# Robust Solution of High Renewable Penetration Planning Cases in SUGAR

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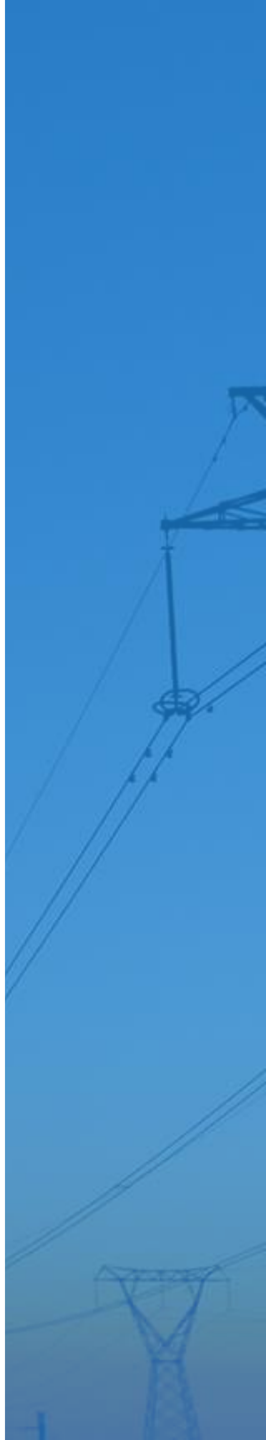
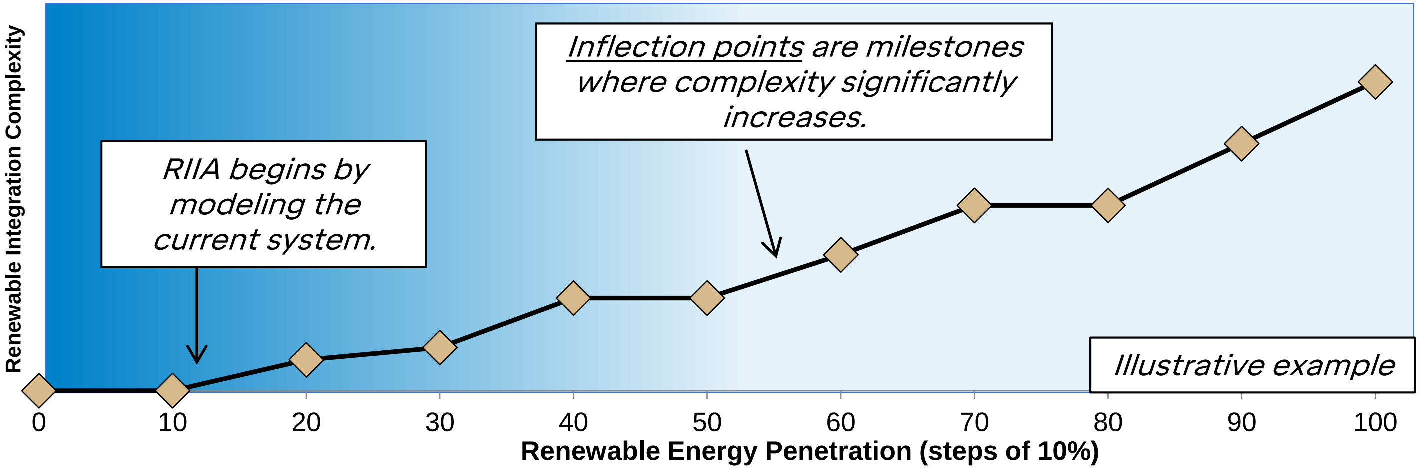


# Renewable Integration Impact Assessment (RIIA) seeks to find inflection points of renewable integration complexity


**Focus Areas**

**Resource Adequacy**

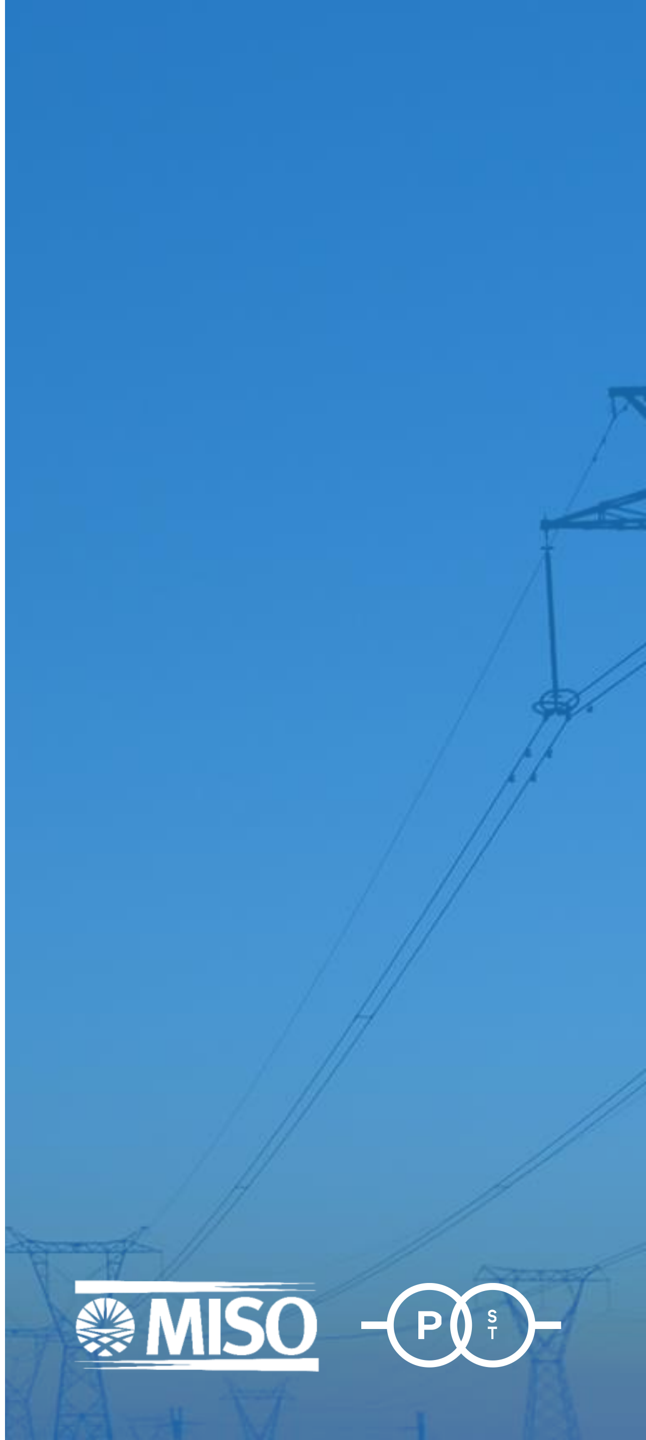
Having the sufficient capacity of resources to reliably serve peak demand

**Energy Adequacy**

Ability to provide energy in all operating hours throughout the year

**Operating Reliability**

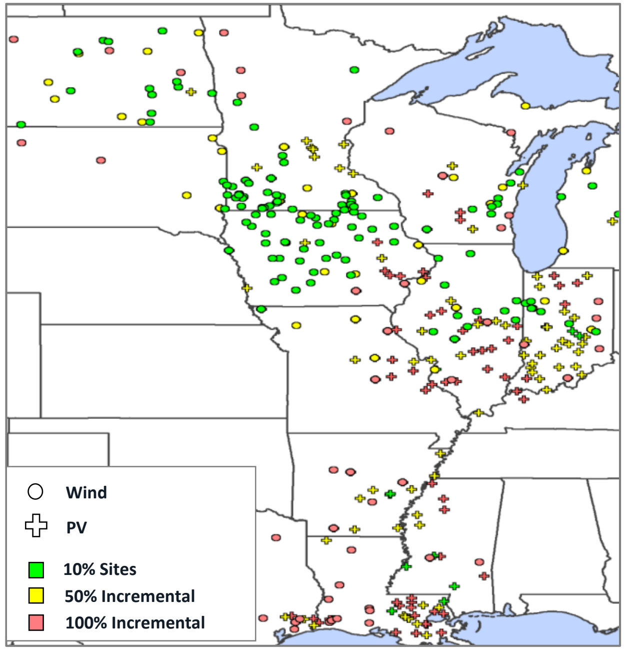
Ability to withstand unanticipated component losses or disturbances



