Understanding Michigan's Transmission Needs: Technical Appendix

June 2023

TELOS ENERGY

GridLAB

Introduction

Purpose: Assess the grid's physical capabilities and constraints for moving power into the lower peninsula

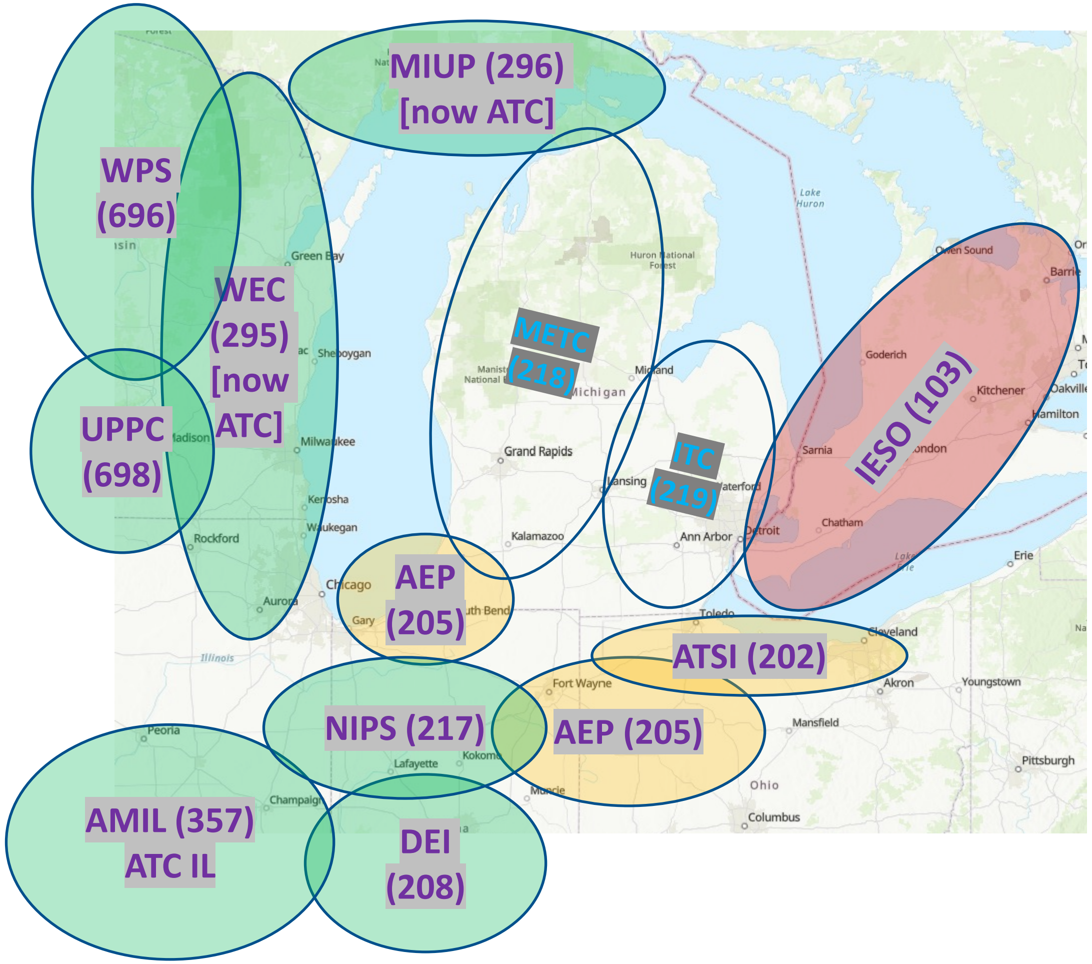
Outline:

- Analysis Approach
- Base Case Development
- PJM and IESO Import Findings
- All Imports and Regional Power Flow Considerations
- Tranche 1 Findings
- Ludington Findings

Note: All transmission maps shown are from publicly available databases found here:
https://www.arcgis.com/apps/mapviewer/index.html

Transmission Analysis

First-Contingent Incremental Transfer Capability (FCITC) analysis to the Lower Peninsula from surrounding areas



Focus is primarily on the summer peak snapshot

MISO Imports (area #)

- 217, 296, 208, 357, 295, 696, 698, 207, 210, 216, 314, 360, 361, 356, 357

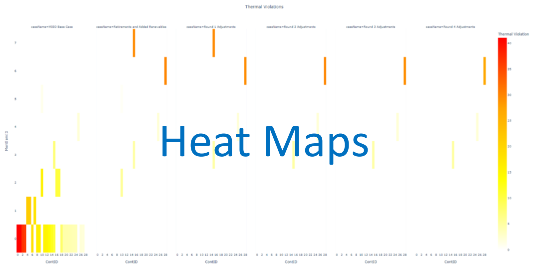
Ontario Imports (area #)

- 103

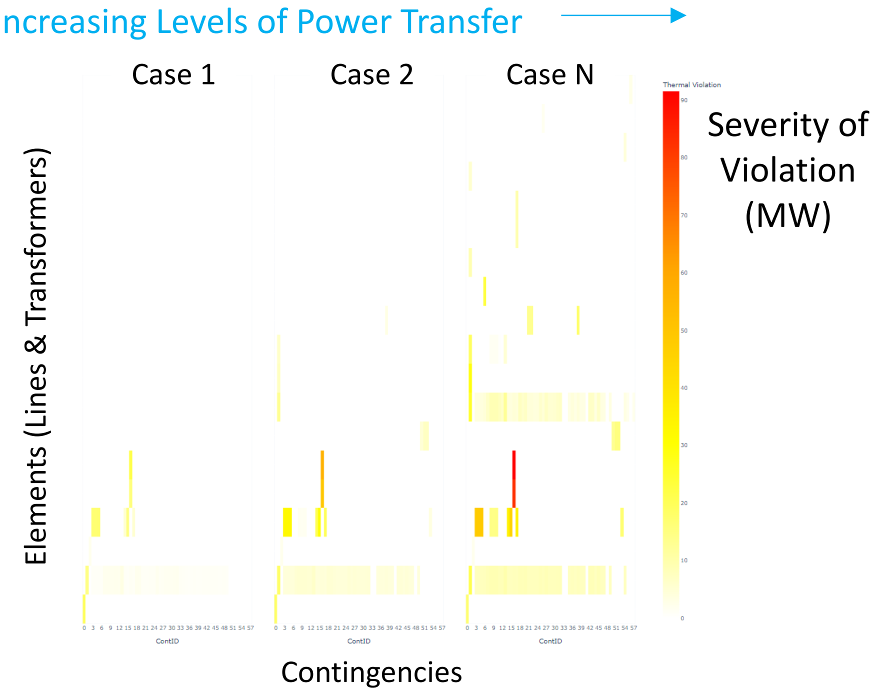
PJM Imports (area #)

- 202 and 205

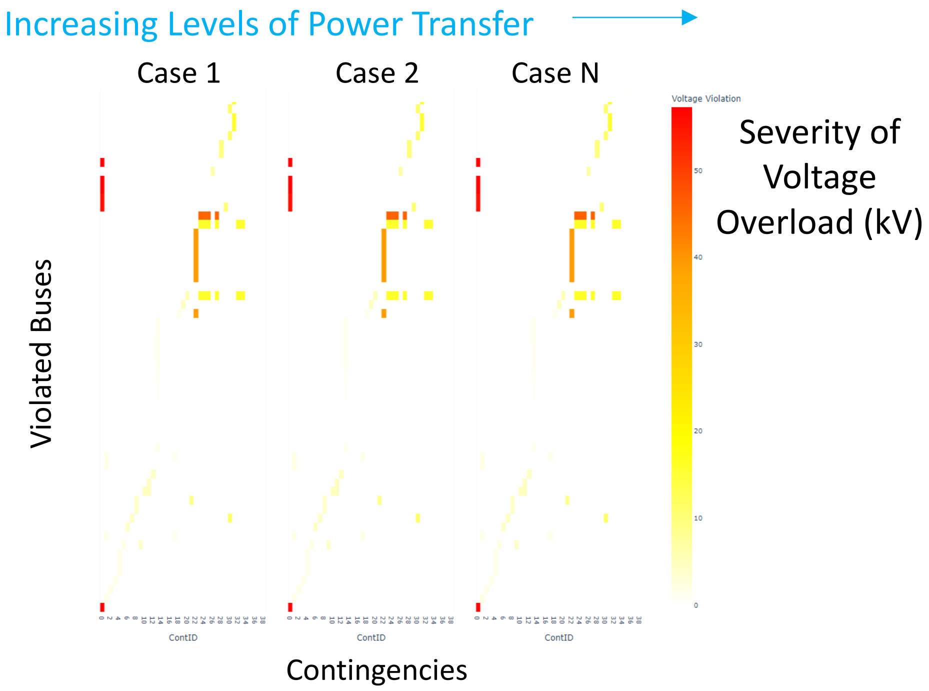
Results Visualizations



Visualizing Thermal Violations
(MW Overloads of Lines & Transformers)



Visualizing Voltage Violations
(Buses / Substations with low voltage)

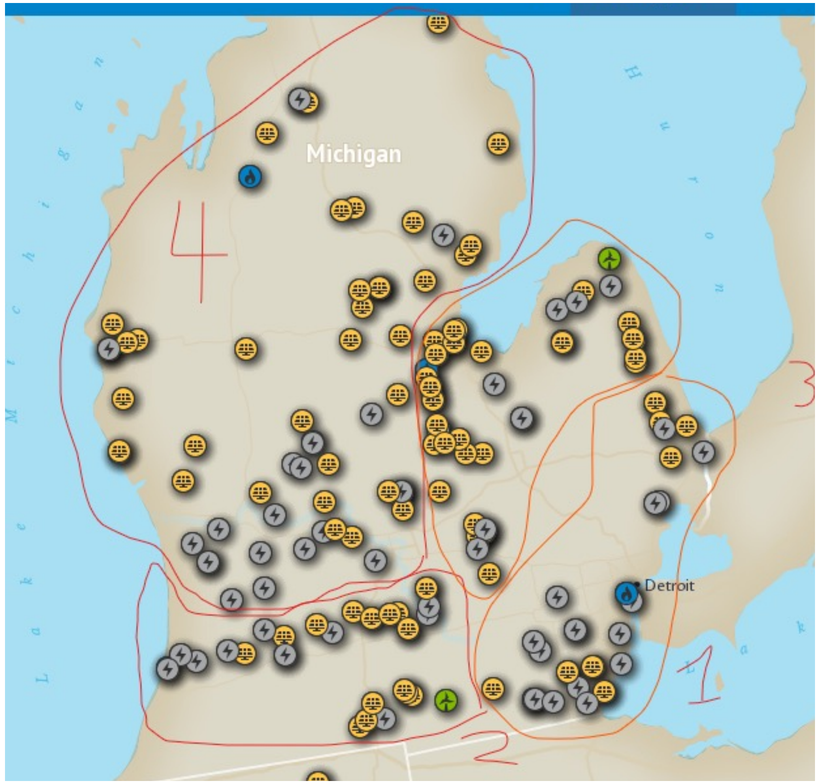


Note: Data for contingencies and overloaded elements are anonymized in the following slides (shown and "ContID" and "MonElemID")

Base Case Development

A 2025 Future Scenario

Base Case



MISO Generator Interconnection Queue Map

2025 MISO cases modified

Retirements (3.9 GW)

- St. Clair (4 units, 1.1GW)
- Trenton Channel (unit 9, 500MW)
- Campbell (4 units, 1.5 GW)
- Palisades (1 unit, 800 MW)

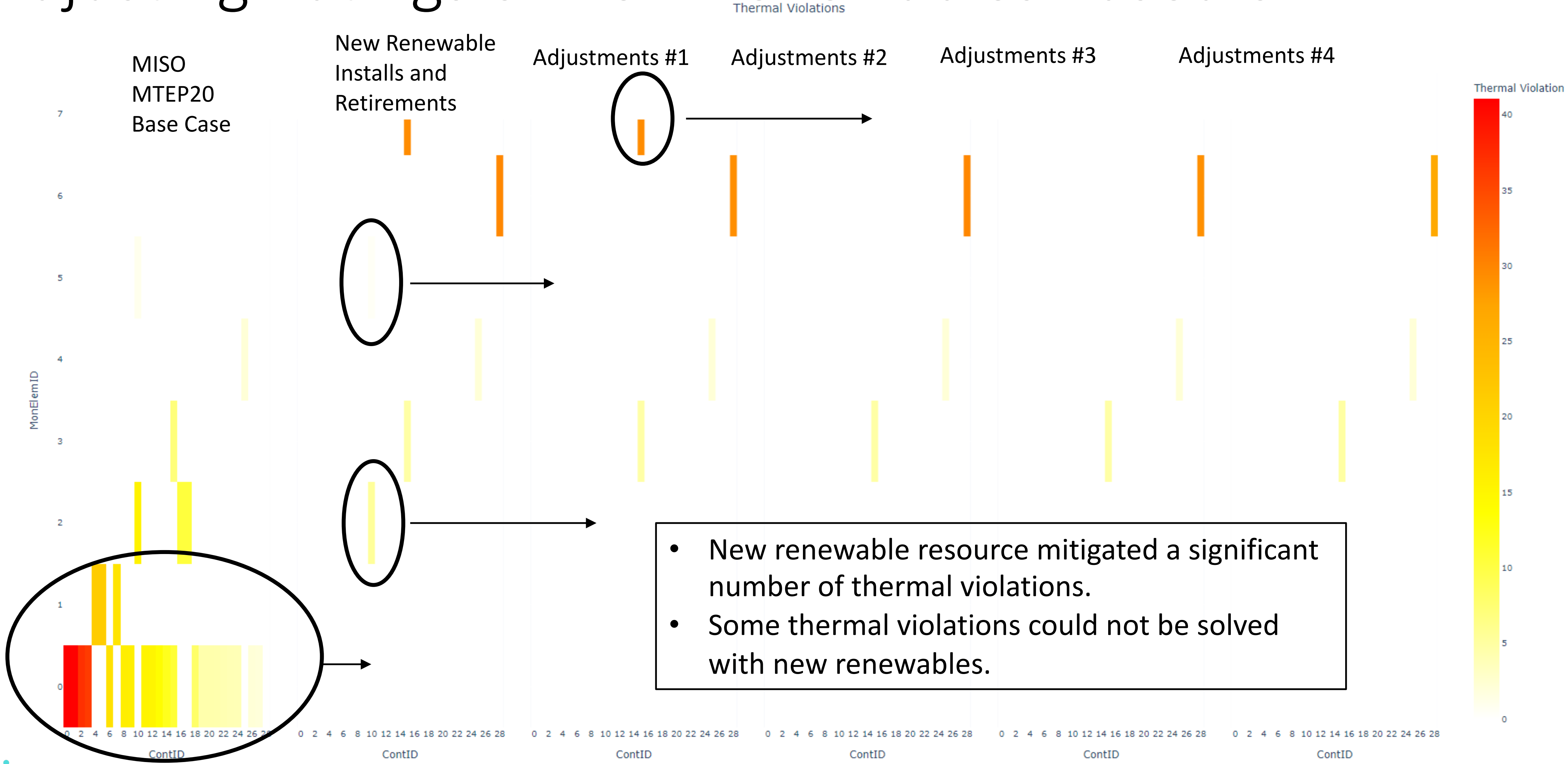
New Generation (3.9 GW dispatched)

- Solar, Wind, Battery (8.6GW installed, 3.9 GW dispatched)
- Locations based on MISO Queue – 12/31/2024
- Dispatch levels for Summer and Shoulder

Our Resource Dispatch Assumptions:

Dispatch level - Verified From MTEP22, 2024 Models							
Case/	Summer		Shoulder		Spring Light		Winter
Type	AA	TA	Average	High	AA	TA	
Solar	48%	48%	33%	0	0	0	0
Wind	16%	17%	28%	83%	0	0	67%

Adjusting Ratings of New Renewables Based on DFAX



- New renewable resource mitigated a significant number of thermal violations.
- Some thermal violations could not be solved with new renewables.

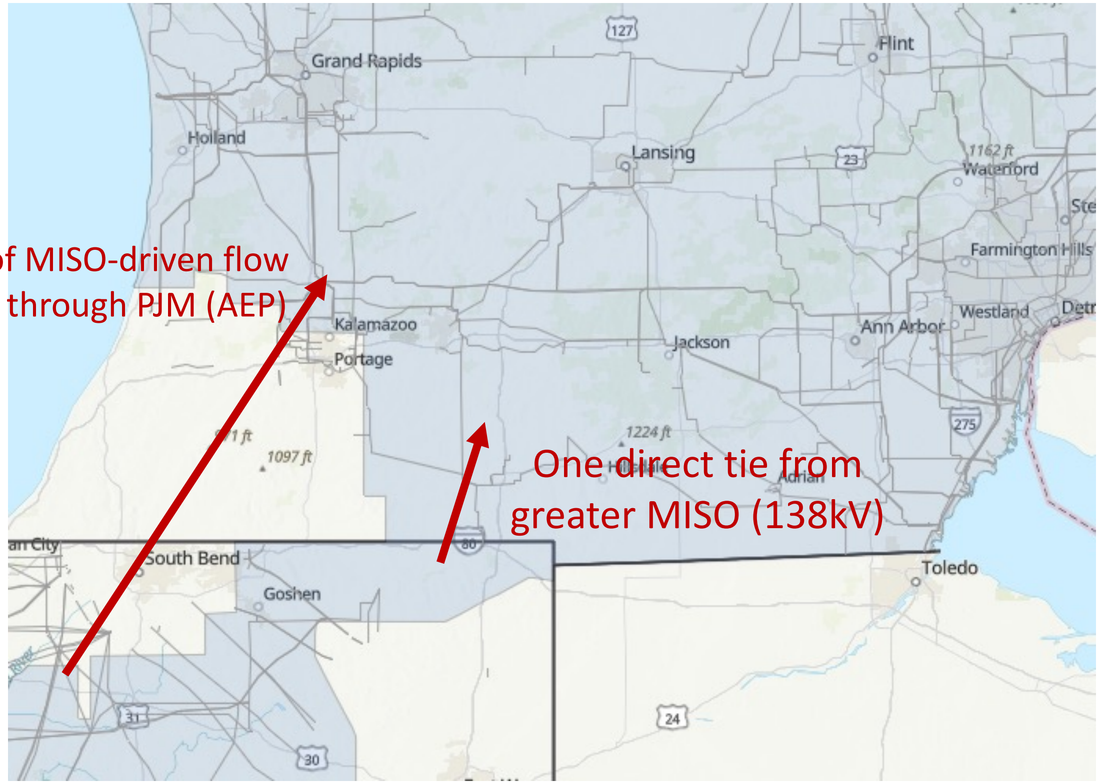
Imports from MISO, PJM

Transmission Import Capability

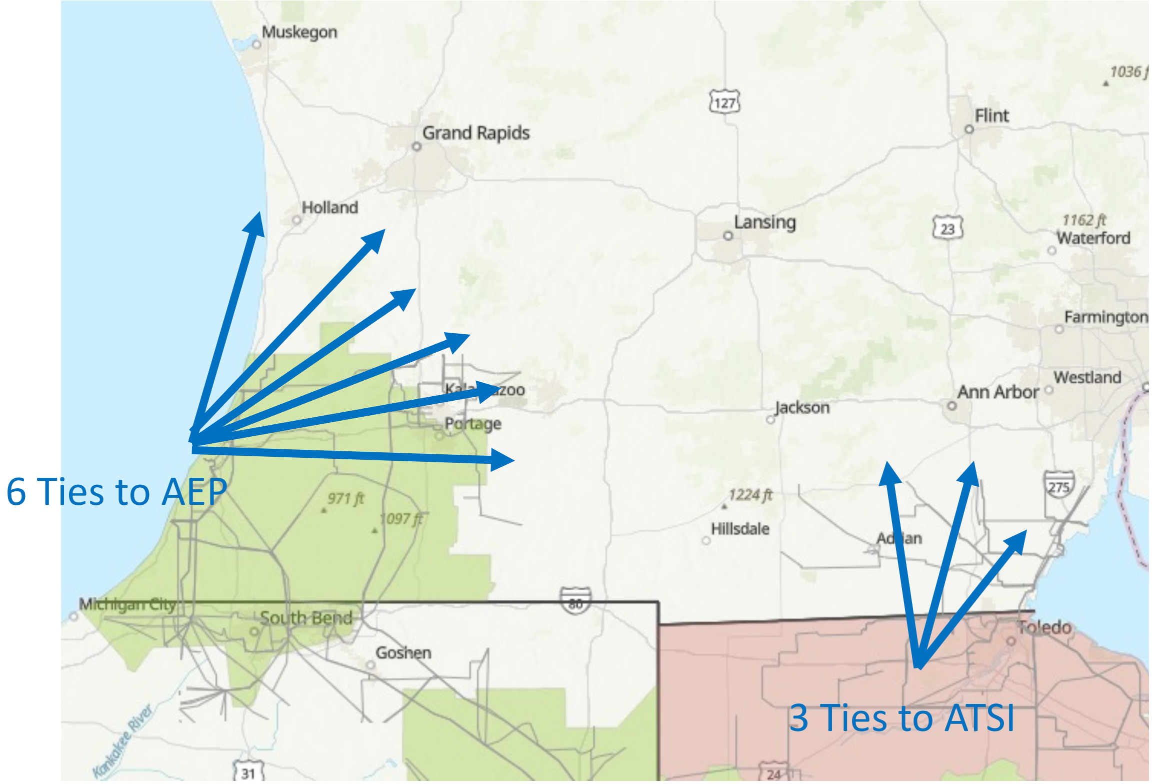
MISO v. PJM Import Flows

MISO Flow Paths

Most of MISO-driven flow comes through PJM (AEP)



