DTA

Devine Tarbell & Associates, Inc.
Consulting Engineers, Scientists, & Regulatory Specialists

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September 23, 2003

32.00.0244.01/8.0

Mr. Anthony J. Como
Office of Fossil Energy (FE-27)
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

VIA FED EX STANDARD
202-586-5935

Subject: **Application of Bangor Hydro-Electric Company for a Presidential Permit Modification**

Dear Mr. Como:

On behalf Bangor Hydro-Electric Company (BHE), Devine Tarbell & Associates, Inc. (DTA) is pleased to submit this application for a Presidential Permit Modification for the Proposed 345 kV Tie Line Project (Project). BHE is requesting a modification of the previously authorized transmission corridor, as issued in Presidential Permit PP-89 authorizing the construction, operation, maintenance, and connection of facilities for the transmission of electric energy between the U.S. and Canada. The authorized facilities consisted of 83.8 miles of 345,000-volt (345 kV) transmission line crossing the border at Baileyville, Maine, and terminating at a substation in Orrington, Maine. At the border, the facilities were to interconnect with similar facilities owned by New Brunswick Power Corporation (NB Power), a Crown corporation of Canada's Province of New Brunswick.

Enclosed is a $150 check (No. 268801) to cover the application fee and one original and 14 copies of the application and supporting Exhibits.

If you should have any questions or need additional information please do not hesitate to contact Fred Leigh of BHE at (207) 973-2543 or myself at (207) 775-4495. We look forward to working with DOE on this project.

Sincerely,

DEVINE TARBELL & ASSOCIATES, INC.

Gil A. Paquette, CWB, PWS
Project Manager

GAP/elt
Enclosures

cc: F. Leigh, BHE
J. Browne, Verrill & Dana
R. McAdam, Emera
Library
B. Scott, NB Power
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UNITED STATES OF AMERICA
BEFORE THE DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
FE DOCKET NO. PP-89
BANGOR HYDRO-ELECTRIC COMPANY

APPLICATION OF BANGOR HYDRO-ELECTRIC COMPANY FOR A PRESIDENTIAL PERMIT MODIFICATION

Prepared for:
BANGOR HYDRO-ELECTRIC COMPANY
Bangor, Maine

Prepared by:
DEVINE TARBELL & ASSOCIATES, INC.
Portland, Maine

SEPTEMBER 2003

APPLICATION OF BANGOR HYDRO-ELECTRIC COMPANY FOR A PRESIDENTIAL PERMIT MODIFICATION

TABLE OF CONTENTS

Section	Title	Page No.
	INTRODUCTION	4
	BACKGROUND	5
A.	INFORMATION REGARDING THE APPLICANT	7
1.	Legal Name of the Applicant	7
2.	The Legal Name of all Partners	7
3.	Communications and Correspondence	7
4.	Foreign Ownership and Affiliations	8
5.	List of Existing Contracts with Foreign Governments or Foreign Private Concerns Relating to the Purchase, Sale or Delivery of Electric Energy	9
6.	Showing Including a Signed Opinion of Counsel	9
B.	INFORMATION REGARDING THE TRANSMISSION FACILITIES	9
1.	Technical Description	10
2.	General Area Map	12
3.	Applications for Facilities at 138 kV or Higher	12
C.	INFORMATION REGARDING ENVIRONMENTAL IMPACTS	14
1.	Statement of the Environmental Impacts of the Proposed Facilities Including a list of each floodplain, wetland, critical wildlife habitat, etc.	14
2.	A List of Known Historic Places	14
3.	Minimum Rights-of-Way for Construction, Operation and Maintenance of the Transmission Lines	14
4.	Threatened or Endangered Wildlife or Plant Life	15
D.	A BRIEF DESCRIPTION OF PRACTICAL ALTERNATIVES AND GENERAL IMPACTS	15

TABLE OF CONTENTS
(Continued)

Section	Title	Page No.

EXHIBITS

EXHIBIT A - CANADA NATIONAL ENERGY BOARD REASONS FOR DECISION - NEW BRUNSWICK POWER CORPORATION (EH-2-2002)
EXHIBIT B - OPINION OF COUNSEL
EXHIBIT C - TYPICAL STRUCTURES
EXHIBIT D - GENERAL AREA MAP
EXHIBIT E - SYSTEM IMPACT STUDY

UNITED STATES OF AMERICA
BEFORE THE DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY
FE DOCKET N0. PP-89
BANGOR HYDRO-ELECTRIC COMPANY

APPLICATION OF BANGOR HYDRO-ELECTRIC COMPANY FOR A PRESIDENTIAL PERMIT MODIFICATION

INTRODUCTION

On January 22, 1996, pursuant to Executive Order 10485, as amended by Executive Order 12038, the Office of Fossil Energy (FE) of the U.S. Department of Energy (DOE) issued Bangor Hydro-Electric Company (BHE or the "Applicant") Presidential Permit PP-89 authorizing the construction, operation, maintenance and connection of facilities for the transmission of electric energy between the U.S. and Canada. The authorized facilities consisted of 83.8 miles of 345,000-volt (345 kV) transmission line crossing the border at Baileyville, Maine, and terminating at a substation in Orrington, Maine. At the border, the facilities were to interconnect with similar facilities owned by New Brunswick Power Corporation (NB Power), a Crown corporation of Canada's Province of New Brunswick. The Order limited use of the transmission line to a maximum rate of transmission, when combined with the facilities authorized to Maine Electric Power Company in President Permit PP-43, to a maximum rate of transmission, in the import mode, of 1,000 megawatts (MW). When the PP-43 facilities are out of service, operation of the BHE facilities was to be limited to a maximum rate of transmission of 700 MW in the import mode. At the time this transmission line is used to export electric energy to Canada, BHE understands that an appropriate exporting entity will be responsible for notifying DOE and obtaining the approvals to do so.

BHE is hereby requesting a modification of the previously authorized transmission corridor. In support of this request, BHE is submitting the following information:

BACKGROUND

As reflected in the initial application and supporting documentation, the planned overhead transmission line and associated existing substation and appurtenant equipment modifications in Maine (the "Project") will interconnect two existing bulk transmission systems, i.e., New England and New Brunswick, and have a thermal capacity of at least 1,000 MW at 345 kV. Actual power flows over the facilities will depend on daily operating and market conditions, and flow sharing with an existing circuit.

The Canadian facilities will be owned and operated by NB Power and will include approximately 60 miles of new overhead 345 kV line to be constructed from Pt. Lepreau, New Brunswick to the U.S. border at Baileyville, Maine. The National Energy Board of Canada has now approved that portion of the project (see Exhibit A).

BHE's portion of the Project was issued U.S. regulatory approvals in the 1990s, which included receipt of a Presidential Permit (PP-89) in January 1996. Those approvals were for a route known as the Stud Mill Road Route (SMRR), connecting Baileyville to Orrington, Maine. That route generally followed the road of the same name, but importantly, did depart from the road by several thousand feet at times. After obtaining both federal and state permits for the proposed facilities, BHE did not commence construction of the Project for various reasons. BHE received the original state permit in 1992, with permit extension requests granted by the Department of Environmental Protection (DEP) in 1994 and 1996. In 1999, Maritimes and Northeast Pipeline, L.L.C. (M&N) constructed a gas transmission pipeline in the vicinity of the Stud Mill Road and the Project's previously approved corridor. In 2001, acting on a request from BHE for a third extension of the relevant state environmental permits, the Board of Environmental Protection (BEP), Maine's primary environmental review entity, conducted a hearing and indicated a preference to use a route more closely consolidated with established linear corridors.

Because NB Power has achieved recent approval from the National Energy Board for the Canadian facilities, BHE is now evaluating various engineering or modified route options with the purpose of designing a project that coordinates with the approved NB Power line and responds to the issues raised by BEP and certain stakeholders. Route options to be evaluated will include a new Consolidated Corridor Route (the CCR) that will utilize some of the previously permitted SMRR (e.g., those portions already adjacent to the Stud Mill Road, the pipeline, or other electric transmission line rights-of-ways [ROW]), while other portions of the proposed route will be moved nearer or adjacent to those features. BHE is in the process of meeting with stakeholders and regulators to assess alternative routes, all of which would be located within the Project area reflected in Exhibit D. BHE believes that coordination of that process with DOE's environmental review will be beneficial.

Characteristics of overhead electric transmission lines and the expected impacts are discussed generally below, however, exact engineering specifications and route modifications for the Project will be determined based on careful analysis of the purpose of the project, engineering and environmental constraints, and agency and stakeholder consultation. In addition to BHE's request for a Presidential Permit modification, BHE will also request DEP and Army Corps of Engineers approval of the modified route, and will request a Certificate of Public Convenience and Necessity from the Maine Public Utilities Commission.

A. INFORMATION REGARDING THE APPLICANT

1. Legal Name of the Applicant

The legal name of the Applicant is Bangor Hydro-Electric Company. BHE is a regulated electric utility operating in eastern and central Maine. BHE is a wholly owned subsidiary of Emera, Inc. of Halifax Nova Scotia, Canada. BHE has its principal place of business at 33 State Street, Bangor, Maine 04401.

2. The Legal Name of all Partners

For this project, BHE is partnering with New Brunswick Power Corporation (NB Power). NB Power is a Crown Corporation and a vertically integrated utility with generation and transmission facilities within the Province of New Brunswick, Canada. However, the Government of the Province of New Brunswick has announced its intention to restructure NB Power into a holding company and four operating companies. One of the operating companies will be NB Power Transmission, which will construct, own, and operate the New Brunswick portion of the Project. BHE will construct, own, and operate the U.S. portion.[1] Development and operation costs are or will be shared between NB Power and BHE per the terms of various existing or contemplated agreements, and recovered under the terms of a FERC-approved tariff.

3. Communications and Correspondence

All communications and correspondence regarding this Application should be addressed to the following persons:

[1] It is also possible that ISO-New England will regulate commerce over the line. In either event, FERC will approve the tariff.

Mr. Robert Bennett
Bangor Hydro Electric Co.
33 State St.
P.O. Box 920
Bangor, Me 04402-0920
207-973-2841

Mr. James L. Connors, Q.C.
Emera, Inc.
1894 Barrington St.
Barrington Tower
Halifax, Nova Scotia
Canada B3J 2A8
902-428-6454

4. Foreign Ownership and Affiliations

BHE is a wholly owned subsidiary of Emera, Inc. of Halifax, Nova Scotia. Emera, Inc. (EMA-TSX) is a diversified energy and services company, with 550,000 customers and $4.0 billion (Canadian dollars) in assets. Emera has two wholly owned regulated electric utility subsidiaries: Nova Scotia Power, Inc., and BHE. Nova Scotia Power supplies over 95 percent of the electric generation, transmission and distribution in Nova Scotia. BHE provides electric transmission and distribution services to 107,000 customers in eastern and central Maine. It is a member of the New England Power Pool, and is interconnected with the other New England utilities to the south, and with NB Power to the north. Emera's other principal holdings are a 12.5 percent interest in the M&N Pipeline, an 8.4 percent interest in the Sable Island Offshore Energy Project offshore platforms and sub-sea field gathering lines, Emera Energy Inc., and Emera Fuels.

As noted above, for this Project, BHE will have an affiliation with NB Power. NB Power is a Crown Corporation, owned by the provincial government of New Brunswick, Canada. NB Power will construct, own and operate the New Brunswick portion of the Project. BHE will construct, own and operate the U.S. portion. Development and operation costs are or will be shared between NB Power and BHE per the terms of various existing or contemplated agreements. In addition, these agreements are intended to provide protections to BHE and NB Power, which recognize the mutual dependence of the two developers.

5. List of Existing Contracts with Foreign Governments or Foreign Private Concerns Relating to the Purchase, Sale or Delivery of Electric Energy

BHE has, or will have, agreements with NB Power, a Crown Corporation, to coordinate development and operation of the Project. These agreements do not address purchase, sale, and delivery of energy, which will be regulated by a FERC-approved tariff. BHE is part owner of the Maine Electric Power Company (MEPCO), which owns and operates an existing 345 kV tie line to New Brunswick, Canada. MEPCO has, or may have, contracts with NB Power or other Canadian entities for transmission service across the existing tie line.

6. Showing Including a Signed Opinion of Counsel

As set forth in an opinion of counsel attached hereto as Exhibit B, the construction, connection, operation or maintenance of the proposed transmission facilities described herein are within the corporate powers of BHE. Further, BHE has complied with, or will comply with, all pertinent federal and state laws related to the construction, operation or maintenance of the proposed Project.

B. INFORMATION REGARDING THE TRANSMISSION FACILITIES

The technical specifications and design details will be finalized after consultation with agencies and stakeholders, and after an evaluation of engineering data and costs. Other detailed information will be provided in a subsequent filing.

1(i). Technical Description

A. Number of Circuits

The Project will include one overhead circuit.

B. Operating Voltage/Frequency

The Project will be 345 kV AC at 60 cycles per second.

C. Conductor Size

The new line will consist of two overhead shield wires and three phases with two conductors per phase. The line will be constructed to have a minimum of 27 feet of ground clearance when the conductors are at maximum design sag. This ground clearance will meet or exceed National Electric Safety Code requirements. The shield and conductor wires are expected to be as follows:

Shield:	Two 7 No. 8 Alumoweld
Conductor:	1192.5 kcml, 45/7 ACSR code “Bunting”
	(2 per phase)
	Diameter: 1.302 inches
	Weight: 1.344 lb/ft
	Rated Breaking Strength: 32,000 lb

One shield wire may be replaced with an optical ground wire (OPGW) if BHE elects to install fiber communication as part of the Project. If BHE later desires to utilize any communication for purposes other than that required to operate the transmission line, BHE will notify DOE.

(ii) Overhead Line Additional Information

A. Wind and Ice Loading Parameters

The line will meet National Electric Safety Code Specifications (radial ice of 0.5-inch thickness and 4 ib/ft^2 of wind pressure).

B. Full Description and Drawing of a Typical Support Structure

Structure types, numbers, strength specifications and locations will be finalized after consultation with agencies and stakeholders, and an evaluation of engineering data and costs. This information will be provided in a subsequent filing.

One option is to use wood H-Frame design as the primary structure type. If this is presumed, tangent structures will be self-supporting. Light and medium angle structures will use guys to support the wood poles. Wood poles will be 70 to 110 feet in length and embedded 9 to 12 feet in the ground. Pole sizes will be class 1, H1, H2, H3, and H4 with an approximate ground-line diameter of 1.5 to 2.0 feet, and pole tops of approximately 1.0 feet in diameter. The use of steel poles that meet or exceed wood pole specifications is also an option that will be evaluated.

Steel pole dead-end and lattice structures could be utilized. If used, the steel pole dead-end structures will be founded on 9-foot concrete cylinders by 27 feet deep. These would typically be galvanized steel lattice design and 85 feet tall. Each lattice tower would have four cast-in-place concrete foundations, 5 feet in diameter and approximately 22 feet deep. Spacing between foundation centers would be 20 to 40 feet in a square pattern. Each would occupy between .02 and .04 acres. Typical steel and wood pole, tangent and lattice tower structure drawings are shown in Exhibit C.

C. Structure Spacing and Spans

The distance between the structures will vary from 340 to 1,240 feet, with an average span of 825 feet.

D. Conductor (phase) Spacing

Phase spacing for a horizontal orientation (as with wood H design) will be 26 feet.

E. Designed Line to Ground and Conductor Side Clearances

At maximum sag, clearance will be 27 feet to the vegetation below (at 212^{o} F). Side clearances will be a minimum of 59 feet.

2. General Area Map

A map of the project area is included in Exhibit D. Among other features, the map identifies the coordinates and ownership of the facilities at the U.S. border with Canada. The various routing alternatives would be located within the area reflected in Exhibit D.

3. Applications for Facilities at 138 kV or Higher

(i) Expected Power Transfer Rating

While the line will have a thermal capacity of at least 1,000 MW, system conditions will limit import and export opportunities. The Project will create additional firm north-south (New Brunswick to Maine) transfer capacity of 300 MW (700 MW exist now) and additional firm south-north (Maine to

New Brunswick) transfer capacity of 400 MW (no firm capacity exists now). As no particular generator is being interconnected with this transmission project, actual transfers will depend on daily system conditions and market conditions for bulk power.

(ii) System power flow plots for the applicant's service area during heavy summer and light spring load periods, with and without the proposed international interconnection, for the year the line is scheduled to be placed in-service, and for the fifth year thereafter. The power flow plots submitted can be in the format customarily used by the utility, but the ERA requires a detailed legend with the power flows.

Power flows were conducted as part of the System Impact Study (SIS) conducted for the Project, which is attached as Exhibit E.

(iii) Data on the Line Design Features for Minimizing Television and/or Radio Interference

Due to the expected distance of the Project from homes, interference with television and radio signals is not expected. However, some radio interference could occur with vehicles but would be limited to localized receptions (particularly in the AM band) as vehicles pass under the line.

(iv) A Description of the Relay Protection Scheme, Including Equipment and Functional Devices

The SIS describes protection equipment and systems associated with the line (see Exhibit E). The actual protection design and equipment selection will be part of a Facility Study to be conducted in 2004. The final design will be subject to approval by the Northeast Power Coordinating Council's Task Force on System Protection.

C. INFORMATION REGARDING ENVIRONMENTAL IMPACTS

1. Statement of the Environmental Impacts of the Proposed Facilities Including a list of each floodplain, wetland, critical wildlife habitat, etc.

Specific information regarding environmental impacts of the proposed facilities will be provided in a subsequent filing. The document will identify the impacts of constructing, connecting, operating and maintaining the proposed facilities, including identification, as appropriate, of floodplains, wetlands, critical wildlife habitats, navigable waterway crossings, Indian lands, and historic sites.

2. A List of Known Historic Places

Information on historic places will be provided to DOE at a later date.

3. Minimum Rights-of-Way for Construction, Operation and Maintenance of the Transmission Lines

In sections designed with wood or steel H-frame construction, a 170-foot corridor will be created where the Project passes though areas that are wooded on both sides. To the extent the Project parallels the existing 345 kV MEPCO line, an additional 100-foot corridor will be cleared immediately adjacent to the existing corridor. To the extent the route follows an existing road or an existing gas pipeline, it will have a cleared width of between 100 and 170 feet. Exact clearing widths and distances will be calculated based on engineering, reliability, applicable requirements, and discussions with stakeholders. Consideration will be given to the safety of road traffic, the operation and maintenance requirements of the Project, the roadway, and the M&N pipeline.

4. Threatened or Endangered Wildlife or Plant Life

The Atlantic salmon (federally-listed endangered) and bald eagle (federally-listed threatened) are the only known federally listed species that may exist in the Project area. When the original Presidential Permit was issued, the bald eagle was listed as endangered. The Atlantic salmon was added as a federally-listed endangered species in eight rivers in Maine in November 2000. Prior to that date, the Atlantic salmon had no endangered species protective status. The Machias, East Machias, and Narraguagus Rivers, and certain tributaries of these rivers, may be crossed by the proposed Project depending on route selection. These rivers are included in the federal Atlantic salmon listing.

Three species of vascular plants that occur in Maine are listed under federal law (50 CFR, Part 17) as threatened or endangered species. The small whorled pogonia, and prairie white-fringed orchid, are both listed as threatened species, and Furbish's lousewort is listed as endangered. None of these three species are known to occur in the Project vicinity.

Throughout the permitting process, state and federal agencies, including the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, Maine's Department of Inland Fisheries and Wildlife, and Atlantic Salmon Commission will be consulted regarding the presence of threatened or endangered wildlife or plant life that exist in the Project area. Specific information related to endangered or threatened wildlife or plant species will be provided to DOE in a subsequent submittal.

D. A BRIEF DESCRIPTION OF PRACTICAL ALTERNATIVES AND GENERAL IMPACTS

The purpose of the Project is to provide a second 345 kV tie line between New England and New Brunswick, with a location sufficiently distinct from that of the existing tie line in order to create a redundant, more reliable energy transfer facility, to reduce line losses and thereby achieve associated environmental and economic benefits, and to improve access to competitive electric power generation sources in order to provide customer benefits in Maine, New England, and New Brunswick. This may include better power marketing opportunities for frequently dormant renewable generating facilities and other facilities in Maine. The increased integration of the New England Power Pool and the Maritimes control area will provide greater energy security for Maine and New England. The SIS supporting the Project indicates that an additional line is required to connect the BHE/MEPCO substation in Orrington, Maine to a new 345 kV overhead electric transmission line approved for construction originating at Pt. Lepreau, New Brunswick.

Once completed and operational, the Project will address the inadequacy of three important operating conditions posed by the existence of only a single 345 kV tie between New Brunswick and the U.S. These issues are as follows: 1) the lack of any redundancy and the associated reliability implications; 2) high line-losses due to operating only a single tie line; and 3) lack of sufficient capacity to facilitate the efficient transmission of generation capacity and the potential to increase competition and customer benefits.

Possible engineering alternatives to the proposed Project include: 1) uprating the MW capacity of the existing New Brunswick tie line; 2) converting the existing tie line to direct current (DC) thus increasing its capacity and changing its electrical characteristics; and 3) additional generation. These options will be evaluated and discussed in a subsequent submittal.

In addition to consideration of engineering alternatives, route options exist for siting the Project. Several potential transmission line corridors will be analyzed to determine suitability. The potential corridors will be assessed in consultation with state and federal agencies, landowners, and interested stakeholders. Several criteria, including location of other linear project corridors (e.g., road, transmission line, and gas pipeline corridors), environmental impacts, costs, access/constructability, landowner impacts, and Project engineering requirements will be considered in assessing the route alternatives. Detailed discussions on route options will be presented in a subsequent submittal.

General Discussion of Transmission Line Environmental Impacts

Construction and maintenance along the Project route would have both permanent and temporary environmental impacts on the existing habitats and associated ecological communities. The temporary effects are generally related to the construction activities required to develop the new ROW, such as the clearing of overstory trees and vegetation, erection of the new structures, and temporary soil disturbance during construction. These impacts will be relatively minor, short term, and at a localized scale. Temporary construction related impacts are minimized by development and adherence to a detailed erosion control plan, and by scheduling to avoid work during particularly sensitive times for certain areas (e.g., avoiding work near waterfowl, bald eagle, or fish habitats during nesting/spawning periods, and by conducting work in wet areas during the winter construction months or on wooden mats).

Permanent terrestrial habitat effects will result from the unavoidable conversion of forested cover types to shrub or herbaceous types due to clearing. The vegetation in these newly cleared areas will be maintained in an early successional stage throughout the life of the Project through periodic maintenance. It is expected that herbaceous and small woody plants such as meadowsweet, alder, highbush blueberry, raspberries, blackberries, and several sedge and grass species, will dominate the ROW. This long-term conversion of forested cover types to shrub or herbaceous types can offer certain benefits to some wildlife species, including succulent grasses and flowering plants for grazing animals, the production of more fruit for wildlife consumption from berry producing species, and the direct benefits of food, cover, and nesting sites for species dependant on early successional habitats.

Maintained ROWs can provide habitat for early successional bird species such as the chestnut-sided warbler, yellow warbler, common yellowthroat, alder flycatcher, eastern kingbird, and the song sparrow. Wide ranging generalist species, such as coyote and red fox, may use the ROW as travel corridors. In addition, maintained utility ROWs are also used for foraging by several important game species such as white-tailed deer and wild turkey.

Alternately, an effect of a cleared ROW is that cover types important to certain species may be impacted. One common impact associated with transmission lines is the removal of dense coniferous forests that provide important winter cover and browse for whitetail deer (these areas are referred to as "Deer Wintering Areas"). BHE will work closely with Maine's Department of Inland Fisheries and Wildlife to identify Deer Wintering Areas in order to minimize or mitigate for impacts to these areas.

The Project will cross both perennial and intermittent streams, and may cross the Narraguagus, East Machias, and Machias Rivers or associated tributaries depending upon final route selection. Common species that comprise area warm water fisheries include smallmouth bass, chain pickerel, and sunfish. Coldwater species that may occur within the Project area include brook trout and Atlantic salmon. Erosion and sedimentation during construction and vegetation removal adjacent to waterbodies are impacts that may be associated with the construction of transmission line corridors. Sedimentation can result in reduced light penetration, smothering of aquatic feeding and spawning areas, and impairment of aquatic respiration. Removal of vegetation adjacent to waterbodies may increase water temperature due to solar exposure, which may impact coldwater fisheries. However, any impact would be short term, as the ROW will become covered by dense shrubs and emergent vegetation within two growing seasons. To minimize any negative impacts, vegetation will remain in place to the extent practicable to act as a buffer, and appropriate erosion and sedimentation controls will be used. Furthermore, all waterbody crossings will be spanned by the Project and no instream work is anticipated.

Some small amount of permanent impact to wetlands may occur as a result of structure placement or building access roads required to construct and operate the project. However, because transmission line structures span long distances, significant wetland impacts can generally be avoided. Also, although the existing wetland woody species may be converted to scrub-shrub cover type, the primary functions and values of water storage and water quality improvement of the wetlands are generally not impacted.

The specific environmental issues associated with the Project will be identified and analyzed with various state and federal agencies and stakeholders, and provided to DOE in a subsequent submittal.

WHEREFORE, BHE respectfully requests that the DOE modify, as necessary, BHE's Presidential Permit (PP-89) re-authorizing the construction, connection, operation, and maintenance for the facilities described herein for the transmission of electric energy at the international boundary between the U.S. and Canada.

Respectfully yours,

____

Ray Robinson
Chief Operating Officer
Bangor Hydro-Electric Company

____

Date

Before me appeared Ray Robinson, who, being duly sworn, did testify that the forgoing was true and correct to the best of his knowledge and belief.

____

EXHIBITS

EXHIBIT A

CANADA NATIONAL ENERGY BOARD REASONS FOR DECISION - NEW BRUNSWICK POWER CORPORATION (EH-2-2002)

National Energy Board
Office national de l'énergie

Reasons for Decision

New Brunswick Power Corporation

EH-2-2002

May 2003

Facilities

National Energy Board

Reasons for Decision

In the Matter of

New Brunswick Power Corporation

Application dated 31 May 2001, revised 26 July 2002, for an International Power Line.

EH-2-2002

May 2003

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Table of Contents

List of Figures i
List of Appendices i
Abbreviations ii
Recital and Appearances iv

1. Introduction 1
1.1 Background 1
1.2 Project Description 2

2. Need for the Facilities 4
2.1 Existing Facilities 4
2.2 Justification for the Second Interconnection 5

3. Design and Safety of the IPL 8
3.1 Basic Design of the IPL 8
3.2 Electro-Magnetic Fields and Human Health 9
3.3 Audible Noise and Radio Interference 10

4. Public Consultation 12
4.1 Early Public Notification 12
4.2 Aboriginal Peoples 13

5. Routing and Land Matters 15
5.1 Corridor Selection Process 15
5.2 Land Requirements 17
5.3 Land Acquisition Process 17

6. Environment and Socio-Economic Matters 18
6.1 Environmental Matters 18
6.2 Socio-Economic Matters 20

7. Disposition 22

List of Figures

1-1 New Brunswick Power's 345 kV Powerlines and Proposed IPL 3
5-1 Proposed Route 16

List of Appendices

I. List of Issues 23
II. Certificate Conditions 24

Abbreviations

ACSR	Aluminum Conductor Steel Reinforced
Act or NEB Act	National Energy Board Act
AC	alternating current
Agency	Canadian Environmental Assessment Agency
Applicant	New Brunswick Power Corporation
Board	National Energy Board
CEA Act	Canadian Environmental Assessment Act
Certificate	Certificate of Public Convenience and Necessity
CSA	Canadian Standards Association
CSA Standard	Canadian Standards Association Standard CAN/CSA-C22.3 No. 1 Overhead Systems
CSR	comprehensive study report
dBA	decibels (A weighting)
DFO	Department of Fisheries and Oceans Canada
EC	Environment Canada
Emera	Emera Energy Inc.
EMFs	electro-magnetic fields
EPN	Early Public Notification
GFR	Guidelines for Filing Requirements
HQ	Hydro-Québec
HVDC	high voltage direct current
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IPL	international power line
km	kilometre(s)
KP	kilometre post
kV	kilovolt(s)

kV/m	kilovolts per metre
line	power line
m	metre(s)
MAWIW	MAWIW Tribal Council
mG	milliGauss
Minister	Minister of Natural Resources
MCA	Maritimes Control Area
MCM	Thousands of Circular Mils
MEPCO	Maine Electric Power Company
MW	megawatt(s) (1,000 kilowatt; 1,000,000 Watt)
NB APC	New Brunswick Aboriginal Peoples Council
NB Power	New Brunswick Power Corporation
NPCC	Northeast Power Coordinating Council
NEB	National Energy Board
NEPOOL	New England Power Pool
NERC	North American Electric Reliability Council
PCP	Public Consultation Program
RI	radio interference
ROW	right of way
Saint John Citizens Coalition for Clean Air	Citizens Coalition
TEDC	Tobique Economic Development Corporation
UNBI	Union of New Brunswick Indians
US	United States of America

Recital and Appearances

IN THE MATTER OF the National Energy Board Act (the Act) and the regulations made thereunder; and

IN THE MATTER OF an application dated 31 May 2001, revised 26 July 2002, by New Brunswick Power Corporation (NB Power) for a Certificate of Public Convenience and Necessity (Certificate) for the construction and operation of an international power line; and

IN THE MATTER OF Hearing Order EH-2-2002 dated 6 December 2002;

HEARD in Saint John, New Brunswick on 24 March 2003;

BEFORE:

J.-P. Théorêt	Presiding Member
K.W. Vollman	Member
G. Caron	Member

APPEARANCES:

I. Blue A. Hamilton	New Brunswick Power Corporation
G. Dalzell	Saint John Citizens Coalition for Clean Air
N. Getty R. Perley	Union of New Brunswick Indians
J. Feron S. Fraser	Emera Energy Inc.
D. Tucker	On his own behalf
I. Blue A. Hamilton	Province of New Brunswick
C. Beauchemin D. Saumure	National Energy Board Counsel

Chapter 1

Introduction

1.1 Background

On 31 May 2001, New Brunswick Power Corporation (NB Power or the Applicant) applied to the National Energy Board (the Board) pursuant to sections 58.16 and 58.23 of Part III.1 of the *National Energy Board Act* (the Act) for a certificate of public convenience and necessity to construct and operate a 345 kilovolt (kV) international power line (IPL). In doing so, the provisions of the Act referred to in section 58.27 would apply in respect of the proposed IPL, rather than the laws of the Province of New Brunswick. NB Power later filed a revised application with the Board on 26 July 2002.

Prior to filing its application, NB Power filed a preliminary submission on 19 April 2001 for the Canadian portion of the 345 kV IPL from Point Lepreau, New Brunswick to Orrington, Maine. Pursuant to the *Canadian Environmental Assessment Act* (CEA Act), the environmental assessment process for the Project commenced on 4 May 2001with the issuance of a letter under section 5 of the *Regulations Respecting the Coordination by Federal Authorities of Environmental Procedures and Requirements*. The 4 May letter also outlined that, if applied for, the proposed IPL would require the completion of a comprehensive study report (CSR) pursuant to the CEA Act as the proposed IPL would have a voltage of 345 kV and would require greater than 75 km in length of new right of way. The Board also requested input from those federal authorities that had expressed an interest in the Project.

As responsible authorities for the project, the Board and the Department of Fisheries and Oceans Canada (DFO) in consultation with the Canadian Environmental Assessment Agency (the Agency) established a process for the preparation of the CSR and advised NB Power on 16 August 2001 that NB Power, as the proponent of the project, would be responsible for carrying out a comprehensive study and preparing a CSR pursuant to section 17 of the CEA Act. Participants in the process included NB Power, DFO and Board staff. Environment Canada (EC) and the Agency also participated by providing specialist advice as federal authorities. More information on the CSR is provided in Chapter 6 of these Reasons.

The Board established a process to assess NB Power's revised application and published Hearing Order EH-2-2002 on 6 December 2002.

NB Power published notices of the hearing in the Canada Gazette, Globe & Mail and National Post (Financial Post), and the following New Brunswick newspapers: the Telegraph Journal (Saint John), Daily Gleaner (Fredericton), Times & Transcript (Moncton), Saint John Times Globe, St. Croix Courier (St. Stephen), and L'Acadie Nouvelle (Caraquet).

The Board held an oral public hearing to consider NB Power's revised application on 24 March 2003 in Saint John, New Brunswick.

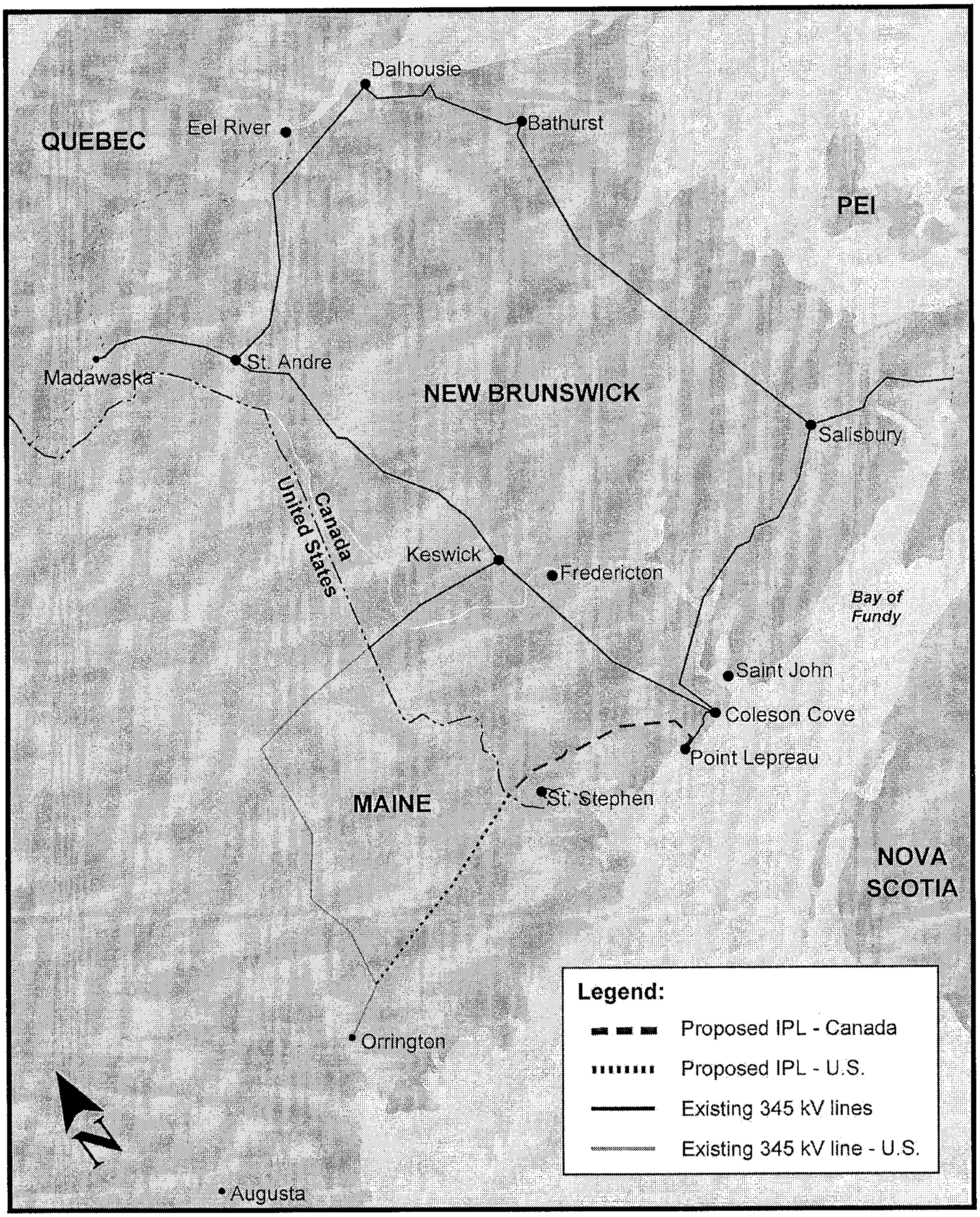
1.2 Project Description

The proposed IPL is a 345 kV transmission line from the Point Lepreau Peninsula on the Bay of Fundy in New Brunswick, through Saint John and Charlotte counties to a point on the international border between Canada and the United States of America (US) near Woodland, Maine (Figure 1-1). The IPL would be 95.5 km long and would cost an estimated $43 million.

The IPL was originally planned to connect with a new 345 kV transmission line running from the international border to Orrington, Maine which would be owned by Bangor Hydro. Bangor Hydro was purchased by Emera Energy Inc. (Emera) which was undecided about whether to proceed with the project. Regardless, NB Power was of the view that the proposed IPL, if approved, will be an important component in opening up the electricity market in New Brunswick and that Emera or others may therefore be interested in completing the proposed IPL.

The stated purpose of the IPL is to improve the reliability, efficiency and market access of the regional electricity system.

Figure 1-1
New Brunswick Power's 345 kV Powerlines and Proposed IPL



Chapter 2

Need for the Facilities

2.1 Existing Facilities

NB Power's electric power system is one of the three Canadian and two US (Northern Maine) electric utility systems comprising the Maritimes Control Area (MCA) of the Northeast Power Coordinating Council (NPCC). The NPCC in turn is one of the ten regional reliability councils of the North American Electric Reliability Council (NERC).

NB Power has one IPL commonly known as the Maritime Electric Power Company (MEPCO) line. This IPL interconnects all MCA members' systems to other NPCC members' systems in the US. It runs between NB Power's Keswick station in Canada and Bangor Hydro's Orrington station in Maine. It is operated at the same voltage level as the equipment and facilities it connects to at its two termination points: 345 kV. The MEPCO line is over 30 years old and is the only alternating current (AC) synchronous linkage between the MCA and other NPCC electric utilities. It is also the only AC link by which the MCA can physically undertake electricity trading within the New England Power Pool (NEPOOL) electricity market.

As a stand-alone facility, the existing MEPCO line has physical, bi-directional electrical transmission capacity of 1000 MW. However, power system constraints within MCA and NPCC currently limit the full use of the MEPCO line to an export capacity to the US of 700 MW and no import capacity.

The Canadian portion of the MEPCO line is built with conductors of a smaller size and capacity than that of the US portion of the power line. NB Power indicated that this situation contributes to the MEPCO line's present capacity constraints, particularly the lack of any import capacity into the MCA.

The MCA also has two interconnects with Hydro-Québec (HQ). However, as with all other power systems that interconnect with the HQ system, these interconnections are high voltage direct current (HVDC) asynchronous, not AC. These links are also within NB Power's system; one link is located at each of Eel River and Madawaska, New Brunswick.

The new IPL that NB Power has applied for would provide a second physical interconnection between NB Power's system and that of Bangor Hydro and would in effect provide a second link between the MCA and southern elements of the NPCC. Like the existing IPL, the new IPL would have initial bi-directional physical transmission capacity of 1000 MW and would be built for and operated at 345 kV. However, the new IPL would be built with a consistent and larger capacity conductor size than the MEPCO line.

2.2 Justification for the Second Interconnection

NB Power advanced seven reasons in support of the second interconnection.

1. NB Power asserted that the new IPL – as a second AC synchronous connection between the MCA and Maine - will improve its and the MCA's response to a first-contingency loss of either the new IPL or the existing MEPCO line. Specifically, concurrent operation of the two lines will provide additional low voltage support in southern New Brunswick and prevent 'islanding' (synchronous electrical separation) of the MCA from Maine and the NPCC, in the event of a first contingency loss of either IPL. The new IPL will therefore improve the reliability of electric power supply for New Brunswick, plus its neighboring Canadian and American areas of the Maritimes Control Area.