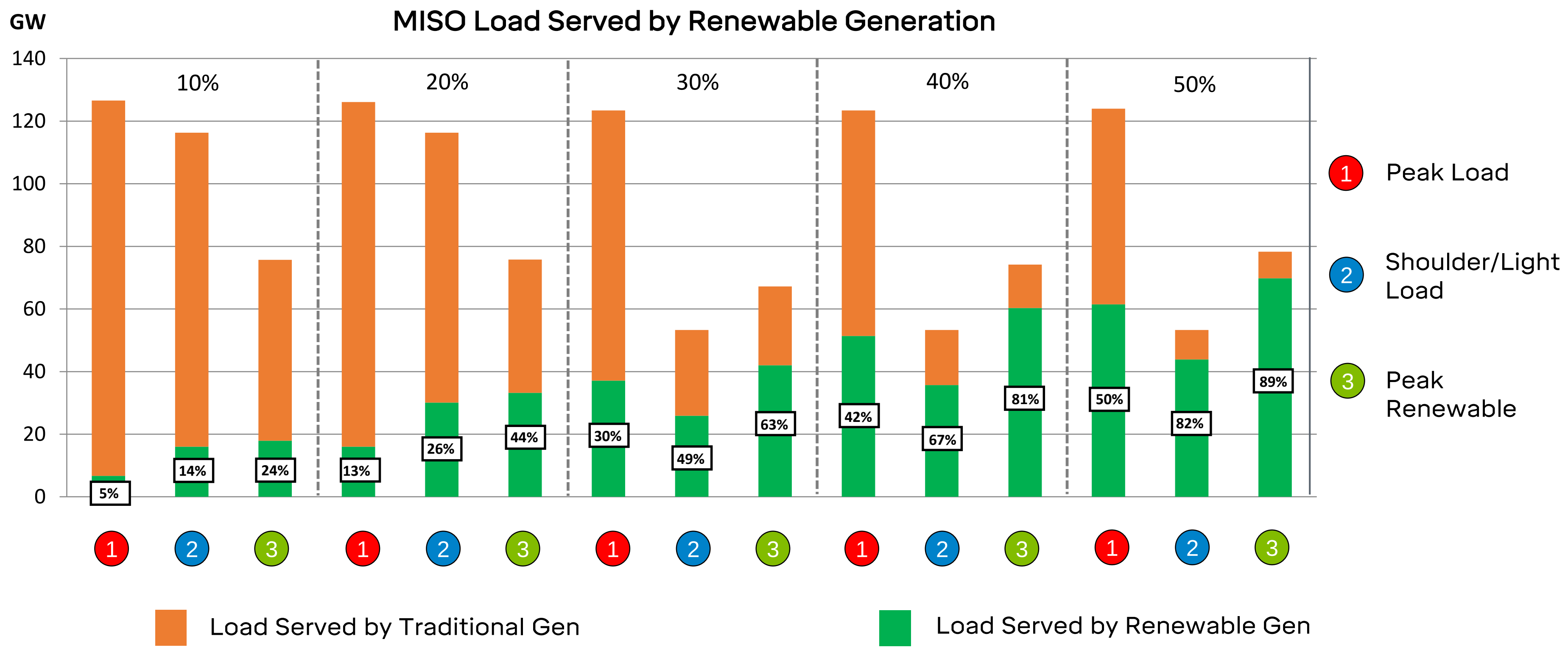
## Modeling difficulty increases significantly from 30 - 40% penetration

- Dispatch from production cost simulation based on DC flow model is infeasible in AC reliability power flow analysis
- As renewable penetration increases, generation dispatch, system operating and flow pattern will change significantly
- Wind and solar are concentrated in specific regions requiring stronger high voltage, long distance transmission paths, and sufficient system-wide reactive support
- Significant amount of effort is required to build and fine tune reliability models that maintain reasonable dispatch consistency with production cost models

