BC Transmission
CORPORATION
Building Connections

Transmission Technology Roadmap

Pathways to BC's Future Grid




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Research and Development Program Office
System Planning and Asset Management Division

ABOUT THE COVER

BCTC's new System Control Centre. This state-of-the-art control centre is BCTC's showpiece of **Smart Grid** technologies, one of four categories of technical focus in the Transmission Technology Roadmap. The control centre will be the platform for expanding BCTC's initiatives in **Synchrophasor-enabled wide area control and security assessment** (Section 6.3.1)	FinGrid urban landscape transmission tower at Jyvaskyla Viherlandia, designed with community input. Using environmentally friendly materials, these structures reduce visual impacts and gain high public acceptance. An example of aesthetic tower design envisioned in Roadmap Category **Conservation, Efficiency and Environmental Leadership,** technical focus area **Environmental and public impacts of transmission** (Section 6.2.2). (Source: www.fingrid.fi)
Vestas V90 3.0MW wind turbine, 48 of which will be installed on the 144MW Dokie I wind-power project in northeast BC, for initial service in 2008. This represents Roadmap category **Energy Security** under which **Integration of Renewable Energy Resources** (Section 6.1.7) is a key technical focus area. (Photo courtesy of Vestas Wind Systems A/S)	Vancouver Island Reinforcement Project 230kV 6000 foot crossing of Montague Harbour, Gulf Islands. This the first application in Canada of 3M's light-weight, high-capacity ACCR composite conductor, allowing higher currents than conventional steel core conductors and utilizing lighter towers. This is an example of BCTC's **Future Grid** roadmap, focus area **Advanced Asset Materials** (Section 6.4.4).

Executive Summary

In response to the BC Energy Plan and other business drivers, British Columbia Transmission Corporation (BCTC) presents the first edition of its Transmission Technology Roadmap. The effective application of power technology is at the core of BCTC's business. The goal of the Roadmap and associated initiatives is to create business value through the research, demonstration and implementation of technology innovations that enhance the reliability, efficiency and public acceptance of electricity transmission in BC. The Roadmap builds on BCTC's heritage of success in transmission by providing strategic guidance on power system technology development over a 20 year time horizon. The Roadmap describes current business challenges that may be addressed through deployment of new technology. The overall vision and goals of BCTC's technology development are presented in the context of government policy direction, BCTC's Corporate Strategic Plan, and analysis of business challenges. A total of 19 technology focus areas are described under four broad themes: Energy Security; Conservation, Efficiency and Environmental Leadership; Smart Grid; and Future Grid. A number of short term, medium term and long term initiatives are proposed under each focus area, as direction for BCTC's Research and Development, Capital and Operational Programs. Several recommendations are provided for implementing Roadmap directions. The Roadmap is a proposed development plan for advancing new transmission technologies, and BCTC's commitment to this path will depend on fiscal constraints, organizational capacity, and regulatory approvals.

Acknowledgement

Many of the ideas and directions contained in BCTC's Transmission Technology Roadmap sprang from very open and fruitful discussions with employees, other utilities, manufacturers, and research partners throughout the world. For this collaborative sharing of the future vision of transmission, the authors are extremely grateful.

Comments?

One of the key purposes of the Transmission Technology Roadmap is to facilitate internal and external communication of BCTC's technology future. We welcome all comments, and will consider these carefully in preparation of action plans and future editions of the Roadmap. Comments may be directed to:

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1. Introduction
Building on BCTC's Heritage of Technology Innovation

"We all need to think and act differently as we develop innovative and sustainable solutions to a clean and reliable energy supply for all British Columbians."

Premier Gordon Campbell
The BC Energy Plan –
A Vision for Clean Energy Leadership
February 2007

In 2007, the British Columbia government released *The BC Energy Plan: A Vision for Clean Energy Leadership* [1]. The Energy Plan describes the government's vision for BC's clean energy future, and emphasizes the continued use of innovation and technology in transmission:

> "As the manager of a complex and high-value transmission grid, BC Transmission Corporation is introducing technology innovations that provide improvements to the performance of the system and allow for a greater utilisation of existing assets, ensuring that BC continues to benefit from one of the most advanced energy networks in the world. BCTC's innovation program focuses on increasing the power transfer capability of existing assets and improving system reliability and security."

The Energy Plan sets out the following specific direction to BCTC:

> "Policy Action #12: BC Transmission Corporation is to ensure that British Columbia's transmission technology and infrastructure remains at the leading edge and has the capacity to deliver power efficiently and reliably to meet growing demand."

The government has also provided policy direction to the BC Utilities Commission through the Utilities Commission Act Amendment (Bill 15) to "encourage public utilities to use innovative energy technologies".

The Transmission Technology Roadmap responds to these policy directions and builds on BCTC's heritage of success in transmission by providing strategic guidance on power system technology development over a 20 year time horizon, to further enhance the reliability, efficiency and public acceptance of transmission in British Columbia.

Section 2 of this document describes the historic and current use of power technology in the BC transmission system.

Section 3 outlines the scope and purpose of the Transmission Technology Roadmap, as well as the process followed to develop the document.

Section 4, Situation Analysis, sets the context for the Roadmap development, identifying current technology-related business challenges, needs and gaps that will be addressed in the Roadmap.

Section 5 presents the overall vision and goals of transmission technology development, in the context of government policy direction, BCTC's Corporate Strategic Plan, and the Situation Analysis.

Section 6 presents the Roadmap initiatives and timelines in four broad themes, each consisting of several technical focus areas. The themes are: Energy Security; Conservation, Efficiency and Environmental Leadership; Smart Grid; and Future Grid.

Section 7 presents the Implementation Plan, addressing such matters as program delivery, innovation process, funding, governance, knowledge management, and processes for implementing R&D results in the business, to ensure effective execution of the Transmission Technology Roadmap within BCTC and with the support of external stakeholders.

The Roadmap represents a proposed development plan, recognizing the current state and opportunities for advancing technology innovation in the transmission system. BCTC's commitment to this path will depend on fiscal constraints, organizational capacity and regulatory approvals.

2. Historic and Current Use of Technology in the BC Transmission System

BC Transmission Corporation (BCTC) and its predecessor organization BC Hydro have used advanced technology over the decades to meet numerous challenges in the development, growth and optimization of the electricity system in British Columbia. In the 1960's through the 1980's, the issue was to efficiently deliver large amounts of power from the Peace and Columbia River systems to the lower mainland. BC Hydro's transmission system pioneered the use of long distance Extra High Voltage (EHV) for this purpose. Several key technologies were introduced, including braking resistors, series capacitors, high speed static excitation systems equipped with power system stabilizers, and microwave-assisted high speed line protection to enhance the stability and transfer capability of the system. Electricity ratepayers continue to see the benefits of those investments.

Through the 1990's and 2000's, electricity systems in North America and world-wide were restructured to introduce competition and wholesale markets. This has had dramatic implications for transmission system usage. Transmission systems must now accommodate electricity trade, an activity never contemplated in the original design of many networks. Market-driven volatility of power flows has added complexity to system operations and has significantly increased utilization factors. BCTC has accommodated the needs of customers by implementing transmission scheduling systems and increased path transfers through use of dynamic security assessment (DSA) tools and automated remedial action schemes (RAS). Remedial action schemes are pre-planned responses to simulated emergencies in the system to isolate the impact of disturbances and prevent blackouts. BCTC's RAS schemes have allowed efficient use of the existing system and avoided the need for new lines to accommodate trade. Other innovations introduced to the power system include static var compensation, high voltage direct current (HVDC), switched capacitors and reactors, phase shifting transformers for control of loop flow, single pole tripping / reclosing and point-on-wave switching.

Today's technology applications are driven by the need for increased investments to sustain and replace aging assets, to accommodate increased load growth, and interconnection of new generation resources throughout the province. BCTC's current ten year Capital Plan [2] includes $5.1 billion of spending on new assets. Noteworthy projects include the Control Centre Modernization Project, Circuit Breaker Replacement Program, Vancouver Island Reinforcement, and Interior to Lower Mainland 500kV Reinforcement. A number of "smart grid" projects are being implemented including the use of real-time synchrophasors for increased visibility of operating margins, and uprating of the Vancouver Island 500kV supply circuits through use of fibre optic temperature monitoring and dynamic rating technology. A detailed description of current BCTC projects may be found in the publication "Continuing Innovation on BC's Grid: Highlights of BCTC's Technology Initiatives" [3]. Technology innovation at BCTC is supported by an active research and development program.

BCTC's technology strategy is to use proven, economic technologies to grow and sustain the assets, serve customers, and improve compliance, efficiency and reliability, as well as mitigate system risks and provide decision-making support. The purpose of the research and development program is to develop and demonstrate new technologies in order to remove technology risk factors prior to application in mainstream operational and capital programs.

3. Roadmap Scope and Purpose

The scope of the Transmission Technology Roadmap is the transmission system high voltage apparatus, associated control, protection and monitoring systems, rights-of-way, control centre technologies, and processes related to the planning, asset management, operation and construction of the transmission system. BCTC has management responsibility for 75,000 hectares of land, 18,300 kilometres of transmission lines, 22,000 steel towers, 100,000 wood poles, 292 substations and two new state-of-the-art control centres.

The Roadmap does not address information technology issues which are covered in strategies and plans issued by BCTC's Chief Information Office. To distinguish the scope of this Roadmap from information technology, the terms "power technology" and "transmission technology" are used throughout this document.

The purposes of the Transmission Technology Roadmap are to:

1. Identify current challenges facing BCTC that impact the future direction of power technology development and application.
2. Identify specific business objectives that will be met or supported in the development and application of power technologies at BCTC.
3. Define an overall vision for the application of power technologies at BCTC.
4. Propose a set of initiatives that will guide the development and application of power technologies at BCTC over a 20 year horizon, aligned to specific technical focus areas. This will assist BCTC in making technology planning and investment decisions.
5. Recommend strategies and processes to support successful implementation of the Roadmap. The Roadmap addresses not only where we are going with technology, but how we will work together both inside and outside the company to achieve the business objectives.
6. Act as a communication document to facilitate internal and external communication on BCTC's power technology objectives and needs, including solicitation of project proposals and updating of the Roadmap as necessary.

The Transmission Technology Roadmap was developed over the past year and involved a number of cross-BCTC employee consultations and review of industry directions with utilities, manufacturers, collaborative research organizations, and technical associations. It is acknowledged that this Roadmap is only a beginning. Business requirements and the landscape of emerging technologies are changing rapidly in today's utility sector, necessitating regular review of priorities and adjustment of Roadmap goals and initiatives. BCTC welcomes all comments on Roadmap content and direction.

4. Situation Analysis

BCTC plans, operates and maintains a complex technology infrastructure, valued at $11 billion replacement cost. In managing this high value enterprise to ensure reliable and efficient electricity supply, the company faces numerous technology-related business challenges which include:

- Increasing complexity of the transmission system and its planning, driven by:
  - uncertainties in market development
  - size and location of generator and load interconnections
  - new mandatory reliability standards required by NERC and BC legislation
  - Energy Plan requirements for uncongested transmission paths to meet electricity energy self-sufficiency by 2016
  - Legislative requirements to conduct 20 year transmission planning scenario studies for long-term build out of the transmission system
  - Regional activities to reduce intertie congestion and integrate more renewables into the WECC system
  - Increasing customer expectations for high reliability and "digital quality" power
  - Changing architecture of distribution systems supplied by the transmission system.
- Need for significant capital investment in coming years, driven by load and system growth and replacement of aging infrastructure (see references 2 and 4).
- A strong desire to control rate increases in the face of expected large increases in growth and sustainment capital expenditures.
- Global demand for raw materials, manufacturing and construction resources which is driving up construction costs and increasing lead times. These effects will drive innovation in seeking alternative solutions with lower lifecycle costs.
- Proliferation of new renewable energy resources providing planning and operational challenges associated with integrating large amounts of intermittent energy to the transmission system.
- Significant public constraints on operation of existing assets and opposition to construction of new transmission and substation assets, based on EMF, aesthetic and cost concerns.
- Energy Plan environmental requirements to achieve crown agency carbon neutrality by 2010, meet 50% of incremental electricity through conservation by 2020, 33% carbon reduction by 2020, and 80% carbon reduction by 2050.
- New environmental regulations such as Species at Risk, environmental risks including wildfires and pine beetle infestation, and increasing awareness and need to adopt sustainability practices throughout BCTC's operations.
- Climate disruption and severe weather events affecting the transmission system.
- Other natural and human hazard risks (physical and cyber), including increased vandalism and security threats.
- "Disruptive" technology changes – plug-in hybrid electric vehicles, Smart Grid, high bandwidth wireless technologies.
- The need to develop the "next generation" technical workforce to replace retiring employees, requiring effective knowledge management systems to retain and gain critical institutional knowledge.

5. Roadmap Strategic Positioning, Goal and Objectives

This section describes the overall goal of the Transmission Technology Roadmap and the technology-related business objectives supported by the Roadmap, in the context of the BC Government's policy direction, BCTC's Corporate Strategic Plan, and the Situation Analysis.

