Planning High Voltage Direct Current (HVDC) and Flexible Alternating Current Transmission Systems (FACTS) in New England

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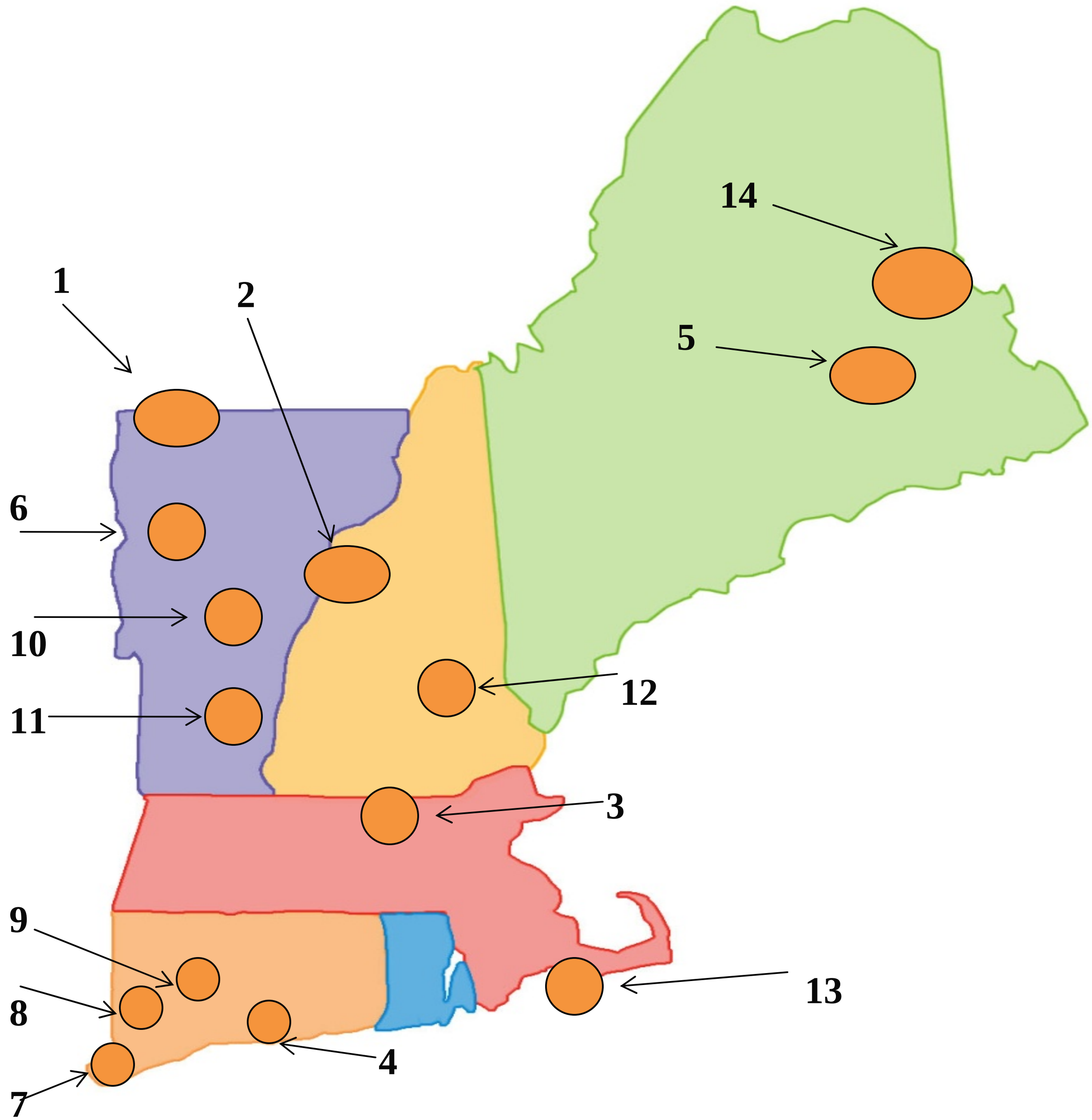
New England's Electric Power Grid at a Glance

