Bipole III: Past, Present and Future

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Outline

• Introduction
• Early Planning Studies
• Bipole III Need
• Bipole III Project Scope
• Bipole III Future
• Video
• Q&A
Manitoba Hydro

- Crown Corporation (owned by Prov. MB) with head office at Winnipeg.
- Services for over 580,000 electricity and 280,000 gas customers.
- A total generating capacity about 5700 MW produced mainly by 15 hydroelectric stations, 2 wind plants and 2 thermal stations.

https://www.manitobahydropower.com/who-we-are/
Current Hydro sites: 5228 MW
Under development (Keeyask) 695 MW
Potential 4300 MW
Interconnections

- B71T - Birtle to Tantallon 2021
- D604I – Dorsey to Iron Range 2020 (MMTP/GNTL)
**Firm Export/Import Capability**


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<th>Export</th>
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<tr>
<td>U.S.*</td>
<td>1950 MW</td>
<td>700 MW</td>
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<td>2833 MW</td>
<td>1398 MW</td>
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<td>Ontario</td>
<td>200 MW</td>
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<tr>
<td>Sask-south</td>
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<td>0 MW</td>
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<td></td>
<td>290 MW</td>
<td>0 MW</td>
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<td>Sask-north</td>
<td>25 MW</td>
<td>60 MW</td>
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* Excludes 150 MW CRSG
Early Planning Studies
1960’s

• 1963 – Government of Canada/Manitoba shared cost of study looking at development of the Nelson River.
• 1966 – Agreed to jointly develop Phase 1 – “Birth of HVDC in Manitoba”
• Phase 1 – 1272 MW Kettle (ISD 1974), two 900 km HVDC lines, Bipole I (ISD June 1972),
AC vs DC Decision

- 500 kV AC with 70% series compensation was compared with HVDC. Series comp had about 15 years of history.
- HVDC selected – lower cost, lower losses and better performance.
- Four bids – one mercury arc only, two thyristor only and one mercury arc and thyristor. ASEA’s first thyristor project (30 MW) only went into service in 1970.
- IEEE Milestone in EE – At 150 kV, they were largest mercury arc valves ever developed.

1970s Projections

- High load growth projected need for Bipole III as early as 1988.
- A nuclear engineering department was formed in 1974.

1980’s

• Load growth slowed
• Completed development of Bipole II in June 1985.
• 2000 MW, 500 kV thyristor technology
• Long Spruce completed 1979.
• Limestone’s original target year was 1983 – deferred to 1990.

Early 1990s

- Potential for a 1000 MW to sale to Ontario moved up the schedule for Bipole III and Conawapa.
Features of the Bipole I and II System

- Link to 70% of the Province’s generating capacity
- Bipole I and II HVdc lines constructed on the same Right-of-way
- 900km overhead lines, difficult terrain and access in the north
- Terminated at a common station – Dorsey (inverter)
- Highest percentage of power concentrated in a single facility - “Too many eggs in one basket”
External Asynchronous Resource (EAR)

• Bipoles I and II allows for hydro to look like a battery. Allows for hydro-wind synergy. Very fast ramping capability.
• EAR is a market-designated resource separated from the main MISO market by a DC tie.
• EAR is very flexible and can provide energy, spinning, supplemental regulating reserves, regulation, ramp products, capacity.
• Currently, EAR is bidirectional and limited to 375 MW. Available since ~2010.
Bipole III Need
Why is Bipole III required now?

• Bipole III is required for reliability
  • Bipole I & II DC transmission line corridor loss
  • Only one southern converter station (Dorsey)
  • Long restoration times

• We’ve experienced loss of corridor before and near misses (downbursts, ice, forest fires and etc.).
  • Real risks, not theoretical
Reliability Risk – Sept. 5th 1996 Wind Event
1.5 miles away from Dorsey Converter Station

- Public appeal for power reduction
- All generation units on maintenance returned to service
- Rotating blackout planned
Reliability Risk – Dorsey Converter Station

- Dorsey is a single terminus point for HVDC system
- Significant weather events (tornados, etc.) in the vicinity of Dorsey in the past
- A complete loss at Dorsey could mean loss of connection to northern generation for up to 3 years.
Manitoba Hydro has worked closely with field experts/consultants to evaluate weather hazards (Tornados, wide front wind, ice) and other risks of losing the HVDC system after the 1996 event.