The Roadmap supports the Government's Policy Direction as set out in *The 2007 Energy Plan – Vision for Clean Energy Leadership*, as well as BCTC's Corporate Strategic Plan [5]. Energy Plan Policy Action #12 states "BC Transmission Corporation is to ensure that British Columbia's transmission technology and infrastructure remains at the leading edge and has the capacity to deliver power efficiently and reliably to meet growing demand". The Energy Plan provides specific recommendations under themes of energy security, environmental leadership, conservation and efficiency, and innovation. Strategic positioning of the Energy Plan, BCTC's vision, corporate strategy and the Transmission Technology Roadmap is illustrated in Figure 1.

The overall goal of the Transmission Technology Roadmap is to

> "Create business value through the research, demonstration and implementation of technology innovations that enhance the reliability, efficiency and public acceptance of electricity transmission in BC."

The Roadmap is intended to guide BCTC's priorities and investment in power technology to meet the following business objectives:

1. Develop the transmission system to maximize transfer capability, reduce losses and enable electricity security and self-sufficiency;

2. Plan and construct transmission system expansions more quickly and with improved lifecycle performance and cost;

3. Manage existing assets and rights-of-way to achieve reliability objectives and minimize long-term maintenance and sustainment costs;

4. Reduce impacts of physical and operational risks (natural and human);

5. Collect and communicate high value operational and asset condition information, and provide related analysis tools, to support effective decision making by system operators, asset managers and planners; and

6. Address emerging sustainability concerns and ensure public acceptance of BCTC's operations and long-term capital and asset management plans.

The Roadmap goals and objectives are illustrated in Figure 2, along with a summary of the Situation Analysis presented in Section 4, initiatives to support achievement of the objectives, and key short term, mid term and long term milestones. The initiatives and milestones are described in more detail in Section 6.

Shareholder Direction: 2007 Provincial Energy Plan

"The BC Transmission Corporation is to ensure that British Columbia's transmission technology and infrastructure remains at the leading edge and has the capacity to deliver power efficiently and reliably to meet growing demand."

Theme: Energy Security

Theme: Environmental Leadership

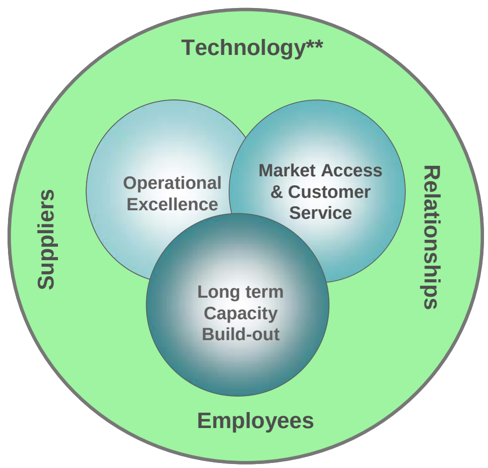
Theme: Conservation and Efficiency

Theme: Innovation

BCTC's Vision:

"To be globally recognized for our innovative and sustainable management of the electric transmission system for the benefit of British Columbians"

BCTC Corporate Strategy



**** Identify and adopt innovative technologies for business information, asset management and system operations**

Transmission Technology Roadmap

Figure 1. Strategic Positioning

TRANSMISSION TECHNOLOGY ROADMAP

SITUATION ANALYSIS

- Replacement of aging infrastructure
- Significant system growth and reinforcement
- Integration of renewable energy resources
- Control rate increases
- Construction challenges
- System complexity: resource size & location; mandatory reliability standards; uncongested transmission; long term planning; regional initiatives
- Customer reliability expectations
- Public acceptance
- Environmental awareness and regulations
- Energy efficiency and conservation
- Greenhouse Gas (GHG) reduction
- Climate change / extreme weather events
- Natural and human hazards
- "Disruptive" technologies
- Aging Workforce / Knowledge Management

GOAL

Create business value through the research, demonstration and implementation of technology innovations that enhance the reliability, efficiency and public acceptance of electricity transmission in BC

OBJECTIVES

- Develop the transmission system to maximize transfer capability, reduce losses and enable electricity security and self-sufficiency
- Plan and construct transmission system expansions more quickly, at lower cost, and with improved lifecycle performance & cost
- Manage existing assets & rights-of-way to achieve reliability objectives and minimize long-term maintenance and sustainment costs
- Reduce Impacts of physical and operational risks (natural and human)
- Collect and communicate high value operational and asset condition information, and provide related analysis tools to support effective decision making by system operators, asset managers and planners
- Address emerging sustainability concerns and ensure public acceptance of BCTC's operations and long-term capital and asset management plans

INITIATIVES – TECHNICAL FOCUS AREAS

ENERGY SECURITY
- High Voltage Cable Technology (Existing and Future)
- System Congestion Reduction
- Risk Assessment and Valuation Framework for Natural and Human Hazards
- Weather and Climate Modeling and Response
- Energy Storage
- Physical and Cyber Security
- Integration of Renewable Energy Resources

CONSERVATION, EFFICIENCY & ENVIRONMENTAL LEADERSHIP
- System Loss Reduction
- Environmental & Public Impacts of Transmission
- Greenhouse Gas Reduction

SMART GRID
- Synchrophasor-enabled Wide Area Control and Security Assessment
- Dynamic Rating of Assets
- Smart Equipment Monitoring and Remote Sensing
- Integrated Information Flow, Simulation and Analysis

FUTURE GRID
- Next Generation Lines and Stations
- Next Generation Control Centre Technologies
- Power Electronics
- Advanced Asset Materials
- Field Work Methods and Robotics

KEY MILESTONES

SHORT TERM (0 - 5 YEARS)

HV cable condition assessment
Dynamic thermal circuit rating - demo projects
Climate & weather modeling
Loss reduction initiatives
Smart Grid synchrophasor platform
Advanced materials demonstration
Robotics demonstrations

MID TERM (5 - 10 YEARS)

Apply XLPE HV cables
Real-time ATC & TTC - all paths
Climate change/weather remediation activities
Aesthetic towers
Robotic work practices - transmission
Synchrophasor-based advanced applications
Equipment embedded smart sensors
"Digital" substation
Advanced materials - field installation

LONG TERM (10 – 20 YEARS)

High temperature superconducting cables
Energy storage (PHEV's, HTS, flywheels)
Ocean energy grid integration
Robotic work practices - substations
Synchrophasor-based wide area control
Automated remote sensing
Integrated enterprise information exchange
SF6 free power switchgear
FACTS devices

Figure 2. Roadmap Summary

6. Roadmap Initiatives

This section presents the Roadmap initiatives in four broad categories, each comprising several technical focus areas:

- Energy Security
- Conservation, Efficiency and Environmental Leadership
- Smart Grid
- Future Grid

The categories are generally aligned with themes of the 2007 Energy Plan described in Section 5.

For each technical focus area, the following information is presented:

- Background (definition, issues, challenges)
- Purpose to be achieved by technology developments in the focus area
- Actions and milestones over a 20 year time horizon, comprising the short term (0 - 5 years), medium term (5 - 10 years) and long term (10 - 20 years)

Actions include activities such as "technology watch", demonstration projects, investigation of technologies to resolve specific BCTC business issues, working with manufacturers to ensure BCTC needs are incorporated into product development, and implementing technologies through capital and operational programs. Roadmap technical focus areas are listed below and are described in detail later in this section.

6.1 Energy Security

6.1.1 High voltage cable technology (existing and future)
6.1.2 System congestion reduction
6.1.3 Risk assessment and valuation framework for natural and human hazards
6.1.4 Weather and climate modeling and response
6.1.5 Energy storage
6.1.6 Physical and cyber security
6.1.7 Integration of renewable energy resources

6.2 Conservation, Efficiency and Environmental Leadership

6.2.1 System loss reduction
6.2.2 Environmental and public impacts of transmission
6.2.3 Greenhouse gas reduction

6.3 Smart Grid

6.3.1 Synchrophasor-enabled wide area control and security assessment
6.3.2 Dynamic rating of assets
6.3.3 Smart equipment monitoring and remote sensing
6.3.4 Integrated information flow, simulation and analysis

6.4 Future Grid

6.4.1 Next generation lines and stations
6.4.2 Next generation control centre technologies
6.4.3 Power electronics
6.4.4 Advanced asset materials (composites, superconductors, nano-materials)
6.4.5 Field work methods and robotics

6.1 Energy Security

A key objective of the BC Energy Plan is *energy security*, involving actions to ensure that the energy needs of British Columbians continue to be met now and into the future. This includes provision of a reliable, secure and non-congested transmission system that is available to support the province's goal of electricity self-sufficiency by the year 2016. The province has also mandated that renewable electricity generation continues to account for at least 90 percent of the province's total generation. Over 8000MW of wind potential has been identified in BC, with the first wind integration projects expected to be in service in late 2008.

The technologies described in this section are critical for maintaining an efficient and reliable transmission delivery system in BC, to ensure adequacy of supply to all customers. They include high voltage cable technologies that are important for continued secure supply to large urban areas and Vancouver Island, technologies for ensuring that the transmission system is un-congested thus improving economic efficiency, ensuring that the system is secure from natural and human hazards including physical and cyber security risks, forecasting and protecting the system against extreme weather events and future climate change impacts, and developing technologies for efficient integration of large amounts of renewable energy, including enabling technologies such as energy storage.

The following technical focus areas comprise the major elements of BCTC's *Energy Security* roadmap:

- 6.1.1 High voltage cable technology
- 6.1.2 System congestion reduction
- 6.1.3 Risk assessment and valuation framework for natural and human hazards
- 6.1.4 Weather and climate modeling and response
- 6.1.5 Energy storage
- 6.1.6 Physical and cyber security
- 6.1.7 Integration of renewable energy resources

6.1.1 High Voltage Cable Technology

BACKGROUND: BCTC relies on a large network of subterranean and submarine 550kV, 230kV and 69kV fluid-filled cables for supply to Vancouver Island and urban areas of Vancouver and Victoria. There is a critical need to maintain high levels of reliability on these cable circuits and to reduce lifecycle costs. Recent explosive stop joint failures in self-contained fluid filled (SCFF) cables have raised reliability and safety concerns, pointing to a need for improved asset condition monitoring. Other issues include seismic withstand, environmental impacts of fluid releases, and shielding to reduce electromagnetic fields. Real-time monitoring of cable operating temperature and loading provides an opportunity to operate cable circuits closer to design ratings, thus increasing capacity by up to 20% at modest cost. For future cable installations, BCTC will evaluate use of new cable materials for improved operating performance, such as cross-linked polyethylene (XLPE), high temperature superconductors (HTS), and nanomaterials. Given the serious impacts of cable failures (long outage duration, expensive repairs), research is required to gain high confidence with the new cable materials before applying them in critical areas of the transmission system and to ensure effective commissioning and post-installation testing.

PURPOSE:

(1) Gain a thorough understanding of the condition of existing self-contained fluid filled (SCFF) and high pressure fluid filled (pipe type) cable systems installed in the high voltage transmission system, including: methods for predicting failures and end-of-life; improved equipment specifications and work methods for replacement equipment; real-time monitoring of equipment condition; and dynamic thermal capacity rating.

(2) Select the "next generations" of cable material for expansion and sustainment cable installations (e.g. XLPE, HTS) that will provide improved lifecycle performance, lower costs and high reliability. Develop effective specifications and test methods for identifying defects and aging.

ACTIONS:

Establish and actively support SCFF user's group of world-wide users and manufacturers to share operating experience and maintenance practices, e.g. inspection frequency, emergency response readiness, etc.		
Continue with demonstration projects to develop expertise in analysis of partial discharge methods for detecting incipient failures in SCFF cables	Permanent installation of partial discharge monitors for detecting incipient failures in SCFF cables	
Establish & support Centre of Excellence at Powertech Labs (or other) for analysis and diagnosis of material failures in SCFF cables		
	Support research in other advanced methods for detecting incipient SCFF & pipe type failures (e.g. tomography, dielectric spectroscopy) – EPRI, CEATI, universities	
Continue EPRI, CEATI & other collaborative programs to investigate XLPE experience, monitoring systems, etc.		
Detailed investigation of world-wide experience with application of HV XLPE cable – utility/manufacturer visits		
Carry out accelerated aging / environmental tests on a test section of HV XLPE cable	Install XLPE cable systems	
Continue with risk assessments, fragility studies & mitigation research for natural hazards (e.g. seismic)	Implementation of risk mitigation measures	
Technology watch on high temperature superconductor (HTS) cable technology and nanotechnology, and their future applications		
Feasibility / costing study for HTS application in downtown Vancouver	Plan HTS pilot installation	First HTS pilot installation
	Evaluation of advanced HV cable materials (e.g. nano dielectrics, carbon nano-tubes)	
Investigate low cost measures to reduce EMF levels in new U/G designs		

0 years | **5 years** | **10 years** | **20 years**

6.1.2 System Congestion Reduction

BACKGROUND: Internal transmission paths and inter-tie paths with the US and Alberta are congested when the amount of transfer capacity requested by customers exceeds the existing capacity of the circuit, due to thermal limits, voltage and stability restrictions, or contingency limits established to assure secure operation in the event of an unexpected network failure. Congested transmission paths generally lead to economic inefficiencies as higher cost generation must be used to supply loads at the receiving end of the congested path. Management of congestion is made complex by the increasing levels of third party transactions on the transmission system, uncertainties in the siting of new generation resources, integration of intermittent resources, increasing load demands, uncertainties in demand side management (DSM) timing and penetration levels, and the recognition that many portions of the transmission system constructed prior to the 1980's are reaching capacity limits.