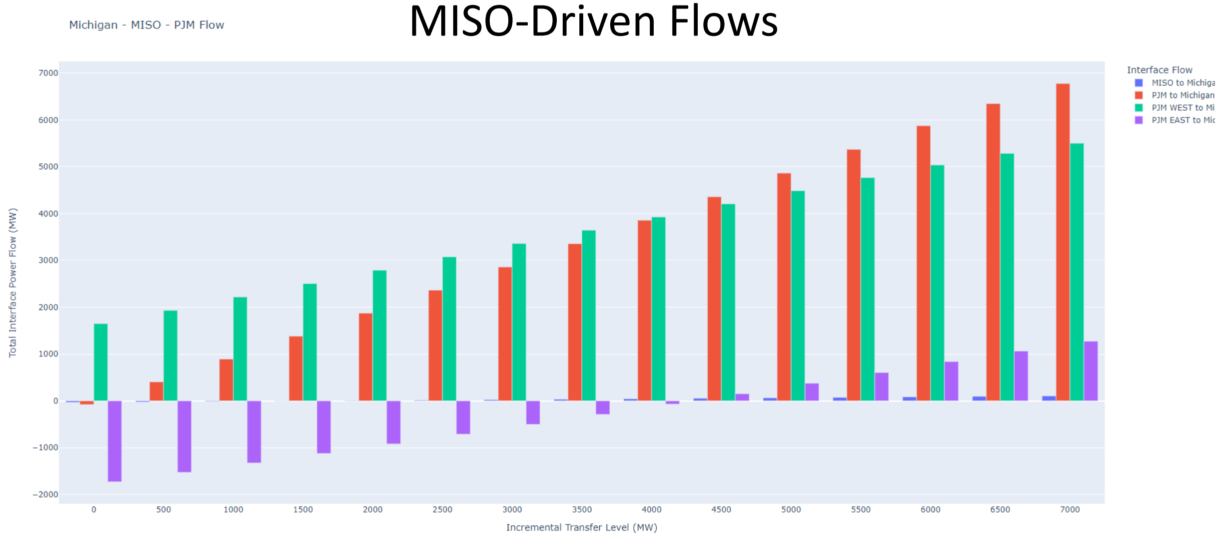
PJM Flow Paths



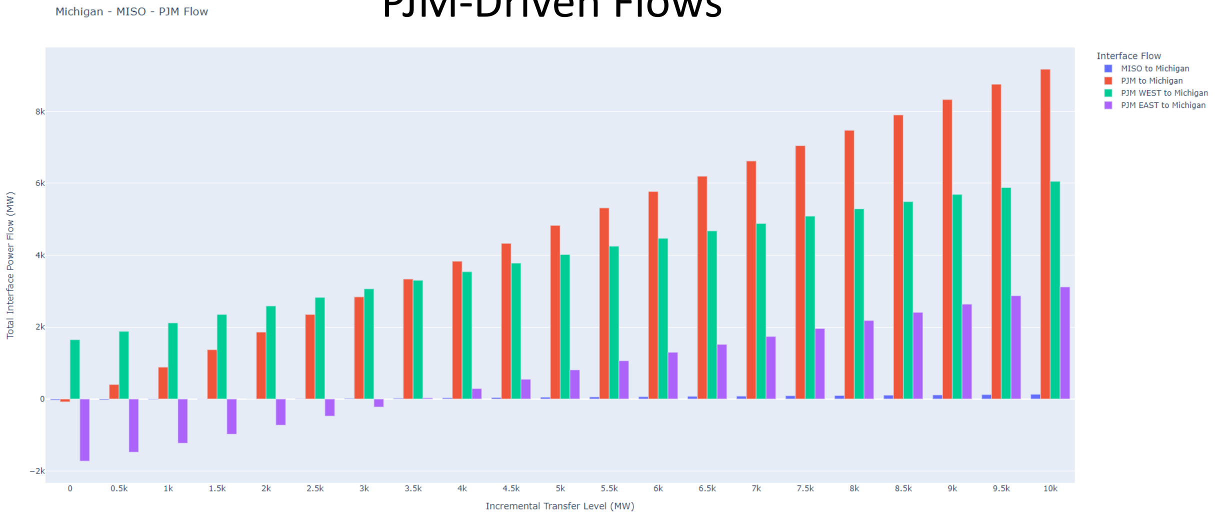
Flows to Michigan Driven from PJM, MISO

Legend
MISO
PJM Total
PJM West
PJM East

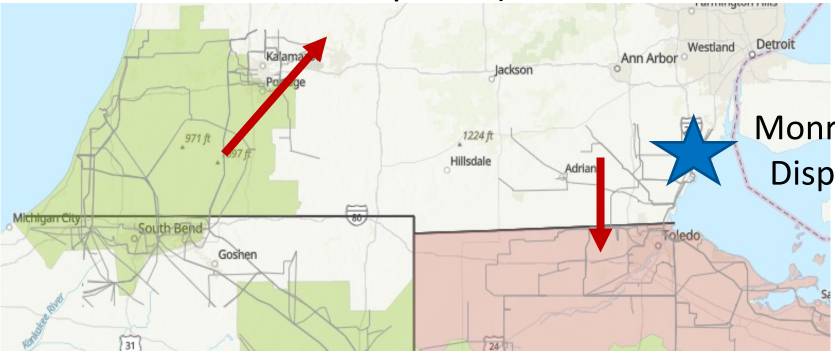
MISO-Driven Flows



PJM-Driven Flows

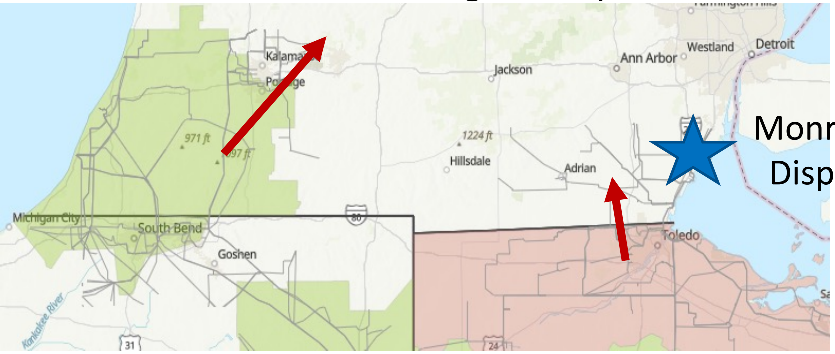


Flows Paths at Lower Imports (near MISO Base Case)



Monroe Fully Dispatched

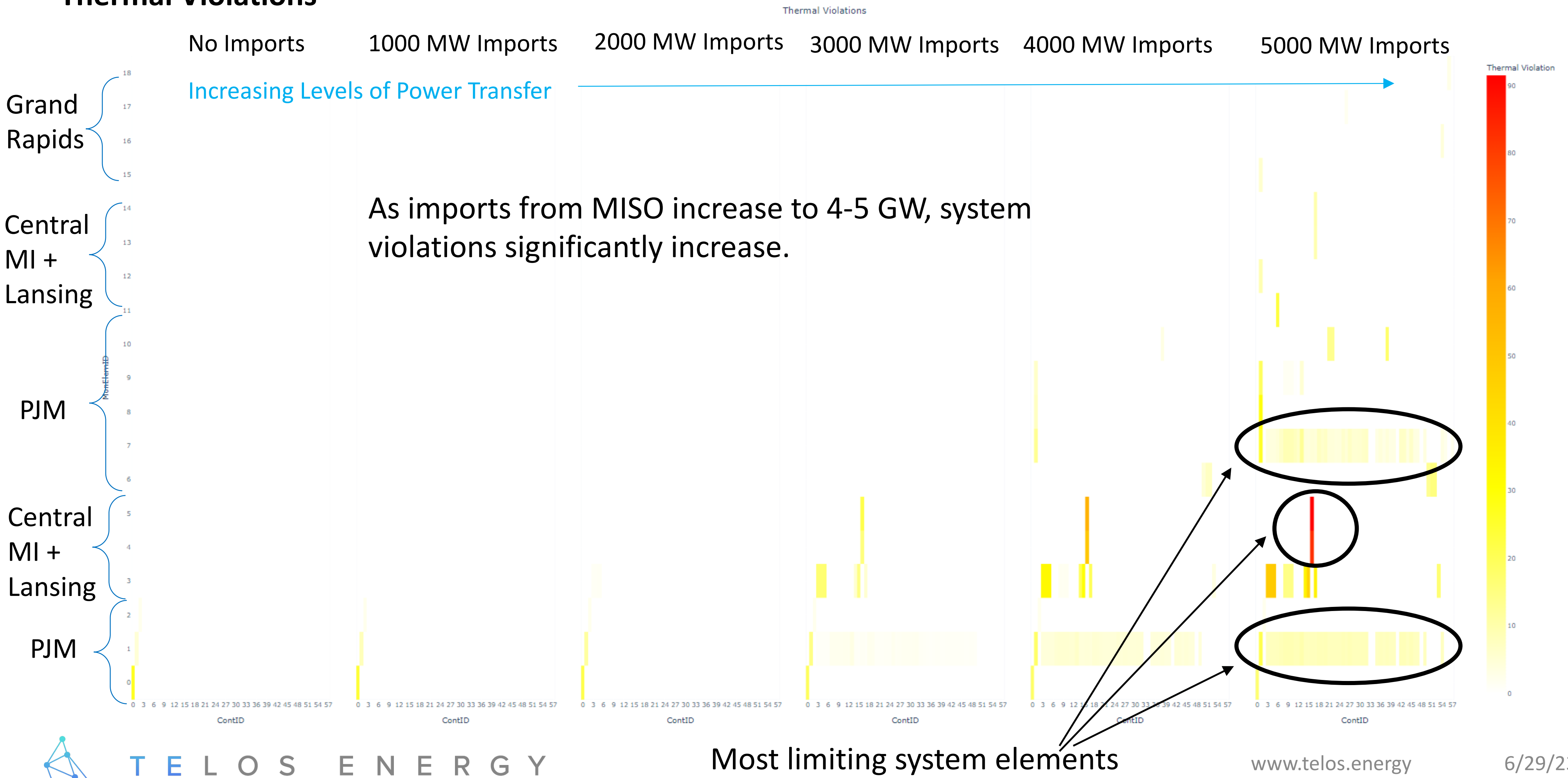
Flows Paths at Higher Imports



Monroe Fully Dispatched

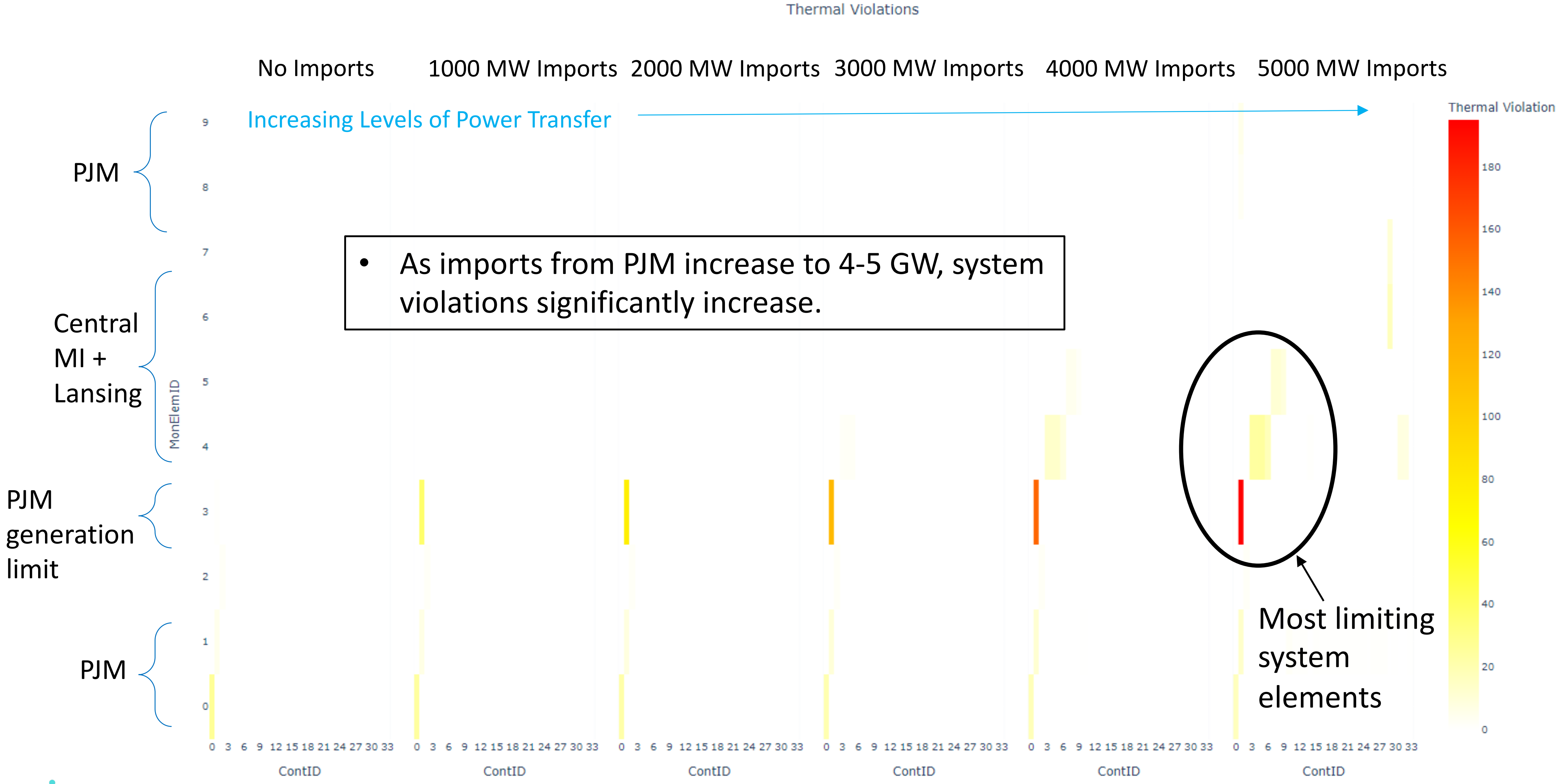
MISO-Driven Transfers, Thermal Violations

Thermal Violations



As imports from MISO increase to 4-5 GW, system violations significantly increase.

PJM-Driven Transfers, Thermal Violations



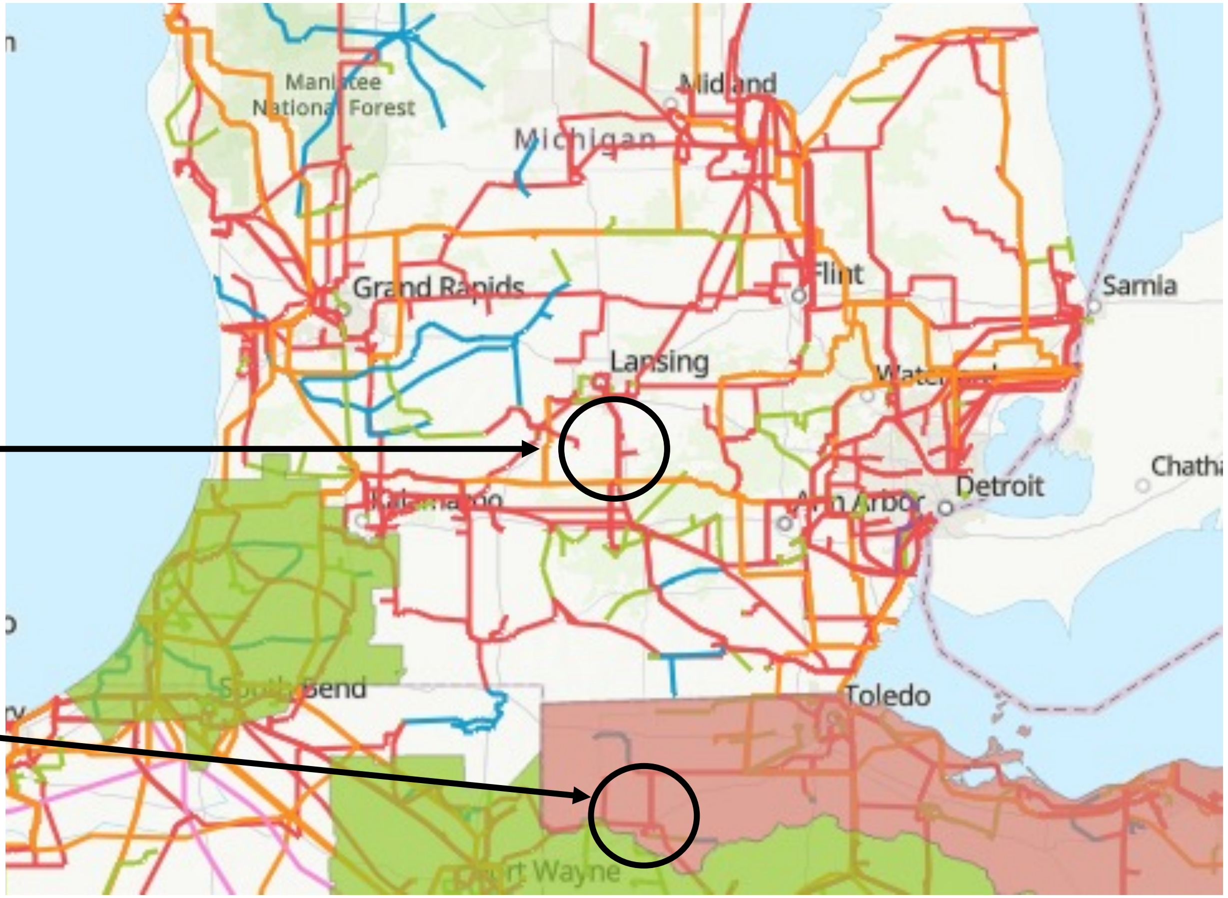
- As imports from PJM increase to 4-5 GW, system violations significantly increase.