<table>
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<th>Events</th>
<th>Return Period of Failure (years)</th>
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<td>Pre-Bipole III</td>
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<tr>
<td>Tornados</td>
<td>17</td>
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<tr>
<td>Synoptic Wind (wide front)</td>
<td>90</td>
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<tr>
<td>Combined Wind and Ice</td>
<td>20</td>
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Deterministic Analysis – Supply Deficit

- Manitoba Hydro assesses the reliability risk of low-probability high-impact events according to NERC Standard TPL-001
- Supply deficit of about 1400MW for the loss of existing Bipole I/II system in the winter of 2017 (pre-Bipole III).
Additional Benefits of BPIII

- Aging BP I and BPII converters (>30 years in service) require life extension upgrades: $1B.
- BPIII offers adequate DC transmission spare to facilitate & optimize BPI/II refurbishment and save outage costs.
- Reduce HVDC transmission loss: about 80MW
- Provide HVdc capacity for future renewable energy development
2000’s

• 2001: Internal report recommends:
  – Building 800 km East side HVdc line by 2010
  – Bipole I and II lines would be paralleled on BP I. Bipole III line would terminate at Dorsey on BP II.

• In 2005, East side becomes unavailable as an application to designate area as a UNESCO world heritage site in progress.

• Decision made in 2007 to proceed with Western route. New DC converters added to scope as impedance of 1388 km route expected to be difficult for Bipole II analog controls.
Bipole III Project Scope
Bipole III Planning Studies

- Power flow studies
- Fault studies
- Stability studies
- Ac and DC harmonic studies
- Small signal stability assessment
- Feasibility studies of VSC technology
Outcome of Bipole III Planning Studies

- Determine BPIII size and operation modes
- Ac system reinforcement for integration of BPIII (new lines/stations, location, upgrades, etc.)
- Static/dynamic reactive power requirements
- Determine equipment rating (breakers, switches, grounding and etc.)
- Estimation of ESCR and MIESCR for dc performance and determine mitigation
- Determine impact on the nearby systems (ac and dc in multi-infeed schemes)
- Determine special requirements (supplementary damping /fast dc reductions)
Feasibility Study - VSC Option

• No synchronous condensers
  - Cost savings: Capital/O&M
  - Reduce system fault levels
  - VSCs can provide voltage and reactive power support, but not inertia that synchronous condensers do

• No commutation failure
  - Large infeed of HVdc schemes in proximity: If all LCC links fail commutation at the same time, it can lead to potential (although very short) loss of significant power to southern system.
  - VSC improves this situation by not failing commutation and ability to maintain power flow.
Feasibility Study - VSC Option

**Disadvantages**
- Not implemented at 500 kV and 2300 MW; Skagarak 4 planned for 2014
- Limited number of vendors
- Dc fault clearing requires ac breakers (half bridge technology)
- Converter losses slightly 1% vs 0.7%

**Decision**
- Permit VSC bids as an option
- Included price break as 4x250 MVAr synchronous condensers not required.
- Required dc faults to be cleared on dc side (full bridge or dc breaker needed).
Bipole III Project Scope - ISD 2018
LCC, ±500 kV, 2000 MW
Locations of BPIII Converters

- **Rectifier KCS**: The location is physically separated from existing Bipole I and II converter facilities at Radisson and Henday stations.
- **Inverter RCS**: about 40km away from Dorsey Station.
- **Considerations of separation to eliminate the common mode failure**
Bipole III Project Implementation

**Turnkey Contracts:**
- Keewatinohk and Riel converter stations & HVDC equipment (> $800M)
- Keewatinohk ac switchyard (~ $112M)
- 4x250MVar, Riel Synchronous Condensers (> $200M)

**Managed by MH:**
- 1388 km transmission line
- AC system upgrades (north/south)
- Other interface components
Project Scope - Converter Stations

• LCC technology with Direct-light Triggered Thyristor (LTT)
• High levels of availability & reliability
  – Two series connected 12-pulse valve groups (VG) per pole
  – Physical separation of valve group & pole controls on a per-pole basis
• -50C to +40C outdoor equipment design
Project Scope - Converter Stations

- Nominal power transfer capacity of 2000 MW with 115% continuous overload
- Transient overload capability of 1.27pu for damping purposes
- Reduced (0.8 pu) dc voltage operation for forest fires conditions.
- De-icing operation: 2 poles transmit power in opposite directions (P6 in forward & P5 in reverse) to allow high DC current flow for melting ice on the HVdc line
- Paralleling with BPII – control capability tested
- Up to 80Hz frequency excursions at the rectifier – permits HVDC reduction
DC reduction

- Monitors status of key components of 500 kV tie lines
- Monitors pre-contingency MW flow at key locations
- Calculates dc reduction required
- Changes power order at rectifier of each Bipole
- Total time delay around 50-100 ms. Modelled as 200 ms
Project Scope - Converter Stations

• Total of 20 converter transformers including spare units
• Controlled switching for energizing two parallel converter transformers (3-phase 5-limb): Pre-insertion resistors at Rectifier and Point-on-Wave (POW) controllers at Inverter (world first!).
• Both POW and PIR can meet the requirements of mitigating transient inrush (typically less than 0.1pu, 1.5 kA base)
• Controlled switching reduced inrush current such that they could be released for operation in 2 minutes rather than 10 minutes.
Field Commissioning & Results