2. NB Power indicated that the use of the new IPL, particularly concurrent with the MEPCO line, will incur less transmission line losses during imports from or exports to Maine, through three means:

   - The new IPL will be a shorter physical path from NB Power's major load center – the Point Lepreau and Coleson Cove plant sites - to Bangor Hydro's Orrington station;
   - Any power transmitted between Orrington and NB Power can be divided between two electrical paths, instead of just one, when both lines are used; and
   - The new IPL will have larger conductors and thereby incur lower losses per unit of electricity transmitted than the MEPCO line.

   As an example, NB Power stated that at an export level of 700 MW, line loss reductions of 28 MW are expected when the new IPL is in place.

3. NB Power stated that the new IPL will improve market access between NPCC/NEPOOL and the Maritime Control Area. NB Power indicated that the new IPL will allow the export transfer capability between itself and Bangor Hydro's Orrington station to rise by 300 MW to 1000 MW and that these exports could now be 'firm' whereas they are currently 'interruptible'. NB Power also indicated that the new IPL will, for the first time, allow imports into the MCA via Orrington of up to 400 MW and that these imports could also be 'firm'. NB Power asserted that electricity customers in the MCA are presently susceptible to the exercise of market power from its existing suppliers, but that the new IPL will allow access to purchases from the larger New England market.

4. NB Power observed that the New England area experiences its peak electrical loads during summer months and can have surplus generation to sell in the winter. In contrast, New Brunswick, Nova Scotia and Québec systems experience their peak loads during winter months. Therefore, NB Power was of the view that the new IPL will increase the availability of additional generation sources to MCA utilities as well as Hydro-Québec, from the New England area, particularly in the event of system contingencies during load peaks, or during the winter.

5. NB Power indicated that it must make a decision whether to refurbish or retire its Point Lepreau nuclear generating facility when it reaches the end of its current operational life in 2006 or soon thereafter. NB Power stated that it will need access to the additional import capacity provided by the IPL either during the minimum 18 month period that Point Lepreau will be off-line for refurbishment, or during the period that it takes for new generation capacity to come on stream in the event the Point Lepreau facility is retired.

6. NB Power pointed to recent developments concerning the present and future availability of natural gas in the Maritime region. It indicated that a 400 MW gas-fired generation facility had been under consideration to meet future load requirements, but that the likelihood that such a unit will be built was presently in doubt, further necessitating the need for the second tie to meet the generation needs of the province during times of peak demand.

7. NB Power noted that the building of the new IPL could provide a cheaper alternative to utilities in northern Maine than the construction of new local sources of generation in that region.

Mr. Tucker, a local intervenor, was of the view that the Board should reject the application for the IPL. He noted that the proposed IPL will not provide enough import capacity to fully cover the 670 MW of generation capacity lost to NB Power when Point Lepreau is either refurbished or retired. Mr. Tucker was of the view that the risks facing New Brunswick electricity consumers are due to a lack of generation capability, particularly during winter months, and not transmission capacity as forwarded by NB Power. He noted that no evidence was placed on the record of any US power generator being interested in using the additional capacity of the applied-for IPL or committing to providing firm power over the line. He asserted that the security of adequate supply will not be guaranteed by construction of the applied-for IPL. He indicated his preference, as a concerned electricity consumer in New Brunswick, that NB Power should channel its financial resources into generating capacity instead of the IPL.

Mr. Tucker expressed concerns regarding the US portion of the IPL. He expressed doubt that the government or the residents of New Brunswick, as ultimate owners of NB Power, will support NB Power's direct involvement in the development of transmission assets in the US should this be required. He asserted that proper and complete examination of the overall line could not be made until all owner/operator agreements are in place and available for study by the Board and other interested parties.

Mr. Tucker further noted that the proposed route in the US had been denied approval and that required environmental approvals have been allowed to lapse. He pointed to statements made by the present US partner in the project, Emera Energy, identifying questions regarding "the extent to which the IPL could capture, on a contractual basis, incremental cross-border flows". He expressed the view that the continued uncertainty regarding fundamental aspects of the IPL creates a situation wherein there remain too many unknowns relative to the project.

NB Power acknowledged concerns that were raised about the ownership of the US portion of the IPL; its design and operation; its construction schedule; and the likelihood of it being permitted by US authorities. NB Power pointed to commitments it had received from Emera Corporation, the present holder of the US rights to the IPL, that it will take steps to enable other developers to advance the project in the event that Emera did not wish to pursue the project. NB Power stated that if Emera did not proceed with the project its intention was to move the project forward in the US by either forming a subsidiary company or finding another business partner on the US side.

Views of the Board

The Board notes that no power line operators filed evidence indicating that the applied-for IPL would negatively affect their systems. The Board understands and accepts NB Power's assertions that the IPL will:

- Provide power system reliability improvements;
- Provide energy efficiency improvements in the form of lower transmission line losses;
- Increase export capability;
- Enable the direct import of power from the New England area;
- Allow 'firm' energy transactions between the MCA and the NEPOOL;
- Improve access to additional generation capacity in New England during the winter season or in the event of system contingencies; and
- Improve access to additional generation capacity in New England to assist in meeting system requirements arising out of the refurbishment or retirement of Point Lepreau.

At the hearing, Mr. Tucker asserted that NB Power lacks generation and not transmission capacity and that the financial resources it is now intending for the applied-for IPL should instead be directed towards generation capacity. However, this assertion is not supported by the record in this proceeding. Therefore, the Board makes no findings on the alternative suggested by Mr. Tucker.

Mr. Tucker also noted that the applied-for IPL will not provide enough import capacity for NB Power to cover the temporary loss or the retirement of Point Lepreau. The Board notes that nothing was placed onto the record which indicates that the applied-for IPL might impede NB Power's ability to secure any additional generation that it might require, in excess of available import capacity, during the period.

The Board continues to have concern about the US portion of the applied-for IPL and would include a condition in a certificate it could issue requiring NB Power to demonstrate to the Board's satisfaction that all US Federal and State regulatory approvals have been granted for the corresponding power line in the state of Maine prior to the construction of the applied-for IPL in New Brunswick.

Chapter 3

Design and Safety of the IPL

NB Power provided preliminary design information for the proposed IPL. NB Power advised that it will complete the final design of the IPL in early to mid-2005.

3.1 Basic Design of the IPL

The proposed IPL will be a three-phase 345 kV AC circuit built on tubular steel 'H'-frame structures using two bundled conductors per phase of 1192 MCM ACSR "Grackle" conductor. NB Power stated that the 'H'-frame structures selected for the IPL are more robust than the traditional steel towers used on its existing 345 kV lines. V-string insulator arrangements are proposed for center phase conductor bundles to reduce clearance requirements and structure widths. The IPL will be constructed within a 50 metre (m) wide right of way. The IPL will be built and operated at 345 kV which is the voltage of the facilities that it will connect to at both the Point Lepreau and Orrington stations. The IPL will be AC to provide additional synchronous connection between the MCA and the New England area of the NPCC.

The terrestrial route that the IPL will traverse is a near-coastal area and could result in the IPL being subjected to significant adverse weather conditions such as very strong winds or severe radial icing accompanied by strong winds at low temperatures. There are several terrain variations of note along the route, such as "Old Ridge", "Red Rock Ridge" and a hill near Angle Hub #6. NB Power engaged expert consultants to develop the transmission line loading cases that it will use to complete its final line design. These load cases were developed using historical weather data collected at stations at Moncton and Saint John, New Brunswick.

NB Power noted that line designs for most Canadian regions typically use a 50 year weather return period as specified in current CSA power line design standards. NB Power indicated that the new IPL will be of particular importance to its system and that they wanted a higher level of reliability from it. Accordingly, NB Power wanted to use more demanding load cases in the design of this IPL than it might use for its other similar transmission lines. NB Power provided consultant reports wherein the use of 100 year weather return period values with an overload factor of 1.35 was recommended. NB Power committed to following this recommendation, which the report states will effectively provide structures capable of withstanding 500 year return period loadings of the four load cases selected and reviewed.

Severe ice storms and the ability of power systems to survive these occurrences is of significant importance to the electric utility industry. NB Power advised that it is part of an international consortium of electric utilities and others involved in undertaking work on this challenge. NB Power stated its intention to incorporate any lessons learned from its participation in the consortium into its design of the proposed IPL.

NB Power to draft or modify its new manuals, procedures and programs accordingly.

3.2 Electro-Magnetic Fields and Human Health

Two intervenors expressed concerns about the strength of electro-magnetic fields (EMFs) that the IPL will produce along its route. NB Power stated that magnetic field strengths associated with the IPL are related primarily to current loading and proximity. According to NB Power, the design of the IPL complies with electrical and mechanical engineering standards. They further stated that the goal of such standards is the assurance, as far as practically possible, of both a safe and efficient operation. NB Power noted that "Health Canada does not presently consider that guidelines are necessary as the scientific evidence is not strong enough to conclude that typical exposures cause health problems." However, NB Power provided figures indicating that calculated EMFs expected along the ROW of the proposed IPL were below guidelines for maximum exposure published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) which operates under the World Health Organization. NB Power stated that while the ICNIRP guidelines are based on acute and not chronic health effects, they are the most often quoted for the general public. NB Power also indicated that it had routed its IPL to avoid areas of residential development.

NB Power noted that it maintains membership on the Canadian Electricity Association's EMF Task Force and, by so doing, monitors the state of the science with respect to EMFs. Current information regarding EMFs is made available by NB Power to concerned customers upon request.

In its Notice of Intervention, the Saint John Citizens Coalition for Clean Air (Citizens Coalition) included the issue of the health risk of electro-magnetic fields. However, during final argument, Mr. Dalzell, on behalf of the Citizens Coalition, stated that the evidence on the record covered the Citizens Coalition's initial concerns and therefore there was no need for further clarification.

In his final argument, Mr. Tucker requested that NB Power take measures to reduce the levels of EMFs at the edge of the ROW below 66 milliGauss (mG) to "demonstrate a proactive approach to a concern widely held with the general public." He stated that "much literature accepts a value of approximately 4 mG as being acceptable" for EMF exposure.

Views of the Board

The Board notes that guidelines and standards for EMF exposures from electrical transmission lines have not been established in Canada, and accepts NB Power's use of the ICNIRP guidelines. The Board notes that no evidence was put on the record regarding the 4 mG value, nor were questions posed to NB Power's witness panels. The Board is satisfied with NB Power's assurances that the EMFs resulting from the operation of the IPL would not reach levels which could be considered to be harmful to public health. The Board is also satisfied that NB Power would continue to respond to concerned customer requests for information concerning EMFs.

The Board is of the view that NB Power has adequately addressed the EMF issue within the preliminary design of the proposed IPL and expects that it would continue to do so within the line's final design.

3.3 Audible Noise and Radio Interference

NB Power noted that there are no regulations in place regarding audible noise emissions emanating from transmission lines. It noted that some jurisdictions impose noise limits of between 45 and 60 dBA depending upon location and time of day. NB Power provided calculated values of the IPL's projected noise levels which were generally 45 dBA or below. NB Power also commented that the potential impact of this noise to the public had been reduced by routing of the IPL at locations affording minimal public exposure.

NB Power reported that it had experienced no radio interference (RI) problems attributable to its existing 345 kV lines and stated that it did not anticipate experiencing any such problems with the proposed IPL. NB Power indicated that it will conform to requirements of the *Radiocommunications Act* which require that it take baseline measurements of RI following energization of newly built transmission lines.

Views of the Board

The Board is satisfied with how NB Power has addressed the issues of radio interference and audible noise in its preliminary design of the IPL and expects that NB Power would continue to address them in a like manner when completing the IPL's final design in 2005.

Chapter 4

Public Consultation

4.1 Early Public Notification

The purpose of the Early Public Notification (EPN) program, which is required under the Board's Guidelines for Filing Requirements (GFR), is to inform the public about the project, to seek public input into the route selection, environmental assessment and socio-economic impact assessment, to identify issues and concerns of those potentially affected by the project and to resolve issues. NB Power indicated that it has been conducting its early Public Consultation Program (PCP) since February 2001.

The objective of NB Power's PCP is to:

- provide information and seek input from members of the general public and other interested parties on NB Power's route selection;
- identify, document and monitor issues and concerns arising from the public consultation process; and
- identify measures that will mitigate or resolve public issues.

NB Power identified several stakeholders to the project including directly affected landowners, federal, provincial and municipal government agencies, Aboriginal peoples, local businesses, environmental groups, community residents and adjacent landowners. NB Power conducted nine information sessions where residents were invited to attend by way of letters of invitation, faxes, radio ads, media advisories and community signage. These public information sessions were conducted in three New Brunswick communities (St. Stephen, Pennfield and Musquash). In addition, one-on-one stakeholder meetings were held. Other consultation techniques included the distribution of printed material/information sheets and maps, and the establishment of a toll-free project information telephone line.

NB Power stated that the PCP identified a number of issues, concerns and questions associated with the proposed IPL Project and provided NB Power and its environmental and socio-economic consultants with important information. This information was considered during the selection of the one km wide Preferred Corridor, the environmental and socio-economic assessment process and in the selection of the preliminary Preferred 50 m ROW.

NB Power committed to continuing its consultation with any individual or groups who may have an interest in the IPL Project.

Views of the Board

Based on the submissions of NB Power, the Board is satisfied that the requirements of the NEB's Guidelines for Filing Requirements, in respect of Early Public Notification requirements, have been met for the IPL Project. The Board is satisfied that stakeholders and Aboriginal persons with possible interests in the IPL were provided with adequate notice of the Project and had sufficient information to clearly understand how the Project could affect them.

4.2 Aboriginal Peoples

In its Application, NB Power submitted that, since February 2001, it had identified and contacted a number of First Nations and Aboriginal groups in respect of the IPL. Specifically, NB Power met with or contacted representatives of the following organizations and communities:

- Big Cove First Nation Community
- Burnt Church First Nation Community
- Madawaska Maliseet First Nation Community
- Maliseet Advisory Committee on Archaeology
- MAWIW Tribal Council (MAWIW)
- New Brunswick Aboriginal Peoples Council (NB APC)
- Oromocto First Nation Community
- Tobique First Nation Community
- Union of New Brunswick Indians (UNBI)
- Wulastuk Grand Council

Based on discussions with these groups, it was noted that UNBI represents 13 bands and some 5,733 individuals while MAWIW represents three bands consisting of approximately 6,000 individuals. The NB APC represents some 3,500 individuals living off reserve. NB Power stated that the consultation program was undertaken to provide Aboriginal communities with the opportunity to voice their issues relating to the proposed IPL Project and to identify current use of lands and resources for traditional purposes as defined by the CEA Act.

The initial discussions focused on introducing the IPL Project and explaining the purpose of the consultation. During these discussions, it was suggested by the Aboriginal representatives that the Chiefs and community members be consulted to identify current use of lands and resources for traditional purposes.

Community meetings were held between November 2001 and January 2002 at the following locations: Madawaska Maliseet First Nation, Big Cove First Nation, Burnt Church First Nation and Tobique First Nation. Information concerning current use of lands and resources by Aboriginal persons was collected using a checklist at the meetings and during other meetings with Elders. NB Power also conducted an Aboriginal Traditional Use Plant survey along the ROW between 5 July and 2 October 2001. The results of the survey showed that no significant impacts will occur on traditionally/historically used plant species which may potentially be used by Aboriginal persons.

In order to facilitate ongoing communication both MAWIW and UNBI retained a Liaison Officer as part of a mutual support agreement with NB Power. The agreements provided financial assistance for the two Liaison Officers, as well as assistance for the Aboriginal groups in the review of environmental documents associated with the Project. NB Power also established an archaeological protocol which will identify First Nations' involvement if a significant heritage resource is located during clearing and construction activities.

Views of the Board

The Board notes that NB Power held numerous meetings with various Aboriginal communities that held an interest in the project and gathered information regarding their current use of the land and resources within the proposed IPL corridor. Moreover, NB Power conducted a study regarding the traditional/historical plant use showing that plant species which could potentially be used by Aboriginal persons would not be significantly impacted upon. The Board also notes that NB Power has established an archeological protocol in the event that significant heritage resources are located during construction activities.

The EH-2-2002 hearing held on 24 March 2003 offered another opportunity for Aboriginal peoples to express their concerns. While some letters of comment were filed and considered, the only Aboriginal group to appear at the hearing was the Union of New Brunswick Indians and its participation consisted of monitoring since it did not avail itself of its opportunity to cross-examine the Applicant nor did it elect to present final argument.

The Board is of the view that NB Power has taken care to ensure that it understands concerns Aboriginal peoples may have regarding the proposed IPL and that NB Power has meaningful measures and plans in place to address these concerns.

Chapter 5

Routing and Land Matters

5.1 Corridor Selection Process

NB Power stated that the proposed IPL will be 95.5 km long and will extend from the Point Lepreau terminal on the Bay of Fundy in New Brunswick, through the Counties of Saint John and Charlotte to a point on the international border between Canada and the US, near Woodland, Maine.

The study area used to locate the one km Preferred Corridor applied for by NB Power encompassed an area approximately 35 km wide by 90 km long. The general study area boundaries included Mount Pleasant, Big Kendron Lake and Lynnefield to the north; St. Stephen, Bartlett Mills, Second Falls and Point Lepreau to the south; Dipper Harbour and South Oromocto Lake to the east; and the St. Croix River to the west.

NB Power selected three corridor alternatives from within the general study area (i.e., the northern, central and southern corridors). The general criteria considered in the corridor routing exercise included environmental (both biophysical and socio-economic constraints), length, cost, market and engineering considerations. The southern corridor was identified by NB Power as the preferred corridor. It has the shortest total distance, resulting in less environmental disturbance and the lowest construction cost (Figure 5-1).

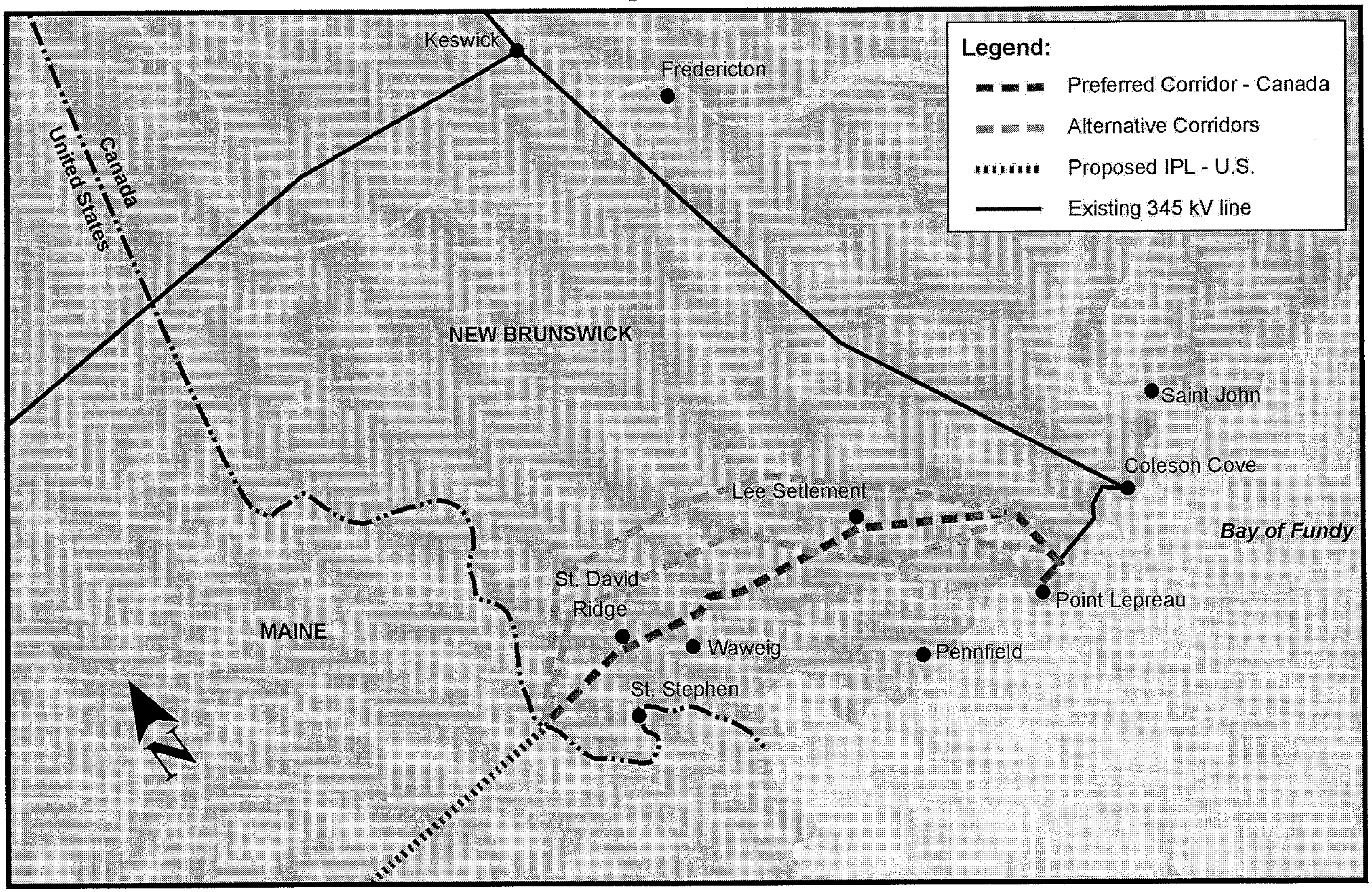
Two route modifications that extend beyond the width of the one km Preferred Corridor were identified during additional detailed investigations. These modifications were addressed in Section 2 of the Comprehensive Study Report. The first route modification was located between Rocky Lake and Bonny River (from approximately KP 28 to KP 48). The main issues addressed were two engineering and environmental constraints, camps and homes in Lee Settlement and a waterfall of high aesthetic value. The second route modification was located between Elmsville and Waweig (from approximately KP 56 to KP 62). The main issues and constraints addressed were a newly developed gravel pit, a blueberry field, some residential homes and farmland.

NB Power has identified a preliminary Preferred 50 m ROW within the one km corridor which it expects to finalize following regulatory approval.

Views of the Board

The Board considers the one km wide corridor and the 50 m route selection process undertaken by NB Power for the proposed IPL to be appropriate. It is the Board's view that NB Power's proposed one km wide corridor location and the Preferred ROW located within that corridor are acceptable.

Figure 5-1
Proposed Route



5.2 Land Requirements

The proposed IPL is approximately 95.5 km long. It will be located within approximately 14 km of existing ROW and 81.5 km of new ROW. The ownership of lands within the proposed one km IPL corridor is approximately 36 percent Crown and 64 percent private. The Preferred 50 m ROW route would traverse 5 percent NB Power land, 46 percent Crown and 49 percent private.

The ROW width was chosen by considering three main factors: the size of the structures; conductor swing-over; and tree falling distances. The proposed tubular steel H-Frame structures have a design height of 22 to 34 m. The average span length between structures is estimated to be 350 m and the minimum height from ground to conductor at low sag will be 9 m. The conductors of a power line are not rigid and will move. These movements can be calculated and the ROW must be wide enough to maintain safe electrical clearances between the conductors at all time. In addition, trees adjacent to the ROW are subject to falling and the ROW must be wide enough to ensure that falling trees do not contact the line conductors to avoid line outages. Based on these requirements, NB Power indicated that a 50 m wide ROW will be required.

Views of the Board

The Board has considered the potential impacts of the construction of the IPL on affected landowners, including the amount of land required for easements. The Board finds that NB Power's anticipated requirements for easements are reasonable and justified in this application.

5.3 Land Acquisition Process

NB Power filed sample land acquisition documents to demonstrate compliance with sections 86 and 87 of the Act.

To ensure commitments made to landowners and stakeholders during the land negotiation and acquisition process are identified and carried out, NB Power will use two complementary methods. The first method is a Line List Report that details and tracks commitments made to landowners. This report will be included in the IPL construction contract. The second is the Commitment Management System that NB Power has developed to track issues relating to the IPL Project.

Views of the Board

The Board has considered NB Power's land acquisition documents and finds that they are in compliance with the requirements of sections 86 and 87 of the Act. Moreover, the Board is satisfied with the acquisition process proposed by NB Power.

Chapter 6

Environment and Socio-Economic Matters

6.1 Environmental Matters

NB Power completed a CSR for the Project in order to satisfy the requirements of the CEA Act and to satisfy its responsibilities pursuant to section 58.16 of the NEB Act relating to environmental and socio-economic matters. The CSR considered comments from the public, as well as advice from DFO, EC, the Agency and Provincial regulatory authorities. The CSR described the Project, the environmental assessment process, the potential environmental effects, the mitigative measures and the criteria used in evaluating the significance of the environmental effects. The CSR concluded that the project is unlikely to cause significant adverse residual environmental effects.

The Board and DFO forwarded the completed CSR to the Agency on 20 September 2002 at which time the Agency facilitated a public comment process on the CSR ending 31 October 2002. Following the comment process the Board and DFO confirmed to the agency their view that the CSR was complete. Having taken into consideration the CSR, public comments filed pursuant to subsection 22(2) of the CEA Act and the Agency's recommendations, the federal Minister of the Environment concluded that the IPL Project, as described with mitigation, is not likely to cause significant adverse environmental effects and that public concerns do not warrant further environmental assessment by a review panel or mediator. As a result, the Minister of the Environment referred NB Power's application back to the Board and DFO for action under section 37 of the CEA Act.

As part of the hearing record, NB Power filed a Project Specific Environmental Protection Plan (EPP) outlining the specific actions NB Power will take to address environmental issues identified for the project. The EPP proposed a construction period commencing in the winter of 2005 and ending in the fall of 2006, a delay of two years from the original schedule outlined in the CSR. NB Power also made commitments to confirm baseline information for a number of site-specific factors, the majority of which were completed at the time of the hearing.

NB Power's CSR includes further commitments to design and implement monitoring and follow-up programs including:

- pre-construction monitoring to confirm baseline information;
- compliance monitoring to ensure the project is carried out in compliance with NB Power's approved commitments; and
- environmental effects monitoring to confirm the accuracy of prediction and the effectiveness of mitigative measures, as required for CSR projects pursuant to subsection 38(1) of the CEA Act.

Views of the Board

Following the CSR process and in the event that the Board approves NB Power's proposed application, the Board has further responsibilities which include:

- ensuring that any mitigation measures referred to in supporting its conclusions on the CSR are implemented pursuant to section 37(2) of the CEA Act and section 58.16 of the NEB Act; and
- designing and implementing a follow-up program pursuant to subsection 38(1) of the CEA Act.

To address these responsibilities the Board proposed a number of conditions at the hearing. These conditions related to:

1. Compliance with all commitments made;
2. The appropriate level and timing for confirming and updating baseline information prior to construction;
3. Updating the associated environmental protection plan prior to construction;
4. Reporting on compliance monitoring; and
5. Designing, implementing and reporting on, a follow-up program pursuant to subsection 38(1) of the CEA Act.

The Board notes that the construction schedule found in the EPP shows a delay in the construction schedule outlined in the CSR of two years. The Board is of the view that the baseline information should be updated for any construction commencing in 2005 or later. This requirement would ensure that changes to the environment which may have occurred in the intervening period between the original surveys and the actual start date are current and issues remain appropriately addressed.

Environmental issues that were not discussed in the environmental assessment of a project may arise during construction. These issues may result in public concern or an on-going requirement for remediation. Therefore, the Board would include a condition requiring that, following construction, the status of all environmental issues be reported to the Board until these issues are resolved to the Board's satisfaction.

The Board notes that the Agency's operational Policy Statement: "Follow-up Programs under the Canadian Environmental Assessment Act (October 2002)" indicates that "new or unproven techniques and technology" should be considered as a factor that would trigger the need for a follow-up program. The Board also notes that access management strategies continue to evolve within the industry and bird diversion devices constitute a relatively new technology. For this reason, the Board is of the view that NB Power should report on the success of these mitigative strategies to increase industry's knowledge level and to make recommendations on appropriate industry practice.

The Board considered the CSR and all evidence on the record. The Board is of the view that, with the implementation of NB Power's proposed mitigative measures and Board-imposed conditions, the Project is not likely to cause significant adverse environmental effects.

6.2 Socio-Economic Matters

NB Power submitted that the main socio-economic effects resulting from the IPL Project will be to generate positive employment and subcontracting benefits and that Project construction will have a beneficial effect on the local economy. NB Power stated that local and regional benefits of the IPL Project will include the purchase or procurement of; food and lodging, hardware, fuel, vehicle maintenance, equipment and vehicle rentals, flagging services, communication costs, local labour, storage rentals and security services.

NB Power indicated that it will advise local businesses and labour unions well in advance of the awarding of the contract for the construction of the IPL. In addition, NB Power committed to emphasizing any requirements for the purchase of material and services and the employment of local residents in its tender documents for construction and maintenance of the IPL. NB Power noted that the ROW survey and clearing work will be carried out by NB Power using a combination of NB Power employees and local contractors. NB Power stated that there are numerous qualified personnel in New Brunswick to conduct this work.

NB Power anticipates clearing of the ROW will require 27 contract employees and three NB Power employees; surveying will require 28 casual employees and three NB Power employees; and line construction will require 80 contract personnel (at peak activity). The expected personnel requirement for operation and maintenance of the IPL includes a total of 282 person days/year for vegetation maintenance, ground patrol, air patrol and general maintenance.

Mr. Beaver Paul, President and CEO of the Tobique Economic Development Corporation (TEDC) indicated in a letter of comment to the NEB dated 17 March 2003 that NB Power lacked a definitive inclusion policy for Aboriginal people to benefit in potential socio-economic benefits of its capital and operational programs. In reply to the TEDC's letter of comment, NB Power stated that "there will be a reasonable opportunity for First Nations to participate in the benefits of the project during the tendering process."

At the hearing, NB Power indicated that it is an equal opportunity employer and welcomes Aboriginal groups to submit tenders for the IPL Project. NB Power committed to continue to communicate with Aboriginal groups prior to issuing the tenders for the IPL and provide information on how they can bid on the tenders. NB Power has a vendor registration database that is used to pre-qualify companies for future tenders. In response to an undertaking at the hearing, NB Power indicated that although the TEDC is not listed as a vendor on its current database, the Tobique Maliseet Indian Band is listed.

NB Power also submitted at the hearing that they are bound by the *Crown Construction Act* and the *Public Purchasing Act*, which clearly outline the methodologies to be used in tendering and the evaluation of tenders.

Views of the Board

The Board concurs with NB Power's statement that construction of the IPL Project will have a beneficial effect on the local economy. The Board is also satisfied with NB Power's intentions to maximize local and regional economic benefits by encouraging its contractors to use local resources as they are available for clearing, surveying and construction of the IPL.

With regard to Aboriginal economic participation in the IPL Project, the Board accepts NB Power's commitment to contact Aboriginal communities prior to clearing and construction tenders being issued.

Chapter 7

Disposition

The foregoing chapters constitute our Decision and Reasons for Decision in respect of the application heard before the Board in the EH-2-2002 proceeding.

The Board is satisfied from the evidence that the proposed international power line is and will be required by the present and future public convenience and necessity. The Board approves NB Power's application made pursuant to section 58.16 and 58.23 of the NEB Act for a new 345 kV IPL and will, subject to approval of the Governor in Council, issue a certificate of public convenience and necessity subject to the conditions set out in Appendix II.

J.-P. Théorêt
Presiding Member

K.W. Vollman
Member

G. Caron
Member

May 2003
Calgary Alberta

Appendix I

List of Issues

The Directions on Procedure identified the following list of issues for discussion in the EH-2-2002 proceeding:

1. The need for the proposed facilities.
2. The appropriateness of the design of the proposed facilities.
3. The safety of the design and operation of the proposed facilities.
4. The potential environmental and socio-economic effects of the proposed facilities.
5. The appropriateness of the route selection, land requirements and land rights acquisition process.
6. The appropriate terms and conditions to be included in any approval that may be granted.

Appendix II

Certificate Conditions

1. The International Power Line to be constructed and operated pursuant to this certificate (the Power Line) shall be owned and operated by New Brunswick Power Corporation (NB Power).

2. The Power Line shall be operated at its nominal design voltage level of 345 kV.

3. NB Power shall cause the Power Line to be designed, manufactured, located within the one kilometre corridor, constructed, installed and operated in accordance with those specifications, drawings, and other information or undertakings set forth in its application and related correspondence.

4. NB Power shall design and construct the Power Line to comply with the most current version of CAN/CSA C22.3 No. 1 Overhead Systems.

5. NB Power shall comply with all of the conditions contained in this certificate unless the Board otherwise directs.

6. Prior to scheduling or providing transmission service to any Party intending or proposing to export electricity from Canada over the Power Line, NB Power shall ensure that the Party obtains all requisite export permits or licences authorizing any such exportation.

Prior to Construction

7. Prior to construction, NB Power shall demonstrate to the Board's satisfaction that all US Federal and State regulatory approvals have been granted for the corresponding power line in the state of Maine.

8. In the event that construction commences after the year 2005, NB Power shall file with the Board for approval, 6 months prior to the start of field construction, a report outlining:

   a) a review of any baseline information for key parameters (e.g. changes in land use, species at risk, raptors, deer wintering areas) which could potentially have changed since the date of approval, based on field assessment during the most appropriate season;

   b) any changes to the project which are considered necessary as a result of changed circumstances or new accepted industry practices; and

   c) any changes to NB Power's mitigative strategy that are considered necessary to address any new circumstances identified in items (a) or (b).

9. NB Power shall file with the Board for approval, no later than sixty (60) days prior to the start of field construction, an update of its project-specific Environmental Protection Plan (EPP) for the Power Line incorporating any updates required pursuant to Condition 8 and a reclamation plan which includes a description of the measurable desired end results to which NB Power intends to reclaim and maintain the right-of-way once the construction has been completed.

10. NB Power shall file with the Board for approval, no later than sixty (60) days prior to the start of field construction, the environmental effects monitoring and follow-up program, as required under the *Canadian Environmental Assessment Act*. The program shall verify the accuracy of the environmental assessment predictions and/or effectiveness of the mitigation for those parameters outlined under NB Power's Environmental Effects Monitoring Section of the Comprehensive Study Report (CSR). Further, the program shall monitor the effectiveness of the proposed mitigation for:

    a) bird diversion devices; and

    b) the access management program as outlined in section 6.5.3 of the CSR.

    Copies of all correspondence demonstrating consultation with Environment Canada in developing the program shall be included in the submission to the NEB. This follow-up program shall include a schedule for the submission of reports.

11. At least sixty (60) days prior to the commencement of construction, NB Power shall submit for Board approval, a quality assurance and compliance program which will outline, in mandatory terms, the policies and procedures NB Power will implement to ensure the Power Line is designed and constructed in conformance with these conditions of approval, company designs and specifications and undertakings set forth in its application or otherwise adduced in evidence before the Board in the EH-2-2002 proceeding. The program should include but not be limited to:

    a) a process or procedure to identify all conditions of approval, company designs and specifications and undertakings set forth in its application or otherwise adduced in evidence that will be subject to the program;

    b) the policies, processes and procedures that will be in place to achieve the program;

    c) the name of the person responsible for each aspect of the program;

    d) the name(s) of the person(s) authorized to stop work should it be in non-conformance with the program;

    e) the qualifications of the person(s) authorized to stop work;

    f) a process or procedure to identify and implement corrective action before recommencing work;

g) a process or procedure to evaluate the effectiveness of the corrective actions taken; and

h) methods by which adherence to the policies, processes and procedures will be monitored, measured, documented and reported to NB Power's management.

12. NB Power shall file with the Board, at least sixty (60) days prior to the commencement of construction activities:

a) NB Power's construction manual for the Power Line, or that of its construction contractor, or both.

b) If contractors are used, NB Power's acceptance of those contractors' construction manuals and health and safety programs.

c) An outline of NB Power's and/or its contractor's training program for the construction safety manual.

Prior to Operation

13. At least sixty (60) days prior to operation of the Power Line, NB Power shall submit a list of the manuals, procedures and programs that it will implement on the 345 kV Power Line which pertain to:

a) the ongoing physical facility maintenance and monitoring requirements and plans for the Power Line;

b) a public awareness program that:

i) keeps the public apprised and aware of ongoing hazards associated with the Power Line; and

ii) provides contact numbers for the public to report issues and concerns;

c) an emergency response and incident management program;

d) vegetation/weed control plans and procedures for the Power Line's right of way;

e) training requirements for personnel implementing these manuals, procedures and programs;

f) a requirement that NB Power conduct documented audits of its records and inspections of the Power Line's facilities and right of way to confirm NB Power's conformance to the requirements of the manuals, procedures and programs; and

g) a requirement that the manuals, procedures and programs be reviewed and updated as appropriate to ensure that these remain current with regulatory requirements and accepted industry practice.

These manuals, programs and procedures shall be made available for Board review and audit.

During Operation

14. NB Power shall retain adequate and appropriate records of operation and maintenance activities for the Board's review should the Board elect to audit these activities.

15. Within thirty (30) days of the date that the approved facilities are placed in service NB Power shall file with the Board a confirmation, by an officer of the company, that the approved facilities were completed and constructed in compliance with all applicable conditions in this certificate. If compliance with any of these conditions cannot be confirmed, the officer of the company shall file with the Board details as to why compliance cannot be confirmed.

16. NB Power shall file with the Board, on or before the 31 January that follows each of the first, second, and third complete growing seasons following construction or as otherwise directed by the Board, a report which describes:

    a) the environmental issues which arose during construction;

    b) whether the environmental issues identified on the right of way are resolved or unresolved;

    c) an assessment of whether NB Power has achieved its desired end results for reclamation; and

    d) the measures NB Power proposes to take to address the unresolved issues.

17. NB Power shall file with the Board, based on the schedule referred to in Condition 10, the report(s) outlining the results of the follow-up program.

Expiration of Certificate

18. Unless the Board otherwise directs prior to 31 December 2006, this certificate shall expire on 31 December 2006 unless the construction of the applied-for facilities has commenced by that date.

EXHIBIT B

OPINION OF COUNSEL

BANGOR HYDRO-ELECTRIC COMPANY
OPINION OF COUNSEL

The undersigned, Richard J. Smith, Assistant Corporate Secretary for Bangor Hydro-Electric Company (the "Company") and Corporate Secretary and General Counsel for Emera Inc., the parent of the Company, states and gives his opinion, pursuant to 10 CFR § 205.322(a)(6) as follows:

1. I have examined and am familiar with the corporate powers of the Company, pursuant to the Company's Articles of Incorporation and By-laws;

2. I have examined and am familiar with the contents of the Company's Application for Presidential Permit, to which this Opinion is attached as an Appendix;

3. I am of the opinion that the construction, connection, operating and maintenance of the facilities as proposed in said Application is within the corporate power of the Company; and

4. The Company will comply with all pertinent federal and state laws with respect to the construction, connection, operation and maintenance of the proposed facilities.

Dated September 4, 2003.