Southern Import Thermal Violations

Summary:
- 4-5 GW of transfer prior to violations (consistent with 202 MISO CEL/CIL study)
- These are relatively minor violations

In Michigan:
- Bus violations south of Lansing
- Violated elements have already been identified for Appendix A projects

In Ohio:
- Defiance area in OH is impacted by scaling generation (redispatch would resolve violations)
- The most affected elements are three 138kV lines (6, 7, and 16 miles)

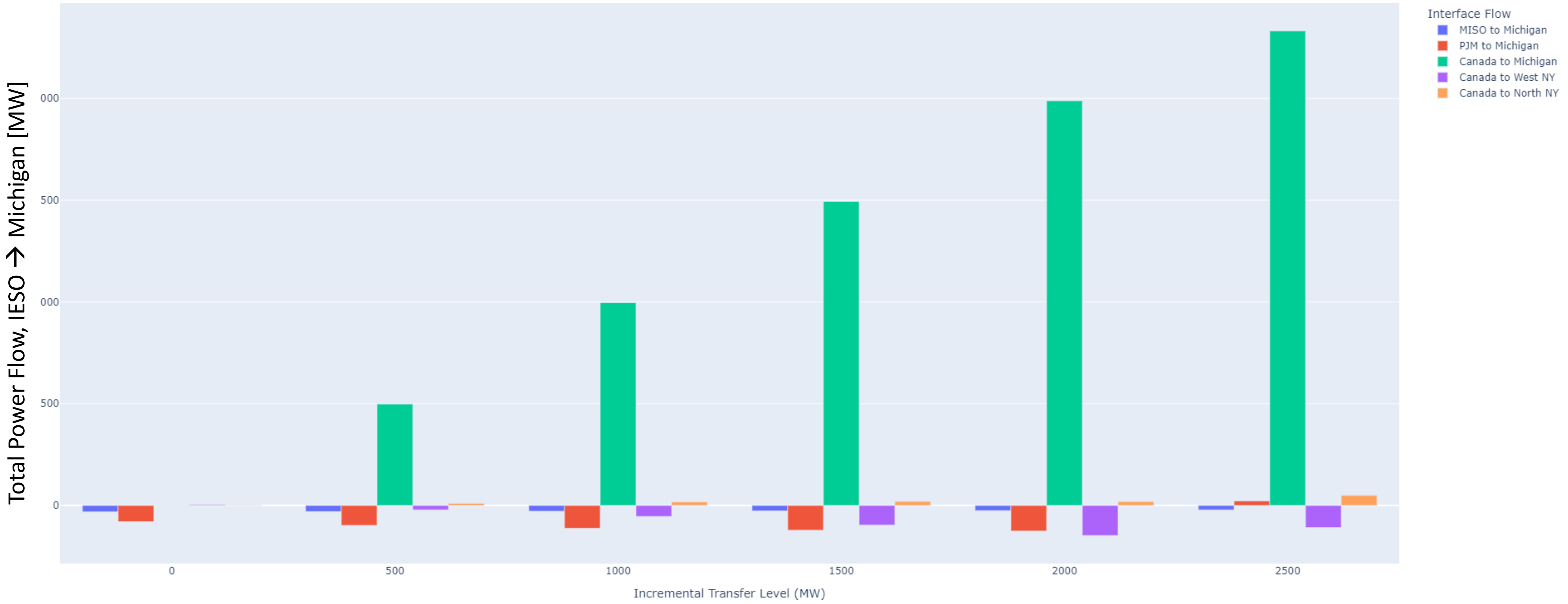


Imports from IESO

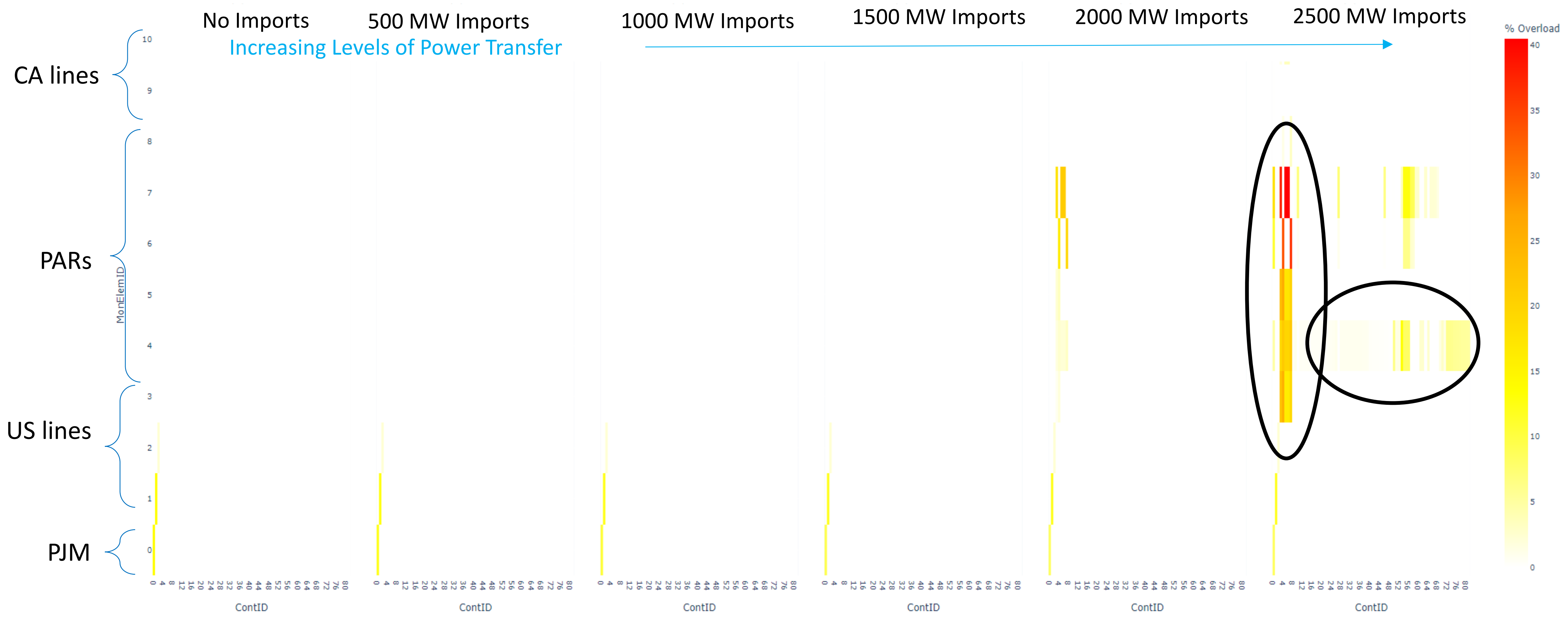
Steady-State Contingency Analysis

Canada Import Results

- Power is driven from Ontario to Michigan by Increasing Generation in Ontario and Modifying PAR Transfers
- Other interfaces are not significantly impacted because the PAR flows are coordinated with the change in Ontario generation

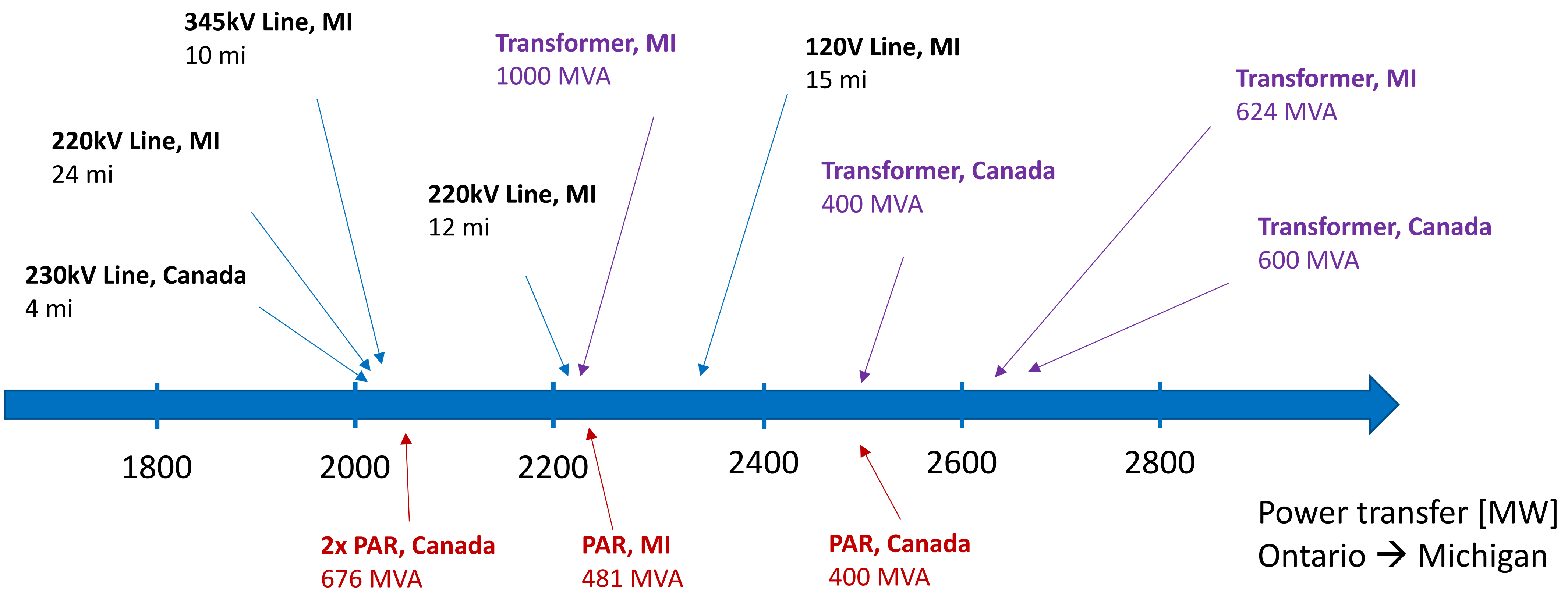


Ontario Export Results, Thermal



PARs themselves, nearby power transformers and lines interconnecting to the PARs become thermally overloaded for at least one contingency beyond 2GW of transfer (IESO → MI)

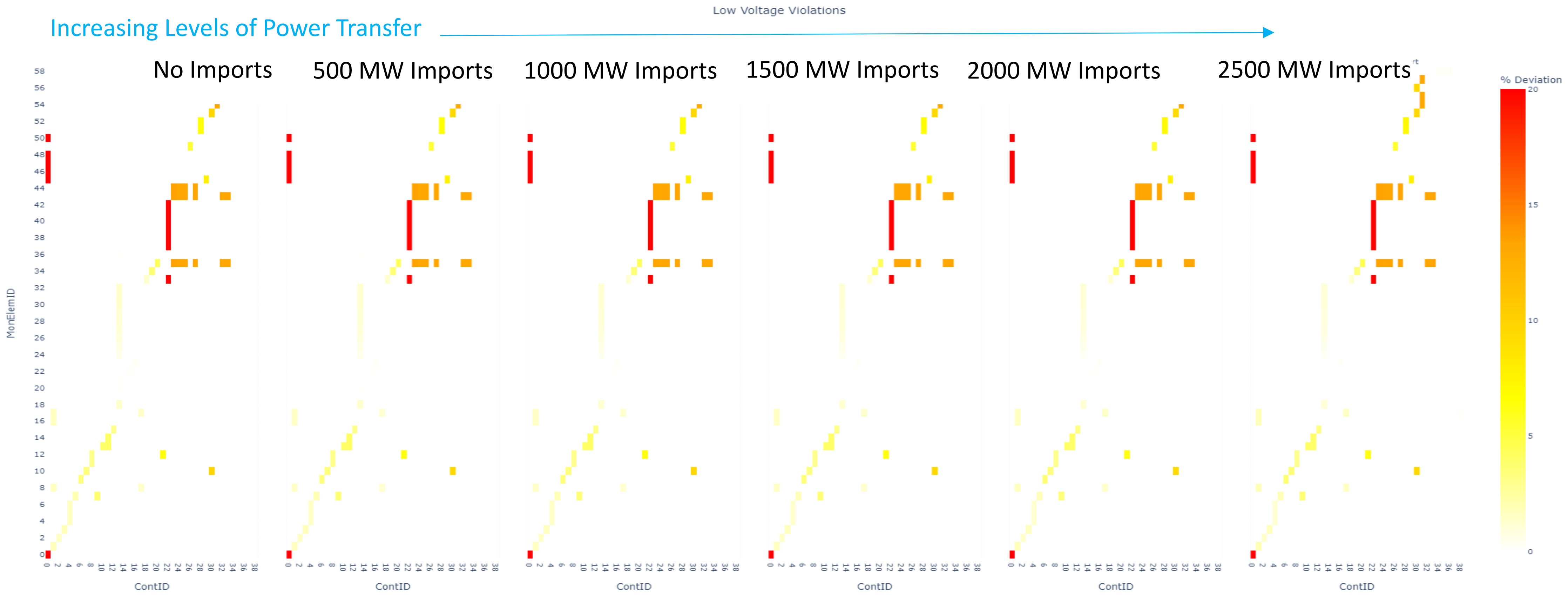
Beyond the PAR limits – MI and Canada Overloads



Ontario Export Results, Voltage

Voltage violations are essentially unchanged as power transfer increases. This is an expected result because:

- Major resources in Detroit remaining online in these scenarios, and
- the addition of voltage-regulating new renewable resources spread throughout the system

