The Hydro-Québec Transmission System: Origins and Current Issues

Information and Discussion Meeting

March 31, 2017
Presentation outline

1. Present
2. Evolution
3. Current issues
Present: some numbers

- **Vast and exceptionally complex system**
  - 11,691 km of 735-kV and 765-kV lines
  - 60 Hz not synchronized with Eastern Interconnection

- **Demand**
  - Record peak demand of 39,240 MW (January 22, 2014 at 7:26 a.m.)
  - 85% of load concentrated in southern Quebec

- **Power to be transmitted**
  - About 47 GW
  - 85% of generation in northern Quebec

- **Assets: $19.2 billion**
  - $18.1 billion in lines and substations
    - 34,020 km of lines
    - 525 substations, including 40 735-kV or 765-kV substations
  - $1.1 billion in other assets
Present: a complex system

- Remote generating stations (1,000 km)
  - Design of reliable system at lowest cost
  - Main constraint: stability
    (voltage and transient)
- Development of 735-kV AC system
  - 2 major corridors
  - Very fast-acting protection systems
  - Static excitation systems
  - Power stabilizers
  - Dynamic shunt compensation (9 + 14)
  - Series compensation (44)
  - Special protection systems
- Interconnections:
  - Synchronous: islanded equipment or loads, variable frequency transformer
  - Asynchronous: HVDC, DC line
Present: regulatory context

  - Sets or modifies OATT
  - Authorizes acquisition, construction or disposal of power transmission assets
  - Approves technical requirements and adopts reliability standards

- **North American Electric Reliability Corporation (NERC)**
  - Sets operating and planning criteria to ensure reliable operation of power systems
  - Develops and enforces reliability standards

- **Northeast Power Coordination Council (NPCC) (1998)**
  - Sets reliability criteria for Northeastern North America
Presentation outline

1. Present
2. Evolution
3. Current issues
1950s: transmission pioneer

- Construction of Bersimis-1 and Bersimis-2 generating stations (1,970 MW)
- Three 315-kV double-circuit lines from Bersimis to Québec and Montréal (~500 km)
1960s and 1970s: adding generation capacity

- Development of Manicouagan, Outardes and Churchill-Falls complexes (11,222 MW) (1965-1978)
  - Manic-2 (1,024 MW) in 1965
  - Manic-1 (184 MW) in 1966
  - Outardes-3 (756 MW) in 1969
  - Outardes-4 (630 MW) in 1969
  - Manic-5 (1,528 MW) in 1970
  - Churchill (5,429 MW) in 1971
  - Manic-3 (1,244 MW) in 1975
  - Outardes-2 (427 MW) in 1978
1960s: choosing 735 kV

- Choosing 735-kV technology for the implementation of the transmission system
  - Technically optimal solution (number of lines, distance and feasibility)
  - Challenges
    - No equipment available; prototype under study
    - Sizing of towers and equipment
    - Electrical phenomena (e.g. switching surges and corona effect)
    - Voltage control
  - First 735-kV line commissioned in 1965 (Manic–Lévis)
- Fixed reactors (associated with lines)
- Synchronous compensators used for dynamic voltage control
1970s: mastering 735 kV

- Continued use of 735-kV technology with shunt compensation
- Use of static excitation and power system stabilizer (PSS)
- Addition of circuit breakers on reactors
  - Independence of lines
  - Increased power flow
  - Enhanced voltage control
1980s: even more generation capacity

- Development of phase 1 of La Grande (10,813 MW) (1979–1986)
1980s: investing in 735 kV

- Construction of 735-kV corridors to La Grande
- Installation of static VAR compensators (SVC) (11)
- Completion of Montréal loop
1980s: growth of interconnections

- 1984: Châteauguay, back-to-back unit linked to New-York (1,000 W)
- 1985: Madawaska, back-to-back unit linked to New Brunswick (350 MW)
- 1985: Highgate, back-to-back unit linked to Vermont (225 MW)
- 1986: Des Cantons and Comerford, DC line to New England (690 MW)
- 1990: Radisson–Sandy Pond, DC line to New England (2,000 MW)
1980s: growth of interconnections

- Multi-terminal DC system (MTDCS)
  - 450-kV DC
  - Des Cantons–Comerford
  - Radisson–Nicolet–Sandy-Pond
  - 2,000-MW capacity
  - Islandable generation facility (La Grande-2-A)
  - Transmission line and interconnection
1980s: unfinished business

- Introduction of higher voltage: 1,100 kV
- Completion of DC system connecting La Grande complex
- Installation of series compensation
### Dem.

<table>
<thead>
<tr>
<th>Decade</th>
<th>Demand Growth Rate</th>
<th>1950s</th>
<th>1960s</th>
<th>1970s</th>
<th>1980s</th>
<th>1990s</th>
<th>2000s</th>
<th>2010s</th>
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<td>10%/yr</td>
<td>5,000 MW</td>
<td>25,000 MW</td>
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<td>39,000 MW</td>
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<td>South: ~200 MW/yr</td>
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### Transmission

- **315 kV**
  - Fixed XL
  - SC
  - XL CB

- **735 kV (65) Manic-CHU**
  - HVDC
  - St. exc. and stab.