Richard J. Smith
Assistant Corporate Secretary, Bangor Hydro-Electric Company
Corporate Secretary and General Counsel, Emera Incorporated

K:\DATA\LEGAL\ELL\Certificates\bhe.wpd

EXHIBIT C

TYPICAL STRUCTURES

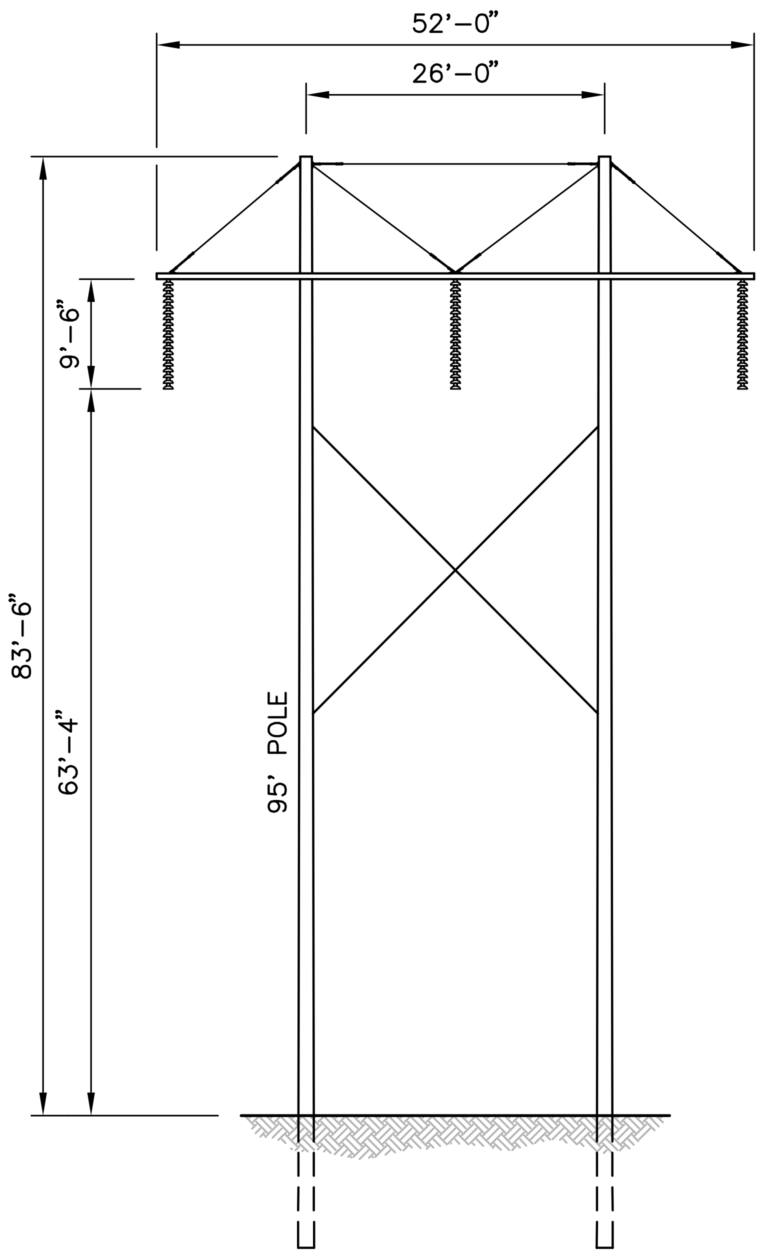


FIGURE 1
TYPE SLW–T (0°), WOOD OR STEEL
POLE TANGENT STRUCTURE

Second 345kV Tie Line to
New Brunswick

BANGOR HYDRO–ELECTRIC COMPANY

FILENAME: Pole Structures.dwg

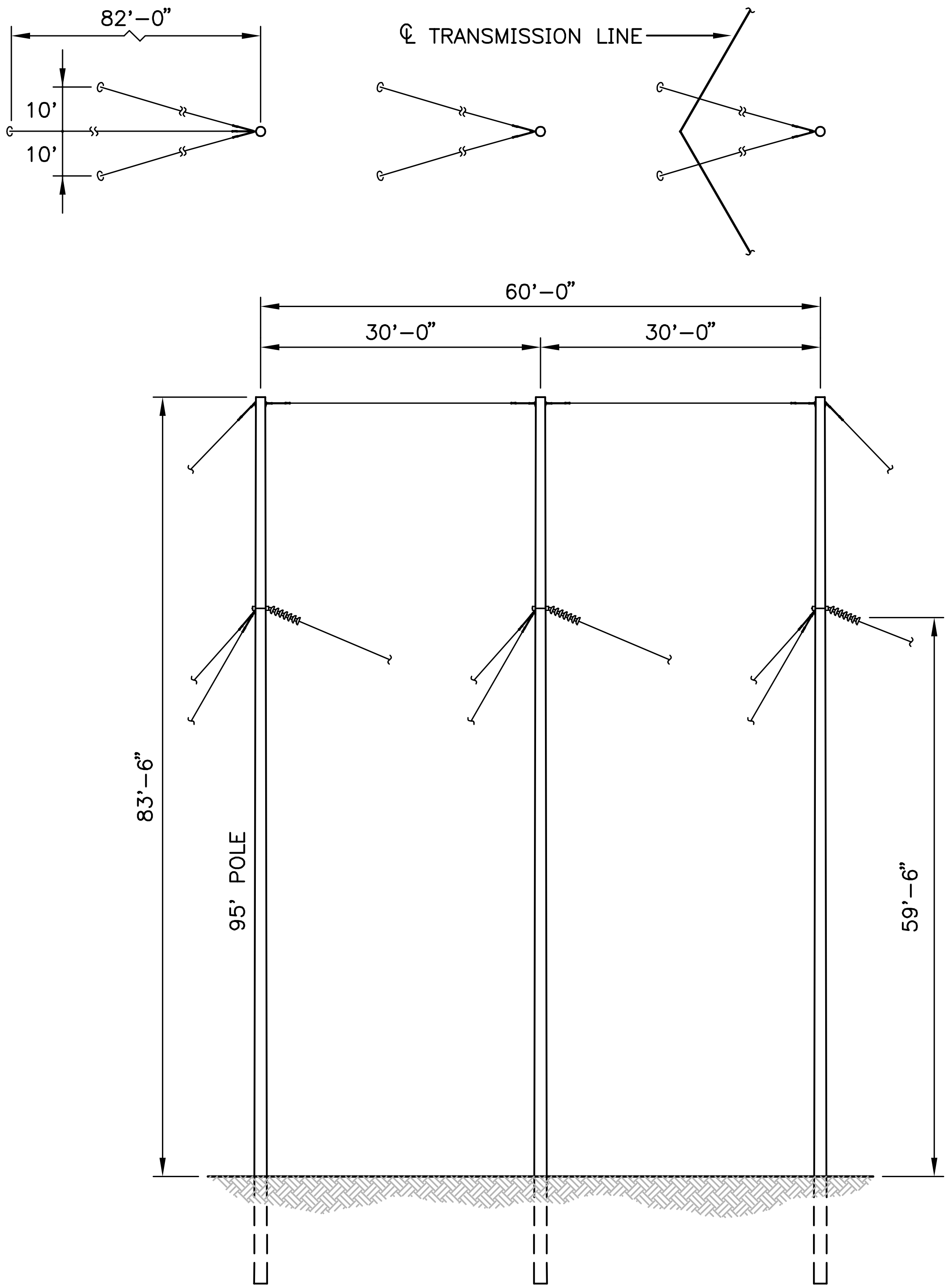


FIGURE 2
TYPE SLW–T (20°–30°), WOOD OR STEEL 3–POLE MEDIUM ANGLE

Second 345kV Tie Line to New Brunswick

BANGOR HYDRO–ELECTRIC COMPANY

FILENAME: Pole Structures.dwg

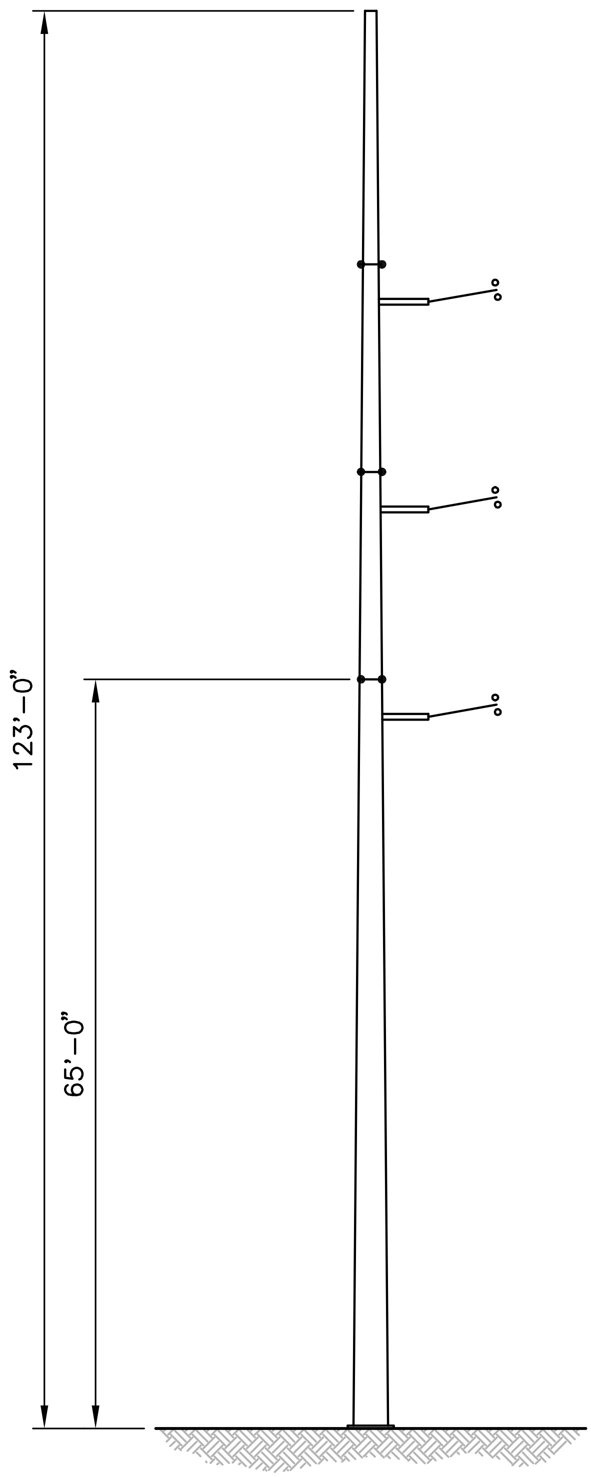


FIGURE 3
TYPE SLSP-LDE (0°-55°)
STEEL POLE DEAD-END STRUCTURE

Second 345kV Tie Line to
New Brunswick

BANGOR HYDRO-ELECTRIC COMPANY

FILENAME: Pole Structures.dwg

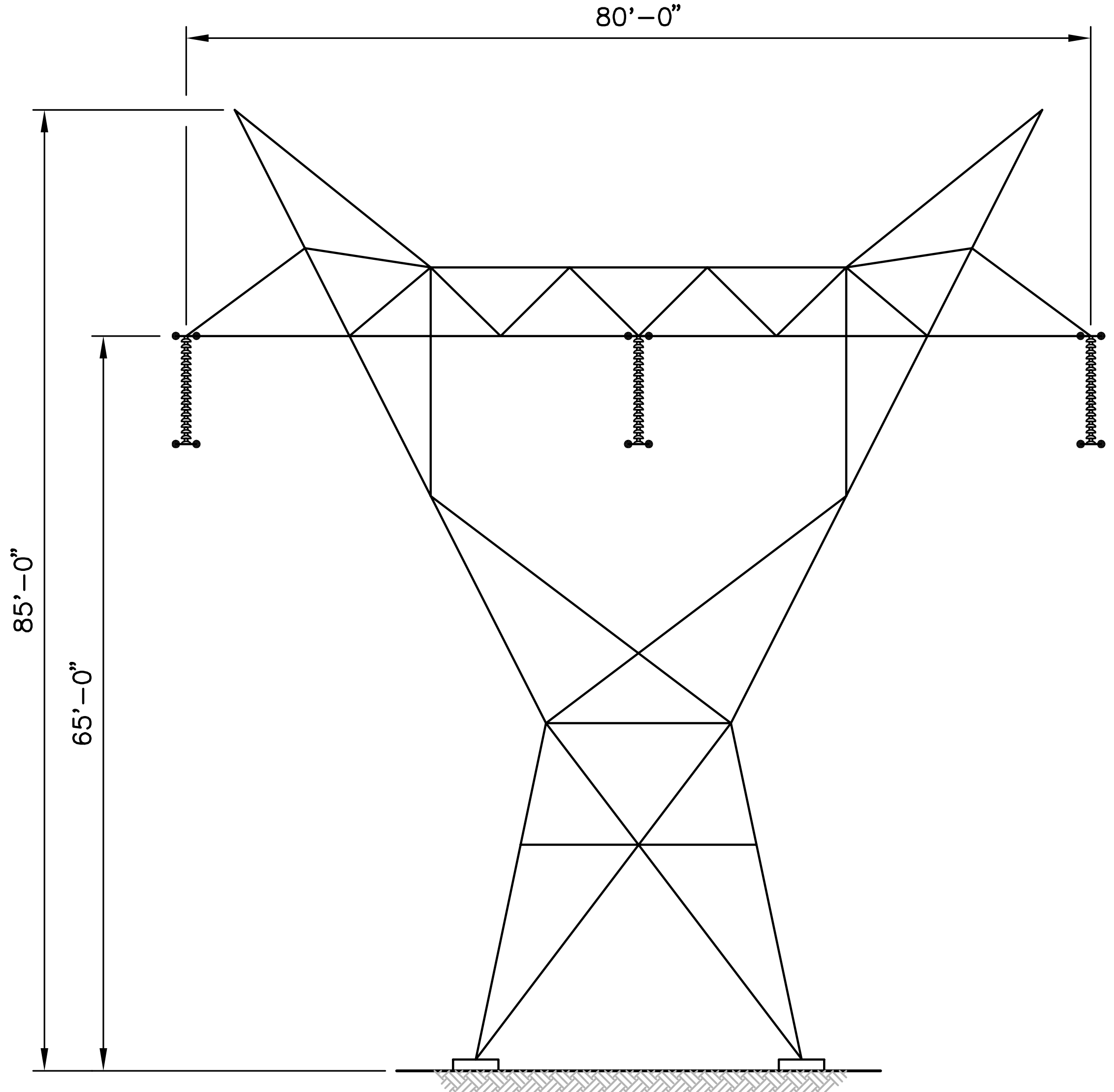


FIGURE 4
TYPE SLL–HDE (55°–90°), LATTICE STEEL
HEAVY DUTY DEAD–END STRUCTURE

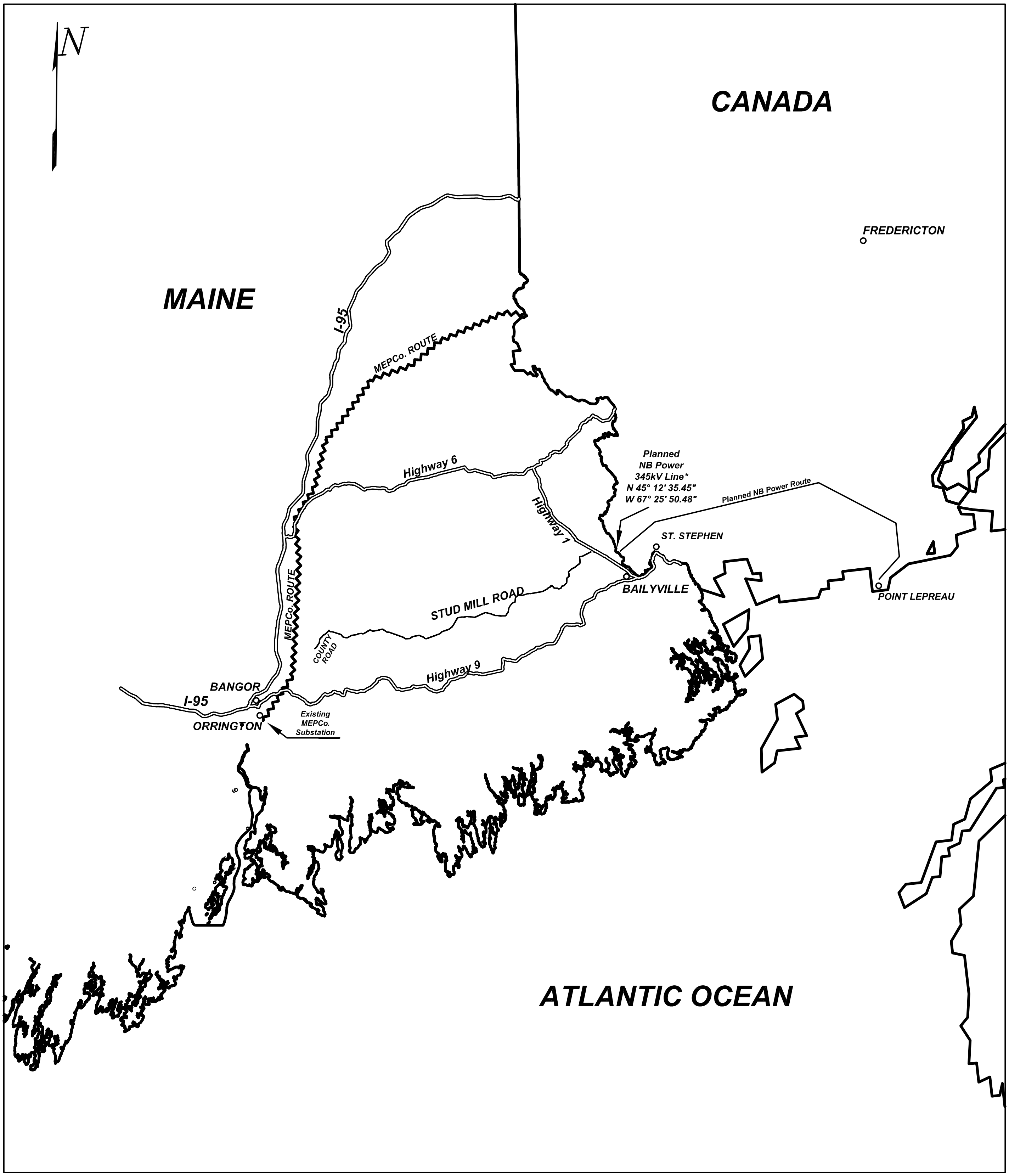
Second 345kV Tie Line to
New Brunswick

BANGOR HYDRO–ELECTRIC COMPANY

FILENAME: Pole Structures.dwg

EXHIBIT D

GENERAL AREA MAP



BANGOR
HYDRO ELECTRIC
COMPNAY

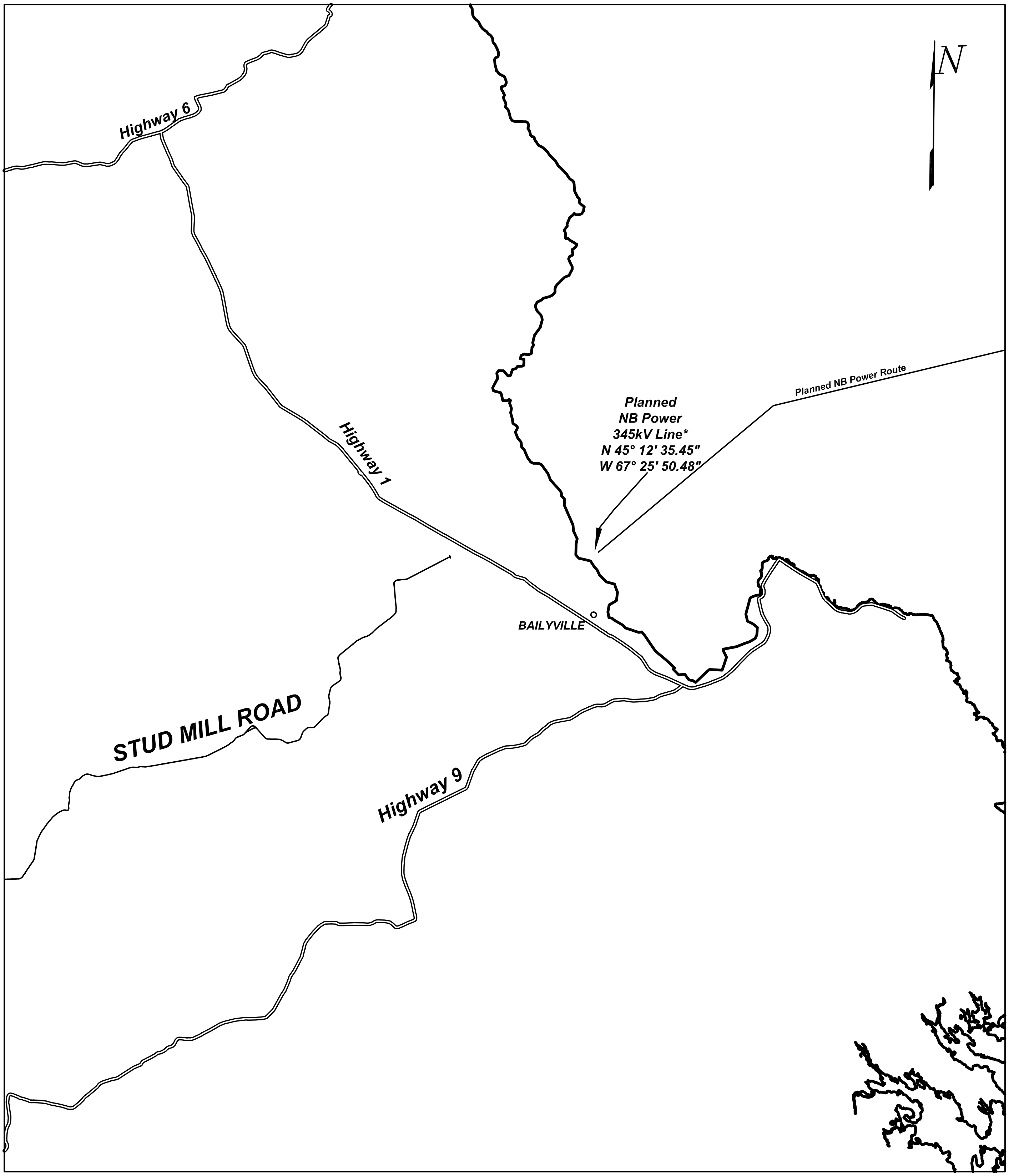
GENERAL AREA MAP

Second 345kV Tie Line to New Brunswick

*NAD 83/NAVD88
U.S. SURVEY FEET

SCALE: 1" = 25 MILES

25 12.5 0 25 50



BANGOR HYDRO ELECTRIC COMPNAY

DETAILED MAP

Second 345kV Tie Line to New Brunswick

*NAD 83/NAVD88
U.S. SURVEY FEET

SCALE: 1" = 5 MILES

5 2.5 0 5 10

EXHIBIT E

SYSTEM IMPACT STUDY

GE Power Systems

Report to:

Bangor Hydro Electric Co.

for

Second New Brunswick Tie Study

Prepared by:

Kara Clark
Nicholas Miller

March 2003

Legal Notice

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Table of Contents

EXECUTIVE SUMMARY .... **VI**

1. INTRODUCTION **1.1**

2. STUDY APPROACH **2.4**

2.1 POWER FLOW STUDY 2.4
2.1.1 Benchmark System *2.4*
2.1.2 Second Tie Project System *2.4*
2.1.3 Performance Criteria *2.5*
2.1.4 Contingency List *2.6*
2.2 TRANSIENT STABILITY STUDY 2.8
2.2.1 Benchmark System *2.8*
2.2.2 Second New Brunswick Tie System *2.8*
2.2.3 Performance Criteria *2.11*
2.2.4 Fault Scenario List *2.11*
2.2.5 Special Protection System Modeling *2.11*
2.2.6 Value *2.18*
2.3 DESIGN STUDIES 2.18
2.3.1 Subsynchronous Resonance Analysis *2.18*
2.3.2 Line Protective Relaying *2.18*
2.3.3 Short Circuit Current Impacts *2.18*
2.3.4 Transient Analysis *2.19*

3. POWER FLOW ANALYSIS RESULTS **3.1**

3.1 BUS VOLTAGE RESULTS 3.1
3.1.1 Reduced Orrington South Transfer Sensitivity Cases *3.2*
3.2 BRANCH LOADING RESULTS 3.3
3.2.1 Double Circuit Tower Outages *3.4*
3.3 PV ANALYSIS 3.7
3.4 REACTIVE POWER MANAGEMENT 3.10
3.5 ADDITIONAL SERIES COMPENSATION SENSITIVITY ANALYSIS 3.16

4. TRANSIENT STABILITY ANALYSIS **4.1**

4.1 GUIDE TO SIMULATION RESULTS 4.1
4.2 LIGHT LOAD NORMALLY CLEARED 3-PHASE FAULTS AND MORE 4.2
4.3 LIGHT LOAD SINGLE-PHASE FAULTS WITH STUCK BREAKERS 4.4
4.4 LIGHT LOAD THREE-PHASE FAULTS WITH STUCK BREAKERS 4.5
4.5 LIGHT LOAD SENSITIVITY CASES 4.8
4.6 LIGHT LOAD SPS FAILURE CASES 4.11
4.7 LIGHT LOAD SECOND SERIES COMPENSATION SENSITIVITY CASE 4.12
4.8 PEAK LOAD NORMALLY CLEARED 3-PHASE FAULTS AND MORE 4.13
4.9 PEAK LOAD SINGLE-PHASE FAULTS WITH STUCK BREAKERS 4.14
4.10 PEAK LOAD THREE-PHASE FAULTS WITH STUCK BREAKERS 4.14
4.11 EXPORT NORMALLY CLEARED 3-PHASE FAULTS AND MORE 4.15
4.12 EXPORT CONDITION SINGLE-PHASE FAULTS WITH STUCK BREAKERS 4.16
4.13 EXPORT CONDITION THREE-PHASE FAULTS WITH STUCK BREAKERS 4.16
4.14 SUMMARY 4.17

5. SHORT CIRCUIT ANALYSIS **5.1**

6. SPS MODIFICATION AND REPLACEMENT **6.2**

6.1 KESWICK GCX FOR OVERLOAD OF LINE 3001/SECTION 396 .... 6.2
6.2 KESWICK POWER RELAYS FOR OVERLOAD OF LINE 3001/SECTION 396 .... 6.3

6.3 New England Section 396 SPS 6.3
6.4 Keswick Loss of Line 3001/Section 396 ..... 6.4
6.5 Maine Yankee Double Circuit Tower SPS 6.5
6.6 New DPL SPS for Line 3001/Section 396 and Line 3016 ..... 6.6
6.7 Summary of SPS Status for Project 6.7

7. CONCLUSIONS AND RECOMMENDATIONS 7.1

7.1 Power Flow 7.2
7.2 Transient Stability 7.3
7.3 Short Circuit Analysis 7.4

APPENDIX A. BENCHMARK POWER FLOW SUMMARIES & DIAGRAMS. A-1

APPENDIX B. SECOND NB TIE POWER FLOW SUMMARIES & DIAGRAMS B-1

APPENDIX C. BENCHMARK POWER FLOW SUMMARIES & DIAGRAMS FOR TRANSIENT STABILITY ANALYSIS C-1

APPENDIX D. SECOND NB TIE POWER FLOW SUMMARIES & DIAGRAMS FOR TRANSIENT STABILITY ANALYSIS D-1

APPENDIX E. SSR CONSIDERATIONS E-1

APPENDIX F. PROTECTIVE RELAYING FOR SERIES COMPENSATED TRANSMISSION LINES F-1

APPENDIX G. CALCULATION OF SYSTEM DAMPING G-1

Executive Summary

A second 345kV transmission line connecting New Brunswick and Maine was proposed and approved by the New England Power Pool NEPOOL more than ten years ago. The purpose of this study is to update the original study and to analyze the impact of the proposed Pt. Lepreau–Orrington 345kV line on the interconnected New England system in accordance with the current NEPOOL standards, and determine the need for any additional enhancements to ensure that the performance of the system with the second tie project meets criteria. The new line is intended to improve system reliability and to increase the north to south power transfer capability across the New Brunswick – New England interface by 300 MW. Reliability benefits include elimination of first contingency system separation between New Brunswick and New England for loss of the existing 396/3001 line (Orrington to Keswick 345kV).

Under the NEPOOL Planning Procedure 5-5, "Subordinate 18.4 Application Policy", the second New Brunswick (NB) tie project is presently subordinate to any projects higher than it in the ISO New England study queue. While several of the higher priority projects are regularly operating (e.g., Westbrook Power and Bucksport Energy), their system impact studies are not necessarily completed or their own subordinate status removed. As a result, all recommendations provided in this report are conditional and subject to reevaluation once the proposed projects ahead of the second NB tie project, and their associated transmission upgrade requirements, receive final approval under Section 18.4 of the NEPOOL Agreement.

The projects ahead of the second NB tie project in the study queue are Neptune Phase 5, Neptune Phase 7, Berwick Energy Center, AEC Expansion, Redington Mountain Wind Farm, Westbrook Power and Bucksport Energy. The second NB tie system impact study completely addressed the present Bucksport Energy and Westbrook Power projects with their present upgrades. The Second NB Tie Project will not be subordinate to them if their subordinate status is removed with their present interconnection design and upgrade requirements.

The study approach for the analysis was to determine system response without the second tie in order to establish the performance benchmark, and then to repeat the analysis with the proposed Pt. Lepreau-Orrington 345kV line in-service. The analysis was performed on the NEPOOL 2000 library cases, which correspond to the expected in-service date for the line (2005-2006). For the benchmark system, the New Brunswick–New England interface was initially loaded at the present limit of 700 MW for import (north to south flow) and 250 MW for export (south to north flow). For the cases with the Pt. Lepreau–Orrington 345kV line in service, the interface was loaded to 1000MW for import, and 400 MW for export.

The intent of this study was to evaluate the impact of a second NB tie and the associated 300 MW increase in transfer across the New Brunswick–New England interface. While much of the power flow study effort focused on conditions with an Orrington South interface flow of about 1400MW, there was no intention of raising the limits of this or any other interface in New England. Rather, the evaluation was performed under these conditions, because they represent a stressed system condition. The Orrington South interface is currently design limited to 1200 MW, due to a Pennsylvania-New Jersey-Maryland (PJM) interconnection and New York ISO loss of source concern for the northeast interconnection reliability. The second tie project is one of several resources that could be limited as a result.

The stability analysis focused on an Orrington South interface flow of 1200MW for light load conditions with the second tie project. Peak load conditions with the project were evaluated at an Orrington South interface flow of approximately 1400MW.

The analysis showed that the second NB transmission line requires additional system reinforcements to meet both power flow and stability criteria. These reinforcements combined with the new transmission line define the *second NB tie project* described in this report. The project includes the following elements:

1. An approximately 144 mile, 345kV single circuit transmission line (1192kcm, two conductor bundle) from the Point Lepreau generating station in New Brunswick to the Orrington substation in Maine. The rating of this line will be at least equal to the rating of Section 396 (item 7).
2. Two additional 345kV circuit breakers at the Orrington substation.
3. A 25 ohm series capacitor (50% compensation of the Orrington-Maxcys-Maine Yankee line impedance) in the Orrington-Maxcys 345kV line.
4. Two shunt capacitor banks, 30 MVAr each, on the Maine 115kV system at Gulf Island and Kimball Road substations.
5. Thermal upgrade of the Augusta East–Maxcys (Section 88) and Augusta East–North Augusta-Puddledock (Section 213) 115kV lines.
6. Substitution of one entirely new dedicated path logic (DPL) special protection system (SPS) for an existing one, Keswick GCX SPS (NPCC #11, Type I), and modification of two other SPSs, the Maine Yankee DCT SPS (NPCC #141, Type I) and the Loss of 3001 SPS (NPCC #5, Type III). Details and extensive discussion of the SPS impacts of the project are provided in Section 5.
7. A wavetrap at Keswick currently limits the continuous, long term emergency (LTE), and short term emergency (STE) ratings of Section 396 to 730, 865, and 1075 MVA. The ratings could be increased to at least the level of the New England line portion (975, 975, and 1031MVA) by replacing the wavetrap.
8. The K84-2 115kV breaker at Maxcys substation will be replaced by a breaker with a higher short circuit current rating.

No other system upgrades are required by other New England transmission companies.

For this study, the shunt capacitors were at Gulf Island and Kimball Road 115kV substations. A screening level analysis indicates that these capacitors could be located elsewhere on the Maine 115kV and still provide sufficient voltage support. Similarly, the series capacitor may be located anywhere along the Orrington-Maxcys 345kV line.

A reactive management scheme, including the control philosophy of the Chester SVC and Maine autotransformers, should be developed with the addition of the second 345kV line to New Brunswick.

Key results of the power flow analysis are:

1. The system with the second NB tie project (including reactive compensation and 115kV line uprates) meets thermal and voltage criteria.
2. The margin to voltage collapse with the second tie project is comparable to or better than the margin in the existing system.
3. The stress on the underlying 115kV system is relieved by the series compensation on the Orrington-Maxcys line. In particular, an upgrade of Section 86 (Bucksport-Belfast 115kV) is not required.
4. Reliability of the system is significantly improved by the addition of the tie, since the loss of one line no longer results in system separation and total loss of the NB import (up to 700MW) as well as a trip of Maine Independence Station (1250MW loss of source).
5. PV analysis suggests that it may be possible for 1100MW to flow on the NB/NE interface and meet voltage criteria with additional shunt compensation in Maine.
6. Export of up to 400 MW to New Brunswick meets thermal and voltage criteria with the second NB tie project for the conditions studied.
7. Post-contingency thermal performance presently constrains the Orrington South interface to about 1060 MW. The second tie project allows the operational limit of 1200 MW to be reached.
8. Thermal overloads resulting from the Kennebec River double circuit tower outage south of Maine Yankee are presently subject to a Northeast Power Coordinating Council (NPCC) and NEPOOL exclusion. Modification of the double circuit tower (DCT) SPS to initiate generation rejection in New Brunswick eliminates the risk of overloads in excess of 150% of STE rating and the need for the thermal exclusion.
9. Thermal upgrade of the Augusta East – Maxcys line (Section 88) to at least 126 MVA LTE is planned by CMP, and is required for this project. (STE rating will be greater than or equal to LTE rating.)
10. Thermal upgrade of the Augusta East–North Augusta–Puddledock 115kV line (Section 213) to at least 103 MVA STE is also required for this project. A thermal upgrade similar to that for Section 88 is proposed.
11. A third 30 MVAr shunt bank would provide voltage support in the area should the Orrington South interface limit ever be increased above 1200 MW.

Key results of the transient stability analysis are:

1. The addition of the second tie project relieves one existing system violation for a normally cleared fault on the Tewksbury-Woburn 115kV line (ncm139; GCX entry) under light load conditions.

2. For the normal contingency Waltham-Brighton-Watertown event (nc282-520) with additional high speed primary protection resulting in 5 cycle clearing at Brighton, both the existing system and the second tie project system meet criteria.
3. The addition of the second tie project relieves a loss of source concern in the existing system (2135 MW) for the Vermont Yankee bus extreme contingency (ecvybus) under light load. The loss of source (LOS) is reduced to the output of Vermont Yankee for the second tie system.
4. The addition of the second tie project relieves the need for the GCX SPS, and removes concerns about unintended operation of that SPS. The requirement for the GCX relay is met, more securely, by the project's proposed New DPL SPS and other modifications to existing SPSs. The GCX will no longer be required under all-lines-in conditions.
5. The addition of the second tie project relieves concerns in the existing system for one Canal extreme contingency (ec342 with 10.5 cycle clearing) for the sensitivity case with maximum Canal area generation at light load (LOS = 2291 MW). The other Canal fault (ec212 with 13.5 cycle clearing) results in a LOS criteria concern for both the benchmark (2590 MW) and second tie project (2204 MW) systems for this sensitivity case.
6. Addition of the second tie allows the NB and NE systems to remain interconnected for the loss of either the existing line or the new line with the New DPL SPS tripping of generation in New Brunswick. These cases result in reduced loss of source compared to the existing system, which causes system separation and loss of the entire NB import as well as the Maine Independence Station.
7. The double circuit tower outages around Maine Yankee meet criteria with the recommended changes to the DCT SPS. Simulations of failure of the new or modified SPSs indicated no stability related problems or issues.
8. Export of up to 400 MW to New Brunswick meets stability criteria with the second tie project for the conditions studied.
9. Four cases (ncm139, nc392 in the primary analysis, as well as dct03 and dct04 in the sensitivity analysis) violate the proposed CMP voltage criteria in the existing system but not in the second tie project system.

Overall, the second tie project meets system reliability criteria. System security is improved in two areas of particular interest:

- Loss of Section 396/Line 3001 to New Brunswick (a nearly annual occurrence)
- Unwanted operation of the Keswick GCX SPS

Two existing reliability concerns are corrected by the addition of the second tie project (items 1 and 3); one additional concern for a sensitivity case is also corrected (item 5). Four violations of the proposed CMP voltage criteria are corrected (item 9). System design studies, including subsynchronous resonance (SSR) analysis, protective relay studies, transient analysis and short circuit impact analysis, are required, and should be performed during the project design and requisition stages.

The short circuit analysis showed that the only new over-dutied breaker was the K84-2 115kV breaker at Maxcys. This breaker will be replaced as part of the second NB tie project.

1. Introduction

A second 345kV transmission line connecting New Brunswick and Maine was proposed more than ten years ago. The purpose of this study was to analyze the impact of the Pt. Lepreau–Orrington 345kV line on the interconnected New England system in accordance with the ISO-NE standards, and determine the need for any additional enhancements to ensure that the performance of the interconnected system with the second tie meets criteria. The new line is intended to improve system reliability and to increase the north to south power transfer capability across the New Brunswick – New England interface by 300 MW. Reliability benefits include elimination of first contingency system separation between New Brunswick and New England for loss of the existing Section 396/3001 line (Orrington to Keswick 345kV).

Under the NEPOOL Planning Procedure 5-5, "Subordinate 18.4 Application Policy", the second NB tie project is presently subordinate to any projects higher than it in the ISO New England study queue. While several of the higher priority projects are regularly operating (e.g., Westbrook Power and Bucksport Energy), their system impact studies are not necessarily completed or their own subordinate status removed. As a result, all recommendations provided in this report are conditional and subject to reevaluation once the proposed projects ahead of the second NB tie project, and their associated transmission upgrade requirements, receive final approval under Section 18.4 of the NEPOOL Agreement.

The projects ahead of the second NB tie project in the study queue are Neptune Phase 5, Neptune Phase 7, Berwick Energy Center, AEC Expansion, Redington Mountain Wind Farm, Westbrook Power and Bucksport Energy. The second NB tie system impact study completely addressed the present Bucksport Energy and Westbrook Power projects with their present upgrades. The Second NB Tie Project will not be subordinate to them if their subordinate status is removed with their present interconnection design and upgrade requirements.

The study approach for the analysis was to determine system response without the second tie in order to establish the performance benchmark, and then to repeat the analysis with the new Pt. Lepreau-Orrington line in-service. This relative approach removes any ambiguities as to the actual impact of the proposed project since existing criteria violations, if any, are identified. Both power flow and transient stability analyses were performed. The analysis was performed on the NEPOOL 2000 library cases, for years 2005 and 2006, which corresponds to the expected in-service date for the line. For the benchmark system, the New Brunswick–New England interface was initially loaded at the present limit of 700 MW import (north to south flow) and 250 MW for export (south to north flow). For the cases with the Pt. Lepreau–Orrington 345kV line in service, the interface was loaded to 1000MW for import, and 400 MW for export.

The intent of this study was to evaluate the impact of a second NB tie and the associated 300 MW increase in transfer across the New Brunswick–New England interface. While much of the power flow study effort focused on conditions with an Orrington South interface flow of about 1400MW, as approved by the transmission and stability task forces, there was no intention of raising the limits of this or any other interface in New England. Rather, the evaluation was performed under these conditions, because they represent a stressed system condition. The Orrington South interface is currently design limited to 1200 MW, due to a Pennsylvania-New Jersey-Maryland (PJM) interconnection and New York ISO loss of source concern for the northeast interconnection reliability. The Orrington South interface includes the 345kV line from Orrington to Maxcys (Section 388) and the 115kV lines from Bucksport to Belfast (Section 86) and to Detroit (Section 203). The second tie project is one of several resources that could be limited as a result.

