Transmission Lessons Learned from the Decarbonization of Minnesota's North Shore

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Minnesota Power Systems Conference
November 13, 2019

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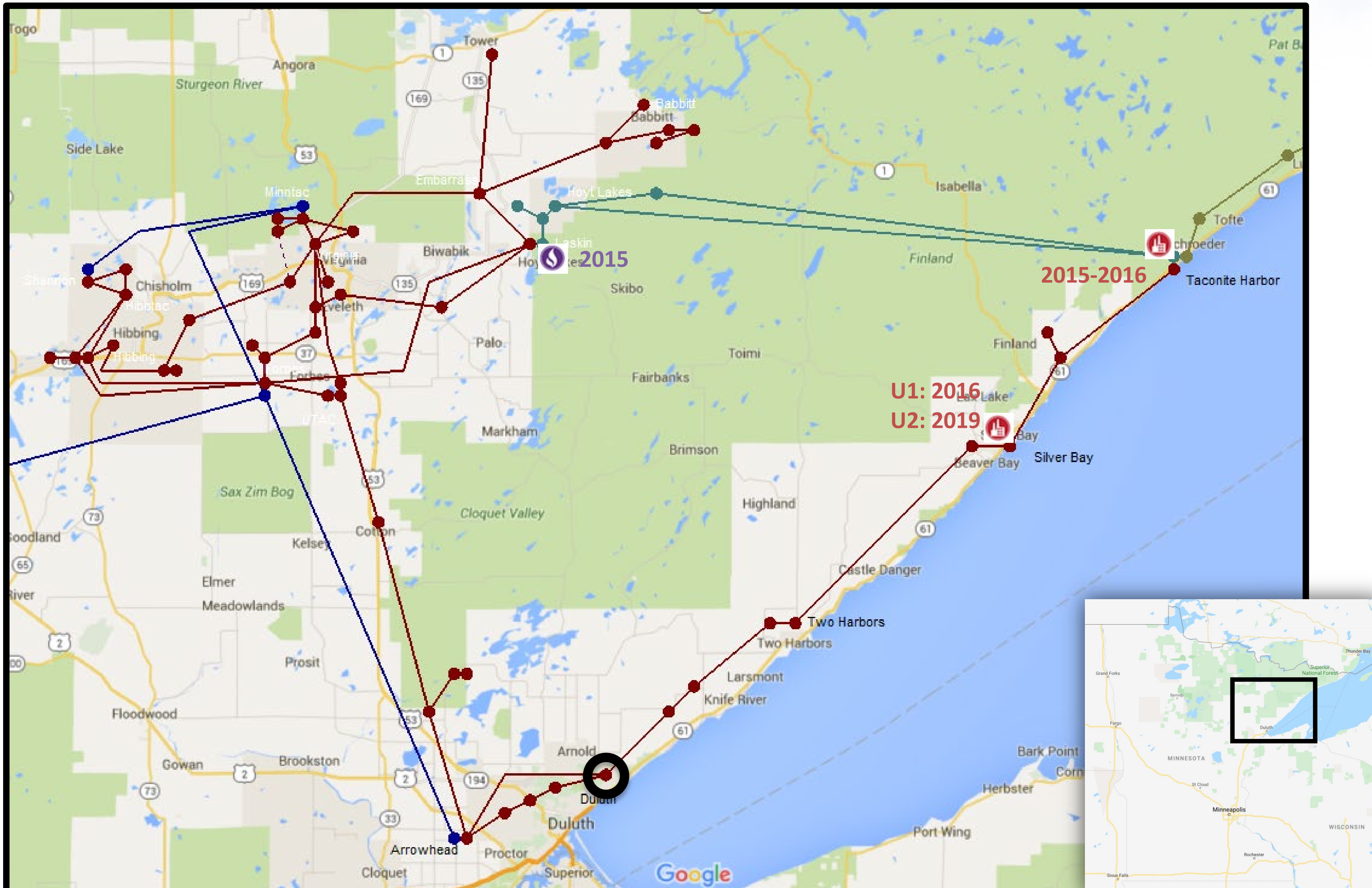
Overview

- Background
- Issues
  - Voltage Support & System Strength
  - Power Delivery Capability
  - Redundancy
- Summary

What is the North Shore Loop?



Transmission Impacts from Fleet Transition

- Voltage Support & System Strength
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- Power Delivery Capability
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- Redundancy
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Transmission Impacts from Fleet Transition

- Voltage Support & System Strength
  - Steady state voltage regulation
  - Dynamic reactive support (Voltage Stability, Damping)
  - Short circuit capability
- Power Delivery Capability
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- Redundancy
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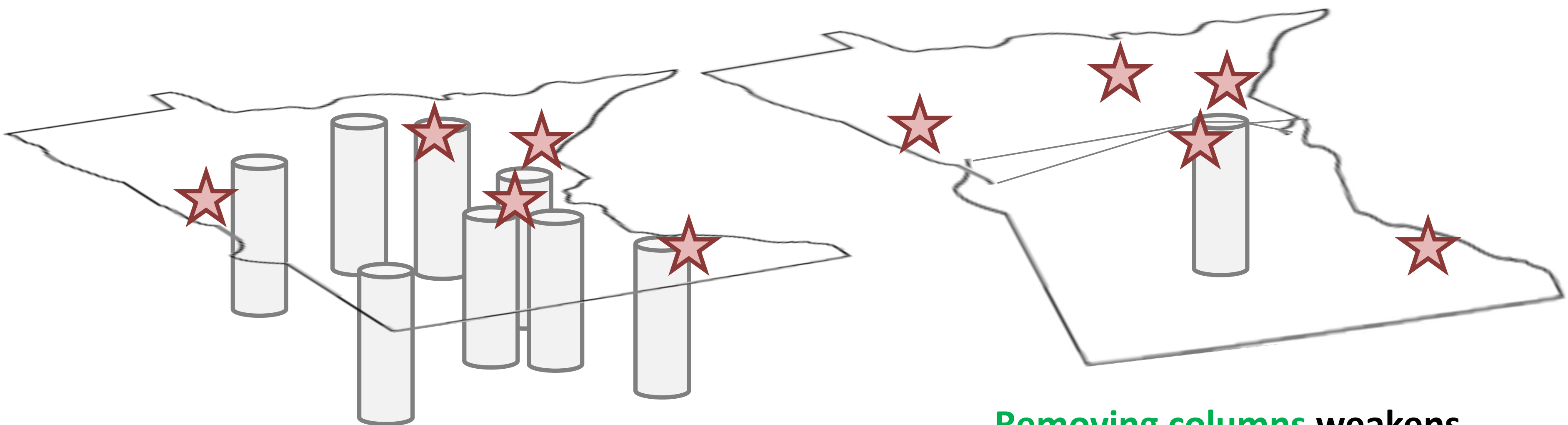
Illustration: Voltage Support

Imagine the power system in Minnesota being supported by columns, representing baseload **generators that supply voltage support and system strength**.



Major Load Centers

Removing columns weakens the support system

CONCLUSION: *Voltage Support & System Strength* presently provided by baseload generators needs to be retained or replaced. Location matters.

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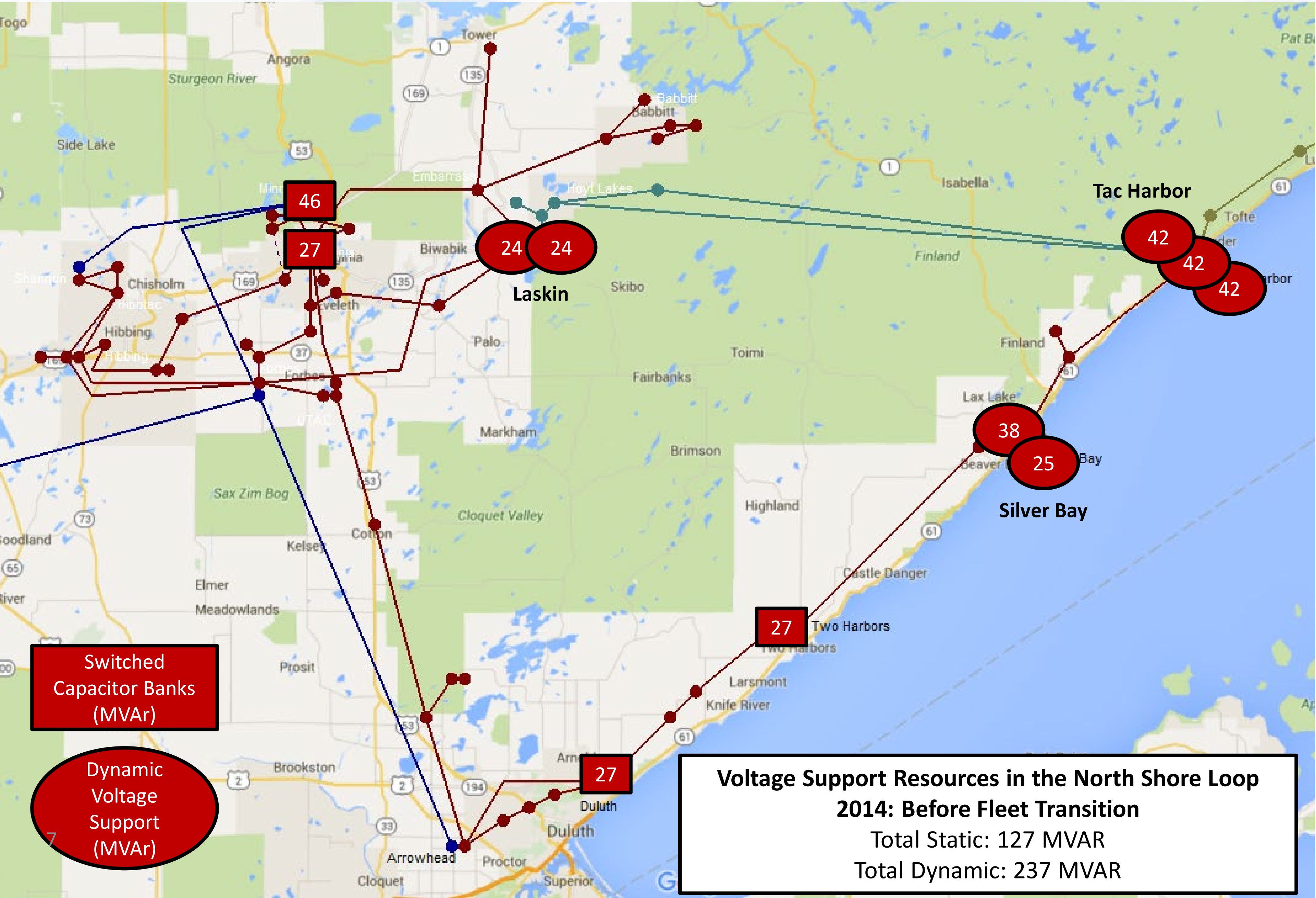
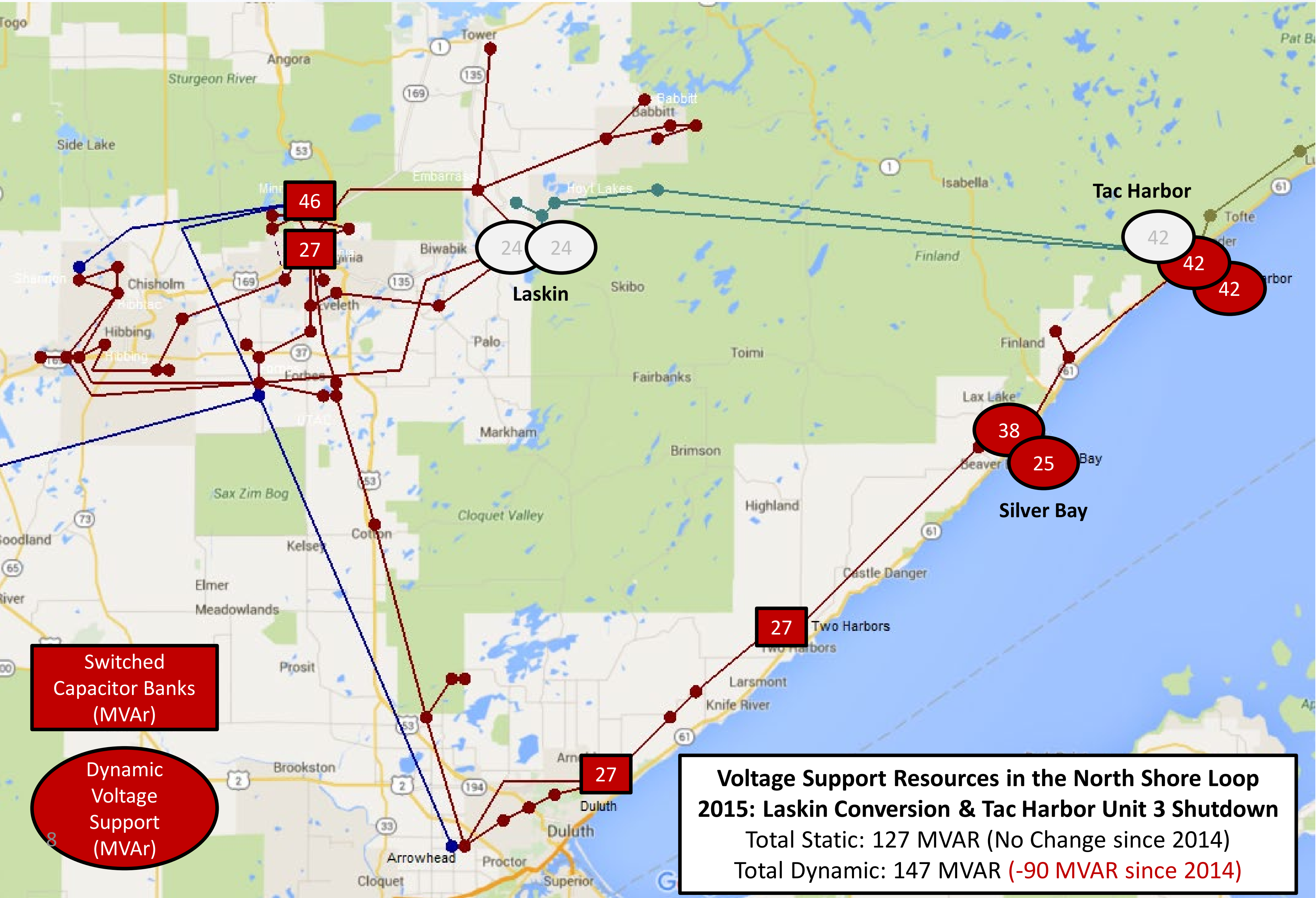
North Shore Loop Reactive Resources (2014)



