)/WECC standards that is capable of driving a WACS system. The WACS algorithms for a RAS controller would use the wide-area measurement system (WAMS) input to provide a response-based control system that can observe, measure system performance and behavior, make decisions and take actions to regulate and stabilize the grid's frequency and voltages within manageable limits by selecting load or generator shedding and/or inserting reactive compensation devices (capacitor/reactor banks). [Pacify the Power, April 2005, p. 2]

Challenges

- A WACS prototype must be reliable, verifiable and testable by System Operations and Planning.
- The design of PDC and PMU functions, configurations and locations must be optimized.

T2: Enhanced Wide-Area Measurement Systems (WAMS)

Description

WAMS is a smart automatic network that applies real-time measurements in intelligent automatic control systems to operate a reliable, efficient and secure electric transmission infrastructure. WAMS continuously monitors grid performance across the power system by monitoring dynamic changes in the system, such as voltage, current, frequency, real and reactive power. WAMS provides operators with high quality data and analytical tools to detect impending grid emergencies or to mitigate grid outages.

An enhanced WAMS should include

- an optimum number and strategic placement of phasor measurement units to cover all identified significant interactions,
- a measurement infrastructure to support compliance measurements,
- tools for system performance analysis and generation compliance monitoring,
- direct data exchange with all WECC utilities,
- improved linkage into the EMS system (SCADA and tools, for example),
- increased real-time monitoring capabilities to alert operations to inconsistent information and potentially unsafe or unstable conditions,
- capability for additional high-speed control actions associated with response-based wide-area control systems and
- improved analysis tools for offline studies.

Challenges

- Fully utilizing the large amount of data collected.
- Overcoming time lags inherent in long-distance information transmission
- Opening a transparent data exchange with WECC utilities
- Resolving current data problems in the WECC base cases that cause inexplicable random variation in calculated system limits and simulated system behavior from season to season and year to year.

- Preventing engineers from wasting valuable time by tracking down and fixing data problems when they should be studying the system.

T3: Communication Technologies

Description

One technology that will have a significant effect on telecommunication requirements is substation automation. Substation automation will use intelligent substation devices that provide different functions but that all communicate over secure substation Ethernet local area networks (LANs). As substation automation technology matures and grows, LAN interconnection will require a more bandwidth-flexible operational wide area network (WAN) or telecommunications network. Data exchange between the control centers and substations within BPA, and external data exchange with other utilities, will become more intensive. Power system control and data exchange will require more bandwidth and will force BPA to utilize existing bandwidth more efficiently. It is envisioned that data services to support WAMS and a subsequent wide-area control system (WACS) will continue to grow. However, the future telecommunication network will mostly rely on existing fiber and radio infrastructure. Future telecommunication networks must still
,

- meet BPA and WECC reliability requirements;
- measure circuit performance or quality of service (QOS);
- heal circuits over known deterministic backup routes;
- heal circuits with minimum switching time;
- minimize transit delays for high priority or high speed protection circuits;
- groom (pack) circuits together more efficiently to maximize bandwidth;
- continue to utilize existing operational fiber plant, which is limited to 12 to 18 fibers per route; and
- continue to utilize a few existing backbone radio routes with limited bandwidth capacities.

Challenges

- Find a software tool to optimize circuit routing and packing (grooming) with the above constraints and calculate or model circuit availability.
- Enhance a control center network management system (NMS) to track circuit routing and log circuit performance or QOS down to the end equipment.
- Explore communication technologies that provide for higher bandwidth over longer fiber distances.
- Explore Ethernet-over–synchronous-optical-network (SONET) equipment technologies to integrate substation LANs.
- Explore fast optical switching technologies that use multiple wavelengths to route high bandwidth services to various stations on a WAN.
- Develop technical principles for an open architecture that enables interoperability among multivendor products.

T4: Robust State Estimation

Description

Robust state estimation is achieved by connecting and interfacing the State Estimator to the Improved Base Case Power Flow and the Real-Time Power Flow. This can be achieved by exporting the online state estimator cases for use in operations studies and by using real-time snapshots of the system state as the base cases for all operations studies. This will allow

- BPA Operations to respond quickly and effectively to forced outages/emergency conditions,
- more efficient utilization of existing transmission capacity,
- OTC levels to be based on the actual prevailing system conditions and
- more reliable OTC limits.

Set targets for speed at which new OTCs should be generated (15 minutes is probably not unreasonable, 5 minutes should be reachable). Automatic generation of OTCs for selected critical paths is needed. Paths such as the I-5 corridor where limits are entirely thermal can be computed very efficiently automatically. This would increase OTCs by hundreds of MW at times.

Challenges

- Generate base case from state estimator.
- Close gap between online and offline tools.

T5: Software Tools for System Performance Analysis and Validation

Description

Software tools for system performance analysis and validation of voltage, frequency and oscillation response, damping characteristics and data filtering.

Challenges

Prototype software tools must be reliable, verifiable and testable by System Operations and Planning.

T6: Real-Time Automated Load Forecasting and Generation Tools

Description

Real-time automated load forecasting and generation tools that are linked to the power flow program should include short-term forecasting and end-use load composition. They are also linked to the state estimator base case for outage studies and snapshot to alter load/generation patterns.

These largely automated tools should take the current state estimator snapshot and alter load/generation patterns to reflect some future anticipated system condition (for example, 0400 hours tomorrow, peak load case for August 30, 2006). These tools will allow engineers to manipulate state estimator base cases for use in outage studies, seasonal OTC studies and the like.

Challenges
Prototype software tools must be reliable, verifiable and testable by System Operations and Planning.

T7: Power Electronic and Flexible AC Transmission Systems (FACTS)

Description
Over the next five-to-20 years, advances in high voltage power electronics could transform many aspects of power system operations and planning by allowing precise and rapid electrical power switching. This will require more research into advanced materials to go beyond silicon (for example, silicon carbide). Diamonds and silicon carbide have promising material properties for use in power electronics. High temperature semiconducting materials need to be developed, tested and used in power electronics devices. These semiconducting materials are better able to operate efficiently in harsh environments, have higher thermal conductivity and can operate effectively at higher frequencies than current materials. A detailed gap analysis of high voltage power electronic technology is presented in Appendix 3.

A top priority is power electronics switches with the ability to work with
- high voltage,
- high frequency,
- high power density operations,
- little or no cooling,
- higher efficiency,
- higher current carrying capacities and
- higher temperature operations

as well as to
- have a high cost-to-benefit ratio,
- demonstrate dynamic voltage support devices for injecting reactive power into key portions of transmission systems,
- maintain voltage levels and prevent cascading system failures and
- lower costs.

Power electronics are at the heart of the power conversion interface necessary for
- energy storage systems;
- integrating direct current or asynchronous sources with the alternating current grid;
- flexible alternating current transmission systems (FACTS) or power flow controllers that improve power system control and help increase power transfer levels (fault-current limiters can help protect FACTS devices from near faults,

reduce the impacts on other equipment of faults that are felt through the system and enable open access to the system for energy storage and distributed generation devices);

- interface among energy storage, distributed generation and the electric system [GridWorks Multi Year Plan, March 2005, p. 9];
- direct current lines;
- superconducting transmission lines;
- faster fault protection;
- conversion of AC to DC and DC to AC;
- AC/DC conversion devices for distributed energy devices that produce DC (photovoltaic, battery storage, fuel cells); and
- adequate voltage support plus a variety of dynamic support functions that maintain power quality during normal conditions and during disturbances.

Power electronic devices can be applied in place of traditional power devices and present numerous opportunities for expanding functionality and improving system operations. Power electronics can be applied in the following devices.

- Switches
- Controllers
- Capacitors
- Condensers
- Converters/inverters
- Inverters
- Static var compensator (produces reactive power to support and maintain voltage levels)
- Fault current limiters
- Solid state current limiters
- Static voltage regulators
- Solid state tap changing on transformers
- Solid state transformers
- Power conditioners

Challenges

- The high cost and lack of proven performance, reliability and durability are challenges to the expanded use of power electronics.
- Investment in field tests can identify problems, lead to corrections, verify and validate product performance and lead to cost reductions and increased reliability. [GridWorks Multi Year Plan, March 2005, p. 11] [Grid 2030, July 2003, p. 15]
- Advanced materials properties that go beyond silicon must be developed. Diamonds and silicon carbide are promising materials but require significant material research and development before prototypes can be used in power electronics.
- BPA must determine whether to participate in a proposed national power electronics test facility to help coordinate and facilitate the evolution of power electronics. [GridWorks Multi Year Plan, March 2005, p. 11] [Grid 2030, July 2003, p. 15]

T8: Energy Storage

Description

Breakthroughs that dramatically reduce the costs of electricity storage systems could drive revolutionary changes in the design and operation of the electric power system. Effectively applied, energy storage could reduce peak load problems and help stabilize power quality disturbances. Energy storage can be applied at the power plant in support of the transmission system, at various points in the distribution system and on particular appliance and equipment on the customer’s side of the meter. [Grid 2030, July 2003, p. 15]

Developing technology to enable storing electrical energy so it can be available whenever needed would represent an important breakthrough. Large-scale megawatt-level electricity storage systems can

- significantly reduce transmission system congestion,
- help mange peak loads,
- make renewable electricity sources more dispatchable and
- increase the reliability of the overall grid.

Energy storage, when complemented with power electronics, forms the basis of solutions to grid-related problems associated with the increasing power quality demands of high-tech digital industries. [Energy Supply and Conservation: Overview, FY 2007, p. 32]

A wide variety of storage technologies is presently being investigated worldwide, including supercapacitors, flywheels, batteries, compressed air, superconducting magnetic energy storage (SMES) and pumped-storage hydro. Important system parameters include instantaneous power output (MW), total stored energy (megawatt-hours), number of charge/discharge cycles, capital cost, operating cost and efficiency. A graphical comparison of performance characteristics of different technologies is presented in Appendix 4.

Supercapacitors

Supercapacitors have a capacitance and energy density that is thousands of times greater than conventional electrolytic capacitors. They are excellent for short-term power quality applications because they can withstand more charge/discharge cycles (tens of thousands) than other storage media. Supercapacitors are also known as ultracapacitors, electrochemical capacitors and electric double-layer capacitors.

Superconducting Magnetic Energy Storage (SMES)

SMES systems store energy in the magnetic field created by the flow of direct current in a coil of superconducting material that has been cryogenically cooled. SMES systems offer system stability and voltage regulation benefits by providing very high power output for a brief period of time with a faster response than a generator. However, SMES systems can only store a small amount of energy, and their associated cryogenics present operations and maintenance challenges. A distributed SMES system has been installed in northern Wisconsin to enhance stability of a transmission loop serving a paper mill.

Flywheels

Flywheels are mechanical energy storage devices that consist of a rotor and a stator. Flywheels can bridge the gap between short-term ride-through and long-term storage with excellent cyclic and load following characteristics.

Batteries

A wide variety of battery technologies employ chemical energy storage. Lead-acid batteries are a well-developed technology with widespread use for power quality and backup power at the industrial level. Utility grid application has been limited by short cycle-life. A handful of megawatt-class installations does exist, including a 10 MW, 40 MWh system installed in Chino, Calif.

Metal-air batteries are compact, inexpensive and environmentally benign. However, they are not easily rechargeable so they are limited to applications in which the battery is the primary source of power.

Lithium-ion (Li-ion) batteries combine high energy density, high efficiency and long cycle-life. However, they have generally been limited to the portable consumer electronics market due to very high cost.

Sodium sulfur (NaS) batteries are applicable for both power quality and peak shaving applications. These batteries operate at very high temperatures (300 Celsius). Systems have been deployed in Japan that are capable of supplying megawatts for several hours.

Flow batteries are a less mature class of devices that offers the potential for greater discharge times. Several types are under development, including polysulfide bromide (PSB), vanadium redox (VRB) and zinc bromine (ZnBr).

Compressed Air Energy Storage (CAES)

This is a hybrid technology that combines an energy storage element with conventional natural-gas-fired generation. Wind farms or other intermittent generation sources can also be included in the system. When surplus electricity is available from the grid (light load, heavy wind), compressors are operated to store air in a reservoir such as an underground aquifer. When electricity is in greater demand due to heavy load or light wind, the compressed air is discharged, mixed with gas and combusted to drive a turbine. A CAES plant can produce the same amount of electricity as a conventional gas plant while using one-third to one-half as much gas.

Two CAES plants that use underground storage are in service, one in Germany and one in Alabama. A group of 74 municipal utilities has proposed the Iowa Stored Energy Plant, which would include a 200 MW CAES facility and a 100 MW wind farm. This plant, with an estimated construction cost of $300 million, received a $1.2 million grant from the U.S. Department of Energy in 2006.

Pumped-Storage Hydro
During off-peak periods, electricity from the grid is used to pump water from a lower reservoir to an upper reservoir. During peak periods, the flow is reversed and electricity is supplied to the grid. Pumped storage provides benefits similar to conventional hydro, including frequency control, system stabilization and reserves. Like CAES, pumped storage is limited by geographical requirements, long construction times and large capital cost.

Conventional pumped storage hydro using surface freshwater reservoirs has been used since the 1890s. Today, over 90 gigawatts of capacity is installed worldwide, with many projects capable of generating hundreds or even thousands of megawatts. The first system to use the ocean as the lower reservoir was a 30 MW unit built in Japan in 1999. Other novel applications use mine shafts or other underground features for the lower reservoir.

<u>Challenges</u>

- One of the main barriers to greater penetration of utility-scale energy storage has been high cost. Reducing electric storage costs is one of the keys to more widespread utility adoption. Effort is needed to assess opportunities for new manufacturing processes to reduce the costs of energy storage devices.
- Greater effort is needed to develop, field test and demonstrate advanced storage devices. Advanced batteries such as flow battery systems need to accumulate more operating data and experience to verify technical performance and address market acceptance.
- Further progress is needed in developing more durable and reliable flywheel storage systems and verifying safety and performance.
- A set of planning criteria would be useful for sizing the power and energy ratings of a system with one storage medium or a hybrid system with multiple storage media. Control optimization would be needed to operate the system efficiently, telling it when to store, when to supply, how fast to supply and how long to supply . Once the systems are installed, BPA will need to develop maintenance capabilities, including personnel training and spare parts management.
- Some of the barriers to energy storage technologies are more political than technical. It’s very likely that external customers like public utility districts and wind farm owners might be uncomfortable relying on new storage technologies, especially installations inside their substation. There could also be internal Power Services versus Transmission Services issues that would need to be resolved.