- **450 kV DC**
  - UFLS

### Generation

- **B1/B2** 1,970 MW
- **Manic–Outardes** 5,793 MW (65-78)
- **LG-ϕ1 (79-86)** 10,813 MW
- **Churchill-Falls** 5,429 MW (71)
- **G2 (83)** 600 MW

### Interchanges

- Isolated units
  - Eel River (72) 350 MW
- CHA-MAD-HG (84-85) 1,575 MW
- MTDCS (86-90) 2,000 MW

### Events

### Reliability

- Baie-James corridors
- HVDC
- 450 kV DC
- UFLS
1980s: major shift

- **14/12/1982**
  - Equipment failure at Lévis substation

- **18/04/1988**
  - Wet snow

- **13/03/1989**
  - Geomagnetic storm
<table>
<thead>
<tr>
<th>Year</th>
<th>Generation (MW)</th>
<th>Interchanges</th>
<th>Transmission</th>
<th>Reliability</th>
<th>Events</th>
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<tbody>
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<td>1950s</td>
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<td>Fixed XL CS XL CB</td>
<td>1969-1989 11 general/20 major outages</td>
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1980s: reliability review

- Full compliance with NPCC standards
- System reinforcement
- Improving voltage control
- Revising design principles for exceptional events: remedial action scheme (special protection systems)
- Enhancing system resilience under geomagnetic storm conditions
- Allowing for future development
1990s: improving reliability

- **Connections**
  - La Grande Phase 2, Manic-5-PA
  - 6th Baie-James line (1994)

- **Transmission system reliability enhancement (AFRT)**
  - $1.3 billion (1989)
  - Addition of series compensation (1st in 1991)
  - Blocking capacitor
  - 2 SVC (Chamouchouane)
1990s: improving reliability

<table>
<thead>
<tr>
<th>EVENT FREQUENCY</th>
<th>OBJECTIVES</th>
<th>ALLOWED MEANS</th>
<th>RESULTS</th>
</tr>
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<tbody>
<tr>
<td>FREQUENT</td>
<td>SERVICE CONTINUITY</td>
<td>Intrinsic robustness of the system, Major features of equipment</td>
<td>NO LOSS OF LOAD</td>
</tr>
<tr>
<td>VERY RARE</td>
<td>SYSTEM INTEGRITY</td>
<td>Special protection systems, Special operating procedures</td>
<td>POSSIBILITY OF PARTIAL OUTAGE WITH QUICK RESTORATION</td>
</tr>
<tr>
<td>EXCEPTIONAL</td>
<td>EQUIPMENT SAFETY</td>
<td>Special features of equipment, Control systems, Restoration, Blackstart capability, Internal emergency plan</td>
<td>RISK OF GENERAL OUTAGE WITH QUICK RESTORATION</td>
</tr>
</tbody>
</table>

INCREASING SEVERITY OF EVENTS

FIRST LINE OF DEFENSE
SECOND LINE OF DEFENSE
THIRD LINE OF DEFENSE

ELECTRICAL INTEGRITY OF SYSTEM
1990s: improving reliability

- Remedial action scheme (special protection systems)
  - System sensitive to multiple line losses
  - Generation rejection and remote load shedding to protect system against extreme events. Detection system in 15 735-kV substations (GRRLS)
  - Undervoltage load shedding (UVRLS)
  - Automatic tripping of 735-kV reactors (ASRS)
  - Generalization of underfrequency load shedding (UFLS)
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**Events:**

- **1969-1989**: 11 general/20 major outages

**Transmission Systems:**

- 315 kV
- 735 kV (65) Manic-CHU
- Fixed XL CS
- XL CB
- HVDC
- Stat. exc. and stab.
- 450 kV DC
- UFLS
- SSRP
- GRRLS JVRLS

**Reliability Review:**

- Reliability review
- Obj.: NPCC compliance
- HQ criteria
- Remedial action scheme
- AFRT (89)

**N-1 Province (~1,500 MW)**: NPCC (98)

**N-1 Interconnection**
1998–2012: Series compensation (CXC) and securement

- **Connections**
  - Over 3,300 MW from HQP
  - 1,000 MW from wind farms in Gaspésie
  - Continued use of series compensation (CXC)
  - VFT, Outaouais

- **Reliability**
  - Post-ice-storm securement: Lévis de-icing system, CAN-MTGIÉ-HER
  - System upgrade (2012): load leveling and voltage sensitivity

- **Long-term operability**
  - System aging: new issue to factor in gradually

- **Regulatory context**
  - NERC (Ohio outage, tree, training, tools)
2012–2021: structuring choices

- **Connections**
  - Romaine complex (1,550 MW)
  - Reaching 4 GW wind energy target

- **Transmission**
  - 735-kV line between Chamouchouane and Montréal: structural bias
  - Interconnections (NPT, CHPE)

- **Innovation: commissioning of IREQ products**
  - Wide-area and local shunt compensator control
  - Power system instability detection
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<td>1990s</td>
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<td>Hydro (94-10) 3,300 MW</td>
<td>TFV (04) 100 MW</td>
<td>400 kV DC Ug</td>
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<td>OUT (09) 1,200 MW</td>
<td>CXC addition MPBSS</td>
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<td>ROX (12-21) 1,550 MW</td>
<td>Wind (00-17) 4,000 MW</td>
<td>VSC</td>
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<td>GRRLS UVRLS</td>
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Interchanges:
- Isolated units
- Eel River (72) 350 MW
- CHA-MAD-HG (84-85) 1,575 MW
- MTDCS (86-90) 2,000 MW
- TFV (04) 100 MW
- OUT (09) 1,200 MW
- NPT, CHPE...