PURPOSE:

(1) Develop short term and long term congestion forecasting methodologies based on committed and future transmission usage, resource locations, etc.
(2) Develop real-time situation awareness and operational tools for assessing congestion and relieving thermal, voltage and stability constraints, with the goal of calculating Total Transfer Capacity (TTC) and Available Transfer Capability (ATC) in real-time.
(3) Develop hardware solutions for relieving congestion, including dispatchable standby generation (DSG), line upgrades, reactive compensation and Flexible Alternating Current Transmission System (FACTS) devices.
(4) Develop alternative "non-wires" solutions, including distributed generation, energy storage, demand side management including demand response programs.

ACTIONS:

0 – 5 years	5 – 10 years	10 – 20 years
Refine congestion forecasting methodologies (planning, operations)		
Refine existing probabilistic transmission planning methodologies to include evaluation of uncertainties in location & size of generation resources & loads		
Participate in industry efforts (NERC, WECC) to standardize definitions & calculation methods for TTC & ATC		
Real-time calculation of TTC & ATC on internal & intertie paths, using dynamic security assessment tools, synchrophasors, improved state estimation, and advanced computational approaches Development (0 – 5 years)	Pilot Projects (5 – 10 years)	Implementation (10 – 20 years)
Develop "technology & best practices" guides for identifying & costing options for increasing power transfers on existing rights of way (substation equipment, conductors / structures, conversion to higher ac voltages and DC, control changes) Development (0 – 5 years)	Implementation (5 – 20 years)	
Dynamic thermal circuit rating demonstration projects	Dynamic thermal circuit rating implementation projects	
Continue initiatives to improve accuracy of primary voltage & current measurements to allow operation closer to design limits (e.g. VT/CT recalibration program)		
Develop "non-wires" solutions (options, costs, pilot projects)	Implement "non-wires" solutions	
Research, pilot and implement demand response programs, with particular emphasis on demand response as a resource for transmission system planning		
Review PG&E 40MW DSG program & evaluate opportunities for congestion relief in BCTC		

0 years **5 years** **10 years** **20 years**

6.1.3 Risk Assessment and Valuation Framework for Natural and Human Hazards

BACKGROUND: Asset risk analysis involves quantification of the probability of occurrence of a potential hazard, the resulting impact (loss of reliability, financial loss, environmental impact, etc.), and establishing risk tolerance levels. A comprehensive risk assessment methodology aids decision-makers to compare and evaluate various risks and to set priorities on mitigation measures to reduce risks to tolerable levels. In addition to aging and wear effects, transmission assets face two types of external hazards, natural and human. Natural hazards include events such as wind storms, icing, earthquakes, land slides, avalanches, wildfires and floods. Human hazards include cyber and physical intrusion to facilities, theft and vandalism. Many of BCTC's assets were designed without considering the full spectrum of natural and human risks and tolerance levels that are faced today and into the future. Given the different classes of assets and diverse range of risks, consistency of risk assessment is difficult. Another challenge is public and regulatory acceptance of the risks and cost trade-offs involved, since it is impossible to mitigate all risks. Emerging NERC reliability standards will require increased emphasis on risk mitigation and emergency response.

PURPOSE:

(1) Develop a framework for assessing natural and human asset risks consistent with the principles of BCTC's corporate Enterprise Risk Management framework, with special attention to low probability, high impact events.
(2) Establish a common basis for prioritizing spending to reduce identified risks to tolerable levels, across all asset classes.
(3) Develop supporting data management systems and probabilistic analysis techniques to support the identification, quantification and mitigation of asset risks from natural and human hazards.

ACTIONS:

Form BCTC work group on Hazard Risk Assessment	
Assess state-of-the-art in Hazard Risk Assessment (CEATI, CIGRE, CSA, IEC, ASCE, ITOMS, other utilities)	
Develop framework for Hazard Risk Assessment	Implementation – risk assessments, tolerance levels, mitigation plans, projects
Develop supporting data management and analysis techniques (using existing asset mgt & system planning probabilistic techniques	
Contribute to industry knowledge & standards in Hazard Risk Assessment & Mitigation (CEATI, CIGRE, IEEE 693, IEC, CSA, ASCE)	
Technology Watch, development & demonstration of hazard detection & mitigation technologies	
Demonstrate UBC Joint Infrastructure Interdependencies research for emergency response	

0 years **5 years** **10 years** **20 years**

6.1.4 Weather and Climate Modeling and Response

BACKGROUND: Weather has a significant impact on the planning, design, asset management and operation of the transmission system, especially given BC's large geographic area with challenging terrain and climatic conditions. Currently, BCTC lacks accurate weather monitoring and forecasting capability. There is a need to develop more accurate weather models to extrapolate available measurements and forecasts to understand specific locational impacts on BCTC's assets (wind, icing, precipitation, lightning). As well, weather statistics, near-term forecasts and models need to be integrated into the planning and design of new facilities, the asset management of existing facilities, and real-time operation of the power system (including emergency response). Looking to the future, the Intergovernmental Panel on Climate Change (IPCC) has stated that the scientific evidence for climate change is unequivocal. BCTC needs to understand the direct impacts of climate change on its high voltage network, and take steps to adjust its planning, design, asset management and operating practices to mitigate potential risks. Changing meteorological conditions, in particular increased frequency of extreme weather events, may significantly increase failures, recovery time and overall reliability of the transmission system. Other adverse impacts on asset management and operation include accelerated corrosion of steel components, more rapid wood decay, wildfire hazards, mud slides, avalanches, flooding, reduced opportunity for live line maintenance, delays in recovery operations, and reduced transmission transfer capability. The potential serious impacts of climate change require new methods to predict failure and deterioration of existing assets and new design standards for the remediation of existing assets and construction of new lines. This focus area involves modeling of climate change impacts in BCTC's service territory, identification and prioritization of risks, and development of long term action plans to mitigate risks to the transmission system. This is a key component of BCTC's Climate Change Response Program (CCRP) - see Section 6.2.3.

PURPOSE:

(1) Improve BCTC's capability to forecast and act upon short-term weather events that affect planning, design, asset management and operation of the power system.

(2) Understand the potential impacts of climate change on the transmission system to ensure adequate long-term plans are in place for mitigation, adaptation and response.

ACTIONS:

Continue development of thematic maps (overlay of weather statistics & other risk factors on transmission circuits)		Remediation to address vulnerabilities identified by thematic maps
Assess current weather forecast services & models to meet BCTC needs (Environment Canada, UBC, BC Hydro)	Install BCTC weather stations in critical locations (mountain passes, fire hazard monitoring for vegetation operations, etc.)	Research / demonstrate / implement advanced weather stations for transmission applications (including telecommunications)
Enhance Environment Canada probabilistic weather forecast techniques for BCTC purposes		
Incorporate Environment Canada and/or UBC weather forecasts into control centre operations (load forecast, storm pre-positioning)		
Continue UBC research on prediction of tree failures based on weather modeling	Implementation	
Continue FERIC and other research on wildfire impacts on rights of way including prevention and mitigation		
Continue research on prediction of ice/wind loads in mountain passes (CEATI / Statnett)		Implementation
Work with Environment Canada, UBC, UVIC, Pacific Climate Consortium to develop climate change models focused on BCTC facilities		Implement necessary changes to BCTC practices, standards, facilities
Collaborative research activities with PSERC, CEATI, EPRI to understand & address impacts of climate change on transmission utilities		

0 years **5 years** **10 years** **20 years**

6.1.5 Energy Storage

BACKGROUND: Energy storage technologies have traditionally taken a lower profile in BC compared to other jurisdictions, due to the presence of large capacity, multi-year hydroelectric storage facilities in the Peace and Columbia River basins, and unconstrained transmission paths. However, three recent trends have prompted a closer focus on energy storage technologies in BC:

1. Increased penetration of low capacity factor intermittent generation resources that require new or up-rated transmission lines for interconnection to the system.
2. Existing bulk and regional transmission lines approaching capacity limits during peak load periods.
3. Technology development that is lowering costs and increasing the performance of energy storage devices, coupled with the potential to utilize large amounts of stored energy in plug-in electric vehicle batteries located in major load centres within ten years.

Energy storage technologies show promise for resource and load levelling to reduce transmission congestion, reduce losses, and increase the “dispatchability” of intermittent resources. The use of high speed power electronics for interfacing the storage device to the power system allows additional benefits including power quality improvement, system regulation, reduced spinning reserve and dynamic reactive power reserves. Promising energy storage technologies include pumped hydro, compressed air energy storage (CAES), lead acid batteries, advanced flow batteries, flywheels, superconducting magnetic energy storage (SMES), supercapacitors, and plug-in electric vehicle battery storage. Challenges in development of energy storage resources include high initial cost, reliability, and operational issues such as design life, maintenance costs and environmental impacts. There is a need to develop economic costing methodologies and industry standards for utility planning and operation.

PURPOSE:

(1) Active technology watch on the state of development and costs and benefits of applying energy storage technologies on the BC transmission system.

(2) Consider energy storage options in planning studies for interconnection of intermittent generation resources, transmission congestion relief and loss reduction. Undertake pilot projects where suitable.

(3) Actively pursue “vehicle to grid (V2G)” studies and demonstration opportunities for utilizing electric vehicle controllable energy storage for transmission benefits (system regulation, spinning reserve, pre-contingency transmission capacity enhancement, loss reduction, firming of intermittent resources).

ACTIONS:

0–5 years	5–10 years	10–20 years
Participate in Electricity Storage Association – early access to latest developments in electricity storage technology		
Technology Watch on energy storage developments (CEATI, PSERC, EPRI, manufacturers, utilities)		
Review potential for large-scale CAES and pumped hydro storage in Lower Mainland and Vancouver Island – determine costs & benefits for transmission congestion relief, loss reduction, and auxiliary services		
Detailed analysis of flow battery costs and benefits (zinc bromide, vanadium, sodium sulphur) – intermittent generation integration, transmission congestion relief, auxiliary services		
Provide current costs & technology status for interconnection and congestion relief planning studies		
	Demonstration projects for interconnection and congestion relief	
		Demonstration projects for advanced storage devices for transmission auxiliary services (flywheels, SMES)
Collaborative studies on costs, benefits and technologies for electric vehicle V2G applications (PSERC, UVIC, BC Govt, Powertech)	Pilot projects	Implementation projects

0 years **5 years** **10 years** **20 years**

6.1.6 Physical and Cyber Security

BACKGROUND: Following the 9/11 attack and increasing incidences of internet-based intrusion of critical infrastructures, there is a significant electricity industry focus on physical and cyber security. BCTC is governed by mandatory reliability standards from the North American Electric Reliability Corporation that include auditable requirements for critical infrastructure protection, both physical and cyber. BCTC has experienced a large number of substation intrusions, related to copper theft, which are costly and seriously impact reliability and safety of the delivery system. The utility operates a complex infrastructure of unmanned stations, cable circuits and overhead transmission lines over a wide geography, much of it in remote areas. Proliferation of local area and wide area networks, intelligent field devices, wireless communications, as well as multiple interconnection points and interoperability among computer-based systems represent an imposing and rapidly changing cyber threat risk to BCTC's control, protection and monitoring systems. Threats to BCTC's physical and cyber assets include theft, intrusion, vandalism, directed threats, extortion, and internal threats (intentional and non-intentional). Not to be overlooked is the need for physical protection of employees and contractors from external threats. This focus area addresses research on physical, cyber and personnel security issues from a technology perspective.

PURPOSE:

(1) Enhance physical and cyber threat risk assessment (TRA) models for physical and cyber infrastructure and personnel including identification of probability and impact of identified risks. Impacts include financial, reliability, environmental and safety (personnel, customer, public).
(2) Utilizing the TRA models, develop mitigation plans and technology solutions for preventing, monitoring, controlling and responding to identified physical and cyber threats.
(3) Ensure effective technology solutions are in place to meet the requirements of mandatory industry reliability standards for critical infrastructure.