T9: Hot-line/ Substation Maintenance, Diagnostic Procedures and Tools

<u>Description</u>
Hot-line maintenance and diagnostic procedures and tools are for work performed on an energized transmission system. The innovation of live-line tools is critical as outage windows become compressed and harder to get. The use of these tools and procedures has a significant impact on equipment reliability, continuity of service, inspection

accuracy and efficiency, and cost-effective maintenance practices. [ESMO 2003 Proceedings: IEEE ESMO 10th International Conference, April 2003, p. 33] Examples of methods used are visual infrared inspection, satellite imaging, resistance measuring in compression splices, replacing conductors, cleaning and de-icing conductors and corona imaging for inspections. Examples of tools include insulated boom trucks, teleoperated robotic arms, motorized de-icing tools and ohm sticks. Live-line maintenance can be used to clean and lubricate moving parts that open and close, replace spacer/dampers, disconnect/connect breakers, tighten or replace bolts and install sensors and measuring devices. [ESMO 2003 Proceedings: IEEE ESMO 10th International Conference, April 2003, p. 27]

Challenges

- Maintain adequate crew size to perform hot work safely.
- Establish live-line standards, procedures and training for BPA.
- Overcome Oregon and Washington state laws that do not allow bare-handing techniques.
- Determine how live-line maintenance interfaces/impacts BPA standards, business/legal case and cost of outages.

T10: Advanced Maintenance and Diagnostic Technologies

Description

Advanced maintenance and diagnostic technologies allow for prioritized equipment ranking, conditioned based maintenance, prevention programs, smart equipment replacement programs and right-of-way maintenance. Smart diagnosis and maintenance provides increased reliability and availability of transmission and substation equipment. The future system must be capable of faster switching. This will take a rethinking of the entire subsystem to move from today's mechanical devices to solid state devices that can react faster. Cost-effective solid state devices, such as fault current limiters, flexible AC transmission system (FACTS) devices and transformers, will help avoid replacing underrated equipment, improve overall power quality and integrate new generation equipment into the present system. Future technologies include fault location prediction and prevention systems with advanced protection strategies and equipment.

In order to use the existing grid infrastructure most efficiently, system operators need better operation and diagnostic tools to identify developing or incipient problems. Advanced technologies include equipment capable of self-diagnoses that is able to address internal problems such as cracked bushings, contact wear and loose connections. Integrating self-diagnostic capabilities with algorithms will help asset managers replace and upgrade the existing infrastructure and reduce catastrophic failures, reduce maintenance costs and improve the overall reliability of the systems.

Challenges

- Identify synergies between technologies by looking at the entire subsystem and not just the individual components to improve their combined performance.

- Obtain cost-effective and reliable sensors for diagnostic use and to enable decision-support tools. The sensors must be nonintrusive, capable of surviving in high voltage environments and inexpensive.
- Develop a standard data protocol to integrate the sensors with presently available decision-support tools.

T11: Improved System Earthquake Risk Assessment Program (SERA)

Description

The future System Earthquake Risk Assessment Program (SERA) will include landslide, liquefaction, flooding, extreme weather and tsunami modeling capabilities. Also, the SERA program output can be used with the power flow program to address cascading events including probability, impact and implications with respect to network upgrades and modes of operation. SERA could also be used to

- study and analyze outage scenarios,
- predict consequences of an event,
- determine potential proactive and reactive measures to an extreme event and
- develop emergency response and recovery capabilities to include operations, dispatch and network planning.

Challenges

Integration of SERA output into the power flow program.

T12: Extreme Event Facility Hardening Technologies

Description

Extreme event facility hardening technologies include tools for

- identification of potential extreme contingencies that are not readily identifiable from a single cause (Murphy's Law);
- diagnosis;
- containment;
- mitigation;
- restoration;
- development of various extreme event scenarios that include SERA, floods, extreme weather, tsunamis and the like:, and
- development of modular equipment designs for lines, substations and novel configurations to manage failures and enable rapid system restoration under catastrophic events.

A study of river crossing towers is needed to identify liquefaction vulnerability. Critical substation components need to be improved to withstand earthquake ground motions. A study of base isolation of transformer motion to 6 degrees of freedom would provide performance test data that can be used to verify the application of this technology.

Challenges

Testing base isolation of transformer motion to 6 degrees of freedom is very expensive, at $60,000 per day, and the only test facility that can handle a full-scale test is in Japan.

T13: Automated Tools for Dispatch and Operation Decisions

Description

Automated tools for dispatch and operation decisions include online tools with the capability to dump out usable state estimator cases and run it through a tool like the Power World applications, then pipe the output results back into the EMS system and have it displayed properly for dispatchers and real-time schedulers. Future capabilities include the ability to automate RAS arming with advance mathematical algorithms and calculator functions based on mapped input EMS data. Automated RAS arming functions would allow dispatchers to keep up with rapidly changing systems conditions.

Challenges

Prototype software tools must be reliable, verifiable and testable by System Operations.

T14: Data Visualization Tools, Dispatch Tools and Displays

Description

Data visualization tools, dispatch tools and displays are needed to increase situational awareness and to maximize system safety, availability and reliability margins**.** Tools needed in the future to support robust analyses will have wide-area overviews with graphical rather than numeric data presentation. They will also have more effective displays of existing data and better arrangement of dispatcher workstations. (For example, Hydro One has found one big display is much better than multiple smaller monitors; BPA RAS has 17 monitors.)

Human factor research is needed for the futuristic work environment that will be required for operations and dispatch personnel to provide quick responses to real-time system conditions. Future workspace reconfigurations will be based on an active ergonometric work environment that will optimize the flow of information between operation study engineers and dispatchers. Human factor work environments will provide continuity of information response flows and support the delivery of a safe and reliable transmission system during normal and emergency operating conditions.

Challenges

These tools and the human factor work environment need to reliably operate during periods of high system stress, multiple planned and/or planned outages and high risk conditions.

T15: Software Tools for Online Real-Time Analysis for Dispatch and Operations

Description
The following online tools need to be made available for BPA Dispatch – real-time contingency analysis, Study Network Analysis (STNET), voltage stability analysis (VSA) and dynamic stability analysis (DSA). The capabilities of the current online toolset need to be expanded. Full implementation of RAS modeling is needed. Online DSA need to be implemented, and the implementation of online VSA needs to be finished.

Challenges
- A training program needs to be initiated to teach BPA dispatchers how to use these tools.
- Prototype software tools must be reliable, verifiable and testable by System Operations.

T16: Real-Time Monitoring and Measurement Technology

Real-time monitoring and measuring of the thermal, mechanical and electrical characteristics of cables, structures and substation equipment is done with sensing devices that monitor the limits or constraints of individual devices as well as of entire systems. With the appropriate communications architecture in place, devices can be designed to be interoperable with one another and to automate a variety of functions that currently require manual controls. The data from real-time grid monitoring is used to help operators recognize, analyze and respond to system anomalies and predict performance and maintenance actions necessary to prevent catastrophic failures that would otherwise lead to outages and the need for emergency maintenance. Integration of sensors, data acquisition devices and control algorithms that are interoperable can improve grid operational efficiency and enable real-time fault detection and system restoration. Technologies that integrate and analyze the data collected by the sensing devices include both hardware and software. [Technology Briefs: Overview of advanced electric delivery technologies, August 2004, p. 14]

There are many different types of sensors at various stages of development that are used to assess the state of cables, transformers and circuit breakers. Infrared, gas analyzers and optical and temperature sensors are commercially available.

Temperature sensors are used to measure conductor and transformer coil temperatures to determine operating constraints.

Optical sensors use visible or invisible light beams to detect objects and make measurements, for example to measure cable sag and rights-of-way data. Optical measurement technologies include optical current transformers (CTs) and potential transformers (PTs) with applications including revenue metering and protective relaying. The advantages of these technologies include safety, system reliability and interoperability with customers. BPA is not currently prepared to meet customer requests to use optical CTs for joint metering on new wind projects.

Wireless sensors based on radio backscatter and nanotubes are technologies that are in development. Back scatter sensors can be used on power line connector splices and insulator contamination. [Ensuring the Health of Our Power Lines, Summer 2006, p. 3]

Two real-time monitoring techniques that deserve consideration for future research are shunt capacitor cell failure relay and turn-to-turn fault detection using traveling wave technology.

The primary goal is to develop flexible remote sensing system architecture, protocols and core sensor design that can be applied to a wide variety of field applications for measuring voltage, current, temperature, pressure, vibration and other valuable parameters of interest. The real-time information stream enables a multiplicity of functions including rapid diagnosis and correction of grid problems and measurement of transmission lines to determine when they are reaching capacity. [Leading the Way to the 21st Century Power Grid, February 2005, p. 4]

Phasor measurement units (PMUs) are synchronized digital transducers that stream data in from phasor data concentrator units (PDCs) to collect data measured regionwide. This data is used to assess limitations on transient, oscillatory and voltage stability. Existing SCADA, WAMS, energy management systems, state estimator and base case power flows are used to operate a reliable, efficient and secure transmission infrastructure. The roadmapping process identified response-based real-time wide-area control systems (WACS) and enhanced wide-area measurement systems (WAMS) as critical technologies that are described on pages 21-22.

Challenges

- Sensors must allow for safe installation on energized lines, avoid interference from electric and magnetic fields and not have sharp edges or protrusions that would generate corona.
- Sensors need to be designed to facilitate interoperability, be field tested and be standardized.
- Optical sensors need improvement in measuring range, accuracy, range resolution and sampling rate. http://optical-sensors.globalspec.com/Industrial-Directory/flight_position_sensors
- Interconnections need to be effectively monitored to discern the current state of the non-BPA utilities (SCE, PG&E, BC Hydro).

T17: High-Current Operating Technologies

Description

High-current operating technologies include innovative uses of existing technologies and development of high temperature modeling of cables, hardware, connectors and the like.

Research on high temperature super conducting material and nanotechnology is currently being strongly supported by the U.S. Department of Energy.

Innovative Use of Existing Technologies
A list of innovative uses of existing technologies is presented in Appendix 5. Alternatives for increasing the ratings of existing transmission lines include raising the voltage to higher levels or increasing current ratings. Raising the voltage level typically requires modifications to towers and a change-out of line insulators. Increasing the current rating is accomplished by replacing the conductor. The extent of tower modifications depends on the conductor selected, with more tower modifications needed as the weight of the replacement conductor increases. In both of these upgrade alternatives, tower design tools are used to examine the existing towers to determine the required modifications.

High Temperature Modeling Capabilities
High temperature modeling capabilities need to be developed to confidently analyze high temperature operation of conventional equipment and emerging new technologies such as high-temperature low-sag cables. Modeling and analyses are needed for

- cable strength material degradation,
- thermal expansion performance,
- creep,
- sag tension simulations modeling for high temperature cables,
- connector performance,
- hardware performance,
- allowable current transfer versus allowable operating temperature,
- thermal performance of substation equipment and
- substation equipment degradation and effect on loss of life.

High Temperature Super Conductivity Materials
High temperature superconductors are advanced materials that have the potential to revolutionize electric power delivery because they conduct electricity with no resistance. The holy grail of superconducting research is the discovery of a material that will act as a superconductor at room temperature. However, all materials discovered so far must be extremely cold to be superconductors. Future applications of high temperature super conducting material is anticipated to be applied to all of the equipment below. [National Electric Delivery Technologies Road Map, January 2004, p. 19]

- Transmission cables
- Transformers
- Motors
- Generator
- Fault current limiters
- Energy storage systems
- Synchronous condensers
- Flywheel energy systems
- Switches
- Refrigeration liquid nitrogen
- Cryogenic devices

High temperature super conducting materials combined with other future innovations have the promise of significant advancements. For example, the combination of a fault current limiter with a superconducting cable could mitigate post-fault cable recovery time. Also, power electronics integrated with high temperature superconductivity is a next-generation technology that can be integrated to limit fault currents.

The U.S. Department of Energy is funding research in high temperature superconductivity with prototype high temperature cable projects targeted for completion in 2007, Below is the fiscal year 2007 Congressional Budget for the Office of Electricity Delivery and Energy Reliability. [Energy Supply and Conservation: Overview FY 2007, Research and Development Funding Schedule by Activity, p. 27-28]

	(dollars in thousands)		
	FY 2005	FY 2006	FY 2007
High Temperature Superconductivity	53,034	49,995	45,468
Transmission Reliability R&D	15,163	12,870	0
Electricity Distribution Transformation R&D	5,418	60,059	0
Energy Storage R&D	3,969	2,970	0
Gridwise	6,267	5,445	0
Gridworks	5,303	4,950	0
Visualization & Controls	0	0	17,551
Energy Storage and Power Electronics	0	0	2,965
Distributed Energy	0	0	29,652
Total Research and Development	89,154	136,289	95,636

Also, DOE and Southwire Company have partnered in a successful high temperature superconductivity (HTS) project near Atlanta, Ga. Since Feb 18, 2000, an 100-foot three-phase HTS power cable system operates unsupervised and delivers power to three Southwire plants. [Columbus HTS Power Cable Project Fact Sheet May 2004, pg 2]

<u>Challenges:</u>

- Continue research to develop electrical insulating materials for high voltage superconducting applications.
- Develop high temperature superconducting cable with minimal alternating current energy losses to reduce size and cost of superconducting equipment cooling systems.
- Improve mechanical properties such as flexibility and strength of wire.
- Mitigate extremely high currents that radiate intense magnetic fields and require long lead times to cool down (one week).
- Coordinate high temperature superconductivity and storage devices.
- Use the fundamental sciences to explore opportunities to use advanced materials for electricity storage.

- Develop high temperature superconducting materials that are
  - lower in cost;
  - more durable;
  - more malleable; and
  - capable of being mass produced and used in transformers, cables and other devices.

Nanotechnology

Descriptions of nanotechnology typically characterize it purely in terms of the minute size of the physical features with which it is concerned – assemblies between the size of an atom and about 100 molecular diameters. That depiction makes it sound as though nanotechnology is merely looking to use infinitely smaller parts than conventional engineering. But, at this scale, rearranging the atoms and molecules leads to new properties. One sees a transition between the fixed behavior of individual atoms and molecules and the adjustable behavior of collectives. Thus, nanotechnology might better be viewed as the application of quantum theory and other nano-specific phenomena to fundamentally control the properties and behavior of matter. [Nanotechnology's Future: Over the Next Two Decades, August 2006, p. 1] Advances in nanotechnology applied to superconducting material offer yet-to-be-fully-known promising new materials and approaches for storing electrons.

The National Nanotechnology Initiative of the Executive Office of the President of the United States is strongly committed to the future of nanotechnology. Research areas include nanomaterials, nanoscale devices and systems, nanomanufacturing and instrumentation research, and standards for nanotechnology. The 2007 National Nanotechnology Initiative budget request for nanotechnology research and development across the federal government is nearly $1.3 billion. [The National Nanotechnology Initiative, July 2006, p. 35]

T18: Advanced Conductor Technologies

Description

Several new conductor designs are in various stages of development and testing. Typically, these new conductors replace steel with a lower-modulus material and are operated at higher temperatures to increase the current rating. Further development and testing of these new conductors will provide more options for upgrading existing transmission lines. Advanced conductor materials and applications have increased current capacity, are lighter weight and provide the same sag as existing conductors. These cables can replace existing cables on existing transmission structures and rights-of-way. Continued material research is needed in lower thermal expansion materials, lighter weight conductors, higher strength conductors, higher operating temperature materials and second generation superconducting materials. [GridWorks Multi Year Plan, March 2005, p. 7]

High-Temperature Low-Sag Cables
Some advanced conductor technologies and cable applications at various stages of commercial development operate at high currents with continuous operation above 100 C without loss of tensile strength or increases in sag. They are lighter and stronger, and transmit more power, than conventional cables but are currently very expensive. The following cable descriptions are referenced from EPRI report Development Status of High-Temperature, Low-Sag Transmission Conductors, 2006, pp. 1-3.