Voltage Support Resources in the North Shore Loop
2014: Before Fleet Transition
Total Static: 127 MVAR
Total Dynamic: 237 MVAR

North Shore Loop Reactive Resources (2015)

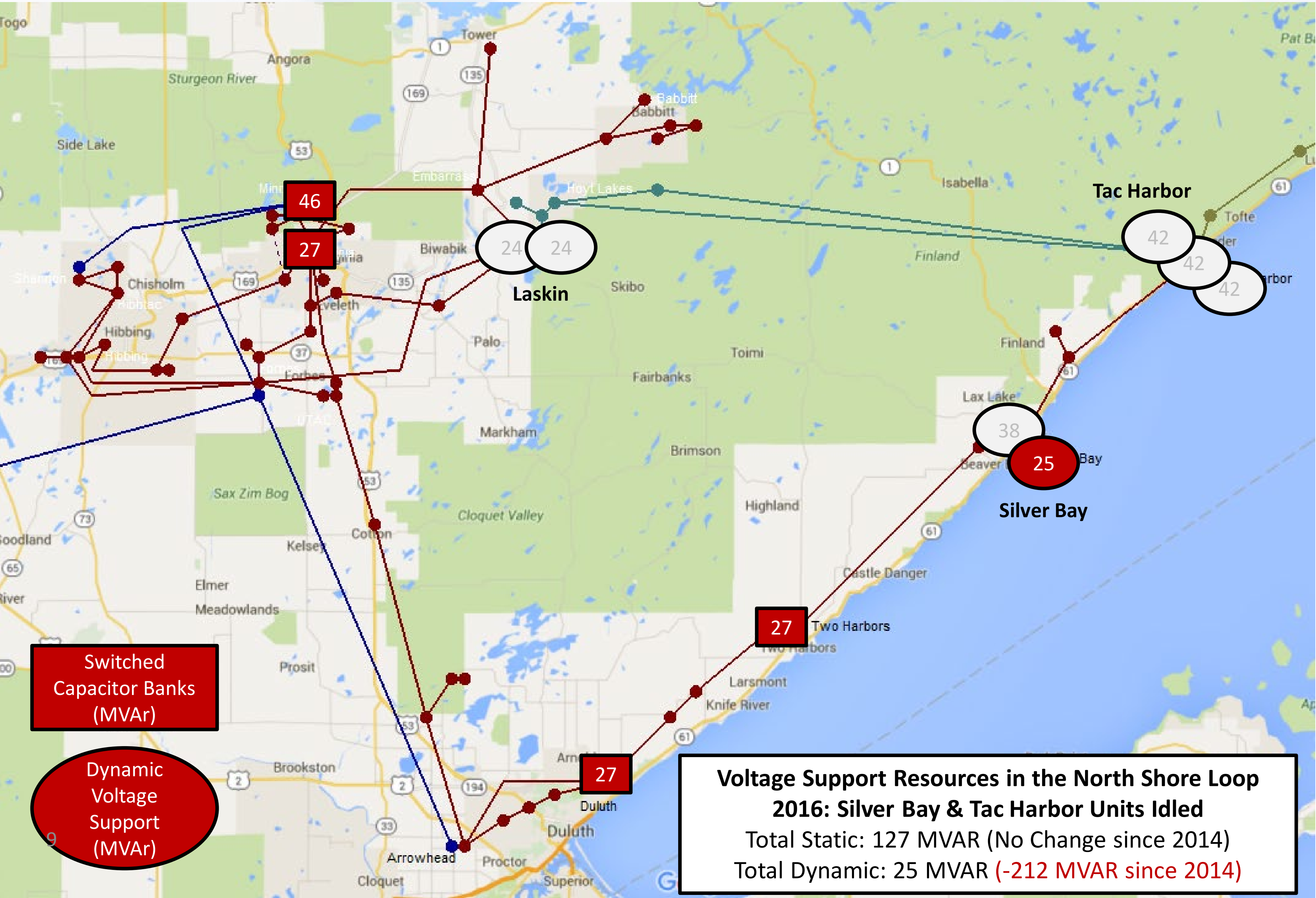


Voltage Support Resources in the North Shore Loop 2015: Laskin Conversion & Tac Harbor Unit 3 Shutdown

Total Static: 127 MVAR (No Change since 2014)

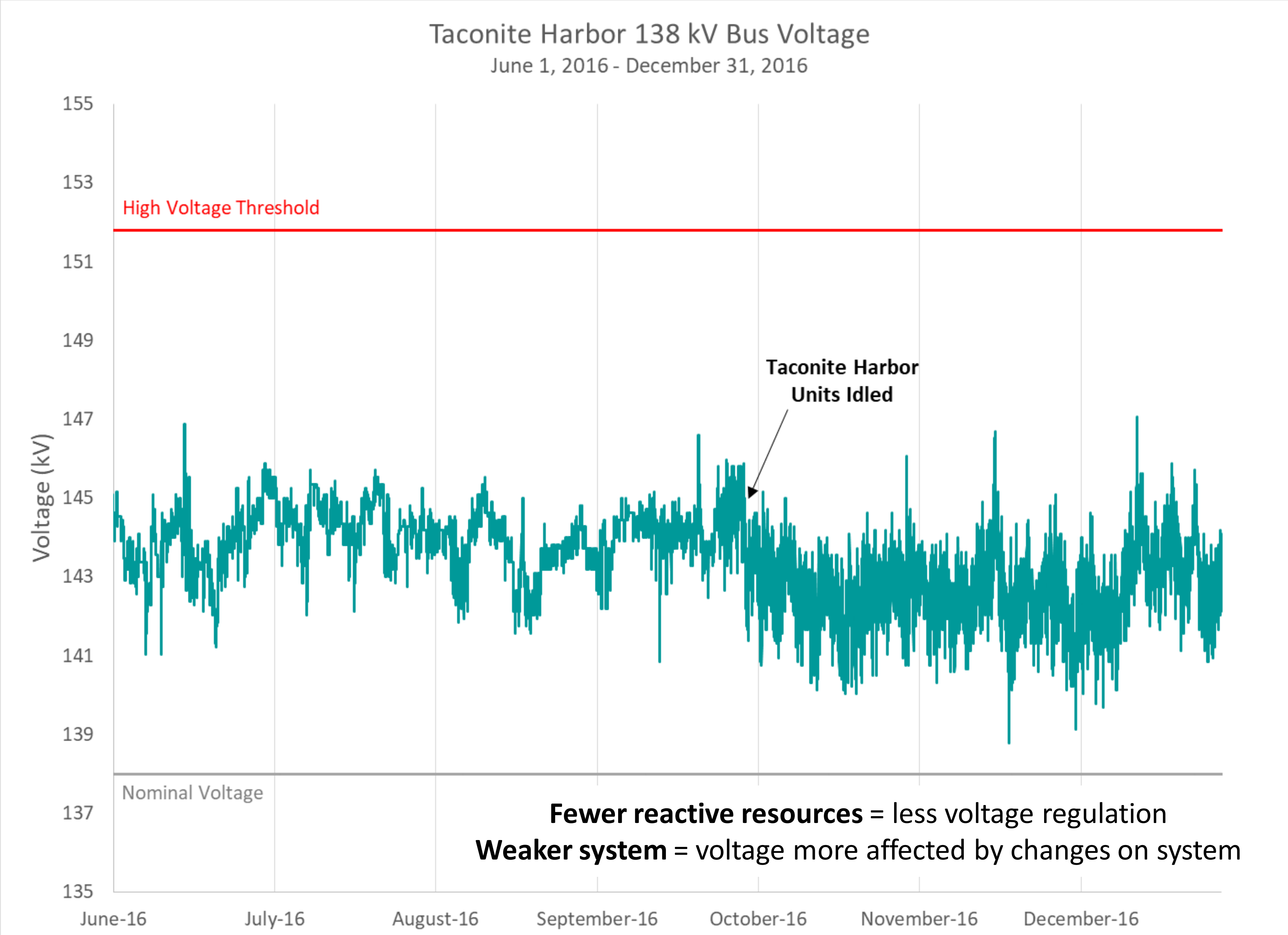
Total Dynamic: 147 MVAR (-90 MVAR since 2014)

North Shore Loop Reactive Resources (2016)



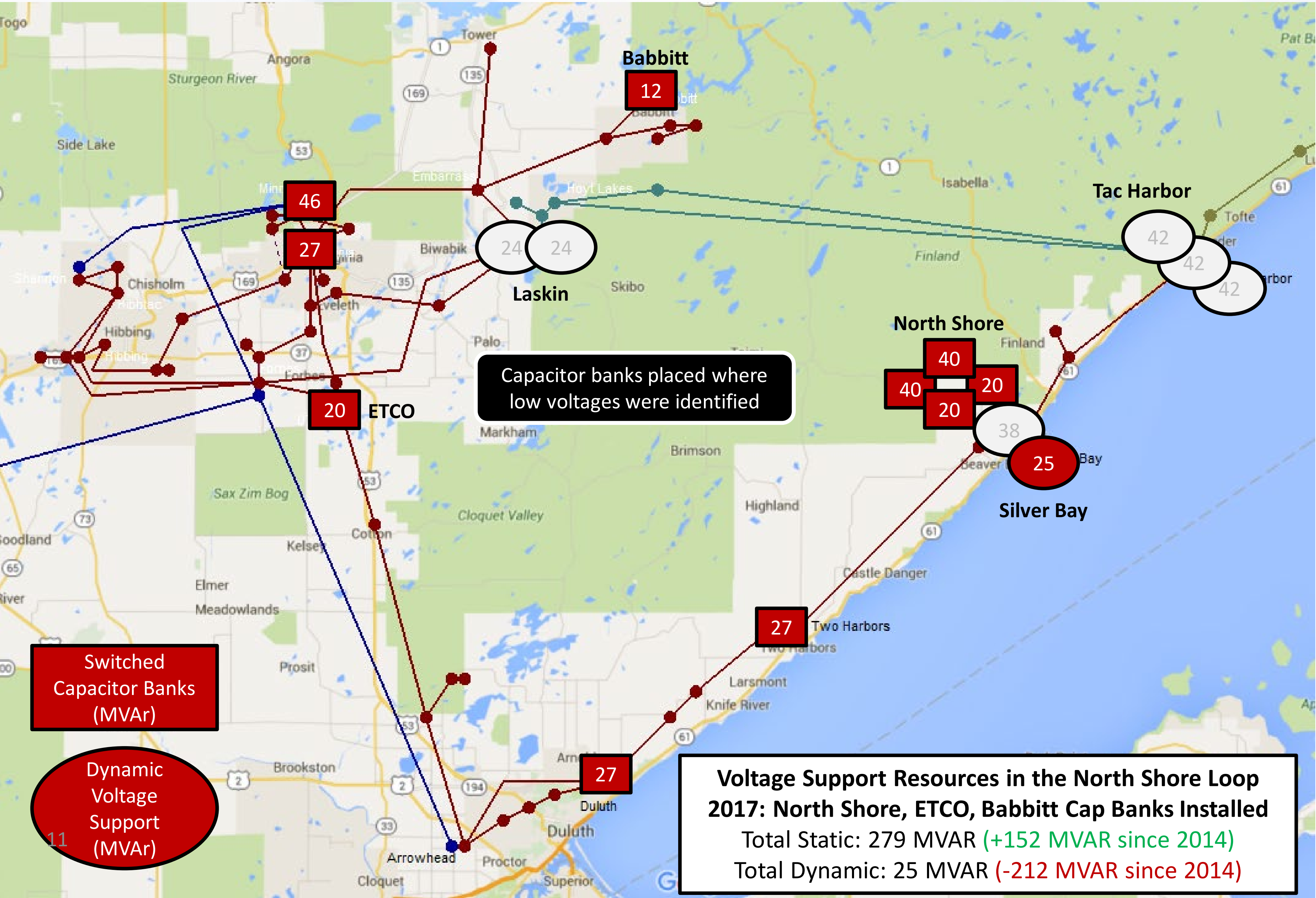
Voltage Support Resources in the North Shore Loop
2016: Silver Bay & Tac Harbor Units Idled
Total Static: 127 MVAR (No Change since 2014)
Total Dynamic: 25 MVAR (-212 MVAR since 2014)

Taconite Harbor Voltage Regulation (2016)

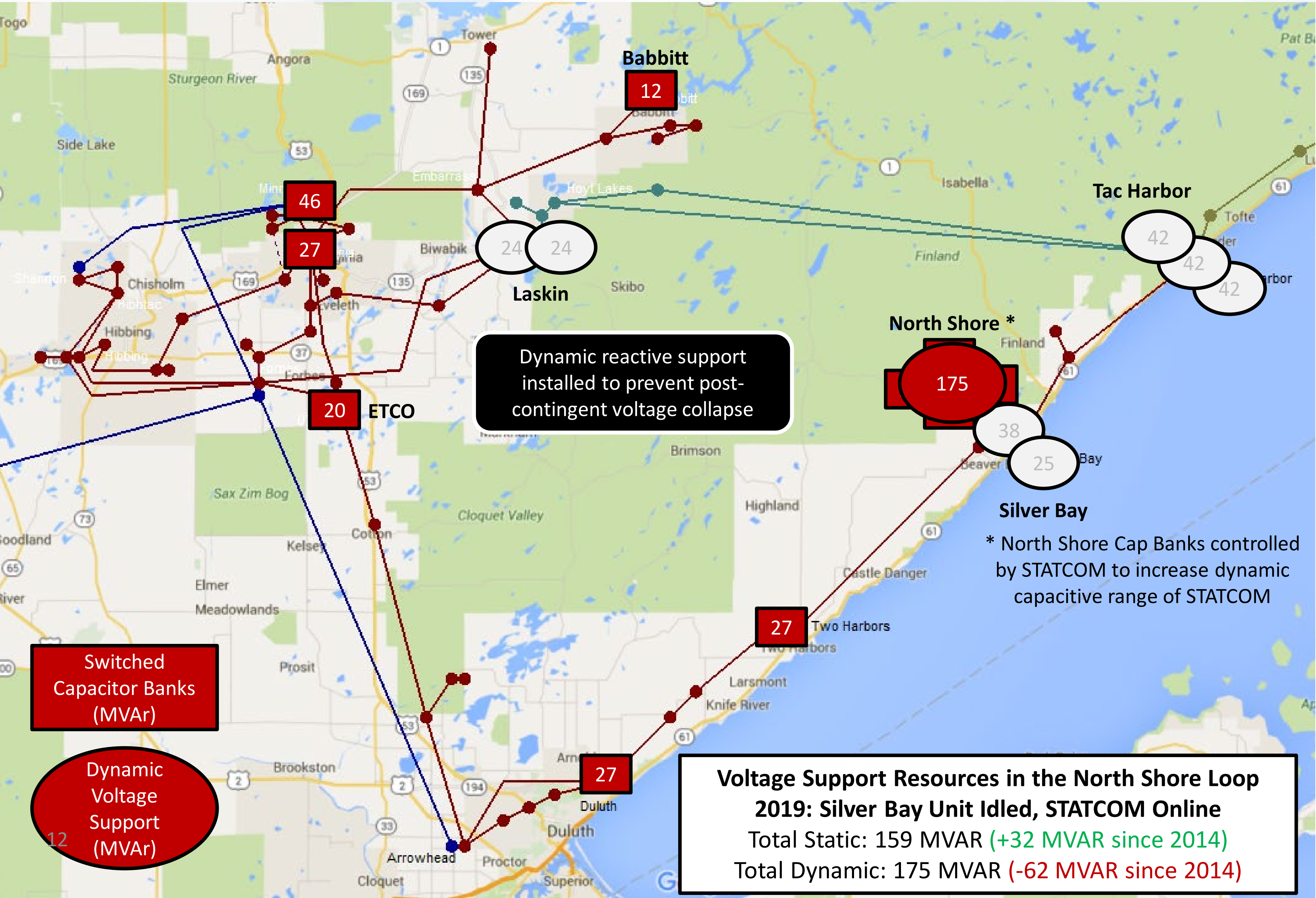


Fewer reactive resources = less voltage regulation
Weaker system = voltage more affected by changes on system