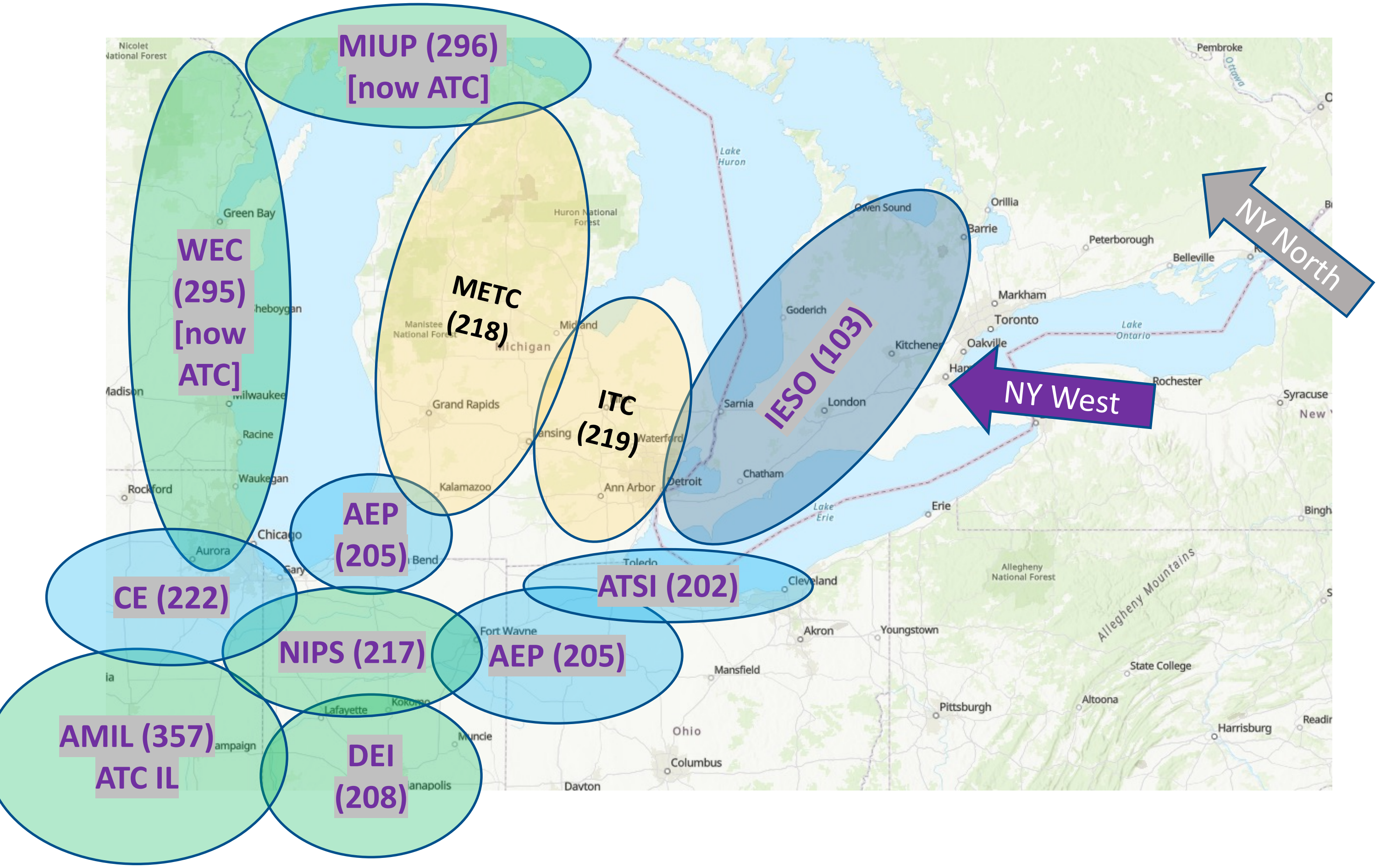


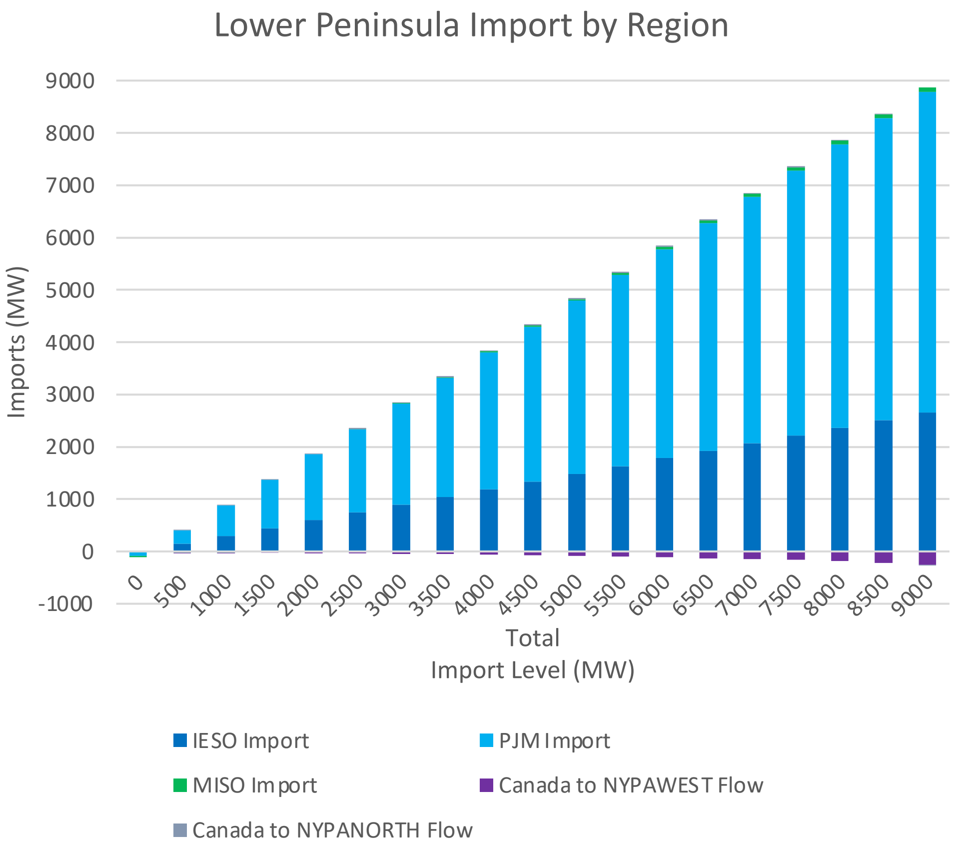
Imports from IESO, PJM, MISO

Regional Power Flow Considerations

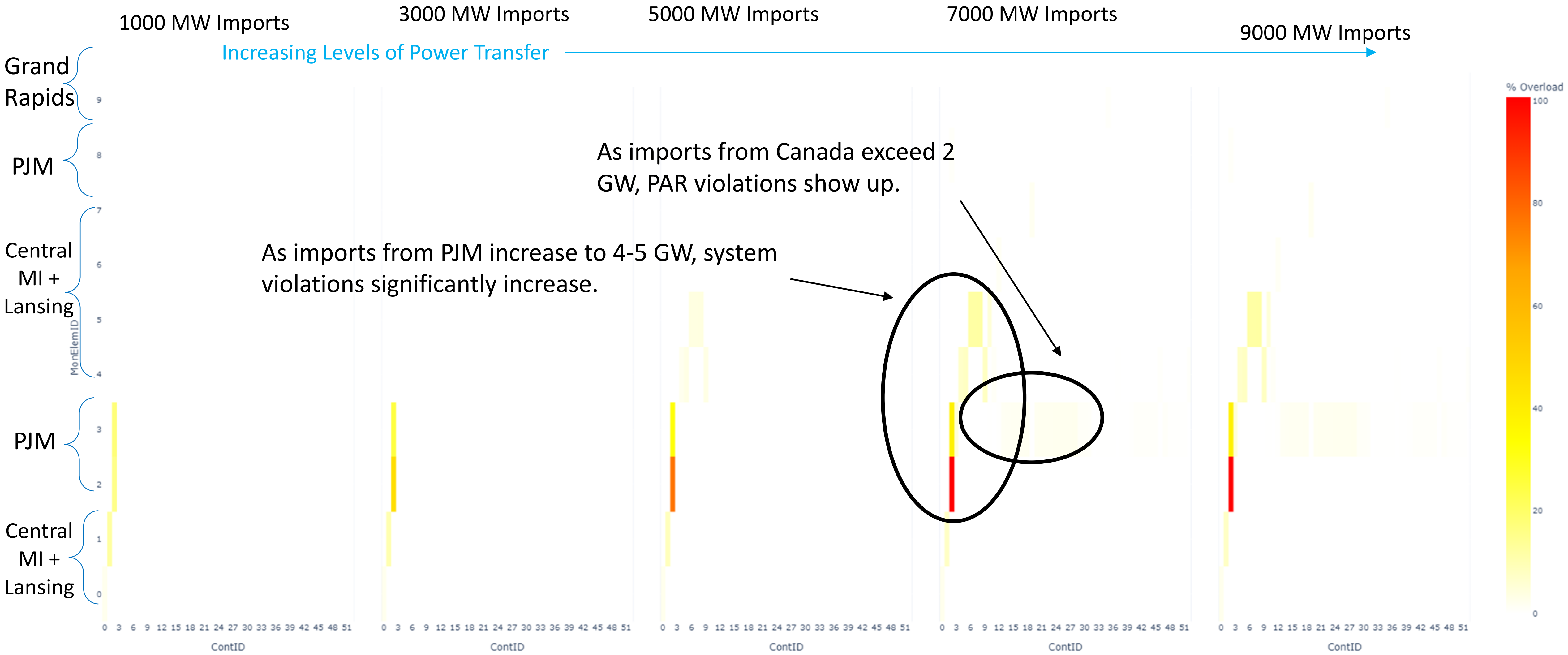
Michigan Imports – All Ties

Power Transfer Proportioning (Initial case: 30% IESO, 70% PJM + MISO)

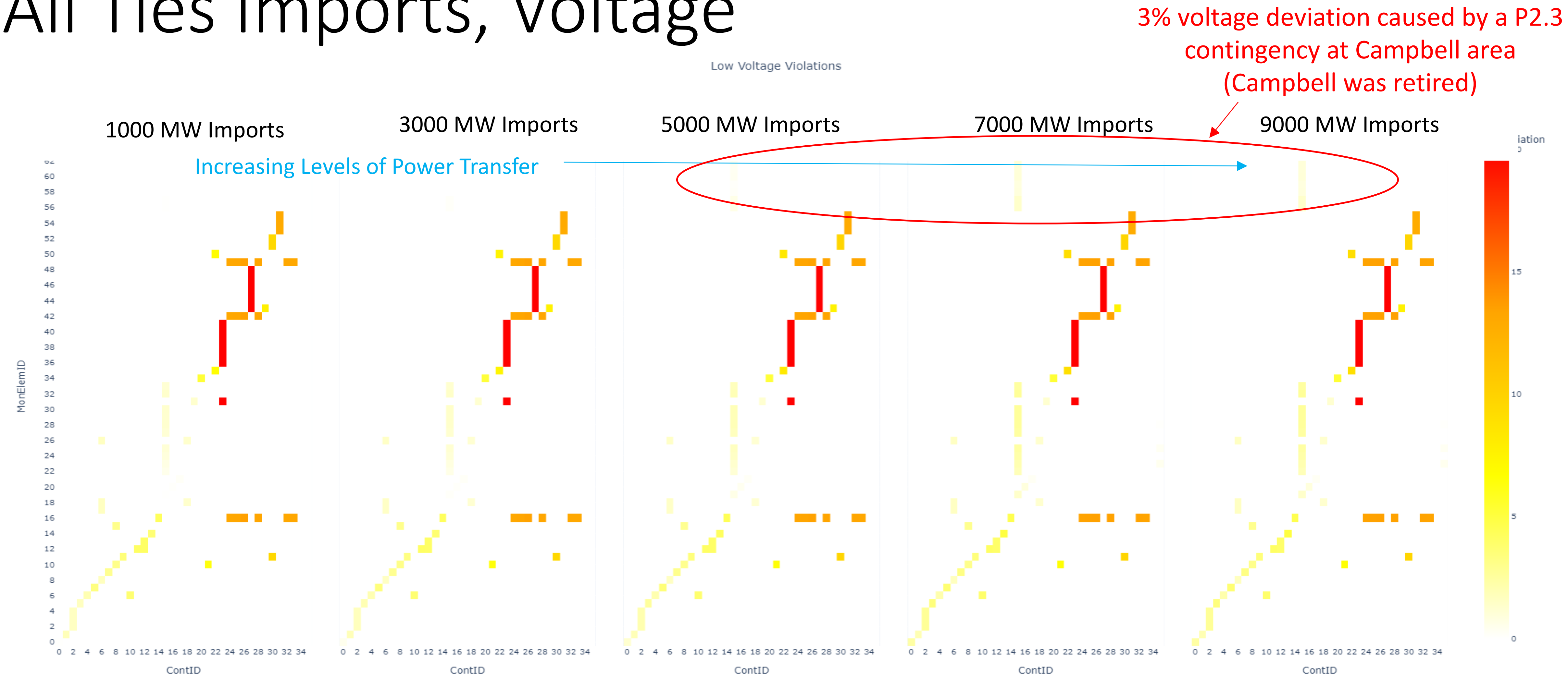




All Ties Imports, Thermal



All Ties Imports, Voltage



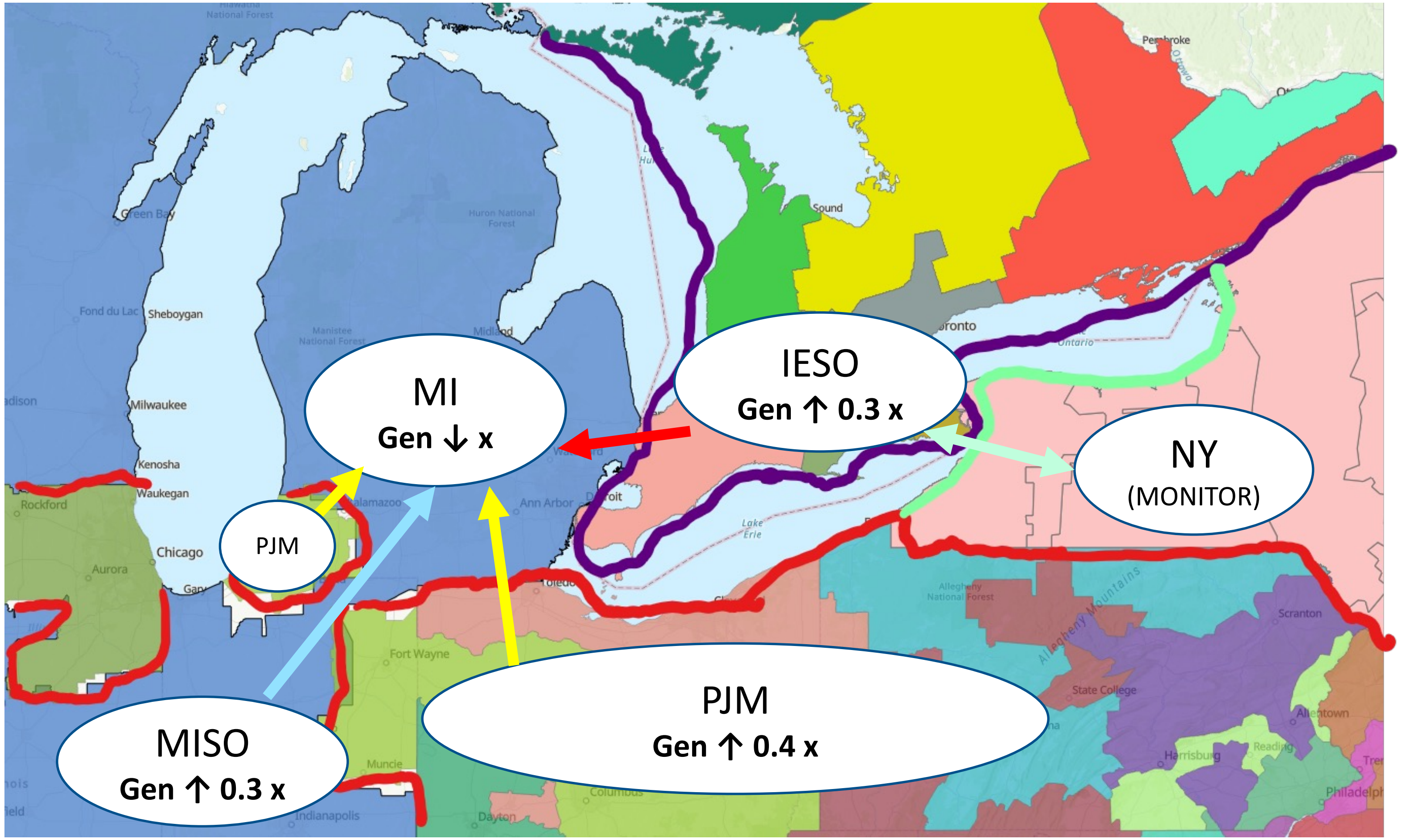
Voltage violations are not a significant constraint in these scenarios

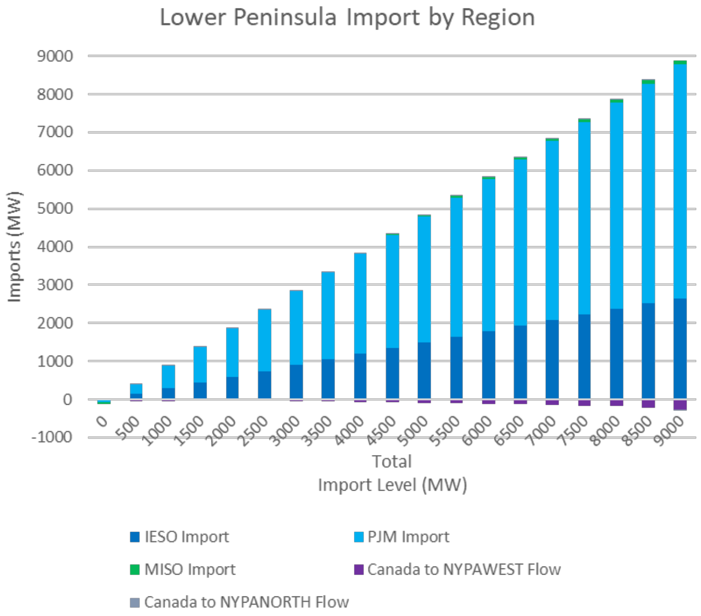
PAR Control Capability

A Closer Look at PAR Tapping

Power Import Balancing Sensitivity

Our Base Case for Driving Power into Michigan

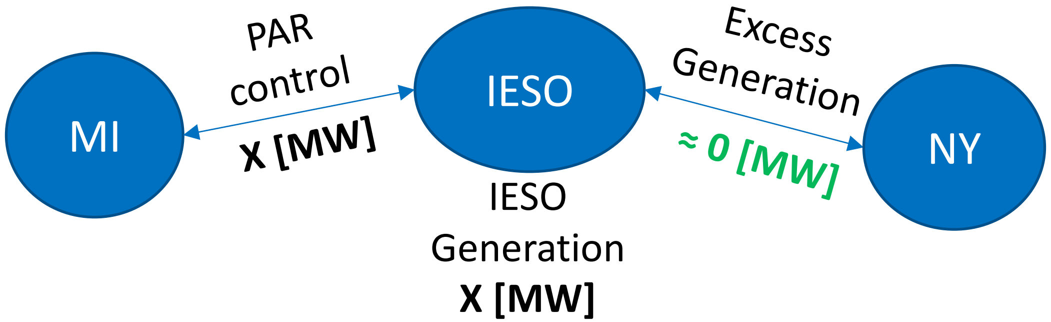




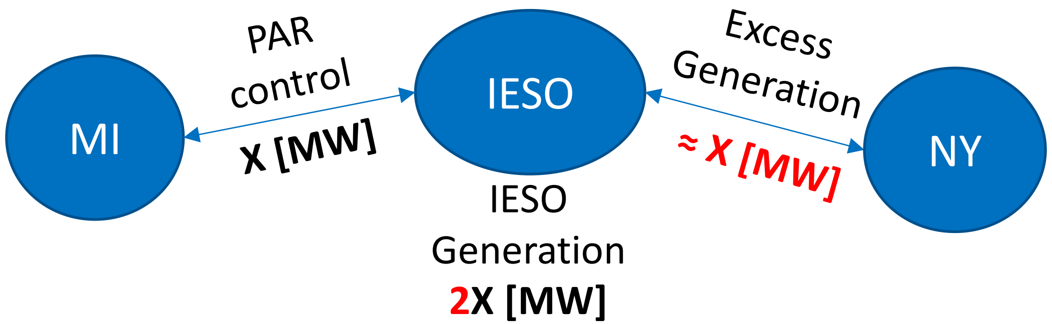
PAR Controllability & Lake Erie Circulation

To assess the impact on the PARs' tapping (controllability) for different regional transfer levels, we looked at 2 sensitivities to the base case:

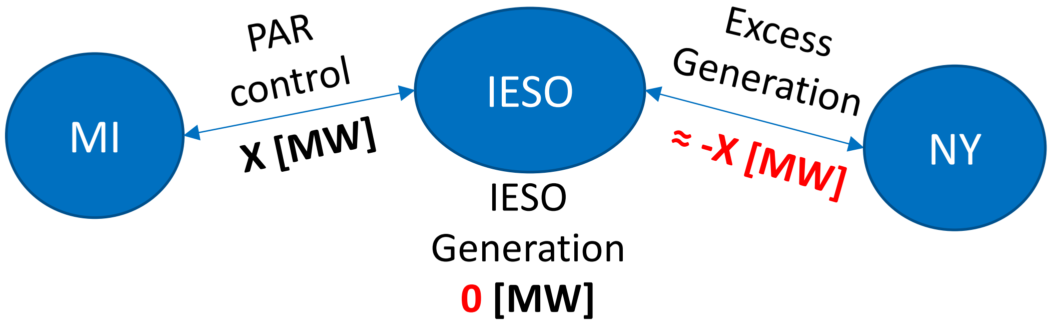
Base Case: Coordinated IESO Generation & PAR Flows



Sensitivity 1: High IESO Exports



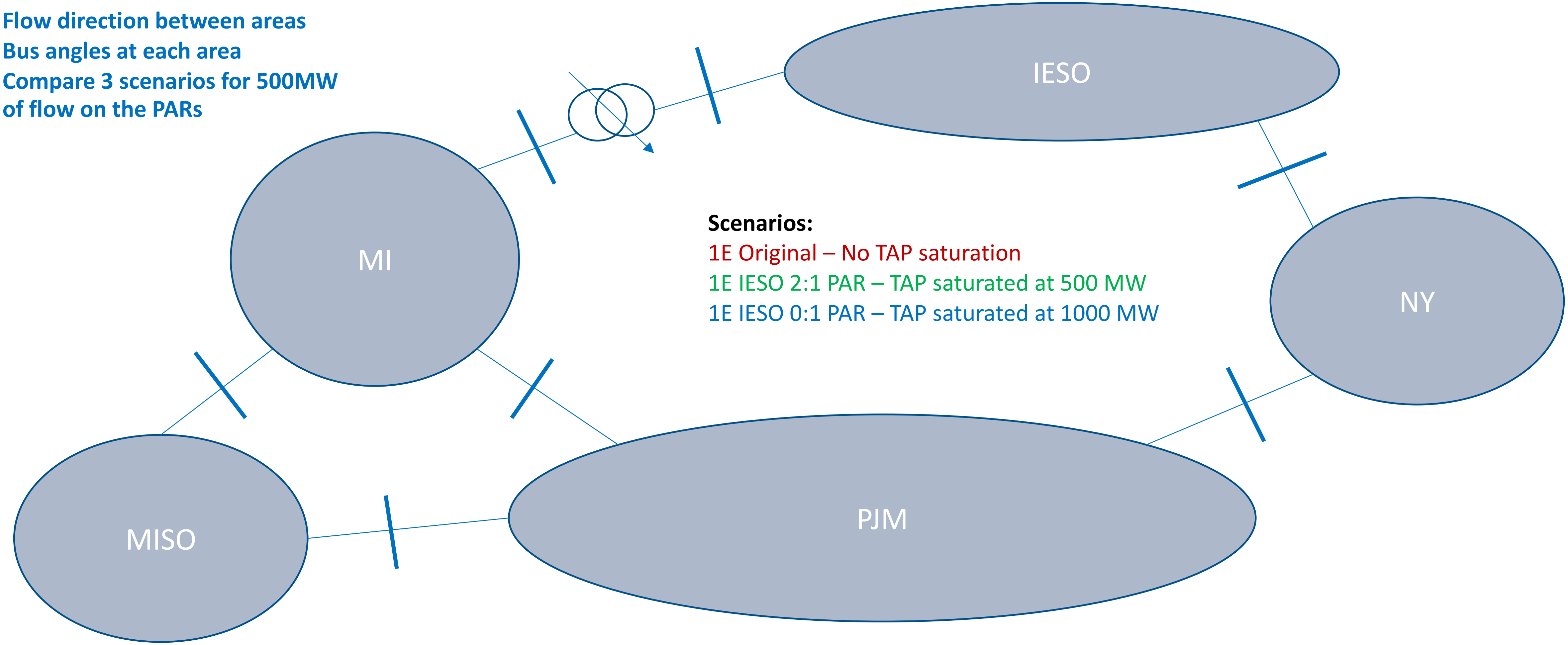
Sensitivity 2: NY Wheeling Power Through IESO



Lake Erie Circulation Findings

What did we look at?