MISO Renewable Siting

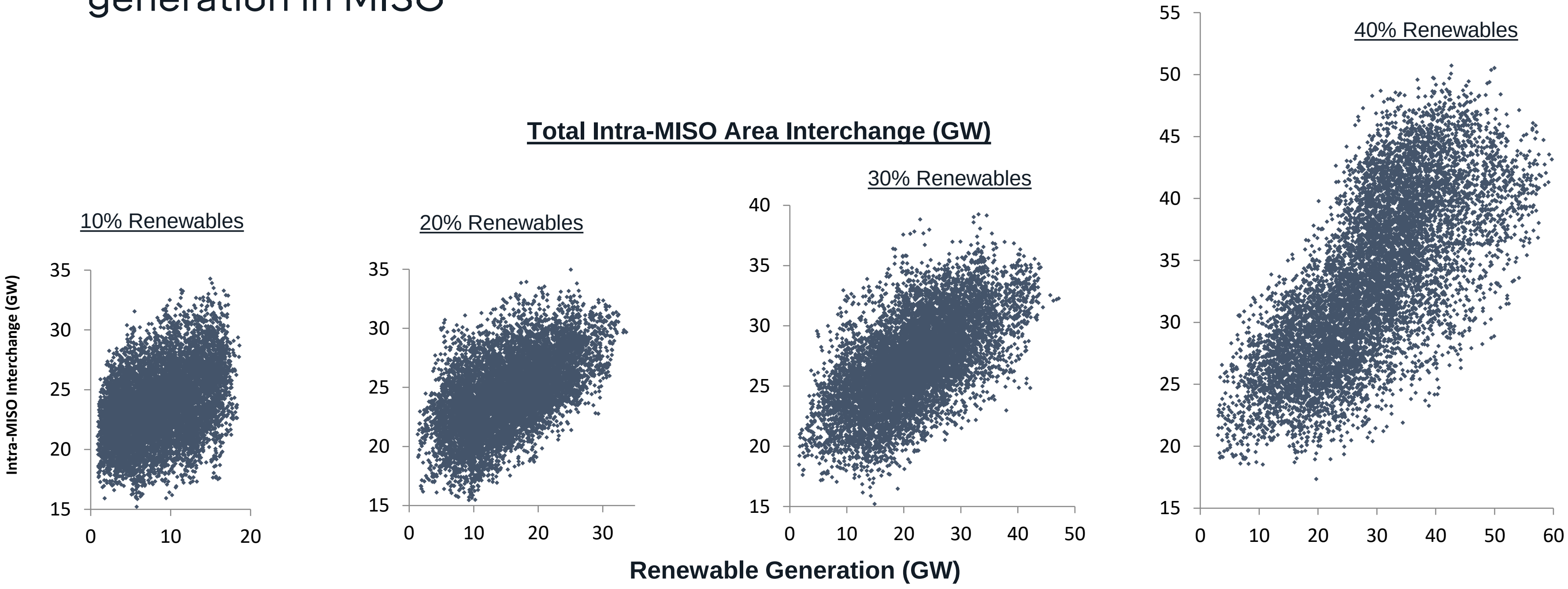


# Operating reliability analysis was conducted on instantaneous renewable penetration snapshots from 5% to 89%

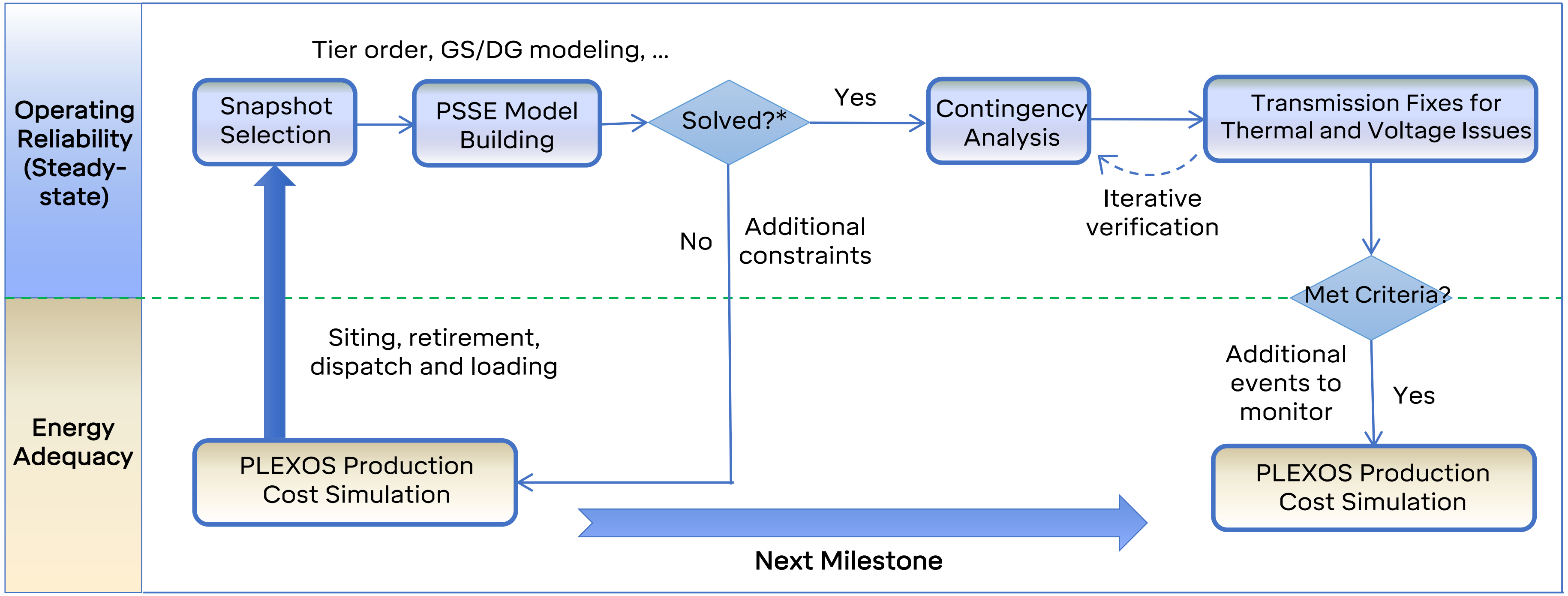


# Intra-MISO interchange increases as renewable penetration grows

- While renewable variability increases in higher milestones, intra-MISO interchange varies within a greater range
- Total intra-MISO interchange is strongly related to total renewable generation in MISO



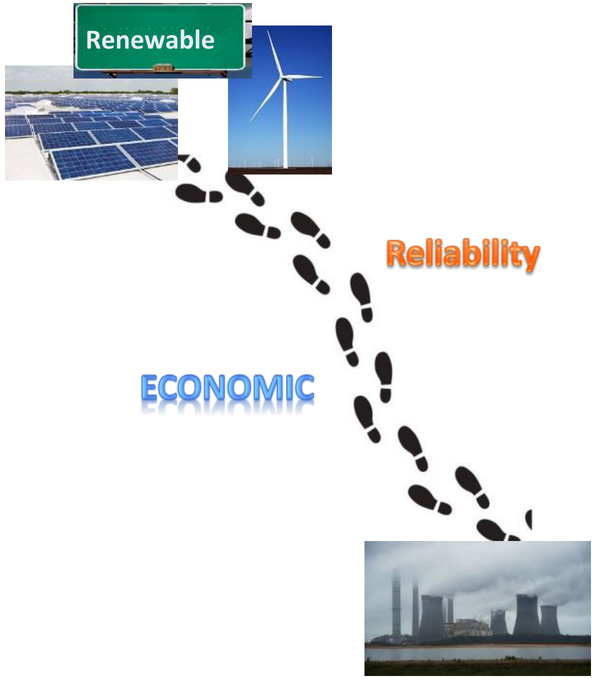
# Integrated production cost and operating reliability analysis framework




* Solutions from DC models with linearized losses are generally "tighter" than AC solutions thus may introduce infeasibilities.

# Significant effort has been made to harmonize production cost and reliability models and to converge the AC power flow models

- Iterative process between production cost and reliability analysis to “close the gap”
- Identify and feedback additional constraints to enhance production cost modeling
- Apply power flow modeling updates step-by-step to help convergence: site and dispatch resources on local area basis and scale loading level gradually
- Advanced innovative model solving tool also tested to help detect model infeasibilities and improve the solving process under high renewable penetration level[1]




[1] Pandey, A., Jereminov, M., Wagner, M. R., Bromberg, D. M., Hug, G., & Pileggi, L. (2019). Robust Power Flow and Three-Phase Power Flow Analyses. IEEE Transactions on Power Systems, 34(1), 616–626. https://doi.org/10.1109/TPWRS.2018.2863042

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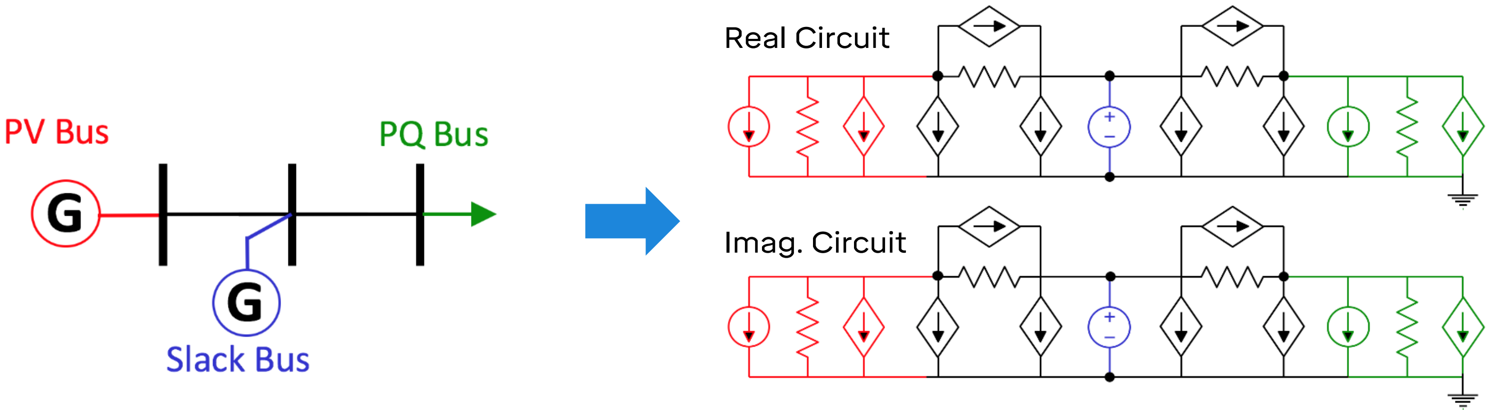
TECHNOLOGIES