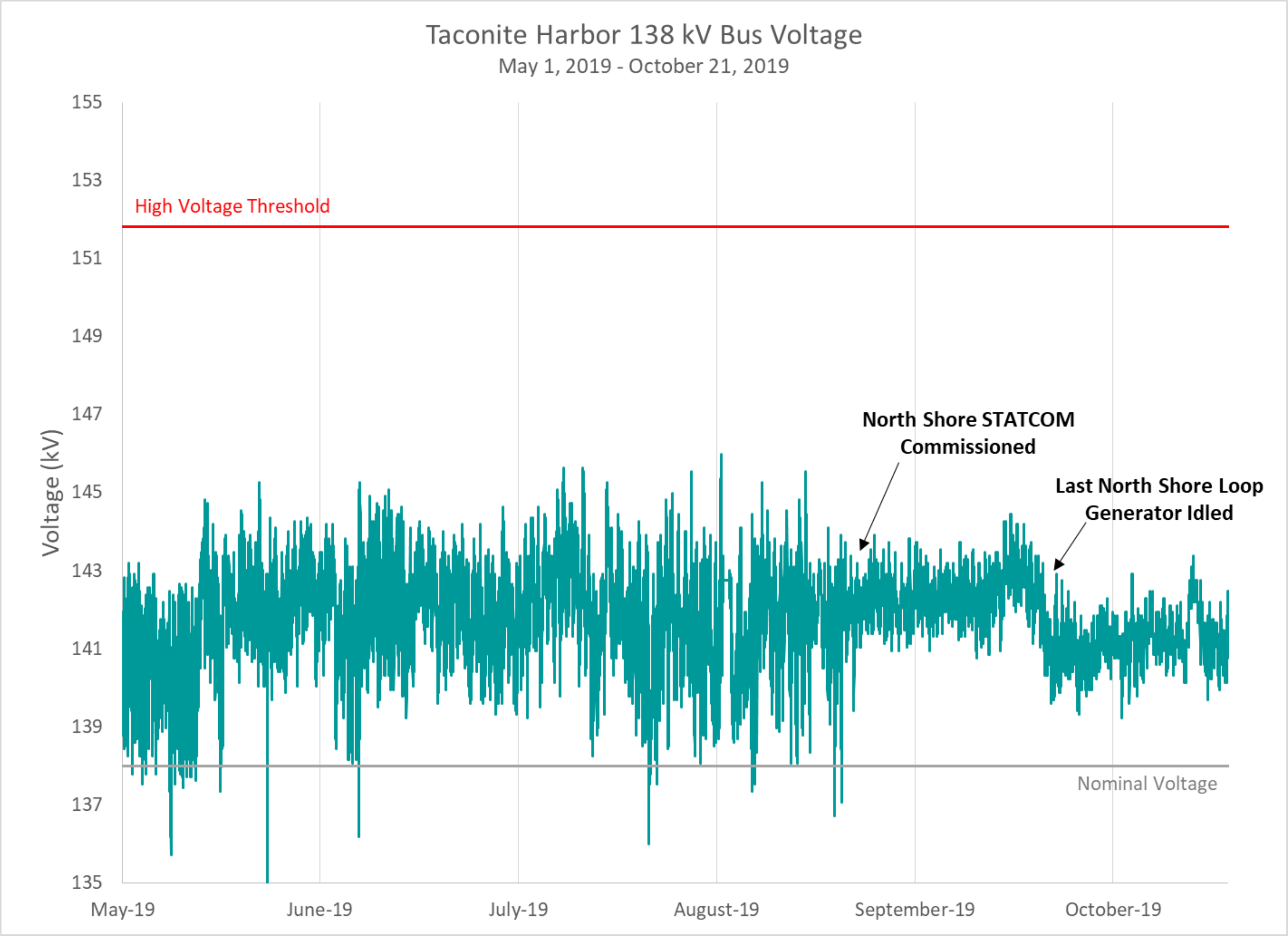
North Shore Loop Reactive Resources (2017)



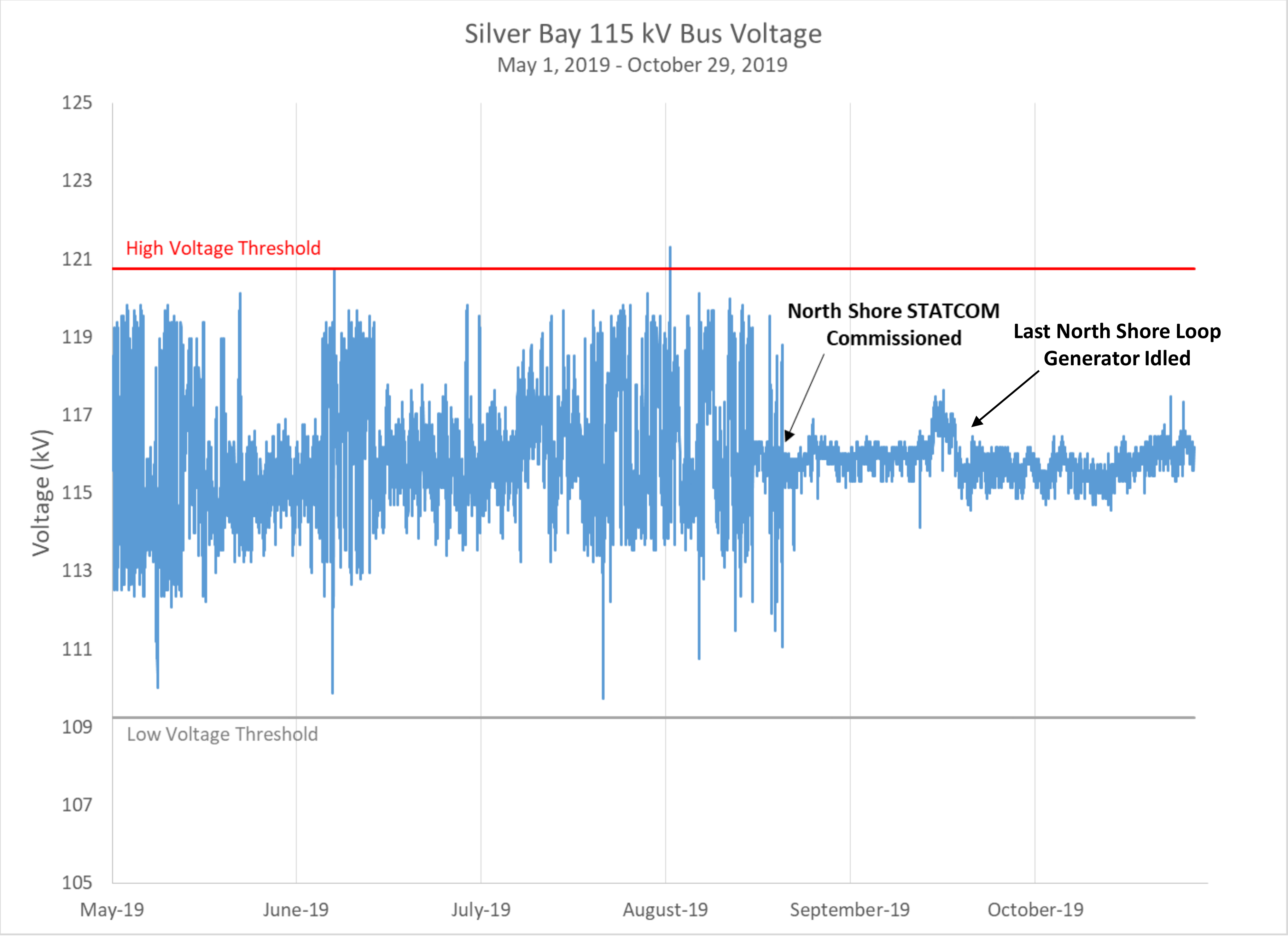
North Shore Loop Reactive Resources (2019)



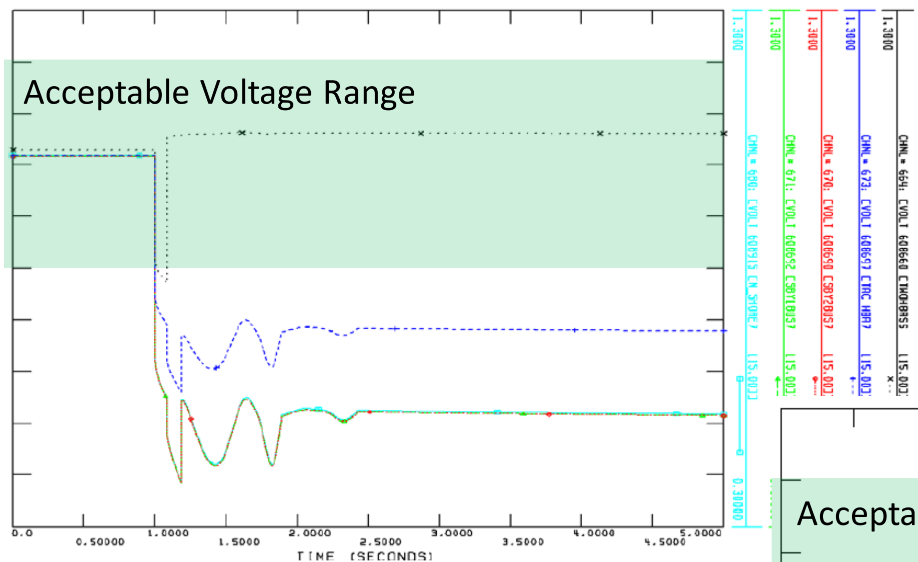
Taconite Harbor Voltage Regulation (2019)



Silver Bay Voltage Regulation (2019)



