Evaluating Dynamic Reactive Support Options for Minnesota’s North Shore

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Overview

• Background
  – North Shore Loop
  – Voltage Collapse Problem

• Solution Development
  – Quantifying the Problem
  – Modeling & Comparison of Solutions
  – Solution Comparison

• Project Development
  – Specification
  – Procurement & Execution
Minnesota’s North Shore

Minnesota Power’s Mission:
Together we safely and reliably create and deliver vital energy to enhance **security**, **comfort**, and **quality of life**.
What is the North Shore Loop?
Near-Term Solution: North Shore Sw. Station

In service December 2017. **Capacitor banks** provide critical voltage support. **Breakers** eliminate limiting contingencies for reliable near-term operations. Interim operating procedures in place during engineering & construction.
Voltage Collapse Problem

Long-term (post-2019): Steady state analysis identified 19 unique* contingency events that cause voltage collapse with all North Shore Loop baseload generators offline.

Generally, any loss of connection between Colbyville & Hoyt Lakes

*Excluding contingencies with identical modeling

This is where MP brought in Siemens PTI to analyze and scope potential dynamic reactive support solutions for the North Shore.
North Shore Loop Stability Study

Study Scope
• Verify the stability (voltage collapse) issue
• Evaluate MSC configurations and develop control strategy
• Determine required SVC/STATCOM ratings
• Identify synchronous condenser solutions

Study Methodology
• Evaluate winter peak load level
• Load modeled using dynamic load models
• Simulate variety of TPL-001-4 contingencies
Performance Criteria

- Synchronous motors maintain synchronism (don’t trip)
- Transient voltage doesn’t dip below 0.82 pu following fault clearing
- Transient voltage doesn’t rise above 1.2 pu following fault clearing
- Post-transient voltage within 0.90 pu to 1.20 pu
- Steady state voltage within 0.95 pu to 1.10 pu
Verify Issues - Voltage Collapse

Contingency: SLG NSH-2H

Motor tripped due to loss of synchronism

Voltage does not recover following fault clearing.
Verify Issues - High Voltage after Load Rejection

Contingency: SLG NSH-SB
Solutions

• Static reactive support (MSC) for steady-state voltage
  – Included with initial North Shore Switching Station

• Dynamic Reactive Support to address dynamic voltage and first swing stability problem.
  – Also to be located at North Shore Switching Station
  – Space reserved for expansion after initial construction

• Dynamic Reactive Support Options:
  – Static VAR Compensator (SVC)
  – Static Synchronous Compensator (STATCOM)
  – Synchronous Condenser (Conversion or New Construction)
Solution Options

**MSC / MSR**
- **Mechanically Switched Capacitors / Reactors**
  - Switchgear
  - Capacitors
  - Reactors

  Response: 2-5 cycles
  Limited switching

  $20 \leq \text{MVAr} \leq 400$

**SVC**
- **Static Var Compensator**
  - Thyristor Valve(s)
  - Control & Protection
  - Transformer
  - Capacitors
  - Reactors

  Response: 2-3 cycles
  Unlimited switching

  $50 \leq \text{MVAr} \leq 1000$

**STATCOM**
- **Static Synchronous Compensator**
  - IGBT Valves (VSC)
  - Control & Protection
  - Transformer
  - DC Capacitors

  Response: 1.5-2 cycles
  Unlimited switching

  $\pm 25 \leq \text{MVAr} \leq \pm 500$

**Synchronous Condenser**
- Generator
- Control & Protection
- Transformer

  Response: 6-30 cycles

  $25 \leq \text{MVAr} \leq 1000$
Mechanically Switched Shunt Capacitors (MSC)

- Inexpensive
- Robust
- Can be connected to any voltage level
- Discrete control
- Cycle (on-off-on) slow due to charging/discharging
- Reactive power output function of $V^2$: $Q_{\text{max}} < 50\%$ nominal for voltages less than 0.7 p.u.
SVC Typical Configuration

1. Transformer
2. Arrestor
3. TCR (Thyristor Controlled Reactor) branch
4. TSC (Thyristor Switched Capacitor) capacitor
5. TSC reactor
6. TSC Valve + arrester
7. Filter branch
SVC V/I Characteristic

- Transformer overload capability
- Continuous operating area
- Time limited operating area

- Capacitive
- Inductive

- \( V_{\text{prim}} \) [pu]
- \( I_{\text{prim}} \) [pu]

2 seconds
STATCOM Arrangement

Network

Coupling Reactor

IGBT Converter

DC Capacitor
• Multilevel STATCOM built by Power Modules connected in series.
• The sum of all power module output voltages form the terminal voltage.
• The reactive power output is controlled via the amplitude of the converter voltage.
STATCOM V/I Characteristic

The diagram illustrates the voltage (V) and current (I) characteristics of a STATCOM. The area represents the continuous operating region, while the dotted line indicates the time-limited operating area (2x 1sec). Capacitive and inductive regions are marked on the horizontal axis.
SVC vs STATCOM
Synchronous Condenser

• A synchronous condenser is a generator, similar to those used at central power plants.
• Generator in a power plant is powered by the steam turbine and delivers power to the system. Synchronous condenser is powered by the power system like a synchronous motor.
• Retired generators can sometimes be converted synch condensers.