- **(**Z)TACIR – Zirconium alloy aluminum conductor INVAR steel-reinforced high-temperature aluminum strands over a low thermal elongation steel core. Operation to 150 C (Tal) and 210 C (ZTAl). INVAR conductors consist of super thermal resistant aluminum alloy (ZTAL) or extra thermal resistant aluminum alloy (XTAL) wires stranded around a central core of INVAR. INVAR steel wire core is about 36 percent nickel and can be aluminum clad or galvanized. INVAR cables transmit two times more power than aluminum conductor steel reinforced (ACSR). It's most important property is the fact that it has a linear expansion coefficient practically invariable with heat.
- GTACSR -"Gapped" TAL alloy aluminum conductor steel reinforced high-temperature aluminum. GAP-type ZT aluminum conductor steel reinforced conductor consists of aluminum wires in the internal layer with a trapezoidal cross section closest to the core, which creates a gap between the steel core and the aluminum layers. This gap is filled with an engineered material suitable for operation at temperatures exceeding 150 C. It may get a 30 percent increase in rating for the same sag.
- ACCR - Aluminum conductor composite reinforced uses ceramic alumina fibers embedded in an aluminum matrix to make the composite core wire and zirconium and aluminum strands that surround the core. ACCR operates up to 210 C without cable degradation and transmits two to three times more power than ACSR.
- ACCC - Aluminum composite core conductor is a proprietary design. Fulfillment of American Society for Testing and Materials standards is least mature for this cable compared to the others. The proprietary new ACCC cable transmits two times more power than comparably sized conventional cables.
- ACSS and ACSS/TW - Aluminum conductor steel supported consists of fully annealed aluminum strands over a stranded Galfan coated steel core. ACCR operates up to 200 C without cable degradation and transmits about two times more power than ACSR.
- CRAC - Composite reinforced aluminum conductor consists of annealed aluminum over a fiberglass/thermoplastic composite segmented core. Probable operation to 150 C.
- ACCFR - Aluminum conductor composite carbon fiber reinforced consists of annealed or high temperature aluminum alloy over a core of strands with carbon fiber material in a matrix of aluminum. Probable operation to 210 C.

<u>Challenges</u>

- Make use of advanced conductors cost effectively.

- Bring connectors, compression fittings, hardware bushings (silicon or neoprene rubber), insulators and spacer dampers up to industry standards for high temperature operation (~240 C). The ACSS is closer to meeting the industry standards then INVAR and ACCR. ACCC is the farthest from meeting industry standards.
- Manage the resulting reactive power from operating advanced conductors at increased thermal capacity. For example, a 50-mile 345-kV line loaded to 1,300 MW during a contingency consumes over 500 megavolt ampere reactive. At 2,600 MW this same line will require more than 2,000 MVAR. [It's Time to Challenge Conventional Wisdom, T&D World, October 2004, p. 3]

High Voltage Direct Current (HVDC)

The fundamental process that occurs in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end and DC to AC (inverter) at the receiving end. Segmentation of AC grids by HVDC can improve system reliability while increasing transfer capability by limiting propagation of disturbances. HVDC can be modulated to damp oscillations or to provide power flow dispatch independent of voltage magnitudes and angles providing active control of real and reactive power transfer. Applications of HVDC include [HVDC Transmission systems Technology Review, March 2000, p. 1]

- long-distance transmission,
- interconnection of two AC networks in an asynchronous manner,
- bidirectional power flow control and added stability and power quality,
- reduction of line cost because HVDC transmission requires two conductors, one is +ve and another is –ve, and
- providing a barrier to cascading blackouts.

The AC to DC conversion is achieved by thyristors connected in series and able to operate at very high voltages (several hundred kV) and net frequency (50 hertz or 60 hertz). By means of a control angle, it is possible to change the DC voltage level of the bridge.

Also, voltage source converters (VSC) use gate turn-off thyristor (GTO) or insulated gate bipolar transistor (ICBT) semiconductors that have the ability to turn on and to turn off, enabling independent control of active and reactive power and power quality. [High voltage Direct Current Transmission Systems Technology Review, pp. 2-3]

Higher voltage line limits are usually based on "load ability' constraints rather than thermal limits. Load ability can be improved by compensating devices or full FACTS control.

<u>Challenges</u>

- Technical and functional specifications for new technology that includes power capacity, distance, availability and reliability requirements and environmental conditions. [HVDC Transmission systems Technology Review, March 2000, p. 18]

- High cost of converter equipment.
- Need for specially trained technicians to maintain equipment.

T19: Advanced Substation

Description

An advanced substation will have control and protection systems that are modular and expandable. When changes are made to a substation, new equipment will be organized in such a way that costly changes to substation control houses will not be needed. Data will be transmitted within the substation and to/from the substation digitally. Modifications will easily produce up-to-date records.

Advanced substation designs will start with a simple process such as drawing a schematic diagram with a function block language to facilitate equipment interoperability. Software will then take the initial design information and translate it into rack layouts, wiring descriptions and ordering information. Scheduling of all phases of construction will be produced automatically.

The substation control and protection equipment will be networked and capable of self-diagnosis. If equipment fails, critical functions will be taken over by the remaining healthy equipment and failure notices sent to maintenance personnel. Communication, surveillance and operation of substations will be done remotely without the need for numerous field operations personnel.

Challenges

- Available assets must be used more efficiently to extend the lifetime of equipment and avoid needing to replace the heavy, high-cost equipment.
- Modular, inexpensive and reliable “next generation” technologies are lacking.
- Next generation equipment must be integrated seamlessly into both the substation and the whole electric delivery system.
- Next-generation components and security measures need to be integrated into the electric grid in a standardized way.

T20: Nonwire Technologies

Description

Nonwire technologies promote programs that provide opportunities for energy consumers to manage their distributed energy resources in response to competitive market forces, including increased price visibility and demand-side participation in energy and ancillary services. In 2004 BPA began funding pilot projects that would allow consumers to curtail energy use during periods of heavy electricity use. These projects include directly controlling irrigation pumps, appliances and heating and ventilation systems. [Challenge for the Northwest, April 2006, p. 23]

BPA is currently testing an Internet Program Demand Exchange in the Olympic Peninsula in which two paper companies and the Navy bid to reduce system demand by using backup generation or by shifting load to off-peak hours. BPA is also testing a load reduction program in Richland, Wash., and a program that allows Ashland, Ore., customers to manage their energy consumption via their personal computers. [Bonneville Power Administration to Host 'Non-wire' Transmission, September 2006, p. 1]

Future demand-response systems will provide automated energy control systems with real-time intelligent communication systems to control real-time pricing, coincident peak pricing, time of use rates and demand bidding program. Advanced distribution devices such as energy storage, protective relaying and two-way power flows are needed.

Challenges

- Advanced meters are needed to record power usage digitally and report it by telecommunication.
- Many critical advanced distribution devices are not ready for the marketplace, cost too much and do not have proven performance, reliability and durability.
- Pilot projects must be implemented to improve distributed energy generation installations by industrial, commercial and residential end users.

TECHNOLOGY GAP ANALYSES WITHIN A 20-YEAR TIME FRAME

Group discussions between BPA transmission specialists identified technology gaps between existing technologies and future technology applications. The gap analyses are presented in figures 9 through 13, which follow.

- Figure 9: Enhance Reliability Gap Analysis
- Figure 10: Extreme Event Protection Gap Analysis
- Figure 11: Increased Transmission and Control of Power Flow Gap Analysis
- Figure 12: Cost-effective Environmentally Sound Energy Supply and Demand Gap Analysis
- Figure 13: Maximize Asset Use Gap Analysis

Each gap analysis lists the gaps between existing and future technologies based on a near-term (0-5 years), mid-term (5-10 years) and long-term (10-20 years) milestones. It is expected that these gap analyses will be revisited and updated every several years. Each gap analysis uses color to unify the technology types and/or themes for the existing technologies, existing gaps and future technologies across the 20-year time frame.

Figure 9: Enhanced Reliability Gap Analysis

Existing Technologies

Planning Modeling, Simulation & Forecasting Technologies
- Base Case Power Flow Model (quasi-snapshot of system conditions)
- Generation & Peak Load Models (deterministic & manual process)
- Stability studies
- Risk & Reliability Probabilistic Analysis based on single contingency
- Technical Study Application Software tools (PowerWorld, Areeva, GE, PTI)
- State Estimator (data not used in Base Case)
- Policies of WECC, NERC n-1 criteria, Reliability Council

Operational Technologies
- Study Process – OTC's generated from off-line WECC power flow cases
- Software - Powerworld Simulator – contingency analysis, voltage stability, ATC calculations; Powertech TSAT – transient stability; GE PSLF – power flow, transient stability
- On-line Tools -State Estimator, Real Time Contingency Analysis (RTCA), Onl-line Power flow (STNET)
- Dispatch – rely on DSOs to determine safe operating limits, no access to power system analysis tools, manual RAS arming, large number of monitors, some trend charts used by AGC desk

Communication Technology
- PathLoss
- Circuit Grooming Analysis
- Reliability Model
- Fiber Optics – Sonet
- Wireliess, Microwave, UHF, VHF

Technology Gaps

Data and software for Accurate **Forecast of Generation and Load Models**

Planning Tools to review FACTS options for new project opportunities

Improved and Expanded Base Case Power Flow Capabilities
- Automation tools to move from snap shot to real time
- Offline case studies with captured real-time PMU data synchronized with SCADA
- Integrate loads, generation and base case together & have overall performance agree with reality

Improved and Expanded Dynamic Simulation Capabilities
- Validation of the system dynamic performance using WAMS data
- Reasonably accurate reproduction of disturbance events in grid simulations
- Analysis of the dynamic response signatures

Enhanced WAMS include
- Tools to analyze WAMs data
- Improved PMU calibration & reliability of telecommunications
- Increased number and/or optimum location of PMUs

Scenario & probabilistic planning & load forecasting tools for multiple constraints, renewable resources, distributed generation, demand response, non-wires, innovative use of existing technologies

Robust State Estimator through Integrated Planning & Operation Capability –
- Generate Base Case from State Estimator
- State Estimator to Operational Tools
- Close gap between online and offline tools

Improve situational awareness and contingency analysis through
- Real time data monitoring & control of operational status of transmission system using a common communication architecture facilitating interoperability
- High speed, high volume data processing
- High performance computing architecture, algorithms & networks for on-line/off-line studies.
- Algorithms for RAS controller that can utilize WAMS input to provide a response based control system that can observe, measure system performance/behavior, make decisions and take actions
- Effective alarming & filtering systems
- Improve TBL WECC wide area monitor awareness

On Line Performance Assessment Tools for Contingency Analysis, Transient stability, PSST enhancements

Tools to measure Dispatcher Training Effectiveness

Study to identify what is required to establish expert **decision making**

Visualization Tools & Systems
- Integration of display technologies, techniques and human factors
- Integrate visualization systems with state estimator & contingency analysis software

Power Electronics -To bring down the cost and to collect information on performance in real-world applications more field tests and demonstrations of existing prototypes and equipment.

Operations Study Process Improvement
- State Estimator to Operational Study tools
- Automation tools to move from snap shot to real time

Digital infrastructure wireless & fiber to
- Replace analog
- Create rings using radio/fiber
- Study substation automation and flexible networks using ethernet over sonet.

Future Technologies

T6. **Real time automated load forecasting & generation tools**

T4. **Robust State Estimation**

T2: Enhanced Wide Area Measurement Systems **(WAMS)**

T1: Study and Monitor Response Based Real Time **Wide Area Control Systems**

T5. **Software Tools for System Performance Analysis & Validation**

T15: **Software Tools for Online Real Time analysis for Dispatch & Operations**

T14: Data Visualization Tools & Dispatch Displays for Improved **Situational Awareness**

T13. **Automate Tools for Dispatch & Operation Decisions, Online Tools and Automate RAS Arming**

T7: **Power Electronics** & FACTS

T16: **Real Time Monitoring & Measurement**

T3: **Communication Technologies**
- Circuit Grooming/Analysis Tool
- Reliability Modeling Tool
- Implement flexible Networks
- Optical Switching

2007 | +5 yrs | +10 yrs | + 20 yrs

Figure 10: Extreme Event Protection Gap Analysis

Existing Technologies

System Earthquake Risk Assessment (SERA) Program can include the following hazards: ice, wind, landslides, floods, tsunamis, and earthquake generated landslides. Import shake maps into SERA for planning & respond to an earthquake event. Currently used for BPA dispatch training.

Hardening Technologies for facilities retrofit and to qualify new equipment (i.e., For 500kV lines west of the Cascades anchored transformers, station service, batteries, engine generators)

Technology Gaps

Integration of SERA output into the Power Flow program to:
- Study & analyze outage scenarios
- Predict consequences of an event
- Determine potential proactive and reactive measures to an extreme event
- Develop emergency response and recovery capabilities to include operations, dispatch and network planning.

Extreme event modeling to address cascading events including probability, impact and implications with respect to network upgrades and modes of operation

Develop various extreme event scenarios that include SERA, floods, extreme weather, tsunamis, etc.

Tools for
- Identification of potential extreme contingencies that are not readily identifiable from a single cause
- Diagnostics
- Containment
- Mitigation
- Restoration

Study of Base Isolation of Transformer Motion to 6 Degrees of Freedom

Improve critical substation components ability to withstand earthquake ground motions.

Study of River Crossing Towers Vulnerability to Earthquake Generated Liquefaction

Develop modular equipment designs for lines & substation and novel configurations to manage failures and enable rapid system restoration under catastrophic events.

Future Technologies

T11: **Improved System Earthquake Risk Assessment (SERA) Program** to include landslide & liquefaction modeling capabilities

T12: **Extreme Event Facility Hardening Technologies**

2007 +5 yrs +10 yrs + 20 yrs

Figure 11: Increased Transmission & Control of Power Flows Gap Analysis

Existing Technologies

Conservative designs which result in greater transfer capacity than load due to;
- •Dynamic behavior of cables
- •Events/failure
- •Regulatory changes (n-corridor)
- •(n-x) for outages
- •Intermittent resources

Line Design Methods used to accommodate increase capacity in existing corridors;
- •Thermal upgrade
- •Reconductor
- •Upgrade voltage
- •Rebuild line (larger conductor, higher voltage**)**

Substation Design & Equipment

Cables Installed (% of total cable installed)
- •Round Rod 87%
- •Copper 5.5%
- •TW 5%
- •ACSS – 2 short lines
- •ACCR 1 demo span

Technology Gaps

Innovative (non-standard) designs using standard material and/or create new standards using existing technology

Study to determine the "know-how" required to **move from conservative designs to operation at capacity limits.**

Real time monitoring of cable tension, sags and temperature to support operations

Evaluation & better monitoring of new materials and high capacity wires & substation equipment.