ACTIONS:

0 years – 5 years	5 years – 10 years	10 years – 20 years
Work with industry associations, electric utilities, other industries, law enforcement agencies, and security agencies / manufacturers to share best practices & develop effective mitigation plans / technologies		
Develop & continuously update physical & cyber Threat Risk Assessments including mitigation plans		
Develop & apply technology solutions for perimeter & device protection for station and transmission assets (blast/ballistic barriers, advanced fencing, detection sensors / systems, CCTV & satellite observation, communication systems for remote sites, etc.)		
	Develop rapid deployment systems for responding to physical risks in remote areas (e.g. UAV)	
Research asset hardening and alternative materials technologies (e.g. non-ceramic insulators, non-copper grounding)	Implementation	
Implement plans for rapidly deployable asset spares		
Conduct vulnerability studies on cyber control, protection, monitoring & communications assets (in particular various generations of SCADA systems used in BCTC)	Implement advanced protective measures	
Develop & install advanced cyber threat monitoring / alert systems for control, protection, monitoring, telecommunications assets		
Continue with UBC interdependency research considering multiple threats to electricity, gas, telecommunications, water sectors	Implementation	
Research internal threat detection systems based on anomalous behaviour, biometrics, etc.	Implementation	
	Research & deploy personnel protection systems, including GPS location capability	

0 years — 5 years — 10 years — 20 years

6.1.7 Integration of Renewable Energy Resources

BACKGROUND: The BC Energy Plan requires that renewable electricity generation continues to account for at least 90% of the province's total generation. These include sources of energy that are constantly renewed by natural processes, such as large and small hydroelectric, solar, wind, ocean wave and tidal, geothermal, wood residue, and energy from organic municipal waste. The majority of renewable generation sources connected to the transmission system will be intermittent in nature, and will present particular technical challenges for grid interconnection and system operations depending on their size, location, turbine/generator type, capacity factor, dispatchability and correlation of generator output with system demand. Some of the challenges were demonstrated in February 2008 in Texas when wind generation dropped nearly instantaneously from 1700MW to 300MW, necessitating load shedding of 1100MW to avoid a system-wide blackout.

PURPOSE:

(1) Develop planning and operational solutions to address the challenges of integrating intermittent renewables to the transmission system in a least cost manner while achieving high levels of reliability.
(2) Develop improved modeling and analysis techniques to simulate steady state and transient behaviour, as well as to forecast short-term and long-term generation capacity for system operations.
(3) Develop probabilistic and deterministic methods to quantify the maximum level of intermittent resources that can be integrated into particular areas or regions, the impacts on generation adequacy and spinning reserve, and long-term development of the transmission system.
(4) Proactively address technical issues associated with potential large new renewable generation such as ocean tidal and wave energy (dynamic models, interconnection issues, build-out of the transmission system).

ACTIONS:

Collaborate with research organizations (PSERC, CEATI, EPRI, universities), other utilities, manufacturers, and technical societies (IEC, IEEE, CIGRE) to develop, implement and standardize best practices in transmission planning and operation of renewables		
System Planning Studies to determine maximum wind penetration by region		
PSERC S-34 Impact on system reliability due to increased penetration of DFIG-based wind generation	Apply results	
Develop / implement instrumentation & monitoring program for assessing power quality impact of intermittent resources on the power system (e.g. harmonics, fast transient voltage, voltage ride-through, etc.)		Advanced technologies to mitigate harmonics, etc.
Powertech studies on integration of BC ocean energy resources	Detailed ocean energy turbine/generator models, interconnection guides	Ocean energy transmission interconnection pilots
Refine renewable generation dynamic models for system planning studies		
Develop advanced generation forecast tools for real-time operations	Implementation	
Provide input to Long Term Transmission Vision updates on outlook for future renewables including integration issues		
Research and demonstrate advanced technologies for more cost-effective interconnection and "firming" of renewable resources (e.g. energy storage, power electronics, automated demand response)		

0 years **5 years** **10 years** **20 years**

6.2 Conservation, Efficiency and Environmental Leadership

BC's Energy Plan and climate change legislation emphasize a number of directions related to energy conservation, environmental leadership and actions to address climate change.

The Energy Plan directs BC Hydro to meet 50 percent of its incremental resource needs through conservation by 2020. All utilities are encouraged to support conservation by adopting cost-effective demand-side management programs. BCTC will contribute to this goal through a comprehensive program to reduce transmission losses that will result in improved efficiency in power delivery throughout the province.

The BC Government has strengthened its commitment to combating climate change through legislation that sets aggressive targets for reduction of greenhouse gases (GHG) and requires crown agencies to be carbon neutral by 2010. As a result, BCTC has formulated a Climate Change Response Plan that will guide its compliance strategies and technology development programs for meeting the stringent GHG reduction targets.

Related to the Government's goals for conservation and environmental leadership, BCTC recognizes the impact of its facilities on the natural environment and the public. In operation of its complex system and in the expansions required to meet new customer requirements, BCTC must carefully consider environmental, aesthetic and public safety values.

These issues and the roadmap for related technology development are addressed in the following technical focus areas:

6.2.1 System loss reduction
6.2.2 Environmental and public impacts of transmission
6.2.3 Greenhouse gas reduction

6.2.1 System Loss Reduction

BACKGROUND: Transmission losses on the BC transmission system are approximately six percent of the electricity used in the province. In fiscal 2006, this represented approximately 3150 gigawatt-hours of electricity. Technical losses include Joule, magnetic, dielectric and corona losses in the power delivery system. Non-technical losses include metering inaccuracies, unmetered energy and energy used for BCTC operations. Remote generation and long transmission lines are two important factors affecting the losses. In support of BC's aggressive conservation and energy efficiency targets, BCTC evaluates the source and magnitude of capacity and energy losses, performs technical and economic evaluations of opportunities to reduce system losses, undertakes loss reduction projects, and seeks improvements in processes, technologies and policies related to management of transmission system losses. BCTC pursues operational and capital projects that provide conservation benefits at a cost equal to or less than other conservation initiatives undertaken in the province.

PURPOSE:

(1) Improve direct measurement and calculation of the magnitude and location of transmission losses, including tracking and reporting of loss reduction over time.
(2) Refine equipment design specifications and loss evaluation methods (conductors, transformers, etc.)
(3) Provide transmission loss information to market participants to improve the efficiency of generation dispatch.
(4) Implement operational changes to reduce losses (voltage profiles, reactive power management, network topology)
(5) Implement physical changes to reduce technical and non-technical losses (reconductoring, parallel lines, station service improvements, etc.)
(6) Investigate new technologies for loss reduction (e.g. metal composite conductors, high temperature superconductors, low loss transformers, UHV AC and DC transmission, etc.).

ACTIONS:

Comprehensive Loss Reduction Study (ABB)	Loss Reduction Action Plan	Implement operational and physical changes for loss reduction (capital and OMA projects)		
		Improve direct measurement of losses (state estimation, metering)		
		Develop & implement loss information for market participants		
		Revise design specifications and loss evaluation methods		
		Improve loss tracking & reporting		
		Implement economic assessment methodologies for quantifying costs & benefits of loss reduction opportunities		
Collaborate with research organizations (PSERC, CEATI, EPRI, universities), other utilities, and technical societies (IEC, IEEE, CIGRE) to develop, implement and standardize best practices in transmission loss management				
Technology watch on future technologies for reduced losses (HTS, UHV AC, DC, low loss transformers, etc.				
				Apply advanced technologies for loss reduction

0 years **5 years** **10 years** **20 years**

6.2.2 Environmental and Public Impacts of Transmission

BACKGROUND: BCTC's transmission lines and substations have an impact on the natural environment and the public. BCTC is cognizant of environmental, aesthetic and public safety issues in the operation of existing facilities and the planning and construction of new facilities. BCTC is faced with increasing challenges in accommodating new environmental regulations such as Species at Risk and greenhouse gas reduction, increased wildfire risks, pine beetle infestation, encroachment on rights-of-way, consultation with First Nations, and public opposition to existing and new rights-of-way. This focus area addresses the large number of environmental and societal issues that affect the transmission of electricity, and the development of cost-effective solutions that will ensure the reliability of electricity supply while meeting stakeholder needs.

PURPOSE:
(1) Identification of risks and mitigation measures for environmental and public concerns affecting the transmission system.
(2) Development of scientific knowledge and new technologies and processes for prudent mitigation of environmental and public concerns.

ACTIONS:

Ensure effective linkage between Enterprise Risk Management process & environmental / aesthetic / public safety technology plans	
Collaborative research with industry technology partners & other utilities to develop & apply technology best practices for vegetation management: cutting practices; herbicides; low growing species; fire control; compatible uses; ecological modification; habitat preservation; access; remote sensing for work planning & encroachment	
Collaborative research with industry technology partners & other utilities to develop & apply technology best practices for transmission circuit siting, design, construction and operation: aesthetic designs with public input; public consultation models; avian interaction; habitat protection, security & public safety	
Fund EPRI EMF and RF Health Assessment Community, Residential & Occupational Studies to keep abreast of scientific developments	
Collaborative research with industry technology partners & other utilities to develop & apply technology best practices for substation siting, design and operation: aesthetic impacts; audible noise; security & public safety; oil spills / containment; PCB elimination, SF6 leakage reduction	
Develop ECO-design standards for equipment purchases	Implementation
Develop lifecycle analyses for transmission & substation materials and implement new processes / technologies: treated wood poles; galvanized steel; etc.	
Research alternative materials with lower environmental footprint, e.g. transformer vegetable oils, composite transmission towers, non-SF6 switching devices, etc.	Implementation
Continue research and deployment of best practices in equipment and facility design and work practices to minimize worker and public safety risks (e.g. arc flash, transmission & substation public access barriers, robotics, energized work procedures, etc.)	

0 years **5 years** **10 years** **20 years**

6.2.3 Greenhouse Gas Reduction

BACKGROUND: BC's Greenhouse Gas (GHG) Reduction Targets Act mandates reduction of GHG emissions in BC by at least 33% by 2020 and by at least 80% by 2050, as compared to emissions in 2007. In addition, crown agencies such as BCTC must be carbon neutral by 2010, to be achieved through a combination of GHG reductions and purchase of emission offsets. BCTC's 2007 CO_2 emissions were 40,147 CO_2 equivalent tonnes, 95% of which was contributed by sulfur hexafluoride (SF_6) emissions from high voltage switchgear and measurement devices (1 kg of SF_6 emissions is equivalent to 23,900 kg of CO_2). By 2010 BCTC expects to reduce its emissions by 53% from 2007 levels, to 18,531 C02 equivalent tonnes. SF_6 emissions will make up 90% of the total 2010 emissions. Other emissions include building heating, vehicles and air travel. BCTC will continue to reduce its emissions as a key component of its Climate Change Response Program (CCRP). The CCRP has three elements:

- Compliance: meet government, regulatory and voluntary requirements
- Risk and Financial Management: identify and manage emissions; assess and manage climate change risk and impacts
- Innovation and Engagement: innovative technologies and processes; employee education and participation

PURPOSE:

(1) Pursue aggressive measures to reduce SF_6 emissions, including leak detection, repair and replacement of equipment.

(2) As part of BCTC's Climate Change Response Program, identify and track all greenhouse gas emissions from BCTC operations and develop effective technology solutions to reduce emissions, prioritized on a net abatement cost basis.

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ACTIONS:

Inventory all GHG emissions from BCTC operations	Develop action plans / business cases / approvals for overall reduction program
Continue with SF6 leak reduction program including circuit breaker replacements	
Continuous improvement of SF6 inventory tracking and reclamation processes	
Research and apply new technologies (Powertech SF6 leak detection camera, new generation high voltage circuit breakers, optical voltage & current sensors)	
Collaborate with industry partners on new approaches and technologies for GHG reduction, including adoption of best practices.	
Explore alternative work methods for reducing GHG (unmanned autonomous vehicles to replace helicopters and fixed wing aircraft, satellite remote sensing	Implementation
Support development of renewable energy resources in BC through innovative transmission integration technologies and practices	
Support research and demonstration of plug-in hybrid vehicles as a means to reduce GHG and provide transmission benefits	Implementation projects
Alternative vegetation management practices on rights of way (mulching, high carbon uptake vegetation)	
Develop and apply high precision measurement devices and synchrophasors for allowing operation of the network closer to theoretical limits	
Transmission loss reduction program – see 6.2.1	

0 years **5 years** **10 years** **20 years**

6.3 Smart Grid

The term *Smart Grid* is used extensively in the electricity industry but a specific and commonly accepted definition is yet to emerge. The US Energy Independence and Security Act of 2007 contains a statement of policy on modernization of the electricity grid. The Act supports the modernization of electricity transmission and distribution systems to maintain a reliable and secure electricity infrastructure that can meet future demand growth and to achieve each of the following, which together characterize a *Smart Grid*:

(1) Increased use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid
(2) Dynamic optimization of grid operations and resources, with full cyber-security.
(3) Deployment and integration of distributed resources and generation, including renewable resources.
(4) Development and incorporation of demand response, demand-side resources, and energy-efficiency resources.
(5) Deployment of “smart” technologies (real-time, automated, interactive technologies that optimize the physical operation of appliances and consumer devices) for metering, communications concerning grid operations and status, and distribution automation.
(6) Integration of “smart” appliances and consumer devices.
(7) Deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.
(8) Provision to consumers of timely information and control options.
(9) Development of standards for communication and inter-operability of appliances and equipment connected to the electric grid, including the infrastructure serving the grid.
(10) Identification and lowering of unreasonable or unnecessary barriers to adoption of smart grid technologies, practices, and services.