The stability analysis focused on an Orrington South interface flow of 1200MW for light load conditions with the second tie project. Peak load conditions with the project were evaluated at an Orrington South interface flow of approximately 1400MW.

The power flow analysis identified branch (e.g. transmission line or transformer) loading violations under both normal and contingency (e.g., single line outage) operating conditions, as well as voltage violations under both normal and contingency conditions. The transient stability analysis evaluated system response to a variety of 3-phase and 1-phase faults with either primary or backup clearing.

The analysis showed that the second NB transmission line requires additional system reinforcements to meet both power flow and stability criteria. These reinforcements combined with the new transmission line define the *second NB tie project* described in this report. The project includes the following elements:

1. An approximately 144 mile, 345kV single circuit transmission line (1192kcm, two conductor bundle) from the Point Lepreau generating station in New Brunswick to the Orrington substation in Maine. The rating of this line will be at least equal to the rating of Section 396 (item 7).
2. Two additional 345kV circuit breakers at the Orrington substation.
3. A 25 ohm series capacitor (50% compensation of the Orrington-Maxcys-Maine Yankee line impedance) in the Orrington-Maxcys 345kV line.
4. Two shunt capacitor banks, 30 MVAr each, on the Maine 115kV system at Gulf Island and Kimball Road substations.
5. Thermal upgrade of the Augusta East–Maxcys (Section 88) and Augusta East–North Augusta-Puddledock (Section 213) 115kV lines.
6. Substitution of one entirely new dedicated path logic (DPL) special protection system (SPS) for an existing one, Keswick GCX SPS (NPCC #11, Type I), and modification of two other SPSs, the Maine Yankee DCT SPS (NPCC #141, Type I) and the Loss of 3001 SPS (NPCC #5, Type III). Details and extensive discussion of the SPS impacts of the project are provided in Section 6.
7. A wavetrap at Keswick currently limits the continuous, long term emergency, and short term emergency ratings of Section 396 to 730, 865, and 1075 MVA. The ratings could be increased to at least the level of the New England line portion (975, 975, and 1031MVA) by replacing the wavetrap.
8. The K84-2 115kV breaker at Maxcys substation will be replaced by a breaker with a higher short circuit current rating.

No other system upgrades are required by other New England transmission companies.

Section 2 describes the study approach in detail. Section 3 discusses the results of the power flow analysis and Section 4 describes the results of the transient stability analysis. The preliminary short circuit analysis results are presented in Section 5. A description of the special protection systems (SPS) associated with the existing Keswick-Orrington 345kV line is provided in Section 6. The impact of the second tie on the existing SPSs is also discussed in that Section. Section 7 presents the study conclusions and recommendations. The report includes seven appendices with additional supporting information. Appendices A to D provide detailed summary and one-line information for the study systems. Appendices E, F and G provide tutorial information on subsynchronous resonance, protective relaying for series compensated lines, and calculation of system damping, respectively.

2. Study Approach

This study used a relative performance approach to determine the impact of the proposed second New Brunswick (NB) tie on the New England (NE) power system. First, system performance without the tie was determined in order to establish the benchmark, and then system performance with the second tie was determined and compared to the benchmark. This relative approach removed any ambiguities as to the actual impact of the proposed project since existing criteria violations, if any, were identified. The following Sections describe the benchmark system conditions, second tie project study scenarios, as well as the performance criteria and contingency list.

2.1 Power Flow Study

2.1.1 Benchmark System

Three NE 2000 library cases representing the 2005 summer peak condition (New England total load 24816 MW), the 2005 75% (shoulder) summer peak load condition (New England total load 18468 MW), and the 2006 summer light load condition (New England total load 11137 MW) were solved and reviewed. A number of minor modifications were made to create the study cases. They included changes to the New Brunswick, Maine, and Vermont systems as requested by NB Power, Central Maine Power Company (CMP), Bangor Hydro Electric Company (BHE), and Vermont Electric Company (VELCO). In addition, the generation dispatch in each case was modified to represent stressed system conditions along the northeast transmission interfaces.

Five peak cases were developed, each with a different generation dispatch in Maine and New Hampshire (i.e., Seabrook) and one with an export of 250 MW from NE to NB. One shoulder load case and two light load cases were also developed. The light load cases represent a high NB/ME transfer level and a near zero NB/ME transfer level. A total of eight benchmark cases were developed. A brief summary of each case, including complete case titles, interface flows and major Maine generation output, is shown in *Table 2-1*. A detailed summary for each case of the generation dispatch across New England, as well as additional interface flows and other information, is included in *Appendix A*. One line diagrams of the Maine and NE 345kV transmission system for each case are also included in this appendix.

2.1.2 Second Tie Project System

The second tie line from Pt. Lepreau to Orrington was added to the benchmark cases to create the second tie test cases. The impedance of this tie line was 0.0048 + j0.0718pu, with a shunt capacitance of 1.24pu and a rating of 1000MVA. Preliminary results indicated that the addition of the second tie and the additional 300MW of transfer from NB failed to meet criteria without additional enhancements. Further evaluation indicated that a series capacitor along the single 345kV transmission line between Orrington and Maine Yankee would greatly improve performance. As such, all of the results reported in this document for the second tie project include the enhancements described below in addition to the second tie itself.

The additional enhancements required by the second tie were a 25 ohm series capacitor on the Orrington-Maxcys 345kV line, which is equivalent to 50% compensation of the Orrington-Maxcys-Maine Yankee 345kV line. Additional shunt compensation on the 115kV system was also required to meet voltage criteria. It consisted of one 30MVAr bank at Gulf Island 115kV substation and another at Kimball Road 115kV substation. Results reported below show that thermal upgrade of 115kV line Sections in the vicinity of Augusta East are also required, and that an additional 30 MVAr bank would be required at Orrington – South interface flows in excess of 1200MW.

Eleven power flow cases with the second NB tie project were developed from the eight benchmark cases described above. Two second tie project scenarios were developed for one each of the peak, shoulder, and light load cases described above. The A dispatch was designed to stress the northern Maine system and the B dispatch was designed to stress the western Maine system. Another four cases were developed based only on the A dispatch, which proved to be the most stressful, and a final peak case with an export of about 400 MW from NE to NB. In total, six cases represent summer peak load conditions, two represent shoulder load conditions, and three represent light load conditions.

A brief summary of each second tie project case, including interface flows and major Maine generation output, is shown in *Table 2-1*. A detailed summary for each case of the generation dispatch across New England, as well as additional interface flows and other information, is included in *Appendix B*. One line diagrams of the Maine and NE 345kV transmission system for each case are also included in this appendix.

2.1.3 Performance Criteria

For the power flow analysis, different thermal, or branch loading, performance criteria were used for normal operation and for contingency operation. Similarly, different criteria were used for voltage violations.

The thermal criteria required branch loading to be less than 100% of normal rating (Rate 1) for pre-contingency conditions, and to be less than the short term emergency (STE) rating (Rate 3) for post-contingency conditions. Any branch loading greater than the STE rating required mitigation. Any branch loading above the long term emergency (LTE) rating (Rate 2) but below the STE rating were acceptable as long as a redispatch of generation could bring that overload below the LTE rating within 15 minutes.

The voltage criteria are summarized in *Table 2-2*.

There was an exception to the criteria for the double circuit tower outages. For those two cases, the minimum acceptable voltage in CMP territory was 0.90pu. In addition, the Kennebec River Crossing double circuit towers (DCT) are currently subject to an exclusion from thermal criteria, granted by the Northeast Power Coordinating Council (NPCC) and NEPOOL, which allows overloads in excess of STE on affected 115kV circuits in the vicinity. The thermal performance with the second NB tie project was evaluated, and results are shown for comparison to existing system performance. Section 3.2.1 below specifically addresses this issue.

Table 2-2. Voltage Performance Criteria for Power Flow Analysis.

Region	kV	Pre-contingency Voltage Criteria	Post-contingency Voltage Criteria
BHE	115kV	0.90 pu < Vbus < 1.05 pu	0.90 pu < Vbus < 1.05 pu
CMP	115kV 345kV	0.95 pu < Vbus < 1.05 pu	0.95 pu < Vbus < 1.05 pu
Chester	345kV	0.97 pu < Vbus < 1.042 pu	0.97 pu < Vbus < 1.042 pu
Seabrook	345k	1.00 pu < Vbus < 1.05 pu	1.00 pu < Vbus < 1.05 pu
NS & NB	345kV	0.95 pu < Vbus < 1.05 pu	0.90 pu < Vbus < 1.05 pu
NE	115kV	0.95 pu < Vbus < 1.05 pu	0.90 pu < Vbus < 1.05 pu
	345kV	0.95 pu < Vbus < 1.05 pu	0.95 pu < Vbus < 1.05 pu

The monitored region consisted of areas 701 (NE), 705 (NB), and 706 (Nova Scotia).

The power flow analysis was performed with pre-contingency solution parameters that allowed SVDs, PARs, and LTCs to move. The post-contingency solution parameters allowed only SVDs and LTCs to move.

2.1.4 Contingency List

The power flow contingency list consisted of single line contingencies, as well as multiple element outages reflecting the results of stuck breaker faults and the Maine Yankee double circuit tower faults. The full contingency list is shown in *Table 2-3*. The single asterisk indicates a non design contingencies. These contingencies include the loss of both Bucksport-Orrington 115kV lines, the loss of either Section 388, 392 or 396 without any SPS actions, the loss of 350MW of load in NB, or either of the Maine Yankee double circuit tower outages. The Maine Yankee- Buxton/Maine Yankee-Surowiec DCT outage has an exclusion from the thermal criteria, but not entirely from the voltage criteria as described in the previous section.

Table 2-3. Power Flow Contingency List.

ID	Description
nne1	Loss of Orrington 345/115kV Transformer (T1), Orrington Capacitor Banks
nne2	Loss of Orrington 345/115kV Transformer (T2)
nne3	Loss of Maxcys 345/115kV Transformer (T3), Maxcys Capacitor Banks
nne4	Loss of Mason 345/115kV Transformer (T9), Mason Capacitor Banks
nne5	Loss of Surowiec 345/115kV Transformer (T1), Surowiec Capacitor Banks
nne6	Loss of Orrington-Bucksport 115kV Line (65)
nne7	Loss of Orrington-BettsRd-Bucksport 115kV Line (205)
nne8*	Loss of Both Orrington-Bucksport 115kV Lines (65 & 205)
nne9	Loss of Bucksport-Belfast-Highland 115kV Line (86)
nne10	Loss of South Gorham-W.Buxton-Waterboro-Sanford 115kV Lines (223, 224, 225)
nne11	Loss of MaguireRd-3Rivers 115kV Line (250)
nne12	Loss of Surowiec-Moshers 115kV Line (167)
nne13	Loss of Bucksport-Detroit 115kV Line (203)
nne17	Loss of ME Yankee-Buxton 345kV Line (375)
nne18	Loss of ME Yankee-Surowiec 345kV Line (377)
nne19	Loss of Surowiec-Buxton 345kV Line (374)
nne20	Loss of Buxton-Deerfield 345kV Line (385)
nne21	Scobie 9126: Loss of Buxton-Scobie & Scobie-Lawrence-SandyPd 345kV Lines (391&326)
nne22	Loss of WF Wyman #4
nne23	Loss of Quaker Hill-3Rivers 115kV Line (197)
nne24a	Loss of Orrington-Maxcys 345kV Line (388) with SPS action
nne24b*	Loss of Orrington-Maxcys 345kV Line (388) without SPS action
nne25a	Loss of Maxcys-ME Yankee 345kV Line (392) with SPS action
nne25b*	Loss of Maxcys-ME Yankee 345kV Line (392) without SPS action
nne26	ME Yankee K378-1: Loss of ME Yankee-Surowiec & ME Yankee-Mason 345kV Lines (377&378), Mason Transformer, Mason Capacitor Banks
nne27a	Loss of Orrington-Keswick 345kV Line (396) with SPS action
nne27b*	Loss of Orrington-Keswick 345kV Line (396) without SPS action
nne28l	Mason KT9L-2: Loss of Sections 81, 204/226, 378, Mason Units 4&5, Mason Transformer, Mason Load, Mason Capacitor Banks
nne28r	Mason KT9L-1: Loss of Sections 68, 207, 378, Mason Unit 3, Mason Transformer
nne28rc	Mason KT9L-1: Loss of Sections 68, 207, 378, Mason Unit 3, Mason Transformer, Mason Capacitor Banks tripped to emulate over voltage protection
nne29	Loss of 250MW of NB Load
nne30*	Loss of 350MW of NB Load
nne31	Surowiec K374/377: Loss of Surowiec-Buxton & Surowiec-ME Yankee 345kV Lines (374&377), Surowiec Transformer, Surowiec Capacitor Banks
nne32	Buxton K391/386: Loss of Buxton-Scobie & Buxton-Yarmouth 345kV Lines (391&386), South Gorham Transformer, South Gorham Capacitor Banks, WF Wyman #4
nne33	Buxton K386-4: Loss of Buxton-Surowiec & Buxton-Yarmouth 345kV Lines (374&386), South Gorham Transformer, South Gorham Capacitor Banks, WF Wyman #4
nne34	Loss of Buxton-Yarmouth 345kV Line (386), South Gorham Transformer, South Gorham Capacitor Banks, WF Wyman #4
nne35	Deerfield 785: Loss of Deerfield-Buxton & Deerfield-Newington 345kV Lines (385&307)
nne36	Deerfield 851: Loss of Deerfield-Buxton 345kV Line (385), Deerfield Transformer
nne37	Deerfield 72: Loss of Deerfield-Newington & Deerfield-Scobie 345kV Lines (307&373)
nne38t	Maxcys K84-2: Loss of 115kV Sections 68, 84, 88
nne38b	Maxcys K80-1: Loss of 115kV Sections 80, 60, 67, Maxcys Load, Maxcys Capacitor Banks
nne39	Surowiec K166-1: Loss of Surowiec-Spring St (166), Surowiec Transformer (T1), Surowiec Capacitor Banks
nne40*	ME Yankee DC Tower 1: Loss of ME Yankee-Buxton & ME Yankee-Surowiec 345kV Lines (375&377) with MIS Transfer Trip
nne41*	ME Yankee DC Tower 2: Loss of ME Yankee-Buxton & ME Yankee-Maxcys 345kV Lines (375&392) with MIS Transfer Trip
nne42	Loss of Pt. Lepreau-Orrington 345kV Line (3016)

2.2 Transient Stability Study

2.2.1 Benchmark System

The light load power flow case, lt2, used in the voltage and thermal analysis, and described in *Sections 2.1.1* and *2.1.2*, was modified for use in the primary stability analysis. Modifications were made to generating unit output such that each in-service unit was generating at its 0^{o} rated output. The overall generation dispatch was also modified to stress the northeastern transmission interfaces up to their stability limits, disregarding thermal limitations as needed. However, the Orrington South interface flow was 1074MW, the maximum achievable while respecting the thermal limits on Section 86.

The peak load power flow case, pk4, as well as a light load export case, were also modified for use in the stability analysis in the same manner.

A sensitivity analysis using the benchmark light load power flow with additional modifications to stress particular areas of the power system was also performed in addition to the primary stability analysis.

A brief summary of both the primary and sensitivity cases, including interface flows and major Maine generation output, is shown in *Table 2-4*. A detailed summary for each case of the generation dispatch across New England, as well as additional interface flows and other information, is included in *Appendix C*. One line diagrams of the Maine and NE 345kV transmission system for the case are also included in this appendix.

2.2.2 Second New Brunswick Tie System

Power flow cases with the second NB tie project, including all series and shunt compensation were developed from the benchmark cases described above. The Orrington South interface power flow was approximately 1200MW under light load system conditions. Under peak load conditions, the Orrington South interface power flow was approximately 1400MW. This increase in interface transfer, above and beyond the interface limit, was intended to test system robustness.

A brief summary of the second tie project cases, including interface flows and major Maine generation output, is also shown in *Table 2-4*. The first pair of columns represent the benchmark and second tie project light load system conditions, the second pair represent the benchmark and second tie project peak load system conditions, and the final pair represent the benchmark and second tie project light load export system conditions. The remaining columns represent system conditions for various sensitivity analyses. Columns six and seven represent the benchmark and second tie system conditions for the light load scenario with one of the Maine Independence Station units replaced by the Bucksport unit. Columns eight and nine again represent light load conditions with maximum generation in the Canal area. Columns ten and eleven represent light load conditions with WF Wyman #4 in-service, and columns twelve and thirteen represent light load conditions under a high Boston export scenario.

A detailed summary for each case of the generation dispatch across New England, as well as additional interface flows and other information, is included in *Appendix D*. One line diagrams of the Maine and NE 345kV transmission system are also included in this appendix.

Table 2-4. Summary of Benchmark and Second New Brunswick Tie Study Cases for Stability Analysis.

Description	slt2	tslt2-r2os12	spk4	tspk4-r2	slt2 buck	tslt2r2 os12-buck	slt2 canal	tlst2r2 os12 canal	slt2 wfw4	tslt2r2 os12 wfw4	slt2 mysx	tslt2r2 os12 mysx	sexl2	tsexl2-r2
second NB Tie Status	out	in	out	in	out	in	out	in	out	in	out	in	out	in
Interfaces														
NB/NE	699	1008	697	1004	699	1008	699	1008	699	1008	698	1008	-250	-401
Orrington South	1074	1203	1013	1327	1079	1205	1074	1204	1074	1203	1074	1203	338	-187
Surowiec-South	1142	1002	1024	1168	1147	1004	1142	1004	1142	1001	1141	1001	517	344
ME/NH	1392	1426	1396	1399	1396	1428	1392	1428	1706	1427	1391	1425	1404	1404
NNE-Scobie+394	2457	2484	2537	2550	2461	2486	2455	2484	2564	2509	2460	2487	2470	2464
North-South	2804	2832	2464	2467	2808	2834	2814	2844	2905	2834	2749	2782	2815	2815
East-West	1477	1507	2436	2438	1481	1509	1445	1477	1506	1509	1486	1516	1488	1488
NY/NE	-5	-36	-8	-10	-9	-38	27	38	29	-37	26	-2	-17	-16
SEMA export	423	423	288	288	423	423	1792	1793	423	423	-1101	-1107	423	423
SEMA/RI export	776	776	1496	1496	776	776	1155	1154	698	776	-1452	-1452	776	776
Boston Import	1146	1147	2287	2287	1146	1146	1557	1559	1147	1147	-969	-958	1146	1146
NEMA-Boston Import	1280	1280	2786	2786	1280	1280	1738	1740	1278	1278	-1064	-1065	1280	1280
Major Generation														
MIS	549	358	549	549	358	179	549	358	549	358	549	358	549	549
Bucksport	0	0	191	191	191	179	0	0	0	0	0	0	191	191
RPA	273	0	273	273	273	0	273	0	273	0	273	0	273	273
AEC	0	0	161	0	0	0	0	0	0	0	0	0	54	54
WF Wyman 1,2,3	114	114	182	57	114	114	114	114	182	57	114	114	114	114
WF Wyman 4	0	0	636	636	0	0	0	0	636	636	0	0	636	636
Westbrook	383	579	0	0	383	579	383	579	0	0	383	579	383	579
Schiller 4,5,6	0	0	145	145	0	0	0	0	0	0	0	0	0	0
Merrimack 1,2	0	0	440	440	0	0	0	0	0	0	0	0	0	0
Newington 1 + New Plant	364	364	542	542	364	364	364	364	364	364	364	0	364	364
Seabrook	1161	1161	1161	1161	1161	1161	1161	1161	1161	1161	1161	1161	1161	1161
Maine Capacitor Banks														
Orrington	201	0	201	0	201	0	201	67	201	0	201	0	0	0
Sum of Maxcys, Mason, Surowiec, South Gorham	400	350	450	450	400	350	400	250	400	350	400	350	0	50

Notes: 1. 1. 1.

spk4 & tspk4-r2 = near peak load, slt2 & tslt2-r2 and variations= light load, sexl2 & tsexl2-r2 = light load export to NB.
2. Interface flows and generating plant outputs (sum of all units) are shown in MW, capacitor bank output in B MVArs.

2.2.3 Performance Criteria

The criteria defining stable transmission system performance for normal contingencies (3-phase faults cleared by the slower of the two fastest protection groups or 1-phase faults with backup clearing) are as follows:

- All units must be transiently stable except for units tripped for fault clearing
- A 50% reduction in the magnitude of system oscillations must be observed over four periods of the oscillation
- A loss of source greater than 1200MW is not acceptable
- Keswick GCX entry is not acceptable
- Central Maine Power (CMP) proposed voltage sag criteria applies to CMP buses

The proposed Central Maine Power (CMP) voltage criteria states that the minimum post-fault bus voltage is 0.70 pu and that the maximum duration below 0.80 pu is 250msec. For the purposes of this study the criteria was applied using a minimum post fault dip of 30%, and a 250msec maximum duration for a voltage dip greater than 20%.

The criteria defining stable transmission system performance for extreme contingencies (3-phase faults with breaker failure and backup clearing) are as follows:

- Transiently stable with positive damping
- A loss of source greater than 1400MW is not immediately acceptable
- A loss of source between 1400MW and 2200MW may be acceptable depending upon a limited likelihood of occurrence and other factors
- A loss of source above 2200MW is not acceptable
- A 50% reduction in the magnitude of system oscillations must be observed over four periods of the oscillation

Selected 345kV and 115kV bus voltages in Maine and throughout NE were monitored. The generator angle, field voltage, terminal voltage, machine speed, real and reactive power output were also monitored for all units in Maine, New Brunswick and Nova Scotia, as well as units with a power output of at least 40MW in the rest of New England. In addition, the angular swings for selected generators in New York were monitored.

2.2.4 Fault Scenario List

A variety of 3-phase and 1-phase faults with both primary and backup clearing were evaluated for this study. *Table 2-5* summarizes all the fault scenarios that were analyzed.

2.2.5 Special Protection System Modeling

The Maine Special Protection Systems (SPS) were modeled for the stability analysis. The models used for the benchmark analysis are described below.

The results of the system study dictated that one new SPS and modifications to two existing SPSs were required. These changes are described in detail in Section 6. Development of the new and modified SPSs was an integral part of the system study. For the final evaluation and proof of performance for the project special attention was given

Table 2-5. Fault Scenario List
(Normal Contingencies and More)

ID	Fault Location	Type	Impedance (1st = existing, 2nd=2nd Tie Project)	Stuck Breaker	Near End Clearing	Far End Location	Clearing
ncm139	Tewksbury 115kV	3ϕ	0.0+j0.0	none	5 cy	Woburn 115kV	41 cy
nc282-520	Waltham 115kV	3ϕ	0.0+j0.0	none	5 cy	Brighton 115kV Watertown 115kV	29 cy 66 cy
nc337	Tewksbury 345kV	3ϕ	0.0+j0.0	none	4 cy	Sandy Pond 345kV	4.75 cy
nc374	Buxton 345kV	3ϕ	0.0+j0.0	none	4 cy	Surowiec 345kV	4 cy
nc375a	Buxton 345kV	3ϕ	0.0+j0.0	none	4 cy	Maine Yankee 345kV	4 cy
nc375b	Maine Yankee 345kV	3ϕ	0.0+j0.0	none	4 cy	Buxton 345kV	4 cy
nc377	Maine Yankee 345kV	3ϕ	0.0+j0.0	none	4 cy	Surowiec 345kV	4 cy
nc385	Buxton 345kV	3ϕ	0.0+j0.0	none	4 cy	Deerfield 345kV	4 cy
nc388	Orrington 345kV	3ϕ	0.0+j0.0	none	4 cy	Maxcys 345kV	4 cy
nc391	Buxton 345kV	3ϕ	0.0+j0.0	none	4 cy	Scobie 345kV	4 cy
nc392	Maxcys 345kV	3ϕ	0.0+j0.0	none	4 cy	Maine Yankee 345kV	4 cy
nc396*	Orrington 345kV	3ϕ	0.0+j0.0	none	4 cy	Keswick 345kV Chester SVC	4 cy 4 cy
nc3016	Orrington 345kV	3ϕ	0.0+j0.0	none	4 cy	Pt. Lepreau 345kV	4 cy
dct03	Maine Yankee 345kV	2ϕ	0.00118+j0.00857 0.00115+j0.00846 0.00113+j0.00803	none	4 cy	Buxton 345kV Surowiec 345kV MIS transfer trip	4 cy 4 cy 15 cy
dct04	Maine Yankee 345kV	2ϕ	0.00118+j0.00857 0.00115+j0.00846 0.00113+j0.00803	none	4 cy	Buxton 345kV Maxcys 345kV MIS transfer trip	4 cy 4 cy 15 cy
mis	Trip MIS	NA	NA	none	NA	NA	NA
ph2	Trip Phase II HVDC	NA	NA	none	NA	NA	NA
ptlp	Trip Pt. Lepreau	NA	NA	none	NA	NA	NA
sbrk	Trip Seabrook	NA	NA	none	NA	NA	NA
wbrk	Trip Westbrook	NA	NA	none	NA	NA	NA
sc381*	Vermont Yankee 345kV	1ϕ	0.0025+j0.0203 (0 to 4cy) 0.0033+j0.037 (4 to 10cy)	381	10 cy	Northfield 345kV VY Auto #4 115kV	4 cy 10 cy

Table 2-5. Fault Scenario List (continued)
(Extreme Contingencies)

ID	Fault Location	Type	Impedance (1st = existing, 2nd=2nd NB tie+SC)	Stuck Breaker	Near End Clearing	Far End Location	Far End Clearing
ec312*	Northfield 345kV	$3\phi/1\phi$	0.0022+j0.0201	3T	8.7 cy	ALPS 345kV Berkshire Auto 115kV VY 345kV	4 cy 5 cy 8.7 cy
ec326*	Scobie 345kV	$3\phi/1\phi$	0.0053+j0.0280	9126	8 cy	Sandy Pond 345kV Lawrence Auto 34.5kV Buxton 345kV	4 cy 6 cy 8 cy
ec328*	Sherman Rd 345kV	$3\phi/1\phi$	0.0020+j0.0162	142	10.5 cy	N. Smith 345kV ANP 336 345kV	4 cy 10.5 cy
ec339	Tewksbury 345kV	$3\phi/1\phi$	0.00286+j0.0165	37-39	10.5 cy	Golden Hills 345kV Golden Hills Auto 115kV Sandy Pond 345kV	4 cy 5 cy 10.5 cy
ec342	Canal 345kV	3ϕ	0.0+j0.0	312	10.5 cy	Pilgrim 345kV Auburn 345kV Canal Auto 115kV	4 cy 4 cy 10.5 cy
ec368*	Card 345kV	$3\phi/1\phi$	0.0044+j0.0211	2T	13.9 cy	Manchester 345kV Millstone 345kV	4 cy 13.9 cy
ec372-2	Mystic 345kV	$3\phi/1\phi$	0.000625+j0.00833	102	10.25 cy	Kingston 345kV Golden Hills	4 cy 10.25 cy
ec374	Buxton 345kV	$3\phi/1\phi$	0.00546+j0.0279 0.00546+j0.0278	K386-4	11.2 cy	Surowiec 345kV S. Gorham Auto 115kV Wyman 345kV	4 cy 11.2 cy 11.2 cy
ec377	Maine Yankee 345kV	3ϕ	0.0+j0.0	K378-1	9.9 cy	Surowiec 345kV Mason Auto 115kV Mason Caps 115kV	4 cy 9.9 cy 9.9 cy
ec385	Deerfield 345kV	3ϕ	0.0+j0.0	785	9 cy	Buxton 345kV Newington 345kV	4 cy 9 cy
ec388-1	Orrington 345kV	3ϕ	0.0+j0.0	K388-3	11.3 cy	Maxcys 345kV Orrington T2 115kV	4 cy 11.3 cy
ec388-2	Orrington 345kV	3ϕ	0.0+j0.0	K396/388	11.3 cy	Maxcys 345kV Keswick 345kV Chester SVC	4 cy 11.3 cy 11.3 cy
ecx388-1	Orrington 345kV	3ϕ	0.0+j0.0	K396/388	11.3 cy	Maxcys 345kV Orrington T1, T2 115kV Keswick 345kV Chester SVC	4 cy 11.3 cy 11.3 cy 11.3 cy
ec391	Buxton 345kV	3ϕ	0.0+j0.0	K391/386	11.2 cy	Scobie 345kV S. Gorham Auto 115kV Wyman 345kV	4 cy 11.2 cy 11.2 cy
ec394a*	Seabrook 345kV	$3\phi/1\phi$	0.00081+j0.01351	294	8 cy	Tewksbury 345kV Ward Hill Auto 345kV	4 cy 4 cy
ec394b	Tewksbury 345kV	$3\phi/1\phi$	0.00253+j0.0161	38-94	10.5 cy	Seabrook 345kV Ward Hill Auto 345kV Woburn 345kV	4 cy 4 cy 10.5 cy
ec396-1	Orrington 345kV	3ϕ	0.0+j0.0	K396-1	11.3 cy	Keswick 345kV Chester SVC Orrington T1 115kV	4 cy 4 cy 11.3 cy

Table 2-5. Fault Scenario List (continued)
(Extreme Contingencies)

ID	Fault Location	Type	Impedance (1st = existing, 2nd=2nd NB tie+SC)	Stuck Breaker	Near End Clearing	Far End Location	Clearing
ec396-2	Orrington 345kV	3ϕ	0.0+j0.0	K396/388	11.3 cy	Keswick 345kV	4 cy
						Chester SVC	4 cy
						Maxcys 345kV	11.3 cy
ecx396-1	Orrington 345kV	3ϕ	0.0+j0.0	K396-1	11.3 cy	Keswick 345kV	4 cy
						Chester SVC	4 cy
						Orrington T1, T2 115kV	11.3 cy
						Maxcys 345kV	11.3 cy
ec3002	Keswick 345kV	3ϕ	0.0+j0.0	K3-2	10 cy	Coleson Cove 345kV	4 cy
						St Andre 345kV	10 cy
						Block Madawaska	10 cy
ec3016	Orrington 345kV	3ϕ	0.0+j0.0	K3016	11.5 cy	Pt. Lepreau 345kV	4 cy
						Orrington T1 115kV	11.5 cy
ec3016-2	Orrington 345kV	3ϕ	0.0+j0.0	K4/3016	11.5 cy	Pt. Lepreau 345kV	4 cy
						Orrington T2 115kV	11.5 cy
ecort1-1	Orrington 345kV	3ϕ	0.0+j0.0	K396-1	12 cy	Orrington T1 115kV	5 cy
						Keswick 345kV	12 cy
						Chester SVC	12 cy
ecort1-2	Orrington 345kV	3ϕ	0.0+j0.0	K3016	12 cy	Orrington T1 115kV	5 cy
						Pt. Lepreau 345kV	12 cy
ecort2-1	Orrington 345kV	3ϕ	0.0+j0.0	K388-3	12 cy	Orrington T2 115kV	5 cy
						Maxcys 345Kv	12 cy
ecort2-2	Orrington 345kV	3ϕ	0.0+j0.0	K4/3016	12 cy	Orrington T2 115kV	5 cy
						Pt. Lepreau 345Kv	12 cy
ecxort1	Orrington 345kV	3ϕ	0.0+j0.0	KBS3/4	11.3 cy	Orrington T1 115kV	5 cy
						Maxcys 345kV	11.3 cy
						Orrington T2 115kV	11.3 cy
						Keswick 345kV	11.3 cy
						Chester SVC	11.3 cy
ecwalauto	W Medway 345kV	3ϕ/1ϕ	0.000644+j0.00699	111	10.25 cy	Waltham 115kV	5 cy
						W Walpole 345kV	10.25 cy
ec212	Canal 345kV	3ϕ	0.0+j0.0	212	13.5 cy	Carver 345kV	4 cy
						Canal Bourne Auto 115kV	13.5 cy

Notes: * = favorite seven

to running all light load cases with the SPSs modeled as close to the proposed implementation as possible. The benchmark analysis was performed with the SPSs modeled as described here. The light load cases with the second tie project included, as well as the new and modified SPSs are described in detail in Section 4.

Maxcys Over-Current SPS (NPCC SPS #28)

The purpose of this SPS is to protect the underlying 115kV system for loss of Section 392. The Maxcys over-current SPS trips the Maxcys 345/115kV autotransformer when current flow on the Maxcys-Mason 115kV line (Section 68) exceeds 960A (equivalent to 191MVA at 1.0pu voltage) for 0.2 seconds.

Bucksport Over-Current SPS (NPCC SPS #21)

The purpose is to protect the underlying 115kV system for loss of Sections 392 and 388. The Bucksport over-current SPS trips the Bucksport-Detroit (Section 203) and Bucksport-Belfast (Section 86) 115kV lines as well as the Bucksport and Maine Independence Station generators when total flow on the Orrington-Bucksport (Section 65) and Betts Rd-Bucksport (Section 205) 115kV lines exceeds a threshold for a specified amount of time.

Specifically, this SPS begins timing if the current flow on Section 65 exceeds 678A (135MVA) and the current flow on Section 205 exceeds 693A (138MVA) simultaneously, or if the Section 65 current exceeds 960A (191MVA), or if the Section 205 current exceeds 960A (191MVA). When the timer reaches 0.2 seconds, Sections 203 and 86 and the Bucksport generator are tripped. In addition, a transfer trip is started and the Maine Independence Station is tripped after 15 cycles.

Bucksport Reverse Power SPS (NPCC SPS #22)

The purpose is to protect BHE from low voltages for loss of Section 388 or 392 as well as Section 396 with low internal generation. The Bucksport reverse power SPS trips the Bucksport-Orrington (Section 65) and Bucksport-Betts Road (Section 205) 115kV lines when the total south-to-north power flow on those lines exceeds 50MW for 0.3 seconds.

In addition, there is an under-voltage supervisory function which prevents operation of this SPS if the Bucksport 115kV bus voltage remains above 0.92pu and allows operation when the voltage has been below 0.92 pu voltage for 0.2 seconds.

Saco Valley Under Voltage Load Shed

Although not an SPS, its purpose is to relieve local undervoltage problems in the vicinity of Saco Valley. This protection system trips the loads at the Saco Valley and Intervale 34.5kV buses when the Saco Valley 115kV bus voltage has been below 0.94pu for 4 seconds.

Maine Yankee Double Circuit Tower Outage SPS (NPCC SPS #141)

The purpose of the DCT SPS is to relieve overloads on the underlying 115kV system for loss of the two 345kV lines crossing the Kennebec River south of Maine Yankee (Sections 375 and 377) or the Maxcys-Maine Yankee and Maine Yankee–Buxton (Sections 392 and 375) 345kV lines. The Maine Yankee DCT SPS trips the Maine Independence Station for these two events.

Keswick Loss of 3001 SPS (NPCC SPS #5)

The purpose of the Loss of L3001 SPS is to detect islanding of the Maritimes due to trips of any one of the existing Maine 345kV connections to southern New England, i.e., Line 3001/Section 396 or Sections 388 or 392. This SPS rejects generation in New Brunswick and/or reduces import in response to a sudden drop in power flow on the Keswick-Orrington 345kV line simultaneous with an increase in frequency at the Keswick 345kV bus. This SPS is only armed when the initial power flow on Line 3001 is greater than 180MW.

The SPS begins when the power flow on Line 3001 falls below 330MW and the first timer is started. If the power flow falls below 260MW before this first timer reaches 3 seconds, then a second timer is started. If the Keswick 345kV bus frequency exceeds 60.3Hz and the second timer has not reached 1.25seconds, then generation is tripped in New Brunswick. The amount of generation tripped approximates the initial flow on Section 3001 less 200MW.

The system operator selects sufficient generation and/or HVDC imports from the list shown in *Table 2-6* to trip about 200 MW less than the initial flow on L3001/396.

Table 2-6. NB Power Generation Rejection Option List.

Facility	Operational Choices
Madawaska 350MW HVDC link	Runback to 175MW or block to zero
Eel River 350MW HVDC link	Runback to 270 ,200, 160, 120, 80 or 40MW
Mactaquac Hydro plant	Up to four of six 110 MW units can be tripped
Beechwood Hydro plant	All three 35MW units can be tripped
Coleson Cove Steam plant	One of three 350MW units can be tripped
Belledune	One 480MW unit can be tripped
Dalhousie	Unit 2 (200MW) can be tripped
Lingan Steam plant (NS)	One or two of four 160MW units can be tripped

Keswick GCX SPS (NPCC SPS #11)

The purpose of the Keswick GCX SPS is to provide overload protection for Line 3001 such that it does not trip for a large load loss in the Maritimes when it is near its maximum export (from NB) capability. The GCX SPS has frequency supervision so that it will not operate for a large source loss in New England. The characteristics of the Keswick GCX relay are shown in *Table 2-7*, where the distance and angle determine the center point and the reach defines the diameter of the impedance circle.

Table 2-7. Keswick Zone 1, Zone 2, and GCX Relay Characteristics.

Zone	Reach (pu)	Center Distance (pu)	Angle (deg)	Operating Time (sec)
1	0.0440	0.0220	75	0.0
2	0.0723	0.0672	75	0.3
3	0.1060	0.0530	60	If over-frequency conditions are satisfied.

Zone 1 and 2 and the line protection are always armed. When the apparent impedance of Line 3001 enters zone 1 or 2, it trips the line (instantaneously in zone 1 and after 0.3 seconds in zone 2). Loss of L3001/396 causes the Section 396 Type I SPS (NPCC SPS #140) to operate to trip the Maine Independence Station.

The zone 3 portion represents the GCX circle of the SPS, and is armed or blocked based upon the Keswick 345kV bus frequency. If the Keswick bus frequency exceeds 60.06Hz for more then 0.1 seconds with a rate of change in excess of 0.1Hz/sec, then the GCX relay is armed on the basis of over-frequency for 8 seconds. If the bus frequency falls below 59.94Hz for more then 0.1 seconds with a rate of change in excess of 0.1Hz/sec, then the GCX relay is blocked on the basis of under-frequency for 10 seconds.

If the apparent impedance enters the GCX circle (zone 3 of the model) and the overfrequency conditions are satisfied, the GCX sends a signal to reject some amount of pre-selected generation in New Brunswick according to the rules of the Loss of 3001 SPS as described above. A 6-cycle delay is allowed between generation rejection and the instant where both the overfrequency conditions are satisfied and GCX entry occurs.

Keswick Power Relay (NPCC SPS #12)

Another SPS called the Keswick Power Relay (KPR), is normally out-of-service and armed only when the Chester SVC is out of service and flows are high (i.e. > 550MW). This SPS causes runback of import from Eel River HVDC link, if the real power flow from Keswick to Orrington exceeds 650 MW and the reactive power flow exceeds 200MVAR. For the purposes of this study it was assumed that this SPS was out-of-service.

Capacitor Switching Model

The shunt capacitors at five Maine 345kV substations (Orrington, Maxcys, Mason, South Gorham, and Surowiec) are allowed to switch during transient stability simulations.

In the power flow, these capacitor installations are modeled as static var devices (SVD) with the appropriate number of banks. Specifically, three 67MVAr banks are represented at Orrington, three 50MVAr banks at Surowiec, and two 50MVAr banks at each of the other three substations.

The generic control logic for dynamic simulations is as follows:

- If the 345kV voltage exceeds the upper voltage threshold for a specified amount of time, then a single bank is switched off.
- If the 345kV voltage falls below the lower voltage threshold for a specified amount of time, then a single bank is switched in.
- If either the 115kV voltage or 345kV voltage exceeds the specified over-voltage thresholds, then all capacitor banks at that location are instantaneously tripped.

The specific voltage switching thresholds are shown in *Table 2-8*.