- **Flow direction between areas**
- **Bus angles at each area**
- **Compare 3 scenarios for 500MW of flow on the PARs**



Scenarios:

1E Original – No TAP saturation

1E IESO 2:1 PAR – TAP saturated at 500 MW

1E IESO 0:1 PAR – TAP saturated at 1000 MW

Case: 500MW IESO→ MI

Sensitivities:

PAR 500MW:500MW IESO Gen

PAR 500MW:1000MW IESO Gen

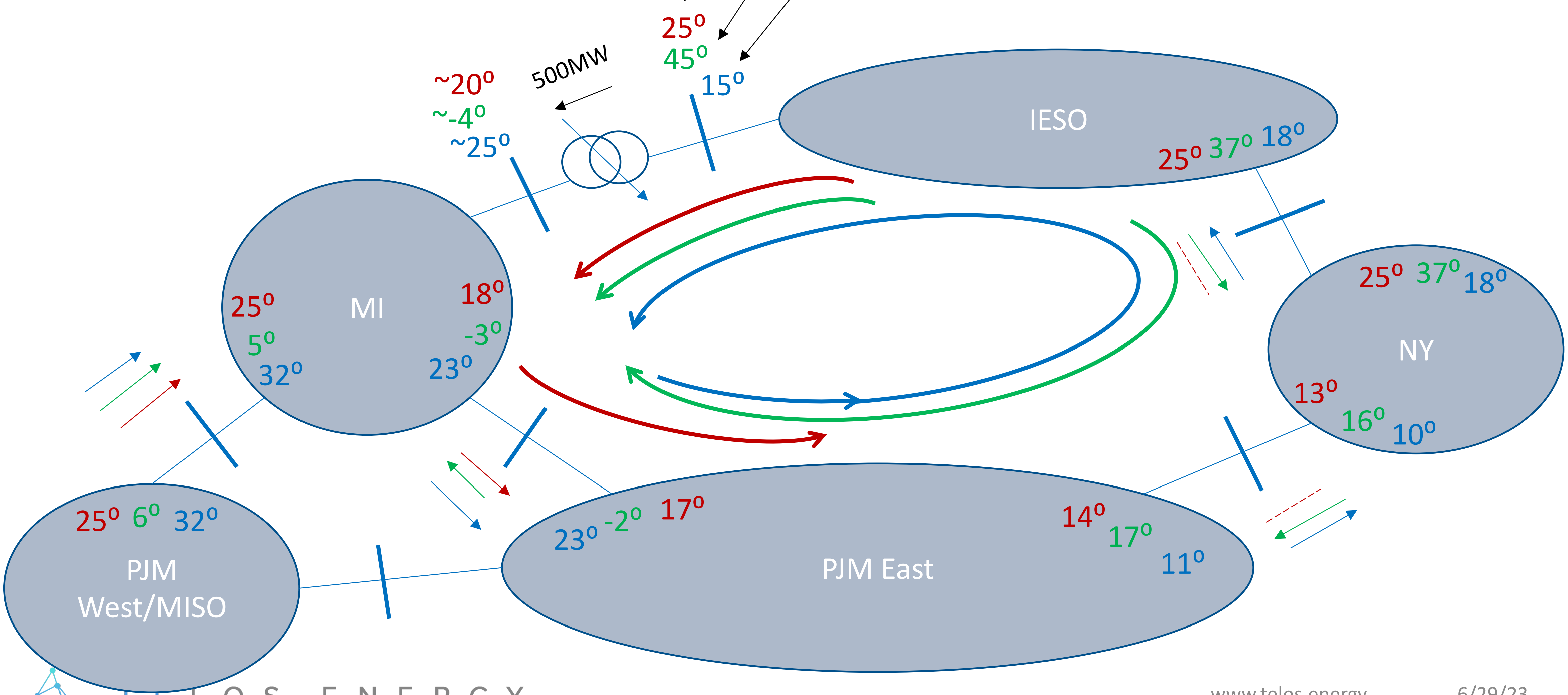
PAR 500MW:0MW IESO Gen

Michigan – Ontario PAR Taps

Small angle (near natural flow)

Large positive (IESO & MI separated)

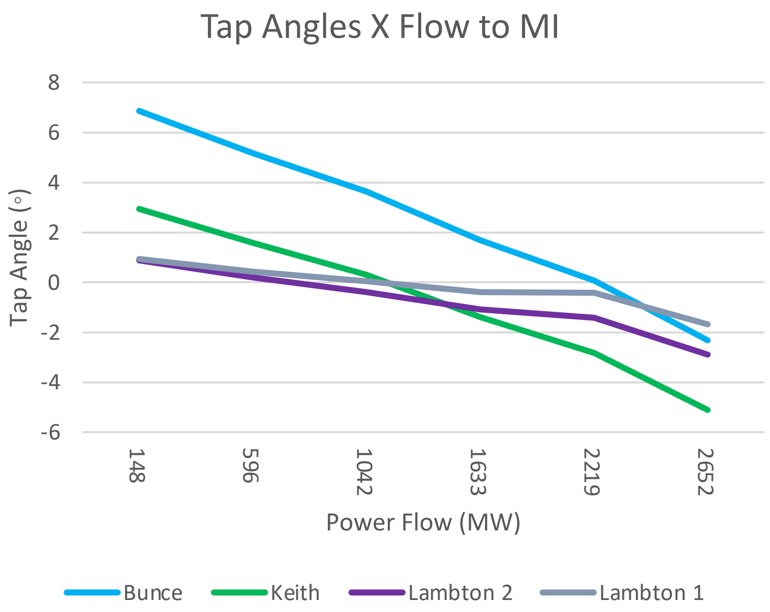
Negative (IESO would want to import, but forced to export)



PAR Tap Angle Findings

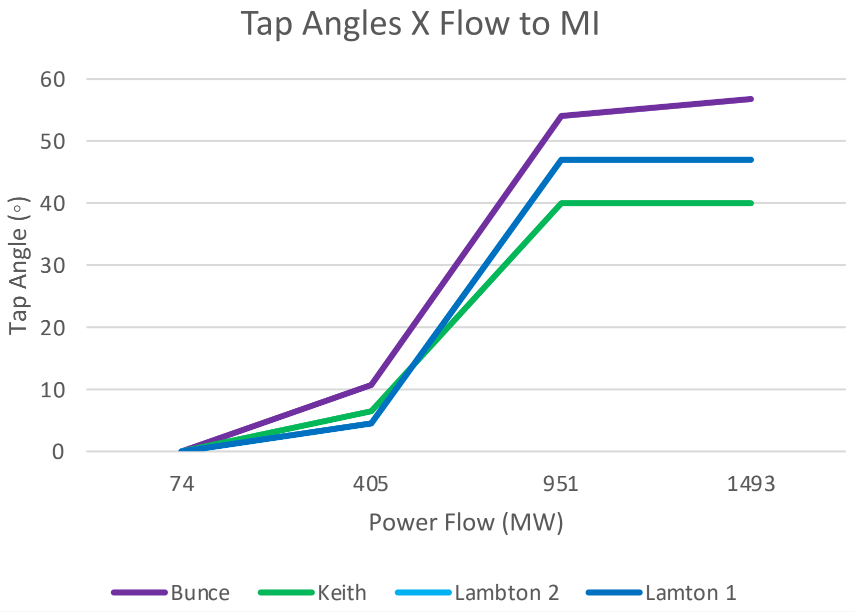
Original Case 1E

- 1:1 balance of PAR flows and change in IESO generation



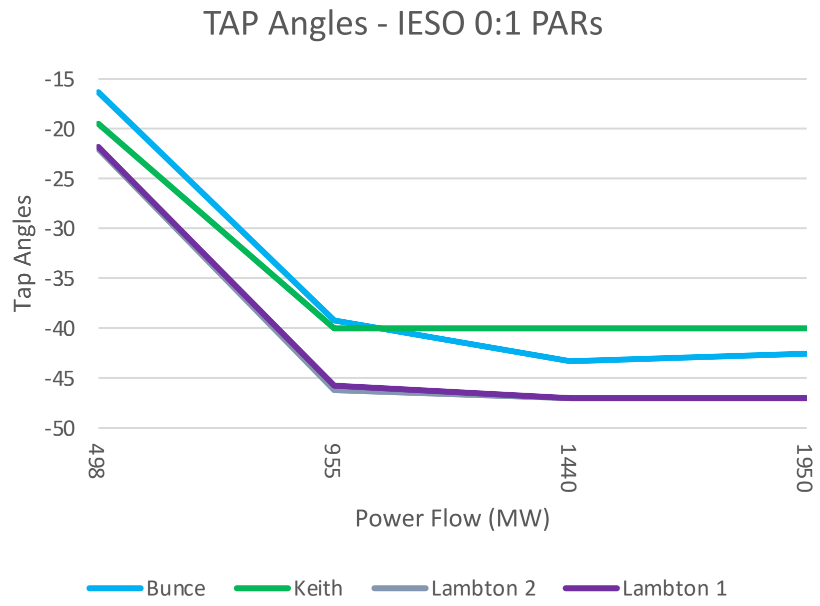
High IESO Generation

- 2:1 change in IESO generation to PAR flows



Low IESO Generation

- 0:1 change in IESO generation to PAR flows



PARs tap (exert control) more when the desired power transfer is farther from the “natural” power transfer level
Therefore, tap control effort is dependent on IESO’s net generation/demand

Findings – PARs & LEC

Southwest Ontario is electrically far from Michigan

- Except for the PAR link
- Ontario is quite peninsular on the EI (only a few weak connections back to MISO)

Therefore, the generation in IESO relative to MISO, PJM, NY impacts how the PARs are used (taps needed to reach desired power flow)

- When IESO is a net gen, the PARs are used to restrain flow
- When IESO is a net load, the PARs can be used for force flow to MI (reverse of the natural flow)

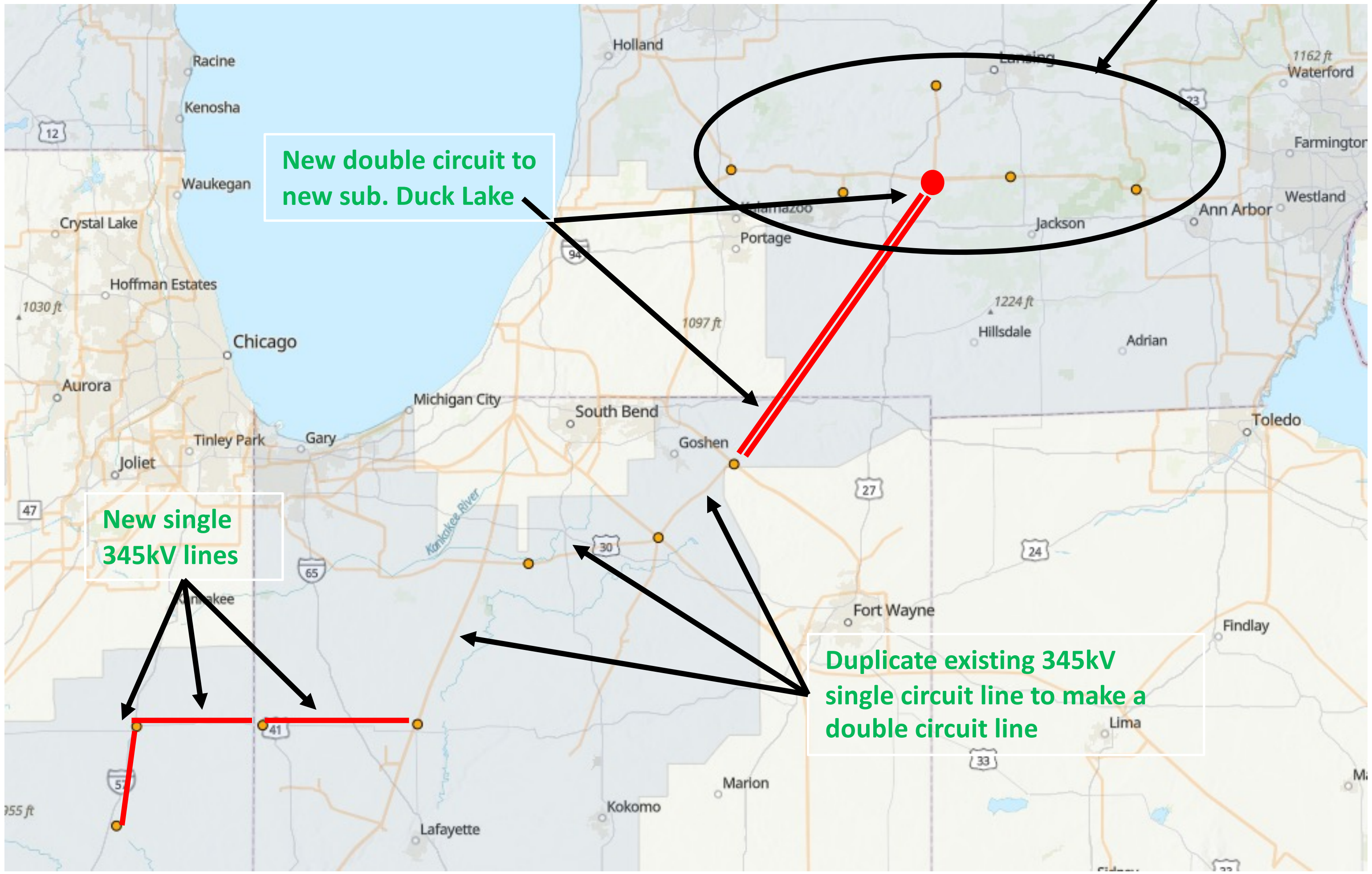
Tranche 1 Sensitivity

Tranche 1 Added, All Regions Importing

Tranche 1 Representation

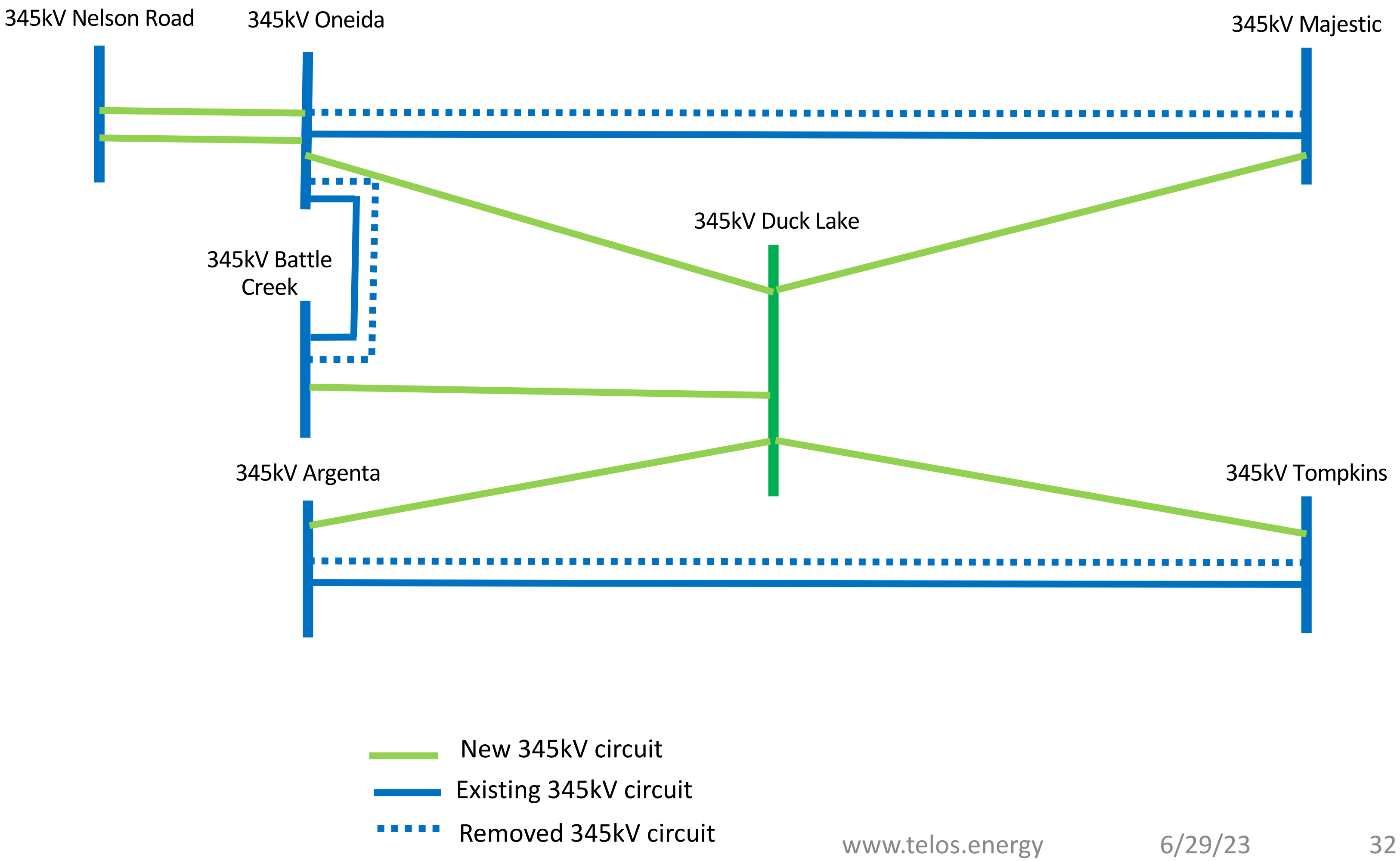
- All assumptions and modifications considered for case 1x
- 345kV lines from IN to MI
- 345kV lines from IL to IN
- New substation in MI (Duck Lake) – Added to existing Loop in Argenta-Tompkins, Battle Creek-Oneida, and Oneida-Majestic