High Temperature Operation Analysis to include;
- •Cable strength material degradation
- •Thermal expansion performance
- •Creep
- •Sag Tension simulations modeling for high temperature cables
- •Connector performance
- •Hardware performance
- •Allowable current transfer vs. allowable operating temperature
- •Thermal performance of substation equipment
- •Substation equipment degradation & effect on loss of life

The following equipment need to "get up to" **industry standards** for high temperature operations:
- •Connectors
- •Compression fittings
- •Hardware bushings
- •Insulators
- •Spacer dampers

Power Electronics - To bring down the cost and to collect information on performance in real-world applications more field tests and demonstrations of existing prototypes and equipment is needed.

Reduce the high cost of HVDC and FACTS systems and the complexity of multi-terminal HVDC links.

Reinforce 230kV with high operating cables to support 500 kV grid operation to respond to 500kV outages.

Use **high current capacity cables** cost effectively.

Future Technologies

T16: Real-time Monitoring of thermal, mechanical & electrical characteristics of cables, structures & substation equipment with novel system protection applications

T17: High Current Operating Technologies that include Innovative uses of Existing Technologies & High Temperature Modeling of substation equipment, cables, hardware, connectors, etc.

T7: Power electronics & flexible AC Transmission systems (FACTS)

T18: Advanced Conductor Technologies (HighTempLowSag, HTSC)

2007 | +5 yrs | +10 yrs | + 20 yrs

Figure 12: Cost-effective, Environmentally Sound Energy Supply & Demand Gap Analysis

Existing Technologies

Power Electronics – Flexible Alternating Current Transmission Systems (FACTS) - SMES

Non Wire Solutions
▪Demand Response
✓Market Incentive Response
✓Direct Load Control
✓Commercial
✓Industrial
✓Aggregation
▪Distributed Generation
▪Energy Storage
▪Peak Energy Efficiency Measures
▪Controls

Technology Gaps

Power Electronics - To bring down the cost and to collect information on performance in real-world applications more field teats and demonstrations of existing prototypes and equipment is needed.

Energy Storage - Development of Standards & Guidelines for Application, Specification, Operation and Maintenance for sizing the power and energy ratings of an energy storage system

Electric Storage Devices
▪Prepare lifecycle cost evaluation criteria to accurately compare
▪Different storage technologies against each other and against traditional solutions (installation costs for new transmission lines and transformers & fuel costs for gas turbines and diesel generators.)
▪The storage media and the power electronics interface that is required when interfacing dc devices to the ac grid.

Field demonstration of energy storage devices to evaluate trade-offs in features and performance and to lower manufacturing costs.
▪Small scale electric storage devices customer's side of the meter
▪Larger scale storage devices at key feeders and substations.
▪Advances in the design of storage systems are needed, especially for batteries, flywheels, and capacitors.

Non Wire Solutions
▪Open Standard Single Architecture
▪Emission Reduction for Distributed Generation
▪Communications Media problematic for rural/remote locations
▪Cost per kW capacity still too high – Energy Storage
▪Improved Understanding of Peak Load Impacts
▪Vendor Agnostic Open Source Compliance

Future Technologies

T7: **Power Electronics –** ETO Thyristors

T8: **Energy Storage**

T20: **Non-Wire Technologies**
▪Ultra Capacitors for Residential/commercial Use
▪Cross Platform & Cross Utility Aggregatability
▪Do It Yourself Network for Panel,Socket & Appliance

2007 | +5 yrs | +10 yrs | + 20 yrs

Figure 13: Maximize Asset Use Gap Analysis

Existing Technologies

Condition & Time Based Maintenance, Equipment Replacement & Vegetation Management is performed on a calendar or "as-needed" basis. The region's foreman & natural resource specialists decides how/when it gets implemented and usually to match outage schedule

Diagnostic & Reliability Centered Maintenance is performed manually by;
- Test results
- Oil samples
- Hand held portables
- Relay monitoring
- Visual inspections by climbing structures
- Photogrammetry tools
- Aircraft patrols
- Low-level video
- Wood Pole Inspection Program

Equipment Life Extension/Preservation
- Wood pole longevity
- Stubbing program
- Ohm stick predicts resistance of compression fitting relative to the conductor

Hot Line Maintenance Techniques:
- Hot Sticking
- Ohm Sticking
- Rubber Glove

Technology Gaps

Monitor, collect, process, manage & analyze data to achieve system wide data integration and determine future maintenance needs and establish interoperability, reporting & ranking criteria.

Real time, on-line monitoring of oil samples, SF6, acoustics, partial discharge, batteries, airway lighting, etc. Monitoring capabilities designed into reactors, transformers, bushings and towers.

Relay controls with programming and logic, sensors integrated into microprocessor based relay design and interoperable with other equipment. Use relay monitoring data to asses health, operation of breakers.

Vegetation monitoring & analysis tools

SMART Substation Demonstration Project
- Digital transducers to provide high bandwidth signals
- Needed by protection & monitoring equipment
- Digital communications networking equipment
- Modular & expandable control & protection equipment

Corrosion diagnostics for structures – identify high risk locations for corrosion by using magnesium anodes w/voltage measurements.

Advanced line & right-of-way inspection tools:
- Fly helicopter for inspection w/technology chip to gather info
- Back scatter technology embedded at base of pole, crossarm, insulators etc. to interrogate its condition
- Lidar & Infrared technologies
- Forward looking infrared light (looking for heat in splices)
- Detail inspections (Haverfield) close visual inspection
- Daycore camera put on helicopter

Policy/criteria for installing **non-ceramic insulators**. Track what brand putting in and problems with EPDM rubber

Power Electronics -To bring down the cost and to collect information on performance in real-world applications more field tests and demonstrations of existing prototypes and equipment is needed.

Monitor existing **porcelain & glass insulators** that are nearing end of life.

Corrosion prevention program for steel, concrete footings, anchor wood poles & guys

Interoperability & integration of new equipment with older existing equipment to maximize use of technology life cycle

Confirmation Study: Investigation of hotline/substation maintenance technologies and standards used by other utilities & how this interfaces/impacts BPA's standards, business/legal case and cost of power/outages.

Study to develop business case and hot line policy & procedures methods for system wide maintenance
- Spacer damper replacement
- Disconnect switch contacts cleaned & lubricated

Implementation of hot line maintenance policy & procedures system wide

Future Technologies

T16: Real-time Monitoring of thermal, mechanical & electrical characteristics of cables, structures & substation equipment with novel system protection applications

T7: Power Electronics & Flexible AC Transmission Systems (FACTS)

T19: Advanced Substations

T10: Advanced Maintenance & Diagnostic technologies to allow for
- Prioritized Equipment Ranking
- Conditioned-Based Maintenance
- Prevention Programs
- Smart Equipment Replacement Programs
- Right-of-way maintenance

T9: Hot Line and Hot Substation Maintenance & Diagnostic technologies, procedures & tools for system wide use

2007 | +5 yrs | +10 yrs | + 20 yrs

RANKING OF THE CRITICAL TECHNOLOGIES

Power Electronics
Out of the 20 critical technologies identified through the roadmapping process, only ***T6: Power Electronics and FACTS*** is used to support all four of the targets that are mapped out in figures 4, 5, 6 and 7. Power electronics are at the heart of the power conversion interface and hold the potential for transforming the electric power system by allowing precise and rapid switching of electrical power.

One of the main barriers to greater market penetration of power electronics has been the high cost and lack of demonstrated performance in real-world applications. The revolutionizing potential of power electronics is based on anticipated research breakthroughs in advanced material properties that will go beyond silicon, for example diamond and silicon carbide. Prototype development and real-world field test demonstrations of high power electronic applications are necessary to validate product performance and lead to cost reductions and market penetration. BPA collaboration in a proposed national power electronics test facility by GridWorks may help coordinate and facilitate the evolution of power electronics. [GridWorks Multi Year Plan, March 2005, pp. 10-11]

Technical Risk
During the Planning/Operation workshop (December 2005) and the Facility workshop (February 2006), participants ranked technology categories as to high or low value to the region and high or low technical risk. The results are presented in appendixes 1 and 2. Using these indicators and the expert input gathered during the roadmapping process, only technologies that have high value to the region were considered critical technologies. The resulting list of critical technologies, T1 through T20, is presented on page 20. Theses critical technologies are then categorized based on high, medium or low technical risk.

High technical risk technologies are best suited for collaborative investments. Pure research projects or projects requiring highly specialized research staff, laboratories or demonstration facilities fit in this category. Examples are material science research in power electronics, energy storage, advanced cables, advanced substation equipment and facility hardening technologies. The high cost and risk of developing these technologies throughout various stages can be reduced through collaborative investments in phased projects.

Medium technical risk technologies are likely a combination of BPA go-it-alone and collaborative/partnership investments. Projects that fit in this category are demonstration projects that transition researched technologies into confirmed technologies that can be integrated into BPA's conservative transmission system. Prototype development and real-world field test demonstrations are necessary to validate product performance and lead to cost reductions and market penetration. Such technologies are communication technologies, power electronics, nonwire solutions, real-time measurement and monitoring hardware, and advanced maintenance and diagnostic technologies.

Low technical risk technologies are well suited for BPA to go-it-alone, if necessary, to satisfy BPA system specific requirements. This is especially the case for software development as compared to hardware technology RD&D investments. Software developments typically are the “best bang for the buck” but do *require extensive prototype testing and validation* by BPA System Operations and/or Planning prior to system application. Also, organizational consideration needs to be given to intellectual property ownership and management of software copyrights. [Intellectual Property Management as it Relates to BPA Sponsored Technology Innovation, pp. 6-7] Such technologies are

- robust state estimator with real-time automated operational transfer capability;
- enhanced wide-area measurement systems;
- real-time automated load forecasting and generation tools;
- software tools for system performance, analysis and validation;
- data visualization tools and displays for dispatch;
- an improved SERA program; and
- models of cables, connectors and hardware high current operation.

The following three technologies require ***rigorous** testing and validation* by System Operations to be of <u>low technical risk</u>, without which they assume a <u>high technical risk</u>:

- response-based real-time wide-area control systems,
- automated tools for dispatch/operations and
- software tools for online real-time dispatch/operations.

The Recommended Next Step

To maintain system reliability, increase transmission capacity and maximize asset use in an environmentally sound manner, a balanced RD&D portfolio between transmission planning, operation, design and maintenance is required. A systems approach is needed to move technologies through the stages of research, development and demonstration into application within the BPA transmission grid. The transmission system is just that, “a system” in which the whole is greater than the sum of the individual parts. This road map cautions against overinvestment in favorite technologies. For example, excessive investment in nonwire solutions at the expense of software tools for online real-time dispatch/operations could cause an overreaction against those technologies if a single blackout event were to occur.

The 2006 Transmission Technology Road Map lends itself to further analyses of the critical technologies in support of future decision making about transmission system RD&D investments. To do this, the use of the Hierarchical Decision Model (HDM) is recommended. The HDM yields a ranking of the decision alternatives according to their contributions to the overall goal through judgment quantifications. [Applying Sensitivity Analysis to the Strategic Evaluation of Emerging Technologies, PICMET, 2005, p. 166] After BPA experts would provide comparative judgments about the relative priorities of the components in each level of the hierarchy diagrams (figures 4, 5, 6, and 7 that show the linkages between targets, needs, technology features and technologies), the results would yield a ranking of the critical technologies according to their contributions to achieve the targets. [An Analytical approach to Building a Technology Development Envelope, PICMET, 2005, p. 123] Also the use of the HDM sensitivity analysis can provide a systematic way to perform a sensitivity analysis specifically for multicriteria multilevel decision models by capturing situations in which single and multiple perturbations are induced at one level of the decision hierarchy while keeping other levels unchanged. The approach can also be applied to various patterns of technology strategies and competitive goals. [Applying Sensitivity Analysis to the Strategic Evaluation of Emerging Technologies, PICMET, 2005, p. 166]

WHO IS DOING WHAT OUTSIDE OF BPA

To assist BPA in making collaborative investment decisions, the Technology Innovation staff investigated who is doing what outside BPA. This information is compiled and presented in Appendix 6: External Contacts and Who is Doing What Outside BPA. Table A provides a list of external contacts with organization name, what the people are doing, who the contact person is, what RD&D projects they are working on and their Web address. Table B provides a list of organizations and the current RD&D projects they are working on and/or their identified RD&D needs.

REFERENCES

California's Electricity System of the Future: Scenario Analysis in Support of Public-Interest Transmission System R&D Planning (Oct. 2003). Sacramento CA: Consortium for Electric Reliability Technology Solutions, Consultant Report for California Energy Commission, P500-03-084F.

Canadian Electric Power Technology Roadmap: Forecast (Mar. 2000) Ottawa, Canada: Industry Canada, Manufacturing and Processing Technologies Branch; ISBN 0-662-28793-2.

Challenge for the Northwest: Protecting and managing an increasingly congested transmission system (Apr. 2006). Portland OR: White Paper; Bonneville Power Administration; DOE/BP-3705.

Chen, H., Kocaoglu, D.F., and Ho, J. (2005) Applying Sensitivity Analysis to the Strategic Evaluation of Emerging Technologies in Taiwan Semiconductor Foundry Industry. *Technology Management: A unifying discipline for melting the boundaries.* Portland, OR: PICMET. Pgs 166-173.

Clark, H.K. (Oct. 2004). It's Time to Challenge Conventional Wisdom. *Transmission and Distribution World*. Overland Park, KS:

Columbus HTS Power Cable Project Fact Sheet (May 2004), Superconductivity Partnerships with Industry, Office of Electric Transmission and Distribution, US Department of Energy.

Development Status of High-Temperature, Low-Sag Transmission Conductors Reviewed in New Report. (2006) Aty Edris, EPRI *Transmission and Substation Highlights* Webpage www.epri.com/programHigh.asp?program=249634&objid=285656 .

Electric Distribution: Multi-year Research, Development, Demonstration, and Deployment Technology Roadmap Plan: 2005-2009 (Dec. 2004). Washington D.C.: Office of Electric Transmission and Distribution; United States Department of Energy.

Electricity Technology Roadmap: Meeting the critical challenges of the 21st Century: 2003 Summary and Synthesis (2003). Palo Alto, CA: Electric Power Research Institute (EPRI);

Product No. 1010929.

Energy Efficiency Technology Roadmap (July 2006). Portland OR: Bonneville Power Administration

Energy Supply and Conservation: Overview (for FY 2007 Congressional Budget). Washington D.C.: Office of Electricity Delivery and Energy Reliability.

Erickson, D. and Taylor, C. (April 2005). Pacify the Power: GPS harness for large-area electrical grid. Santa Ana, CA: GPS World.

ESMO 2003 Proceedings: IEEE ESMO 10th International Conference on transmission and distribution construction, operation and live-line maintenance proceedings. (April 2003 Orlando, FL) IEEE catalog number 03CH37473.