The control logic and values were originally derived from a combination of sources. The logic is a simplified version of the Surowiec capacitor bank control as described in the operating study report, "Maine System Operations in Year 2000 Following the Addition of Merchant Generating Projects". The same logic and parameter values were then used for the Maxcys, Mason and South Gorham banks as well. The logic is again the same for the Orrington capacitor banks, and the parameter values were derived from the minimum and maximum voltages shown in that old power flow database as well as from the operating study.

Table 2-8. Generic Switching Logic for Maine Mechanically Switched Capacitors.

Parameter	Description	Maxcys Mason South Gorham Surowiec	Orrington
vmax	upper voltage threshold	1.044 pu	1.043 pu
vmin	lower voltage threshold	0.988 pu	0.986 pu
tdelay	time delay before switching	4 sec	5 sec
vinrg	345kV bus instantaneous overvoltage threshold	1.159 pu	1.159 pu
vinlo	115kV bus instantaneous overvoltage threshold	1.191 pu	1.191 pu

Chester SVC Low Voltage Blocking Function Model

The dynamic modeling of the Chester SVC consists of a voltage regulating SVC (vwscc), which regulates to the scheduled voltage from the power flow, a power oscillation damping control (pss2a) and a supervisory low voltage blocking function. This blocking function reduces the SVC output to 0MVAr when the Chester 345kV bus voltage is below 0.60pu. Voltage control is restored to the SVC when the 345kV bus voltage returns to 0.68pu or greater.

Load Model

Load was modeled as constant impedance P and constant impedance Q.

Line Relay Models

As part of this study, it was requested that line relays be modeled for Sections 388 (Orrington-Maxcys 345kV), 392 (Maxcys-Maine Yankee 345kV), 65 (Orrington-Bucksport 115kV), 86 (Bucksport-Belfast-S86B Tap-Highland 115kV), 203 (Bucksport-Detroit 115kV), and 205 (Orrington-Betts Rd-Bucksport 115kV). Information on the relays applied on these transmission lines was provided by CMP. That information was converted into the necessary parameters for PSLF's individual impedance distance relay model, zlin1. Note that this is a simple impedance distance relay and does not model all aspects of the relaying system for a particular line. For example, there are no out of step or comparison blocking functions available. Therefore, the line relays were simulated in only the most simple fashion with the impedance distance relay model, zlin1.

The relay model calculates the apparent line impedance from the voltage and current at one end and compares it to the protective zones. If the apparent impedance enters a protective zone, and remains there for sufficient time, the line is opened at that end.

The Zone 1 and Zone 2 impedances, pickup times, and break operation times for each zlin1 model is shown in *Table 2-9*. This relay modeling information was presented and accepted at the March 2002 project review meeting in Bangor, Me.

A comparison of relay data to actual line impedance is also illustrated in *Table 2-9*. The final two columns in this table show the impedance of the line segment between the from and two buses. For the Section 86 and 205 line relay models the protective zone impedances exceed the line segment impedance. The relay protective zone impedances are, however, less than the total line impedance. For instance, the Section 86 Bucksport-Belfast relay Zone 1 reactance is 0.175pu, the impedance between Bucksport and Belfast is 0.086pu, and the total line impedance from Bucksport to Highland is 0.219pu. Similarly, the Section 205 Orrington-Betts Road relay Zone 1 reactance is 0.0479pu, the impedance between Orrington and Betts Road is 0.0296pu, and the total line impedance from Bucksport to Orrington is 0.0683pu. This is also true for the far end relays on Sections 86 (Highland-S86B Tap) and 205 (Bucksport -Betts Rd).

For the analysis of the second tie project, the zone impedance for Section 388 was reduced by the value of the series capacitor proposed for that line. This only approximates the line relaying system. A complete protective relaying analysis for Section 388 and its neighboring lines should be performed as part of a facilities study.

In addition to the individual relay models described above, a world relay model (zlinw) was used to monitor (not trip) all other transmission lines in Maine. This world relay model represents a generic impedance distance relay for all 115kV, 230kV, and 345kV transmission lines, as specified in the model data shown in *Table 2-10*. The apparent impedance of each line is computed at both ends of the line. If the apparent impedance at either end enters the Zone 1 circle, the monitoring function indicates that tripping would have been initiated instantaneously. In general, if it stays inside the Zone 2 circle continuously for a specified time, the monitoring function indicates tripping would have been initiated. However, for lines with a nominal voltage above 220kV, the monitoring function would note tripping was initiated instantaneously if the apparent impedance at both ends enters Zone 2. This function assumes communication channels for a transfer trip.

Both the individual and world relay models were included in all simulations.

Table 2-9. Individual Impedance Distance Relay Model (zlin1) Data Compared to Actual Line Impedances.

Section	From Bus	To Bus	R Zone 1 (pu)	X Zone 1 (pu)	Zone 1 Pickup Time (sec)	Zone 1 Breaker Time (sec)	R Zone 2 (pu)	X Zone 2 (pu)	Zone 2 Pickup Time (sec)	Zone 2 Breaker Time (sec)	Line R From-To (pu)	Line X From-To (pu)
388	Orrington	Maxcys	0.00686	0.0256	0.0167	0.0833	0.0118	0.0439	0.4	0.0833	0.0025	0.0281
388	Maxcys	Orrington	0.00686	0.0256	0.0167	0.0833	0.0118	0.0439	0.4	0.0833	0.0025	0.0281
392	Maxcys	ME Yankee	0.00316	0.0118	0.0167	0.0833	0.0052	0.0194	0.4	0.0833	0.0012	0.013
392	ME Yankee	Maxcys	0.00316	0.0118	0.0167	0.0833	0.0052	0.0194	0.4	0.0833	0.0012	0.013
65	Orrington	Bucksport	0.00813	0.0514	0.0167	0.0833	0.0163	0.1027	0.4	0.0833	0.0108	0.0683
65	Bucksport	Orrington	0.00976	0.0616	0.0167	0.0833	0.0168	0.1058	0.4	0.0833	0.0108	0.0683
86*	Bucksport	Belfast	0.0277	0.175	0.0167	0.0833	0.0413	0.314	0.4	0.0833	0.0105	0.0861
86*	Highland	S86B Tap	0.0277	0.175	0.0167	0.0833	0.0875	0.326	0.4	0.0833	0.0028	0.0263
203	Bucksport	Detroit	0.0259	0.163	0.0167	0.0833	0.0466	0.294	0.4	0.0833	0.0308	0.1958
203	Detroit	Bucksport	0.0249	0.157	0.0167	0.0833	0.0778	0.29	0.4	0.0833	0.0308	0.1958
205*	Orrington	Betts Rd	0.00759	0.0479	0.0167	0.0833	0.0163	0.1027	0.4	0.0833	0.0047	0.0296
205*	Bucksport	Betts Rd	0.00868	0.0548	0.0167	0.0833	0.0276	0.174	0.4	0.0833	0.0061	0.0387

*Note: Total line impedance of Section 86 (Bucksport-Belfast-S86B Tap-Highland 115kV) = 0.0245 + j0.2188 pu.
Total line impedance of Section 205 (Bucksport-Betts Rd-Orrington 115kV) = 0.0109 + j0.0683 pu.

2.3.4 Transient Analysis

Addition of both shunt and series compensation has the potential to impact the transient behavior of the system. For the shunt compensation, back-to-back switching of the cap banks must be taken into account in the bank design. The series compensation has the potential to impact transient recovery voltages on circuit breakers and must be analyzed.

3. Power Flow Analysis Results

The power flow analysis was performed using GE's PSLF program. For pre-contingency solutions, transformer tap and phase shifting transformer angle movement as well as static var device switching were allowed. For post-contingency solutions, phase shifter angles remained fixed, while transformer tap and static var device switching were allowed.

The bus voltage and branch loading performance was compared against appropriate criteria; as described in Section 2.1.3. The results of this analysis are described in the following subsections.

The results of both the base case and contingency analysis for the 19 study conditions (8 benchmark cases and 11 cases with the second tie) are shown in the linked Excel workbook. The voltage and thermal violations are presented in several tabbed worksheets and are discussed below.

Entries in the tables that are in violation of criteria are indicated in red type. Black type and zero entries indicate that the result is within criteria. There are a few cases included in the workbook that did not solve. These cases are indicated with a red 9 or 999 in the reports, and are also discussed below.

3.1 Bus Voltage Results

The first tab of the workbook contains the contingency list. The second tab (**all VVs**) documents all voltage violations in New England and New Brunswick. The results are grouped by bus and then by contingency. There are many buses throughout the region that have minor high and low voltage violations. The voltage violations outside of Maine are largely unaffected by the addition of the second tie. Minor differences outside of Maine between the benchmark cases and corresponding second tie cases are due mostly to differences in unit commitment between the cases.

The third tab of the workbook (**all ME VVs**) is a subset of the first tab, reporting only bus voltage violations within Maine. There are many minor high violations on the 115kV system which are only slightly influenced by the second tie. Some 345kV buses in Maine experience voltages ranging from 1 to 3% above the 105% criteria for events involving system separations with SPS operation (i.e. contingencies 24a, 25a, and 27a). Performance with and without the tie is similar. The table shows that some cases, especially those with failure of the SPSs, result in voltages below minimum criteria. However, these are not design contingencies. All required cases solve with the second tie in service.

The fourth tab of the workbook (**ME low VVs design 1**) contains the voltage results, sorted by bus, for cases that are expected to meet voltage criteria. The asterisk cases from *Table 2-3* are excluded, except for the double circuit tower outages (40 and 41), which must satisfy a relaxed voltage criteria. The fifth tab of the workbook (**ME low VVs design 2**) contains the same information, sorted by outage. Some of the post-contingency conditions for peak load represent a severe voltage stress on the system.

Since these cases are expected to meet criteria, a brief discussion of each outage that results in any highlighted (red) entry follows.

Cases 24a and 25a, result in separation of the northern Maine and Maritimes systems from New England. Minor violations on the 115kV system in the vicinity of Ricerips result. CMP considers the modeling of reactive power reserves in this area to be very conservative and considers this result to be acceptable.

Case 27a trips the 396 line. The low voltages at Chester 115 are recognized as a pre-existing limitation.

Cases 31 and 39 trip half of the Surowiec substation, including the autotransformer and shunt capacitors. The low voltages are a dispatch related condition, since they result primarily with AEC off-line. Further, the trip of the shunt capacitors in this scenario is a conservative assumption and not guaranteed.

Cases 38t and 38b trip half of the Maxcys substation. The resulting slight voltage violations are not considered significant by CMP.

3.1.1 Reduced Orrington South Transfer Sensitivity Cases

Two of the peak loading conditions with the second tie project were tested under reduced Orrington–South interface flow. Two peak load cases, pk4 and pk5, for the A1 dispatch, were modified by removing the generator at Bucksport and adding one unit at RPA. This brings the Orrington – South interface flow down to the present loss-of-source operational limit of 1200 MW, and leaves all other quantities the same as reported in Table 2-1. For each of these two loading conditions, three loadflows with one, two and three 30 MVAr 115kV capacitor banks were created. Oneline diagrams and summaries for these six cases are provided by the links *in Table 3-1.*

Table 3-1. Maine One-line Diagrams for 1200 MW Orrington South Interface flow and Various 115kV Capacitors.

.Case	Brief Description	ME One Line
pk4a1r2xc3	pk4 with 1200 MW OrSo, three 115kV cap banks (2 at Gulf Island, 1 at Kimball Rd)	pk4a1r2xc3me
pk4a1r2xc2	pk4 with 1200 MW OrSo, two 115kV cap banks (1 at Gulf Island, 1 at Kimball Rd)	pk4a1r2xc2me
pk4a1r2xc1	pk4 with 1200 MW OrSo, two 115kV cap banks (1 at Gulf Island, 0 at Kimball Rd)	pk4a1r2xc1me
pk5a1r2xc3	pk5 with 1200 MW OrSo, three 115kV cap banks (2 at Gulf Island, 1 at Kimball Rd)	pk5a1r2xc3me
pk5a1r2xc2	pk5 with 1200 MW OrSo, two 115kV cap banks (1 at Gulf Island, 1 at Kimball Rd)	pk5a1r2xc2me
pk5a1r2xc1	pk5 with 1200 MW OrSo, two 115kV cap banks (1 at Gulf Island, 0 at Kimball Rd)	pk5a1r2xc1me

A contingency analysis was performed on these conditions. The results of the contingency analysis are reported in the Orrington South at 1200 MW worksheet. For these conditions, two115k shunt capacitors are required to meet minimum voltage criteria. A single 30 MVAr bank, however, results in voltage violations at Belfast. Violations at Ricerips have been discussed above, and the DCT contingency, nne41, is discussed further below. There are no stability cases in which the 115kV shunt capacitors are significant. Therefore, discussion of the third capacitor bank is only relevant for power flow results with an Orrington South interface flow in excess of the current limit of 1200MW.

3.2 Branch Loading Results

The sixth tab of the workbook (**LTE OLs**) documents all long-term emergency thermal violations in New England. The results are grouped by branch and then by contingency. There are many branches throughout the region that have minor thermal violations. The violations outside of Maine are largely unaffected by the addition of the second tie project. Minor differences outside of Maine between the benchmark cases and corresponding second tie cases are mostly due to differences in unit commitment between the cases.

The seventh tab of the workbook (**ME LTE OLs**) is a subset of the first tab, reporting only branches within Maine. As expected, there are several severe overloads on the 115kV system that are due to SPS failure or the double circuit tower outages.

The eighth tab of the workbook (**ME LTE OLs design**) includes only design cases. The double circuit tower cases are not included here, because of the exclusion. The line between Chester and the border and from the border to Keswick was overloaded for the loss of the new line and without any NB generation rejection (no New DPL SPS modeled). With the New DPL SPS, there is no overload. The overload on the Highland-New Castle line does not violate criteria, since it can be eliminated by modifying the dispatch and reducing the output of Bucksport and/or MIS. The Belfast-Bucksport overload is a function of the dispatch in the benchmark cases only. Similarly, the overloads on the Louden-S250A Tap and Dover-3 Rivers 115kV lines are a function of the dispatch and the high ME/NH power flows. The remaining overloads also exceed the STE rating and will be discussed below.

The ninth tab of the workbook (**ME STE OLs by branch**) reports short term emergency thermal violations only for branches within Maine. The results are similar to the LTE cases, and as expected, there are several severe overloads on the 115kV system that are due to SPS failure or the double circuit tower outages. Double circuit tower outages are discussed further below. The tenth tab (**ME STE OLs by outage**) reports the same information as the previous tab, with the results sorted by outage.

The eleventh and twelfth tabs of the workbook (**ME STE OLs design by branch** and **ME STE OLs design by outage**, respectively) include only design cases. The most notable violations are for two line Sections 88 and 213 in the vicinity of Augusta East. These Sections are presently rated 79 MVA STE. CMP has stated that the ratings of Section 88 will be increased to a minimum LTE rating of 126 MVA before the second tie is built. A short portion (7 miles) of Section 213 limits the STE capacity of this line. The second tie project will include thermal upgrade of this Section as part of the project. This brings all the loading results in all cases within criteria. The Bucksport-Belfast and Dover-3 Rivers lines were discussed above. The S83C Tap- SDW SOMS 115kV line is an existing condition due to high flows in this area for the light load cases.

Tab thirteen of the workbook (**Chester Q**) reports the MVAr output for the Chester SVC for every case. Entries of 999 correspond to unsolved cases. In general, the SVC tends to contribute much less to the support of the system following addition of the second tie. This is discussed further below.

Tab fourteen of the workbook (**SVD B**) reports the capacitor susceptance (B) of each of the important mechanically switched shunt capacitors in Maine every case. Again, entries of 999 correspond to unsolved cases.

3.2.1 Double Circuit Tower Outages

The STE overloads (tabs 9 and 10) for the double circuit tower (DCT) outage cases were subjected to closer examination. The DCT cases are 40 (Maine Yankee–Surowiec 345kV and Maine Yankee–Buxton 345kV) and 41 (Maine Yankee-Maxcys 345kV and Maine Yankee-Buxton 345kV). When the Maxcys and Bucksport overcurrent SPSs do not operate, both DCTs result in very heavy flow on the underlying 115kV circuits. The circuits overloaded by the Kennebec River Crossing DCT (40) is subject to NEPOOL and NPCC thermal exclusions.

In the existing system, the DCTs result in STE violations on four Sections under light load (lt2) conditions. The overloaded Sections are

- Highland-New Castle-Mason (Sections 204 and 226)
- Mason-Maine Yankee-Bath (Sections 207 and 69)
- Mason-Topsham-Surowiec (Section 81)
- Maxcys–Mason (Section 68)

The maximum overload for import cases on the benchmark system is 108% occurring on the Highland-New Castle line for the lt2 light load condition. An overload of 130% occurs on Mason–New Castle line for the export case.

As discussed above, the study condition for the second tie project includes approximately 300 MW of additional power transfer on the Orrington South interface. For the double circuit tower outages, most of the additional 300 MW flow is directed to the underlying 115kV system, making the overloads more severe. These Sections are subject to significant violation of STE limits for most of the conditions studied. Overloads range reach as high as 191% of STE on Section 81, from Mason to Topsham. This occurs for the lt2-b1 light load, B dispatch condition.

The peak conditions were examined further with the second tie project. For these cases, the Maxcys and Bucksport overcurrent SPS operation was not emulated, since this lack of operation is the desirable response to DCTs. LTE and STE violations under six peak load system conditions are shown in dct overloads. The thermal exclusion is based on the present system. Thermal loading of Section 86 (Bucksport – Belfast 115kV) limits the Orrington South interface in the present system to about 1060 MW, which is reflected in the table. Two peak conditions with the second tie were created with the Orrington South interface loaded to the design, but presently unreachable, limit of 1200 MW. These conditions are shown as pk4a1br2 and pk5a1cr2 in the table, with the Orrington South interface flow reduced to 1200 MW by the removal of Bucksport and the addition of one RPA unit. The two peak conditions with the second NB tie project (pk4a1r2 and pk5a1r2) have the Orrington South interface loaded to 1385 MW.

The 115kV overloads with the second tie project are less with the 1200 MW Orrington South interface loading case than with the 1385 MW flow. They are still significantly higher than those found for the benchmark cases. The addition of the series compensation tends to reduce the loading on the Bucksport-Belfast line, which somewhat aggravates the overloading of the Maxcys-Mason line for the Maine Yankee-Maxcys and Maine Yankee-Buxton DCT (41).

The overloads that result when the full 300 MW of incremental import is added to the Orrington South interface are severe. One option for addressing these overloads is to modify the Maine Yankee DCT SPS to activate the Loss of 3001 SPS, which trips generation in New Brunswick to supplement the Maine Independence Station transfer trip (discussed in detail in Section 6). Cases with the modified DCT SPS operating are shown in the LTE portion of the table (cases 40dt and 41dt). The NB generation tripped is targeted to reduce the Orrington South interface flow to around 200 MW, and to be less than 1200 MW loss of source. The NB generation trip arming and priorities for this arrangement would be the same as presently used for the Loss of 3001 SPS. For both DCTs this improvement results in healthy voltages, all lines loaded within limits and within 1200 MW loss of source. The modified DCT SPS completely eliminates the LTE and STE overloads for all cases – therefore it does not appear on the STE sheet. The need for the present thermal exclusion is eliminated.

The most limiting condition, which sets the existing thermal exclusion for the present system, occurs under light load with Maine Independence Station out-of-service and maximum loading on the Orrington – South interface. Since the present DCT SPS only trips MIS, there is no relief for the underlying 115kV circuit following the DCTs. With Maine Independence Station off-line, there are limited generation resources available to load the Orrington South interface. Two light load cases, one for the existing system (lt4) and one with the second NB tie project (lt4a1r2), were created with maximum loading on Orrington South interface. The benchmark system condition results in 706 MW loading on the interface. The second NB tie condition results in 1013 MW loading. The DCTs for these two conditions result in very severe thermal overloads for both the existing system and with the second tie in service, as shown in the light load DCT worksheet. In the present system, there are four violations in excess of 150% of STE rating, with 167% on Highland-New Castle being the worst. With the second NB tie project, four violations exceed 200%. As with the peak load cases discussed above, the modified DCT SPS completely eliminates the thermal violations for both DCTs with the second NB tie project and do not appear on the spreadsheet.

One-line diagrams for Maine of all the conditions displayed in the two spreadsheets are included in *Table 3.2*.

Table 3-2. Maine One-line Diagrams for Double Circuit Tower Outages.

Case	Brief Description	ME One Line
pk4s86o_nne40	pk4 base, contingency 40	pk4s86o_nne40
pk5s86o_nne40	pk5 base, contingency 40	pk5s86o_nne40
pk4s86o_nne41	pk4 base, contingency 41	pk4s86o_nne41
pk5s86o_nne41	pk5 base, contingency 41	pk5s86o_nne41
pk4a1br2_nne40	Pk4 with second tie, A1B dispatch (1200 MW OrSo) cont 40	pk4a1br2_nne40
pk5a1cr2_nne40	Pk5 with second tie, A1C dispatch (1200 MW OrSo) cont 40	pk5a1cr2_nne40
pk4a1br2_nne41	Pk4 with second tie, A1B dispatch (1200 MW OrSo) cont. 41	pk4a1br2_nne41
pk5a1cr2_nne41	Pk5 with second tie, A1C dispatch (1200 MW OrSo) cont. 41	pk5a1cr2_nne41
pk4a1r2_nne40	Pk4 with second tie, A1 dispatch contingency 40	pk4-a1r2_nne40
pk5a1r2_nne40	Pk5 with second tie, A1 dispatch contingency 40	pk5-a1r2_nne40
pk4a1r2_nne41	Pk4 with second tie, A1 dispatch contingency 41	pk4-a1r2_nne41
pk5a1r2_nne41	Pk5 with second tie, A1 dispatch contingency 41	pk5-a1r2_nne41
pk4s86o_nne40dt	pk4 base, contingency 40 with modified DCT SPS	pk4s86o_nne40dt
pk5s86o_nne40dt	pk5 base, contingency 40 with modified DCT SPS	pk5s86o_nne40dt
pk4s86o_nne41dt	pk4 base, contingency 41 with modified DCT SPS	pk4s86o_nne41dt
pk5s86o_nne41dt	pk5 base, contingency 41 with modified DCT SPS	pk5s86o_nne41dt
pk4a1br2_nne40dt	Pk4 with second tie, A1B dispatch (1200 MW OrSo) cont. 40 with modified DCT SPS	pk4a1br2_nne40dt
pk5a1cr2_nne40dt	Pk5 with second tie, A1C dispatch (1200 MW OrSo) cont. 40 with modified DCT SPS	pk5a1cr2_nne40dt
pk4a1br2_nne41dt	Pk4 with second tie, A1B dispatch (1200 MW OrSo) cont. 41 with modified DCT SPS	pk4a1br2_nne41dt
pk5a1cr2_nne41dt	Pk5 with second tie, A1C dispatch (1200 MW OrSo) cont. 41 with modified DCT SPS	pk5a1cr2_nne41dt
pk4a1r2_nne40dt	Pk4 with second tie, A1 dispatch contingency 40, with modified DCT SPS	pk4-a1r2_nne40dt
pk5a1r2_nne40dt	Pk5 with second tie, A1 dispatch contingency 40, with modified DCT SPS	pk5-a1r2_nne40dt
pk4a1r2_nne41dt	Pk4 with second tie, A1 dispatch contingency 41, with modified DCT SPS	pk4-a1r2_nne41dt
pk5a1r2_nne41dt	Pk5 with second tie, A1 dispatch contingency 41, with modified DCT SPS	pk5-a1r2_nne41dt
lt4_nne40	Lt4 base system without MIS, contingency 40	lt4nne40me
lt4_nne41	Lt4 base system without MIS, contingency 41	lt4nne41me
lt4a1_nne40dt	lt4 with second tie, contingency 40, with modified DCT SPS	lt4a1r2nne40dctme
lt4a1_nne41dt	lt4 with second tie, contingency 41, with modified DCT SPS	lt4a1r2nne41dctme

3.3 PV Analysis

The calculation of maximum power transfer provides additional insight into system security. Therefore, the maximum power transfer across the peak load pk4 benchmark and second tie project systems was determined.

The evaluation was designed to determine the margin to voltage collapse across the 345kV corridor from New Brunswick across Maine and into the rest of NE. In each of the cases run, the export from New Brunswick was increased from the base condition of 700 MW for the benchmark cases to 1000 MW for the second tie cases. The increased export was matched by a corresponding increase in load south of the ME-NH interface. Specifically, all loads in zones 24, 28, 80, 91, 92, 96, 138, 171 and 186 were scaled up to match the increased import. As the transfer was increased, shunt capacitors and other control devices were allowed to act.

At the point of maximum power transfer, attempts to push incremental power through the system will result in decreasing voltages and decreasing power transfer. This is the so-called nose of the PV curve. The difference in power transfer between the study condition and the maximum power transfer is the power margin (P_{margin}). In general, a larger P_{margin} indicates a more secure system. Informal criteria within NEPOOL have aimed at maintaining a minimum of around 100 MW $P_{margin.}$ Another useful measure is the difference between the bus voltage at the point of collapse, the critical voltage, and the initial voltage, i.e. the voltage margin, V_{margin}. In systems with a high level of shunt compensation, the V_{margin} can be more limiting than the P_{margin} .

The bulk transmission system is at greatest risk of voltage collapse under high load and heavy transfer conditions. Therefore, simulations were run on the peak load pk4 and pk4-a1 conditions. The pre-contingency P_{margin} is greater than 300 MW for both the benchmark and second tie cases. Post-contingency conditions are of more interest. One of the most severe design contingencies is the Surowiec stuck-breaker case, N31, which includes the loss of both Surowiec 345kV lines, the transformer and the shunt capacitors. The remaining 345kV system, which is a single circuit from Orrington to Buxton under this condition, is highly stressed. *Figure 3-1* shows the PV curves for selected 345kV buses along the corridor. The benchmark system collapse occurs at about 940 MW total transfer, so the P_{margin} for the case is about 240MW (i.e. 240 MW above the initial transfer level of 700 MW). The lowest voltages at the point of voltage collapse are around Maxcys and Maine Yankee, which indicates that these buses are at the center of the voltage collapse. The critical voltage is around 86%, which indicates that the benchmark system is not overcompensated. The voltage at Chester (the red trace) is held at 97% by the SVC nearly to the point of voltage collapse. Voltage collapse occurs very shortly after the SVC exhausts its capacitive range.

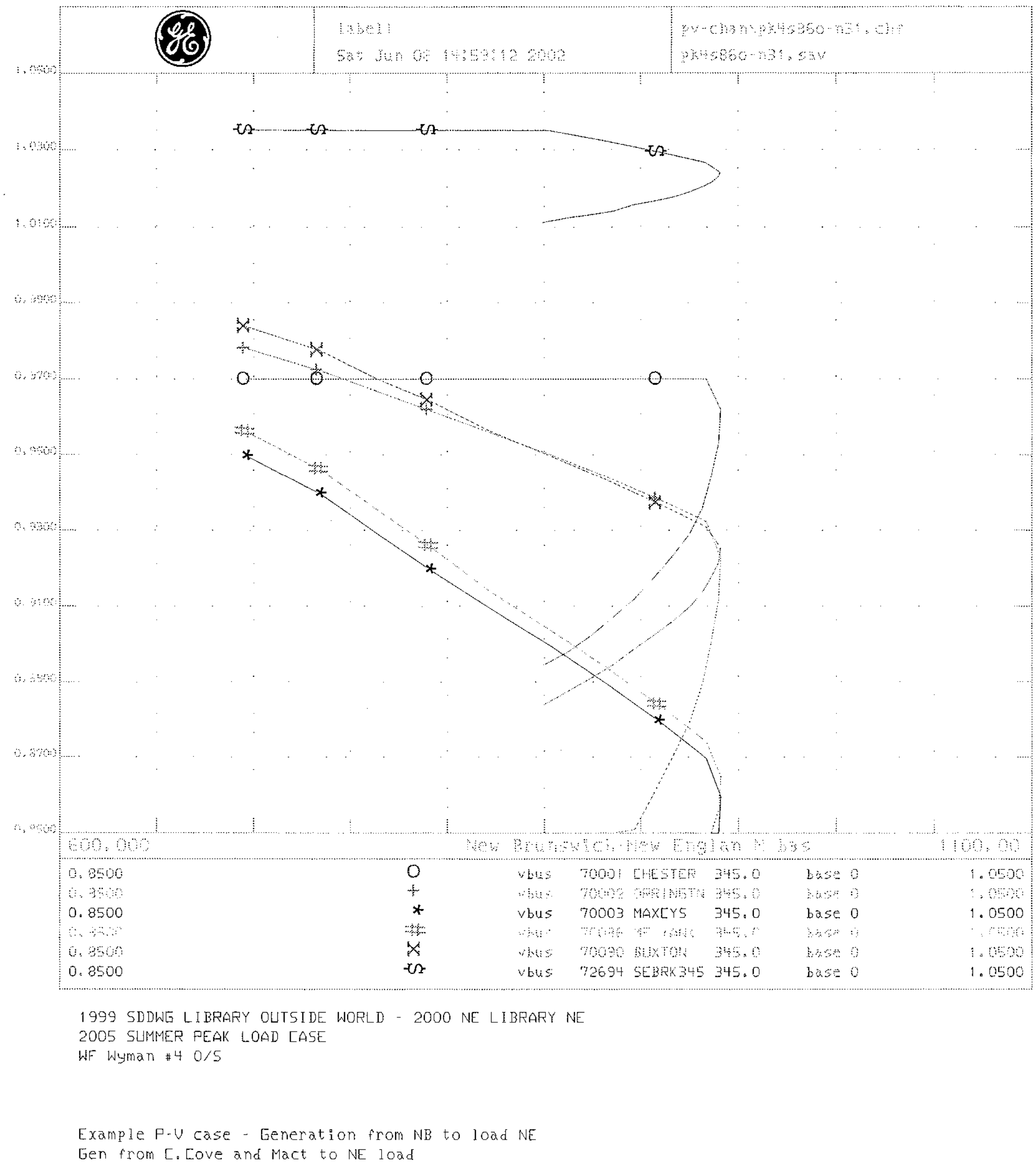
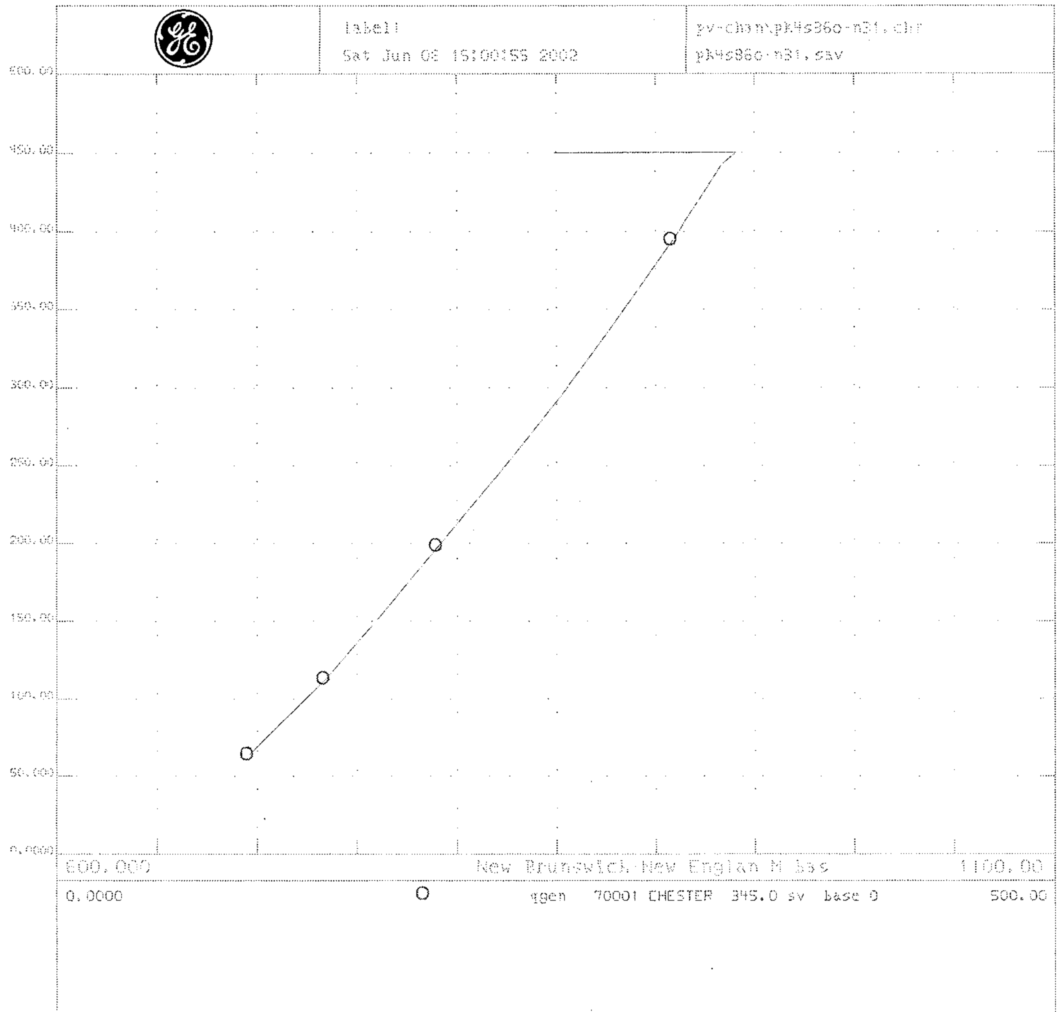


Figure 3-1. PV Curves for pk4 Benchmark System for the Surowiec Stuck Breaker (N31) Contingency.

The corresponding PV curves for the second tie project system are shown in *Figure 3-2.* In these curves, the initial condition is 1000 MW of transfer on the NB-ME interface. The maximum power transfer is more than 1400 MW, corresponding to a P_{margin} of more than 300MW. For this case, the critical voltage occurs beyond 1400 MW transfer, and is below 85%.

3.4 Reactive Power Management

The behavior of the Chester SVC is key to the voltage security of the benchmark system. As noted above, the system experiences voltage collapse in the PV analysis almost as soon as the SVC has exhausted its capacitive range, as shown in *Figure 3-3.* These figures show the output of the SVC increasing with power transfer, as the voltage regulator maintains a minimum 97% voltage on the Chester 345kV bus (Chester SVC in Breg mode). The SVC reaches a maximum output of 450MVAr just as the maximum transfer is reached. If the SVC had additional capacitive range, the P_{margin} would be higher. The flat Section on the curve is the SVC at limits, as the power transfer drops under the nose. The SVC is approximated with a constant Q device. In practice, this behavior would be slightly worse, since the Q output would drop with the square of the voltage. The fact that the SVC reaches saturation just at the point of voltage collapse is an indication that the reference voltage of 97% is a good choice for the system. The SVC in effect becomes the reactive power supply of last resort.



1999 SDDWG LIBRARY OUTSIDE WORLD - 2000 NE LIBRARY NE
2005 SUMMER PEAK LOAD CASE
WF Wyman #4 O/S

Example P-V case - Generation from NB to load NE
Gen from C.Cove and Mact to NE load

Figure 3-3. Chester SVC Reactive Output for pk4 Benchmark System for the Surowiec Stuck Breaker (N31) Contingency.

The behavior of the Chester SVC with the second tie in service is markedly different. In the PV curves shown in *Figure 3-2,* the Chester 345kV bus maintains 97% voltage, even after the system farther south experiences voltage collapse. The behavior of the SVC for this case is plotted in *Figure 3-4*. The SVC is never exhausted, and has more than 200

MVAr still in reserve at the point of voltage collapse. With the addition of a second line, the SVC is no longer in the best location to help the system for these events. The SVC is under utilized for these cases. The present voltage regulation set point contributes to the problem.

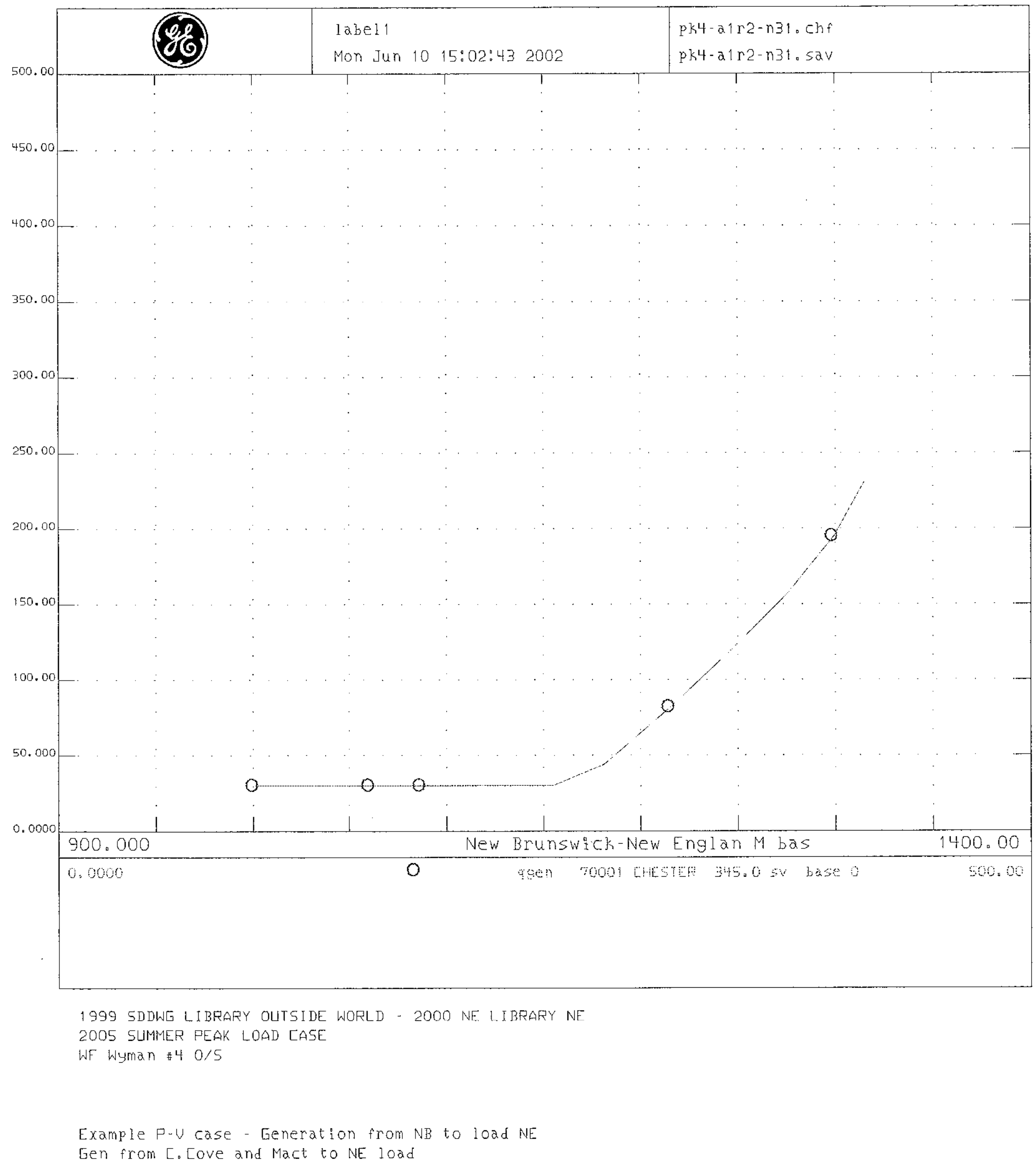
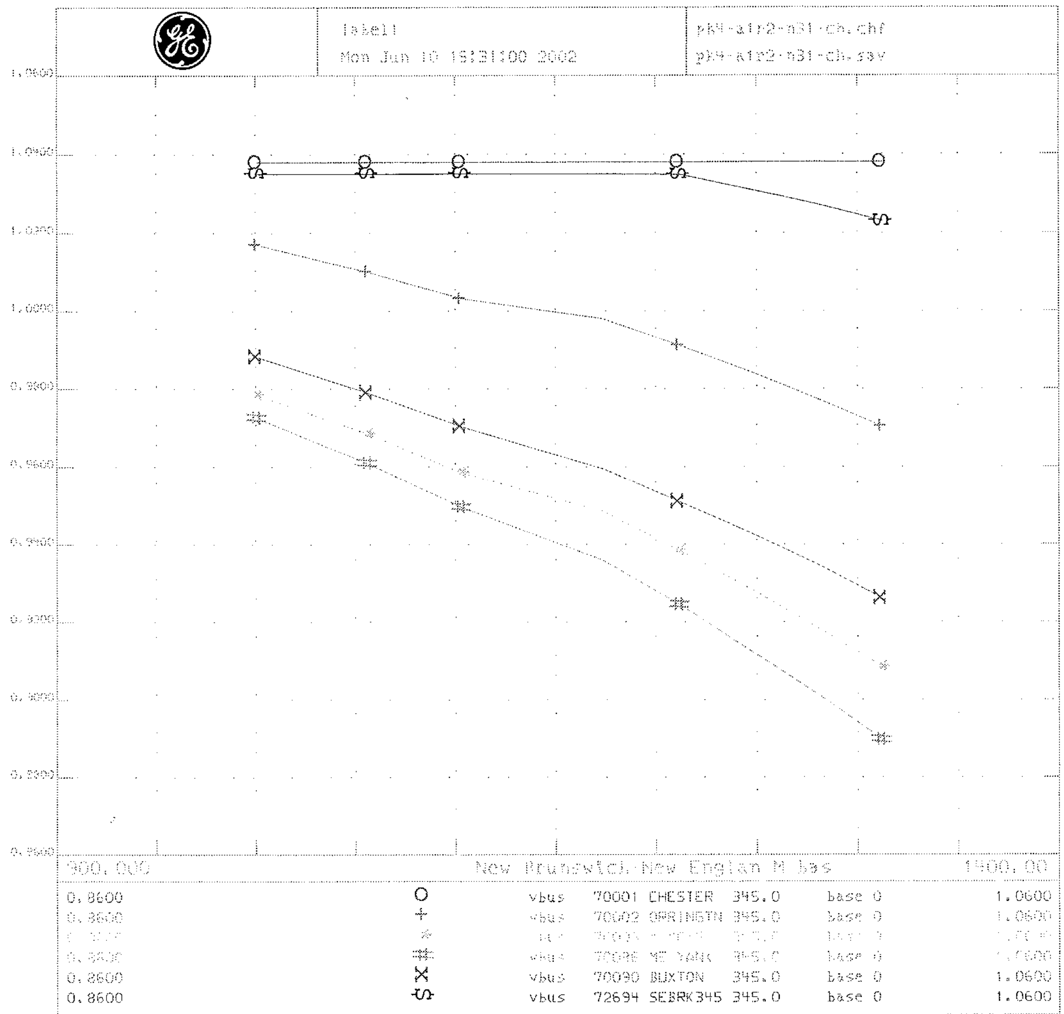


Figure 3-4. Chester SVC Reactive Output for pk4 a1 Second Tie System for the Surowiec Stuck Breaker (N31) Contingency.