# MISO High Renewable Penetration Case

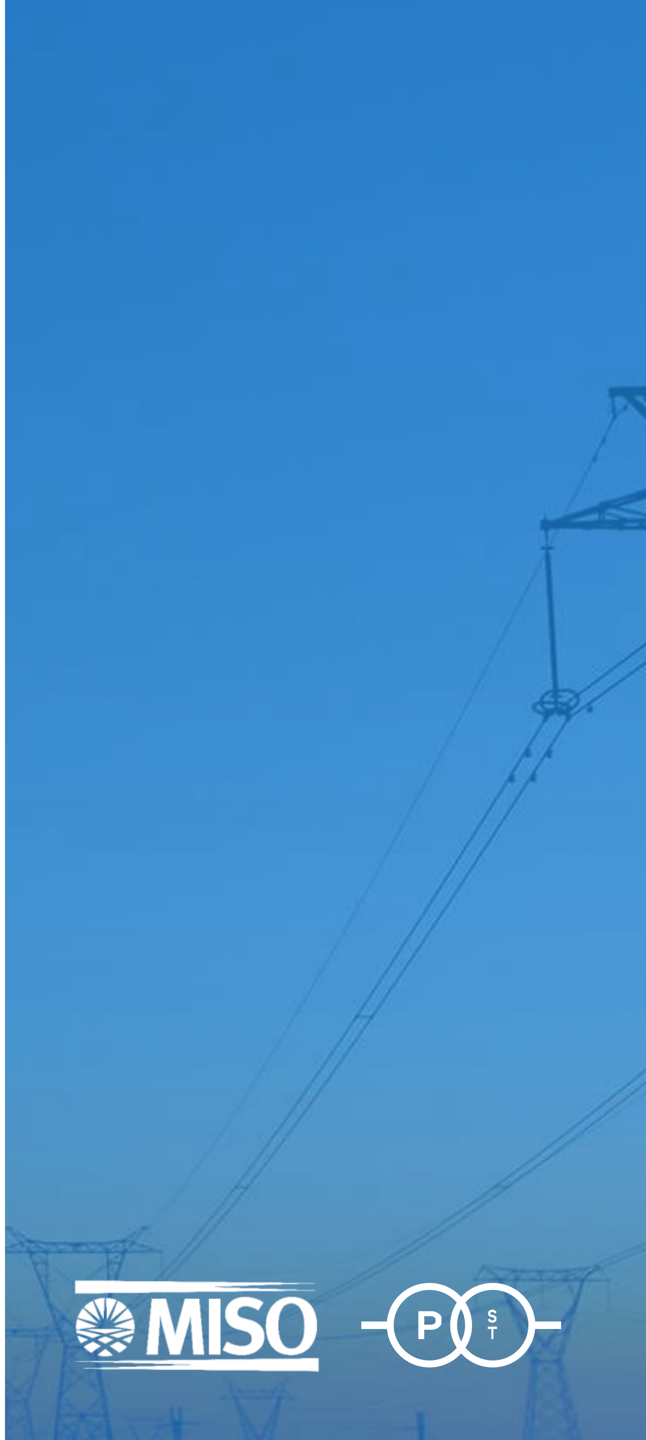
- Recap of the changes between the original, working case and the planning case in question:
  - Utility-scale and distributed wind and solar generation added throughout the system
  - Subset of existing conventional generation retired or re-dispatched
  - Loads throughout the system were scaled
- Planning case is infeasible: no physical solution unless changes to the system are made
- Goal: develop a procedure to automatically create a solved power flow case with no user interaction

# SUGAR

- Suite of Unified Grid Analyses with Renewables
- Licensed breakthrough technology from Carnegie Mellon University
  - Split equivalent circuit models the power grid using true state variables: “I” and “V”
  - Applies circuit simulation methods used to simulate chips with a billion transistors




Split equivalent circuit with I-V variables linearized for (k+1)th Newton-Raphson iteration



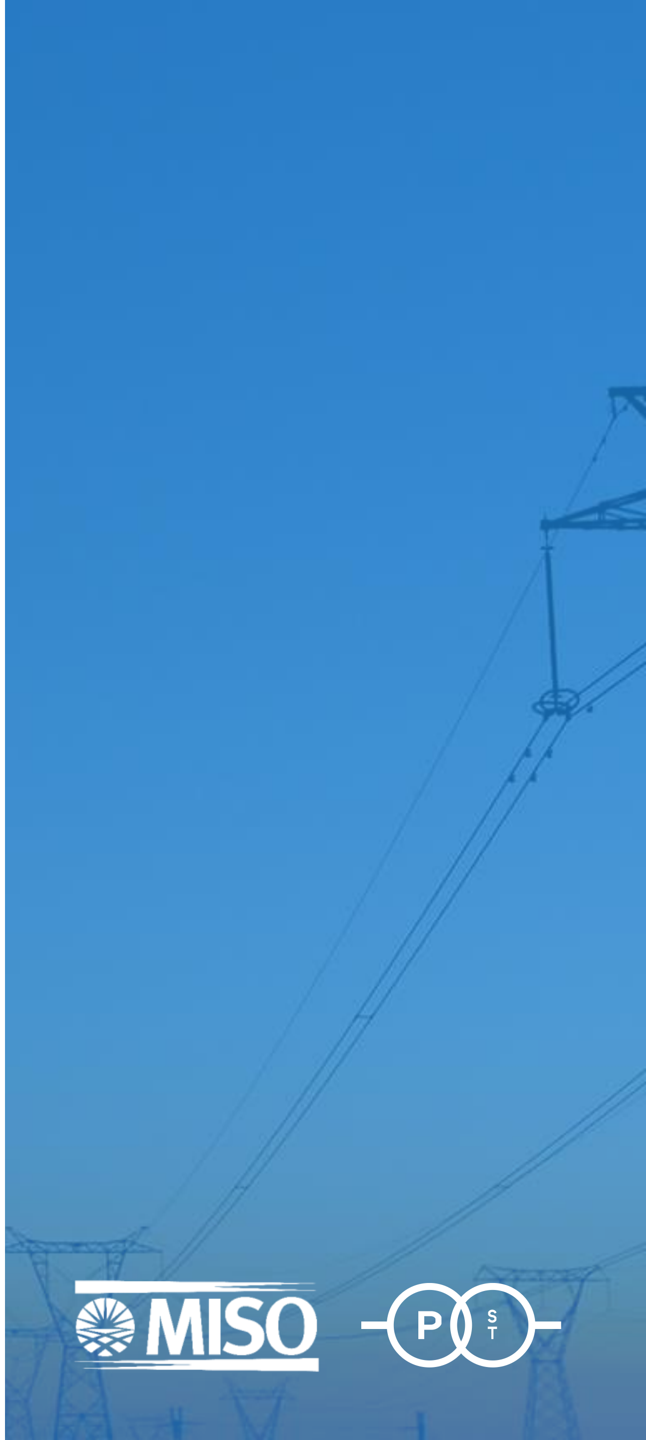
# Scalable and Robust

- SUGAR's robust convergence scales to any system size or complexity
- Example: US Eastern Interconnection
  - Converges from any initial conditions in SUGAR

**Extreme Contingency Operation**

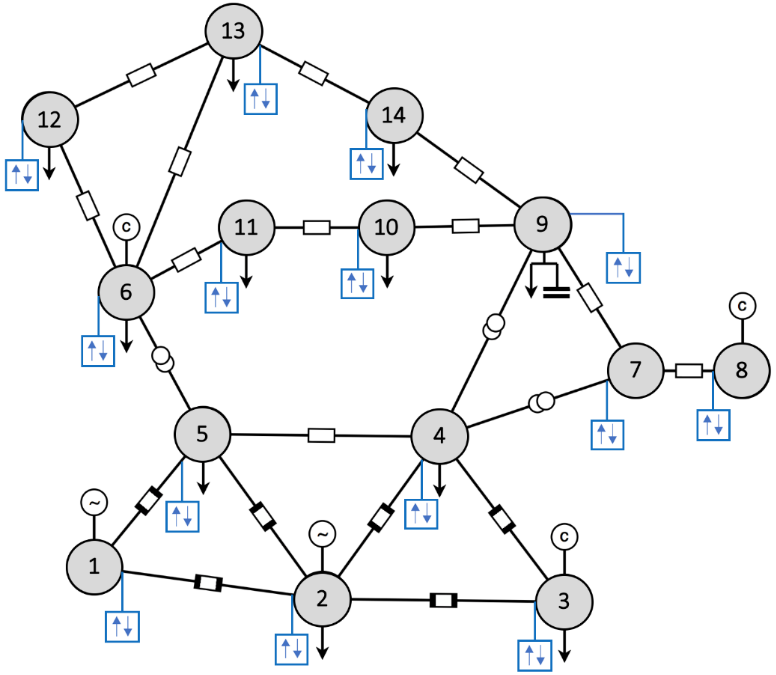
| Case | Contingency Type | No. of Buses | Standard Tool | SUGAR |
|---|---|---|---|---|
| | | | From initial solution or arbitrary initial conditions | |
| 1 | N-2 | 75456 | X | ✓ |
| 2 | N-2 | 78021 | X | ✓ |
| 3 | N-3 | 80293 | X | ✓ |
| 4 | N-3 | 81238 | X | ✓ |