George, K. (June 2006).DC Power Production, Deliver and Utilization: An EPRI White Paper. Knoxville, TN: EPRI Solutions, Inc.

Grid 2030: A national vision for electricity's second 100 years (July 2003). Washington D.C.: Office of Electric Transmission and Distribution; United States Department of Energy.

Gerdsri, N. (2005). An Analytical Approach to Building a Technology Development Envelope (TDE) for Roadmapping of Emerging Technologies. *Technology Management: A unifying discipline for melting the boundaries.* Portland, OR: PICMET, Pgs 123-135.

GridWorks Multi Year Plan (Mar. 2005). Washington D.C.: Office of Electric Transmission and Distribution; United States Department of Energy.

Intellectual Property Management as it Relates to BPA Sponsored Technology Innovation (July 2005). BPA Technology Innovation Office, July 2006.

Major, J.M. (Summer 2006). Ensuring the Health of Our Power Lines: SwRI engineers are working with EPRI to develop remote sensors for electric transmission lines. San Antonio, TX: Technology Today, Southwest Research Institute.

Mazza, P. (DRAFT, Feb. 2005). Leading the Way to the 21st Century Power Grid: A

Northwest Smart Energy initiative to create jobs, secure energy supplies and control power costs. Olympia WA. Climate Solutions.

National Electric Delivery Technologies Roadmap: Transforming the grid to revolutionize electric power in North America (Jan. 2004). Washington D.C.: Office of Electric Transmission and Distribution; United States Department of Energy.

Roadmap to Secure Control Systems in the Energy Sector (Jan. 2006). Columbia, MD: Energetics Incorporated, for U.S. Department of Energy and U.S. Department of Homeland Security.

Roco, M. C. (August 2006). Nanotechnology's Future: Over the next two decades, this new field for controlling the properties of matter will rise to prominence through four evolutionary stages. Scientific American.com http://www.sciam.com/article.cfm?articleID=00029E0B-34C6-14C0-AFE483414B7F4945&chanID=sa006 .

Rudervall, R., Charpentier, J.P. and Sharma, R., (2000). High Voltage Direct Current (HVDC) Transmission Systems Technology Review Paper. The World Bank; Presented at Energy Week 2000, Washington, DC, March 7-8, 2000.

Stranzl, J. (Sept 2006). Bonneville Power Administration to Host ‘Non-wire’ Transmission. Portland OR: Daily Journal of Commerce.

Technology Briefs: Overview of advanced electric delivery technologies (Aug. 2004). Columbia, MD: Energetics Incorporated, for U.S. Department of Energy and the Office of Electric Transmission and Distribution.

Technology Innovation Summary (July 2005). Portland, OR: Technology Innovation Office, Bonneville Power Administration.

The National Nanotechnology Initiative: Research and development leading to a revolution in technology and industry (July 2006). Washington D.C.: Supplement to the President’s 2007 Budget; National Science and Technology Council.

APPENDIX 1: Transmission Roadmapping Workshop Products for Planning & Operations

Notes from the 12/14/05 Transmission Planning & Ops Roadmapping Workshop
Wall Chart: **Analysis of Technologies**

Column 1 – Expert Systems (Rule Based) for assisting Dispatch and Operations with complex decision-making;
Decision Analysis to apply solutions:

- **Network**
- **RAS/WACS**
- **Operator**

Identify key product features with high impact on one or more drivers

Note 1: Balance between operation and system functions

Essential Challenges

Note 2: - Identify operator limitations – identify what can be automated.
Note 3: - Identify what to protect for. (And what not.)

R & D Implications

Note 4: Determine balance and biggest payback items.
Note 5: (See Decision Analysis Diagram)

Column 2 – Data Visualization Tools

Identify key product features with high impact on one or more drivers

Note 1: Better reliability
Note 2: More efficient operation (less staff)

Essential Challenges

Note 3: Convert data into useful information
Note 4: Validate ideas under different conditions
Note 5: Partnerships for data presentation

Column 3 – Real Time OTC's

Identify key product features with high impact on one or more drivers

Note 1: Better asset use
Note 2: Better reliability real time
Note 3: Higher sales

Essential Challenges

Note 4: Not user friendly; not flexible (Arena EMS)
Note 5: Results validation problems
Note 6: Implementing transient stability analysis

R & D Implications

Note 7: Testing and validation
Note 8: Determine end user

Column 4 – Model Benchmarking & tuning tools; Benchmark power system models

Identify key product features with high impact on one or more drivers

Note 1: Less wasted work effort
Note 2: Reliable and consistent transfer capacity

Essential Challenges

Note 3: FTE to support tools (SE primarily)
Note 4: Ability to capture disturbances; adequate info from outside BPA
Note 5: Incentivise Business processes

R & D Implications

Note 6: Benchmarking methodology and tools
Note 7: Defining benchmark parameters; parameter identification

Column 5 – SMART Towers & Wires (temp, wind, strain) Real time capacity tools

Identify key product features with high impact on one or more drivers

Note 1: Increase R/T OTC and/or Availability and/or Reliability

Note 2: More efficient outages
Note 3: More $ from sales (maybe)
Note 4: Better Info utilization (i.e., ST forecasting)

Essential Challenges

Note 5: Planned obsolescence & technology deployment
Note 6: Aging infrastructure (putting new tech on old poles)
Note 7: Info sharing with customers or other users
Note 8: Data validation & error tolerance (algorithms)
- *correct data*
- *inputs*
- *validation*

R & D Implications

Note 9: Define info to gather and how
Note 10: Define number of towers and scope of project measurement

Column 6 – Consolidated vs. Distributed Data Systems (RTU, SER, PMU, etc.)

Identify key product features with high impact on one or more drivers

Note 1: Silo'd systems; Now, some very old; Retirement

Essential Challenges

Note 2: Prototyping

R & D Implications

Note 3: Partners: Intelligrid
Note 4: Use case > System integration > Prototype > Bid

Column 7 – Response-based Controls (WACS)

Identify key product features with high impact on one or more drivers

Note 1: Active controls: maximize system capacity
Note 2: Safety nets: Fast response

Essential Challenges

Note 3: Identify fast/slow automatic control needs
Note 4: Investigate unintended consequences (i.e., trip signal)

Note 5: Understand system dynamics
Note 6: RAS culture

R & D Implications

Note 7: Prototype safety net applications
Note 8: Define acceptance criteria
Note 9: Run in parallel until technology is confirmed
Note 10: Link to other efforts (East coast, WAMS)

Column 8 – Load Demand & Composition; Forecast Assessment

Identify key product features with high impact on one or more drivers

Note 1: Asset utilization
Note 2: Load demand control

Essential Challenges

Note 3: Participation from other utilities

Notes from the 12/14/05 Transmission Planning & Ops Roadmapping Workshop
Wall Chart: **Hot Dot Technology Prioritizing**

Technologies grouped after prioritizing for evaluation purposes.

Technology	# Dots
- Expert systems (rule-based) for assisting dispatch w/ complex decisions. **- Decision Analysis to apply solutions Network, RAS/WACS, Operator** - Risk Assessment (probability and Impact analysis/ Expert system / How-to-get-out-of-trouble advice for dispatchers, What to cut and how much	4 3
- Data visualization tools - Information Visualization (system monitoring) - Visualization of complex data (Minority Report) G.I.S & operation (i.e. outages, scada, misc.), Enhanced visualization for outages & ops / Improved HMI / Information display concepts for dispatchers / Visualization	5 1 1
- Real time OTCs - Real-time display of DSO choices and consequences - Online determination of load-generation to stay within network capability - RT Diagnostic tools (what happened) - Better CC tools (e.g. contingency analysis w/RAS Tools to limit scope of disturbances and improve restoration / Integrate weather data into RT operating data & short term ops studies / Real time tools for monitoring system security / Real time tools	4 3 2 2 2
Real time system robustness measurement & visualization	5
- Model benchmarking & tuning tools **- Benchmark power system models** PI & Power World connection & data exchange / simulation tools to better predict cascading scenarios / Better base-case development process region wide /Models	3 2
- SMART towers & wires (temp, wind, strain) Real time capacity tool - Energy storage Lower cost reactive support control technology for power quality issues do to wind /High ampacity conductors (includes super conductors) / Lower cost FACTS devices / Sub automation – Smart subs / Hardware	7 1
Consolidated vs. distributed data systems (RTU, SER, PMU, etc.)	3

Technology	# Dots
- Response-based controls (WACS) Response-based Grid controls (WACS) / Getting to response-based control (WACS) / WACS – Intelligent island – Monitor coherent generation cluster / WACS	3
- PMUs? Phase Angles? Limit? How to use real time Improved situational awareness (WAMS) / Online risk monitoring (MVAR margin, oscillation detection, etc.) / CSM Constraint Schedule Mngmt / Generator performance monitor / Intelligent load drop in CAL (not generation drop)	1
- High speed, secure, reliable operation network between control center & field (substations, etc.) - More real time data exchange between WECC utilities Internal instant messaging with presence within BPA & between utilities / Communications	2 1
- Game simulation for Dispatch training Party poker for PBL / Enhanced Training	2
- Load demand & composition forecast assessment - GFA (grid friendly appliances) Load response measurement / Load demand control / load	2 1
Security / cyber security- bade software causes cyber security problems, How to prevent bad software? No Microsoft / No "J"	

Notes from the 12/14/05 Transmission Planning & Ops Roadmapping Workshop
Wall Chart: **Business/Technology Drivers (Hot Dots)**

Grouped Drivers		# Dots
Operations Integration	Wind Power Integration Regulation V.C. Reserves Subgrid Studies Wind modeling: How much wind is too much	4
	Wind generation forecasting to better define study assumptions	2
	Renewable resources, distributed generation	3
	Wind requirements on the system/ Large wind penetration	0
	Distributed generation/ Centralization vs. Distr. Gen./ Counter trends: DG but larger central station projects (Big wind)	0
Load/ End Use Changes	Customer tailored services	0
	Load Demand Control: Non-wires	3
	Suburbanization of population and industry	0
	Not enough oil/gas ($$) for heating- Electric heating increases too much	0
	Smaller Elec Intensive industry	0
	Population Changes in NW	0
	Hydrogen economy	0
Assets	Inability to take maintenance outages due to market demands	2
	Better utilization of transmission capacity	3
	Aging infrastructure- Condition monitoring- Limited maintenance	1
	Greater utilization of the transmission asset	0
	Sell transmission- Provide more with existing system	0
Information	Outage – Maximize capacity through better info. (i.e. temp., etc.)	4
	Improve availability of existing infrastructure though real time monitoring, Max OTC	6
	Hi speed 2-way communication to every consumer	0
	Increased congestion with $ constraints	0
	$$ interruptions	0
	Increasing business dependency on electricity	0
	Better ways to predict cascading scenarios in studies	2
	Need for transaction continuity (Buss effect & ops)	1
	Better ways to assess TX inventory of existing system	0
How We Operate	Changing hydro system operations/ Loss hydro (Judge Redden)	0
	Better wind simulation models to fully capture impacts up front	0
	Inadequate ability to manage flows – Inefficient curtailments	6
	System operation is changing, historical patterns not repeated	0
	Ultra high reliability expectations/ crossing our fingers too much	0
	Inventory vs. recoverability	0
	Changing neighbors (SEAMS)	0
	Impacts of what we don't know (operating problems)	0
	More blackouts we can't prevent (politician backlash, think Katrina and FEMA's Brown)	0
	Expectations on dispatch greater, faster response, technical competency	0
	Dispatch workroom displays/ Info impact/ Accept changes	7
Regulators	FERC reliability standards	0
	FERC *#%! (bad regulations)	0
	Regulations asking for more training - auditing	0
	BPA Sold? / RTO? ISO?	0
	ERO 'Take no Prisoners' (Electric Reliability Organization	2
	2005 EPA initiatives (Innovation driver)	1

Notes from the 12/14/05 Transmission Planning & Ops Roadmapping Workshop
Wall Chart: **Business/Technology Drivers (Hot Dots)**

Money	Limited BPA access to capital	2
	Keep rates low – less overhead (more Indians, fewer chiefs) (Cain says "hey, wait a minute.")	0
	Maintain low energy costs with higher primary fuel costs	0
	Cost of Energy	1
	OMB cuts, BPA credit limit, Capital drives TBL	0
Security	Security for variety of threats	1
	Hackers cause blackout! Insider threats?	0
	Cyber security, auditing, reporting	4
	DOE Rules, Foreign nationals – visits, contracting, etc.	
Staffing	Experience levels lower – personnel changing rapidly	8
	BPA Demographics - Define the job right (need more done than people can do with existing tools. - Buggy whip (older dispatchers like methods, new tools, new culture, new people)	
	Large # of retirees. Need to hire large #s of new people. Hard to find. Sara vision	
	No engineers in dispatch, etc.	
	OMB cuts BPA FTE drastically	

Technology Risk/Value Matrix

Technology	Technology Risk	Value to Region	Commercial Risk
Load response measurement/Load Demand control/ Online determination of load-generation reductions to stay within network capability	3 Low	4 High	2 Low
Lower cost reactive support control technology/Lower cost FACTS devices	2 High	2 High	3 High
Simulation tools to better predict cascading scenarios/ Benchmark power system models/Model benchmarking & tuning	5 Low 1 High	6 High	3 Low 2 High
GFA (Grid Friendly Appliances)	2 High	1 Low 2 High	1 Low 1 High
Improved (w) MMI/ Game simulation for dispatch training – Party power for PBL	3 Low 1 High	1 Low 2 High	2 Low
Generator performance monitor	4 Low	3 High	3 Low 1 High
Real time tools for monitoring system security/ Improved situational awareness	3 Low 2 High	5 High	1 Low 2 High
Load demand & Composition forecast	4 Low	4 High	3 Low
Intelligent load drop in CAL (not generation drop)	3 Low 1 High	5 High	4 High
WACS – Intelligent island – Monitor coherent gen clusters/ Response-based controls (e.g. WACS)	2 Low 5 High	2 Low 5 High	5 High
Constraint Schedule Mngmt (CSM) / Auto CSM-Curtail redispatch in real time (1 min market, Locational Margin Pricing (LMP)	1 High	1 High	1 Low
Sub Automation/ Integrated instead of 'siloed' data systems (RTU, SEE, PMU, etc.)	2 Low 1 High	2 High	3 Low 2 High
PMOs?, Phase Angles? Limit? How to use in real time	2 Low	2 Low 3 High	2 Low
Bad software-Cyber problems, How to find and prevent bad software. (No Bill Gates)	1 High	1High	1 Low
Online risk nonitoring (MVAR margin oscillation detection, etc.)/ Real time robustness measurement & visualization	1 Low 3 High	5 High	2 Low
Risk assessment (probability & impact analysis)	3 Low 1 High	5 High	3 Low
RT diagnostic tools (what happened?)/ Dynamic Security Assessment (DSA) TSA/ Tools to limit	4 Low	6 High	2 low
High Ampasity Conductors	2 Low	2 High	2 High
SMART Towers and Wires (temp, wind , strain), real time capacity tool	8 Low	8 High	5 Low 1 High
Real time OTCs	3 Low 1 High	4 High	1 Low
Better base case development processes region-wide	2 Low	4 High	1 Low 3 High
Decision analysis to apply solutions: - Network - RAS/WACS - Operator	2 Low	3 High	1 Low
Integrate weather data into R.T. operating data & short term Ops studies	4 Low	5 High	3 Low