Smart Grid is often described as the foundation for a new era of power system management based on extensive communication systems that monitor and allow automatic optimization of interconnected elements of the power system, from the generator through the high voltage network and distribution system, to end-use customer loads. The goal is to advance information and grid based technologies to increase efficiency, reliability and flexibility of the delivery infrastructure. The majority of recent activity in *Smart Grid* development is occurring in distribution systems (for example, automatic switching of field devices) and at the customer interface (for example, Smart Meters).

The thinking among many transmission utilities is that existing transmission networks already exhibit many of the attributes of *Smart Grid*, which are essential for instantaneous matching of generation resources to loads, while ensuring reliable and stable operation for credible contingencies. This requires the use of sophisticated automatic systems for protection against faults and for real-time control of the system, enabled by high speed microwave and fibre-optic telecommunications systems. BCTC has made a number of innovations over the past several years to apply smart technology to the transmission system (see Reference 3, Section 3). Of particular note are BCTC’s new state-of-the-art system control centre and real-time synchrophasor applications that provide solid platforms for development of future advanced applications.

BCTC's strategy is to continue to "make BC's *Smart Grid* smarter", moving toward the vision of a more intelligent, self-monitoring, adaptive and resilient network that can be operated safely and reliably to the limits of its design capacity. This will involve the application of incremental, prudent investments in grid intelligence, focused on delivering business value to all users of the transmission system. BCTC's expenditures on *Smart Grid* will be balanced with other critical infrastructure technology needs, such as physical structures, switching equipment and rights-of-way.

The technical focus areas described in this section comprise the major elements of BCTC's *Smart Grid* roadmap:

- 6.3.1 Synchrophasor enabled wide area control and security assessment
- 6.3.2 Dynamic rating of assets
- 6.3.3 Smart equipment monitoring and remote sensing
- 6.3.4 Integrated information flow, simulation and analysis

Smart Grid initiatives are also included as components of other technical focus areas, including 6.4.1 Next Generation Lines and Substations, 6.4.2 Next Generation Control Centre Technologies and 6.4.3 Power Electronics.

An underlying requirement of *Smart Grid* development is the need to communicate vast quantities of data and information for supporting new applications in generation, transmission, distribution and customer systems. The resulting impacts on utility telecommunication infrastructure is addressed in Section 6.3.4. BCTC will also provide an important role in supporting initiatives such as distribution feeder voltage control and automation, control centre distribution management systems (DMS), smart metering, demand response programs, and electric vehicle charging and energy storage.

6.3.1 Synchrophasor-enabled Wide Area Control and Security Assessment

BACKGROUND: Synchronized phasors ("synchrophasors") are highly accurate voltage, current and phase angle "snapshots" of the instantaneous state of the transmission system. Currently, BCTC acquires nine synchrophasor measurements at key locations in its 500kV network, precisely synchronized using the GPS satellite clock, and updated 30 times per second. BCTC pioneered the use of real-time synchrophasors in its control centre state estimator for improving the accuracy of advanced dynamic security assessment, thus enabling the transmission system to be operated closer to its design limits. Synchrophasor data provides insights for the management and control of the power system which were previously not possible. BCTC considers synchrophasor technology to be the most critical component of its Smart Grid development, which will lead to highly accurate computer applications for detecting and visualizing the onset of instability ("security assessment") and expert systems that will take automatic control action to stabilize grid dynamics on a region-wide basis ("wide area control"). The ultimate goal is to maximize the transfer capability on the BC transmission network without risking system performance.

PURPOSE:

(1) Expand the network of synchrophasor measurement units to improve state estimator visibility of all 500kV and underlying transmission circuits, and other WECC utilities.
(2) Ensure security and quality of high volumes of synchrophasor information (accuracy of primary measurement devices, data transmission, data concentrator architecture, filtering of bad data, redundancy, archiving).
(3) Provide clear and actionable operational information to control centre operators (phasor-based visualization systems).
(4) Define safe and reliable operating zones in real-time (dynamic security assessment, line ratings).
(5) Detect and automatically correct abnormal operating conditions (protective relay applications, power system stabilization, generation shedding, etc.)
(6) Improve power system modeling and post-disturbance analysis.

ACTIONS:

S-P = synchrophasor   PMU = phasor measurement unit

Participate in North American SynchroPhasor Initiative (NASPI) and WECC work groups to share information & develop common systems for measurement & applications			
Definition Phase Study to develop architecture for permanent S-P infrastructure in new control centre, incl'g telecom requirements	Initial Implementation Phase (incorporate DOE/NETL NASPInet features	Build-out of S-P and supporting telecom systems	
Plan & implement mass deployment of S-P at lower voltages (PMU + protective relay firmware)			
Interchange S-P measurements with WECC utilities		Develop WECC-wide state estimation	
Install RTDMS S-P visualization applic'n in control centre		Improve accuracy of primary VT & CT inputs to PMU's	
Patent filing / demo voltage stability detection relay			
Patent filing / demo S-P bad data detection			
Research / demo U of A S-P based on-line modeling tool			
Research S-P enabled visualization & dynamic security assessment		Implementation projects	
		Research S-P enabled wide area control	Implementation (closed loop control, adaptive islanding, smart gen shed, etc.
Develop & improve tools for system performance analysis, compliance monitoring & off-line studies			
Participate in industry standards development.			

0 years **5 years** **10 years** **20 years**

6.3.2 Dynamic Rating of Assets

BACKGROUND: Dynamic circuit rating (DCR) refers to the utilization of real-time information to develop accurate ratings of lines, cables and substation components to either increase circuit ratings above design ratings or to maintain transfer capacities at safe levels. In the absence of monitoring, circuit ratings are established in a conservative fashion wherein the most unfavourable conditions are assumed. With dynamic rating, it is possible to increase the thermal capacity of transmission assets such as lines and transformers, based on actual conditions (for example, conductor temperature, loading history, wind speed). In some cases, power flows may be increased by 10-20% (for example, recent up-rating of Vancouver Island 500kV submarine cables). DCR challenges include: reliably determining the conditions that affect asset ratings; cost and complexity of incorporating dynamic rating in operations; limitations in modeling dynamic behaviour to predict circuit ratings into the future; the need to consider the ratings of all components in a circuit to ensure that the “weakest link” is considered; and determination of limiting factor at each instant (thermal, transient stability, voltage stability).

PURPOSE:

(1) Increase power flow over existing static rating
(2) Defer or eliminate the need for more expensive capital expenditures by obtaining greater capacity from existing assets
(3) Integrate independent power producers without costly equipment upgrades
(4) Avoid damage to system components and extend asset life
(5) Identify system constraints as a focus for potential upgrades

ACTIONS:

0–5 years	5–10 years	10–20 years
Co-fund EPRI, CEATI, PSERC and university research on DCR technologies		
Work with manufacturers on development, demonstration and installation of DCR technologies. Goal: low cost, wide deployment		
Indian Arm 230kV Crossing demonstration of available DCR technologies for thermally limited lines	Implementation in thermally limited lines	
Transformer dynamic thermal rating pilot demonstration (3 sites)	Implementation in transformers approaching maximum	
Develop dynamic models for predictive rating of submarine cables with complex cooling systems	Implementation of “look-ahead” rating system for VI 550kV cable circuits	
Refine dynamic models for predictive rating of subterranean cable circuits	Implementation of “look-ahead” rating system for metro Vancouver and Victoria subterranean cables	
Develop effective control centre operator displays for dynamic ratings		
Develop telecommunications technologies / architecture for remote monitoring of DCR devices		
		Grid automation and optimization using DCR technologies

0 years — **5 years** — **10 years** — **20 years**

6.3.3 Smart Equipment Monitoring and Remote Sensing

BACKGROUND: Many areas of system operation, planning and asset management rely on information collected throughout the transmission infrastructure. Data collection is often labour-intensive, time consuming, and in many cases data sources are non-existent. The Smart Grid enables the acquisition and communication of large quantities of asset performance data on which to base critical operating, planning and asset management decisions. The availability of accurate and timely asset information will enable a progression to fact-based data-driven decision making. Benefits in the asset management area will be particularly strong, speeding the move from time-based to condition-based and predictive maintenance. Real-time and near real-time measurement of thermal, mechanical and electrical characteristics of BCTC's assets requires an array of sensors, communications and analysis technologies. In addition to sensors embedded directly in the equipment, performance can be inferred by measurement of other parameters such as fault clearing time (acquired by computer-based protective relays). Condition assessment of transmission line assets and rights-of-way presents particular challenges given BC's geography. Remote sensing technologies such as satellite and fly-over hyperspectral imaging, LiDAR, and back-scatter radio sensors show promise for evaluating above-ground and below-ground corrosion, tree encroachments, conductor health, and other asset condition issues, as well as aiding in emergency response efforts. The goal of this program is to support the development, demonstration and deployment of high value sensor technologies that can be applied quickly and cost effectively. Communications systems required to support the transfer of information and associated analysis systems are covered in Section 6.3.4. [check PSERC projects]

PURPOSE:

(1) Research and demonstrate equipment sensors and remote sensing technologies for high value operational, planning and asset management decision making.

(2) Reduce data acquisition costs through standardized products, interoperable communications protocols and multiple suppliers.

ACTIONS:

Continue hyperspectral image research for determining tower corrosion & vegetation health (UVIC)		
Investigate satellite imaging & flyover (manned & unmanned) imaging for asset condition assessment		
Investigate back-scatter radio, eddy current, thermography, corona & other advanced sensors for transmission line splice, conductor, core & insulator condition assessment		
Continue development of robotic platforms for live line condition assessment		
	Implementation / operationalization of remote sensing technologies	Automated remote sensing of transmission lines & rights of way
Continue investigation / implementation of weather modeling / thematic mapping for predicting asset condition (lines, vegetation)	Implement weather modeling	
Continue research & deployment of real-time condition sensors for transformers, circuit breakers and other substation equipment.		
Develop a consortium to establish a transformer test centre at Powertech Labs for research and demonstration of advanced sensor technology for power transformers		
Support development of communication standards to facilitate low-cost, mass deployment of equipment sensor technology		
	Develop robotic platforms for live line substation condition assessment	

0 years **5 years** **10 years** **20 years**

6.3.4 Integrated Information Flow, Simulation and Analysis

BACKGROUND:

A common theme among all Roadmap employee workshops was the need to improve the collection, communication and sharing of high value operational and asset condition information, and to provide related analysis tools to support decision making by System Operations, Asset Management and System Planning. Information sources cover a wide range: power system model; reliability data; real-time operational data; generation, load and interchange levels; network losses; asset condition; asset performance; security; weather; synchrophasors; geographic information system (GIS); fault recording and event recording; protective relay settings / performance. Applications include analysis tools for power system simulation, long term planning based on uncertain load and resource scenarios, reliability analysis, asset condition analysis and power system visualization. Many of the applications require multiple data sources, and often the same information is required by multiple applications. There is a need to implement open standards to allow seamless information flow across the enterprise, utilizing industry-specific standards such as IEC CIM, Intelligent Utility Network (IUN), DOE GridWise Interoperability Framework and Service Oriented Architecture (SOA).

PURPOSE:

(1) Reduce the cost and wait time for acquiring field information.
(2) Improve the accuracy, quality, consistency and security of information, preferably acquired from a single source.
(3) Improve data management ("taming the data deluge") – update rates, archiving, retrieval, automation.
(4) Develop protocols and standards for information exchange and interfacing with multiple applications (within BCTC and external).
(5) Develop a robust telecommunications infrastructure to support increasingly large information flows.
(6) Develop high value decision support applications to make the best use of available information.

ACTIONS:

Develop comprehensive inventory of information requiring telecom network communication	Develop strategies & architecture (e.g. WAN, service classes, backbone infrastructure, interoperability, security, data historian)	Implementation	
Research / demonstrate / adopt information exchange standards (e.g. IEC CIM, IEC 61850, IEEE C37.1, ESB, SOA, IUN, etc.)			
Research / demonstrate / adopt low-cost communications and integration methods (wireless, satellite, Internet protocols, plug & play, etc.)			
Enhance asset management applications (e.g. predictive & condition based, lifecycle view, hazard identification, etc.)			
Enhance system planning simulation models for power flow, dynamics, transients (load, generation and network models, dynamic reduction, etc.)			
Develop scenario-based models for uncertain load & resource long-term planning. Optimization based on objective functions such as least investment cost, minimum losses, etc.			
Enhance probabilistic planning & asset management models			
Develop weather forecast applications (emergency response, load forecast, wind generation forecast)			
Measurement accuracy improvements – CT/VT re-calibration software, optical measurement devices, etc.		Advanced techniques for improving accuracy of substation information (e.g. distributed state estimation)	
Enhance control centre applications (outage scheduling, automated operating orders, visualization, etc.)			
Research / demonstration / adoption of high speed computing to support computationally intense applications			
		Support implementation of expert systems for all applications	

0 years 5 years 10 years 20 years

6.4 Future Grid

This Roadmap theme addresses the technologies that will transform the way that transmission and station facilities are planned, designed, constructed, operated and maintained over the next 20 years, and beyond. It presents a forward looking view of promising technologies on the horizon that could help to modernize and expand the network while addressing rising costs, complexity, reliability and societal concerns regarding siting and visual impacts. It includes short-term and long-term activities to develop new technologies, tools and processes to support development of the network to meet the requirements of the 21st century.