✓ converged X diverged



# Power Flow with Feasibility

- Enhance power flow simulation to indicate if a system is infeasible
- Place “feasibility sources” at all (or selected) buses and minimize the injected power while satisfying network constraints

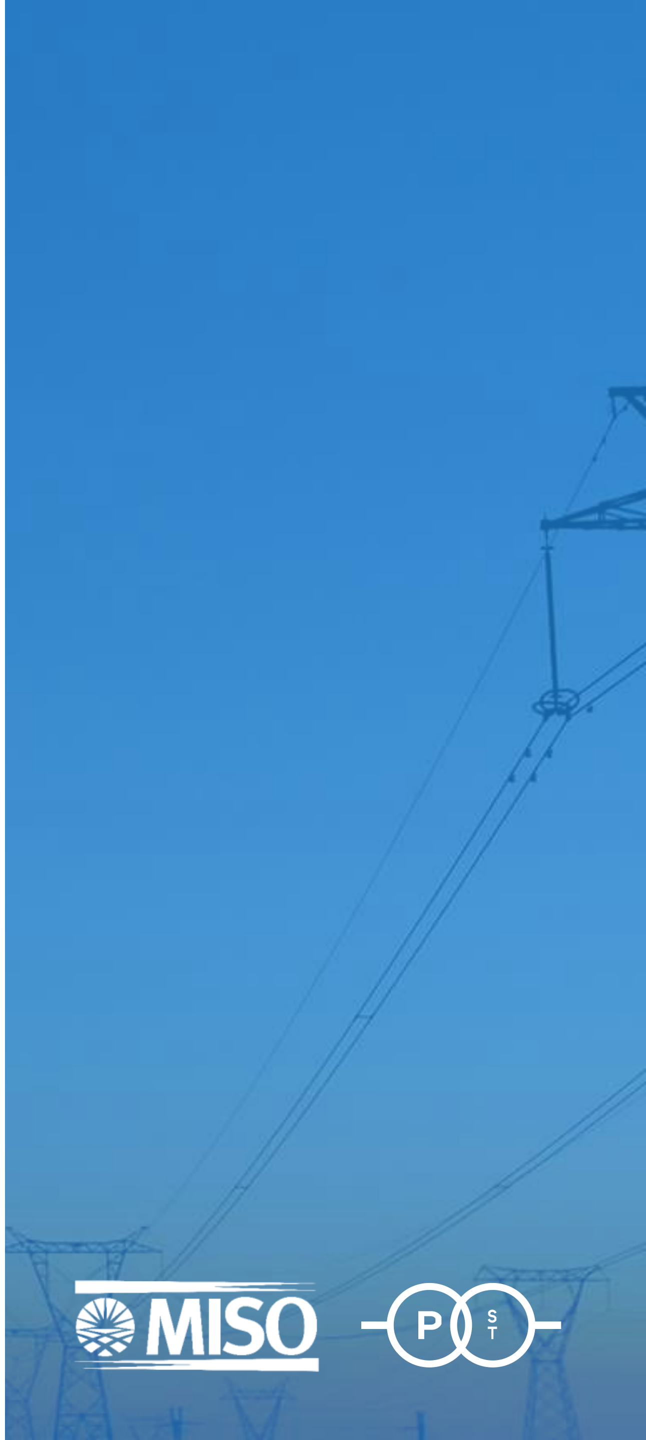



### Feasible system

Source values are zero, power flow solution unchanged

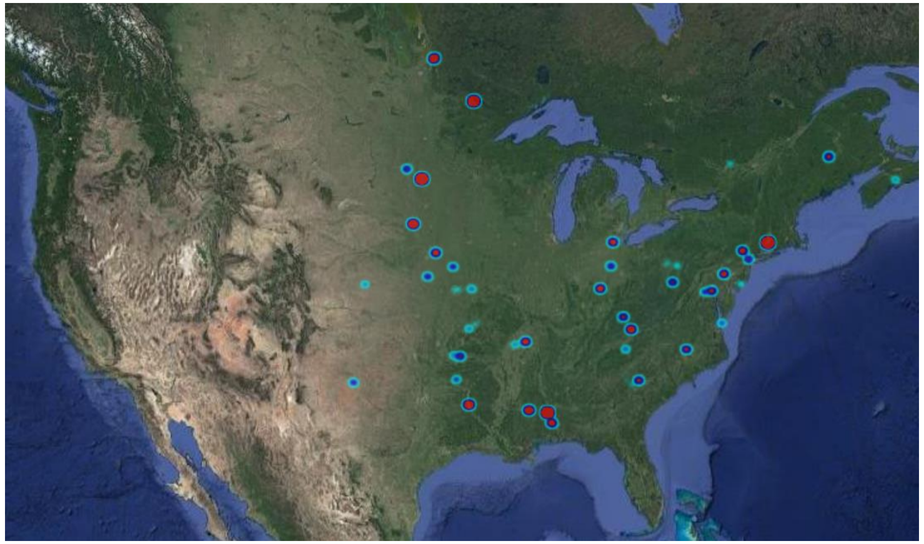
### Infeasible system

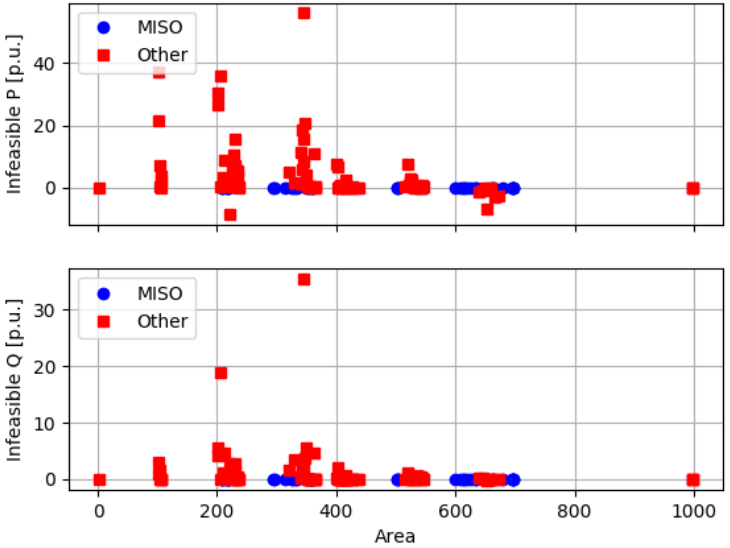
Nonzero injected power at buses that cause infeasibility