Duck Lake added to the loop (some circuits turned off)



Loop in Argenta-Tompkins, Battle Creek-Oneida, and Oneida-Majestic

- Length and ratings of new lines are given in MTEP20 Appendix A
- R, X, and B calculated using length and typical 345kV line parameters

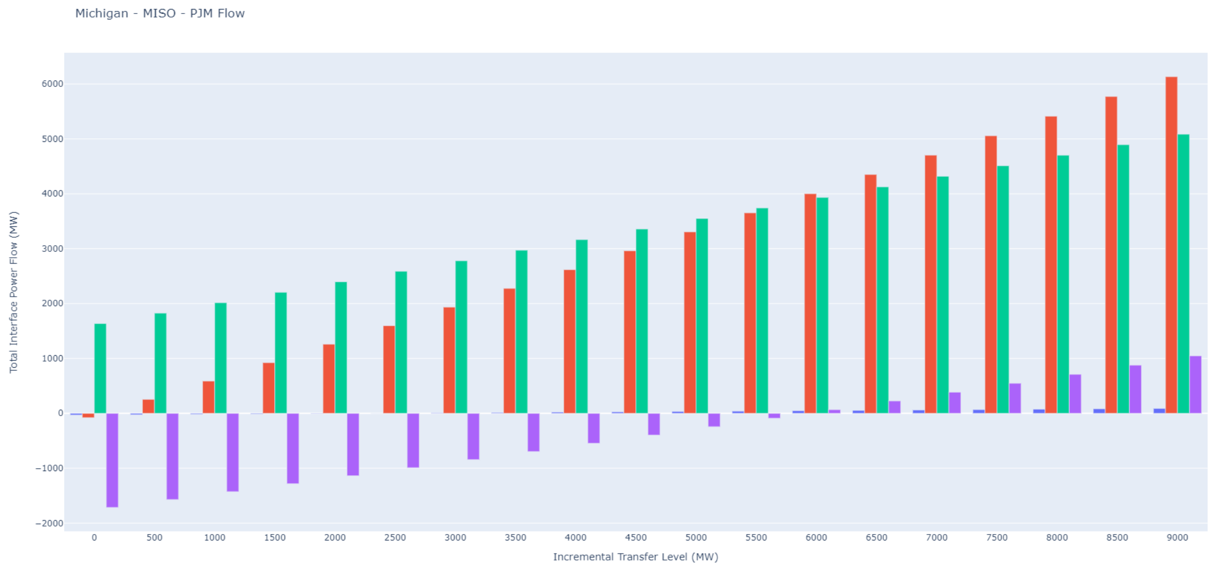


Regional Power Transfers – Tranche 1 Sensitivity

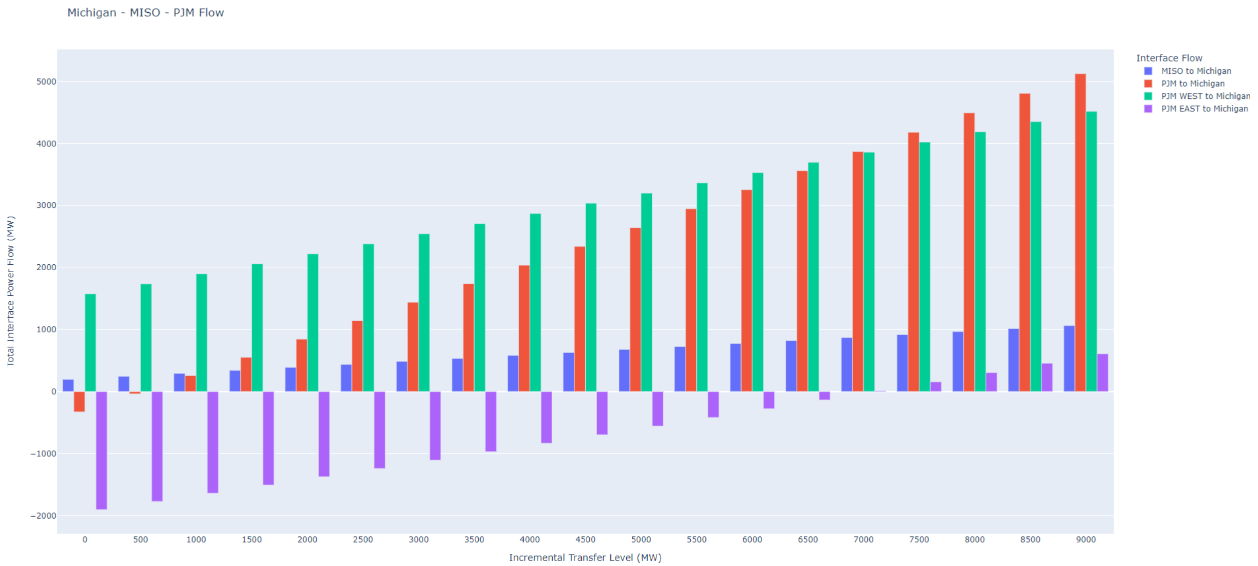
- In our cases, the Tranche 1 double circuit into Michigan is set to transfer about 1 GW of additional power
- The dispatch could have been further adjusted to maximize utilization of the line's thermal capability

Substation from	Substation to	Length	Rating
Hiple (IN – existing substation)	Duck Lake (MN – new substation)	127 miles	1793 MVA

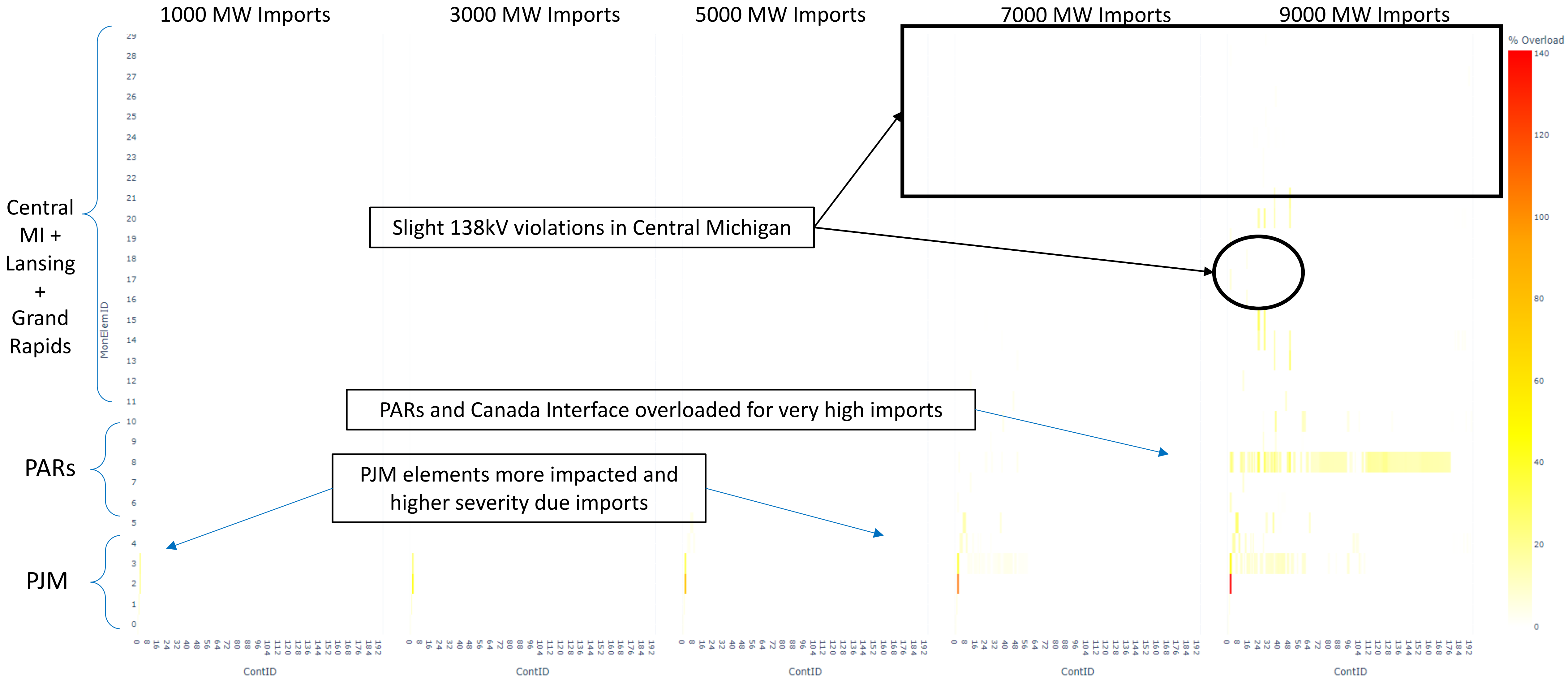
Regional Power Transfer without Tranche 1



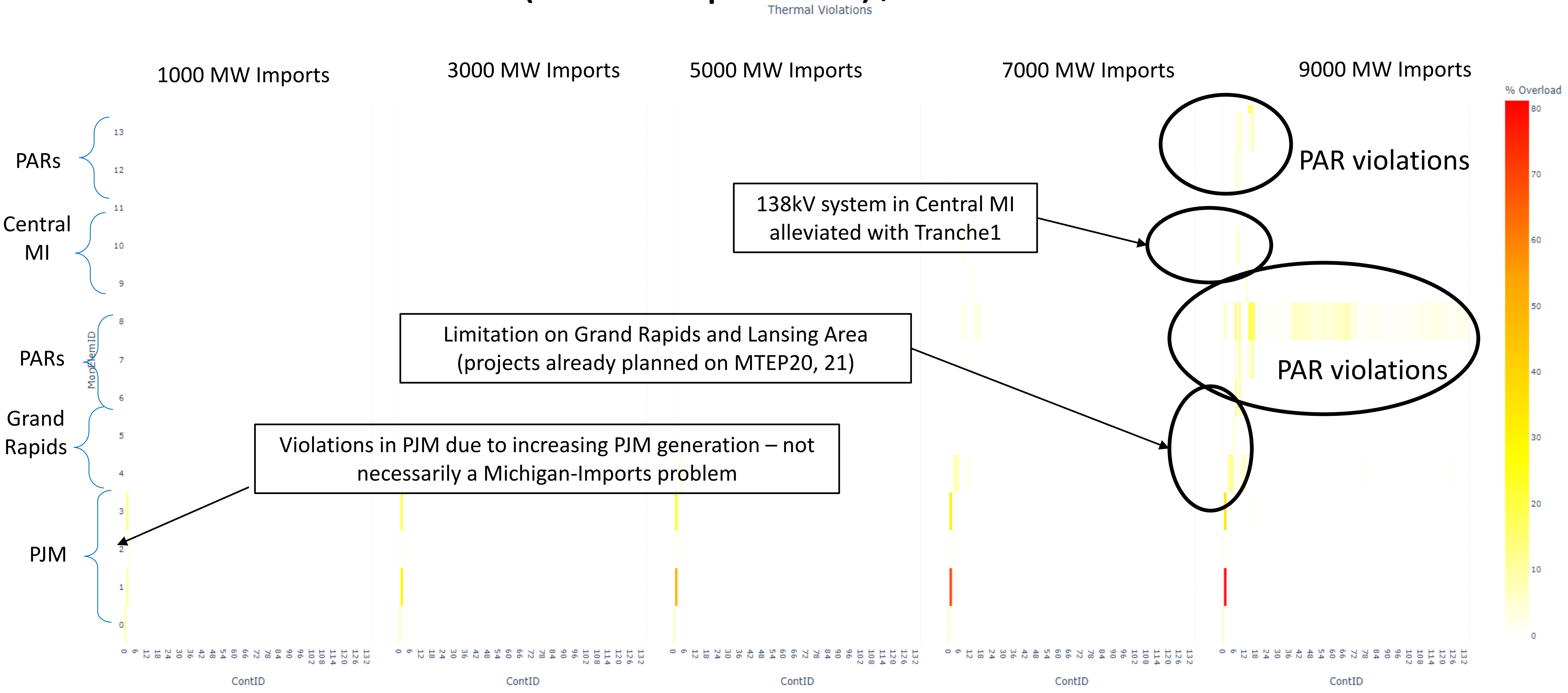
Regional Power Transfer with Tranche 1 Included



Without Tranche 1(All Imports), Thermal



With Tranche 1 (All Imports), Thermal



Thermal Violations, Graphically

Lansing Region:
Violations reduced with Tranche 1 (6 violations were mitigated)

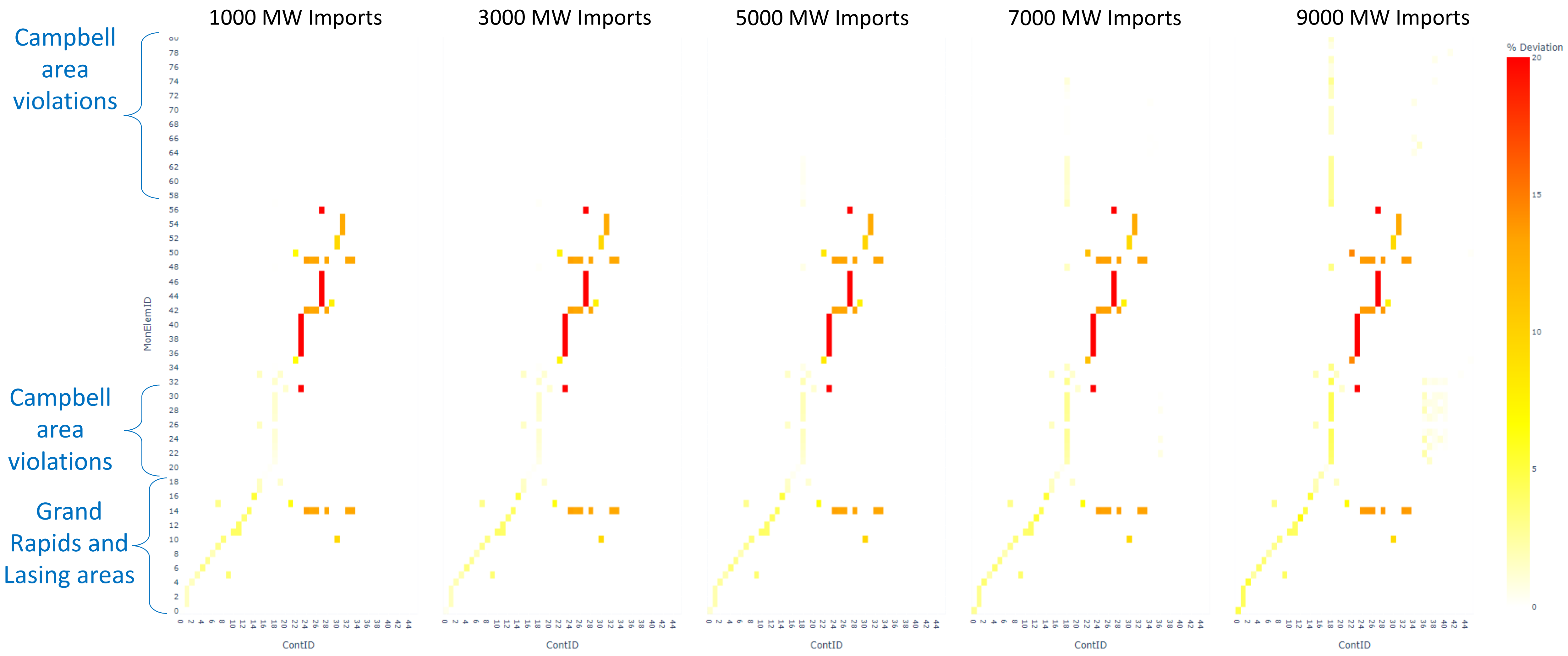
Grand Rapids Region:
Violations reduced with Tranche 1 (5 violations were mitigated)

MI-ONT Region:
PARs and lines not impacted by Tranche 1

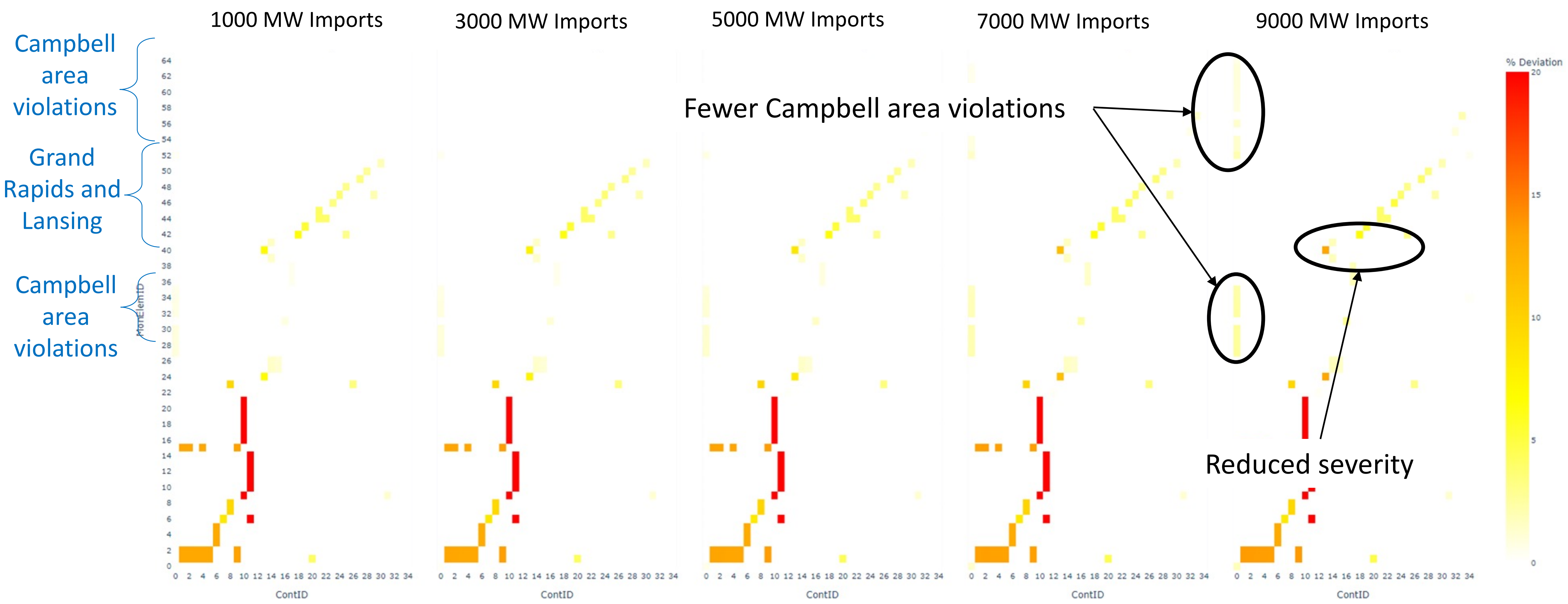
PJM*:
Some thermal violations mitigated with Tranche 1 (138kV)

*The largest violation in PJM is related to generation dispatch, which can be mitigated operationally