- 6.5 million customer meters; population 14 million
- 300+ generators
- 8,000+ miles of high voltage transmission lines
- 12 interconnections to three neighboring systems
  - New York, New Brunswick, Quebec
- 32,000 megawatts (MW) of installed generating capacity
  - Includes 1,951 MW of demand response
- 300+ market participants
- $10 billion annual total energy market value (2007)
- System peak
  - Summer: 28,130 MW (August 2006)
  - Winter: 22,818 MW (January 2004)



EXISTING FACTS

HVDC Facilities

1. Highgate
2. Comerford Phase I
3. Sandy Pond Phase II

VSC HVDC Facility

4. Cross Sound Cable

SVC

5. Chester

STATCOM

6. Essex

7Glenbrook

DVAR

8. Stony Hill (2)
9. Bates Rock

FACTS STUDIES

STATCOM/SVC

10. Granite
11. Coolidge
12. Deerfield
13. Barnstable

TCSC

14. NB-NE Tie

HVDC and FACTS Applications

- Controllable power transfers and frequency modulation between asynchronous control areas
- Controllable power transfers between synchronous control areas
- Dynamic voltage support to mitigate the impact of inter-area power swings
- Dynamic voltage support to mitigate potential local area voltage instability or collapse

Existing HVDC and FACTS

- HVDC Facilities
  - Three (3) Conventional HVDC Facilities
    - Highgate
    - Comerford Phase I (retired)
    - Sandy Pond Phase II
  - One (1) Voltage Source Converter HVDC Facility
    - Cross Sound Cable
- FACTS Controllers
  - One (1) Static VAR Compensator (SVC)
    - Chester
  - Three (3) STATCOMs
    - Essex
    - 2 at Glenbrook
  - Three (3) DVAR
    - 2 at Stony Hill
    - 1 at Bates Rock

Lessons Learned

- Extensive planning studies and adequate modeling of the control systems is required
- Field Tests are necessary to verify the design and performance of the installation
- Shakedown Period is required prior to declaring commercial operation
- System Events should be captured
  - Verify and Update models
  - Revisit Operating Procedures
- Watch System Protection and Control System designs and responses
  - Ensure consistency with desired performance

Compare FACTS with Conventional Solutions

- FACTS Controller Issues
  - High Cost
  - Poor Reliability and Availability
    - Unwanted trips of controllers
      - Multiple controllers could trip for a common contingency
    - Valve failures
    - Maintenance and need for spare parts
  - Operating Issues
- Alternatives
  - Power System Stabilizers
  - Synchronous Condensers
    - Generator clutch technology

Potential FACTS Applications Replaced by Conventional Solutions

- The following potential FACTS applications were considered in New England, but replaced by conventional solutions
  - Three (3) STATCOM/SVC
    - Granite replaced by synchronous condensers
    - Coolidge replaced by “wire in the air”
    - Deerfield replaced by substation improvements and “wire in the air”
  - One (1) Thyristor Controlled Series Compensation (TCSC)
    - New Brunswick – New England Tie replaced with a series capacitor

Potential Future HVDC and FACTS Applications Under Consideration

- Merchant and regulated HVDC lines
  - Several proposals to connect sources of renewable energy in Northern New England and Canada with load centers in Boston and Connecticut areas
- Dynamic voltage support to mitigate potential local area voltage instability or collapse
  - SVC planned for Barnstable
  - SVCs and STATCOMs are considered as viable planning solutions
- Pilot program in place to provide Regulation and Frequency Service will encourage use of flywheel, battery, and other storage technologies

Proposed Renewable and Other Low- and Non-emitting Resources in New England and Eastern Canada