# MISO 40% Penetration Case

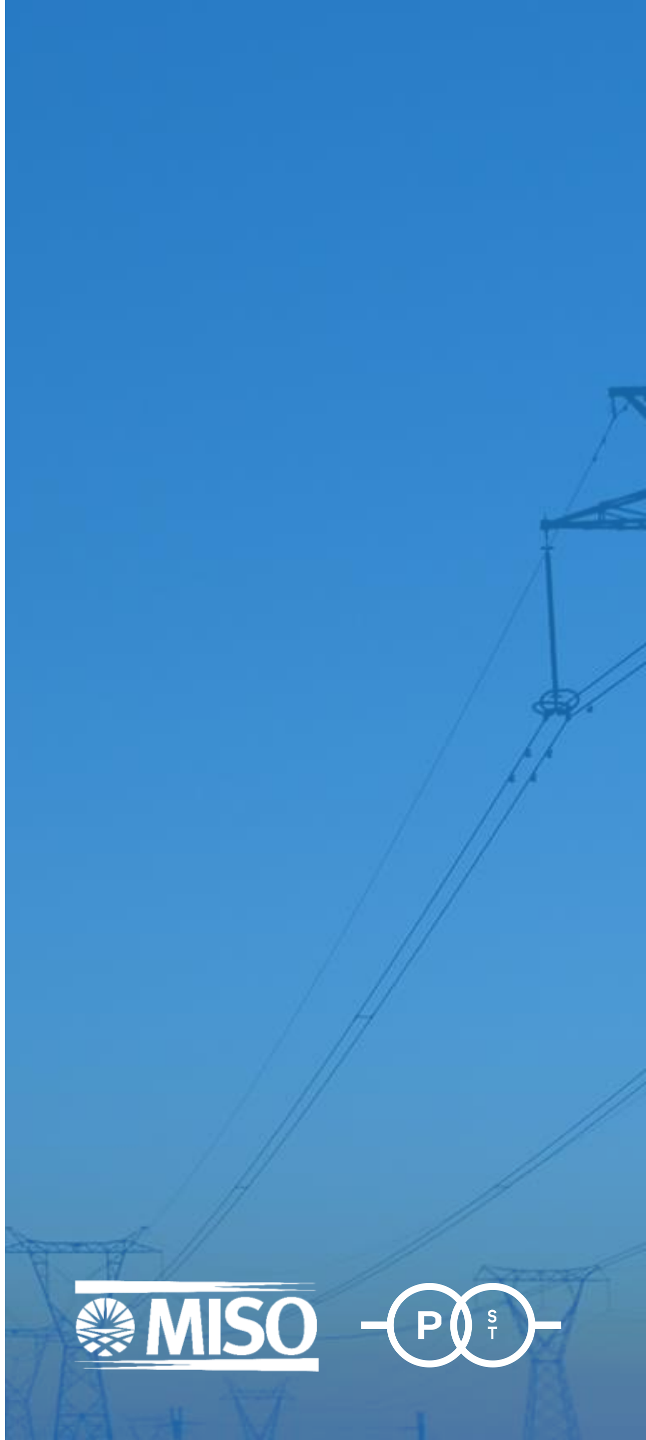
- Use feasibility sources to locate and quantify power deficiencies
- Solved with feasibility sources only outside of MISO
  - Goal was to leave everything in the MISO territory untouched





# Solving the Case: Adjustable Variables

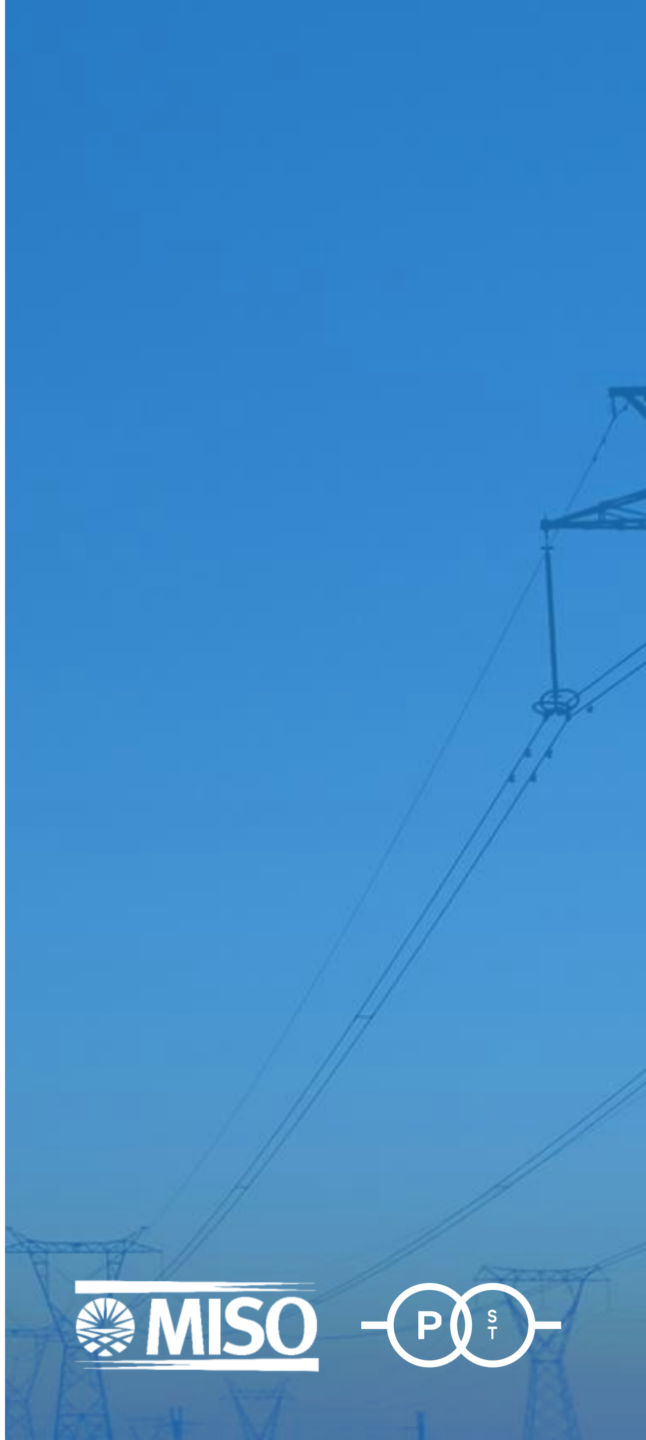
- Creating a solved power flow case based on the infeasibility information requires adjusting resources in the grid
  - SUGAR is flexible enough to allow the user to decide what is allowed to change
- MISO’s choice of adjustable variables:
  - Real power for generators (including turning generators on) outside MISO that meet other user-specified requirements (e.g., not labeled “retired”)
  - Reactive power compensation
  - Generators should increase (or decrease) their real power output following an economic preference given in a separate file



# Automated “Model Building” Approach

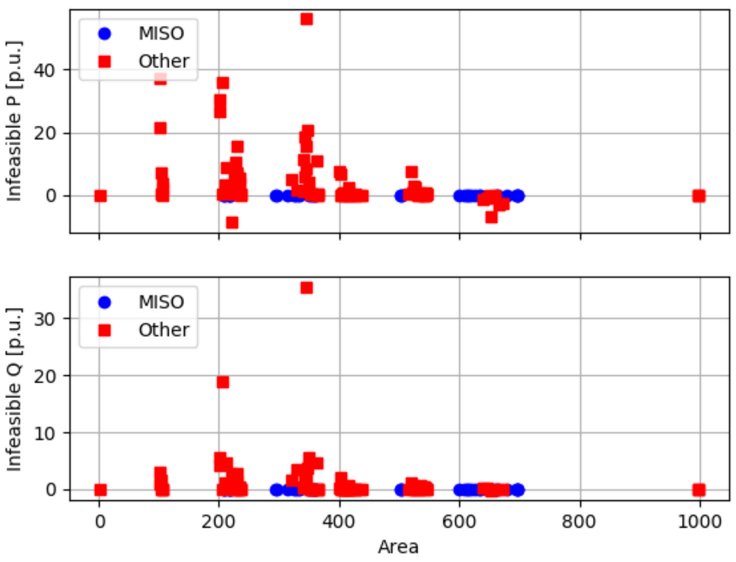
1. Solve the unsolved case with feasibility sources on all buses outside MISO
2. Given the infeasible real power computed at each bus:
   - Aggregate all the infeasible real power on an area-by-area basis
   - Redistribute the area’s infeasible real power among available generators in the area “greedily”
     - Real power is absorbed by the most economic (cheapest) generators in order
     - The least-economic generators reduce their real power in areas where there is an excess of real power
     - New generators may be turned on (given previous criteria)
   - Create shunts to compensate for reactive power deficiency