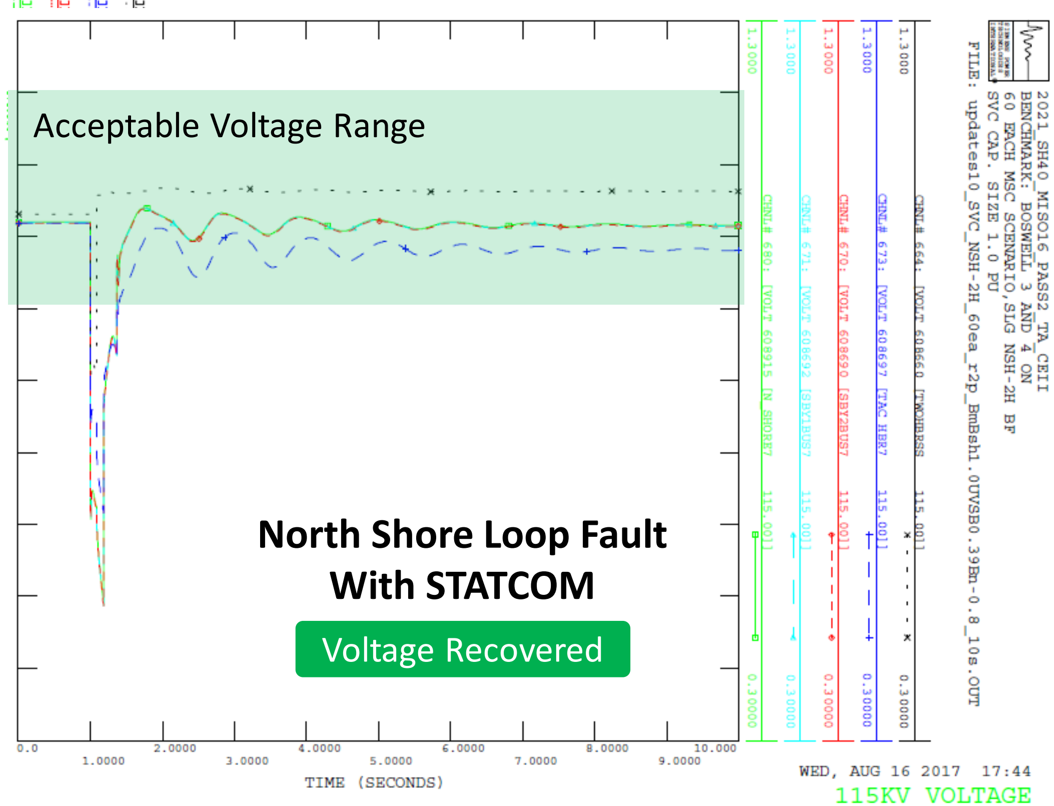
North Shore Loop Voltage Stability



North Shore Loop Fault
Without North Shore STATCOM

Voltage Collapsed

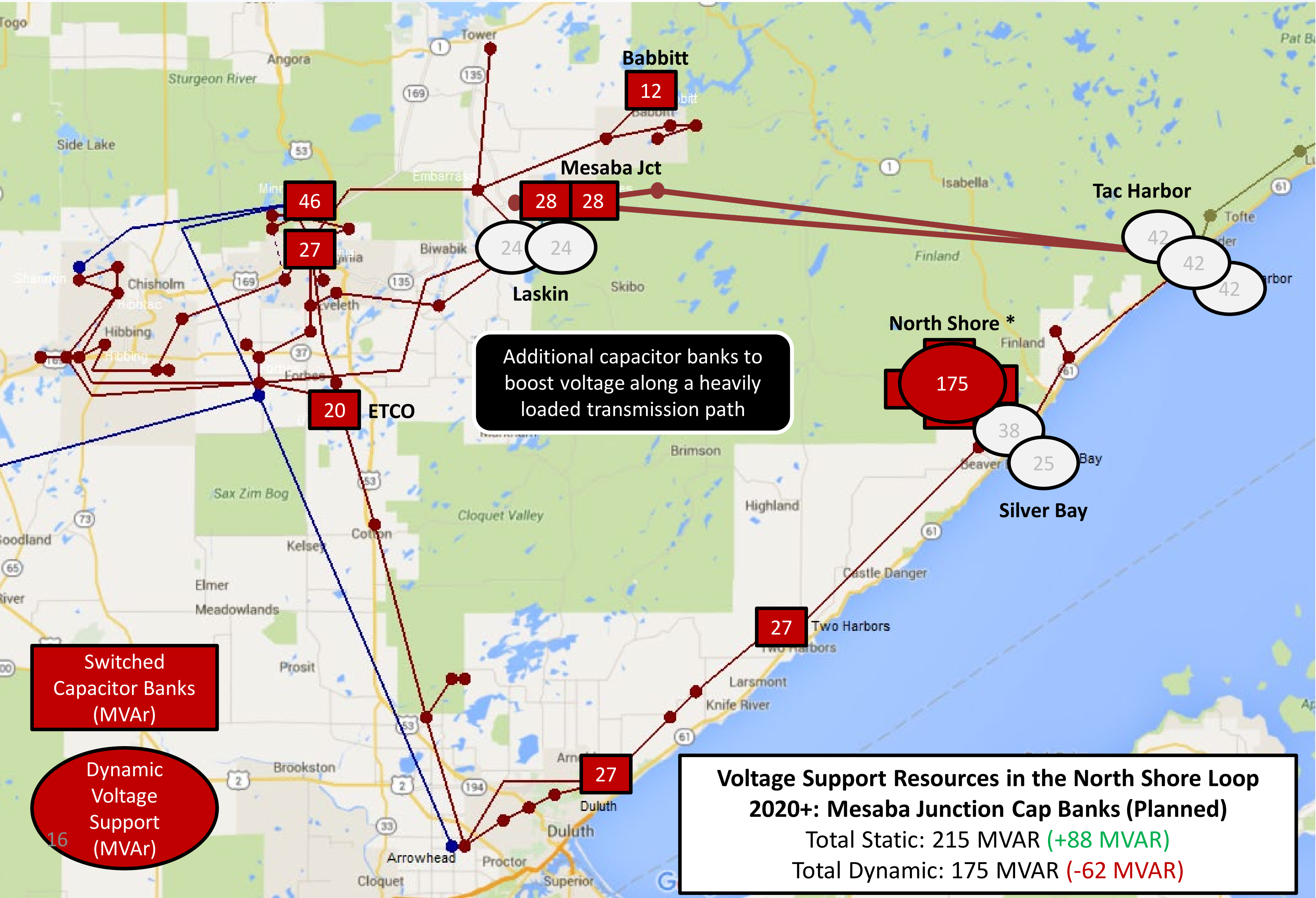
<u>Voltage Stability</u>
Must provide sufficient dynamic (fast-responding) reactive support to ensure system voltage can recover after a fault event



North Shore Loop Fault
With STATCOM

Voltage Recovered

North Shore Loop Reactive Resources (2020+)



Voltage Support Resources in the North Shore Loop 2020+: Mesaba Junction Cap Banks (Planned)
Total Static: 215 MVAR (+88 MVAR)
Total Dynamic: 175 MVAR (-62 MVAR)

Transmission Impacts from Fleet Transition

- Voltage Support & System Strength
  - Steady state voltage regulation
  - Dynamic reactive support (Voltage Stability, Damping)
  - Short circuit capability
- Power Delivery Capability
  - Increased reliance on external sources
  - Increased power flow on incoming transmission lines
- Redundancy
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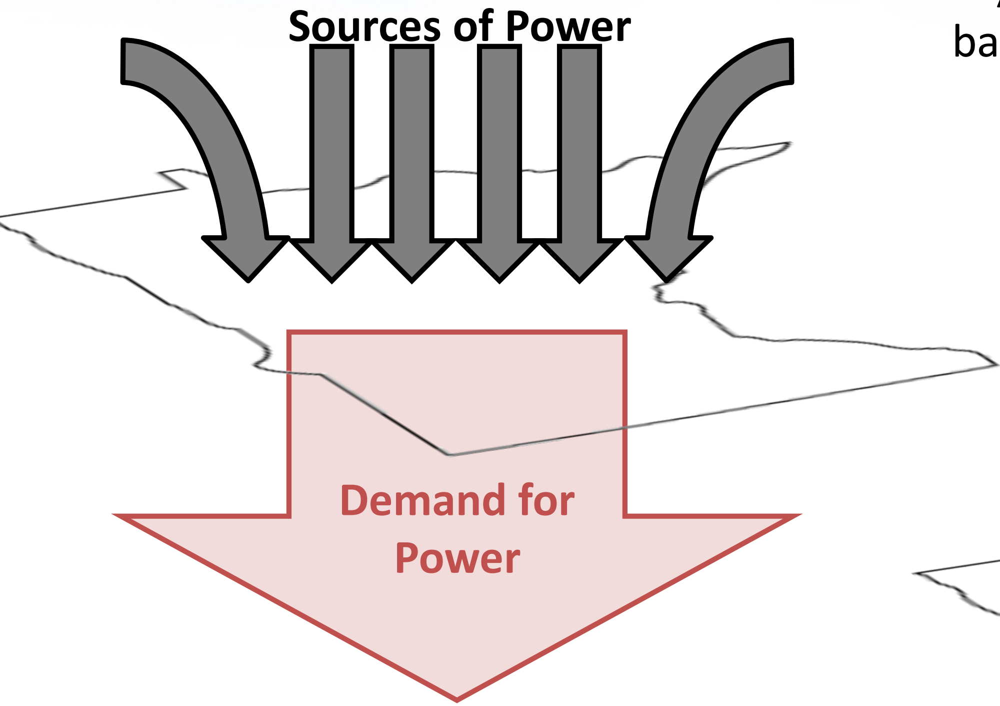
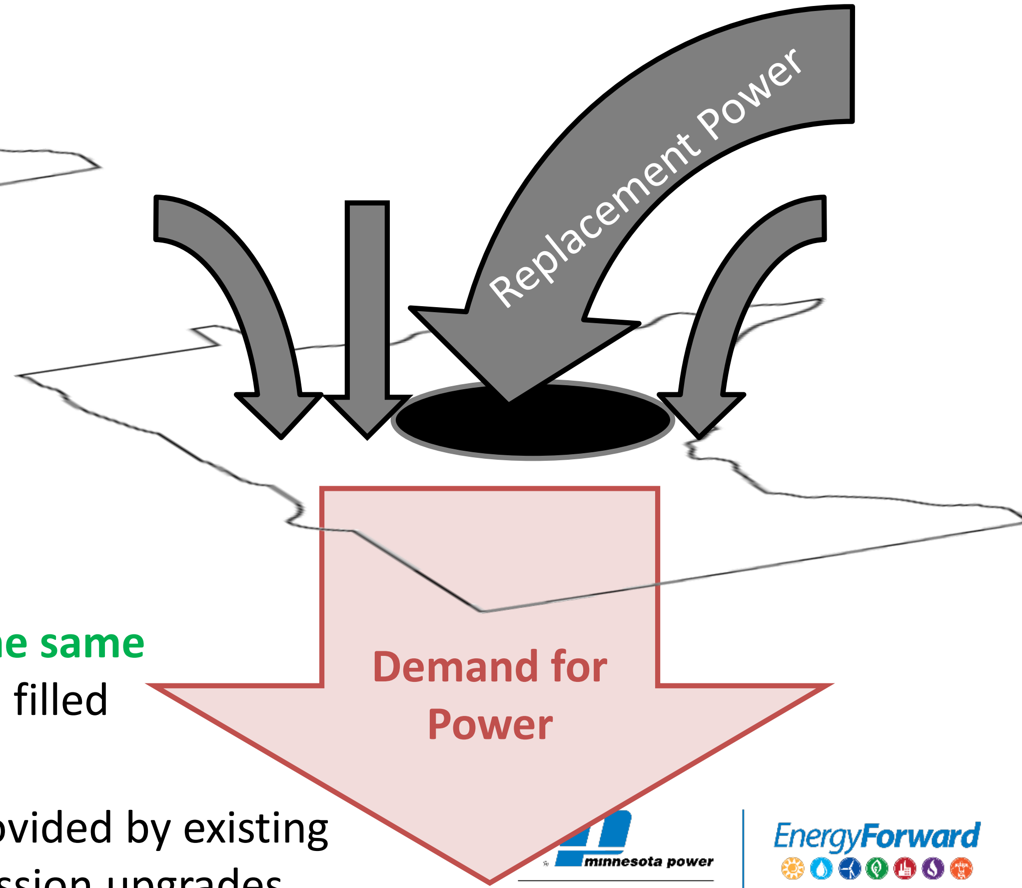
Illustration: Power Delivery Capability



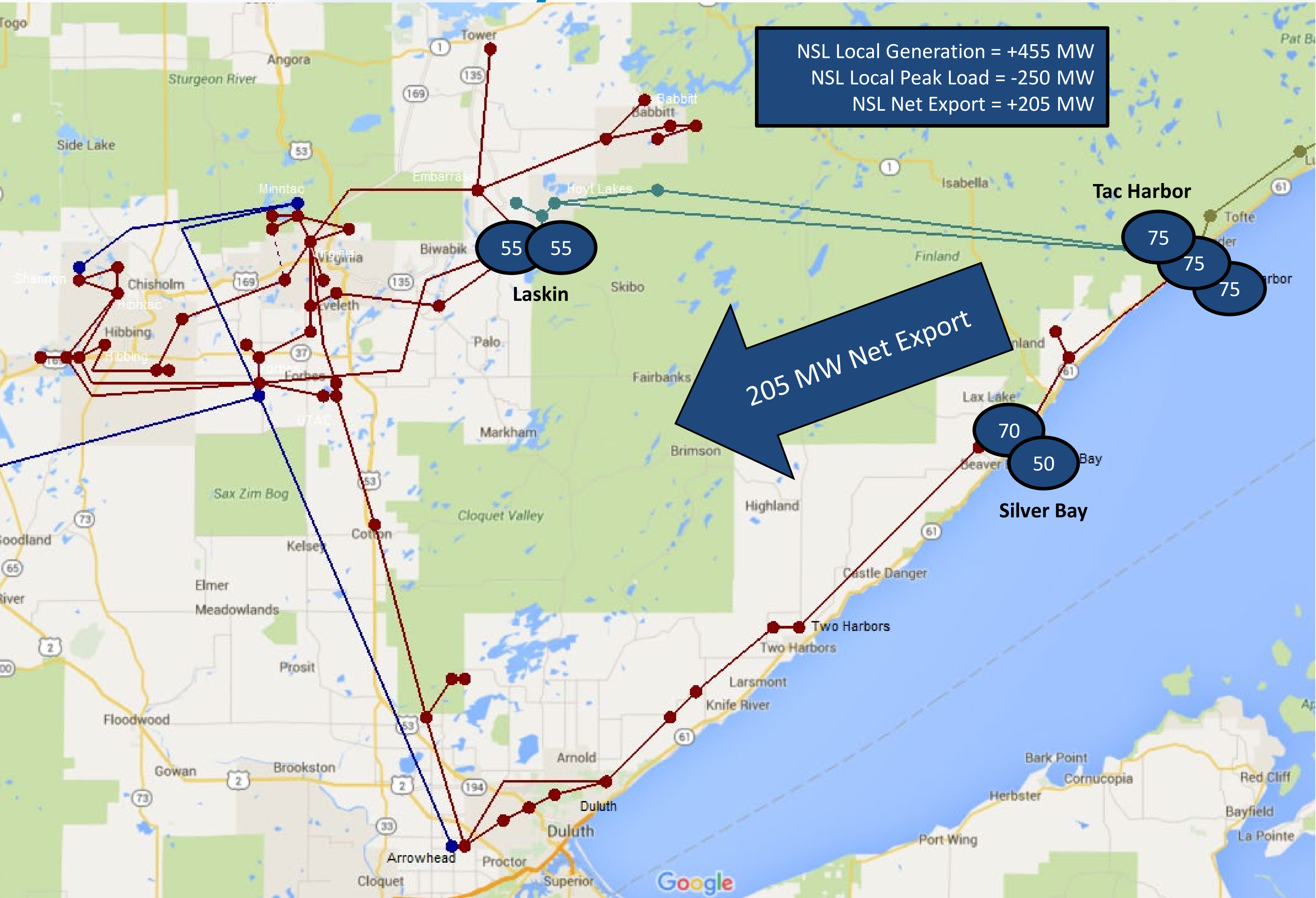
Today, a certain amount of power is provided by baseload generators at particular locations