The technical focus areas described in this section comprise the major elements of BCTC's Future Grid roadmap:

- 6.4.1 Next generation lines and stations
- 6.4.2 Next generation control centre technologies
- 6.4.3 Power Electronics
- 6.4.4 Advanced asset materials
- 6.4.5 Field work methods and robotics

6.4.1 Next Generation Lines and Stations

BACKGROUND: A foundation of BCTC's Future Grid vision is the "next generation" of stations and transmission lines that will meet the needs of our growing province. These facilities must be planned and constructed more quickly using standardized designs and equipment, will need to be low cost, be acceptable to stakeholders, use less land per unit of power delivery, and have better lifecycle performance compared to their predecessors. In many areas of the province, inability to acquire new rights of way may drive increased utilization of existing transmission corridors, by up-rating existing lines, adding additional circuits or by innovations such as ac to dc conversion, ultra high voltage (UHV) to 1100kV, asymmetric operation, and flexible ac transmission systems (FACTS) devices for directed power flow. Next generation stations will be a fusion of information technology, power apparatus technology, communication infrastructure, and user interfaces. New materials and related power apparatus technologies will result in more compact designs, leading to reduction in substation size. The main power apparatus such as circuit breakers and transformers will be smaller and elements such as busbars, insulators and ground grids will be more densely packaged. The sensors and communication modules will be embedded in the power apparatus and primary high voltage measurements will utilize high accuracy optical devices with direct digital outputs. This will allow new approaches for monitoring, control and protection including reduced wiring, reliable and accurate filtering of data, improved data security, self-diagnosis of problems, and industry standard approaches for information exchange. The systems will be modular, allowing low cost expansion capabilities. In addition to "greenfield" installations there will be a need maintain the operation of existing lines and stations as long as is economically feasible. This will require continued innovation in asset management methodologies, life extension technologies, and ingenuity in adapting new generation replacement equipment within existing systems.

PURPOSE:

(1) Develop the "next generation" standardized line and station designs for improved lifecycle reliability, cost, environmental and security performance.
(2) Develop feasible options for maximizing the power transfer capability of existing transmission rights of way.
(3) Invest in life extension methodologies and technologies.

ACTIONS:

Collaborative research with industry technology partners, other utilities, technical societies and manufacturers to monitor & evaluate new technologies for lines & stations (e.g. UHV ac & dc, dc segmentation, ac to dc conversion including tripole dc, asymmetrical operation, FACTS devices, high surge impedance load line reconfiguration, hybrid switchgear, power electronics switchgear, IEC CIM enabled control, protection & monitoring)	Demonstration projects, BCTC standards development and implementation projects	
Monitor CIGRE/IEC activities in UHV ac and dc		
Long Term Transmission Vision reports to include outlook & costing of new technologies for future transmission expansion		
Develop designs for aesthetic towers, or adapt from other utilities. Involve public in design reviews.	Incorporate aesthetic designs in new installations	
Continue demonstration of digital optical primary measurement devices as an enabler of the "digital substation"	Implementation	
Pilot projects on substation data integration using IEC 61850 standards	Implementation	
Installation of hybrid switchgear – Ingledow Sub	Wide-scale deployment where feasible	Development & application of next generation power switchgear (SF6-free)
First installation of 3M composite core conductor – VITR project	Further installations of composite core conductors for higher line capacity	
Participate in industry standards development (IEEE, IEC) to drive down costs of new line and station equipment		
Continue research, demonstration and deployment of life extension technologies (e.g. transformer winding life extension, corrosive sulphur removal, etc.)		
Evaluate impact of distribution microgrids on evolution of transmission / distribution substations		High temperature superconductor applications

0 years **5 years** **10 years** **20 years**

6.4.2 Next Generation Control Centre Technologies

BACKGROUND: BCTC's new system control centre is a state-of-the-art facility that contains a number of innovative applications for monitoring and control of the interconnected power system. The control centre architecture, computing facilities and user interfaces provide a solid technical base on which to develop and apply "next generation" system control applications for improved operator visibility of emerging problems on the power system and greater intelligence for operating the system closer to theoretical limits while maintaining high supply reliability. While there is a need to increase visibility of the power system at all voltage levels and for a full range of contingencies, the resulting deluge of data can lead to "information overload" for system operators, especially during emergencies. Given the complexity, cost and rapidly evolving nature of advanced system control concepts, it is recommended that a detailed roadmap be developed as a separate initiative specifically for this focus area, identifying challenges, benefits and costs of alternative technology paths. The priorities identified below are directional at this stage, based on feedback from employee workshops.

PURPOSE:

(1) Advance existing control centre functions to provide decision support tools in reliability and optimization.
(2) Develop control centre capabilities to expand visibility of the network from generation through to loads, including neighbouring systems.
(3) Develop advanced expert systems, visualization and situation analysis tools to aid system operators in managing significantly increased information flow.
(4) Develop advanced real-time dynamic security analysis and wide area control concepts to improve security margins and to operate the power system closer to theoretical limits.
(5) Develop and implement the Distribution Management System to improve operation of the BC Hydro distribution system.

ACTIONS:

- Develop detailed roadmap with full evaluation of alternatives
- Develop & implement applicable tools & processes recommended in "NERC Real-time Tools Survey Analysis & Recommendations" report
- Develop operational processes & enable application of Optimal Powerflow tool to minimize losses & provide remedial actions to remove security violations
- Enhance existing on-line transient stability calculations to provide automated remedial actions in real time
- Develop real-time calculation of TTC & ATC using on-line transient & voltage stability tools | Enhance TTC/ATC with fast computation
- Develop & implement Distribution Management System
- Continue collaboration with research partners (PSERC, CEATI, EPRI, universities, utilities, manufacturers) to evolve industry direction on advanced applications
- Collaborate in R&D for Human Factors: OSH, "big picture" visualization & situation analysis including knowledge systems for integrating information & advising operators in emergencies, automated operating orders, data mining
  Development — Pilot Projects — Implementation
- Advanced State Estimation: mass synchrophasor deployment at all voltages; WECC visibility; improved load models
  Development — Pilot Projects — Implementation
- Synchrophasor enabled dynamic security assessment, wide area control, adaptive islanding, auto-arming of RAS for contingencies (see also 6.3.1)
  Development — Pilot Projects — Implementation
- Automatic systems for reactive power mgt to achieve improved voltage control, loss reduction and pre-positioning of the system for voltage stability contingencies
  Development — Pilot Projects — Implementation
- Collaborate in R&D for processes & tools for probabilistic outage planning & risk-based security assessment
  Development — Pilot Projects — Implementation
- Collaborate in R&D of tools for improved emergency response and restoration
  Development — Pilot Projects — Implementation
- Advanced distribution automation, load management, state estimation & advanced applications, integrated with BC Hydro Smart Grid initiatives
  Development — Implementation

0 years — **5 years** — **10 years** — **20 years**

6.4.3 Power Electronics

BACKGROUND: While BCTC has considerable experience with power electronics devices in static var compensators, series capacitors, statcoms and HVDC, further developments in high-voltage power electronics hold substantial promise for transforming the electric power system. Power electronics devices allow precise and rapid switching of electric power and are the key component in flexible ac transmission systems (FACTS) for increasing power flow and stability, HVDC systems, and the interface between the power system and electric storage and many renewable energy resources (wind, ocean). Ultimately, power electronics devices may replace conventional circuit breakers for interrupting fault current and isolating circuit elements. Barriers to expanded use of power electronics are the relatively high costs and need for improvements in performance, reliability and durability over extended time periods. To increase performance in high voltage, high current applications, breakthroughs are needed in materials technology to replace silicon (silicon carbide and diamond are leading contenders). Promising switching technologies such as voltage source converters (VSC) and insulated gate bipolar transistors (IGBT) will continue to drive down costs and increase performance. The US Department of Energy is encouraging research and testing in this area, and equipment manufacturers are funding significant product development efforts to deploy higher capacity power electronics devices and drive down costs. EPRI is pursuing an innovative new silicon-based device, the super-gate turnoff thyristor (S-GTO), which promises to substantially increase the current rating and switching efficiency of power electronics controllers.

PURPOSE:

(1) Keep abreast of developments in power electronics technologies, including advances in product applications, ratings and features.
(2) Maintain close contact with equipment manufacturers to include BCTC application requirements in product development.
(3) Consider existing and emerging power electronics devices as options in transmission planning studies and equipment replacement.

ACTIONS:

Collaborate with research organizations and manufacturers to describe BCTC needs and keep aware of latest developments	
Work with standards and research organizations to standardize equipment specifications, maintenance and operational requirements	
Investigate membership in or formation of user's groups for specific equipment types to share experience on specification, installation, maintenance and performance	
Monitor developments in voltage source converters for both overhead and underground circuit applications	
Investigate applications including costs and benefits of new power electronics apparatus e.g. VSC HVDC, tri-pole DC conversion of ac circuits, DC segmentation of networks for stability control, UHV HVDC, statcoms, FACTS power flow controllers, energy storage integration, etc. — Investigation / Pilot Projects / Implementation	
Research / measurements / mitigation of power quality impacts of large scale power electronics applications, e.g. harmonics	
	Advanced applications utilizing next generation semiconductors, e.g. circuit breaker replacement

0 years **5 years** **10 years** **20 years**

6.4.4 Advanced Asset Materials

BACKGROUND: A diverse range of materials are used in the transmission system, each subject to a wide variety of physical and electrical conditions. Many opportunities exist to improve the lifecycle performance of assets through more effective material condition monitoring, protection, remediation and use of alternative materials. A large number of BCTC's 20,000 steel lattice towers have exceeded the design life of galvanized coating protection on above ground and below ground components. Life extension programs are underway, however, environmental regulations may require a change from existing coating systems to alternatives. For new and replacement towers, there is a need to consider new corrosion protection systems and advanced materials such as fibre reinforced polymers (FRP) and polymer modified concrete. BCTC's 100,000 wood poles are subject to varying levels of decay, particularly in coastal climates and in high pollution areas. Challenges include difficulties in acquiring good quality timber replacements, particularly for cross-arms. BCTC is investigating a shift toward use of engineered materials of known properties where the mechanical, electrical, weather, fire and corrosion resistance can be specified to meet system and investment needs. The use of engineered materials will lead to a reduction in design margins typically determined from statistical assessments for wood and natural materials which have a high variability in physical and chemical properties. Corrosion of substation steel structures presents a difficult challenge due to the difficulty of accessing the structures for repairs while the equipment is energized. Alternatives for weed-prone substation gravel surfaces are needed. These may include composite materials with water permeable filtration, allowing minimal long-term maintenance. Investigations are underway on the long-term performance of new composite-based electrical insulators for replacement of traditional porcelain and glass insulators. Significant research and development has taken place on high temperature, low sag (HTLS) transmission line conductors which use lightweight high strength composite cores in place of traditional steel cores. This allows much higher current capacities without violating the maximum sag allowed for a transmission line under heavy load conditions. Future developments in materials technologies include high temperature superconducting cable and nano-materials for improved cable insulation and low resistance conductors.

PURPOSE:

(1) Improve the lifecycle cost and performance of asset materials used in BCTC's infrastructure through effective condition monitoring, protection, remediation, and use of alternative materials.

(2) Investigate and demonstrate the use of advanced materials for improving asset cost and performance.

ACTIONS:

Develop & assess water-based coating systems for improved protection and environmental performance	Implementation
Evaluate use of inhibitor coatings such as carbon sulfonate for corrosion protection of steel structures	Implementation
Collaborate with research organizations and manufacturers to develop and apply advanced materials for above ground & below ground transmission structures	
Evaluate double coating systems for lifecycle effectiveness	Implementation
Develop & assess alternative substation surface materials	Implementation
Develop improved gasketing materials to prevent oil / gas leaks	Implementation
Develop improved fire retardants for wood poles	Implementation
Develop coatings to prevent substation faults due to animal intrusion	Implementation
Develop wood decay thematic maps to identify high risk wood pole structures	Operationalize
Assess long term reliability & application constraints for composite insulators	Apply results in design and purchasing decisions
Technology watch and assessment of advanced material for substation equipment foundations, sound control, security barriers.	
Investigate & demonstrate advanced materials for high capacity transmission (HTLS, HTS, nano-materials)	
Technology watch on outcomes from MIT's Materials Genome Project (designer materials for specific utility applications)	

0 years **5 years** **10 years** **20 years**

6.4.5 Field Work Methods and Robotics

BACKGROUND: BCTC spends over $200 million per year in labour costs for capital and operational work programs involving field construction, equipment maintenance, switching, vegetation management and emergency response. This amount is expected to grow significantly as the capital program increases due to system expansion and replacement of aging assets. At the same time, operation of the network at higher utilization factors reduces our ability to take equipment out of service for maintenance and construction purpose, thus increasing the need to perform work on energized equipment. BCTC and its service provider BC Hydro Field Operations have been leaders in the utility industry in performing maintenance work on energized transmission lines using bare-hand and live line work methods, with personnel safety being the paramount objective. There is an opportunity to expand the use of these techniques in energized substations and transmission lines for maintenance and construction, utilizing advanced technologies such as tele-operated robotic arms, “on-the-wire” robots, and insulated boom trucks. Inspections can be carried out safely on energized equipment utilizing inspection devices such as high resolution visual, infrared and hyperspectral cameras, corona probes, resistance measurements and other non-destructive test (NDT) methods, directed by operators inside or outside the limits of approach, flown by manned or unmanned aerial vehicles, or performed by robotic systems. Repairs and maintenance such as steel recoating and insulator washing may also be assisted with tele-operated or robotic devices. A number of opportunities exist for new approaches to right of way vegetation management, including adapting technologies used in the forest industry. BCTC places a very high priority on the safety and health of its employees and contractors. With this in mind, we will invest in technologies and practices that minimize safety and health risks arising from occupational hazards in the workplace.