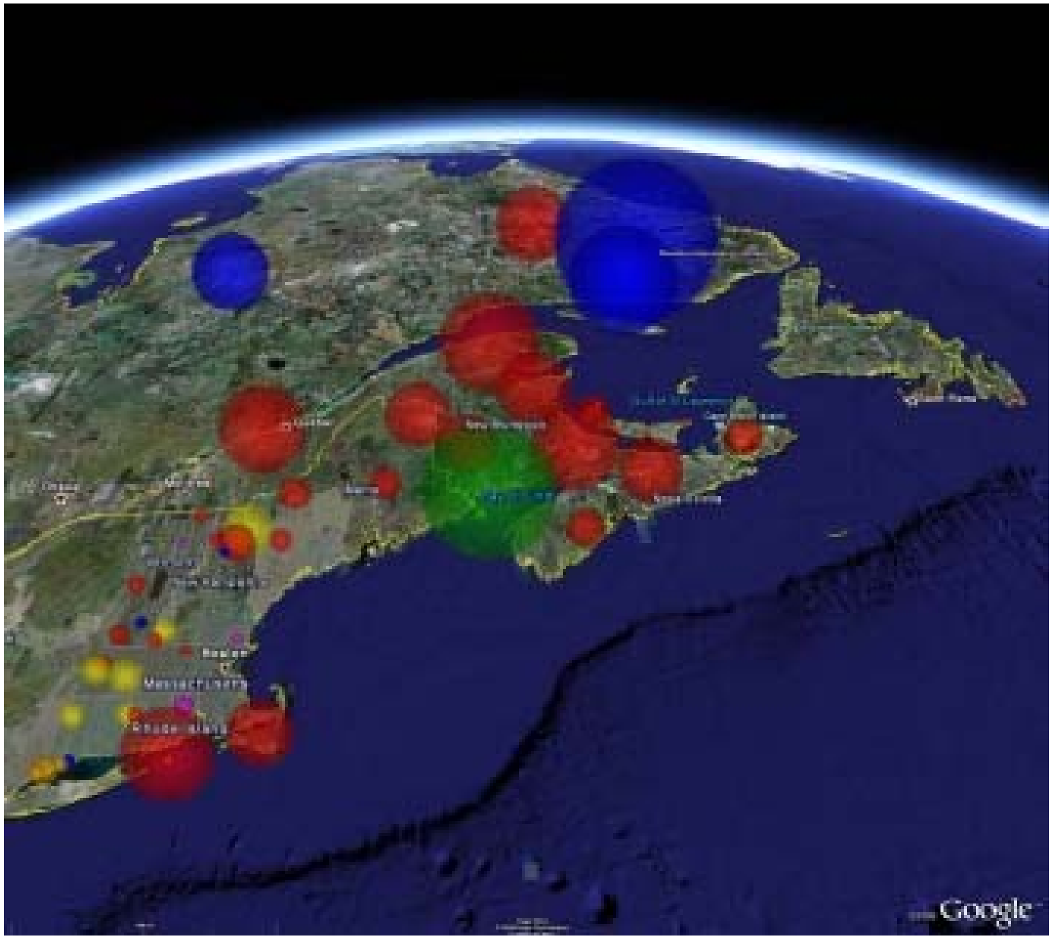
Blue is hydro

Red is wind

Green is nuclear

Yellow is biomass

Orange is fuel cells



Summary

- HVDC and FACTS Controllers have been successfully applied to the New England system
  - Dynamic Stability
  - Voltage Control
  - Asynchronous and Synchronous HVDC interconnections
- Many potential future system needs will likely be met with conventional solutions rather than FACTS
  - Damp Dynamic Oscillations
  - Dynamic Voltage Support
  - Steady State MW Control
- HVDC and FACTS Controllers still have potential applications in New England
  - HVDC is a likely solution to gain access to renewable resources in Northern New England and Canada
  - Shunt FACTS solutions are likely to be realized
  - Few applications of series FACTS controllers anticipated

Appendix

Existing FACTS Controllers

Highgate Back-to-Back HVDC

- Performance Objective
  - Interconnect southern Quebec to northern Vermont to supply northern Vermont load
  - The interconnection between the two control areas must be asynchronous

Highgate Back-to-Back HVDC, *cont.*

- Solution
  - Construction of a 225 MW conventional HVDC back-to-back converter station in Highgate Vermont
  - The Vermont side is weak
    - Highgate has special controls and voltage support provided by switched shunts