Technology	Technology Risk	Value to Region	Commercial Risk
Visualization of complex data (Minority Report)/ Information display concepts for dispatchers	5 Low	6 High	3 Low 3 High
How-to-get-out-of-trouble advice for dispatchers. What to cut?, How much? / Real time display of DSO choices & consequences / Expert systems (rule-based) for assisting Dispatch & operations, Complex decisions	1 Low 5 High	9 High	1 Low 2 High
Internal instant messaging with presence within BPA and between utilities	4 Low	3 Low 1 High	1 Low
Better CC tools (e.g. contingency analysis w/RAS / G.I.S & operation (i.e. outages, scada, misc.), Enhanced visualization for outages & ops	4 Low	5 High	2 Low
Wireless communication in control center and field / High speed, secure reliable operation network between control center and field (substations, etc.)	3 Low 1 High	4 High	3 Low
PI and Power World connection and data exchange	4 Low	1 Low 3 High	1 Low
More real time data exchange between WECC utilities	2 Low 3 High	4 High	3 Low 2 High
Storage	2 Low 3 High	8 High	2 Low 3 High
Free doughnuts	3 Low	2 Low 2 High	4 Low

APPENDIX 2: Transmission Roadmapping Workshop Products for Transmission Facilities

Notes from the 02/08/06 Transmission Facilities R&D Roadmapping Workshop

Grouped Drivers		# Dots
Regulation Politics	Open Access/Competition for transmission capacity	6
	Market Based Rates	1
	New NERC/FERC reliability standards	1
	Political Pressure	0
	Power/conglomerate greed	0
	Single grid controller will reinstall regulation of the system	0
	Feds will privatize the grid	0
Cost of Power	Money Commitment	5
	Customer cost pressures to control rates	3
	Change in defining capital work to expense	2
	Capacity limits	0
	Increased/reduced business risks	0
Security	Heightened security	5
	Safety	3
	System Reliability will dictate hot line/bare hand maintenance	2
	Work practices to safely allow work on energized lines and buses	1
	Focus on physical security: terrorists, paranoia	0
Co-Generation	Increased cost of oil/gas will make coal, nuclear, and wind attractive	4
	Resource constraints: new sources of power hard to obtain; wave power	1
	Montana coal will require new 500kV lines	0
	DC transmission will be more widely used because it is more efficient	0
	Work with Co-Generation producers to bring power into the system	0
	Electrical demand increases in California (non-firm)	0
Load	Greater loads, public resistance to building new lines	12
	High demand for power (with population density changes)	0
	Customer demand for energy (source or load) faster than now	0
	A system that supports a digital society	0
	Less industrial load, more commercial and residential load	0

Environmental	No new transmission lines and increasing load	2
	Increased spending in fish programs	2
	Green power generally has unique characteristics requiring new ways of operating	1
	Depleting ecosystem with increase in population	0
	Increasing worldwide demand for fossil fuels	0
	Need for more green power	0
	Global warming affecting salmon, in turn reducing generation	0
Staff	BPA demographics: employee experience leaving in the next 5 years through attrition	11
	Primarily what we don't know yet	2
	Fewer power engineers will be graduating from college	1
	Energy policies from Washington, D.C. will force change	0

Power Reliability	An aging system	8
	Aging equipment needs more maintenance as we can't afford to raise rates to pay for it	6
	The RAS system will fail, driving the need for new lines	5
	New FERC regulations on reliability	4
	Need and demand for power quality	2
	Pressures to use existing grid drives higher voltage and reconductoring	2
	Reduce outages	1
	Customers increasingly scrutinize the quality of power, BPA will have to respond to provide clean power	1
	Brown/Black outs	1
	Improved reliability for economic reasons	1
	Balance between reliability and cost	0
Siting NIMBY	Increased difficulty siting transmission in load centers	3
	Reduce required land area needed for lines; need new structures	2
	Increased difficulty in siting generation near load centers	0
	Societal, environmental, and economic limitations on new ROW's	0
	Increasing demand for transmission - fewer corridors available	0
Available "NEW" Technologies	Data management analysis of online equipment for expert systems	6
	Tri-pole DC line conversion	3
	Technology improvement; conductors, communications, generation	1
	Diamond based high band gap semiconductors	0
	Technology from overseas	0
Power System Becoming More & More Complex	Power System Becoming More & More Complex	5
	The next major blackout	5
	Increased inability to take line outages for maintenance and construction	2

	Outages will be very hard to get	1
Decentralize	Local Generation	3
	Decentralized small generation interconnections	2
	Moving generation and load	1
	Decreased costs of alternative sources - Generation pattern shifts	1
	Significant population growth in the region & distribution changes	0
	Compensate customers for our outages	0
	Growth of the region will require change	0

Disruptive Technology	# Dots
Changing technology results in obsolete equipment and techniques before the life cycle completes	5
Cost effective HVDC for shorter distances	5
Remote sensing and measurement using fiber/satelite/phone	4
Electric Vehicles	2
Vendor support issues: Past was 15-20 years support, present is <3-5 years support	2
Outsourcing	2
Management consultants	2
Substation IEDs give info overload, Intelligent Devices	1
Over dependence on RAS, defers wires	1
DC Distribution in office complexes (Eliminate DC/DC supplies in office equipment)	0
High yield, cheap photo cells	0
Load centered generation	0
Widely distributed quality monitors	0
LiDAR for line/ROW modeling	0
Wireless installations on our structures	0
Nano Technologies	0
Mr. Fusion (distributed generation)	0
Cold fusion type of innovation	0
Substation control thru Uproc. Relays	0
Fuel Cells	0
Room temperature super-conductors	0

Category	Technology	# Dots
Security + ROW	Digital Photogrammetry	2
	Physical Security monitoring of grid	2

	Unmanned aircraft/ aerial surveillance	1
Measurement	Use monitoring to maximize power equipment usage	6
	Real time line monitoring	3
	Remote sensing technologies	2
	Line sag monitors	2
	Back scatter technology for component monitoring (wood poles)	1
	Use existing relays to monitor power breakers	1
	Widely distributed power quality monitors	1
	Satellite based monitoring	0
	Automated equipment monitoring system	0
	Online monitoring	0
	Central collector sites for multiple small generation plants (i.e.. Wind farms)	0
Smart Grid	Develop reliable, secure, fast, highly redundant wide area network	5
	Smart materials	3
	Remote Monitoring	3
	Finite element analysis for transmission line modeling	3
	Detailed and complex seismic monitoring system of grid	2
	Measurement using fiber	1
	Phasor measurements for auto RAS	1
	Advanced analysis programs	1
	Intelligent devices at all levels	1
	Handheld collection devices that expedite sharing of info to analysts	0
	Dispatch logging system replacement - real time issue	0
Data	Adaptive protection and control	4
	Communication and network technology improvement	3
	Identify cost of outages	3
	Better simulation and analysis software	2
	Expert control systems	1
	Data base estimating system (expert system)	1
	Expert systems (A.I.)	0
	Enterprise data solution; security, access, ease of use.	0
	A.I. to manage data flood	0
	Self healing grid	0
Demand Side	Demand management and peak shaving	1
	Residential load dropping at peak load	0
	Low VAR motors	0
Aging System	Identify equipment's end of life	6
	Remote line/equipment aging status	1
	Telemeter instruments	1
	Networks in substations (including wireless)	0
HVDC	AC-DC conversion, VSC tri-pole plum	5
	DC Transmission	4
	>500kV AC	3

Fish	Fish friendly dams	1
	Artificial salmon developed	0
New Generation	Ocean Power: wave, tide, and thermal	5
	Nuclear Power: fission, fusion, and sonoluminescence	3
	System isolated wind turbine peaking plants (windmills running pumps for pumped storage)	2
	Solar	1
	Clean coal generators	1
	Sodium cooled fast neutron reactors	0
Misc. New Technologies	New battery plant technologies	1
Conductor Technology	High temperature/low sag conductor	6
	Super conductors	1
	Mobile stringing tensioner device	0
Maintenance	Bare hand work on lines	6
	Work off skids of helicopter	5
Asset Management	Asset management of NEP	0

Category	Technology	Technology Risk	Value to Region	Commercial Risk
HVDC Conversion	* Voltage sourced conversion, triple conversion, PWM converters * Cost effective HVDC for shorter distances * DC Transmission * Low voltage DC distribution in office complexes. Eliminate DC/DC supplies in office equipment	3 Low	5 High	1 High
Conductor Technology	* High temperature/Low sag conductor * Rome temperature super conductor * Super conductors	4 High 7 Low	5 High 1 Low	1 High
Monitoring	* Overdependence on RAS - defers wires * Phasor measurements for auto RAS * Enterprise DATA solutions: security, access, ease of use * Automated equipment monitoring systems * Detailed and complex seismic monitoring system of grid * Substation control through U Processor based relays * Physical/Security monitoring of grid	5 High 11 Low	8 High	3 Low

	* Relay based event recording * Substation IEDs give info overload * Use monitoring to maximize power equipment usage * Use existing relays to monitor power breakers * Measurement using fiber * Adaptive protection and control * Handheld collection devices that expedite sharing of info to analysts * Dispatch logging system replacement/ real time issue			
Remote Monitoring	* Remote sensing technologies * Back scatter technology for component monitoring (wood poles) * Real time monitor * Online monitoring * Wireless installations on our structures * Line sag monitors * Remote line/equipment aging status * Unmanned aerial surveillance * Satellite based monitoring * Remote sensing measurement using fiber, satellite, or phone * Satellite monitor for lines/equipment ratings	13 Low	17 High	6 Low
Fish	* Fish friendly dams * Artificial salmon developed	1 Low	1 High 4 Low	3 High
Energy Efficient Products	* Low Var Motors * Electric Vehicles	1 High 7 Low	5 High	1 Low
Cost Management	*Identify the costs of outages	1 Low	4 High	4 Low

Alternative Energy	* System isolated wind turbine peaking plants (windmills running pumps for pumped storage) * Sodium cooled fast neutron reactors * Nuclear Power: fission, fusion, sonoluminescence * High yield - cheap photocells * fuel cells * Cold fusion type innovation * Mr. Fusion (distributed generation)	2 High 1 Low	10 High	2 High 4 Low

	* Ocean Power: wave, tide, and thermal * Solar * Clean coal generators			
Products	* LiDAR for line and ROW modeling * New communications and substations battery plant technologies * Mobile stringing tensioner device * Digital Photogrammetry * Telemeter instruments	4 Low	5 High 2 Low	2 Low
Maintenance/TLM	* Work off skids of helicopter * Barehand Maintenance	2 High 7 Low	11 High	4 Low
Network Improvements/ Communications	* Develop reliable, secure, fast, highly redundant wide area network * Communications and network technology improvements * Networks in substations (including wireless)	7 Low	7 High	1 Low
Intelligent Design & Devices	* Nano technology * Self healing grid * Smart materials * Expert control systems * Expert systems (A.I.) * Develop more universal standards * Industry standard structural, analysis/design software * A.I. to manage data flood * Intelligent devices at all levels	3 High 3 Low	3 High 1 Low	1 Low
Computer Modeling	* Better simulation and analysis software * Finite element analysis for transmission line modeling * Advanced analysis programs	3 Low	5 High	4 Low
Managing Data	* Identify equipment end of life * Data base estimating system * Changing technology results in obsolete equipment and techniques before life cycle complete	2 Low	1 High	1 Low
Asset Management	* Asset management of NEP	1 High 12 Low	15 High	1 High 2 Low
Demand Side Management	* Load centered generation * Demand management and peak shaving * Central collector sites for multiple small generating plants (wind farms) * Residential load dropping at peak load	2 Low	1 High	0

Appendix 3: Power Electronics Gap Analysis

Existing Products

By Switching Frequency

Slow Switching Frequency Devices
1) Silicon Controled Thyristor – Line commutated
Utility Applications are in VAR Compensation, FACTS and HVDC
2) GTO Thyristor – Gate Turn off commutated
Utility Applications are in VAR Compensation, Power Quality, FACTS, Voltage Source Conversion (VSC)

Medium Switching Frequency Devices
1) IGBT – Gate Forced commutation
Utility Applications in Power Quality, VSC transmission, Wind turbine generator control, Motor Drives, Inverters
2) IGCT – Gate Forced commutation
Application same as 1)

High Switching Frequency Devices
MOSFET
No significant utility use. On resistance too large at high current with present Silicon technology.

By System Topology

Slow Switching Topologies
1) Line Commutated 60Hz
a) Series Thyristor stack for HVDC quadri-valve and SVC systems
b) Bi-directional Valves
c) Thyristor Controlled Series Compensator systems
2) Gate Turn Off Commutated
Utility Applications are in VAR Compensation, Power Quality, FACTS (Unified Power Flow Controller),

Medium Switching Topologies
1) 2 level Pulse Width modulation Topology
2) Multi level Conversion matrix topology (5 levels and greater)

TECHNOLOGY GAPS

Future Products will be founded on new:
Semiconductor devices that are combinations of the best characteristics of present devices.
Devices that are analogous to present devices but constructed from high band gap materials (extreme temperature withstand, high current capacity & high voltage withstand).
New semiconductor devices that are used in new topologies or novel modulation techniques.
Present power electronics that are used in new topologies or novel modulation techniques.

Power Electronics Cooling is *weak point* in most systems.
- Cooling usually involves mechanically driven fluid at high voltage potential.
- Chemical properties of cooling fluid have to be carefully maintained
- High maintenance and needs high reliability auxiliary power sources.