PURPOSE:

(1) Adopt new technologies and related work methods on energized and de-energized equipment to improve productivity and reduce failures in construction, maintenance and operations activities.

(2) Develop new technologies and related work methods to reduce occupational risks to employees and contractors.

ACTIONS:

Collaborative programs with research organizations, other utilities and contractors to adopt best practices in technology application for improved worker safety and productivity		
Explore robotic applications for inspection, maintenance & construction (substations, lines, series capacitors, etc.)	Demonstration projects (e.g. line robots, UAV, tele-operated arms, automated inspection applications).	Implementation
Provide technology mitigation solutions for personnel risks identified in Safety & Health Risk Assessments		
Explore new technologies for vegetation management – forest industry (FERIC), other industries	Demonstration and implementation	
Develop / demonstrate live line optical VT test trailer for substation CVT calibration	Implementation – CVT calibration program for improved state estimation and system operation	
Develop and apply technologies for improved safe work procedures – arc flash, personnel grounding, skeletal muscle injuries, use of hazardous materials such as paint, etc.		
Fund EPRI Occupational studies in health effects of EMF and RF		

0 years **5 years** **10 years** **20 years**

7. Implementation Plan

The success of the Transmission Technology Roadmap depends on effective program delivery and processes for implementing research results into company operations, supported by a well-defined funding and approval process, governance structure, sourcing strategy, knowledge management and communication processes, and a technology roadmap refresh process. The current state and recommendations for each of these areas are discussed in this section.

7.1 Program Delivery

The largest proportion of BCTC's annual expenditures on power technology is for current projects in the maintenance, operations, sustaining capital and growth capital programs. BCTC's technology strategy is to use proven, economic technologies to grow and sustain the assets, serve customers, and improve compliance, efficiency and reliability, as well as to mitigate system risks. The Research and Development Program invests a relatively small amount ($1.5M per annum) to identify, develop, demonstrate and prove out technologies either new to BCTC or new to the world, for eventual incorporation into the mainstream maintenance, operations and capital programs. This approach minimizes the cost and reliability risks inherent in using unproven technology on the power system.

Approximately 80-90 R&D projects are conducted concurrently, with expenditures extending over one, two or multiple years. The breakdown of project funding is approximately 50% for transmission related assets (including vegetation and rights-of-way), 35% for substation related assets and 15% for control centre related assets. Projects are developed and selected on a continuous basis during the year, through consultation with BCTC department representatives. Program funding and the project financial evaluation process are described in Section 7.2.

The R&D Program Office is responsible for facilitating and managing the Research and Development Program and will assume responsibility for managing execution of the Transmission Technology Roadmap. Staff in all technology departments within BCTC are integrally involved in project definition, monitoring of technical progress, and implementing results. Current staffing in the R&D Program Office is 2.5 full time equivalents.

R&D projects are managed using the "stage gate" concept which is a common industry approach for research and development programs. This involves approval of funding for project stages based on achievement of identified milestones. If it is realized at a particular stage gate that the research project will not be successful, the project is suspended.

Projects are monitored in a comprehensive database available to all employees through a Sharepoint portal. Project business cases, progress summaries, deliverables and financials are updated on a regular basis. Project deliverables are posted on the Sharepoint site, which includes search capabilities. The R&D Program Office manages the relationship with external contractors, research organizations, manufacturers and universities, for contract management, financial management and tracking of deliverables. For larger, more complex projects, project management services are provided by the R&D Program office.

Recommendation 1:
Develop a business case to increase the current R&D program management staff to accommodate the increased level of activity associated with Roadmap execution. In particular, it is necessary to increase liaison among R&D program staff and department personnel, to ensure communication of technology needs, development of projects and implementation of R&D results into the business.

Recommendation 2:
Increase project management capability in managing R&D projects and supplement the current financial and project reporting system with a more effective project management information system.

Recommendation 3:
Develop strategies for increasing the support provided by BCTC user departments for implementing the Roadmap.

Recommendation 4:
Given the critical linkage among information / data / telecommunications initiatives defined in the Roadmap and other information technology projects underway in BCTC, establish strong interfaces among the various initiatives to ensure a coordinated approach.

7.2 Funding Levels and Value Analysis

The cash flow on committed and new R&D projects is managed within an annual approved budget of $1.5M. The budget is established on a program basis (not zero based). Each year, approximately $1.5M in new projects is committed, having expenditures of approximately $0.5M in each of three years, on average. Therefore, in each year $0.5M is spent on new projects, $0.5M on projects initiated in the previous year, and $0.5M on projects initiated two years earlier. Total committed project value is approximately $4.5M at any given time.

Individual project proposals are evaluated on a benefit-to-cost basis where benefits and costs include the estimated full costs and benefits of implementing the R&D results into company operations, and taking into account the probability of a successful R&D outcome. BCTC targets a long-term benefit-to-cost greater than 2 for the overall R&D Program, along with measurable improvements in reliability, environmental performance and safety performance.

In some cases, the benefits of the R&D phase of a project are realized immediately (for example, solving the cause of an equipment failure), or determining whether it is feasible to proceed to the next stage of an investigation or to move to the implementation phase. In other cases, the benefits are realized over time through the application of the acquired knowledge in BCTC's planning, asset management and operations decision making. In cases where the R&D project develops and tests a concept or prototype which leads to an implementation phase, the benefits are realized over the life of the implementation phase.

BCTC estimates R&D project financial benefits at three key stages:

1. R&D project initiation;

2. R&D project completion – results are reviewed and recommendations made on the best way to incorporate results in company operations; and

3. After implementation - benefits are quantified based on actual operating experience, one or more years after implementation.

The evaluation formula for estimating the financial value of an R&D project is:

Expected benefit / cost ratio of implemented project	$= w V / (wI_c + R_c)$
Expected value of implemented project, NPV	$= w (V – I_c) – R_c$
Expected value of R&D portion of implemented project	$= (NPV * R_c) / (w I_c + R_c)$

where

- w = Probability of successful R&D outcome
- V = Net present value of future net benefits (revenue, savings or monetized reliability improvements minus operating costs)
- I_c = Net present value of project implementation costs funded by OMA or capital programs
- R_c = R&D project cost (funded by R&D Program)

The calculation at the R&D project initiation stage utilizes an estimate w of the probability of success of the R&D phase. Normally, at the completion of the R&D phase, when a decision is made to proceed to the implementation phase, the factor w becomes 1 as the R&D phase has eliminated uncertainly regarding success of the subsequent implementation phase.

A large number of R&D projects completed by BCTC have moved to the implementation phase and are producing long-term benefits. The combined benefit-to-cost ratio for the completed projects is greater than 7.5, indicating that the R&D Program is providing good value to BCTC's ratepayers. The project benefit included in this calculation is the net present value of all benefits achieved to date and in the future and the project cost includes both the R&D phase and the implementation phase.

Based on the expected ramp-up of R&D activity as a result of initiatives identified in the Roadmap, BCTC has increased its R&D budget by $200K in Fiscal 2010. Regulatory approval will be requested for further increases in later years, based on development of specific business cases for initiatives identified in the Roadmap. It may also be possible to fund some of the Roadmap initiatives as a component of regular operational and capital projects.

Recommendation 5:
Develop a business case to increase the R&D Program budget for funding Roadmap activities. Change the existing "program level" budget to a "zero-based" approach, with specific business cases for large value "strategic" projects over a threshold level of $300K. Seek required regulatory approvals.

Recommendation 6:
Develop a criteria and policy for funding some Roadmap initiatives as part of operational and capital projects.

Recommendation 7:
As part of the annual budget cycle, develop a detailed two year project workplan, annual objectives and metrics aligned to the Roadmap goals and initiatives. Provide regular accountability reports on achievement of the objectives and metrics.

Recommendation 8:
Business cases for individual R&D projects should demonstrate alignment with Roadmap objectives and the purpose and actions of specific Roadmap technical focus areas.

7.3 Governance

Governance involves the corporate oversight of the overall R&D Program and Technology Roadmap execution. In recent years, R&D program relationships have been directly between the R&D Program Office and the various department representatives, with approval of all projects delegated to the R&D Program Manager. R&D annual business plans and regulatory applications are reviewed by executive management at a program level.

In interviews with comparable electric utilities during development of the Roadmap, it was noted that there is significant value in having a senior management steering committee oversee the R&D Program. This provides greater visibility and support for technology initiatives throughout the corporation. Given today's focus on technology innovation at BCTC, and the fact that the Roadmap will be driving increased expenditures in technology, it would be worthwhile to establish a senior management steering committee to oversee the R&D Program and execution of the Transmission Technology Roadmap.

Recommendation 9:
Establish a senior management steering committee for the R&D Program and Technology Roadmap execution, to review and advise on business plans, strategies, budgets and sign-off on strategic projects above a funding threshold of $300K. Managers of key technology user departments within BCTC should actively participate in the governance process.

7.4 Technology Sourcing

BCTC lacks the size to retain in-house "hands-on" R&D resources. Its strategy has been to leverage internal resources by contracting the majority of R&D projects to organizations such as Powertech Labs Inc., BC Hydro Engineering, manufacturers, consultants, universities and industry research consortia such as CEATI International, Electric Power Research Institute, and Power Systems Engineering Research Center (PSERC). These collaborative relationships bring many benefits to BCTC through the sharing of research costs and adoption of industry best practices.

Given the high level of funding in R&D and product development by manufacturers compared to utilities, it very important that BCTC maintain close relationships with manufacturers on emerging technologies and utility needs.

There is an opportunity to strengthen BCTC's collaborative relationships through "open innovation" partnerships with manufacturers, research organizations and other utilities. By example, BCTC recently partnered with the University of British Columbia Department of Electrical and Computer Engineering to sponsor an undergraduate Energy Systems Option, which provides benefits to BCTC in terms of directed projects and a future pool of well qualified employees.

Recommendation 10:
Investigate establishing strategic partnering relationships with industry research entities, including establishment of Centres of Excellence, to ensure increased understanding of needs and quick access to quality services.

Recommendation 11:
Establish formal relationships with key equipment manufacturers to ensure that BCTC's technology needs and gaps are communicated, and to gain early insight into product developments.

Recommendation 12:
Establish strategic relationships with key utilities for sharing technology best practices and performing collaborative development.

Recommendation 13:
Explore internet-based models for exposing BCTC technology needs and gaps to the marketplace, to solicit formal and informal proposals for technology solutions.

7.5 Implementation of R&D Results

The Roadmap lays out a program of initiatives that will explore and bring new technologies to the attention of technical staff and decision makers in BCTC. However, it is critical that these investments deliver value through implementation of the technologies in operational and capital projects. This is often the critical gap in technology programs and BCTC must strive to avoid the problem of unimplemented R&D results. Accountability and commitment are needed to guarantee that successful R&D projects are operationalized.

Recommendation 14:
All project approvals for technology investigations will include an implementation plan, identifying costs and the person(s) responsible for implementation.

Recommendation 15:
One or more R&D Program Office staff should be assigned responsibility for facilitating the implementation into company operations of new technologies investigated by BCTC, supported with appropriate tools for tracking implementation progress.

Recommendation 16:
Evaluation of project options in capital, operational and long term planning projects should include a full range of technology solutions linked to the Roadmap objectives and initiatives, and results of completed R&D projects.

Recommendation 17:
Modify the capital project optimization tool to include an assessment of technology innovation and alignment with Roadmap objectives and initiatives.

Recommendation 18:
Raise internal awareness of R&D project results (see recommendations in Section 7.6).