Riel CS Operation: Optimal Scenario

Inrush current: 0.023, 0.02 & -0.018
Project Scope - Converter Stations

- Highly flexible operation modes (bipolar, monopolar ground return, monopolar metallic return, combinations of different VGs) achieved with dc yard design

![Diagram of Converter Station with labels for MRTB (1), GRTB (1), NBGS (2), NBS (4), ELTS (1), BPS (8)]
Project Scope - Converter Stations

- DC switchyard
- DC filter banks (multi-turned, N-1)
- Smoothing reactors (two individual units for redundancy)
Project Scope - Converter Stations

- 230 kV Air Insulated Switchyard (AIS)
- New 230 kV bays & apparatus at KCS
- Expansion of 230kV yard at RCS
- Four AC filter banks at each station (with controlled switching)
Project Scope - Riel Synchronous Condensers

- Four +250/-125 MVAr synchronous condensers; hydrogen cooled.
- Each synchronous condenser requires a unit transformer.
- Provide voltage, reactive support, and system inertia: critical for HVDC operation in Manitoba’s southern weak ac system.
- Minimum MIESCR of 2.5 at Riel.
- Multi-infeed Effective Short Circuit Ratio (MIESCR) – considers the closeness of converters via an impact factor. If the inverters are on the same bus, the factor is 1; if they are infinitely far away the factor is 0.
Project Scope – HVdc Line

- 1388km, 500KV overhead
- Self-supporting and guyed towers
- Base reliability level of 150 year return period for weather loads and increased to 500 year return design at some sections
- Anti-cascading towers (every 5-10 km)
Project Scope – HVdc Line

• 3-bundle Configuration vs. 2-bundle of existing Bipole I&II lines
• Conductor surface gradient less than 23kV/cm.
  • Bipole II is 28 kV/cm. Reduced noise, corona loss and hopefully reduced risk of anomalous (pseudo-random fair weather on negative pole) flashovers.
• OPGW for Lightning protection and communication; 4 repeater stations
Project Scope – AC System Upgrades

• Five new 230kV ac lines (north) and sectionalization of one 230kV ac line in the south
• Upgrades of two existing ac stations for line terminations
• Breaker upgrades at various stations due to fault level increases
**BPIII Replica C&P HIL Testing**

**Model Improvements**
- In-house Bipole I&II model
- Freq-Dependent TLine
- Transformer saturation & OLTC
- 55 µs time-step; 6 racks
- MH SPS & supplementary controls
- HVDC reduction allocator, 500 kV SPTR
- Custom SC exciter & JVC
- MH & US ac dynamic equivalent

**Diagram Details**
- Bipole I, Bipole II, Bipole III
- LIMESTONE 1260MW
- KETTLE 1224MW
- LONG SPRUCE 980MW
- FORBES
- CHISAGO
- DORSEY
- RIEL
- RADISSON
- KEEWATINOHK
- Reduced MH
- Southern AC System
- Existing
- Reduced AC System

**Real-time simulation**
- RTDS (PB5)
Bipole III Project Timeline

• EIS was filed in 2011 for western route and Environmental License was received in August 2013.

• Various RFP packages were released after 2013.

• Line construction started in 2013.

• Converter contract was released and awarded in 2014. Both VSC and LCC were considered in the HVDC converter station tendering process – only LCC bids received.

• System commissioning tests in 2018 (4 months, ~250 tests, ~400 transformer energizations, 5 staged faults with drone/pendulum)

• ISD of July 2018
Bipole III Future
Business as Usual

• Conawapa will utilize Bipole I-III. Full 2300 MW rating of Bipole III will be utilized (6x250 MVAR syncs). Maintain a minimum valve group spare above generation.
• Statcom with or without energy storage will be considered instead of syncs.
• After Conawapa, northern generation will be integrated using new north south 230 kV and 500 kV ac.
• Bipole IV (LCC or half-bridge VSC) not permitted.
With BPIII VSC taps (full bridge)

- Stage 1 – Integrate 680 MW Burntwood River; 700 MW VSC near Thompson plus new collector system (370 km)
- Stage 2 – Integrate 500 MW of Upper Nelson generation; 500 MW parallel VSC tap at Thompson and 500 MW tap at Brandon
With BPIII VSC taps

- Stage 3 – Integrate 1130 MW Conawapa plant; 700 MW parallel VSC tap at Brandon; Conawapa connects to Riel via east side Bipole. Salvage and relocate DC lines. End up with a 1200 VSC point to point link to Brandon and a 2000 MW LCC link between NCS and Winnipeg, which creates three north-south corridors.
Summary

• Bipole III has a long history!
• Bipole III is a large investment ($B) by Manitoba Hydro to address the lack of redundancy in the HVdc system and load serving deficiency under catastrophic HVdc contingencies.
• The in-service of Bipole III reliability project significantly enhances our system reliability and resilience.
• BP3 offers adequate HVdc transmission spare to facilitate & optimize BPI/II refurbishment.
• Provides additional HVdc capacity for future renewable energy development in northern Manitoba.
Video
Questions?