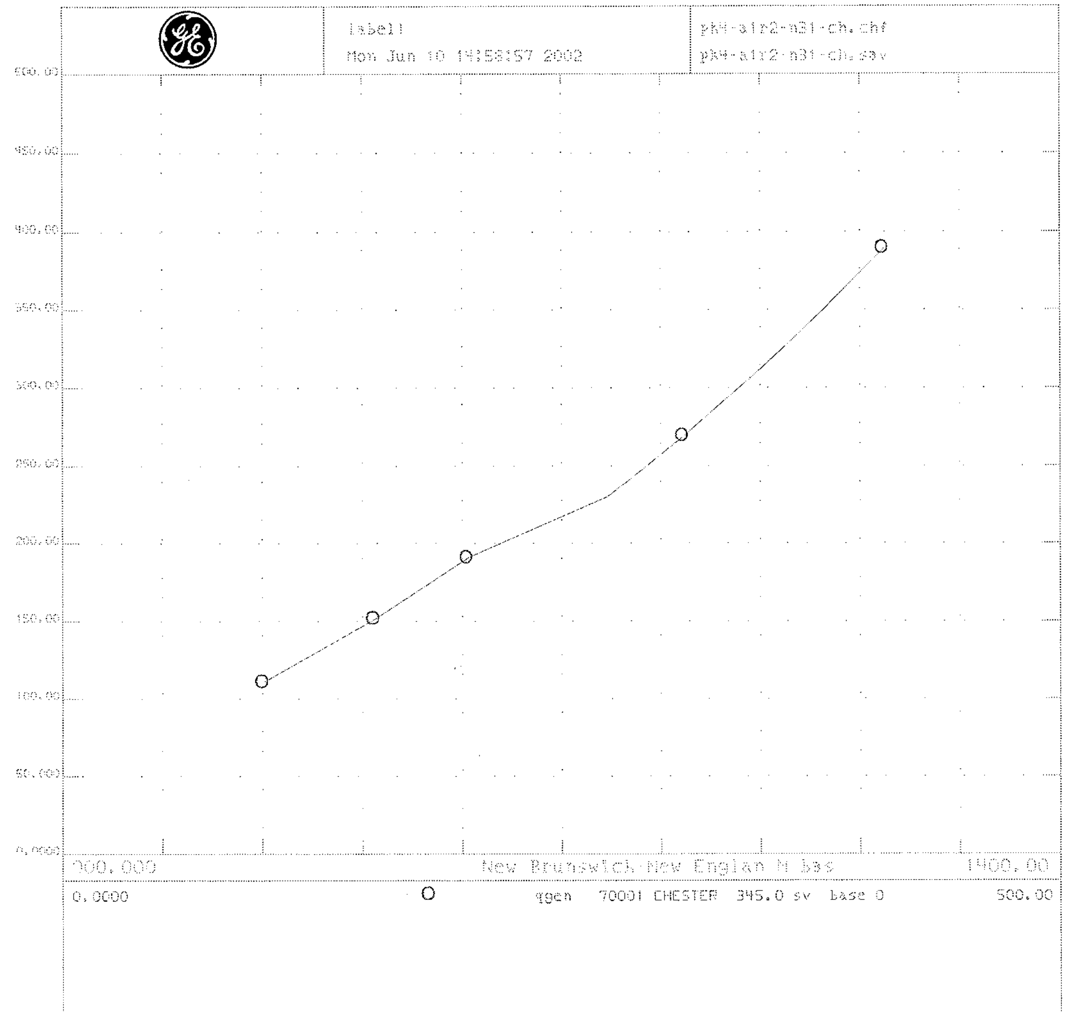
The Chester SVC can be used more effectively, increasing system security with the second tie, by raising the voltage reference point. *Figure 3-5* shows the PV curves for the second tie system with the Chester SVC voltage reference raised to 103.8%. This is the voltage setpoint for the SVC to reduce output below 30MVAr and hold down voltage in light load cases. The results show an improved voltage profile, including a higher margin until Seabrook reaches maximum reactive power output. The maximum power transfer is greater than 1400 MW, and significantly higher than without this change. The corresponding plot of Chester Q output is shown in *Figure 3-6*.



1999 SDDWG LIBRARY OUTSIDE WORLD - 2000 NE LIBRARY NE
2005 SUMMER PEAK LOAD CASE
WF Wyman #4 O/S

Example P-V case - Generation from NB to load NE
Gen from C.Cove and Mact to NE load

Figure 3-5. PV Curves for pk4 a1 System with the Second Tie for the Surowiec Stuck Breaker (N31) Contingency with Chester SVC holding 103.8% Voltage.



1999 SDDWG LIBRARY OUTSIDE WORLD - 2000 NE LIBRARY NE
2005 SUMMER PEAK LOAD CASE
WF Wyman #4 O/S

Example P-V case - Generation from NB to load NE
Gen from C.Cove and Mact to NE load

Figure 3-6. Chester SVC Reactive Output for pk4 a1 Second Tie System for the Surowiec Stuck Breaker (N31) Contingency with Chester SVC holding 103.8% Voltage.

It should be emphasized that this change in control of the SVC was not assumed in the results presented elsewhere in this report. The system performance with the second tie project, meets the system performance criteria without relying on this improvement. However, these cases show that the control of the Chester SVC could be improved to make the performance of the system with the second tie project even better.

Another aspect of reactive power control that could result in better system performance is coordination of the 345/115kV transformer taps at stations in Maine (especially Maxcys, Orrington and Mason). The present control philosophy can result in an underutilization of reactive resources on the 115kV system when the 345kV system is in a highly stressed post-contingency condition. These improvements are not required for the second tie project, but may be beneficial to the security of the system, regardless of whether the project goes forward.

3.5 Additional Series Compensation Sensitivity Analysis

With the addition of the second NB tie, the loss of the Keswick-Orrington 396 line when the New Brunswick–New England interface is loaded above 700MW requires the New DPL SPS, as described in Section 6, to reduce flow on the new line to 700 MW or less. A sensitivity case examining the addition of series compensation to the new line, as a possible alternative to the SPS, was run. A second series capacitor of the same parameters as that added to the Orrington-Maxcys line (i.e. 25 ohm, 300 MVAr) was added to the Pt. Lepreau-Orrington line. At 1000 MW NB-ME transfer, the power split between the two circuits becomes significantly unbalanced due to the relative impedance mismatch between the 396 and 3016 circuits. Trip of line 396 without the New DPL SPS results in no voltage or thermal violations with this second series capacitor.

4. Transient Stability Analysis

A transient stability analysis was performed under the assumptions described in Section 2. The results for the light load cases are summarized in the Excel file slt2stabsum10.xls. Results for the peak cases are summarized in the Excel file spk4stabsum2.xls, and results form the export cases (derived from light load case, and with Pt Lepreau out of service) are summarized in the Excel file sexl2stabsum2.xls. Sections 4.2 through 4.5 describe the primary light load stability simulation results, with particular emphasis on violations (red entries). The order of the discussion corresponds to fault type groups in the spreadsheet summaries. Section 4.6 examines SPS failure cases. Section 4.7 examines a sensitivity case with a second series capacitor on the new Pt. Lepreau-Orrington line for loss of 396 (nc396). Sections 4.8 through 4.10 describe the peak load stability results, and Sections 4.11 through 4.13 describe the light load export stability results.

4.1 Guide to Simulation Results

At the top of each Excel file, and above the major column groupings, is a summary of the initial conditions. The Pre-fault Caps shows the total on-line MVArs for each Maine 345kV shunt capacitor bank. WF Wyman #4 shows the initial power output of this unit. Interface Flows shows ten key interface flows in the following order: NBNE (New Brunswick–New England), OrSo (Orrington South), SuSo (Surowiec South), MENH (Maine–New Hampshire), NNE (Northern New England-Scobie + 394), NS (North–South), EW (East–West), NYNE (New York–New England), SEMARI Export (Southeast Massachusetts and Rhode Island, SEMA Export (Southeast Massachusetts).

NB Gen max is the total New Brunswick generation that might be rejected by the GCX Zone 3 or Loss of 3001 SPSs. When NB load rejection occurs, this value is used in calculation of loss of service (LOS), even when the actual amount tripped is less. Phase II is the initial power transfer on the Phase II HVDC tie. Key generator dispatches shows the dispatch on five key machines (MIS, Bucksport, Seabrook, Westbrook, Pt. Lepreau).

The summary tables list the faults in the first set of columns, the results of the benchmark system analysis in the second set, and the results of the second tie project system in the third and final set. The individual columns in each set of results represent the details of the simulation.

For the existing system set of columns, column 1 indicates system response in terms of transient stability. Simulations are either stable, stable with violations of the proposed CMP voltage criteria, or result in a system separation. Cases which result in a system separation note the location of the split. Cases with violations of the proposed CMP voltage criteria have addition details provided in the cell comments. Column 2 shows the damping of the least damped mode of oscillation in this system (0.25 Hz). It is calculated as the real part of the 0.25Hz component of a measured signal. The 0.25Hz component is derived from an FFT frequency decomposition. The Seabrook machine angle is used unless that machine is tripped. A detailed discussion of the damping calculation method is included in *Appendix G*. In that case, the Westbrook machine angle is used to calculate damping. The third column indicates the total MW of generation tripped by a generic out-of-step tripping function during the simulation. The individual machines tripped are identified in the comment box.

Columns 4 through 11 show the time of a specific SPS operation. Column 12 shows circuit numbers for lines tripped by relay operation. The comment box shows lines that may have tripped ("w") by the world line relay. Column 13 shows the timing of generation tripped in NB by the Loss of 3001 SPS.

The final column shows the total loss of source (LOS) in the simulation. It is the sum of the unstable units tripped (column 3), the units tripped by SPS operation (e.g., Maine Independence Station in response to Bucksport OC SPS operation), any NB generation rejection, and any generation tripped as part of the fault. For faults that involve system separation, the calculation of loss of source is the total import flow across the separated interface plus the sum of the generation tripped south of the interface. For cases that result in a system separation other than Orrington South, a drawing has been included showing the separation interface and detailing the LOS calculation. The drawing is accessed by a hyperlink on the LOS number in the spreadsheet.

The set of results for the second tie presents the same information in the first 12 columns. Columns 13,14 and 15 document details of operation of the new and modified SPSs, as described in detail in Section 6. Column 13 shows the time at which the flow based Loss of 3001/3016 (Maritimes Islanding) SPS activates, tripping 640 MW of generation in New Brunswick. Column 14 shows the time at which the New DPL SPS trips 320 MW of generation in New Brunswick. Column 15 shows the time at which direct signal tripping of 640 MW of generation occurs in New Brunswick due to a DCT event or tripping of Sections 388 or 392. The final column shows the total loss of source. Again, cases which result on system separation other than Orrington South include a system drawing, accessible from the spreadsheet, showing the separation interface and detailing the calculation of loss of source.

4.2 Light Load Normally Cleared 3-Phase Faults and More

The normally cleared 3-phase fault simulation results, double circuit tower faults, generation and load tripping scenarios are described in this Section. A brief summary of each fault is shown in *Table 4-1*, which also provides hyperlinks to the plotted results.

The ncm139 fault (Tewksbury-Woburn 115kV) has a very long fault clearing time. In the benchmark case voltage violations of the proposed voltage criteria are observed throughout Maine. In the benchmark case, the Keswick-Orrington apparent impedance enters the GCX zone 3 at 1.53 seconds, which violates criteria. The addition of the second tie improves performance and eliminates the violation and all LOS. The addition of the second tie removes the CMP voltage criteria violations as well.

The nc282-520 (Waltham-Watertown-Brighton 115kV) fault with 29 cycle clearing at Brighton results in severe voltage violations for both the benchmark and second tie project systems. A loss of source in excess of criteria occurs. Violent system swings occur in the benchmark system; these are evident in many voltage signals (e.g. Maxcys). A second backswing is substantially worse than the first voltage swing showing that the system barely avoids a system breakup. The initial system swing of the second tie case results in an immediate system separation in Maine at about two seconds. The extreme severity of this fault makes it difficult to determine whether the second tie project aggravates this system deficiency. Calculation of loss of source for such an extreme event is nearly meaningless. Sensitivity cases, reported below, show that the second tie project will eliminate these violations for either lower stress conditions (i.e. at peak load) or less violent fault (i.e. a reduced fault clearing time) before they are eliminated in the benchmark system. This is evidence that the second tie project improves the system performance for this pre-existing deficiency.

The nc388 (Orrington-Maxcys 345kV) and nc392 (Maxcys-Maine Yankee 345kV) cases result in a loss of the Orrington South interface, which consists of Section 388 and the Bucksport-Belfast and Bucksport-Detroit 115kV lines. The LOS for both faults is, therefore, equal to the Orrington South interface flow of 1203MW for the second tie and 1074MW for the benchmark case. For nc392 the benchmark system fails to meet the proposed voltage criteria; this is corrected by the addition of the second tie project.

The nc385 (Buxton-Deerfield 345kV) fault is representative of the most severe normally cleared faults. This case, as well as cases nc374, nc375a, nc375b, nc377, and nc391, meets criteria for both systems with no LOS. The post-fault topology allows for a sensible side-by-side comparison of system performance. These cases illustrate the similar performance between the two systems.

The nc396 (Keswick-Orrington 34kV) fault illustrates one of the significant reliability impacts of the new line. In the present system, this disturbance results in separation of New Brunswick from New England. The LOS is equal to the total NB/NE import of 700MW in the benchmark system plus Maine Independence Station by the 396 SPS, or up to approximately 1250MW. The addition of the second tie allows the two systems to remain synchronized, with the LOS limited to the dedicated path logic (DPL) tripped generation in New Brunswick plus MIS, or up to approximately 850MW. Thus, the second tie substantially reduces the loss of source. The second tie system requires the DPL SPS to trip generation to remain stable.

The nc3016 fault (Orrington-Pt. Lepreau) case shows that trip of the new line does not result in system separation, with LOS limited to the generation tripped by the New DPL SPS. Without the New DPL, the Chester SVC supports the additional flow on Section 396 without any New Brunswick generation rejection and all criteria are met. However, the high post-disturbance flow on 396 would be above the existing limits for a single NB tie. Therefore it is recommended, but not required, that the New DPL SPS act to trip generation for this event in similar fashion to the 3001/396 event.

The dct03 (Maine Yankee-Buxton 345kV, Maine Yankee-Surowiec 345kV) fault meets criteria for both the benchmark and second tie systems. The dct04 (Maine Yankee-Buxton 345kV, Maine Yankee-Maxcys 345kV) fault, like nc388 and nc392, results in the loss of the Orrington South interface. The LOS for the second tie system is, therefore, equal to the Orrington South interface flow.

In response to any of the generation tripping scenarios, there is no significant difference in performance between the two systems, both of which meet criteria.

The loss of 350 MW of load in new Brunswick is not a design basis event. This case, nbload, results in activation of the Bucksport OC SPS and GCX runback, for a total loss of source of 1248 MW in the benchmark system. The SPS actions and loss of source are eliminated with the addition of the second tie project.

Table 4-1. Normally Cleared 3-Phase Fault Results and More.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
ncm139	Tewksbury 115kV	3ϕ	none	Tewksbury-Woburn 115kV
nc282-520	Waltham 115kV	3ϕ	none	Waltham-Brighton 115kV Waltham-Watertown 115kV
nc337	Tewksbury 345kV	3ϕ	none	Tewksbury-Sandy Pond 345kV
nc374	Buxton 345kV	3ϕ	none	Buxton-Surowiec 345kV
nc375a	Buxton 345kV	3ϕ	none	Buxton-Maine Yankee 345kV
nc375b	Maine Yankee 345kV	3ϕ	none	Maine Yankee-Buxton 345kV
nc377	Maine Yankee 345kV	3ϕ	none	Maine Yankee -Surowiec 345kV
nc385	Buxton 345kV	3ϕ	none	Buxton-Deerfield 345kV
nc388	Orrington 345kV	3ϕ	none	Orrington-Maxcys 345kV
nc391	Buxton 345kV	3ϕ	none	Buxton-Scobie 345kV
nc392	Maxcys 345kV	3ϕ	none	Maxcys-Maine Yankee 345kV
nc396*	Orrington 345kV	3ϕ	none	Orrington-Keswick 345kV Chester SVC
nc3016	Orrington 345kV	3ϕ	none	Orrington -Pt. Lepreau 345kV
dct03	Maine Yankee 345kV	2ϕ	none	Maine Yankee-Buxton 345kV Maine Yankee Surowiec 345kV MIS transfer trip
dct04	Maine Yankee 345kV	2ϕ	none	Maine Yankee -Buxton 345kV Maine Yankee-Maxcys 345kV MIS transfer trip
mis	Trip MIS	NA	none	NA
ptlp	Trip Pt. Lepreau	NA	none	NA
sbrk	Trip Seabrook	NA	none	NA
wbrk	Trip Westbrook	NA	none	NA
nbload	Loss of 350 MW New Brunswick Load	NA	none	NA

Notes: * = favorite seven

4.3 Light Load Single-Phase Faults with Stuck Breakers

The single-phase fault with stuck breaker simulation results are described in this Section. A brief summary of the sc381 (Vermont Yankee-Northfield 345kV) fault is shown in *Table 4-2*, which also provides hyperlinks to the plotted results. The response of both the benchmark and the second tie systems meets criteria.

Table 4-2. 1-Phase Stuck Breaker Fault Results for Light Load Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
sc381*	Vermont Yankee 345kV	1ϕ	381	Vermont-Yankee-Northfield 345kV VY Auto #4 115kV

Notes: * = favorite seven

4.4 Light Load Three-Phase Faults with Stuck Breakers

The three-phase fault with stuck breaker simulation results are described in this Section. A brief summary of each fault is shown in *Table 4-3*, which also provides hyperlinks to the plotted results. Several of the cases in this category exhibit similar behavior, and are discussed in groups.

Faults ec312, ec326, ec339, ec372-2, ec374, ec377, ec385, ec394a, and ec3002 are acceptable for both the benchmark and second tie systems. For all cases in this group, the LOS from the benchmark system is reduced to zero with addition of the second tie.

Faults ec328, ec368, and ec394b, meet criteria for both the benchmark and second tie systems For all cases in this group, the LOS is zero in both cases. Fault ec342 performance is acceptable for both the benchmark and second tie systems. For this cases, the LOS from the benchmark system is 1176 and that of the second tie project system is 576 MW.

Faults ec391meets LOS objectives for the benchmark system and for the second tie system. For this fault, the system splits across the Maine Yankee-New Hampshire interface. The LOS and system separation is essentially the same with and without the second tie project.

The addition of the second tie changes the bus topology at Orrington, such that the Orrington faults on the benchmark system differ from those on the second tie system.

Therefore, fault ecx388 (Orrington–Maxcys 345kV) applies to the benchmark system, while ec388-1 and ec388-2 apply to the second tie system. As with nc388, these faults result in the loss of the Orrington South interface. These cases all meet extreme contingency criteria.

Faults ec396-1 (Orrington-Keswick 345kV) and ec396-2 apply to the second tie. The system remains stable and synchronized in response to both faults. Both cases meet criteria. The ecx396 fault only applies to the benchmark system. This fault results in the separation of New Brunswick and New England. LOS in this case corresponds to the Orrington South flow, and is within criteria.

Faults ec3016, ec3016-2, ecort1-1, ecort1-2, ecort2-1, and ecort2-2 apply only to the second tie system and complete the stuck breaker fault scenarios for the future Orrington substation configuration. System response to these six faults meets criteria. The ecxort1 fault applies only to the benchmark system. It is similar to ecx396 and exc388, in that it clears the entire Orrington substation. The results are acceptable.

The ecwalauto fault (WMedway-Waltham transformer, WMedway-WWalpole 345kV) meets criteria for the benchmark case and for the second tie case. For the benchmark system, the system splits across the Orrington South interface, with activation of the GCX runback and the Bucksport overcurrent SPS. For the second tie system, the system splits across Section 392 and the underlying 115kV system. The separation interface is shown in the figures linked with the LOS entry in the spreadsheet table. The LOS of 1146 MW for the second tie case is slightly higher than that of the benchmark case, but well within performance objectives.

The Vermont Yankee bus fault (ecvybus) results in a substantial disruption in the benchmark system. The system separates across Section 388 and southern Maine, with a resulting LOS (2135 MW) in excess of criteria. The separation interface is shown in the figure hyperlinked with the LOS entry in the spreadsheet table. Addition of the second tie project eliminates the system separation and reduces the LOS to the output of Vermont Yankee, which is acceptable.

Table 4-3. 3-Phase Stuck Breaker Fault Results for Light Load Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
ec312*	Northfield 345kV	3ϕ/1ϕ	3T	Northfield-ALPS 345kV Northfield-Vermont Yankee 345kV
ec326*	Scobie 345kV	3ϕ/1ϕ	9126	Scobie-Sandy Pond 345kV Scobie-Buxton 345kV
ec328*	Sherman Road 345kV	3ϕ/1ϕ	142	Sherman-N. Smith 345kV Sherman-ANP 336 345kV
ec339	Tewksbury 345kV	3ϕ/1ϕ	37-39	Tewksbury-Golden Hills 345kV Golden Hills Auto 115kV Tewksbury-Sandy Pond 345kV
ec342	Canal 345kV	3ϕ	312	Canal –Pilgrim-Auburn 345kV Canal Auto 115kV
ec368*	Card 345kV	3ϕ/1ϕ	2T	Card-Manchester 345kV Card-Millstone 345kV
ec372-2	Mystic 345kV	3ϕ	102	Mystic-Kingston 345kV X & Y Mystic-Golden Hills 345kV
ec374	Buxton 345kV	3ϕ/1ϕ	K386-4	Buxton-Surowiec 345kV Buxton-Wyman 345kV S. Gorham Auto 115kV
ec377	Maine Yankee 345kV	3ϕ	K378-1	Maine Yankee -Surowiec 345kV Maine Yankee-Mason 345kV Mason Auto & Caps 115kV
ec385	Deerfield 345kV	3ϕ	785	Deerfield-Buxton 345kV Deerfield-Newington 345kV
ec388-1	Orrington 345kV	3ϕ	K388-3	Orrington-Maxcys 345kV Orrington T2 115kV
ec388-2	Orrington 345kV	3ϕ	K396/388	Orrington-Maxcys 345kV Orrington- Keswick 345kV Chester SVC
ecx388	Orrington 345kV	3ϕ	K396/388	Orrington-Maxcys 345kV Orrington- Keswick 345kV Chester SVC Orrington T1, T2 115kV
ec391	Buxton 345kV	3ϕ	K391/386	Buxton-Scobie 345kV Buxton-Wyman 345kV S. Gorham Auto 115kV
ec394a*	Seabrook 345kV	3ϕ/1ϕ	294	Seabrook-Tewksbury 345kV Ward Hill Auto 345kV
ec394b	Tewksbury 345kV	3ϕ/1ϕ	38-94	Tewksbury-Seabrook 345kV Ward Hill Auto 3 Tewksbury-Woburn 345kV
ec396-1	Orrington 345kV	3ϕ	K396-1	Orrington- Keswick 345kV Chester SVC Orrington T1 115kV
ec396-2	Orrington 345kV	3ϕ	K396/388	Orrington-Maxcys 345kV Orrington- Keswick 345kV Chester SVC
ecx396	Orrington 345kV	3ϕ	K396-1	Orrington-Maxcys 345kV Orrington- Keswick 345kV Chester SVC Orrington T1, T2 115kV
ec3002	Keswick 345kV	3ϕ	K3-2	Keswick-Coleson Cove 345kV Keswick-St Andre 345kV Block Madawaska

Table 4-3. 3-Phase Stuck Breaker Fault Results for Light Load Simulations (continued).

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
ec3016	Orrington 345kV	3ϕ	K3016	Orrington-Pt. Lepreau 345kV Orrington T1 115kV
ec3016-2	Orrington 345kV	3ϕ	K4/3016	Orrington-Pt. Lepreau 345kV Orrington T2 115kV
ecort1-1	Orrington 345kV	3ϕ	K396-1	Orrington- Keswick 345kV Chester SVC Orrington T1 115kV
ecort1-2	Orrington 345kV	3ϕ	K3016	Orrington-Pt. Lepreau 345kV Orrington T1 115kV
ecort2-1	Orrington 345kV	3ϕ	K388-3	Orrington-Maxcys 345kV Orrington T2 115kV
ecort2-2	Orrington 345kV	3ϕ	K4/3016	Orrington-Pt. Lepreau 345kV Orrington T2 115kV
ecxort1	Orrington 345kV	3ϕ	KBS3/4	Orrington-Maxcys 345kV Orrington- Keswick 345kV Chester SVC Orrington T1, T2 115kV
ecwalauto	W Medway 345kV	3ϕ/1ϕ	111	W Medway-Waltham 115kV Transformer W Medway-W Walpole 345kV
ecvybus	Vermont Yankee	3ϕ	379	Vermont Yankee Autotransformer Vermont Yankee-Amherst-Scobie 345kV

Notes: * = favorite seven

4.5 Light Load Sensitivity Cases

Selected sensitivity cases were evaluated to determine system performance with different, and generally more stressed, initial conditions. The simulation results are described in this Section. A brief summary of each fault is shown in *Table 4-4*, which also provides hyperlinks to the plotted results.

The two double circuit tower (DCT) outages were simulated with Bucksport in service instead of one Maine Independence Station unit. This initial condition is more severe because Bucksport is not part of the present DCT SPS transfer trip of MIS. This leaves more generation north of the Orrington South interface, which results in higher stress on the underlying 115kV system. These sensitivity cases meet criteria for both the benchmark and second tie systems. Both DCT03 (Maine Yankee-Buxton 345kV, Maine Yankee-Surowiec 345kV) and DCT04 (Maine Yankee-Buxton 345kV, Maine Yankee-Maxcys 345kV) result in some violations of the proposed CMP voltage criteria in the benchmark system but not in the second tie system.

Only Canal unit 1 and Pilgrim were included in the base analysis of ec342 (Canal-Auburn 345kV). This sensitivity case added Canal G2 (576MW) and the new Edgar combined cycle plant (854MW). The ec342 fault causes an out-of-synchronism trip of any units at Canal. Under conditions with both Canal units on line, both trip. For the benchmark system, the Bucksport SPS takes out Maine Independence Station and Bucksport, and the GCX initiates runback, causing a severe violation of LOS objective (2291 MW). For the second tie system, the GCX and Bucksport SPSs do not activate, only the Canal units contribute to the LOS. Therefore the addition of the second tie project eliminates this pre-existing violation.

Sensitivity cases for faults ec394a (Seabrook-Tewksbury 345kV) and ec394b (Tewksbury-Seabrook 345kv) with the WF Wyman #4 unit were evaluated. Both ec394a and ec394b result in Keswick GCX Zone 3 operation for the benchmark system. Fault ec394a also trips Section 388 and the Bucksport OC SPS operates causing a system separation on the Orrington South interface for the benchmark system. These cases are acceptable. The second tie system eliminates activation of these SPSs and reduces the LOS to zero, resulting in acceptable performance for both faults.

Sensitivity cases with a high Boston export condition were performed for cases sensitive to that condition. Fault ec339 (Tewksbury-Golden Hills 345kV) results in a split across the Maine-New Hampshire interface for the benchmark system. Addition of the second NB tie results in a separation across Section 392 and western Maine. The response is acceptable.

Fault ec372-2 (Mystic-Kingston 345kV) results in system separation in Maine for this sensitivity condition. The benchmark system separates across Section 388 and opens the Orrington South interface. The second tie system separates across Section 392 and the Maine 115kV system. The separation interfaces are shown in the figure liked with the LOS entry in the spreadsheet table. The performance of both systems is acceptable for this sensitivity case.

As mentioned above in the discussion of the Waltham-Water-Brighton 115kV event, both the benchmark and second tie systems are in violation of criteria. The bolted (zero impedance) three-phase fault persisting for 29 cycles results in widespread disruption. Several sensitivity case for this fault were performed to evaluate performance under peak load conditions, with a reduced fault clearing time representing additional high speed primary protection, and with different generation dispatches. As in the primary analysis, system performance is unacceptable for both the benchmark and second tie project systems under primary power flow conditions with the Salem unit in service instead of N. Boston 2 and the original 29 cycle clearing at Brighton. Under peak load conditions with the original clearing, the benchmark system enters GCX zone 3 in violation of criteria. This violation is eliminated with the addition of the second tie. With additional high speed protection (5 cycle clearing at Brighton), the benchmark system and the second tie project system meet criteria.

Two fault simulations were performed without modeling any line relays. System performance in response to the Tewksbury fault (ec339) failed to meet the LOS objective for both the benchmark and second tie project systems. The LOS for the second tie system was less than that for the benchmark system. System performance in response to the Waltham autotransformer fault (ecwalauto) met criteria for both the benchmark and second tie project systems.

An additional 3-phase stuck breaker fault at the Canal substation was evaluated. Performance of both systems resulted in an excessive LOS.

Four single phase equivalents of EC faults were evaluated. System performance was acceptable for both the benchmark and second tie systems in response to the Buxton (sc391) and Tewksbury (sc339) faults. System performance was not acceptable for the benchmark case (GCX entry) for the Waltham autotransformer (scwalauto) and Mystic (sc372-2) faults, but was acceptable for the second tie project system.

Table 4-4. Sensitivity Results for Light Load Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements	Sensitivity
dct03	Maine Yankee 345kV	2ϕ	none	Maine Yankee-Buxton 345kV Maine Yankee Surowiec 345kV MIS transfer trip	Bucksport replaces 1 MIS unit
dct04	Maine Yankee 345kV	2ϕ	none	Maine Yankee -Buxton 345kV Maine Yankee-Maxcys 345kV MIS transfer trip	Bucksport replaces 1 MIS unit
ec342	Canal 345kV	3ϕ	312	Canal –Pilgrim-Auburn 345kV Canal Auto 115kV	Maximum Canal area generation
ec394a	Seabrook 345kV	3ϕ/1ϕ	294	Seabrook-Tewksbury 345kV Ward Hill Auto 345kV	WF Wyman #4 in service
ec394b	Tewksbury 345kV	3ϕ/1ϕ	38-94	Tewksbury-Seabrook 345kV Ward Hill Auto 3 Tewksbury-Woburn 345kV	WF Wyman #4 in service
ec339	Tewksbury 345kV	3ϕ/1ϕ	37-39	Tewksbury-Golden Hills 345kV Golden Hills Auto 115kV Tewksbury-Sandy Pond 345kV	High Boston export
ec372-2	Mystic 345kV	3ϕ	102	Mystic-Kingston 345kV X & Y Mystic-Golden Hills 345kV	High Boston export
nc282-520	Waltham 115kV	3ϕ	none	Waltham-Brighton 115kV Waltham-Watertown 115kV	Primary power flow with Salem instead of N. Boston 2
nc282-520	Waltham 115kV	3ϕ	none	Waltham-Brighton 115kV Waltham-Watertown 115kV	Peak load
nc282-520	Waltham 115kV	3ϕ	none	Waltham-Brighton 115kV Waltham-Watertown 115kV	Additional High Speed Primary Protection
ec339	Tewksbury 345kV	3ϕ/1ϕ	37-39	Tewksbury-Golden Hills 345kV Golden Hills Auto 115kV Tewksbury-Sandy Pond 345kV	Reduced fault clearing time
nc396	Orrington 345kV	3ϕ	none	Orrington-Keswick 345kV Chester SVC	Series capacitor in 3016
ec339	Tewksbury 345kV	3ϕ/1ϕ	37-39	Tewksbury-Golden Hills 345kV Golden Hills Auto 115kV Tewksbury-Sandy Pond 345kV	High Boston export with no relay models
ecwalauto	W Medway 345kV	3ϕ/1ϕ	111	W Medway-Waltham 115kV Transformer W Medway-W Walpole 345kV	No relay models
ec212	Canal 345kV	3ϕ	212	Canal-Carver 345kV Bourne Autotransformer	New fault scenario with maximum Canal area generation
sc391	Buxton 345kV	1ϕ	K391/386	Buxton-Scobie 345kV Buxton-Wyman 345kV S. Gorham Auto 115kV	Single phase equivalent of EC
scwalauto	W Medway 345kV	1ϕ	111	W Medway-Waltham 115kV Transformer W Medway-W Walpole 345kV	Single phase equivalent of EC
sc339	Tewksbury 345kV	1ϕ	37-39	Tewksbury-Golden Hills 345kV Golden Hills Auto 115kV Tewksbury-Sandy Pond 345kV	Single phase equivalent of EC
sc372-2	Mystic 345kV	1ϕ	102	Mystic-Kingston 345kV X & Y Mystic-Golden Hills 345kV	Single phase equivalent of EC

(The last twelve cases in this table appear after the SPS failure cases in the worksheet)

4.6 Light Load SPS Failure Cases

Selected simulations were run to test the consequences of SPS failures. Tests were applied for normal contingencies which rely on the operation of the failed SPS to meet criteria. Description of the cases discussed here are provided in *Table 4-5*.

The first pair of cases are for failure of the existing DCT SPS to transfer trip Maine Independence Station generation. DCT03 results in a system separation across Maine for the benchmark system. The separation interface is shown in the figure linked to the LOS entry (1176MW) in the spreadsheet table. This separation is eliminated with the addition of the second tie.

Failure of the Maxcys Overcurrent SPS for nc392 (Maxcys-Maine Yankee) results in trip of 388 and activation of the Bucksport OC SPS. The system splits across Orrington South. With the second tie project, the 392 fault causes a direct trip of generation in New Brunswick. This eliminates the system separation and reduces the LOS from 1074MW to 640MW.

Failure of the Bucksport Overcurrent SPS for nc388 (Orrington-Maxcys) results in line relays opening Sections 86 and 203 and Maine Independence Station tripping for both cases. In the benchmark case the Loss of 3001 SPS operates. With the second tie system, New Brunswick generation is tripped by a direct signal due to the opening of Section 388. For both cases, the LOS is equal to the Orrington South interface flow (1074MW in the benchmark case and 1203MW in the second tie case). Voltage excursions exceed the proposed voltage criteria. Failure of only the Maine Independence Station transfer trip portion of the Bucksport overcurrent SPS results in similar behavior, with less severe voltage swings.

The remaining SPS failure cases tested failures of the new or modified SPSs and were, therefore, only performed on the second tie system.

Failure of the New DPL SPS for trip of the Orrington-Keswick line (nc396) results in a trip of the new 3016 line. Total LOS equals Maine Independence Station plus the NB-ME import or 1366MW (Maine Independence Station output = 358MW, NB-NE flow = 1008MW). Note that it is not possible to respect the 1200MW limit on the Orrington South interface and have both the NB-NE interface and Maine Independence Station output at their maxima. Hence, it is not possible for the LOS in this case to be 1550MW (Maine Independence Station output = 550MW, NB-NE flow = 1000MW). The voltage swings violate the proposed voltage criteria.

Failure of direct tripping of new Brunswick generation for loss of Section 388 (nc388) causes the flow based loss of 3001/3016 (Maritimes Islanding) SPS to activate. The LOS is 1063MW.

Failure of the modified DCT SPS to direct trip generation in New Brunswick results in the out-of-step tripping of 304 MW of generation in Maine for DCT03. The flow based Loss of 3001/3016 (Maritime Islanding) SPS trips generation in New Brunswick later. The system stays synchronized, with several violations of the proposed voltage criteria. The LOS is 1302MW. The DCT04 case results in activation of the Bucksport OC SPS and the flow based Loss of 3001/3016 SPS, with a resulting separation on Orrington South. The LOS is 1203MW, equal to the Orrington South interface flow.

Failure of the modified DCT SPS to direct trip generation in New Brunswick in conjunction with Bucksport on instead of one Maine Independence Station unit, results in system separation across Maine for DCT03. The separation interface is shown in the figure linked to the LOS entry (1303MW) in the spreadsheet table. DCT04 causes the Bucksport OC SPS to activate, with a resulting separation on Orrington South for a LOS of 1203MW.

The last SPS failure scenario is for failure of all new or modified SPSs to trip generation in New Brunswick for the Orrington-Maxcys (nc388) fault. This causes the Bucksport OC SPS to activate, with a resultant separation on Orrington South for a LOS of 1203MW.