Applications

• Provision of Reactive Power
  – Generation/consumption of reactive power is achieved by regulating the excitation current.
  – Reactive power output independent of terminal voltage.
• Provision of additional short circuit power.
• Provision of Inertia.
Synchronous Condenser – Main Components

1. Synchronous Condenser
2. Generator Step-up Transformer
3. Static / Brushless excitation
4. Pony Motor / Starting Frequency Converter
5. Isolated Phase Busduct
6. Auxiliary Transformer
7. Generator Circuit Breaker
Synchronous Condenser

Indicative Steady-State V/Q Diagram
North Shore SVC/STATCOM Modeling

• Used PSS®E Standard Library Models SVSMO1U2/ SVSMO3U2
• Size defined in terms of short-term rating at 115 kV PCC
• MSC switching controlled by SVC/STATCOM

• Defined critical parameters for Minnesota Power RFP
  – Short-term ratings
  – MSC switching sequence and time delays
  – Low voltage control strategy
  – PI controller gains
STATCOM Short-Term Ratings

Contingency: SLG NSH-2H
Synchronous Condenser Operation

- Considered construction of new synchronous condenser at North Shore or conversion of existing generators
- Results influenced by machine excitation assumptions

<table>
<thead>
<tr>
<th>Location</th>
<th>Size</th>
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<tbody>
<tr>
<td>New Synch Cond at North Shore</td>
<td>Multiple Sizes Tested</td>
</tr>
<tr>
<td>Silver Bay Unit 1</td>
<td>62.5 MVA</td>
</tr>
<tr>
<td>Silver Bay Unit 2</td>
<td>96.0 MVA</td>
</tr>
<tr>
<td>Taconite Harbor Unit 1</td>
<td>93.8 MVA</td>
</tr>
<tr>
<td>Taconite Harbor Unit 2</td>
<td>93.8 MVA</td>
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</tbody>
</table>
Comparison of STATCOM and SVC

- STATCOM response time and undervoltage performance allows smaller short-term rating.

115kV NSH Voltage

3PH NSH-2H Contingency

- with STC, 80Mvar
- with SVC, 100Mvar
- with SVC, 90Mvar
Comparison of STATCOM and SVC

STC and SVC Mvar Output

3PH NSH-2H Contingency
Comparison of STATCOM and Synchronous Condenser

• Response with synchronous condenser is more oscillatory.

115kV NSH Voltage

3PH Colbyville Bus Fault
Comparison of STATCOM and Synchronous Condenser

SC and STC Mvar Output

3PH Colbyville Bus Fault
Solution Comparison

<table>
<thead>
<tr>
<th>Solution</th>
<th>Short-Term Ratings</th>
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<tbody>
<tr>
<td>SVC</td>
<td>+100/-80 Mvar</td>
</tr>
<tr>
<td>STATCOM</td>
<td>+80/-90 Mvar Note 1</td>
</tr>
<tr>
<td>New Synch Cond at North Shore</td>
<td>&gt;280 MVA</td>
</tr>
<tr>
<td>Convert Generators to Synch Cond</td>
<td>250 MVA Note 2</td>
</tr>
</tbody>
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Notes
1. These are minimum requirements, actual STATCOM ratings will be symmetric
2. Synch Cond located at Silver Bay (62.5) MVA and Taconite Harbor (2x93.8 MVA)

- Key differences between solution options
  - Response time
  - MSC control
  - Controllability and observability
Project Development - Procurement

- Specification developed for either:
  - SVC: +100/-80 MVAR Nominal
  - STATCOM: +/- 75 MVAR Nominal

- Short-term overload capability:
  - SVC: +120/-96 MVAR (20%) for 1 second
  - STATCOM: +/-96 MVAR (28%) for 1 second

- Integrated control of local MSCs per stability study recommendations

- Commissioned by Sept. 2, 2019

- Full turnkey design (EPC Contract)

- Technology selection left to bidders based on most efficient/effective overall solution

POWER Engineers assisted MP with specification development
Expansion area cleared & graded east of North Shore Switching Station in 2017.

Topo constraints significant to bidder solution development.
Project Execution – Contract Award

- Received four STATCOM proposals. Zero SVC proposals.
- Project awarded to Siemens in February 2018
- Construction began on site in September 2018
- Project on schedule for commissioning in August 2019

RBJ Engineering assisted MP with bid review and is also assisting MP with design review.
Project Execution – Construction Progress

9/12/2018 – Building Foundation Prep
Project Execution – Construction Progress

9/18/2018 – Building Foundation Prep
Project Execution – Construction Progress

9/25/2018 – Building Foundation; Pouring Cooler Foundations