Without Tranche 1 (All Imports), Voltage



With Tranche 1 (All Imports), Voltage



Voltage violations are similar for all import levels

Summary of Tranche 1 Impact

- 15 (15 v. 30) fewer thermal violations
- 41 (66 v. 107) fewer voltage violations
- Approximately 800 MW more imports from MISO, which could be nearly 1.7GW if the case is re-dispatched to maximize flow on Tranche 1
- The addition of Tranche 1 enables more imports from PJM and IESO before violations are reached because of its redistribution of import power flows

Topic	Without Tranche 1	With Tranche 1 (800MW Import)
Elements thermally impacted	30	15
Import level with major violations	4.33 GW	6.31 GW
Import level when PAR area is impacted	7 GW	7 GW
Elements with Voltage violations	107	66

Ludington Operations

A Sensitivity to Ludington's Charging/Discharging Operations

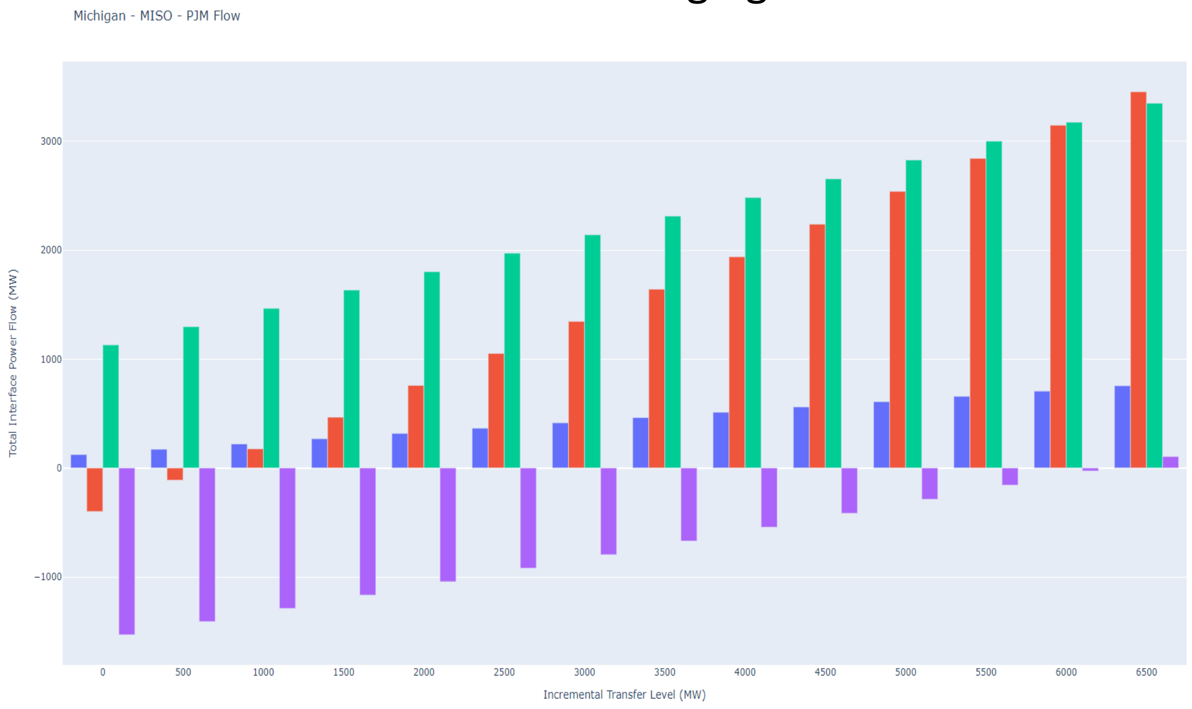
Setting up the Ludington Sensitivity

- MISO MTEP summer and shoulder cases had Ludington fully discharging (2.1GW)
- We did a sensitivity on the shoulder case with and without Tranche 1
- We set Ludington to charge at 2.3 GW (full charging)
- To make up the power (net new demand of 4.5 GW):
  - Increased the new renewable generation (installed capacity) to compensate for the 4.5 GW of Ludington
  - This was in addition to making up for the thermal retirement generation

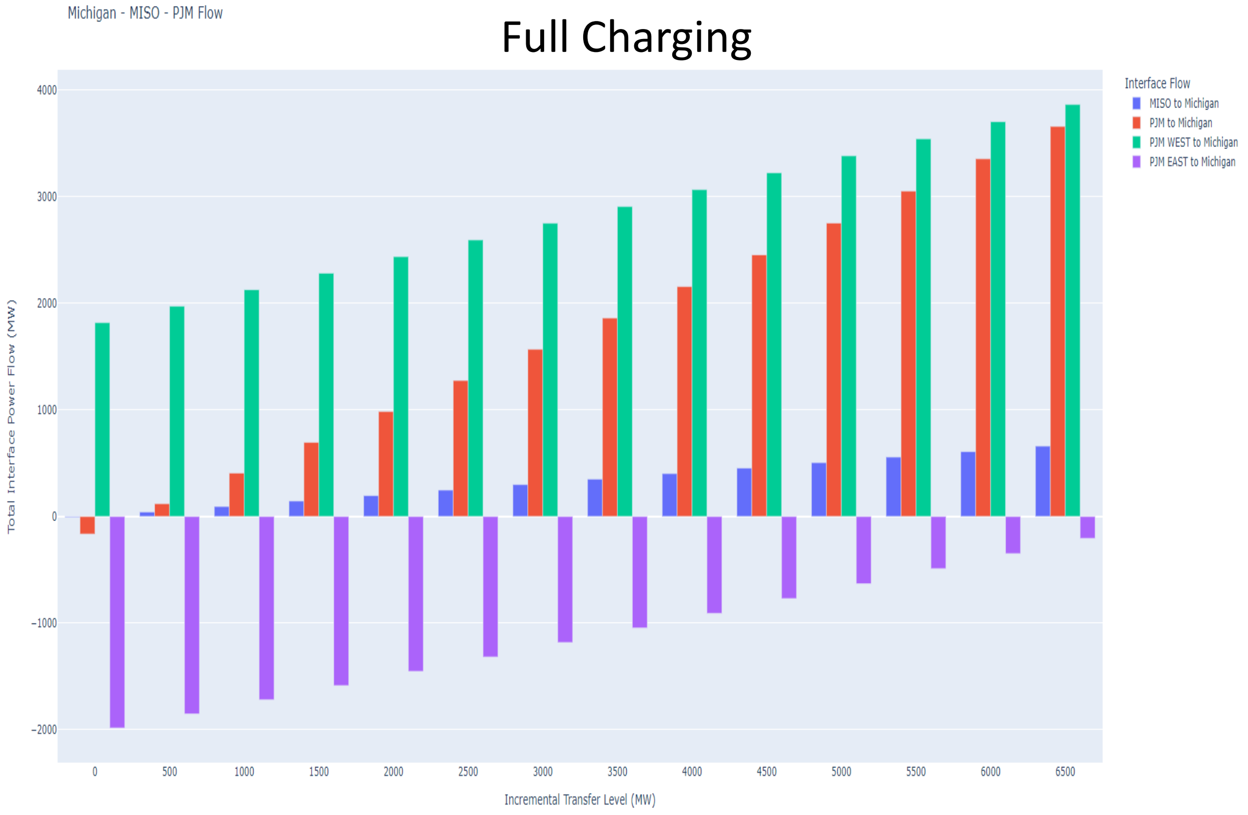
Target	Power Change
Retirements	- 3.89 GW
Ludington	- 4.57 GW
New generation	+ 8.46 GW

Ludington Impact on Imports

Full Discharging

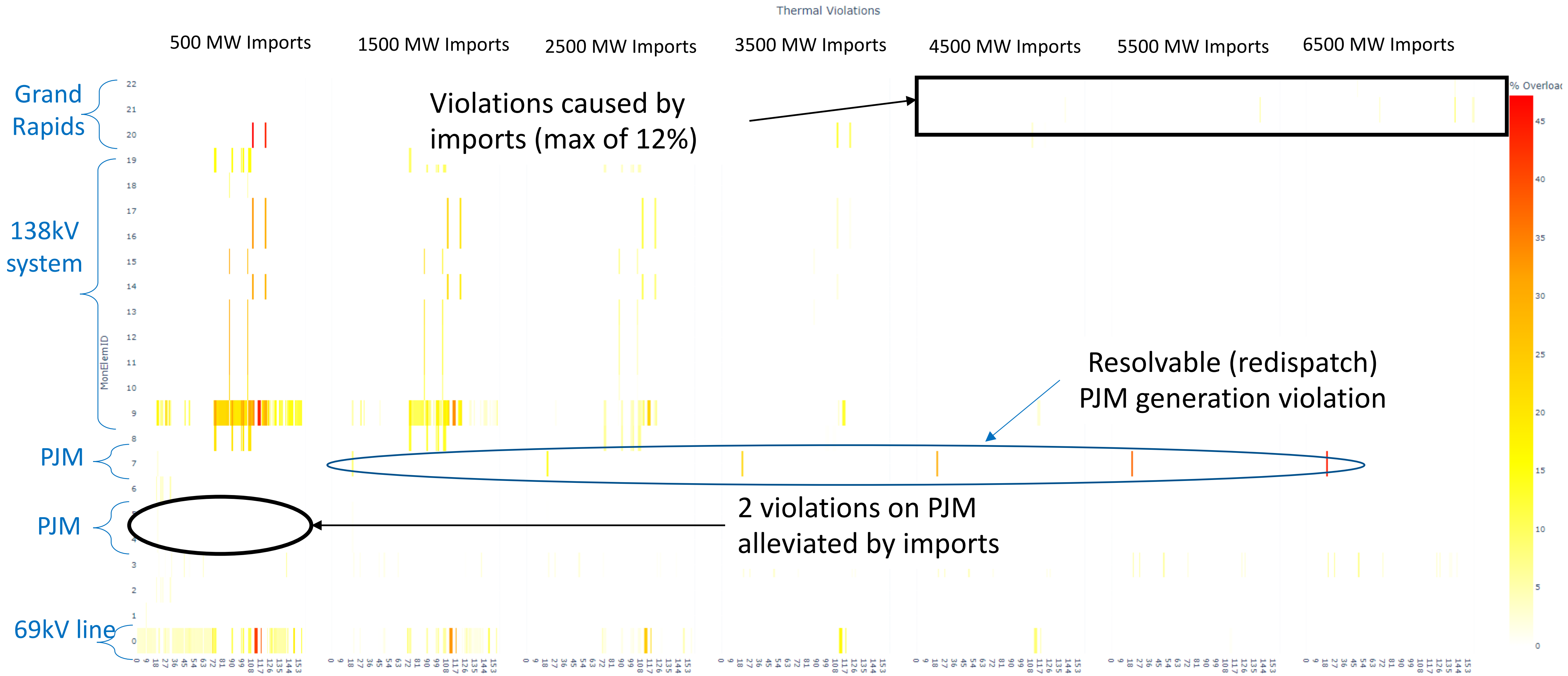


Full Charging



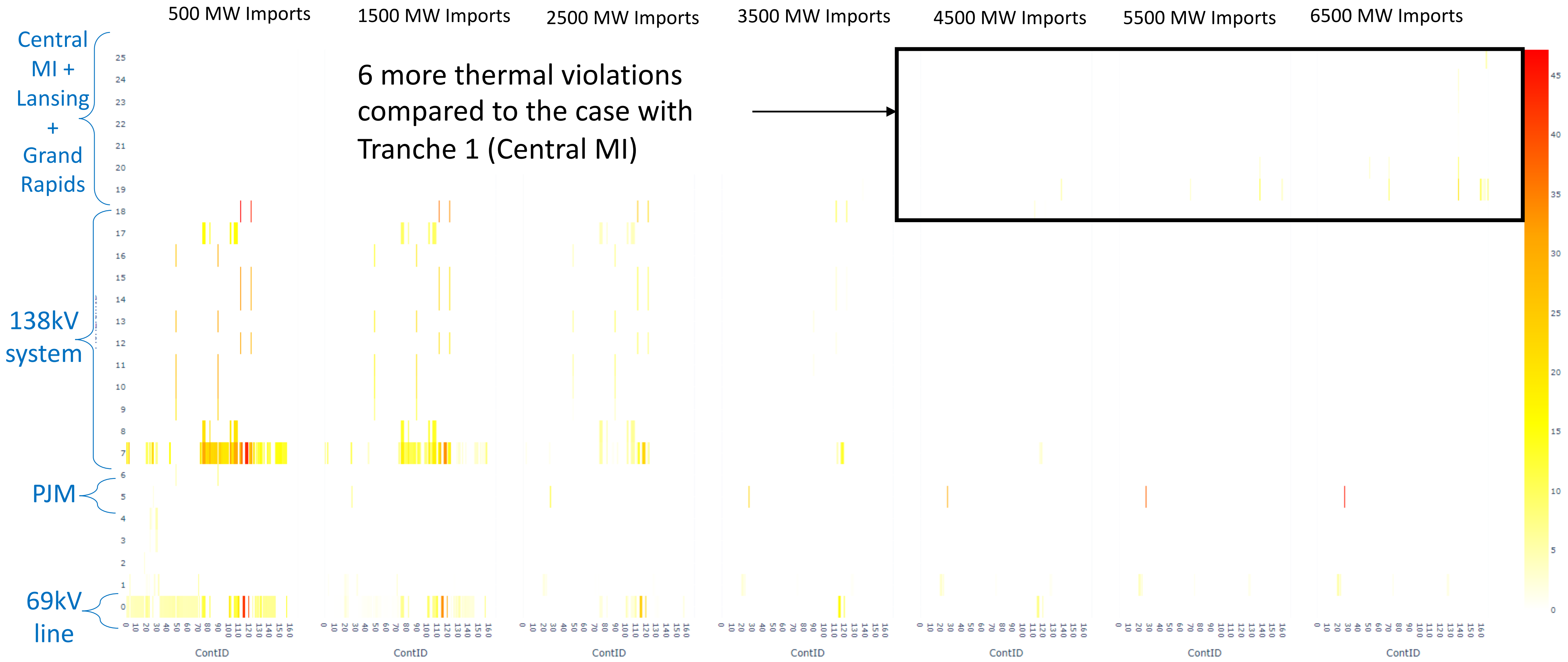
Ludington charging draws incremental power from PJM West

Shoulder Case Imports (Full Charging) – Thermal Violations

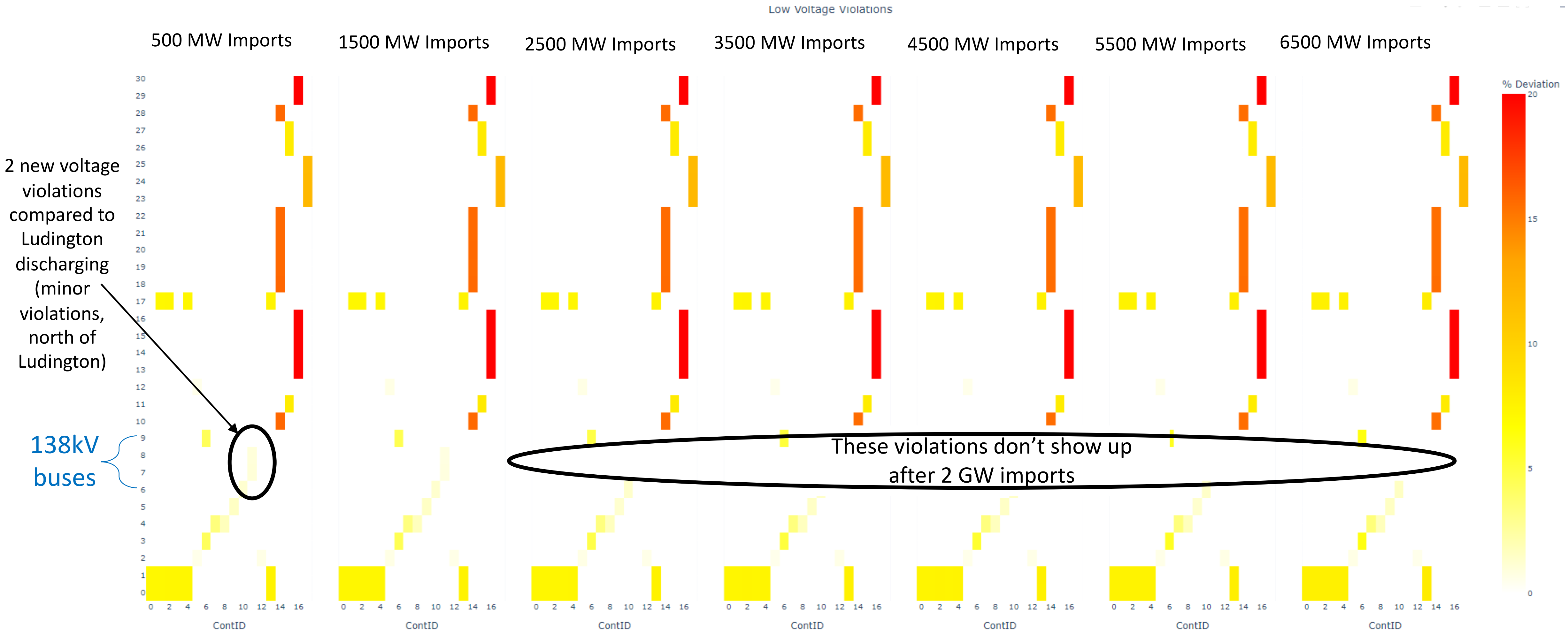


Michigan grid is most stressed when Ludington is charging heavily and generation in SW Michigan is low