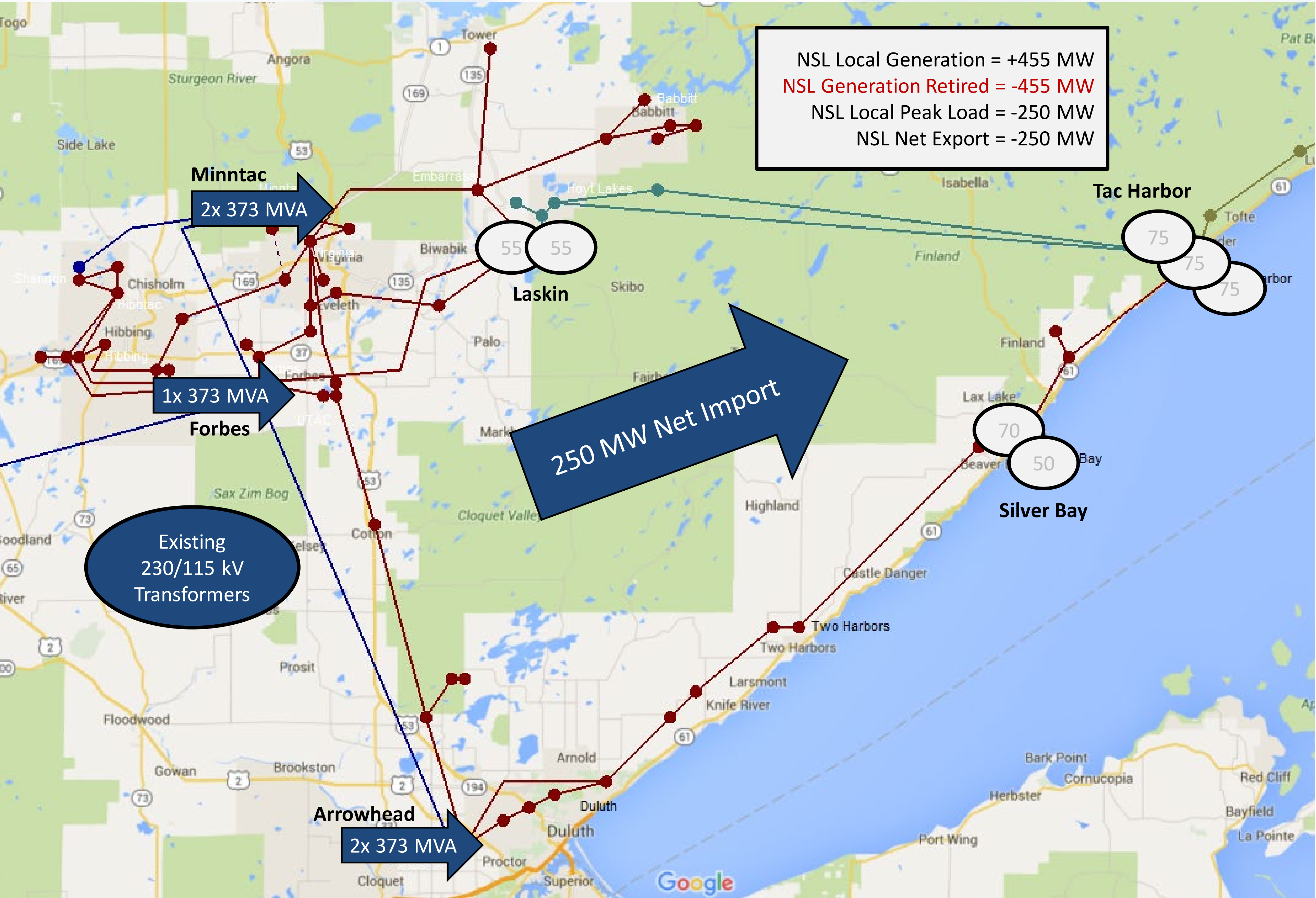
When this power is **no longer supplied at the same locations**, a "hole" is created that must be filled

CONCLUSION: *Replacement* of power provided by existing generators may cause a need for transmission upgrades

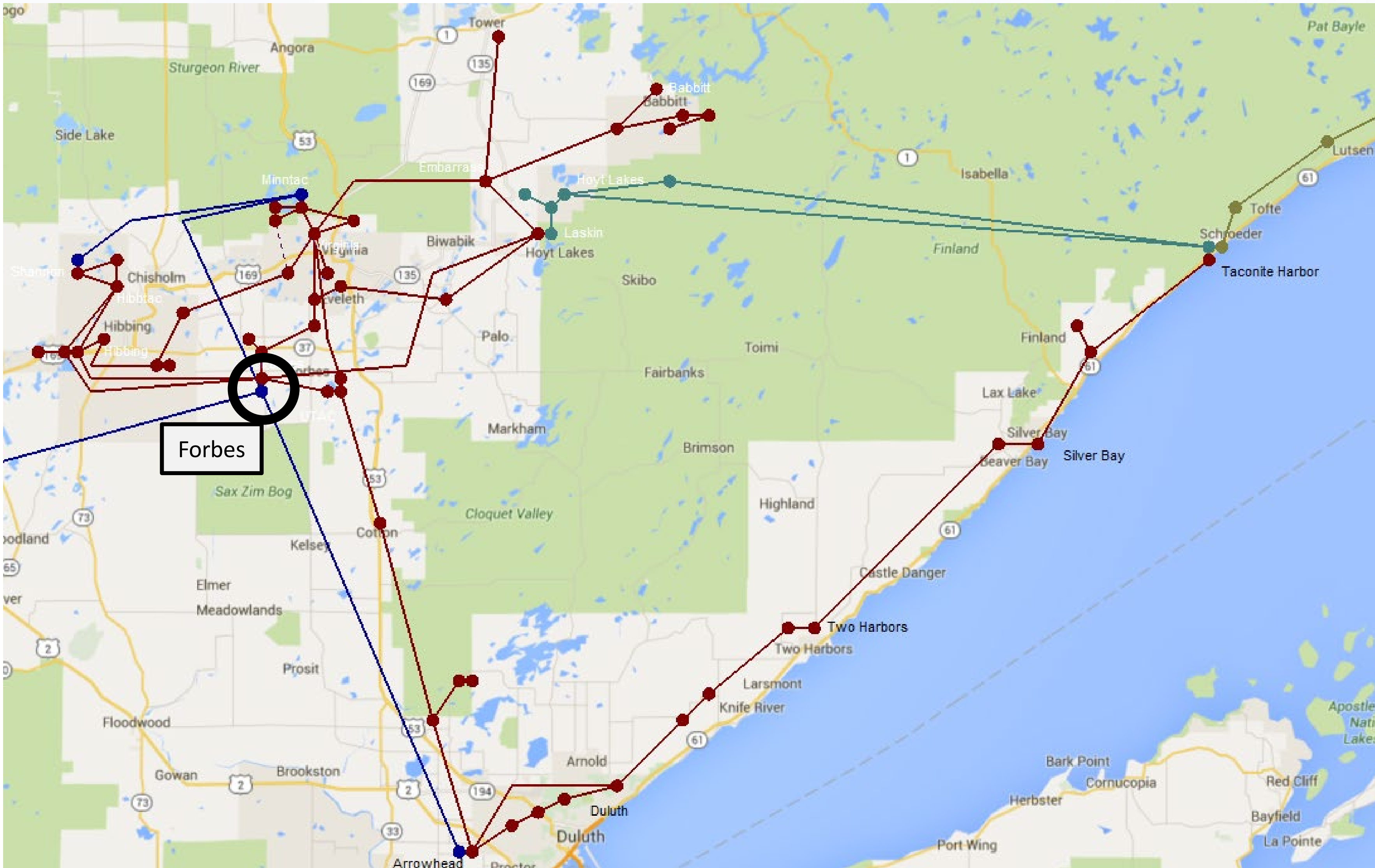
Power Provided by Baseload Generators



Increased Reliance on External Sources



Strengthening the Forbes Source



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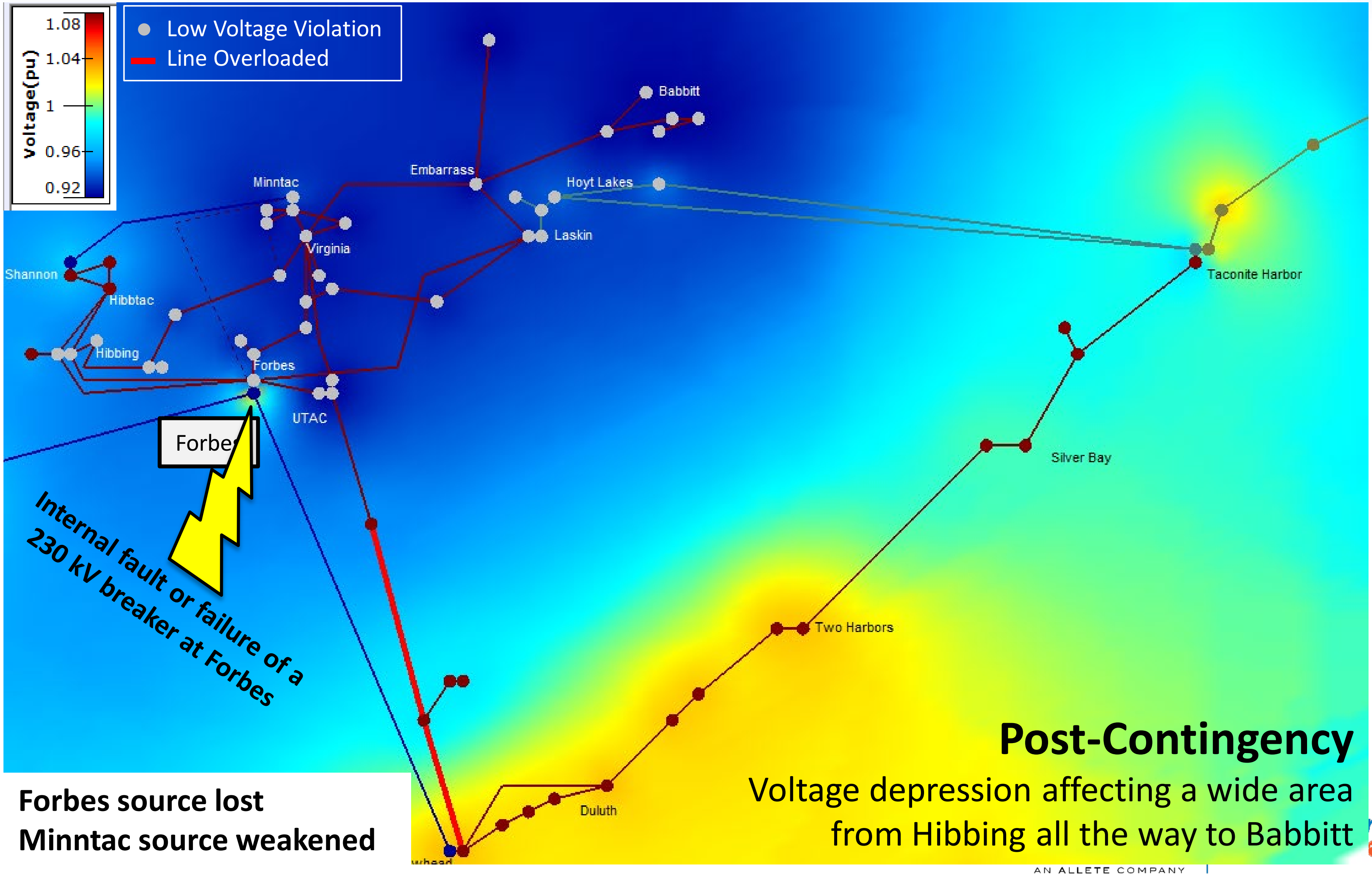
Forbes: Critical Contingency



Forbes source lost
Minntac source weakened

Post-Contingency

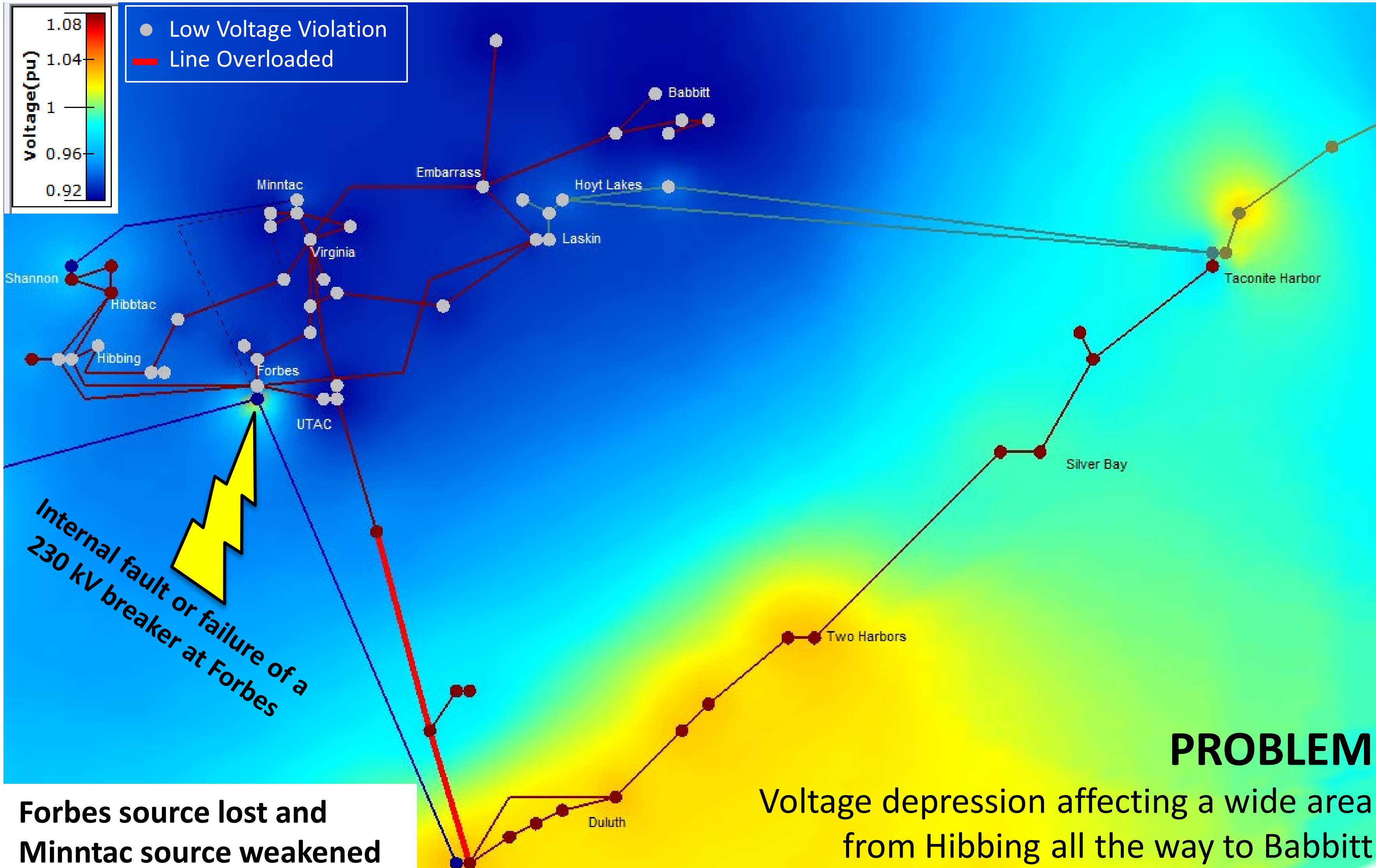
Voltage depression affecting a wide area from Hibbing all the way to Babbitt

Solution: Forbes Transformer Addition

PROBLEM SOLVED:

- Re-establish a second 230/115 kV transformer at Forbes
- **NOW** the connection between 230 kV and 115 kV remains intact
- **ALSO** adds much-needed transformer capacity to support increased reliance on 230/115 kV connection

Forbes: Critical Contingency (Pre-Project)

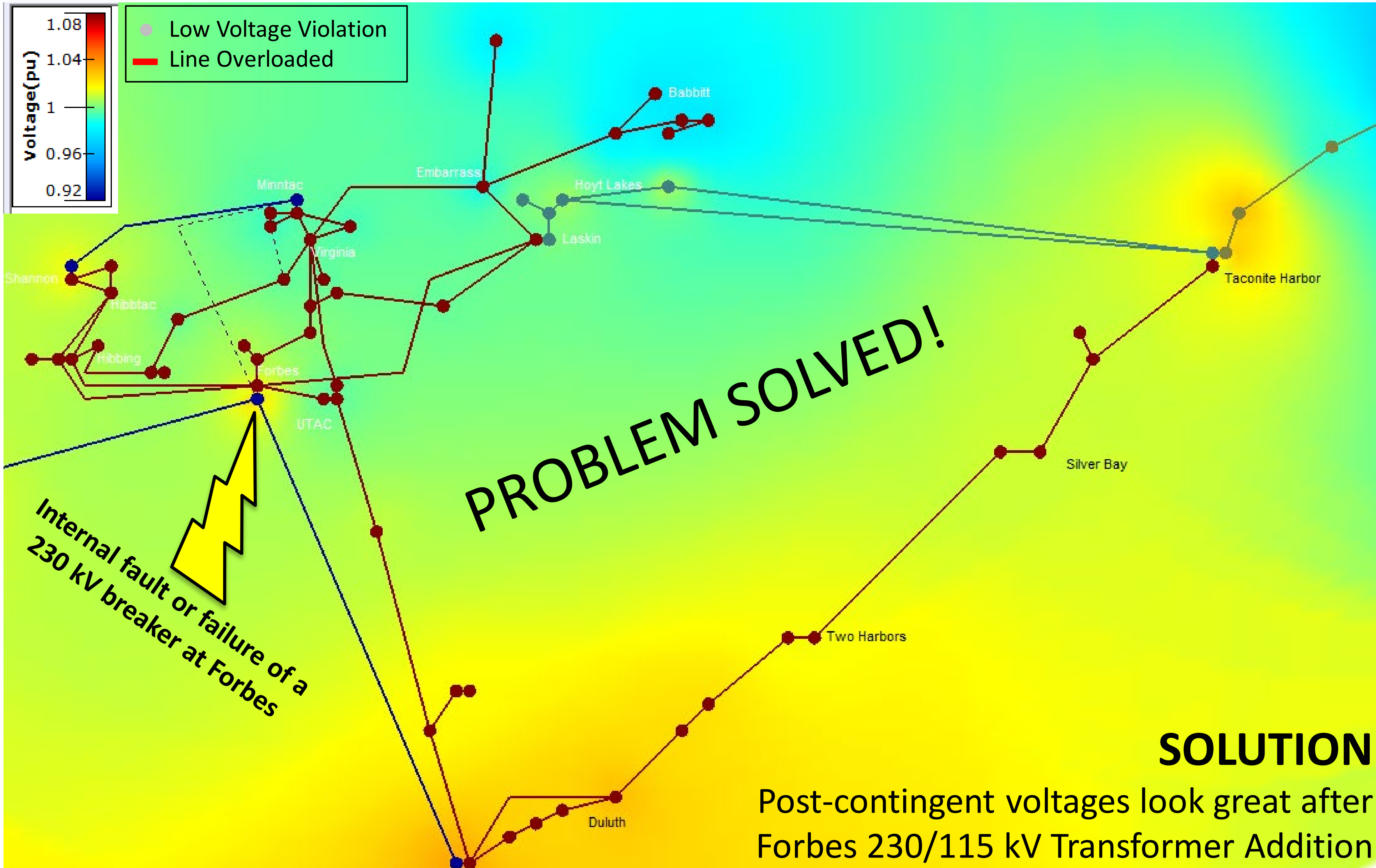


PROBLEM

Voltage depression affecting a wide area from Hibbing all the way to Babbitt

Forbes source lost and Minntac source weakened

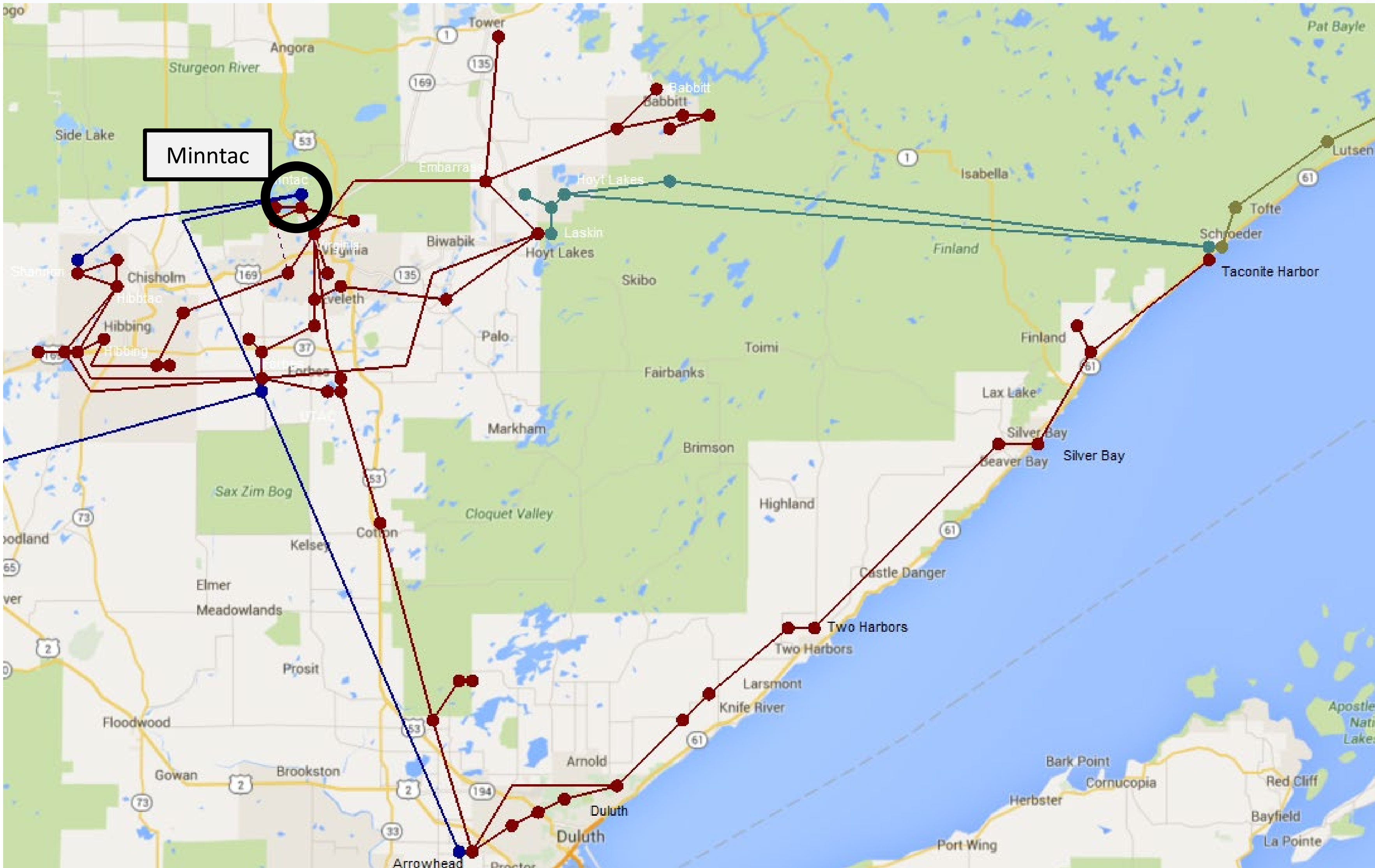
Forbes: Critical Contingency (Post-Project)



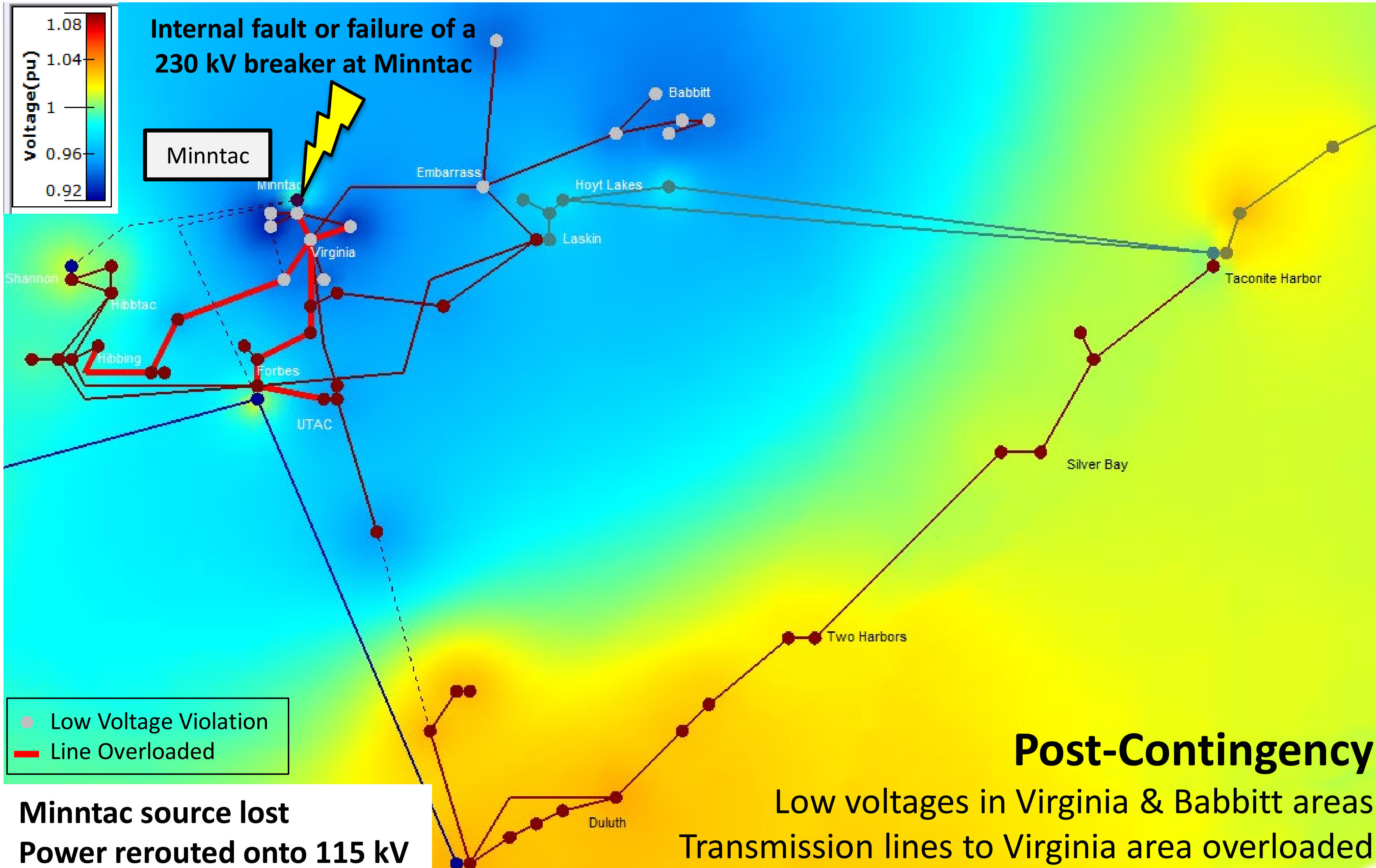
SOLUTION

Post-contingent voltages look great after Forbes 230/115 kV Transformer Addition

Strengthening the Minntac Source



Minntac: Critical Contingency



Internal fault or failure of a 230 kV breaker at Minntac

Minntac source lost
Power rerouted onto 115 kV

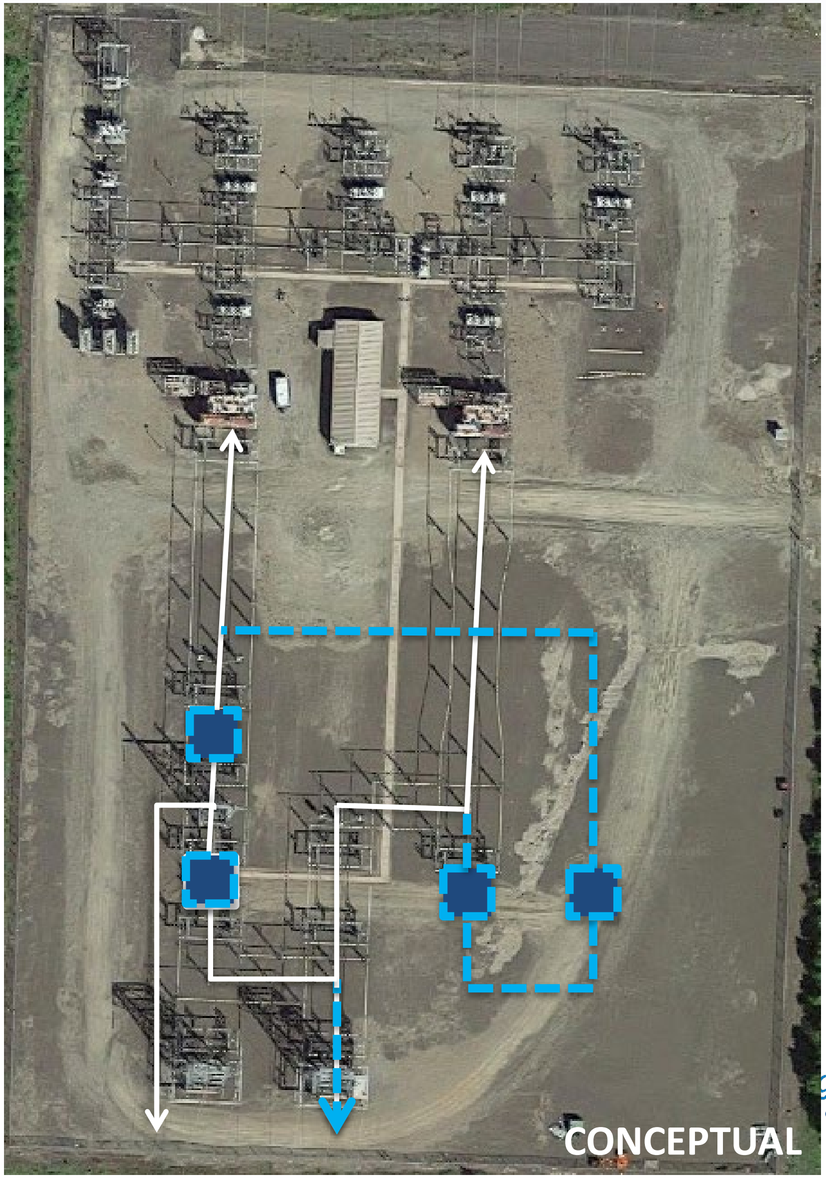
Post-Contingency

Low voltages in Virginia & Babbitt areas
Transmission lines to Virginia area overloaded