Table 4-5. SPS Failure Cases for Light Load Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements	Failed SPS
dct03	Maine Yankee 345kV	2ϕ	none	Maine Yankee-Buxton 345kV Maine Yankee Surowiec 345kV	DCT SPS transfer trip of MIS
dct04	Maine Yankee 345kV	2ϕ	none	Maine Yankee -Buxton 345kV Maine Yankee-Maxcys 345kV	DCT SPS transfer trip of MIS
nc392	Maxcys 345kV	3ϕ	none	Maxcys-Maine Yankee 345kV	Maxcys OC SPS
nc388	Orrington 345kV	3ϕ	none	Orrington-Maxcys 345kV	Bucksport OC SPS
nc388	Orrington 345kV	3ϕ	none	Orrington-Maxcys 345kV	Bucksport OC SPS transfer trip of MIS
nc396*	Orrington 345kV	3ϕ	none	Orrington-Keswick 345kV Chester SVC	New DPL SPS
nc388	Orrington 345kV	3ϕ	none	Orrington-Maxcys 345kV	Direct trip of NB Generation on loss of 388
dct03	Maine Yankee 345kV	2ϕ	none	Maine Yankee-Buxton 345kV Maine Yankee Surowiec 345kV	Direct trip of NB Generation on DCT
dct04	Maine Yankee 345kV	2ϕ	none	Maine Yankee -Buxton 345kV Maine Yankee-Maxcys 345kV	Direct trip of NB Generation on DCT
dct03	Maine Yankee 345kV	2ϕ	none	Maine Yankee-Buxton 345kV Maine Yankee Surowiec 345kV	Direct trip of NB Generation on DCT, Bucksport replaces 1 MIS unit
dct04	Maine Yankee 345kV	2ϕ	none	Maine Yankee -Buxton 345kV Maine Yankee-Maxcys 345kV	Direct trip of NB Generation on DCT, Bucksport replaces 1 MIS unit
nc388	Orrington 345kV	3ϕ	none	Orrington-Maxcys 345kV	All NB generation trip

Notes: * = favorite seven

4.7 Light Load Second Series Compensation Sensitivity Case

The fault and trip of the Keswick-Orrington 345kV line, nc396, requires the New DPL SPS, as described in Section 6. Addition of a second series capacitor on the proposed Pt. Lepreau-Orrington 345kV line is a possible alternative to this SPS. A second series capacitor of the same parameters as that on the Orrington-Maxcys 345kV line (25 ohm, 300 MVAr) was added to line 3016 for a light load sensitivity case. Results of the nc396 event, with no DPL SPS action, are shown with the other the light load sensitivity cases. System performance meets criteria with no generation rejection in NB.

4.8 Peak Load Normally Cleared 3-Phase Faults and More

A selected subset of faults, as agreed upon by ISO-NE, was simulated for peak load system. Description of the cases discussed here are provided in *Table 4-6*.

As noted in Section 2.2, the cases reported here were run with the Orrington South interface loaded above the 1200 MW limit for second tie cases. Therefore, normal contingency cases resulting in trip of the Orrington South interface results in violation of the 1200 MW LOS criteria. For operation at or below 1200 MW, no violation would occur.

With one exception, all normally cleared three phase faults meet criteria for the peak load condition, in both the benchmark and second tie cases. The exception is nc282-520 for the benchmark case, which causes an entry into zone 3 of the GCX, and therefore violates criteria. The addition of the second New Brunswick tie corrects this violation. This case was presented above in Section 4.6 as a sensitivity case, and is included in the light load Excel worksheet.

The nc385 fault (Buxton-Deerfield) is representative of the most severe normally cleared faults. Performance of the system for the two conditions is comparable and meets criteria.

The nc396 fault (Keswick-Orrington) illustrates one of the significant reliability impacts of the new line. In the present system, this disturbance results in separation of New Brunswick from New England. The LOS is for the total NB-NE import of 700 MW only. The 396 SPS was not enabled for these cases, otherwise the LOS for the benchmark system would be up to 1250MW. The addition of the second tie allows the two systems to remain synchronized, with LOS limited to the DPL tripped generation in New Brunswick (approximately 300MW). Both systems meet criteria, regardless of whether the 396 SPS is enabled to transfer trip MIS.

The nc3016 fault (Orrington-Pt. Lepreau) case shows that trip of the new line does not result in system separation or any LOS. The Chester SVC supports the additional flow on Section 396. All criteria are met even without New DPL SPS action.

The double circuit tower faults meet criteria for both systems. Without the modified DCT SPS, the voltage excursion with the second tie system is more severe than the benchmark system, and violates the proposed voltage criteria for some 115kV buses in Maine. However this occurs with an Orrington South interface flow of approximately 1400MW. Reducing transfer levels to 1200 MW would eliminate the voltage violations.

The Phase II HVDC trip case was only performed for the peak condition, since HVDC will likely not be on line for light load conditions. Performance meets criteria for both systems, except that the loss of the HVDC violates LOS in both cases.

Table 4-6. Normally Cleared 3-Phase Fault Results for Peak Load Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
nc282-520	Waltham 115kV	3ϕ	none	Waltham-Brighton 115kV Waltham-Watertown 115kV
nc385	Buxton 345kV	3ϕ	none	Buxton-Deerfield 345kV
nc396*	Orrington 345kV	3ϕ	none	Orrington-Keswick 345kV Chester SVC
nc3016	Orrington 345kV	3ϕ	none	Orrington-Pt.Lepreau 345kV
dct03	Maine Yankee 345kV	2ϕ	none	Maine Yankee-Buxton 345kV Maine Yankee Surowiec 345kV MIS transfer trip
dct04	Maine Yankee 345kV	2ϕ	none	Maine Yankee -Buxton 345kV Maine Yankee-Maxcys 345kV MIS transfer trip
ph2	none	NA	none	Phase II HVDC trip

Notes: * = favorite seven

4.9 Peak Load Single-Phase Faults with Stuck Breakers

The response of both the benchmark and the second tie systems to the sc381 (Vermont Yankee-Northfield 345kV) fault meets criteria. A description of that case is provided in *Table 4-7.*

Table 4-7. 1-Phase Stuck Breaker Fault Results for Peak Load Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
sc381*	Vermont Yankee 345kV	1ϕ	381	Vermont-Yankee-Northfield 345kV VY Auto #4 115kV

Notes: * = favorite seven

4.10 Peak Load Three-Phase Faults with Stuck Breakers

The three-phase fault with stuck breaker simulation results are described in this Section. A brief summary of each fault is shown in *Table 4-8*, which also provides hyperlinks to the plotted results. Several of the cases in this category exhibit similar behavior, and are discussed in groups.

Most of the cases in this category (ec312, ec326, ec328, ec339, ec368, ec374, ec377, ec385, ec394a) are directly comparable for both systems, result in acceptable performance, and have no LOS for either the benchmark case or the second tie case.

The ec3016 fault trips the second tie. Both the New DPL SPS and the flow-based Loss of 3001/3016 (Maritimes Islanding) SPS activate for this case, bringing the LOS to 628 MW. The New England system remains synchronous with New Brunswick. The results are acceptable.

Table 4-8. 3-Phase Stuck Breaker Fault Results for Peak Load Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
ec312*	Northfield 345kV	3ϕ/1ϕ	3T	Northfield-ALPS 345kV Northfield-Vermont Yankee 345kV
ec326*	Scobie 345kV	3ϕ/1ϕ	9126	Scobie-Sandy Pond 345kV Scobie-Buxton 345kV
ec328*	Sherman Road 345kV	3ϕ/1ϕ	142	Sherman-N. Smith 345kV Sherman-ANP 336 345kV
ec368*	Card 345kV	3ϕ/1ϕ	2T	Card-Manchester 345kV Card-Millstone 345kV
ec374	Buxton 345kV	3ϕ	K386-4	Buxton-Surowiec 345kV Buxton-Wyman 345kV S. Gorham Auto 115kV
ec377	Maine Yankee 345kV	3ϕ	K378-1	Maine Yankee -Surowiec 345kV Maine Yankee-Mason 345kV Mason Auto & Caps 115kV
ec385	Deerfield 345kV	3ϕ	785	Deerfield-Buxton 345kV Deerfield-Newington 345kV
ec394a*	Seabrook 345kV	3ϕ/1ϕ	294	Seabrook-Tewksbury 345kV Ward Hill Auto 345kV
ec3016	Orrington 345kV	3ϕ	K3016	Orrington-Pt. Lepreau 345kV Orrington T1 115kV

Notes: * = favorite seven

4.11 Export Normally Cleared 3-Phase Faults and More

A selected subset of faults, as agreed upon by ISO-NE, was simulated for the export system. A brief summary of each fault is shown in *Table 4-9*, which also provides hyperlinks to the plotted results. Under export conditions, the New DPL SPS , the modified Loss of 3001/3016 (Maritimes Islanding) SPS and the modifications to the DCT SPS are not armed, as described in detail in Section 6.

All normally cleared three phase faults meet criteria for the export condition, in both the benchmark and second tie cases

The nc396 fault (Keswick-Orrington) again illustrates one of the significant reliability impacts of the new line. In the present system, this disturbance results in separation of New Brunswick from New England. The addition of the second tie allows the two systems to remain synchronized.

The nc3016 fault (Orrington-Pt. Lepreau) case shows that trip of the new line does not result in system separation or any LOS. The Chester SVC supports the additional export flow on Section 396. All criteria are met.

Both DCTs meet criteria for the export condition, in both the benchmark and second tie cases.

Table 4-9. Normally Cleared 3-Phase Fault Results for Export Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
nc385	Buxton 345kV	3ϕ	none	Buxton-Deerfield 345kV
nc396*	Orrington 345kV	3ϕ	none	Orrington-Keswick 345kV Chester SVC
nc3016	Orrington 345kV	3ϕ	none	Orrington-Pt.Lepreau 345kV
dct03	Maine Yankee 345kV	2ϕ	none	Maine Yankee-Buxton 345kV Maine Yankee Surowiec 345kV MIS transfer trip
dct04	Maine Yankee 345kV	2ϕ	none	Maine Yankee -Buxton 345kV Maine Yankee-Maxcys 345kV MIS transfer trip

Notes: * = favorite seven

4.12 Export Condition Single-Phase Faults with Stuck Breakers

The response of both the benchmark and the second tie systems to the sc381 (Vermont Yankee-Northfield 345kV) fault meets criteria. A brief summary of the fault is shown in *Table 4-10*, which also provides a hyperlink to the plotted results.

Table 4-10. 1-Phase Stuck Breaker Fault Results for Export Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
sc381	Vermont Yankee 345kV	1ϕ	381	Vermont-Yankee-Northfield 345kV VY Auto #4 115kV

Notes: * = favorite seven

4.13 Export Condition Three-Phase Faults with Stuck Breakers

The three-phase fault with stuck breaker simulation results are described in this Section. A brief summary of each fault is shown in *Table 4-11*, which also provides hyperlinks to the plotted results. Several of the cases in this category exhibit similar behavior, and are discussed in groups.

Most of the cases in this category (ec312, ec326, ec328, ec368, ec377, ec385, ec394a) are directly comparable for both systems, result in acceptable performance, and have no LOS for either the benchmark case or the second tie case.

The ec374 fault (Buxton-Surowiec 345kV) requires the tripping of Wyman #4, for a LOS of 636 MW. System response is acceptable for both the benchmark system and the second tie system.

The ec3016 fault trips the second tie. The Bucksport Reverse Power relay trips Maine Independence Station for a 549 MW LOS. The New England system remains synchronous with New Brunswick. The results are acceptable.

Table 4-11. 3-Phase Stuck Breaker Fault Results for Export Simulations.

ID	Fault Location	Type	Stuck Breaker	Cleared Elements
ec312*	Northfield 345kV	3ϕ/1ϕ	3T	Northfield-ALPS 345kV Northfield-Vermont Yankee 345kV
ec326*	Scobie 345kV	3ϕ/1ϕ	9126	Scobie-Sandy Pond 345kV Scobie-Buxton 345kV
ec328*	Sherman Road 345kV	3ϕ/1ϕ	142	Sherman-N. Smith 345kV Sherman-ANP 336 345kV
ec368*	Card 345kV	3ϕ/1ϕ	2T	Card-Manchester 345kV Card-Millstone 345kV
ec374	Buxton 345kV	3ϕ	K386-4	Buxton-Surowiec 345kV Buxton-Wyman 345kV S. Gorham Auto 115kV
ec377	Maine Yankee 345kV	3ϕ	K378-1	Maine Yankee -Surowiec 345kV Maine Yankee-Mason 345kV Mason Auto & Caps 115kV
ec385	Deerfield 345kV	3ϕ	785	Deerfield-Buxton 345kV Deerfield-Newington 345kV
ec394a*	Seabrook 345kV	3ϕ/1ϕ	294	Seabrook-Tewksbury 345kV Ward Hill Auto 345kV
ec3016	Orrington 345kV	3ϕ	K3016	Orrington-Pt. Lepreau 345kV Orrington T1 115kV

Notes: * = favorite seven

4.14 Summary

Two pre-existing violations of NC criteria were identified in the study. Specifically, under light load conditions fault ncm139 violates the prohibition on GCX entry, and fault nc282-520 with the original 29 cycle clearing at Brighton violates the loss of source (LOS) criteria. Fault ncm139 is corrected by the addition of the second tie. The extreme violation of nc282-520 is not corrected by the addition of the second tie, but sensitivity analysis shows that the second tie reduces the severity of this event for higher load levels or reduced fault clearing times. Addition of high speed primary protection at Brighton corrects this violation for both systems.

For the light load condition, two three-phase stuck breaker faults result in unacceptable performance in the benchmark system. Of these, the Vermont Yankee bus fault (ecvybus) is corrected by the addition of the second tie. The other case, Canal-Carver 345kV (ec212), results in essentially the same performance with and without the second tie project. One sensitivity case also results in unacceptable performance of the benchmark system, and is corrected by the addition of the second tie (ec342). Several extreme contingency cases result in system separation in Maine.

Simulations of failure of the new or modified SPSs indicated no stability related problems or issues.

The fault scenarios or other considerations that drove the design of the second tie project are described below. The Orrington-Maxcys series capacitor as well as the 115kV shunt capacitors were required to meet steady state thermal and voltage criteria. Therefore, all stability analysis was performed with the series and shunt capacitors in service. Fault nc396 requires the new DPL SPS to trip NB generation in response to the loss of either 396 or 3016 and maintain system integrity. The failure of this SPS, as described in Section 4.6, is equivalent to its nonexistence and results in a system split when the 3016 line relay operates. The modification of the Maine Yankee DCT SPS to send a signal to the Loss of 3001 SPS is required by dct03 (loss of Maine Yankee-Buxton and Maine Yankee-Surowiec) to eliminate thermal overloads and transient voltage violations. The modification of the Loss of 3001 SPS to accept direct tripping signals from Sections 388 and 392 is not absolutely required. It is faster than the flow based Loss of 3001 function, and therefore preferred. Finally, the addition of the Loss of 3016 function is required by the addition of the second line and will allow for the detection of a Maritimes islanding event.

6. SPS Modification and Replacement

The following Sections describe the current special protection systems (SPS) associated with Section 396, as well as the reduced need for several SPSs and those required for the second tie.

6.1 Keswick GCX for Overload of Line 3001/Section 396

The Keswick GCX SPS (NPCC #11, Type I) was installed to prevent trips of the Keswick-Orrington 345kV line caused by excessive overloads. Historically, the line was vulnerable to overload trips because of its electrical "weakness" due to its 150 mile length, its frequent operation at the full 700 MW export level, and the poor voltage support at the Orrington end.

The SPS consists of GCX type distance relays installed at Keswick, nominally set at 950 MVA such that they would detect power swings before the swing enters the trip zone of the line protection relays. The intention of the SPS was to provide overload protection by rejecting pre-selected NB generation such that the power swing was halted before it entered the trip zone of the line protective relaying.

Because the GCX SPS was installed to deal with line overloads caused by a generation surplus (high frequency) in the Maritimes, it should not operate if the overload is caused by a sudden generation loss external to the Maritimes. The distance relay power flow sensing portion is supervised by over- and under-frequency relays. Activation of the SPS is only allowed if system frequency has risen above 60.06 Hz. This arming signal is held for 8 seconds to allow the distance relay portion to react to the power swings as necessary. Similarly, activation is blocked if frequency has suddenly dropped below 59.94 Hz. This blocking signal is held for 10 seconds. The logic is such that the under-frequency blocking logic always has priority over the over-frequency portion.

If the distance relay power swing measuring and the over- and under-frequency logic portions of the SPS agree to allow rejection to proceed, the SPS rejects all of the generating and HVDC stations listed under the Loss of Line 3001 SPS (NPCC #5) described in a following Section. The amount rejected depends on the pre-selected arming pattern for the Loss of Line 3001 SPS chosen by the system operator based on dispatch conditions and export flow levels. The amount of generation rejected can be as high as 600 MW.

The second NB tie project will cause the flow from NB to split between two 345 kV tie lines. As a result, the power measuring function of the GCX would no longer be effective. In addition, transmission reinforcements in the Orrington area (the new Maine Independence Station and the series compensation portion of the second NB tie project) have made voltage collapse much less likely. The GCX SPS will no longer be needed under all-lines-in conditions and flows will be managed such that the largest Maritimes loss of load contingency will not result in an overload trip of the 345 kV path to New England.

6.2 Keswick Power Relays for Overload of Line 3001/Section 396

The Keswick KPR SPS (NPCC #12, Type I) was installed as the first quick response to prevent overload trips of the 345 kV tie. The SPS consists of power relays that will operate if the flow leaving Keswick is above 650 MW and 200 MVAr simultaneously. Consequently, at 700 MW export flow the SPS is already half-activated. It was originally set up to detect the MVAr surge into the line following the loss of the 200 MVAr Orrington capacitors, which were required at flows above 600 MW. Because of its sensitivity, rejections by this SPS are limited to a maximum of 200 MW at Mactaquac, Dalhousie unit 2 or Eel River HVDC. If the 200 MW rejection initiated by the KPR SPS was not sufficient to halt the overload condition, the Keswick GCX SPS would eventually act to reject further generation if required.

The additional voltage support at Orrington due to the commissioning of the Chester SVC in 1990 removed the need for this sensitive first-level overload protection on Section 396. Consequently, the KPR SPS is normally out of service and is only used during infrequent cases when export flows above 550 MW are expected at the same time that Chester SVC is unavailable.

The addition of a parallel path between NB and NE makes the use of the KPR SPS even more unlikely. Coupled with the additional voltage support available in the Orrington area, the KPR SPS will no longer be needed under all-lines-in conditions.

6.3 New England Section 396 SPS

ISO-NE's Section 396 SPS (NPCC #140, Type I) is designed to trip Maine Independence Station generation when Section 396 is opened on either of the following three conditions: (1) both line breakers open at Keswick, (2) both line breakers open at Orrington, or (3) the Section 396 protective relays operate at Orrington.

This SPS was installed based on an analysis performed as part of the Maine Independence Station System Impact Study. The analysis determined that a fault on Section 396, and the resulting separation of New Brunswick from New England, caused lightly-damped or negatively-damped oscillations for several cases studied with Maine Independence Station in-service and high North-South, East-West and New England-New York transfers. In lieu of reducing transfer limits when Maine Independence Station was in-service, the analysis concluded that tripping Maine Independence Station following a contingency on Section 396 resulted in a positively damped system response. Note that this SPS creates a loss-of-source contingency for New England of up to 1250 MW (700 MW NB import and 550 MW Maine Independence Station output) which violates LOS criteria for normal contingencies. With the second tie, this SPS combined with the action of the New DPL SPS (Section 6.5), limits the LOS to 850 MW (550 MW at Maine Independence Station plus 300MW for the DPL) or less.

With Section 396 operating in parallel with the new line 3016, it may not be necessary to have Maine Independence Station armed for rejection following a fault on either of the tie lines. It is possible that this SPS could be retired, and the system operated to remain secure for this contingency under the rare case when either of the two NB ties are out of service. Further study would be required to retire or modify this SPS.

6.4 Keswick Loss of Line 3001/Section 396

The Loss of L3001 SPS (NPCC #5, Type III) uses power and frequency relays at Keswick to sense two different conditions involving loss of power flow to New England:

1. Power decrease on Section 396 from above 330 MW export to below 260 MW export (but above 100 MW) within 3 seconds indicates a possible separation in Maine south of Orrington with Bangor, Me tied to NB Power. If system frequency rises above 60.3 Hz within 1.25 seconds of the power flow decrease, the SPS will immediately act to halt acceleration of the islanded Maritimes system (actual steps depend on dispatch and export conditions at the time)
2. Power decrease on Section 396 from above 180 MW export to below 100 MW within 3 seconds indicates a possible complete loss of 396 with no Bangor radial load. If system frequency rises above 60.3 Hz within 1.25 seconds of the export decrease, the SPS will act depending on dispatch and export conditions.

The SPS action in both of the above situations is as follows:

Ramp Eel River HVDC to 3rd Level of VAR Loss (270, 200, 160, 120, 80, 40 MW)
Ramp Madawaska HVDC to either 175 MW or zero
Trip Mactaquac hydro units (up to four 110 MW units)
Trip Beechwood hydro units (up to three units – 100 MW total)
Trip Dalhousie U2 thermal (200 MW)
Trip Coleson Cove U1-U3 thermal (any one of three units – 350 MW)
Trip Belledune U2 thermal (480 MW)
Trip Lingan, Nova Scotia thermal units (any one or two of four units--160MW each)
Close 2 x 37.5 MVAr Reactors at Keswick (for item 1 only)

The export flow level at Keswick is monitored by SCADA and alarms are sounded to alert the System Operator to the need to adjust the selection of armed stations if the mismatch between the flow on Section 396 and the total amount selected for rejection deviates outside pre-determined boundaries. The amount tripped should be between 100-300 MW less than the actual flow on the line. This arming level provides some margin against under-frequency load-shedding on the islanded system if it is left supplying the Bangor area load.

As a consequence of the second NB tie project, a similar set of relays will be added at Point Lepreau for the new tie line. These relays will act on power flow on each of their respective lines and on frequency measured at the sending end of the line, either Keswick or Point Lepreau. Pickup on either line will result in the initiation of generation rejection. There is a maximum delay of 5 cycles between the relay pickup (i.e. initiation of generation rejection) and the trip of the generation. The power pickup thresholds for the relays are modified so that pickup occurs if the power flow drops from above 250MW to below 150 MW in 3 seconds. The candidate generation would follow the same rules as are presently used in the Loss of 3001 SPS, however the arming would be based on the Orrington South flow instead of the NB-NE flow. The amount tripped would be selected with the objective of leaving the Maritimes/Bangor island with a surplus of about 200MW following loss of Orrington South and would take the status of Maine Independence Station and Bucksport generation into consideration. As it presently does, the SPS would be capable of detecting remote separations due to the loss of Section 388 or 392.

The name of this scheme, "Loss of 3001 SPS", becomes misleading with the addition of the new tie. New Brunswick Power is expected to make a formal request that the name be changed to "Maritimes Islanding SPS". This report has retained the existing name throughout.

The second tie project recommends that this SPS be modified to respond directly to the trip of lines 388 and 392. Breaker contact information from Orrington, Maxcys and Maine Yankee substations would be transmitted to New Brunswick. This is an extension of the function served by the Bucksport overcurrent SPS (NPCC #21). As with the present Maine Independence Station transfer trip scheme, there is a maximum delay of 15 cycles between fault inception and the generation tripping in New Brunswick. If the Bucksport OC SPS is upgraded, this rather long delay is expected to be shortened. This arrangement avoids the delay associated with the power and frequency determination of the Loss of 3001 SPS. When either line 388 or 392 are tripped, the New Brunswick generation rejection occurs within 15 cycles. The power and frequency functions in the Loss of 3001 SPS provide a technology independent backup to this direct tripping logic. Failure of the power and frequency functions would not result in significant adverse impact, since it would be backed up by the direct tripping, and vice versa. New Brunswick Power has agreed to implement these modifications so that the SPS meets Type I design criteria.

Alternatives to the modified Loss of 3001 SPS involve system modifications. Specifically, generation rejection in response to the loss of Sections 388 or 392 could be eliminated by adding new 345kV transmission south of Orrington. New 345kV transmission south of Orrington would cost on the order of $50 to 100 million, depending on the route, termination and substations involved.

Failure of the SPS results in separation of the system in Maine, and is discussed in Section 4. Undesired activation of this SPS would cause a reduction in the power import from New Brunswick. The SPS never arms enough generation to cause the 1200 MW loss of source criteria to be violated by misoperation. No other adverse consequences would occur, since operation of the SPS moves the system to a condition of lower stress.

6.5 Maine Yankee Double Circuit Tower SPS

The purpose of the present Maine Yankee DCT SPS is to maintain stability and to relieve overloads for loss of the two 345kV lines south of Maine Yankee (375 and 377) or the Maxcys-Maine Yankee and Maine Yankee–Buxton (392 and 375) 345kV lines. The SPS presently trips MIS. Under some existing conditions, this SPS action is insufficient to relieve STE overloads on some of the underlying115kV lines. As a result, these lines are subject to a special NEPOOL thermal exclusion. With the addition of the second line, the potential for overload of these lines is substantially increased. Therefore, it is proposed that the DCT SPS be modified to send a signal to the NB Loss of 3001 SPS which initiates additional generation rejection. This generation tripping would supplement the existing Maine Independence Station transfer trip. The amount armed for generation tripping in New Brunswick would be according to the same rules as those of the Loss of

3001 SPS and would result in a less than 1200 MW loss of source. The time delay for the New Brunswick generation rejection is 15 cycles after the line relay pickup, which is the same as for the trip of MIS. This timing is expected to be improved when the Bucksport overcurrent relay is upgraded, however, faster action is not required for this project.

This arrangement addresses potential problems that can occur with the present SPS scheme. Simultaneous high Orrington South transfer and off-line Maine Independence Station units increase the risk of thermal overloads as high as 167% of STE rating, which is avoided with the modified SPS. This SPS will remain a Type I.

Alternatives to the modified DCT SPS involve system modifications. When the thermal exclusion was granted, the NEPOOL Reliability Committee required CMP to return in January 2001 with options and costs for alternatives to the double-circuit tower exclusion. A report, dated January 9, 2001, describes the alternatives examined by CMP. Those alternatives include several operational and minor equipment changes to reduce exposure, which costs ranging from $100k to $1M, and major transmission construction alternatives (e.g. separating the lines), with costs ranging from $3.4M to $14.7M.

Failure of the SPS results in operation of the Loss of 3001 (Maritimes Islanding) SPS (NPCC #5), and system separation by line relays across Orrington South. These are discussed in Section 4. Undesired activation of this SPS would cause a reduction in the power import from New Brunswick. The arming of the SPS is such that the 1200 MW loss of source criteria would not be violated by misoperation. No other adverse consequences would occur, since operation of the SPS moves the system to a condition of lower stress.

6.6 New DPL SPS for Line 3001/Section 396 and Line 3016

Plans are to install a direct path logic (DPL) SPS to protect both New Brunswick-New England 345 kV tie lines. This SPS would have breaker/protection trip output monitoring at both ends of Section 396 (Keswick-Orrington) and Line 3016 (Point Lepreau-Orrington) to detect the opening of either line. Because the proposed 1000 MW maximum export flow when both ties are in-service would place a strain on the remaining line following loss of the other, this new SPS (Type I) would immediately act to reject approximately 300 MW of pre-selected generation to bring the flow levels down to a manageable level. The New DPL SPS would be armed at about 700MW of New Brunswick to New England transfer. The DPL will act when either line is issued trip signals, with a five cycle delay until the New Brunswick generation trips. The generation armed for tripping will be a subset of that armed for the Loss of 3001 SPS, and assigned by the same priority. Thus, under conditions in which both this New DPL SPS and the Loss of 3001 SPS act, the total generation rejection in New Brunswick will be that armed by the Loss of 3001 SPS.

Alternatives to the New DPL SPS involve system modifications. Specifically, the sensitivity cases reported in Sections 3.5 and 4.7 show that the requirement to trip New Brunswick generation in response to the loss of Section 396 could probably be eliminated by adding series compensation to Line 3016, at a cost of approximately four million dollars.

Failure of the New DPL SPS results in activation of the Loss of 3001 (Maritimes Islanding) SPS for the loss of Section 396 and temporary thermal overload of Line 3001 for the loss of Line 3016. Results are discussed in Section 4. Undesired activation of this SPS would cause a reduction in the power import from New Brunswick. The SPS arms about 300MW of NB generation so that the loss of source criteria would not be violated by misoperation. No other adverse consequences would occur, since operation of the SPS moves the system to a condition of lower stress.

6.7 Summary of SPS Status for Project

The overall impact of the project on Special Protection Systems in Maine and New Brunswick is summarized in *Tables 6-1* and *6-2*. *Table 6-1* summarizes the SPSs that are unchanged by the project. *Table 6-2* summarizes the two retired, two modified and one new SPS for the project. The SPSs listed as retired were found to be unnecessary with the second tie under the all-lines-in study conditions. Details of the existing schemes as modeled are provided in Section 2.2.5.

Table 6-1. Summary of Unchanged Special Protection Systems.

SPS Name	Function	Comments
Maxcys Over-Current SPS (NPCC #28, Type I)	Purpose is to protect the underlying 115kV system for loss of 345kV line (392). Trips Maxcys Autotransformer in response to Maxcys - Mason 115kV (Section 68) overload	
Bucksport Over-Current SPS (NPCC #21, Type I)	Purpose is to protect the underlying 115kV system for loss of 345kV lines 392 and 388. Trips the Bucksport-Detroit (203) and Bucksport-Belfast (86) 115kV lines and Bucksport and MIS generators for overload of Orrington-Bucksport (65) and Betts Rd-Bucksport (205) 115kV lines.	Under review by CMP. Does not meet NEPOOL Planning Procedure 5-5 Special Protection Systems Applications (PP5-5) Guidelines. Should be called "Loss of 388/392 SPS". See discussion of NPCC#5 below.
Bucksport Reverse Power SPS (NPCC #22, Type I)	Purpose is to protect BHE from low voltages for loss of Section 388 or 392 as well as Section 396 with low internal generation. Trips the Bucksport-Orrington (65) and Bucksport-Betts Road (205) 115kV lines for excessive south-to-north power flow.	Under review by CMP.
New England Section 396 SPS. (NPCC #140, Type I)	Purpose is to assure positive damping following three conditions: (1) both line breakers open at Keswick, (2) both line breakers open at Orrington, or (3) the Section 396 protective relays operate at Orrington. Trips MIS.	Could possibly be retired or modified; subject to further analysis by others. Does not meet NEPOOL PP5-5 Guidelines.

Note: NEPOOL PP5-5 Special Protection Systems Application Guidelines requires Type I SPSs to have local monitoring and limits action to within one station.

Table 6-2. Summary of Modified and New Special Protection Systems.

SPS Name	Function	Comments
Keswick Power Relay (KPR) (NPCC #12, Type I)	Purpose was to prevent overload trips of the 345 kV tie. Only used with Chester SVC out of service. Operates if the flow leaving Keswick is above 650 MW and 200 MVAr simultaneously.	No longer armed for all-lines-in conditions. Does not meet NEPOOL PP5-5 Guidelines
Keswick GCX SPS. (NPCC #11,Type I)	Purpose was to provide overload protection to Line 3001 such that it does not trip because of a large load loss in the Maritimes when it is already running near its maximum export (from NB) capability.	No longer armed for all-lines-in conditions. Removes widespread concerns about unintended operation for New England delayed fault-clearing events. Does not meet NEPOOL PP5-5 Guidelines
Keswick Loss of 3001/396 SPS *"Maritime Islanding SPS"* *(NPCC #5, Type III)*	Purpose is to detect islanding of the Maritimes due to trips of any one of the series of 345kV connections to southern New England. This SPS locally detects frequency and power changes, then rejects generation in New Brunswick.	Modified to monitor frequency and power on each of the NB-NE lines. The SPS will independently test power flow and frequency at the sending end of the two lines, and initiate generation trip in New Brunswick when trip criteria are met on either line. This will detect the loss of 388 and 392, and trip generation in New Brunswick. The SPS will be modified so that generation tripping in New Brunswick will be armed when transfer on the Orrington South interface (minus MIS and Bucksport output) exceeds about 200 MW. This arming logic will result in a slight generation surplus in the Maritimes/Bangor island following separations caused by trips of 388 or 392. New Brunswick Power has agreed to implement the SPS in accordance with Type I design criteria, and will formally request a name change to "Maritimes Islanding SPS". It is recommended that additional signals from Sections 388 and 392 be sent to this SPS to make this function faster and more secure. This provides a secure complement to the remote sensing frequency and power logic at Keswick and Pt. Lepreau. This function could be considered a modification to the Loss of 3001 SPS.
Maine Yankee Double Circuit Tower SPS (NPCC #141, Type I)	Purpose of the DCT SPS is to maintain stability and relieve overloads on the underlying 115kV system for loss of the two 345kV lines south of Maine Yankee (375 and 377) or the Maxcys-Maine Yankee and Maine Yankee – Buxton (392 and 375) 345kV lines. The DCT SPS trips MIS.	Modified to send a signal to activate NPCC #5 above Loss of 3001 (Maritime Islanding) SPS. This modification removes the need for the present DCT thermal exclusion. Avoids risk of thermal overloads in excess of 150% of STE rating. Does not meet NEPOOL PP5-5 Guidelines
New DPL SPS for 396/3001or 3016 (Type I)	Purpose is to maintain system stability and to avoid overloads for events on 345kV lines between Maine and New Brunswick. Dedicated Path Logic (DPL) trips about 300 MW of New Brunswick generation for loss of either existing Section 396/3001 or new Line 3016.	This is a new SPS. DPL function is more robust than the existing flow-based Loss of 3001/396 SPS. The SPS will be armed when New Brunswick export is about 700 MW. The amount tripped will be set to reduce the New Brunswick export to below 700 MW. This SPS will trip a subset of the generation armed for tripping by the Loss of 3001/396 SPS. Does not meet NEPOOL PP5-5 Guidelines.

Note: NEPOOL PP5-5 Special Protection Systems Application Guidelines requires Type I SPSs to have local monitoring and limits action to within one station.

7. Conclusions and Recommendations

A second 345kV transmission line connecting New Brunswick and Maine was initially proposed and approved by NEPOOL more than ten years ago. The purpose of this study is to update the original study and to analyze the impact of the Pt. Lepreau–Orrington 345kV line on the interconnected New England system in accordance with the current NEPOOL standards, and determine the need for any additional enhancements to ensure that the performance of the interconnected system with the second tie would meet criteria.

Under the NEPOOL Planning Procedure 5-5, "Subordinate 18.4 Application Policy", the second NB tie project is presently subordinate to any projects higher than it in the ISO New England study queue. While several of the higher priority projects are regularly operating (e.g., Westbrook Power and Bucksport Energy), their system impact studies are not necessarily completed or their own subordinate status removed. As a result, all recommendations provided in this report are conditional and subject to reevaluation once the proposed projects ahead of the second NB tie project, and their associated transmission upgrade requirements, receive final approval under Section 18.4 of the NEPOOL Agreement.

The projects ahead of the second NB tie project in the study queue are Neptune Phase 5, Neptune Phase 7, Berwick Energy Center, AEC Expansion, Redington Mountain Wind Farm, Westbrook Power and Bucksport Energy. The second NB tie system impact study completely addressed the present Bucksport Energy and Westbrook Power projects with their present upgrades. The Second NB Tie Project will not be subordinate to them if their subordinate status is removed with their present interconnection design and upgrade requirements.

The intent of this study was to evaluate the impact of a second NB tie and the associated 300 MW increase in transfer across the New Brunswick–New England interface. While the majority of the power flow study effort focused on conditions with an Orrington South interface flow of about 1400MW, there was no intention of raising the limits of this or any other interface in New England. Rather, the evaluation was performed under these conditions, because they represent a stressed system condition. The Orrington South interface is design limited to 1200 MW, due to a PJM and NYISO loss of source concern for the northeast interconnection reliability. The second tie project one of several resources that could be limited as a result.

The stability analysis focused on an Orrington South interface flow of 1200MW for light load conditions with the second tie project. Peak load conditions with the project were evaluated at an Orrington South interface flow of approximately 1400MW.

The analysis showed that the second NB transmission line requires additional system reinforcements to meet both power flow and stability criteria. These reinforcements combined with the new transmission line define the *second NB tie project* described in this report. The project includes the following elements:

1. An approximately 144 mile, 345kV single circuit transmission line (1192kcm, two conductor bundle) from the Point Lepreau station in New Brunswick to the

Orrington substation in Maine. The rating of this line will be at least equal to the rating of Section 396 (item 7).

2. Two additional 345kV circuit breakers at the Orrington substation.
3. A 25 ohm series capacitor (50% compensation of the Orrington-Maxcys-Maine Yankee line impedance) in the Orrington-Maxcys 345kV line.
4. Two shunt capacitor banks, 30 MVAr each, on the Maine 115kV system at Gulf Island and Kimball Road substations.
5. Thermal upgrade of the Augusta East – Maxcys (Section 88) and Augusta East – North Augusta - Puddledock (Section 213) 115kV lines.
6. Substitution of one entirely new dedicated path logic (DPL) special protection system (SPS) for an existing one, Keswick GCX SPS (NPCC #11, Type I), and modification of two other SPSs, the Maine Yankee DCT SPS (NPCC #141, Type I) and the Loss of 3001 SPS (NPCC #5, Type III). Details and extensive discussion of the SPS impacts of the project are provided in Section 6.
7. A wavetrap at Keswick currently limits the continuous, long term emergency (LTE), and short term emergency (STE) ratings of Section 396 to 730, 865, and 1075 MVA. The ratings could be increased to at least the level of the New England line portion (975, 975, and 1031MVA) by replacing the wavetrap.
8. The K84-2 115kV breaker at Maxcys substation will be replaced by a breaker with a higher short circuit current rating.

No other system upgrades are required by other New England transmission companies.

For this study, the shunt capacitors were at Gulf Island and Kimball Road 115kV substations. A screening level analysis indicates that these capacitors could be located elsewhere on the Maine 115kV and still provide sufficient voltage support. Similarly, the series capacitor may be located anywhere along the Orrington-Maxcys 345kV line.

As described in Section 3.5, the control philosophy of the Chester SVC should be reconsidered with the addition of the second 345kV line to New Brunswick, as well.

7.1 Power Flow

The results of the power flow analysis are described in Section 3 and show the following:

1. The system with the second NB tie project (including reactive compensation and 115kV line uprates) meets thermal and voltage criteria.
2. The margin to voltage collapse with the second tie project is comparable to or better than the margin in the existing system.
3. The stress on the underlying 115kV system is relieved by the series compensation on the Orrington-Maxcys line. In particular, an upgrade of Section 86 (Bucksport-Belfast 115kV) is not required.
4. Reliability of the system is significantly improved by the addition of the tie, since the loss of one line no longer results in system separation and total loss of the NB import (up to 700MW) as well as a trip of Maine Independence Station (1250MW loss of source).

5. PV analysis suggests that it may be possible for 1100MW to flow on the NB/NE interface and meet voltage criteria with additional shunt compensation in Maine.
6. Export of up to 400 MW to New Brunswick meets thermal and voltage criteria with the second NB tie project for the studied conditions.
7. Post-contingency thermal performance presently constrains the Orrington South interface to about 1060 MW. The second tie project allows the design limit of 1200 MW to be reached.
8. Thermal overloads resulting from the double circuit tower outage south of Maine Yankee are presently subject to a Northeast Power Coordinating Council (NPCC) and NEPOOL exclusion. Modification of the double circuit tower (DCT) SPS to initiate generation rejection in New Brunswick eliminates the risk of overloads in excess of 150% of STE rating and the need for the thermal exclusion.
9. Thermal upgrade of the Augusta East– Maxcys line (Section 88) to at least 126 MVA LTE is planned by CMP, and is required for this project. (STE rating will be greater than or equal to LTE rating.)
10. Thermal upgrade of the Augusta East–North Augusta–Puddledock 115kV line (Section 213) to at least 103 MVA STE is also required for this project. A thermal upgrade similar to that for Section 88 is proposed.
11. A third 30 MVAr shunt bank would provide voltage support in the area should the Orrington South interface limit ever be increased above 1200 MW.