Phase II HVDC Project

- Performance Objective
  - Interconnect the LaGrande, Quebec region generation with load centers in southern Quebec and New England
  - The interconnection between the two control areas must be asynchronous

Phase II HVDC Project, *cont.*

- Solution
  - Construction of a conventional multi-terminal direct current transmission system
    - 2,250 MW Radisson converter terminal near LaGrande, Quebec
    - 2,138 MW Nicolet converter terminal near Montreal, Quebec
    - 690 MW Des Canton converter terminal near Montreal, Quebec
    - 690 MW Comerford converter terminal near the Vermont – New Hampshire border
    - 2,000 MW Sandy Pond converter terminal near Boston, Massachusetts
    - 920 mile +/- 450 kV direct current transmission line
  - Also required the installation of the + 450/-125 MVAr Chester SVC to operate the Sandy Pond converter terminal at 2,000 MW

Chester SVC

- Performance Objective
  - Dynamic shunt support stabilizes the system
  - Prior to the addition of the second New Brunswick tie
    - To enable the simultaneous operation of the Sandy Pond Phase II HVDC facility and New Brunswick to New England imports at their full capabilities (2,000 MW and 700 MW respectively), while avoiding the need for New Brunswick generation rejection and/or the tripping of the New Brunswick – New England Tie (Orrington – Keswick 345 kV Section 396), for the loss of Phase II imports
    - These consequences of the loss of Phase II are caused by transient inter-area power swings that result in the apparent impedance of the New Brunswick – New England Tie entering the Keswick GCX SPS characteristic, which will reject generation in New Brunswick, and/or the tripping of the New Brunswick – New England Tie via the operation of the line protection

Chester SVC, *cont.*

- Solution
  - The Chester SVC was selected as the appropriate solution
    - Connected to the New Brunswick – New England Tie approximately 50 miles north of Orrington in Chester, Maine
    - +450/-125 MVAr range provided by three thyristor switched capacitors (TSC), two groups of fixed harmonic filters, and one thyristor controlled reactor
    - The dynamic capability of the Chester SVC prevents the apparent impedance of the New Brunswick – New England Tie from entering the Keswick GCX SPS characteristic, and/or the tripping of the New Brunswick – New England Tie via the operation of the line protection, by regulating the voltage during the transient inter-area power swings

Essex STATCOM

- Performance Objective
  - Significant load growth in Vermont's Burlington area had required generation to be must-run in order to meet first contingency coverage for significant periods of time. The threat of widespread, severe under-voltage and/or voltage collapse had been identified in various operating and planning studies
  - Find an alternative to the current dependence of must-run generation and future reliability risks as load in the area continued to grow

Essex STATCOM, *cont.*

- Solution
  - Fixed compensation to meet additional load in the area would result in an inoperable system
  - Either EHV transmission reinforcement or dynamic reactive compensation options would be adequate to address problem
  - The lower cost of the dynamic reactive compensation option lead to its selection
  - Located at the Essex 115/34.5 kV Substation in Vermont
  - +/- 75 MVAr STATCOM and two 24.75 MVAr capacitor banks
  - Has a master controller for pre-contingency switching of remote shunts (SCADA back-up is available to system operators)

Cross Sound Cable HVDC

- Performance Objective
  - Install a bi-directional merchant transmission interconnection between Long Island, New York and Southern Connecticut
  - Controllability facilitates commercial implementation of merchant transmission facility
    - Transmission rate structure
    - Open season

Cross Sound Cable HVDC, *cont.*

- Solution
  - Approximately 24 mile, 330 MW net, +/- 150 kV Voltage Source Converter (VSC) HVDC Interconnection
  - HVDC submarine cable between the East Shore 345 kV Substation in New Haven, Connecticut and the Shoreham 138 kV Substation in Long Island, New York
  - Tuned CSC away from natural frequencies of local generating units