Solution: Minntac Bus Reconfiguration

PROBLEM SOLVED:

- Add 3 new breakers & replace the existing breaker with a newer one
- Expand the Minntac 230 kV bus into a more reliable "ring" bus
- Relocate a transmission line to a different position on the bus
- **NOW** for any single breaker failure, one transmission line and one 230/115 kV transformer are still connected



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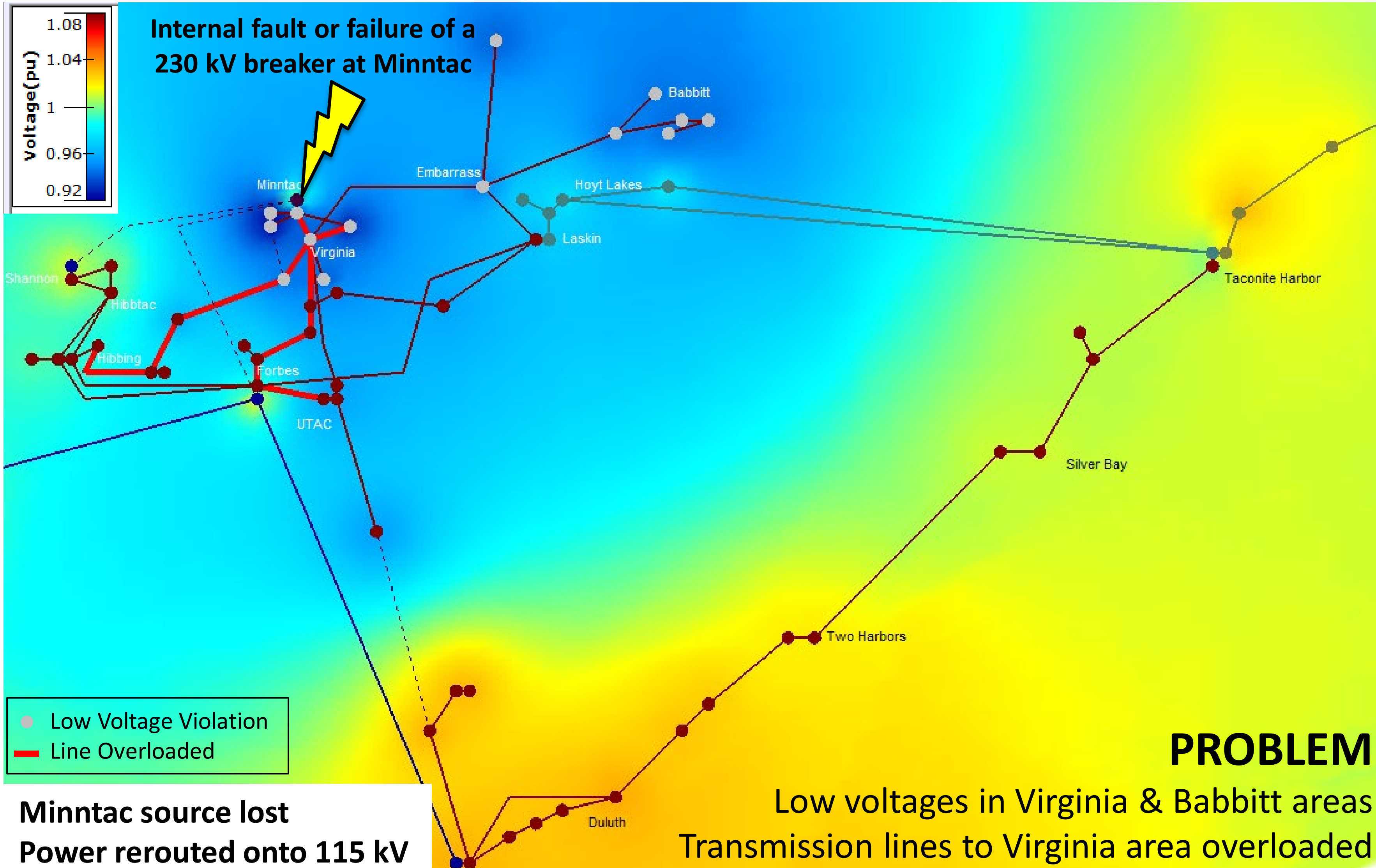
Minntac: Critical Contingency (Pre-Project)

Internal fault or failure of a 230 kV breaker at Minntac

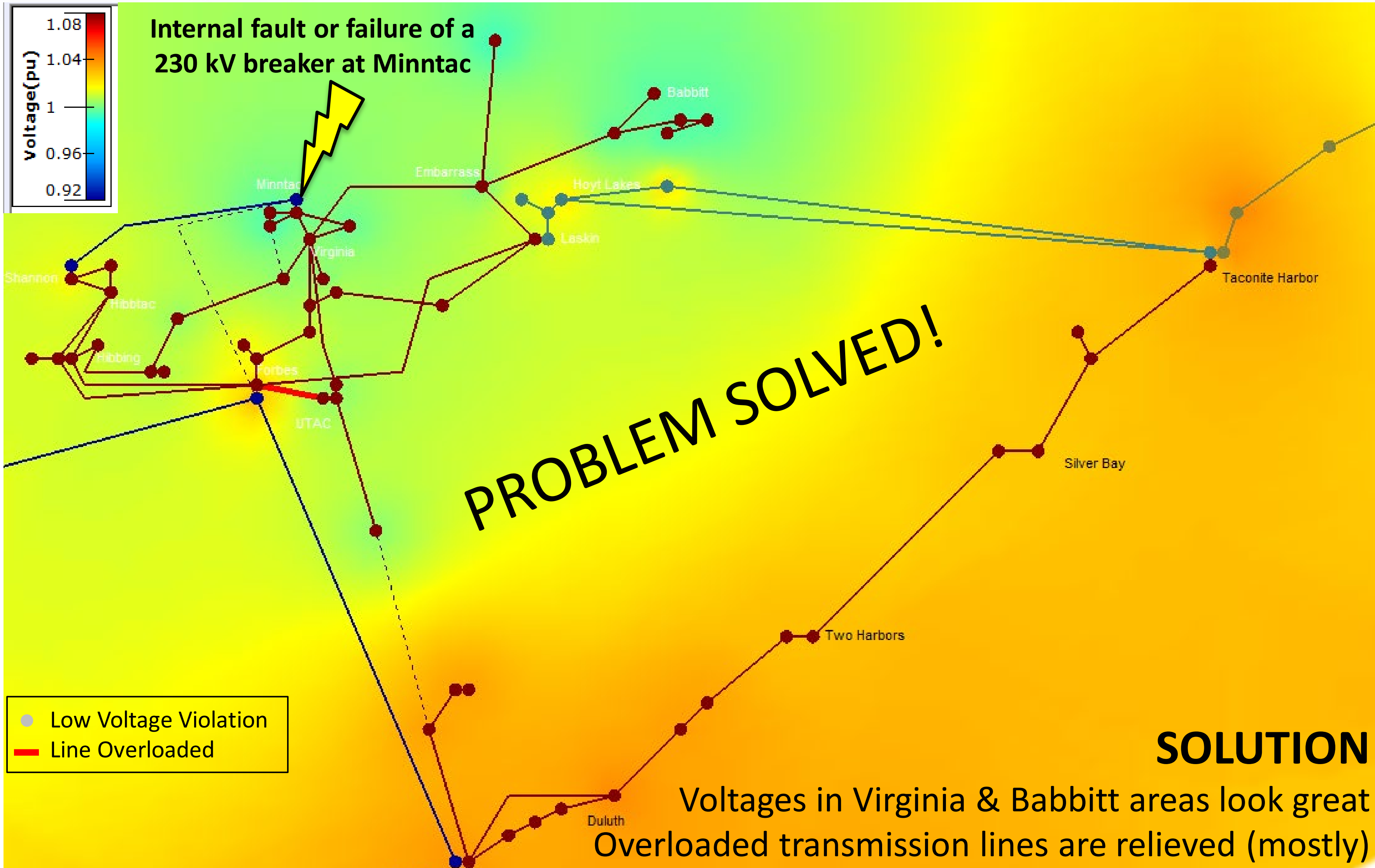


Minntac source lost
Power rerouted onto 115 kV

PROBLEM

Low voltages in Virginia & Babbitt areas
Transmission lines to Virginia area overloaded

Minntac: Critical Contingency (Post-Project)

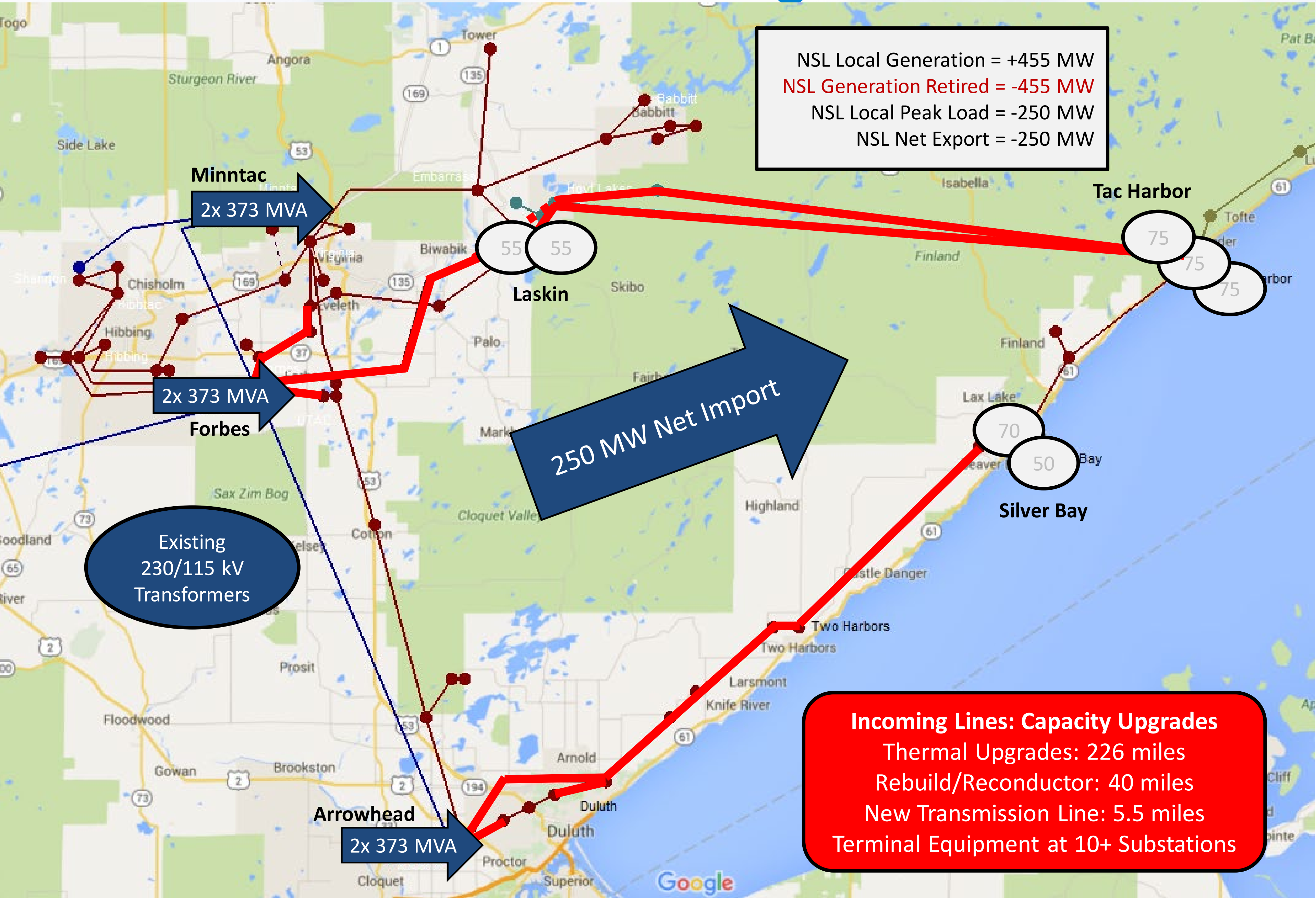


SOLUTION

Voltages in Virginia & Babbitt areas look great

Overloaded transmission lines are relieved (mostly)