GAP = Minimize cooling demand with new semiconductor material that can tolerate very high internal junction temperatures.
Silicon Carbide Gallium Nitride Diamond

DC –AC forced commutation systems, the tradeoff is – "For the same performance, the fewer the switching levels (hence a simpler device matrix) the faster the power electronics must switch. The slower the switching cycle, the more switching levels are needed and the more complex the multi-level converter becomes.
GAP = Complexity of parallel , series converter matrix to provide both high voltage withstand and high current capability. Solution = a) semiconductors with higher voltage withstand & b) novel multilevel switching topologies
GAP = Inability to control magnitude of fault current on DC side of converter

Present device trade-off's Voltage withstand and On resistance versus switching speed.
GAP = Material Properties, geometry, doping, purity, gating

SYSTEM COSTS GAP = Lack of Standardization and no mass production
Power Electronics main market is the drives industry (lower voltage levels)

Multi–Terminal HVDC Current Source Converters -All Inverter taps must be rated for full system power regardless of tap need. GAP = Control of Current magnitude under commutation failure

High voltage Power Transformers often required in overall Power Electronic system.
GAP = Solid State Transformation or Elimination of need for isolation / source voltage reduction

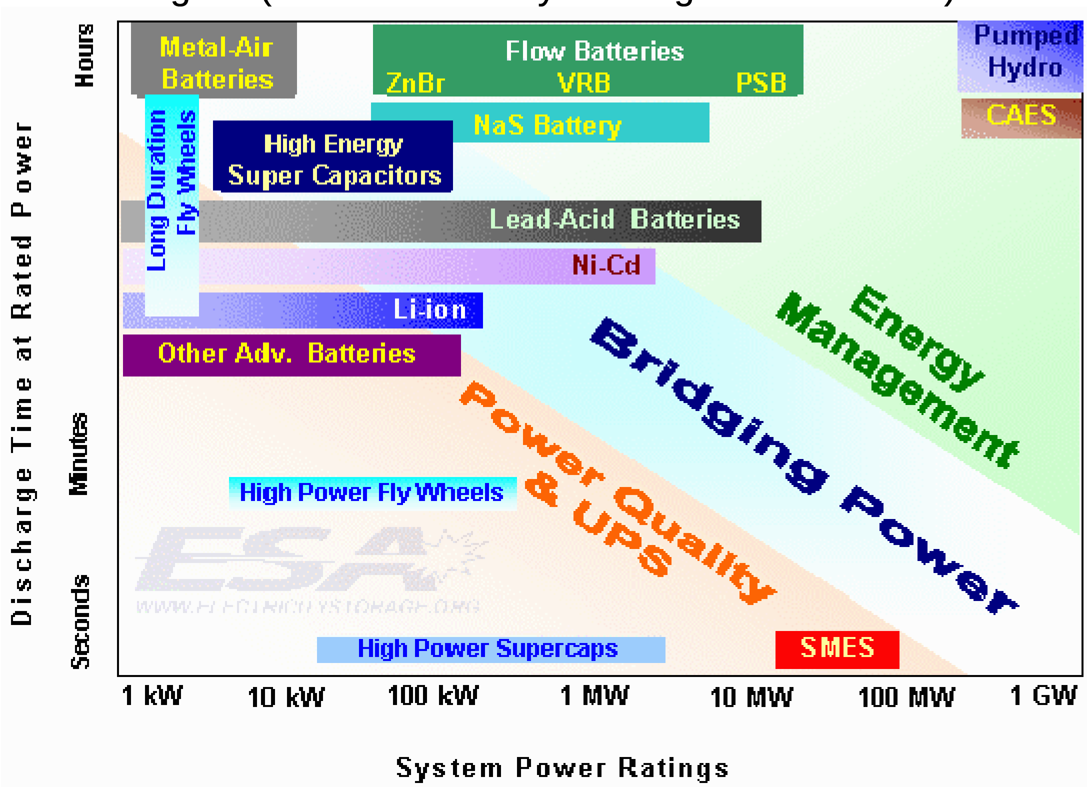
High Power Utility DC – DC Conversion will require High Voltage, high frequency power switching devices with low loss.

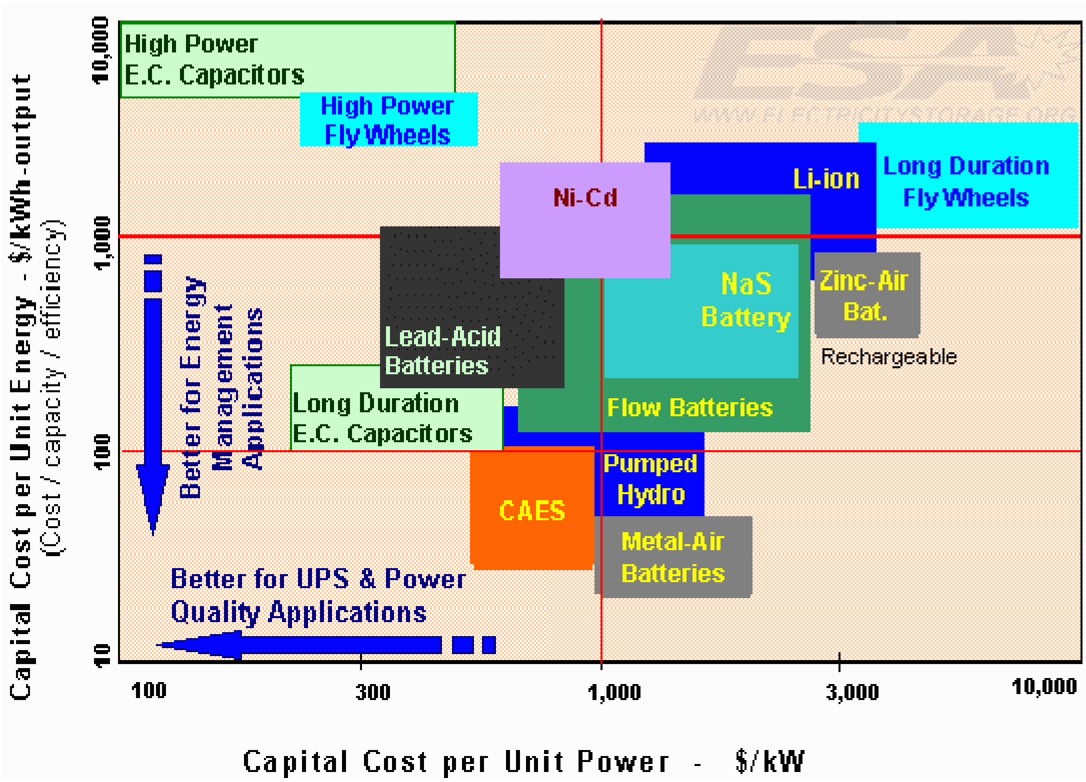
2007 +5 yrs +10 yrs +15 yrs + 20 yrs

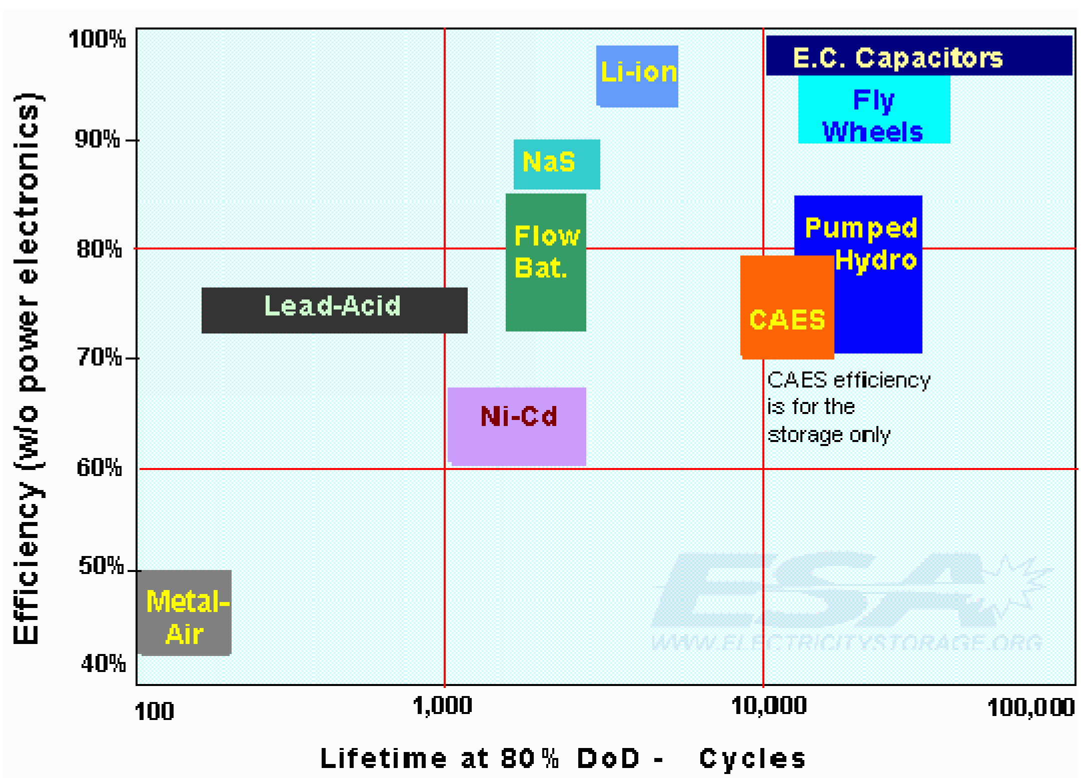
Future Products

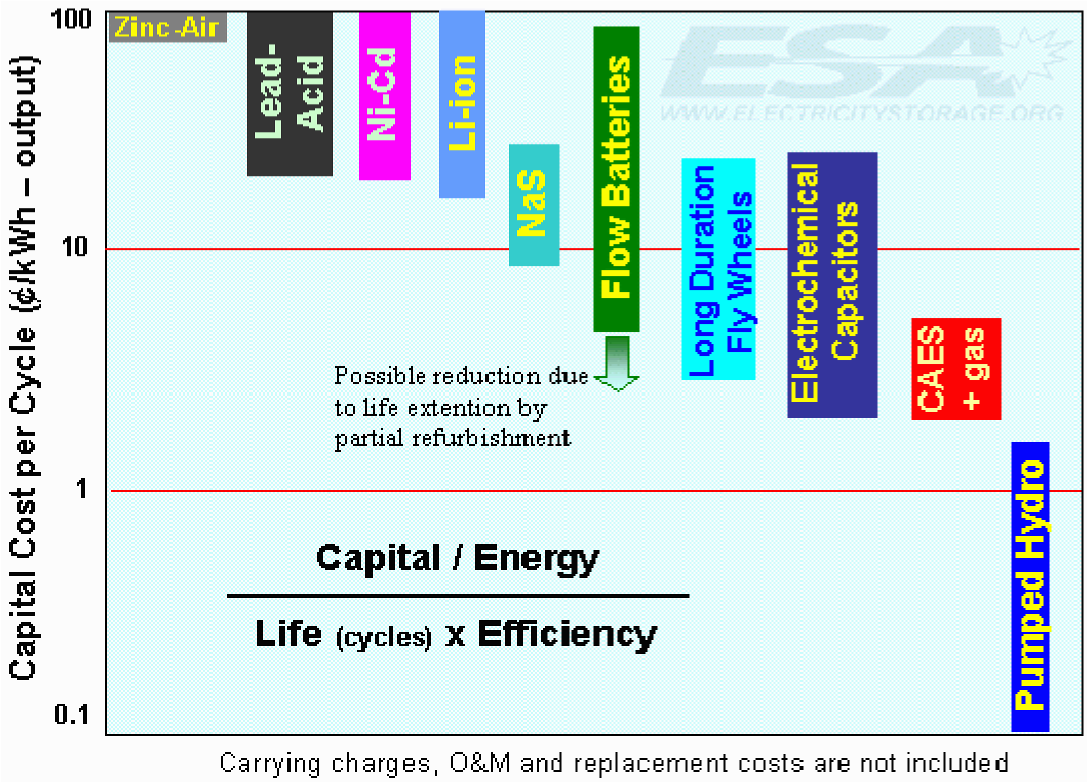
- Tri Pole HVDC (Topology advancement and switching device packaging innovation)
- Multi-Terminal Voltage Source Converter Overhead line Transmission
- Diamond Emitter Technology - Solid State "vacuum tube"
- Super Conducting DC Cable transmission Superconducting Storage systems
- Power System Grid Control / FACTS systems
- Solid State Circuit Breakers and Fault Current Limiters
- Distributed Generation / Renewable Resource integration of any none symmetric energy source output into the AC grid.
- Control of Energy Storage Systems (Capacitor, battery, flywheel, pressure, SMES)
- Power Quality – Flicker mitigation and harmonic suppression
- Dynamic Voltage Support
- Multi function Transmission Building Block (MFTB) that will combineinto an economical universal unit that fulfils many needs at once. (STATCOM)
- Solid State Transformers
- Large Metropolitan DC Distribution systems for workplace DC Power needs

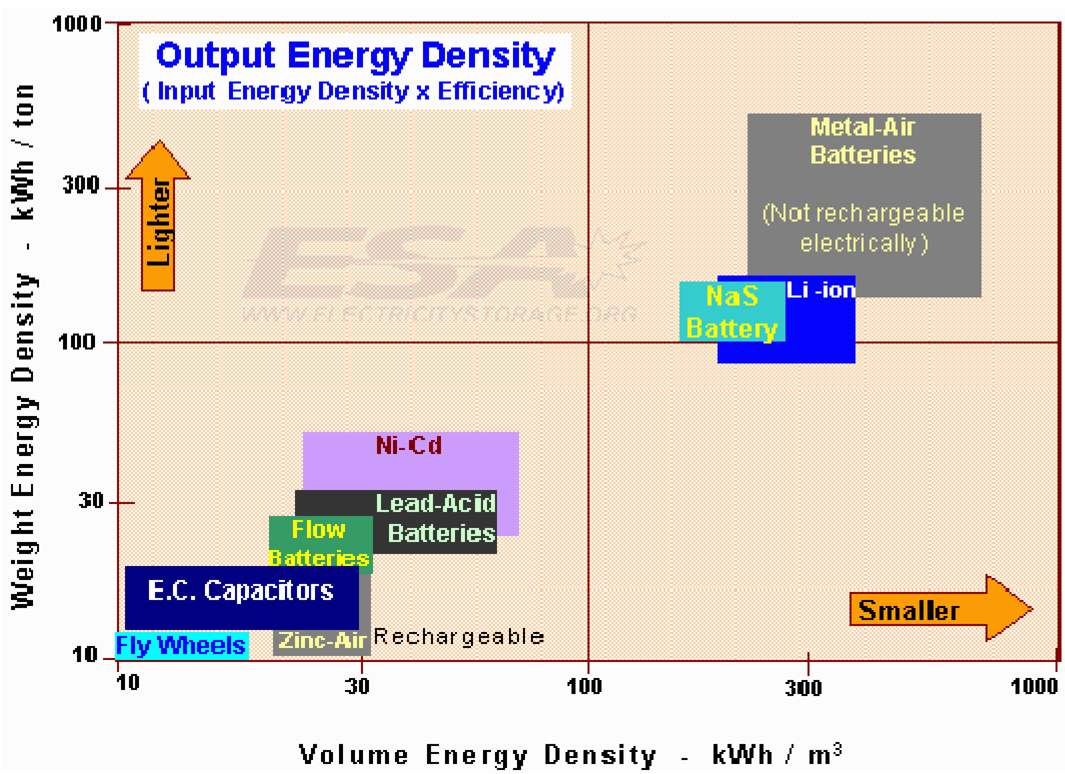
Appendix 4: Performance Comparison of Different Storage Technologies (from Electricity Storage Association)