Glenbrook STATCOM

- Performance Objective
  - Improve the voltage sag response in the Norwalk-Stamford area of Connecticut
  - As a result of a double circuit tower contingency voltages in the area were as low as 30-40% and took 7 to 10 seconds to return to the 90% level
  - Post fault voltage recovery was considerably delayed by the stalling or lock-up of air conditioner compressor motors

Glenbrook STATCOM, *cont.*

- Solution
  - Mechanically switched capacitor banks, upgrading existing transmission lines to a higher voltage level and installation of a FACTS controllers were possible alternatives
  - Without dynamic voltage support, mechanically switched capacitors were found to create an inoperable system, transmission line upgrades would have required total rebuilds
  - FACTS controller was technically and economically the best solution
  - Two +/- 75 MVAr STATCOM and 150 MVAr of mechanically switched capacitor banks
  - Located at the Glenbrook 115 kV Substation in Stamford, Connecticut

Bates Rock & Stony Hill DVAR

- Performance Objective
  - Increase the line-out Southwest Connecticut voltage limit by 100 MW to reliably serve load
  - Complete the installation of the project in less the one year

Bates Rock & Stony Hill DVAR, *cont.*

- Solution
  - Due to the in-service date of the project, alternatives were limited
  - Mechanically switched capacitors without dynamic voltage support resulted in an in operable system
  - Two +/- 8 MVAr DVAR devices and two 37.8 MVAr mechanically switched capacitors, controlled by the DVAR devices, at the Stony Hill 115/13.8 kV Substation
  - One +/- 8 MVAr DVAR device and one 37.8 MVAr mechanically switched capacitors, controlled by the DVAR device, at the Bates Rock 115/13.8 kV Substation

FACTS Controllers Studies

Northwest Vermont Reliability Project

- Performance Objective
  - To reliably serve the future northwest Vermont load requirements
  - The Northwest Vermont Reliability Project was determined to be the optimum solution that included several transmission upgrades. The major upgrades originally considered the following, including a FACTS controller connected to the 115 kV system
    - 345 kV line from West Rutland to New Haven
    - 115 kV line from New Haven to Queen City
    - 230 kV line from Granite to Middlesex
    - 230 kV Phase Angle Regulator (PAR) at Granite
    - 115 kV PAR at Blissville
    - +/- 150 MVAr FACTS controller (STATCOM/SVC) at Granite 115 kV substation

Northwest Vermont Reliability Project, *cont.*

- Solution
  - Mechanically switched capacitors resulted in an inoperable system
  - +/- 150 MVAr FACTS controller replaced by Synchronous Condensers due to performance concerns
    - Vermont is a relatively small, weak system with three current operational FACTS controllers, Essex +/- 75 MVAr STATCOM, Highgate HVDC, and Comerford Phase I HVDC
    - Instantaneous phase change results in undesired STATCOM block, such as commutation failures of HVDC facilities
    - Critical station service may trip at less severe voltage characteristic than FACTS controllers, resulting in loss of FACTS controllers
    - Replacement parts in the future

Monadnock Region Reliability Project

- Performance Objective
  - To reliably serve the future southeast Vermont/southwest New Hampshire/north central Massachusetts area load requirements, relieve the need for local under voltage load shedding schemes
  - The Monadnock region Reliability Project was determined to be the optimum solution, that included substantial upgrades to the area's transmission system. The major upgrades consist of the following, originally including a FACTS Controller
    - Construction of a new 345/115 kV Substation in Fitzwilliam, New Hampshire
    - Substantial thermal upgrades, including over 120 miles of 115 kV transmission line rebuild or re-conductoring
    - +/- 75 MVAr FACTS Controller (STATCOM/SVC) at Coolidge

Monadnock Region Reliability Project, *cont.*

- Potential Solution
  - Mechanically switched capacitors resulted in an inoperable system
  - +/- 75 MVAr FACTS Controller replaced by transmission facilities due to performance issues
    - “Wire in the air” resulted in better performance
    - Vermont is a relatively small, weak system with three current operational FACTS controllers, Essex +/- 75 MVAr STATCOM, Highgate HVDC, and Comerford Phase I HVDC
    - Instantaneous phase change results in undesired STATCOM block, such as commutation failures of HVDC facilities
    - Critical station service may trip at less severe voltage characteristic than FACTS controllers, resulting in loss of FACTS controllers
    - Replacement parts in the future