Transmission:
- 315 kV
- 735 kV (65) Manic-CHU
- 450 kV DC
- CXC (91) MBPSS
- GRRLS UVRLS

Reliability:
- Reliability review Objective: NPCC compliance
- HQ criteria
- V sensitivity
- Except. peak
- Remedial action sch.
- Securement
- Standard watch/benchmarking
- Connection Req.
- N1 Province (~1,500 MW)
- N1 Interconnection

Events:
- 1969-1989 11 general/20 major outages
- 1998 ice storm
- 2003 Ohio
Presentation outline

1. Now
2. Evolution
3. Current issues
Current issues

- Fluctuation of mining load (e.g. Abitibi)
- Load growth in south
  - 250 MW per year in Montréal and interconnection(s)
- Loss of generation and reserve in south
  - Closure of generating stations
    - Gentilly-2 (2012)
    - La Citérie (2012)
    - Tracy (2011)
- Load reduction in northeast
  - Closure of industries in northeast
- Generation capacity increase in Côte-Nord region
Current issues

• Aging equipment
  – Capital spending level and smoothing
  – Control and monitoring (e.g. HVDC, CXC and SVC)
  – Equipment (transformers, lines, etc.)

• System loading
  – Outage
  – Maintenance
  – Projects
Current issues

- **Project implementation**
  - Meeting demand in timely fashion
  - Cost-effectiveness
  - Environmental acceptability
  - Favorable reception by host communities

- **Variability of quantities**
  - Load (decentralized generation? batteries?)
  - Wind power (Volume? Integration mode MW/MWh)
  - Interchange (volume, nature of contracts)
Opportunities

• **Highly diversified toolbox**
  - Classic: lines, CXC, SVC…
  - Innovative: control systems, wide-area control…
  - Must pay attention to implementation time: in time to contribute to reliability

• **Continuing R&D**
  - Switch to smart power grid "2.0"
  - Batteries
  - Frequency response of loads
Demand
- Quantities: Transmission/Energy efficiency/Negawatts?
- Nature: MW vs. MWh
- Controllability: smart loads/batteries/water heaters

Generation
- Continued development of wind power? Solar? Biomass?
- Big Hydro?

Interconnections
- NPT, CHPE...
- USA/Canada energy transition

Transmission
- Aging system
- Maintenance of 735-kV/CXC technologies
- SVC long-term operability
- CXC long-term operability
- HVDC long-term operability
- VSC
- WALCC
- Corridors or DC system?
- Long-term operability/Redesign of control and protection systems

Reliability
- Set reliability level so as to maintain supply quality
- Watch/Adaptation

Events
- Questions
Irreversible aggregation

- **System development incentives**
  - Growth (generation, interchanges)
  - Reliability (lessons learned, monitoring, best practices, knowledge)
  - Long-term operability of equipment (risk analysis)

- **Main dimensions of system development**
  - Technical
  - Economic
  - Environmental
  - Social
  - Regulatory
Conclusions

• Well positioned to contribute to the energy transition reliably and cost-effectively
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>AC</td>
<td>Alternating Current</td>
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<tr>
<td>AFRT</td>
<td>“Amélioration de la Fiabilité du Réseau de Transport” [transmission system reliability enhancement] program</td>
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<td>ASRS</td>
<td>Automatic Shunt Reactor Switching</td>
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<td>CB</td>
<td>Circuit Breaker</td>
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<td>CHPE</td>
<td>Champlain Hudson Power Express</td>
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<td>CXC</td>
<td>Series Compensation</td>
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<td>DC</td>
<td>Direct Current</td>
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<td>GRRLS</td>
<td>Generation Rejection and Remote Load Shedding</td>
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<td>HQ</td>
<td>Hydro-Québec</td>
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<td>HVDC</td>
<td>High-Voltage Direct Current</td>
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<td>MBPSS</td>
<td>Multi-Band Power System Stabilizer</td>
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<td>MTDCS</td>
<td>Multi-terminal DC system</td>
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<td>NERC</td>
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<td>Northeast Power Coordination Council</td>
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<td>NPT</td>
<td>Northern Pass Transmission</td>
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<td>OATT</td>
<td>Open Access Transmission Tariff</td>
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<td>PSID</td>
<td>Power System Instability Detection</td>
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<td>Power System Stabilizer</td>
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<td>System Separation Problem Resolution</td>
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