7.6 Knowledge Management (Idea Generation, Information Sharing, Communications)

The success of BCTC technology innovation depends on employee idea generation, the breadth and quality of information that can be acquired within and external to the company, and the ability of employees to widely share and communicate knowledge. The Roadmap relies on effective employee identification of technology needs, gaps and potential solutions. Awareness of potential solutions is most easily gained through participation in industry activities such as technical societies, standards development organizations, and collaborative research programs. BCTC lacks the size to have employees represented in all possible technical areas that are of interest to the company. It is important for BCTC to take a strategic view on how technical information is acquired from external sources, and then ensure that processes and systems are in place to make the information available within the organization. It is also important that employees in various disciplines and functional areas gain awareness of the problems and solutions being pursued in other areas of the company, to ensure that the best solutions are put forward. External communication of technology successes to the general public and to technical audiences is also important for facilitating dialog on technology needs and solutions. Several recommendations are provided for improving BCTC's processes in this area.

Recommendation 19:
Continue development of searchable knowledge and document management systems to improve technical information sharing across BCTC (for example, Wiki, R&D Sharepoint). Link to on-line technical information services such as IEEE XPLORE, on-line standards, etc.

Recommendation 20:
Convene regular cross functional and one-on-one meetings of technical staff to explore technology needs, gaps and possible solutions, similar to employee workshops held during development of the Transmission Technology Roadmap. Use the results to formulate R&D project initiatives and updates to the Roadmap.

Recommendation 21:
Hold cross-functional employee meetings to present results of BCTC R&D projects, and presentations by manufacturers, research organizations and university researchers.

Recommendation 22:
Develop a strategy for employee coverage of key technical society, standards organizations and collaborative research organizations, including associated information dissemination within the company.

Recommendation 23:
Increase internal and external communication of technology project results, through internet / intranet, press releases and technical journal articles.

Recommendation 24:
Dedicate one full time equivalent staff to facilitate technology knowledge management and communications.

7.7 Roadmap Refresh Process

The Transmission Technology Roadmap is a living document and should be updated on a regular basis to reflect changes in corporate priorities, technology developments and comments received from employees and external stakeholders.

Recommendation 25:
Refresh the Roadmap at least annually based on BCTC's strategic planning outcomes and employee and public comments, as well as input from research partners including manufacturers, research organizations and other utilities.

8. References

1. The BC Energy Plan http://www.energyplan.gov.bc.ca/

2. BCTC F2008 to F2018 Transmission System Capital Plan http://www.bctc.com/regulatory_filings/capital_plan/current_capital_plans/

3. Continuing Innovation on BC's Grid: Highlights of BCTC's Technology Initiatives, British Columbia Transmission Corporation, 2008

4. 2007 State of the Transmission System Report, Reference 2, Appendix B http://www.bctc.com/regulatory_filings/capital_plan/current_capital_plans/

5. BCTC Corporate Strategic Plan: see BCTC Service Plan posted at http://www.bctc.com/about_bctc/reports_performance/

9. Glossary of Terms

ACCR – Aluminium Conductor Composite Reinforced. A new type of high voltage overhead conductor that utilizes lightweight materials for increased current carrying capacity.

Adaptive islanding – a process whereby appropriate mitigation actions are taken to limit the extent of a power failure, prevent a blackout and facilitate restoration. This process involves separating the system into smaller islands at lower capacity and then applying adaptive load shedding to bring the frequency back to an acceptable level.

Arc flash – breakdown of electrical resistance in air resulting in an arc to ground or to a lower potential. The energy released can cause injury or fire to nearby equipment or personnel.

ASCE – American Society of Civil Engineers.

ATC – Available Transfer Capability. Unit of measure for the transfer capability remaining in the physical transmission network for further commercial activity, over and above committed uses.

Back-scatter radio – use of reflected radio waves from a remote device to an originating transmitter to transfer information from the remote device, often used in radio frequency identification tags (RFID). The technology is a low cost means to interrogate the condition of remote assets such as transmission line hardware using flyover technology.

Braking resistors – high capacity resistors switched onto the power system to control generator frequency rise during line faults, thus maintaining transient stability of the network. BCTC utilizes braking resistors at GM Shrum Generation Station for transient stability control of the Peace River transmission system.

CAES – Compressed Air Energy Storage.

CCRP – BCTC's Climate Change Response Program.

CCTV – Closed Circuit Television.

CEATI International Inc. - Centre for Energy Advancement through Technological Innovations (formerly Canadian Electricity Association Technologies Inc.)

CIGRE - International Council on Large Electric Systems

CIM – Common Information Model. A set of standards developed by the International Electrotechnical Commission (IEC) for facilitating the exchange of data and information among electric utility applications, both within the utility and externally.

Closed-loop control – A control system in which the output (controlled variable) is fed back and compared to a reference signal (setpoint) for purposes of maintaining the output at a value close to the setpoint. Thermostatic control of home heating is an example.

Corona discharge – the creation of ions in air by the presence of a strong electric field such as near a high voltage conductor. Corona discharge causes power loss and creates audible and radio-frequency interference.

CSA - Canadian Standards Association.

CT – Current Transformer. An electromagnetic device used to measure current flow in high voltage apparatus. The device produces a low current replica of the actual current that can be used safely in metering and protection devices.

CVT – Capacitive Voltage Transformer. A device used to measure voltage in high voltage apparatus, utilizing capacitors and electromagnetic components. The device produces a low voltage replica of the actual voltage that can be used safely in metering and protection devices.

DCR – Dynamic Circuit Rating. Methodologies for determining the maximum instantaneous or future rating of a circuit based on measurement of actual operating conditions rather than published design ratings.

DFIG - Doubly Fed Induction Generator. A type of induction generator often used for wind generation, allowing a variable speed turbine to be connected to a synchronous power system.

Dielectric – A material that is non-conducting, used for electrical insulation.

DMS – Distribution Management System.

DOE – U.S. Department of Energy.

DSA - Dynamic Security Assessment.

DSG – Dispatchable Standby Generation.

DSM - Demand Side Management. A wide range of initiatives undertaken to reduce customer capacity and energy requirements.

Eddy current – the induced electric current circulating in a conducting material that results from a varying magnetic field.

Electricity self-sufficiency – the ability to generate sufficient electricity to meet domestic loads without the need for import from connecting networks.

EMF - The electric field and the magnetic field created by electrically charged particles. The electric field is produced by the voltage on a component, irrespective of current flow. The magnetic field is produced when electric current is flowing.

ESB - Enterprise Service Bus, a standards-based software architecture for integrating various business and real-time applications utilizing middleware infrastructure.

EPRI – Electric Power Research Institute.

EHV - Extra High Voltage, commonly in the range of 360 kV to 765 kV.

FACTS – Flexible Alternating Current Transmission Systems.

Fast transient voltage – A sudden or momentary overvoltage condition caused by electrostatic discharge, lightning or switching of power system components.

FERIC – Forest Engineering Research Institute of Canada.

FinGrid – Finnish national transmission system grid operator.

Flywheel – A rotating disc used to store kinetic energy.

FRP – Fibre reinforced polymers.

Future Grid – A focus area for the Transmission Technology Roadmap comprising technology for next generation substations, control centres, and other components of the network.

GHG – Greenhouse Gas.

GIS – Geographic Information System.

Harmonics – Voltages and currents existing in the power system that are multiples of the fundamental frequency of 60 Hz. These may cause problems in power system and customer equipment.

HTLS – High temperature, low sag.

HTS - High temperature superconductors.

HVDC - High Voltage Direct Current.

Hyperspectral imaging – The use of special sensors to collect images from the electromagnetic spectrum ranging from infrared to ultraviolet bands. The images are used for detection of chemical content, abnormal heating, etc.

IEC – International Electrotechnical Commission

IEEE – Institute of Electrical and Electronic Engineers Inc.

IGBT – Insulated Gate Bipolar Transistors. A power switching device consisting of series connected semiconductor elements and commonly used in high voltage applications in conjunction with voltage source converters.

IPPC – Intergovernmental Panel on Climate Change

ITOMS - International Transmission Operations and Maintenance Study. A consortium of international transmission companies involved in benchmarking and best practices studies. .

IUN – Intelligent Utility Network. An IBM-led initiative, IUN is an information architecture and infrastructure that enables the continuous automated monitoring of a utility’s assets and operations as well as customer electricity usage, and uses this “on demand” information to improve service, reliability and efficiency.

LiDAR – Light Detection and Ranging. Sensor technology using the properties of scattered light to find the range and orientation of targets.

NASPI – North American Synchrophasor Initiative.

NASPInet - A communications architecture proposed by NASPI for enabling the communication and integration of large amounts of synchrophasor information.

NDT – Non-destructive test

NERC – North American Electric Reliability Corporation.

NETL – National Energy Technology Laboratory.

OMA – Operations, Maintenance and Administration. A category of BCTC spending that is expensed in the fiscal year that it is incurred.

OSH - Occupational, Safety and Health

PCB - Polychlorinated biphenyls. Used as a coolant and insulating fluid in transformers, capacitors and other power equipment.

Peak-shaving – Using stored energy, distributed generation or other means to supplement electricity delivered to customers during peak periods.

Phasor – See Synchrophasor.

PHEV - Plug-in Hybrid Electric Vehicle

PMU – Phasor Measurement Unit. A technology for measuring voltage, current and phase angle quantities and tagging the measurements with a time signal derived from the Global Positioning Satellites (GPS), usually 30 times per second.

Point-on-Wave Switching – the process of operating the contacts of the independent phases of a circuit breaker at a specific time synchronized to the ac waveform to minimize transients.

Power system stabilizers – Equipment installed on the automatic voltage regulator of generators to improve power system stability by detecting changes in the generator output power and making appropriate adjustments.

Protocol – The conventions or standards governing data transfer and communication between two computing devices.

PSERC – Power Systems Engineering Research Center.

RAS - Remedial Action Scheme. Pre-planned responses to emergencies in the power system to isolate the impact of disturbances and prevent blackouts.

RF – Radio Frequency.

RTDMS – Real-time Dynamics Monitoring System.

SCADA – Supervisory Control and Data Acquisition.

SCFF - Self-contained fluid filled. A type of high voltage cable.

SF6 – Sulfur hexafluoride. A colorless, odorless, non-toxic and non-flammable gas used as an insulator in high voltage electric equipment.

S-GTO - Super Gate Turnoff Thyristor, a new silicon-based switching device that promises much higher current ratings and improved switching efficiency in power electronics controllers.

Smart Grid – A focus area of the Transmission Technology Roadmap. The foundation for power system management that is based on extensive communication systems that monitor and allow automatic optimization of interconnected elements of the system.

SMES – Superconducting Magnetic Energy Storage.

SOA – Service Oriented Architecture, a standards-based software architecture for exchanging information among various business and real-time applications.

S-P - Synchrophasor

Spinning reserve – The reserve generating capacity that is synchronized to the system but running at zero load.

Stage gate – an approach used in R&D to determine if a project should be continued or suspended based on achievement of identified milestones.

Statcom – Static Compensation. A type of FACTS device used for control of reactive power.

State estimation – A system control application that processes telemetered power measurements to obtain a snapshot of the magnitude and phase angle of all power system quantities. Used as the primary input to advanced control centre applications such as transient stability assessment and voltage stability assessment.

Static excitation – High speed thyristor based equipment used to generate the DC field current for control of synchronous generators.

Static var compensator – A FACTS device used to provide fast reactive power compensation on high voltage transmission networks.

Surge impedance load – The real power loading of a line at which there is reactive power balance and the voltage profile becomes flat.

Synchrophasor – Also called synchronized phasors. Highly accurate voltage, current, and phase angle snapshots of the instantaneous state of the transmission system, synchronized to the time signal of the Global Positioning Satellites, usually 30 times per second.

Thermography – A type of imaging using the infrared spectrum.

TRA – Threat Risk Assessment.

Transients – Sudden, short-lived changes in voltage or current.

Transient stability – The ability of a transmission network to maintain stability after the occurrence of a fault, trip or generator / load shedding event.

Tripole DC – A high voltage DC configuration in which one bipole and one monopole are configured in parallel to eliminate earth return current. The maximum power transfer is 1.37 times the level achievable with a bipole on the same three-conductor system.

TTC – Total Transfer Capacity. The total amount of power that can be transferred reliably over a transmission circuit or path.

UAV – Unmanned Autonomous Vehicle.

UHV – Ultra High Voltage, usually define as 800 kV and above.

Up-rating – An increase in the voltage or power capacity of a circuit element.

V2G – Vehicle to Grid. A concept in which plug-in electric vehicles return energy to the power system under control of the utility.

Voltage Ride-through – Relating mainly to wind-turbine generators, to conform to reliability standards, a generator must remain connected and synchronized to the grid when the voltage at the terminals of the generator fall to a certain level.

Voltage stability – The ability of a power system to withstand voltage collapse due to inadequate reactive power reserves following contingencies such as line tripping, generation tripping, etc.

VSC - Voltage Source Converter. A power electronics device used to couple a direct current link to an alternating current network or a direct voltage source to an alternating current network. It can also provide reactive power compensation and active filtering.

VT – Voltage Transformer. A device used to measure the voltage in high voltage power apparatus. It produces a low voltage replica of the actual voltage that can be used safely in metering and protection devices.

WECC – Western Electricity Coordinating Council.

XLPE –Cross-linked polyethylene. A type of insulating material used in high voltage power cables.