7.2 Transient Stability

The results of the power flow analysis are described in Section 4 and show the following:

1. The addition of the second tie project relieves one existing system violation for a normally cleared fault on the Tewksbury-Woburn 115kV line (ncm139; GCX entry) under light load conditions.
2. For the normal contingency Waltham-Brighton-Watertown event (nc282-520) with additional high speed primary protection resulting in 5 cycle clearing at Brighton, both the existing system and the second tie project system meet criteria.
3. The addition of the second tie project relieves a loss of source concern (2135 MW) in the existing system for the Vermont Yankee bus extreme contingency (ecvybus) under light load. The LOS is reduced to the output of Vermont Yankee for the second NB tie system.
4. The addition of the second tie project relieves the need for the GCX SPS, and removes concerns about unintended operation of that SPS. The requirement for the GCX relay is met, more securely, by the project's proposed New DPL SPS. The GCX will no longer be required under all-lines-in conditions.
5. The addition of the second tie project relieves LOS concerns in the existing system for the Canal extreme contingency (ec342 with 10.5 cycle clearing) for the maximum Canal area generation sensitivity case at light load (LOS = 2291 MW). The other Canal fault (ec212 with 13.5 cycle clearing) results in a LOS concern for both the benchmark (2590 MW) and second tie project (2204 MW) systems for this sensitivity case.
6. Addition of the second tie allows the NB and NE systems to remain interconnected for the loss of either the existing line or the new line with the New DPL SPS tripping of generation in New Brunswick. These cases result in reduced

loss of source compared to the existing system, which causes system separation and loss of the entire NB import as well as the Maine Independence Station plant.

7. The double circuit tower outages around Maine Yankee meet criteria with the recommended changes to the DCT SPS. Simulations of failure of the new or modified SPSs indicated no stability related problems or issues.
8. Export of up to 400 MW to New Brunswick meets stability criteria with the second tie project for the studied conditions.
9. Four cases (ncm139, nc392 in the primary light load analysis, as well as dct03 and dct04 in the Bucksport sensitivity analysis) have violations of the proposed CMP voltage criteria in the existing system but not in the second tie project system.

Overall, the second tie project meets system reliability criteria. System security is improved in two areas of particular interest:

- Loss of Section 396/Line 3001 to New Brunswick (a nearly annual occurrence)
- Unwanted operation of the Keswick GCX SPS

Two existing reliability concerns are corrected by the addition of the second tie project (items 1 and 3); one additional concern for a sensitivity case is also corrected (item 5). Four violations of the proposed CMP voltage criteria are corrected (item 9). System design studies, including subsynchronous resonance (SSR) analysis, protective relay studies, transient analysis and short circuit impacts analysis, are required, and should be performed during the project design and requisition stages.

7.3 Short Circuit Analysis

The short circuit analysis showed that the only new over-dutied breaker was the K84-2 115kV breaker at Maxcys. This breaker will be replaced as part of the second NB tie project.

Appendix A. Benchmark Power Flow Summaries & Diagrams.

Case	Brief Description	ME One Line	NE One-Line	Summary
ex3	peak export to NB	ex3me	ex3ne	ex3sum
lt2	light w/ MIS	lt2me	lt2ne	lt2sum
lt3	light no NB/NE flow	lt3me	lt3ne	lt3sum
pk2	peak w/ WFW#4	pk2me	pk2ne	pk2sum
pk3	peak w/o WFW#4	pk3me	pk3ne	pk3sum
pk4	pk3 w/ Bucksport	pk4me	pk4ne	pk4sum
pk5	pk4 w/o Seabrook	pk5me	pk5ne	pk5sum
sh2	shoulder	sh2me	sh2ne	sh2sum

Appendix B. Second NB Tie Power Flow Summaries & Diagrams

Case	Brief Description	ME One Line	NE One-Line	Summary
ex3x1r2	peak export to NB	ex3-x1r2me	ex3-x1r2ne	ex3x1r2sum
lt2a1r2	light w/ MIS, A1	lt2-a1r2me	lt2-a1r2ne	lt2a1r2sum
lt2b1r2	light w/ MIS, B1	lt2-b1r2me	lt2-b1r2ne	lt2b1r2sum
lt3x1r2	light no NB/NE flow	lt3-x1r2me	lt3-x1r2ne	lt3x1r2sum
pk2a1r2	peak w/ WFW#4, A1	pk2-a1r2me	pk2-a1r2ne	pk2a1r2sum
pk2b1r2	peak w/ WFW#4, B1	pk2-b1r2me	pk2-b1r2ne	pk2b1r2sum
pk3b1r2	peak w/o WFW#4, B1	pk3-b1r2me	pk3-b1r2ne	pk3b1r2sum
pk4a1r2	pk3 w/ Bucksport, A1	pk4-a1r2me	pk4-a1r2ne	pk4a1r2sum
pk5a1r2	pk4 w/o Seabrook, A1	pk5-a1r2me	pk5-a1r2ne	pk5a1r2sum
sh2a1r2	shoulder, A1 dispatch	sh2-a1r2me	sh2-a1r2ne	sh2a1r2sum
sh2b1r2	shoulder, B1 dispatch	sh2-b1r2me	sh2-b1r2ne	sh2b1r2sum

Appendix C. Benchmark Power Flow Summaries & Diagrams for Transient Stability Analysis

Case	Brief Description	ME One Line	NE One-Line	Summary
slt2	light load	slt2me	slt2ne	slt2sum
spk4	peak load	spk4me	spk4ne	spk4sum
sexl2	light load export	sexl2me	sexl2ne	sexl2sum
slt2canal	Canal sensitivity	slt2canalme	slt2canalne	slt2canalsum
slt2buck	Bucksport sensitivity	slt2buckme	slt2buckne	slt2bucksum
slt2wfw4	WFW#4 sensitivity	slt2wfw4me	slt2wfw4ne	slt2wfw4sum
slt2mysx	Boston sensitivity	slt2mysxme	slt2mysxne	slt2mysxsum

Appendix D. Second NB Tie Power Flow Summaries & Diagrams for Transient Stability Analysis

Case	**Brief Description**	**ME One Line**	**NE One-Line**	**Summary**
tslt2-r2	light load	tslt2-r2os12me	tslt2-r2os12ne	tslt2-r2os12sum
tspk4-r2	peak load	tspk4-r2me	tspk4-r2ne	tspk4-r2sum
tsexp4-r2	light load export	tsexl2-r2me	tsexl2-r2ne	tsexl2-r2sum
tslt2r2canal	Canal sensitivity	tslt2r2os12canalme	tslt2r2os12canalne	tslt2r2os12canalsum
tslt2r2buck	Bucksport sensitivity	tslt2r2os12buckme	tslt2r2os12buckne	tslt2r2os12bucksum
tslt2r2wfw4	WFW#4 sensitivity	tslt2r2os12wfw4me	tslt2r2os12wfw4ne	tslt2r2os12wfw4sum
tslt2r2mysx	Boston sensitivity	tslt2r2os12mysxme	tslt2r2os12mysxne	tslt2r2os12mysxsum

Appendix E. SSR Considerations

When series capacitors were first applied to transmission networks in the 1930's, there were concerns about the impact of the resonance created between the series capacitor and the inductance of the transmission network. Charles Concordia wrote papers on the potential for adverse interactions with turbine generators in the late 1930's. However, the initial use of series capacitors were generally limited to situations where the compensation seen from any individual generator was relatively low, and there existed several parallel paths for the currents flowing in the generators. Also the transmission networks of those times had sufficient resistance to prevent high interactions with generator units.

In 1970, and again in 1971, the Mohave generator in Arizona experienced a severe vibration that grew slowly over several minutes. This vibration eventually led to breakage of the shaft Section between the generator and the rotating exciter. Investigations determined that this problem was caused by a near coincidence of the first torsional vibration mode of the turbine-generator and the complement of the electrical resonance caused by the series-compensated 500 kV transmission network. The torsional mode frequency was 30.1 Hz. The electrical resonance was 29.9 Hz, which causes torques at the 60 Hz complement frequency of 30.1 Hz. Because the electrical resonance frequency is below the nominal synchronous frequency of the system, the interaction came to be known as subsynchronous resonance (SSR).

The events at the Mohave plant are the only recorded SSR incidents that led directly to a shaft failure. Subsequently, the utilities in the southwestern United States established practices of limiting the amount of series capacitors that are permitted in operation. The limits are developed on the basis of combining analytical studies and measurements on generator torsional vibration modes. This practice has proven sufficient to permit continued operation of the Mohave unit without SSR problems, and is also adequate for all but extreme contingencies on most other units in the western US. The constraints are only associated with thermal power plants. The mechanical characteristics of hydro power plants are such that no adverse SSR effects occur.

Special equipment has been used on some installations to reduce the interaction so that higher levels of compensation can be tolerated without risking an SSR problem. Special protective relays have also been applied to certain generators deemed to be at risk in rare contingency situations.

Recently, thyristor control has been applied to series capacitors, creating a thyristor-controlled series capacitor (TCSC), to damp the oscillations at their source. Both simulation and field tests show that the control is sufficient to render the series capacitor "neutral" with respect to SSR. This means that a transmission line including a TCSC is no different from an SSR perspective than a conventional uncompensated ac transmission line.

Worldwide, there are approximately 200 series capacitor banks installed, with more going into service every year. This is clear indication that the SSR issues can be dealt with in a satisfactory manner.

SSR Phenomena

Two aspects of the SSR phenomenon are described in the following paragraphs.

Torsional interaction relates to the tendency of the series compensated ac transmission network to produce a negative damping influence on torsional vibrations. When this negative damping influence overcomes the inherent mechanical damping of the shaft torsional system, the torsional vibrations will grow exponentially until damage occurs. Generally, such growth in shaft vibrations occurs with a rather long time constant, on the order of many seconds. This is the phenomena which caused the shaft breakage at the Mohave unit in 1970. It can be important in many different system conditions, even when the electrical and torsional resonances are not in exact coincidence.

The solution to such a situation is to either avoid situations where the SSR-induced negative damping is excessive, or to add damping in some manner to the power circuit.

Transient torque relates to the tendency of series capacitors to amplify the shaft stresses during major network transient events, over and above that which would exist without the series capacitors. Generally, the critical aspect of this phenomenon is the magnitude of shaft vibrations after the electrical transients have decayed substantially, which is on the order of one second.

There is no record of severe damage from series-capacitor induced transient torque amplification. However, the anticipation of this potential problem has led to a number of design and operating criteria for power systems where an individual generator might be exposed to a highly-compensated transmission network after clearing a fault. It is only in cases where the generator becomes nearly radial on heavily series compensated lines that transient torque considerations become important.

The solutions to this type of problem are to reduce or isolate the transient energy in the capacitor from the generator. One method is to limit the voltage across the capacitor, and hence the stored energy, by metal-oxide varistors or gaps. Another method is to provide a blocking filter at the generator location.

SSR Screening Analysis (for Torsional Interaction)

SSR studies are typically done in various stages. The first stage involves a screening process using the impedance-vs-frequency characteristics of the network, as seen from the generator bus. This frequency-scanning technique provides an approximate assessment of potential torsional interaction, and is useful to define critical contingencies and estimate overall risk of a torsional instability.

Evaluation of actual interaction potential and shaft transient stresses requires more in-depth analysis. General concepts and methods typically used for these detailed evaluations are described in the following subsections.

SSR Damping Analysis (for Torsional Interaction)

The effect of the electrical transmission system on torsional damping can be characterized by the effective electrical damping, which is a function of frequency, generator load, and the nature of the electrical transmission system. For a given generator in a given network condition, the electrical damping can be expressed as a function of frequency. While electrical damping exists for all frequencies, its value is only important in the near vicinity of a natural torsional frequency.

Electrical damping can be calculated using only a model of the electrical portion of the system. The system is perturbed by modulating the speed of the generator shaft, and the response of electrical torque is determined. At a given modulation frequency, the component of electrical torque which is in-phase with the speed is the value of electrical damping.

A positive electrical damping component indicates that if the generator shaft speed increases, then the electrical torque will also increase by an amount proportional to the value of the damping component. This increase in electrical torque will oppose the original perturbing force, and cause the succeeding oscillations to decay more quickly. A negative electrical-damping component indicates that if the generator shaft speed increases, then the electrical torque will decrease. This decrease in electrical torque will aid the original perturbing force, and cause subsequent oscillations to have less damping, or to become unstable.

The net damping of a torsional mode of vibration consists of the electrical component and the mechanical component. The mechanical damping is due to all factors other than changes in electrical torque on the generator shaft (primarily steam flow, friction, and windage). In most cases, the contribution of the exciter torque is considered as part of the inherent damping, and lumped together with the other truly mechanical contributions. Mechanical damping is quite small, but it is always positive. Mechanical damping is minimum when a machine is at no-load, and monotonically increases with the machine load.

A torsional mode of vibration will be stable when the net damping is positive. A torsional mode will be unstable when the net damping is negative. This unstable condition is indicated if electrical damping at the torsional frequency is negative and larger in magnitude than the inherent mechanical damping.

This type of analysis is somewhat approximate for situations of resonance, since the actual frequency of torsional vibration will vary a little due to the synchronizing effect of the electrical network. By using such analysis to determine a worst-case electrical damping within a certain frequency window, e.g., ±1 Hz, the procedure can be used for design purposes.

Transient Torque Analysis Method

The consequences of transient torque amplification are related to fatigue, which means an accelerated loss-of-life of the turbine-generator shaft. A complete analysis of fatigue damage involves performing a large number of transient simulations with the complete network, where all conceivable switching sequences and fault timings are considered in a statistical manner. For each case, the torque responses of each shaft section are evaluated in a nonlinear manner to estimate the fatigue loss-of-life for the event.

Such a detailed fatigue evaluation is warranted only for situations where the generating unit becomes substantially radial on a highly series-compensated line. A brief evaluation is appropriate as a design proceeds to ensure proper consideration is being given to transient stresses. Generally, systems designed for adequate positive damping and without direct radial configurations from the generating station will not exhibit severe transient stress from the series capacitors.

Mitigation Options

This Section introduces existing SSR countermeasures that have been installed or seriously considered. Nearly all of the actual installations are in the western portion of the United States. Generally SSR countermeasures are needed only when thermal power plants are connected to transmission lines having more than 35% series compensation.

The list is organized by where the countermeasure is placed in the power system, and whether it involves high-power equipment or operating/relaying practices. Only those systems that have been placed in service are included here.

Countermeasures installed at the generator

A series blocking filter is a complete solution to the transient torque problem at high levels of series compensation. The filter is installed in series with the generator to block the flow of subsynchronous currents at the complement of the shaft torsional frequencies. This is a tuned filter with multiple series stages of parallel inductance and capacitance. The filter is in the neutral end of the generator step-up (GSU) transformer. This type of filter has been in service at Navajo Plant in Arizona for over 20 years.

A supplementary excitation damping control senses torsional motion in the shaft speed signal, and modulates generator field voltage via a specially-designed transfer function. The transfer function is designed so that the resulting modulation of torque on the generator and exciter shafts act in a manner that adds damping to selected torsional modes. This control is useful for moderate destabilization problems or as a supplement to a series blocking filter. The control requires a high response excitation system. This controller is in operation at the Navajo, Jim Bridger, and Coronado generating units in the Western USA.

A number of shunt damping controller designs have been considered whereby an active device is installed in shunt with the generator, either on the high-side or low-side of the generator step-up transformer. The control objective is to pull subsynchronous currents away from the generator. Generally this requires more high-power equipment than a series-connected device. One such system has been in service on one unit at San Juan in New Mexico for about 15 years.

Countermeasures installed at the series capacitor bank

Metal oxide varistors in parallel with the series capacitors limit the voltage on the capacitors during transients allowing the series capacitors to remain in service. Limiting the voltage reduces the transient torque problem on the generators. Varistor protection has been installed on virtually all new series capacitor banks built in the late 1980's and later.

A thyristor-controlled series capacitor is an active approach, where thyristors are used to phase-control an inductive branch in parallel with the series capacitor. Extensive study and field tests have confirmed good performance with respect to mitigating SSR. Two installations exist in the western United States, the Kayenta installation in Arizona and the Slatt installation in Oregon. The Slatt TCSC, built by GE, is the world's only system where all performance aspects, including SSR neutrality, have been demonstrated.

Automated operating systems

Transfer tripping and/or capacitor insertion schemes are used at several series capacitor installations in the USA. They only allow the series capacitors to be inserted when line flows and/or generation levels require them. At Jim Bridger in Wyoming, all units on-line must be above 50% load before the high levels of series capacitors are used. Other schemes will bypass series capacitors upon certain line contingencies that expose the generation to SSR problems.

SSR protection

SSR protective relays are primarily used as a backup to other countermeasures, to cover unanticipated contingencies. Another application is for situations where an SSR problem occurs only after multiple contingencies and other countermeasures are not applied to cover those remote possibilities.

Torsional stress relays provide protection by tripping the unit for excessive torsional oscillations. Shaft oscillations of the unit are monitored directly. These relays are installed on many units.

Line-current subsynchronous oscillation relays sense subsynchronous frequencies in line current. Installed at the capacitor location, the action is to bypass the series capacitor in the event of excess subsynchronous content in line current. Coordination with the generator torsional constraints is difficult, and leads to a very sensitive relay. Several of these have been installed in Sweden, most recently by GE.

Generator shaft torsional performance monitoring

Torsional vibration monitoring systems and torsional stress analyzers provide information on the torsional performance of the unit and other protective devices. They can be used to provide post disturbance information on shaft torques, shaft fatigue, and torsional damping.

Appendix F. Protective Relaying for Series Compensated Transmission Lines

Protection of series compensated lines is a well understood field. While standard distance relaying is not applicable, there are other commercial relays that are appropriate. The primary problem with standard distance relays is that they may misoperate for faults on or close to series compensated lines. The problems with standard distance protection are as follows:

- Voltage and/or current inversion may lead the relay to determine an incorrect direction. This, in turn, may result in either a failure to operate for a forward in-zone fault or a misoperation for a reverse fault. Both distance and over-current directional elements can be affected.
- Series capacitors decrease the apparent impedance of the line, such that a forward fault may appear much closer to the relay than the actual fault location. The apparent impedance may be shifted towards the relay by as much as the total reactance of the series capacitors. This extreme steady state overreach happens during low current faults when the air gaps do not flashover or the MOVs do not conduct any significant current.
- In addition to the above steady-state overreach effect, sub-synchronous oscillations in both current and voltage may cause significant transient overreach.

The technical remedies for the above are described in the following Sections.

Voltage Inversion

Voltage inversion problems are eliminated by using 100% memory polarized directional comparators. The memory duration is set longer than the slowest fault clearing time for reverse faults, ensuring that the distance element would not pick-up for a reverse fault with a voltage inversion.

At the same time, the distance elements would pick-up for all forward faults regardless of any voltage inversion as long as the memory voltage is used. Before the memory expires the relay would respond to any fault on the protected line. Time delayed stepped distance backup zones would operate after the memory voltage expires.

Current Inversion

A multi-input-comparator approach is used to address current inversion. Should the current inversion happen, the distance elements are secure on reverse faults because multiple conditions involving fault-loop, negative-sequence and zero-sequence currents and the memory voltage are checked prior to declaring a forward fault.

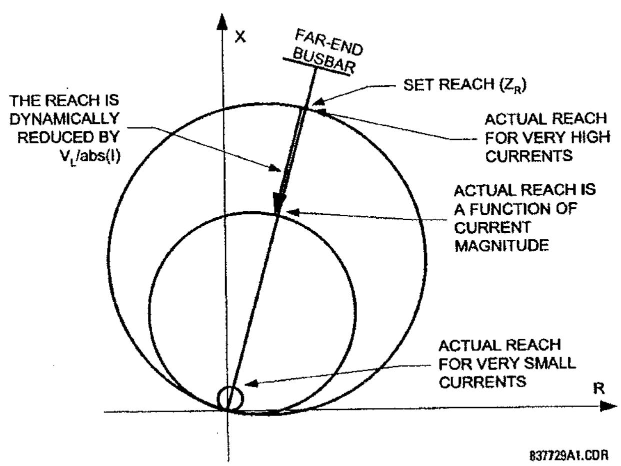
For close-in forward faults beyond the series capacitor (as seen from the relay), the current inversion phenomenon may take place for a short period of time. The condition cannot be sustained because very high fault currents would occur, causing large voltage drops across the series capacitors and prompting the over-voltage protection of the capacitors to operate. This would effectively remove the series compensation and eliminate the current inversion. However, when the currents used by a distance comparator (fault-loop current for ground and phase distance protection, and the negative- and zero-sequence currents for ground elements) stay shifted by more than 90 degrees from their natural fault position, the distance elements may fail to pick-up on such a forward fault for the brief period of current inversion before MOV or air gap conduction. This is an inherent attribute of the 100% memory polarized mho element.

Therefore, it is recommended to use high-set phase overcurrent protection for direct tripping on close-in faults potentially causing current inversion, and overreaching ground fault directional over-current functions (such as negative-sequence, ground or neutral) for communication-aided schemes.

Steady State & Transient Over-Reach

The problem of steady-state overreach due to the negative reactance of the series capacitors may be addressed by shortening the reach of an under-reaching distance element. This generic approach has two major drawbacks. First, it leaves a large portion of the line uncovered by the directly tripping distance protection. Second, it does not solve the transient overreaching problem caused by sub-synchronous oscillations.

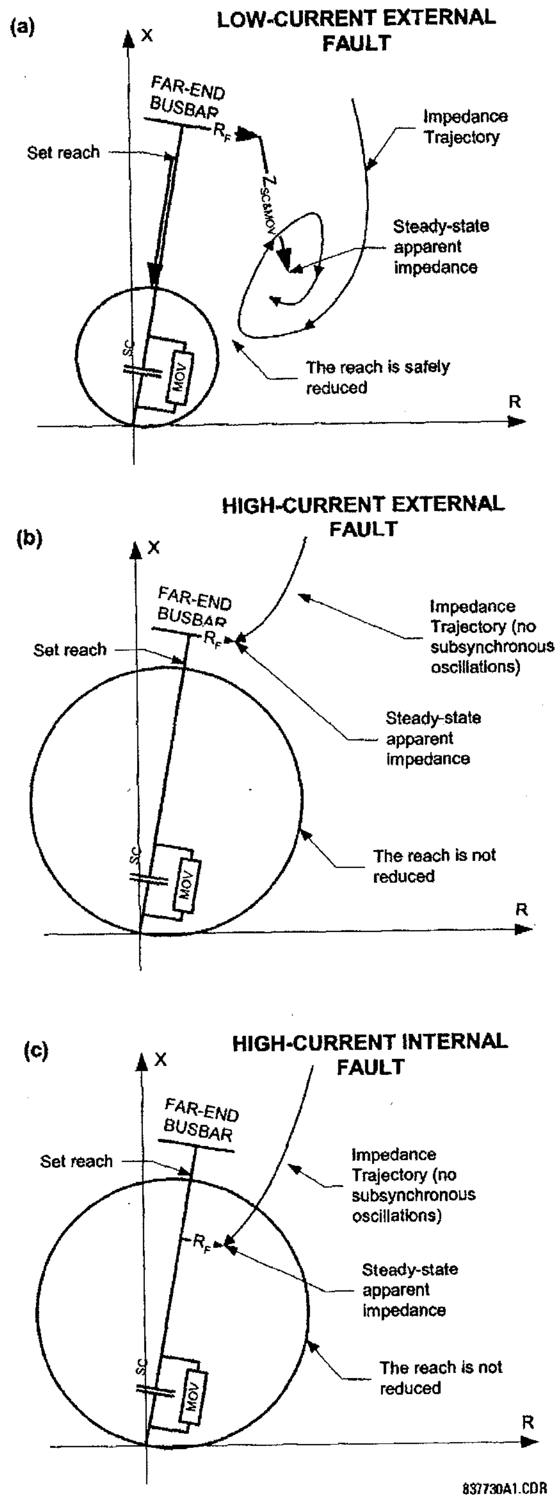
Therefore, a dynamic reach control based on the magnitude of the current flowing through the series capacitor bank can be used. The under-reaching distance function would be set for an uncompensated line, and the relay would control an effective reach by using the current magnitude as illustrated in the figure below.



Dynamic Reach Control

The reach is, therefore, reduced sufficiently to cope with both steady-state and transient overreach phenomena, and the relay would not operate for external faults. Overreaching ground fault directional over-current functions (such as negative-sequence, ground or neutral) would be used for increased dependability.

Section (a) of the figure on the next page shows the effect of adaptive reach control for a low-current external fault. The reach is reduced sufficiently to cope with both transient and steady-state overreach. Section (b) shows a high-current external fault. The air gaps or MOVs conduct the majority of the fault current and neither steady-state nor transient overreach occurs. The relay does not reduce its reach as it is not necessary. Section (c) shows a high-current internal fault. Because of the large current, the reach is not reduced and the element responds to this internal fault. The traditional approach would leave this fault out of the relay reach.



Adaptive Reach Examples

Conclusions

Series compensated lines may cause problems for standard distance relays. However, the problems and remedies are well understood. Commercial products are available that provide the necessary functions and the practice for determining settings is relatively standardized. More than 100 series compensated transmission lines in North America alone operate with reliable protection schemes.

Appendix G. Calculation of System Damping

One ISO-NE stability performance criteria requires a 50% reduction in the magnitude of system oscillations over four periods of that oscillation. To ensure that system performance of both the existing system and the proposed Second NB Tie Project system met this criteria and to improve the method of calculation, a MATLAB based computational tool was used to determine system damping. The calculation was performed using a signal selected by the SSG task force as representative of system damping – the Seabrook machine angle.

Before calculating the system damping in response to specific faults, the damping criteria needed to be converted from a 50% reduction in magnitude definition to a modal damping, σ, definition. An example plot of a 0.25Hz signal as well as its envelope is shown in *Figure G-1*.

The oscillatory signal in this figure can be represented mathematically as follows:

$$x(t) = X_O e^{-\sigma t} \sin(\omega t)$$

where: X_o = initial signal amplitude
ω = frequency of oscillation = 2πf = 2π(0.25Hz)
σ = damping of oscillation

To calculate the σ criterion, use the 50% magnitude reduction definition and set x(t) after four periods of oscillation equal to 50% of the initial signal amplitude. The time, t, can be replaced by 4 times the period of oscillation (4sec) or 4T or 16sec. Therefore, the magnitudes on either side of the above equation are set equal to each other in the following equation:

$$x(4T) = 0.50 X_O = X_O e^{-\sigma(4T)}$$

which can be reduced to:

$$0.50 = e^{-\sigma 16}$$

or

$$\sigma = -\ln(0.5)/16 = 0.043$$

Thus, the criteria for a 50% reduction over four periods of oscillation is equivalent to a damping, σ, greater than or equal to 0.043. The next step is to calculate system damping in response to specific fault and compare it to this criterion.

A sample Seabrook machine angle signal, shown in *Figure G-2*, will be used to illustrate the calculation procedure. This sample signal is from the simulation of a 3-phase fault near the Orrington 345kV substation and resulting trip of Section 396 on the Second NB Tie Project system. The damping calculation was performed in two steps.

First, an FFT (Fast Fourier Transform) was performed on the Seabrook machine angle signal. The resulting plot of signal amplitude versus frequency and time is shown in *Figure G-3*. This figure shows that the 0.25 Hz mode dominates the signal. A different plot of the same signal, shown in *Figure G-4*, shows the log of signal amplitude versus time for only the 0.25Hz signal component. Since this mode was so dominant, the damping was calculated for this component of the Seabrook machine angle signal.

Second, a least squares approximation of the log of the amplitude of the 0.25Hz component was determined. This linear approximation, as well as the 0.25Hz signal amplitude, are shown in *Figure G-5*. The slope of this straight line, -0.21, is approximately equal to the negative of signal damping, using the same sign convention as the criterion. This level of damping meets the ISO-NE criteria of a 50% amplitude reduction, which is equivalent to a damping of 0.043. Both the damping criteria of 0.043 and the damping calculated from the Seabrook machine angle, e.g. 0.21, are rounded in the summary sheets to reflect a more reasonable amount of precision.

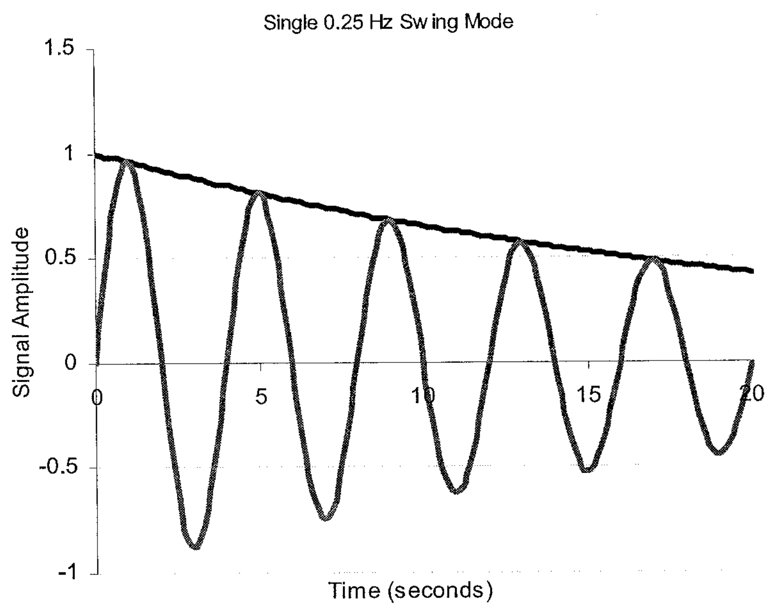


Figure G-1. 0.25Hz Damped Oscillatory Signal and its Envelope.

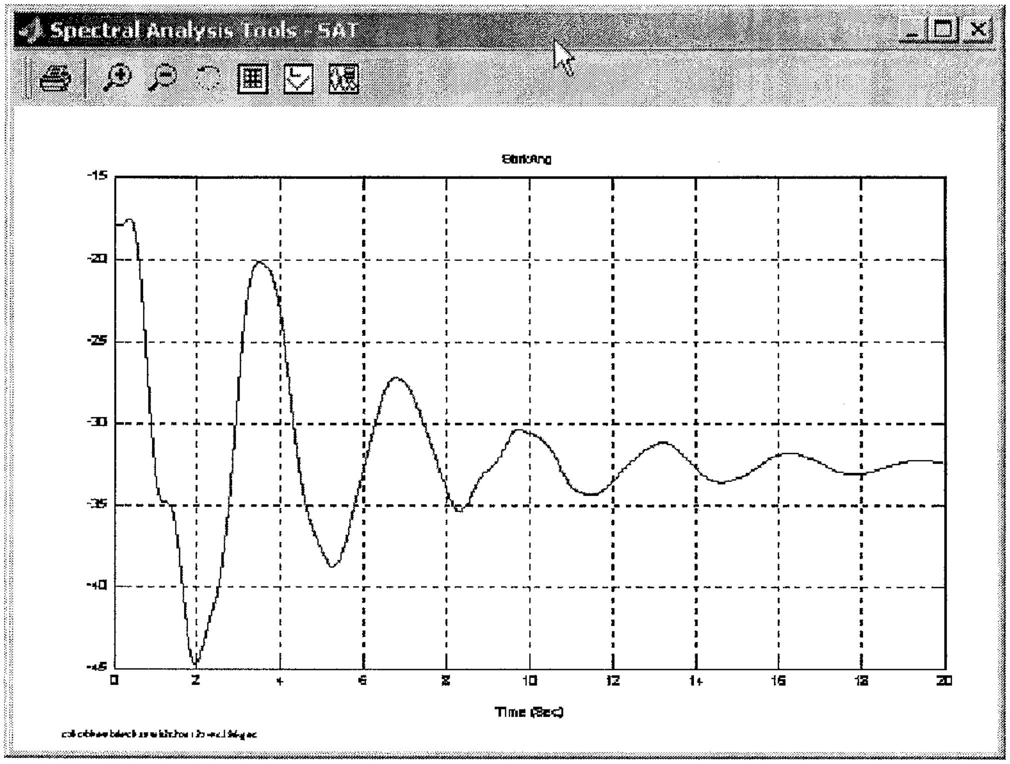


Figure G-2. Seabrook Machine Angle.

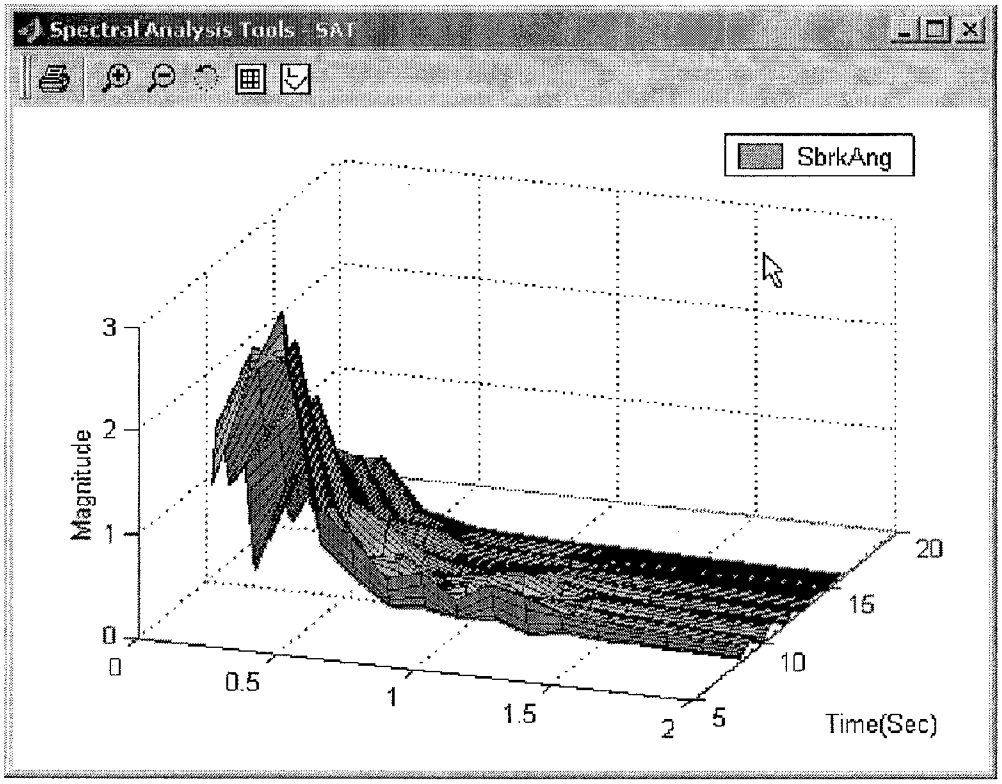


Figure G-3. Amplitude of Seabrook Machine Angle versus Frequency and Time.

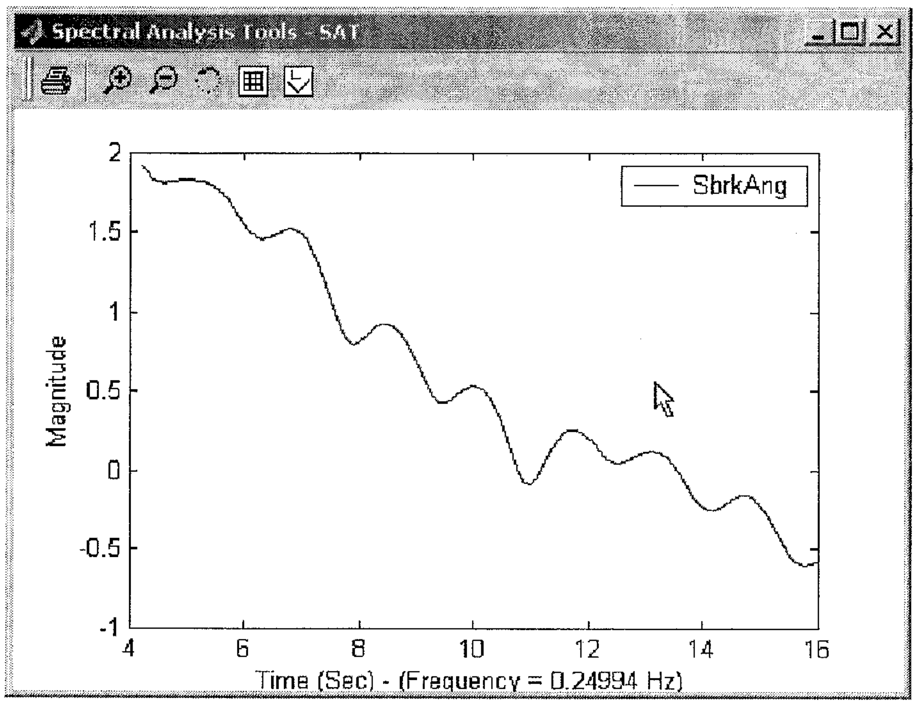


Figure G-4. Log Amplitude of 0.25Hz Component of Seabrook Machine Angle versus Time.

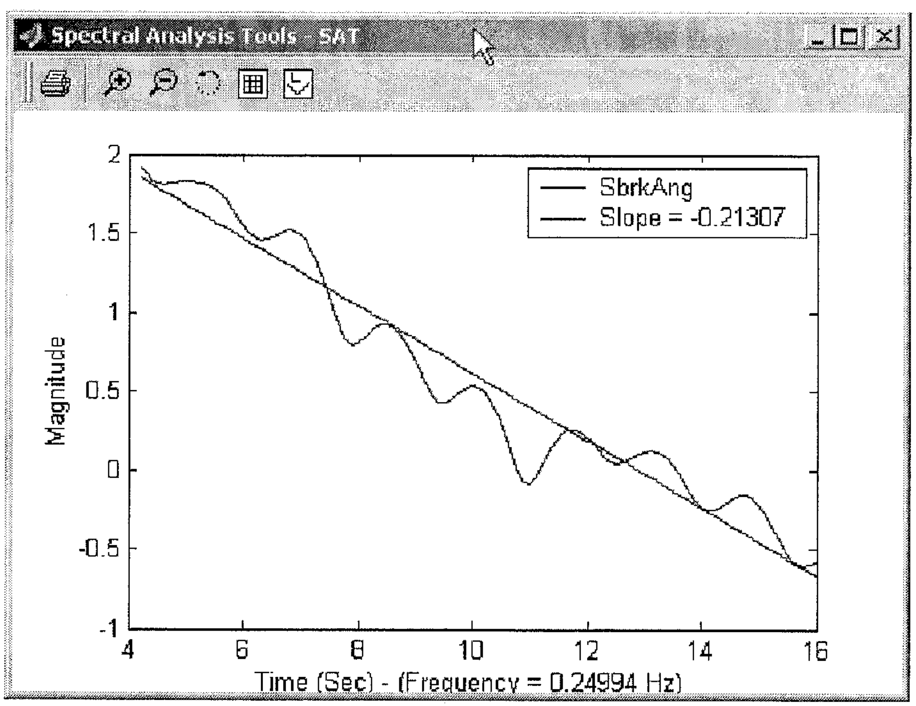


Figure G-5. Superposition of the Linear Approximation (and Slope) on the Log Amplitude of 0.25Hz Component of Seabrook Machine Angle versus Time.