Shoulder Case, Tranche 1 Out (Full Charging) – Thermal



Voltage Violations – Ludington Full Charging Shoulder Case



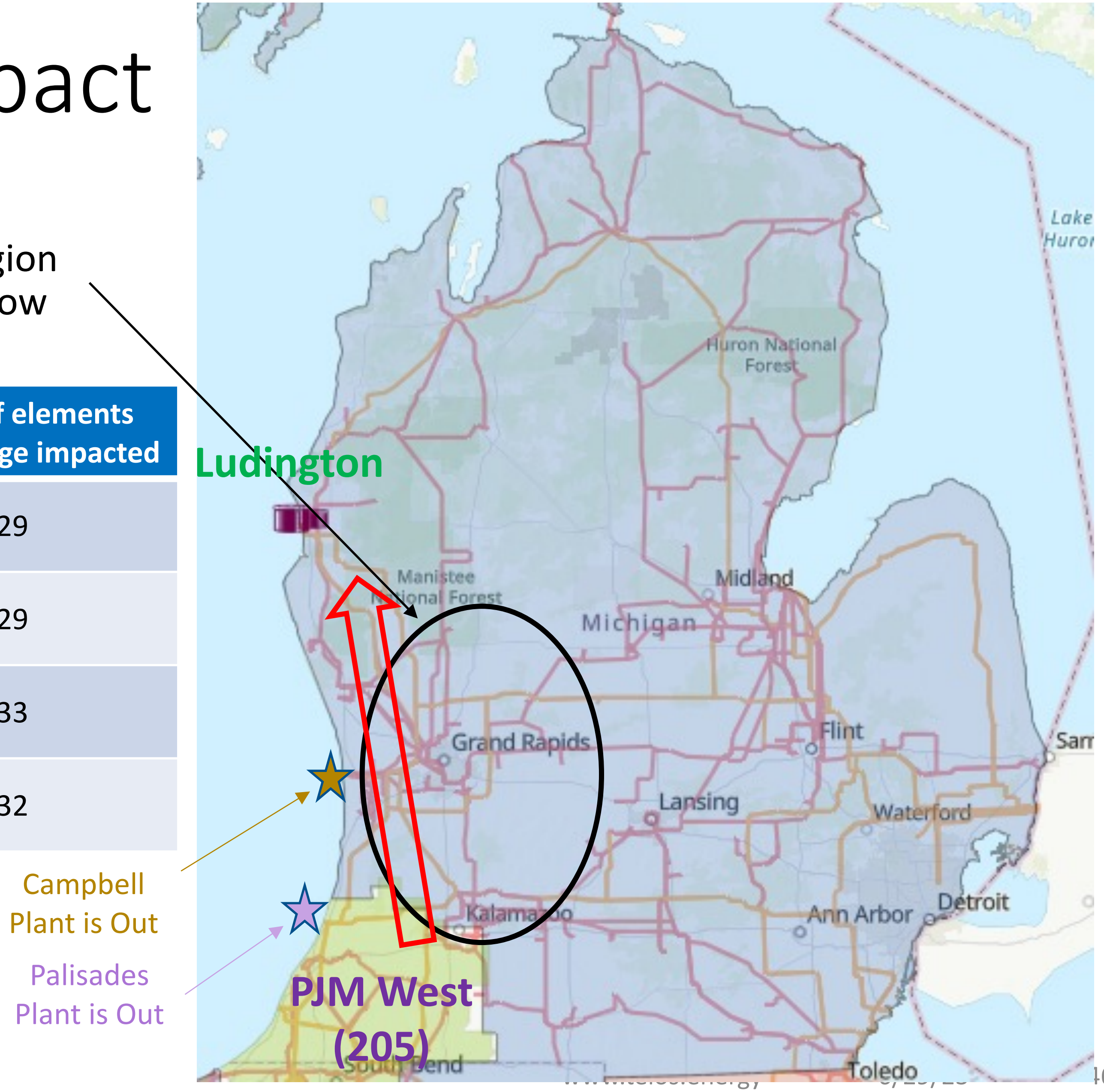
Voltage violations are similar for all import levels

Ludington Charging Impact

Thermal violations increase in the Grand Rapids region when charging is high and generation in SW MI is low

Shoulder Case	Count of elements thermally impacted	Count of elements with voltage impacted
Tranche 1 Out Ludington Discharging	17	29
Tranche 1 In Ludington Discharging	11	29
Tranche 1 Out Ludington Charging	29	33
Tranche 1 In Ludington Charging	25	32

- Voltage violations are slight, north of Ludington
- Tranche 1 has a modest positive impact on violations in the Grand Rapids region



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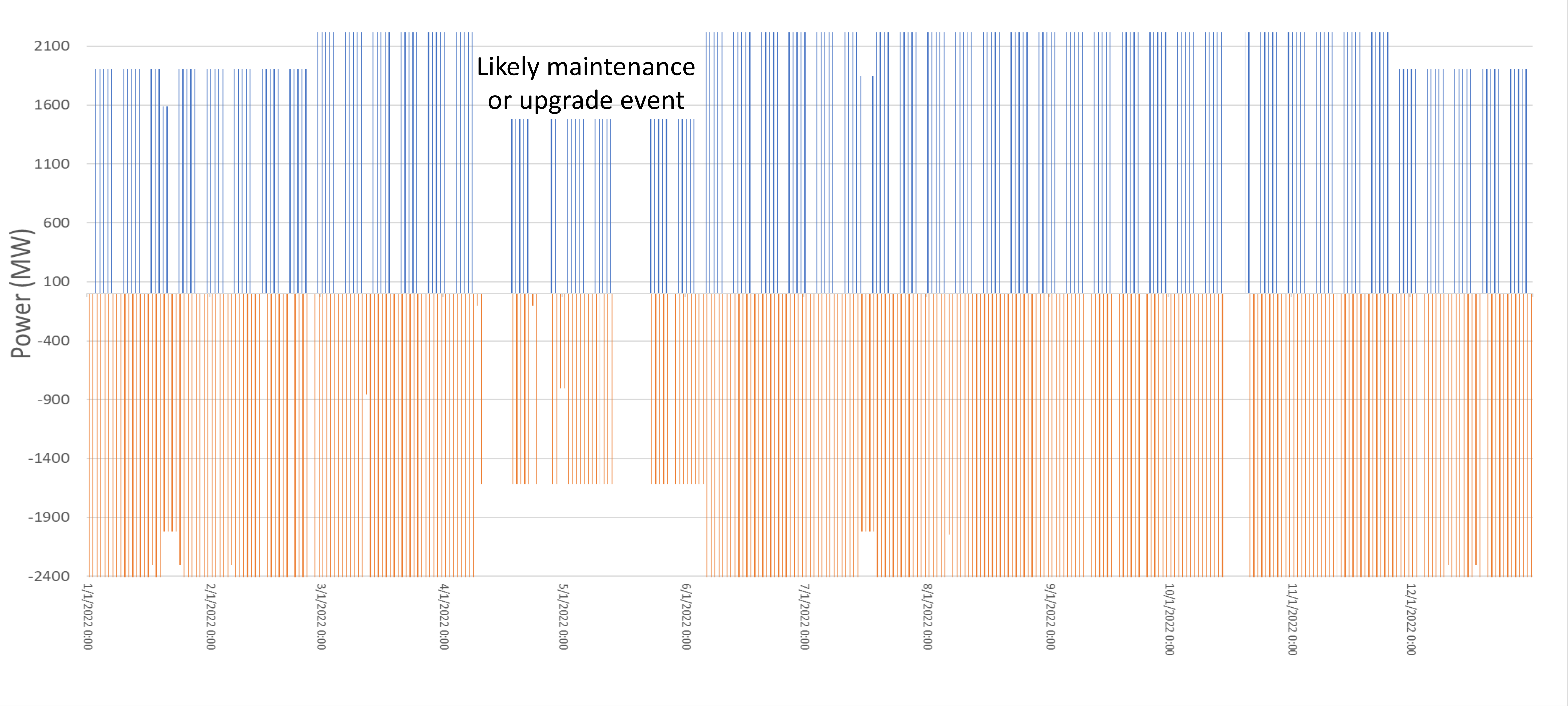
Ludington Historical Data

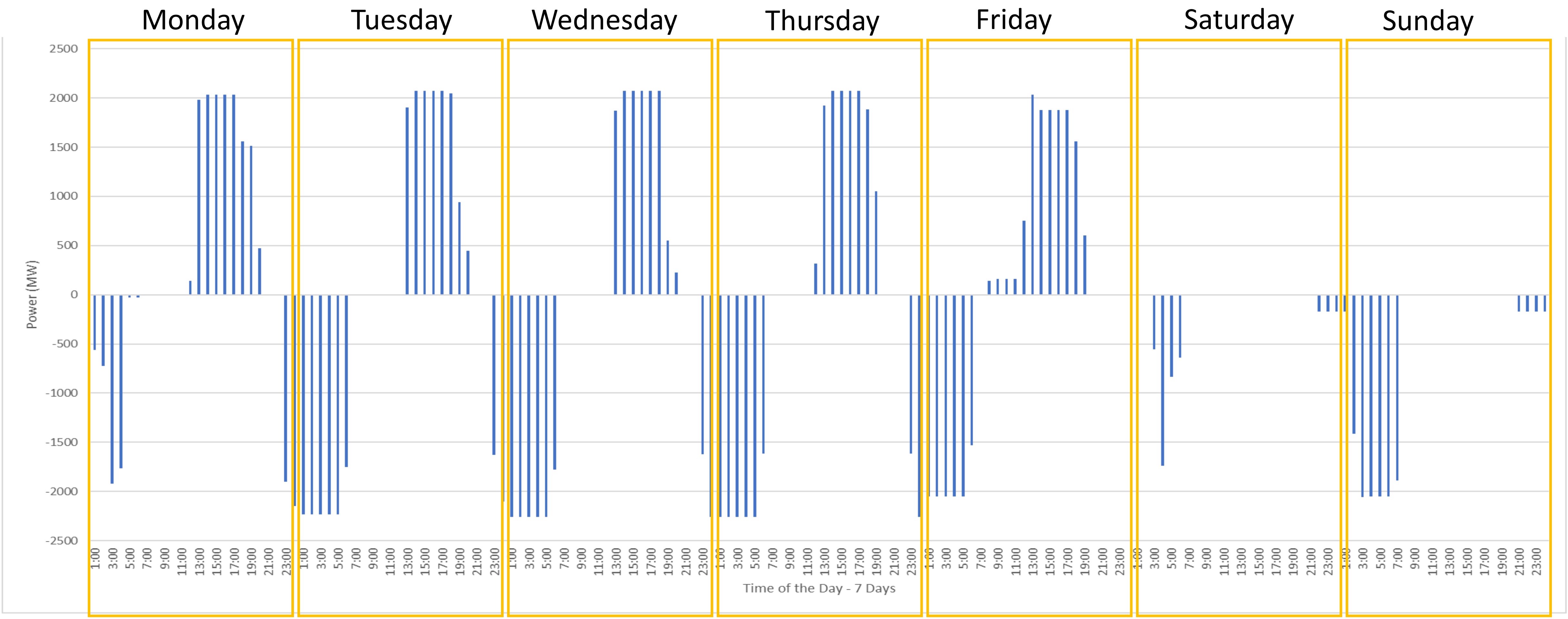
Analysis of Charging/Discharging Patterns

Ludington Operation Data - 2022



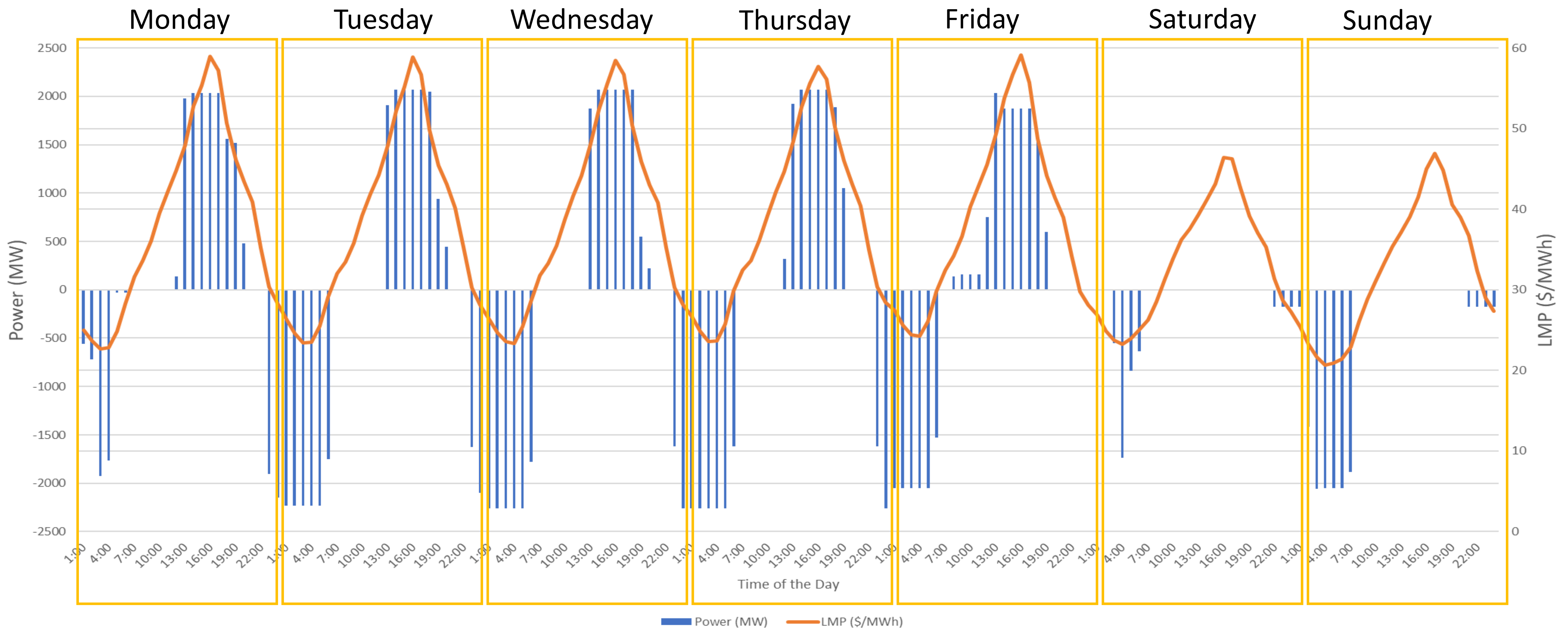
Ludington Summer Average Week

Summer 2022 (June 20 – Sep 20) Average
Discharging: Afternoon and early evening weekdays
Charging: Overnights, lighter on weekends



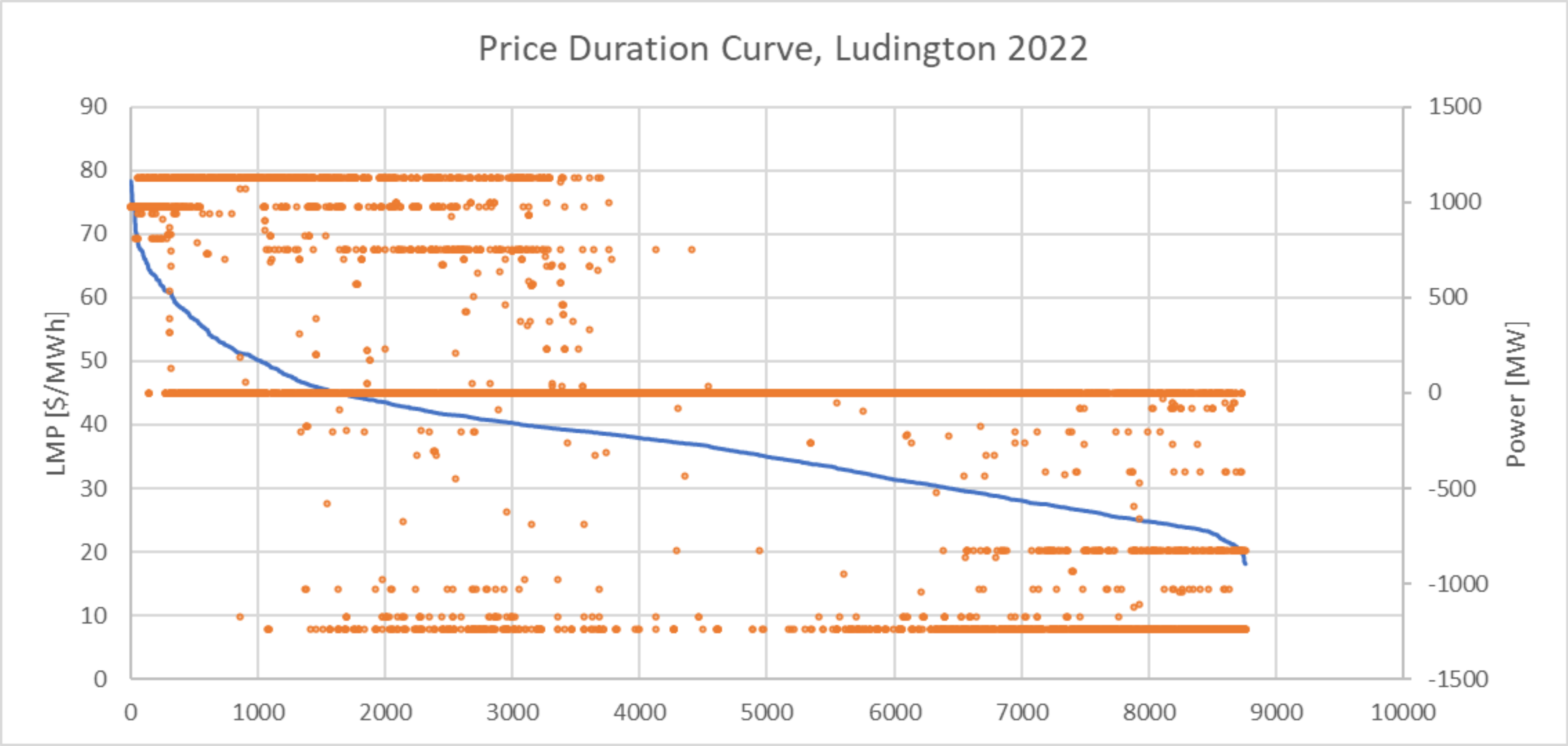
Ludington Summer with LMP

Summer 2022 (June 20 – Sep 20) Average (hour-by-hour average)



Ludington Price Duration Curve with Operations

No significant discontinuities in the price duration curve
Operations generally reflects an arbitrage between weekday evenings (high prices) and nighttime (low prices)



Transmission Analysis Summary

Power Import Capability to Lower Michigan

Summary of Transmission Analysis (1)

Benchmarking Findings

- MISO CIL/CEL: Different constraints were identified, likely because of lots of existing thermal gens (Trenton & St Clair) online, over all the ~4GW import is in the ballpark
- MISO Appendix A: Many thermal violations we've found have been noted and proposed to be addressed

Power Imports to Michigan

- The major path of power transfer to Michigan is PJM West
- By increasing the generation in the MISO region, the power is transferred to Michigan through PJM
- It is possible to import ~4 GW without excessive thermal violations
- The biggest thermal limitations are
  - PARs, given an assumed participation factor
  - PJM, violations driven by increasing PJM generation
- Voltage violations did not increase much with imports (Note: No major Detroit area retirements assumed)

Summary of Transmission Analysis (2)

Michigan/Canada Transfer

- The only connection of Ontario to MISO are the four PARs in the Detroit area
- It is possible to import ~2 GW from Canada; rating of transmission lines is similar to PAR ratings
- SW Ontario is expected to have substantial load growth by 2030 – several new transmission projects planned
- Ontario is quite peninsular on the EI; Southwest Ontario is electrically far from Michigan
- Therefore, the generation in IESO relative to MISO, PJM, NY impacts how the PARs are used (taps needed to reach desired power flow)
  - When IESO is a net gen, the PARs are used to restrain flow
  - When IESO is a net load, the PARs can be used for force flow to MI (reverse of the natural flow)

Interregional Transfers, Particularly ISO Seams

- Increasing interregional power transfers will likely require evaluating transmission contingencies not only at the seams (as is done today), but also contingencies across the border from the primary study region
- This may cause some additional overlap in the contingency analysis but would help capture constraints on imports/exports due to contingencies in a different region or ISO

Summary of Transmission Analysis (3)

Tranche 1

- Tranche 1 enabled 1GW of imports from MISO territory
- Considering all the interface imports, it is possible to import 6.3 GW without major violations (>2 GW more than without Tranche 1)
- Tranche 1 is effective in mitigating some thermal violations near Lansing and PJM
- Voltage violations are essentially unchanged
- The addition of Tranche 1 helps reduce the violations (system stress) when Ludington is charging

Ludington Operation

- When Ludington is fully charging, a power deficit is created in the area, which Michigan's generation is not capable of supplying, especially in N-1 operation
- With more imports from PJM, thermal overloads caused by Ludington operation are reduced and even mitigated in some cases
- Voltage violations are essentially unchanged
- Tranche 1 has a positive impact on thermal violations, reducing overloads in Central Michigan (Thermal violations caused by larger imports decreased from 8 to 2, which were around 6% lower)