Repeat steps 1 and 2 until infeasible real, reactive power are zero everywhere

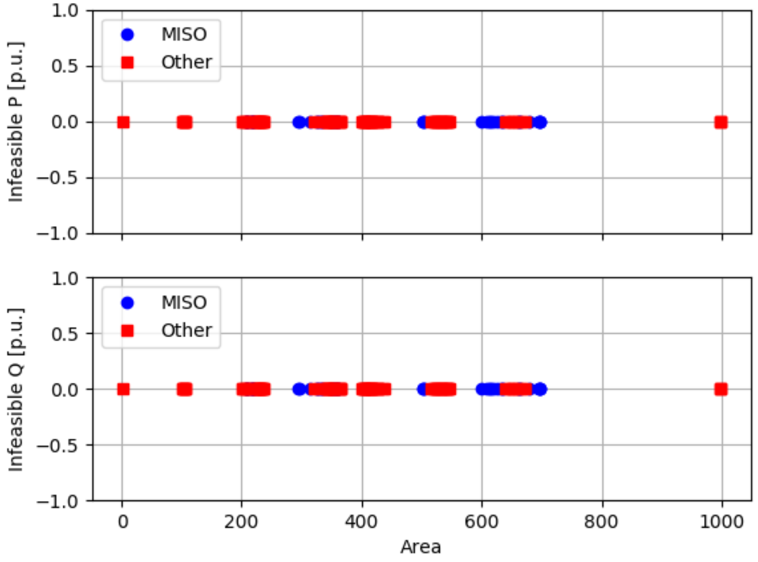


# MISO 40% Penetration Case

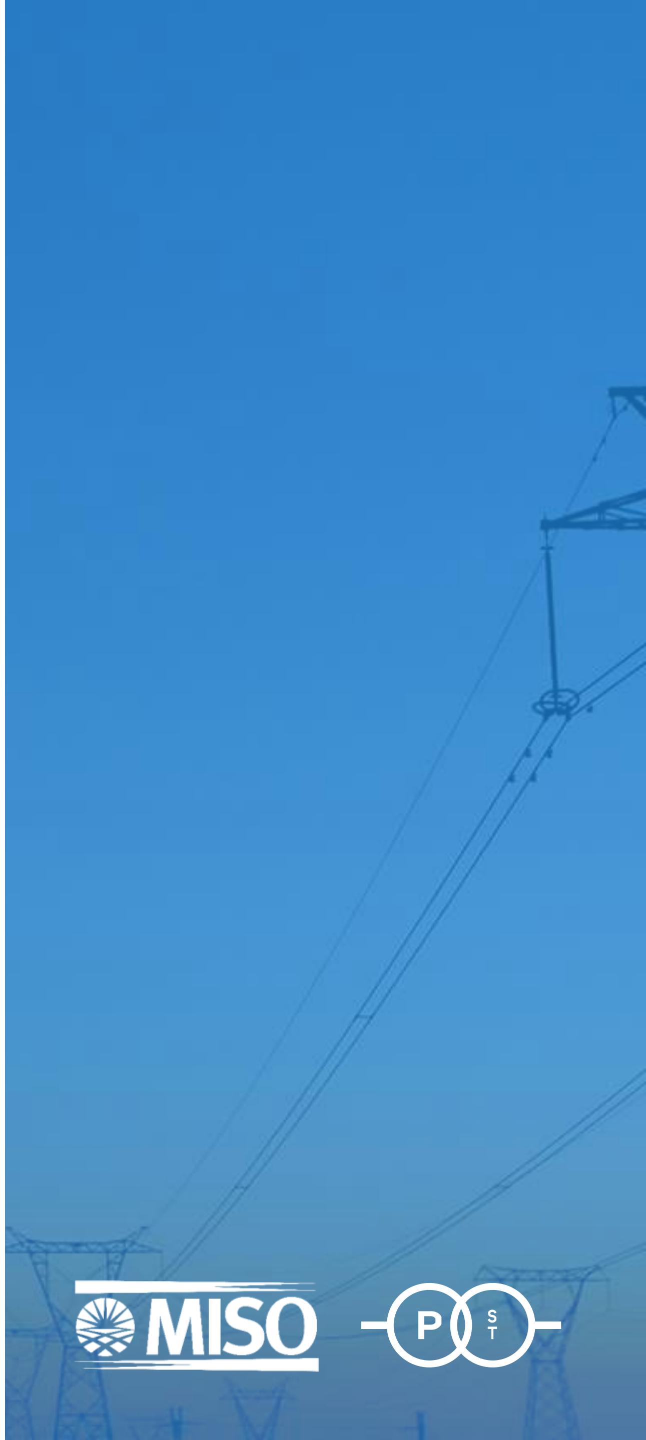
Original case
Infeasible throughout the system