Deerfield FACTS Controllers

- Performance Objective
  - Increase the Maine - New Hampshire Interface transfer limit
  - Simplify the operational complexities of the interface
  - Reduce the interdependencies of generation dispatch on the interface
  - Under different conditions, the interface can be limited by thermal, voltage or stability performance

Deerfield FACTS Controllers, *cont.*

- Potential Solution
  - Combinations of potential solutions included
    - Substation modifications to eliminate limiting stuck breaker contingencies and strengthen the transmission system
    - Build additional 345 kV transmission circuits and add shunt capacitors
    - Installation of an approximately 500 MVAr STATCOM/SVC at the Deerfield 345 kV Substation
  - The addition of a large dynamic device was shown not to be required

New Brunswick – New England Tie TCSC

- Performance Objective
  - Mitigate transient inter-area power swings that can result in generation rejection in New Brunswick, or Islanding of the Maritimes
    - Design Contingencies in New England can result in the apparent impedance of the New Brunswick – New England Tie entering the Keswick GCX SPS characteristic. This requires New England transfer reductions or New England system upgrades to prevent
    - Three-phase stuck breaker Extreme Contingencies in New England can result in large source losses that are compounded by generation rejection in New Brunswick, or Islanding of the Maritimes
    - Source losses that are compounded by generation rejection in New Brunswick, or Islanding of the Maritimes require facilities in New England to be built to, or upgraded to meet Bulk Power System criteria

New Brunswick – New England Tie
No TCSC

- Solution
  - Northeast Reliability Interconnect Project (NRI) mitigates transient inter-area power swings that can result in generation rejection in New Brunswick, or Islanding of the Maritimes
    - Currently in service
  - The following alternatives feasibilities were assessed
    - Additional STATCOM/SVC to compliment the Chester SVC's ability to dynamically control voltage demonstrated marginal benefit
    - Series compensation on the NRI was shown to have reliable performance without TCSC

HVDC Projects Under Consideration

Suggestions by Participants

- FPL Energy
  - Interconnect resource-rich areas north of Boston to the critical load centers in Boston and Cape Cod
- New England Independent Transmission Company, LLC
  - Study regional benefits of increased transmission capacity between northern Maine and the Northeast Massachusetts (NEMA) market
- NSTAR
  - Supports NU's request to study to review north-south transfers
  - Requests separate study of injecting a conceptual 600 MW or 1,200 MW source in the north into Boston and, alternatively, into Cape Cod
- MMWEC
  - Consider source that would resolve Reliability Must Run (RMR) issues in Southeast Massachusetts (SEMA)

Suggestions by Participants, *cont.*

- Northeast Utilities
  - Increase the North-South (Vermont and New Hampshire into Massachusetts) New England transfer capability by 1,500 MW to 2,500 MW. New supply resources include new HVDC to Canada and renewable development in New Hampshire. Build reliability upgrades in Maine, New Hampshire and Vermont
- UI, CMEEC, and MMWEC proposal is a multifaceted study
  - Comprehensive proposal to build HVDC from New Brunswick and Maine to SEMA and SWCT
- Bangor Hydro and National Grid
  - Interconnect NEMA/Boston and/or SEMA and SWCT with resources in Northern Maine, New Brunswick and others in Atlantic Canada

Transmission Projects to Maintain Reliability are Progressing

1. Southwest Connecticut Phase I
2. Southwest Connecticut Phase II
3. NSTAR 345 kV Project
    a. Phase I
    b. Phase II
4. Northwest Vermont Reliability Project
5. Northeast Reliability Interconnect
6. Monadnock Area
7. New England East-West Solutions
    a. Greater Rhode Island
    b. Springfield 115 kV Reinforcements
    c. Central Connecticut
    d. Interstate
8. Southeast Massachusetts
9. Maine Power Reliability Program
10. 1385 Replacement
11. Vermont Southern Loop