High Power
E.C. Capacitors
High Power
Fly Wheels
Ni-Cd
Li-ion
Long Duration
Fly Wheels
NaS
Battery
Zinc-Air
Bat.
Rechargeable
Lead-Acid
Batteries
Long Duration
E.C. Capacitors
Flow Batteries
Pumped
Hydro
CAES
Metal-Air
Batteries
Better for Energy
Management
Applications
Better for UPS & Power
Quality Applications
Capital Cost per Unit Energy - $/kWh-output
(Cost / capacity / efficiency)
10,000
1,000
100
10
100
300
1,000
3,000
10,000
Capital Cost per Unit Power - $/kW


E.C. Capacitors
Li-ion
Fly
Wheels
NaS
Flow
Bat.
Pumped
Hydro
Lead-Acid
CAES
CAES efficiency
is for the
storage only
Ni-Cd
Metal-
Air
Efficiency (w/o power electronics)
100%
90%
80%
70%
60%
50%
40%
100
1,000
10,000
100,000
Lifetime at 80% DoD - Cycles


Capital Cost per Cycle (¢/kWh – output)
100
10
1
0.1
Zinc-Air
Lead-Acid
Ni-Cd
Li-ion
NaS
Flow Batteries
Long Duration Fly Wheels
Electrochemical Capacitors
CAES + gas
Pumped Hydro
Possible reduction due to life extention by partial refurbishment
Capital / Energy
Life (cycles) x Efficiency
WWW.ELECTRICITYSTORAGE.ORG
Carrying charges, O&M and replacement costs are not included


Output Energy Density
(Input Energy Density x Efficiency)
Weight Energy Density - kWh / ton
1000
300
100
30
10
Lighter
Metal-Air Batteries
(Not rechargeable electrically)
NaS Battery
Li-ion
Ni-Cd
Lead-Acid Batteries
Flow Batteries
E.C. Capacitors
Fly Wheels
Zinc-Air
Rechargeable
Smaller
WWW.ELECTRICITYSTORAGE.ORG
10
30
100
300
1000
Volume Energy Density - kWh / m^3

APPENDIX 5: Examples of Innovative Applications of Existing Technologies

- Single Pole relaying used on 500Kv Lines
- Series Compensation on long 500Kv lines
- Series Capacitor insertion on 500kv lines
- Static Var Compensators located at 500Kv substations in load areas
- TCSC applied at Slatt 500kv substation on the Buckley 500kv line
- Rapid Adjusting Network Impedance device similar to TCSC, control damping and or phasing
- Transient Excitatin Boost applied on hydro Generation at Grand Coulee
- DC modulation controls at Celilo
- DC ramping controls at Celilo
- Phase shifter applications as applied on 230Kv lines
- Dynamic Braking at Chief Joseph substation for 500kv line outages
- Power Rate Realy applications at John Day, Chief Joseph, Grizzly and Malin substations
- RR-Dot relay application at Malin 500kv substation on California Lines
- ReTermination of lines at critical substations i.e. Hanford
- Wide Area Monitoring (WAMS) System
- WACS
- Remedial Action Scheme controllers consolidation at Dittmer
- Line Loss Logic and application as applied for multiple 500kv lines
- Fast AC Transient Reactive Insertion as applied at Malin
- Mechanically Switched Capacitors (MSC) as applied at Malin 500kv substation
- Hydro Condensing applications as applied at Grand Coulee, John Day and The Dallas
- Selective Load dispatching in the SpringFields area.
- Under Frequency Load Shedding application and momentary Direct Load Tripping of large industrial loads
- NE/SE seperation scheme applied on California Intertie lines
- Phasor measurements as applied for a few 500Kv substations in NW and around west coast utilities
- High Speed Utility Data Exchange from foreign utilities outside the Pacific NW
- Fiber optic applications on high voltage equipment
- High Temperature Conductor applications
- Line designs raised to 100 degree C
- Conductor Sag monitoring
- Conductor strain monitors
- 1100KV line designs and applications
- Conductor bundling on 500kv and 230kv lines
- Double (multi) circuit Steel towers
- Harden tower structures
- Pole replacement technology
- Weather monitoring forecasting for transmission corridors
- High speed Cogenal breaker (1 cycle breakers) applications at Ashe and Coulee 500kv substations
- Breaker and Half bay configuration at critical 500kv substations.
- Smart applicances as being developed in PNNL and manufacturers
- High Voltage cabling in restrictive exposed corridors

Using a mix of these technologies:

- Phasor measurements from western utilities to insert Dynamic Brake to control for gen loss in SW area
- Selective area load dispatching based on system conditions for voltage and frequency.
- Series compensation on critical 230kv lines

- Utilize 230kv sinlge pole relaying on critical infrastructure lines.
- System sectionalizing schemes for advance smart grid applications.
- Bundled 230kv lines Multi-circuit super 230kv towers and line designs
- High temp Line designs raised to 120-150 degree C on critical transmission facilities
- Line volates raised to new KV level i.e. 500kv-525kv, so 230kv to 240kv or to 287kv, 115kv to 120kv or 132kv
- 345kv to 400kv operations
- Advanced bay configuration (dual breakers) to protect for critical breaker failure outages.
- Line reterminations at critical substations
- TEB for advanced gen control during critical seasonal loading
- Advance appliance application relays to trip for frequency deviations with random load restoration times.
- Line monitors on critical lines into load service areas designed to trigger system sectionalizing schemes.

Appendix 6: External Contacts & Who is Doing What Outside of BPA

To assist BPA in making collaborative investment decisions an investigation was done by the Technology Innovation staff with regards to who is doing what outside BPA.
Table A provides a list of external contacts with the organizations name, what they are doing, who is the contact person, what R,D&D projects they are working on and their website address.
Table B provides a list of organizations and the current RD&D projects they are working on and/or their identified RD&D needs.

Table A: External Contacts Outside BPA

Organization	What they are doing	Contact	R,D&D Projects	Website
University of Washington	Advanced Energy Systems and Technologies	Alexander Mamishev	CAREER: Condition based maintenance of electric power systems	http://www.ee.washington.edu/research/projects/proj_power_system_maint.html
		Alexander Mamishev	NSF Research Experiences for Undergrads Program - Identification of incipient faults	http://www.ee.washington.edu/research/projects/proj_nsf_reu_2004.html
		Alexander Mamishev	Robotic Assessment of Incipient Faults in Underground Cable Systems	http://www.ee.washington.edu/research/projects/proj_robotic_assessment.html
		Kai Strunz	CAREER: Real Time Digital Simulation Methodology for Next-Generation Distributed Energy Systems	http://www.ee.washington.edu/research/projects/proj_career_rtdsm.html
		Kai Strunz	Enabling Methods for interactive Co-Simulation of Switched Electric Circuits	http://www.ee.washington.edu/research/projects/proj_electric_circuits_mthd.html
		Mohamed A. El-Sharkawi, Robert J. Marks	Missing Sensor Data Restoration	http://www.ee.washington.edu/research/projects/proj_mised002.html
Washington State University		http://www1.eere.energy.gov/informationcenter/	Distributed Generation	http://www.energy.wsu.edu/projects/distributed/
			Renewable Energy Projects	http://www.energy.wsu.edu/projects/rem/
			Energy Efficiency	http://www.energy.wsu.edu/projects/engineering/
Virginia Tech.		Robert Broadwater: dew@vt.edu	Real time control of distributed generation	http://www.ece.vt.edu/news/ar04/generation.html
		Yilu Liu: yilu@vt.edu	Undergraduates Build Equipment to Monitor Power Grid	http://www.ece.vt.edu/news/fall03/fnet.html
		Alex Huang: chuang@vt.edu	semiconductor power switch	http://www.ece.vt.edu/news/fall03/rd100.html
		Yilu Liu: yilu@vt.edu	Power monitoring system	http://www.ece.vt.edu/news/ar03/monitor.html
		Yilu Liu: yilu@vt.edu	Virtual Hospital for Power Equipment	http://www.ece.vt.edu/news/ar03/hospital.html
Carnegie Mellon Electricity Industry Center		Jay Apt, Granger Morgan, Lester Lave	Markets and Investment	http://wpweb2.tepper.cmu.edu/ceic/research.asp?id=msp
			Distributed Energy Resources	http://wpweb2.tepper.cmu.edu/ceic/research.asp?id=der
			Advanced Generation, Transmission, and Environmental Issues	http://wpweb2.tepper.cmu.edu/ceic/research.asp?id=agtei
			Reliability and security	http://wpweb2.tepper.cmu.edu/ceic/research.asp?id=rs
			Demand Estimation	http://wpweb2.tepper.cmu.edu/ceic/research.asp?id=de
Sandia National Laboratory	Complex Adaptive System (Wide Area Control)			http://www.sandia.gov/mission/energy/index.html
Battelle	National Renewable Energy Laboratory (NREL)		They manage and co-manage 5 national laboratories for DOE	http://www.battelle.com/
PNNL	Electrical Power Systems, GridWise	Jeff Dagle (jeff.dagle@pnl.gov) Rob Pratt (robert.pratt@pnl.gov)	Transactive Technologies-Grid Friendly Appliances	http://gridwise.pnl.gov/technologies/transactive_controls.stm
		Steve Widergren	Simulations for coupled systems	http://gridwise.pnl.gov/technologies/simulations.stm
		Dave Chassin	Modeling and Theory for GridWise	http://gridwise.pnl.gov/technologies/modeling_theory.stm
CERTS-Lawerence Berkely labs	Real Time Grid Reliability Management	Carlos Martinez: 626-685-2015	Reliability Adequacy Tools	http://certs.lbl.gov/certs-rt-rat.html
		Pete Sauer (Sauer@ece.uiuc.edu)	System Security Tools	http://certs.lbl.gov/certs-rt-sst.html
		Carl Imhoff (Carl.Imhoff@pnl.gov)	Advanced Measurements and Control	http://certs.lbl.gov/certs-rt-amc.html
		Steve Widergren (Steve.Widergren@pnl.gov)	Eastern Interconnection Phasor Project	http://certs.lbl.gov/certs-eipp.html

	Distributed Energy Resources Integration	Robert Lasseter (Lasseter@engr.wisc.edu)	The CERTS Migrogrid	http://certs.lbl.gov/certs-der.html
	Reliability Technology Issues and Needs Assessment	Joseph Eto (JHEto@lbl.gov)	The National transmission Grid Study	http://certs.lbl.gov/certs-rtinakey-ntgs.html
		Joseph Eto (JHEto@lbl.gov)	U.S. Department of Energy Power Outage Study Team	http://certs.lbl.gov/certs-rtinakey-outage.html
		Joseph Eto (JHEto@lbl.gov)	Grid of the Future White Papers	http://certs.lbl.gov/certs-rtinakey-gwp.html
EPRI	Equipment ranking. Acoustic Device Monitoring		Energy Portfolio, Overhead Transmission (AIM), Substations, Increased Transmission Capacity, Gid Operations & Planning, ROW Siting	http://bpaweb/sites/EPRI/default.aspx
TVA	Non-silicon materials	Mike Ingram	Measurement & Control	http://www.tva.gov/index.htm
Oakridge National Lab	Superconductivity, Reliability, GridWorks, Infrastructure Security		Superconductors	http://www.ornl.gov/sci/htsc/
		John Stovall (stovalljp@ornl.gov)	Transmission Reliability	http://www.ornl.gov/sci/oetd/trans_systems.htm
		Brendan Kirby (kirbybj@ornl.gov)	Electric Reliability	http://www.ornl.gov/sci/oetd/elec_reliability.htm
			GridWorks	http://www.ornl.gov/sci/oetd/gridworks.htm
Idaho National Lab	* Had trouble finding info on their site			http://www.inl.gov/
Northwest Energy Efficiency Alliance	Energy Efficiency Information and products	1-800-411-0834	EnergyStar	http://www.nwalliance.org/
Florida State University	Center for Advanced Power Systems	(850) 644-1035	SMES, superconducting devices	http://www.caps.fsu.edu/
ELECTRIC TRANSMISSION AND DISTRIBUTION FUTURE R&D NEEDS February 1 st – 2 nd , 2006 Workshop	Organized by the Florida State University (FSU) Center for Advanced Power Systems (CAPS), with the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability (OE)			http://www.caps.fsu.edu/EPAct05_doe_workshop.asp
APT	Advanced Power Technologies	Alexander Mamishev (mamishev@ee.washington.edu)	Substation Automation and Monitoring	http://www.ee.washington.edu/energy/apt/
		Chen-Ching Liu, Ting Chan	Implementation of Reliability Centered Maintenance for Power System Equipment	http://www.ee.washington.edu/energy/apt/2002aptproject3.html
		Dr. Kai Strunz	FACTS	http://www.ee.washington.edu/energy/apt/2003aptproject2.htm
		Alex Mamishev	Predictive maintenance of power networks	http://www.ee.washington.edu/energy/apt/2003aptproject4.htm
National Renewable Energy Lab	Integration of distributed energy and advanced distribution technologies	Ben Kroposki (benjamin_kroposki@nrel.gov)	Key Activities	http://www.nrel.gov/eis/activities.html
			Interconnection Standards and Codes	http://www.nrel.gov/eis/standards_codes.html
			Interconnection and Control Technology	http://www.nrel.gov/eis/techology_development.html
Cigre	Design Standards for Communication Infrastructure for new Installations		Collaboration with EPRI	http://www.epri.com/newsletter.asp?issueid=223603&marketnid=249634#ARTICLE8
			Committee	http://www.cigre-usnc.org/committees.htm
DOE		Phil Overholt, Bill Parks		

Table B: Who is Doing What Outside BPA

Organization Technologies Note: Data was compiled using information for the **Electric Transmission and Distribution Future R&D Needs conference organized by FSU (Feb. 1-2, 2006), and the Transmission Research Program presentation given by PIER (March 7, 2006).**

	Real-Time wide area control & measurement	Measurement & Control Technologies	Energy Storage	Advanced Conductors	Transmission Line Configuration	Distributed Generation	Controllable Load	HTSC	People/Training	Modular Substation Equipment
Southern Company	X	X	X	X						
Sandia National Labs	X ~	X	X	X						
Jacksonville Electric Authority	X	X	X	X		X				
TRS Energy	X	X	X	X		X	X	X		
CA PIER	X	X			X	X	X			
Oakridge National Laboratory - Battelle	X ~	X		X ~	X	X		X		X
GE Energy	X	X								
NERC	X	X							X	
Midwest ISO	X	X		X						
University of Texas	X	X								
CERTS	X ~	X ~	X	X		X				
AEP	X	X ~	X	~						
American Superconductor	X	X ~						X ~		
PJM	X						X			
Carnegie Mellon	X			X		~	~			
PNNL	X ~						X ~			
CEATI		~								
Consultant - Narain Hingorani		X	X	X		X				
TVA		X ~	X	X	X			X		
Silicon Power Corporation		X ~								
ITC				X						
Shawano Municipal Utilities							X			
TCS- University of Houston								X		
Center for Advanced Power Systems								X		
CCAS				X						
Southwire				X				X		
U of W	~	~								
WSU						~	~			
Virginia Tech	~	~				~				
FSU								~		
APT	~	~								
EPRI	~	~			~		~		~	

KEY	
Identified R&D Needs	X
Current RD&D Project	~

Minor revisions made 2/28/07