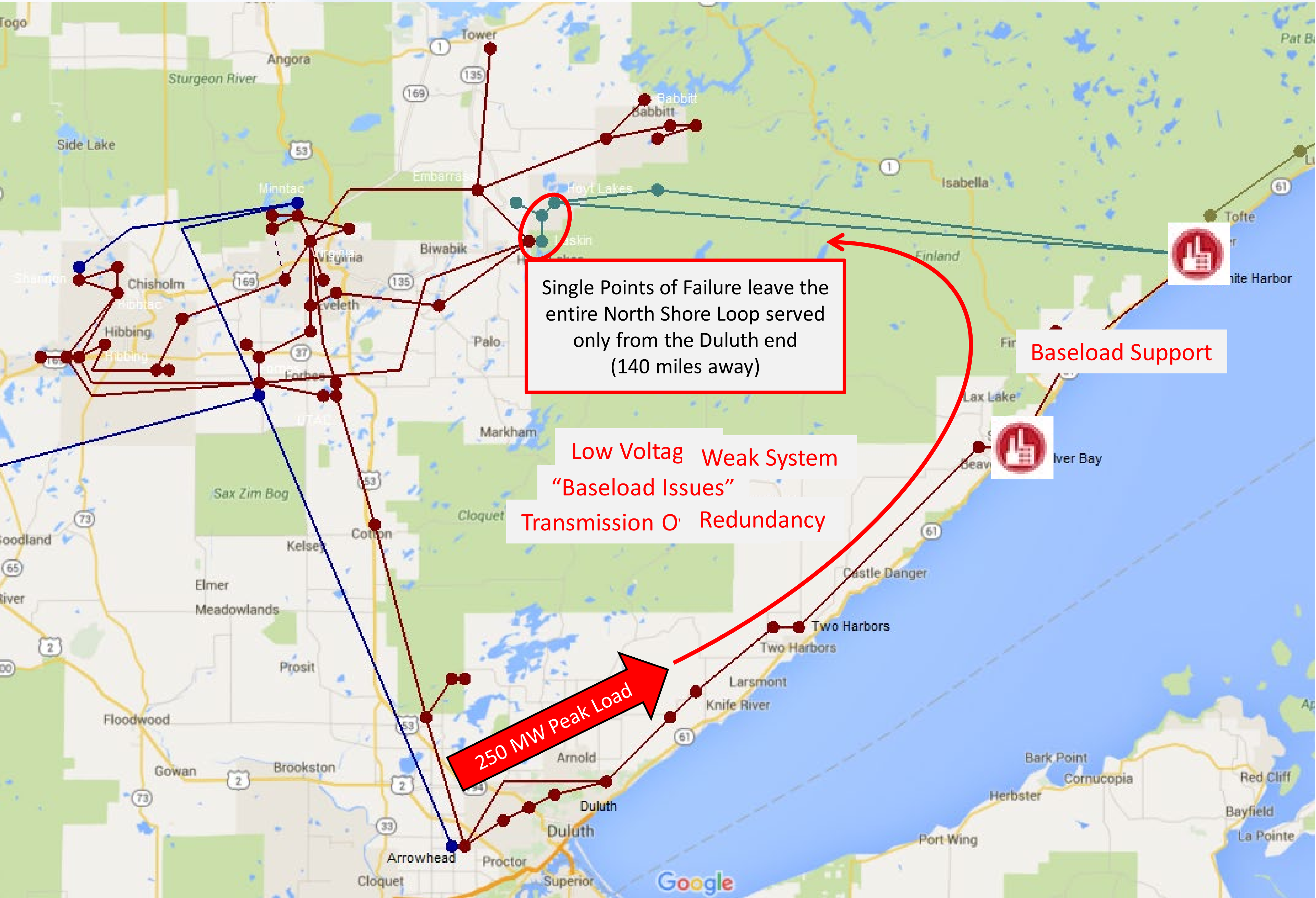
Increased Flow on Incoming Lines



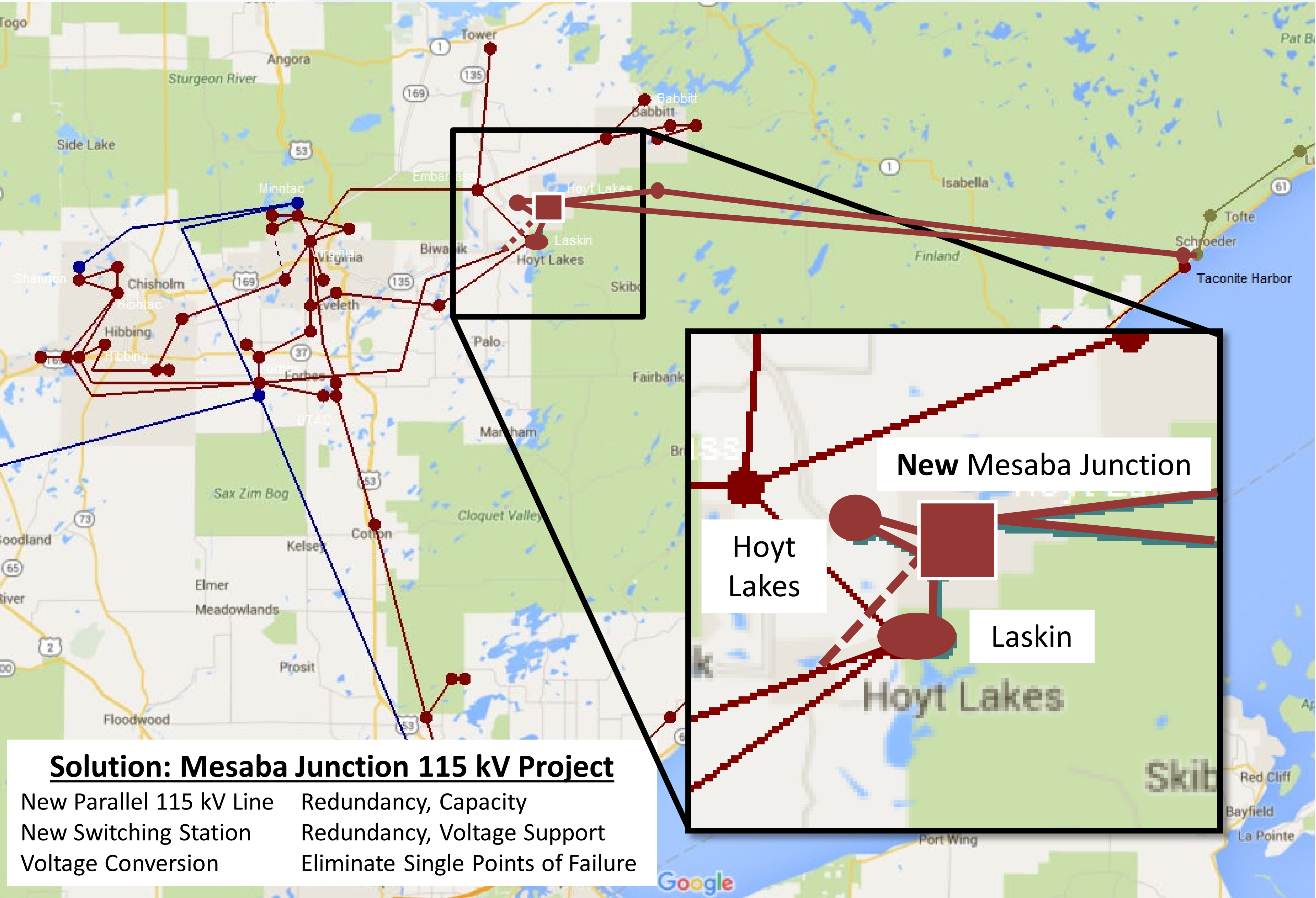
Transmission Impacts from Fleet Transition

- Voltage Support & System Strength
  - Steady state voltage regulation
  - Dynamic reactive support (Voltage Stability, Damping)
  - Short circuit capability
- Power Delivery Capability
  - Increased reliance on 230/115 kV Sources
  - Increased power flow on 115 kV system
- Redundancy
  - Fewer sources available in the area
  - Limited options for mitigating issues

Redundancy: Hoyt Lakes End



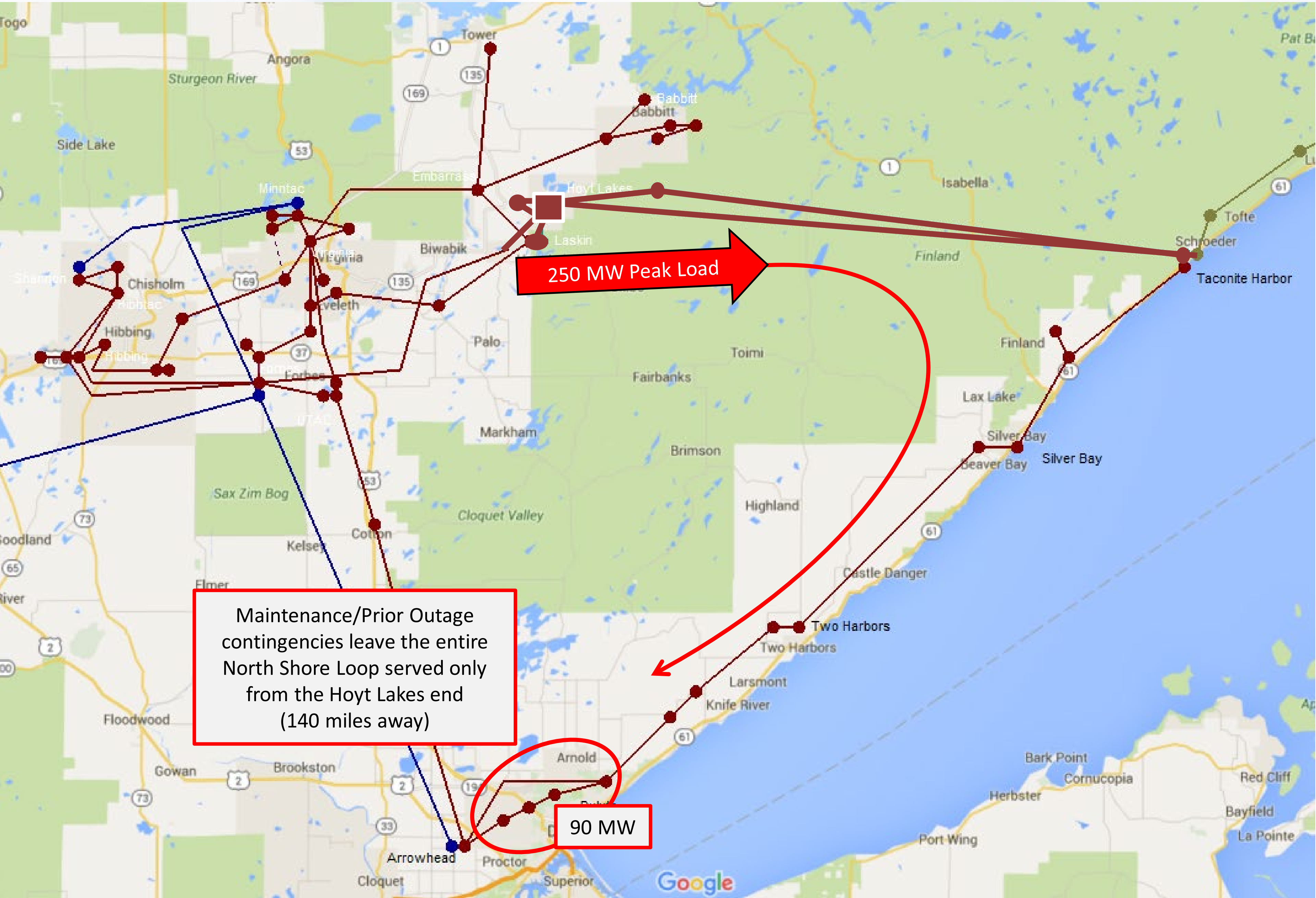
Mesaba Junction 115 kV Project



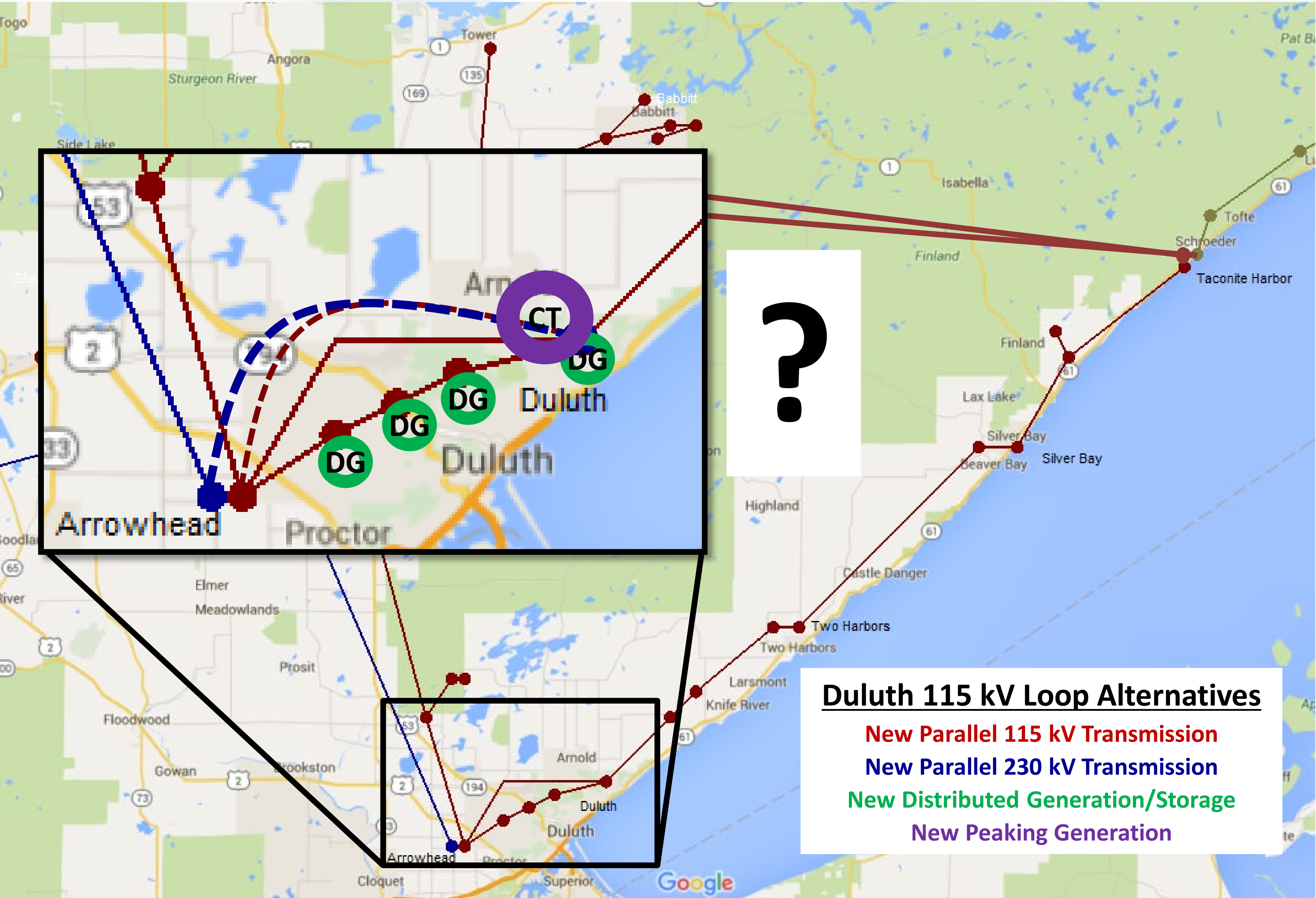
Solution: Mesaba Junction 115 kV Project

New Parallel 115 kV Line	Redundancy, Capacity
New Switching Station	Redundancy, Voltage Support
Voltage Conversion	Eliminate Single Points of Failure

Redundancy: Duluth End



Duluth 115 kV Loop Solution Alternatives



North Shore Loop Transmission Projects