After infeasibility-based re-dispatch
Solved, feasible case

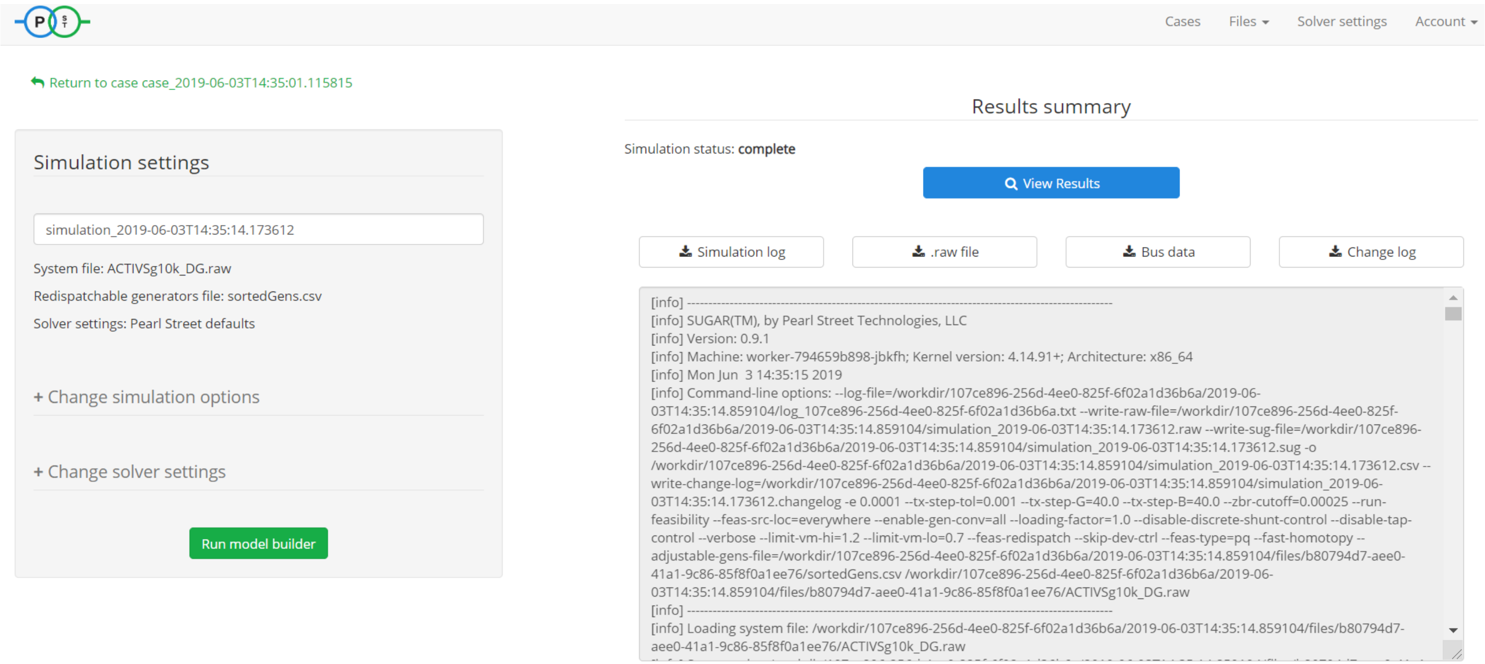



Solved in minutes with no user action required

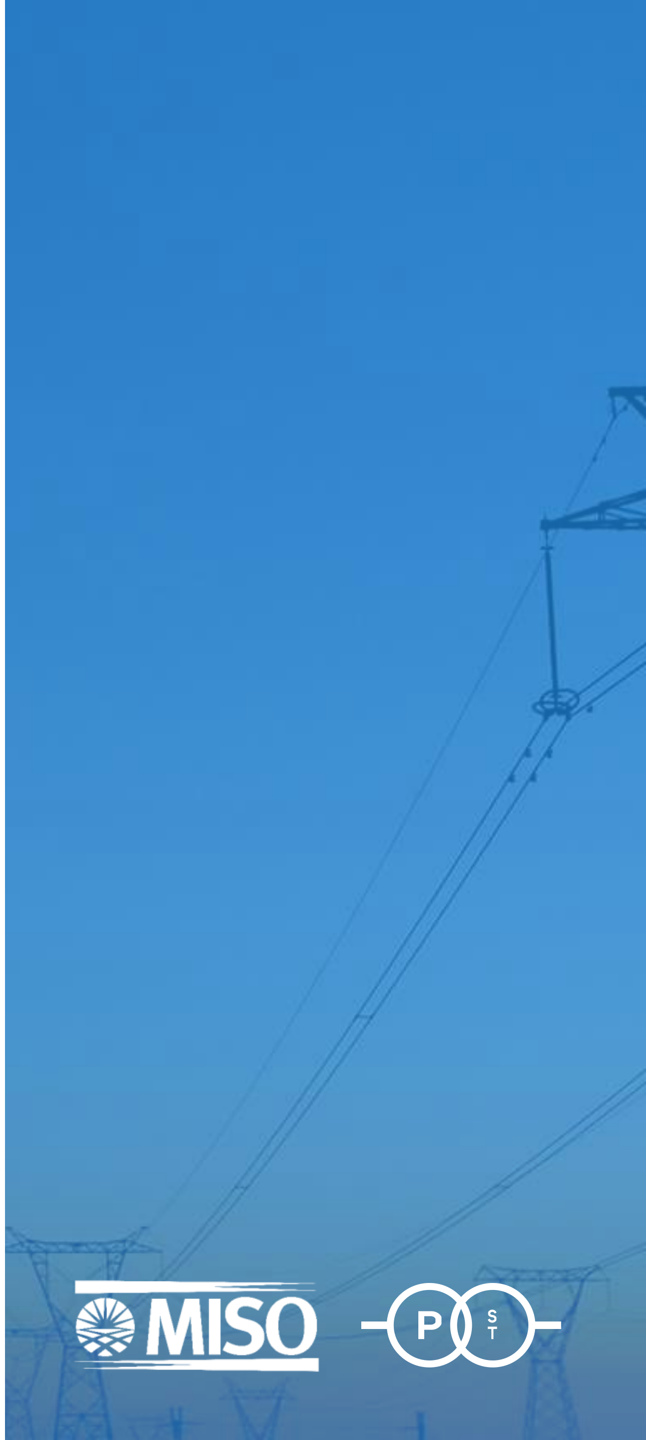


# Web Application Access

- Access to SUGAR, including the model-building feature, is provided through a secure web application

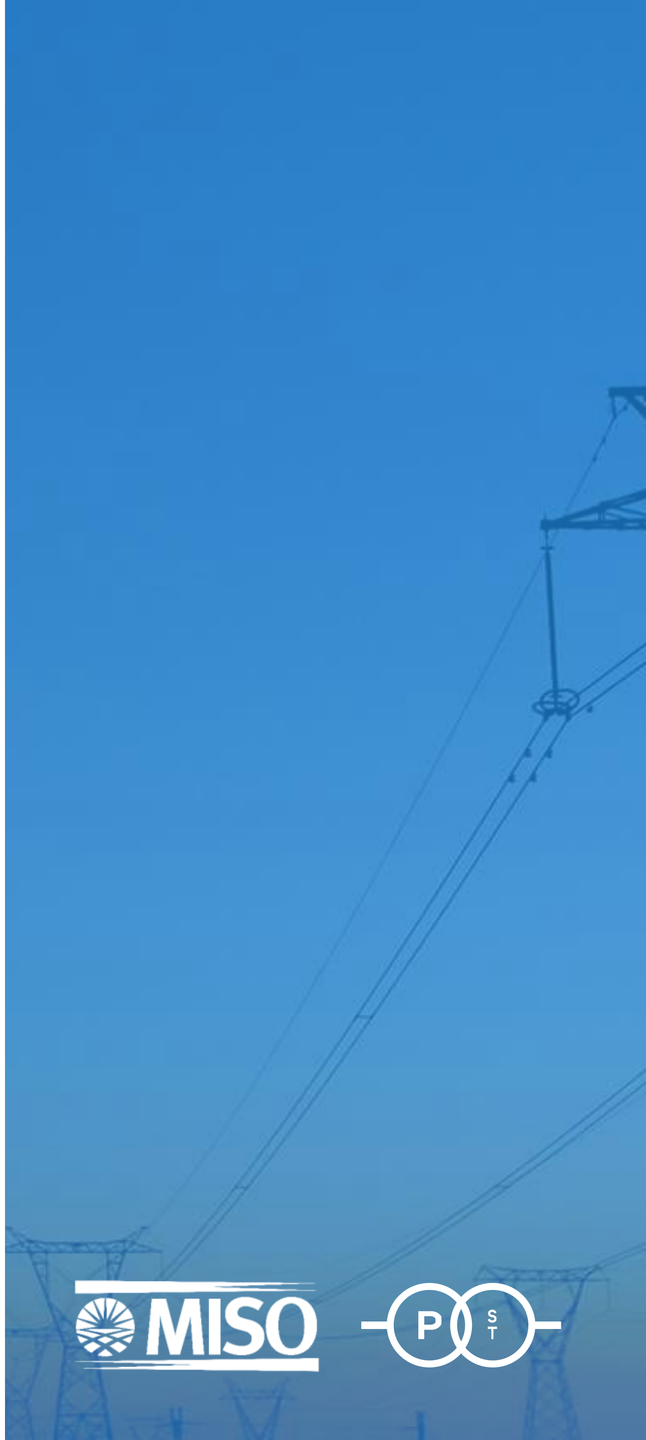



For more information, please visit www.pearlstreettechnologies.com



# Summary

- SUGAR solves power flow cases that are infeasible or otherwise hard to solve
  - MISO high renewable penetration study cases
- Targeted and quantifiable infeasibility information enables automated re-dispatch of grid resources
- SUGAR eliminates extensive manual effort in solving complex grid analysis problems



# Questions?

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All RIIA-related documents can be found on MISO’s web page.

Home > Planning > Policy Studies > Renewable Integration Impact Assessment

Selected Publications:

[1] Chen-Hao Tsai, et., al. "Challenges of Planning for High Renewable Future: Experience of the U.S. Midcontinent”, Under preparation.

[2] B. Heath and A. L. Figueroa-Acevedo, "Potential Capacity Contribution of Renewables at Higher Penetration Levels on MISO System," *2018 IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*, Boise, ID, 2018, pp. 1-6. doi: 10.1109/PMAPS.2018.8440442

RIIA Workshop will be held in September, 2019 in Eagan MN