



Robust Solution of High Renewable Penetration Planning Cases in SUGAR

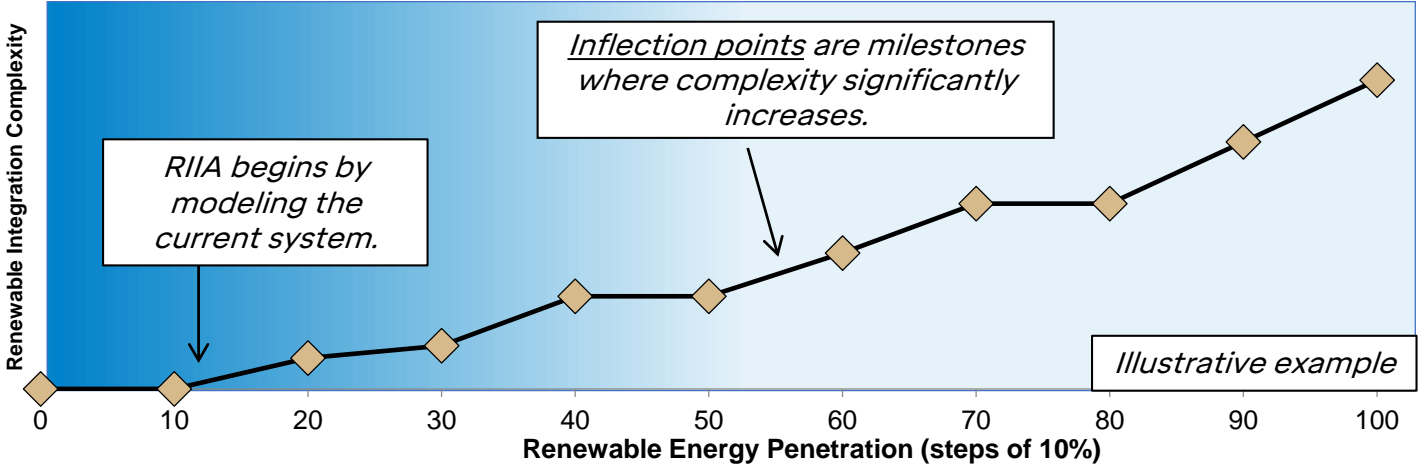
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Renewable Integration Impact Assessment (RIIA) seeks to find inflection points of renewable integration complexity



Focus Areas

Resource Adequacy

Having the sufficient capacity of resources to reliably serve peak demand

Energy Adequacy

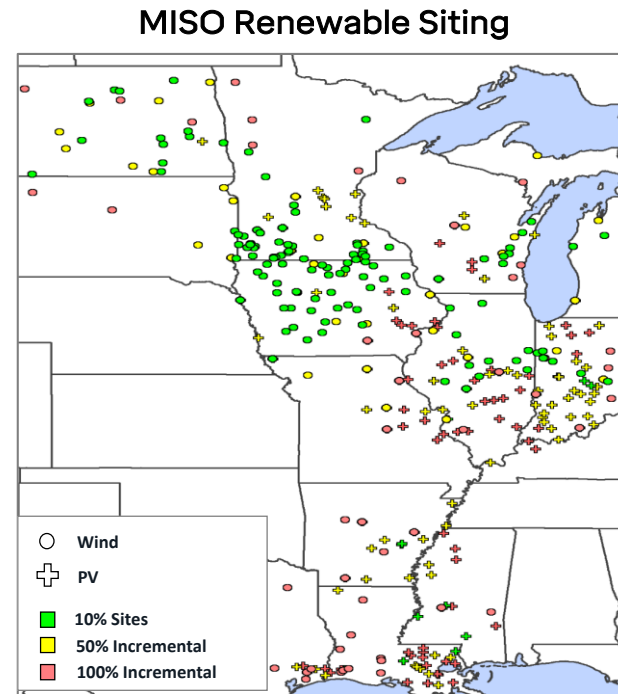
Ability to provide energy in all operating hours throughout the year

Operating Reliability

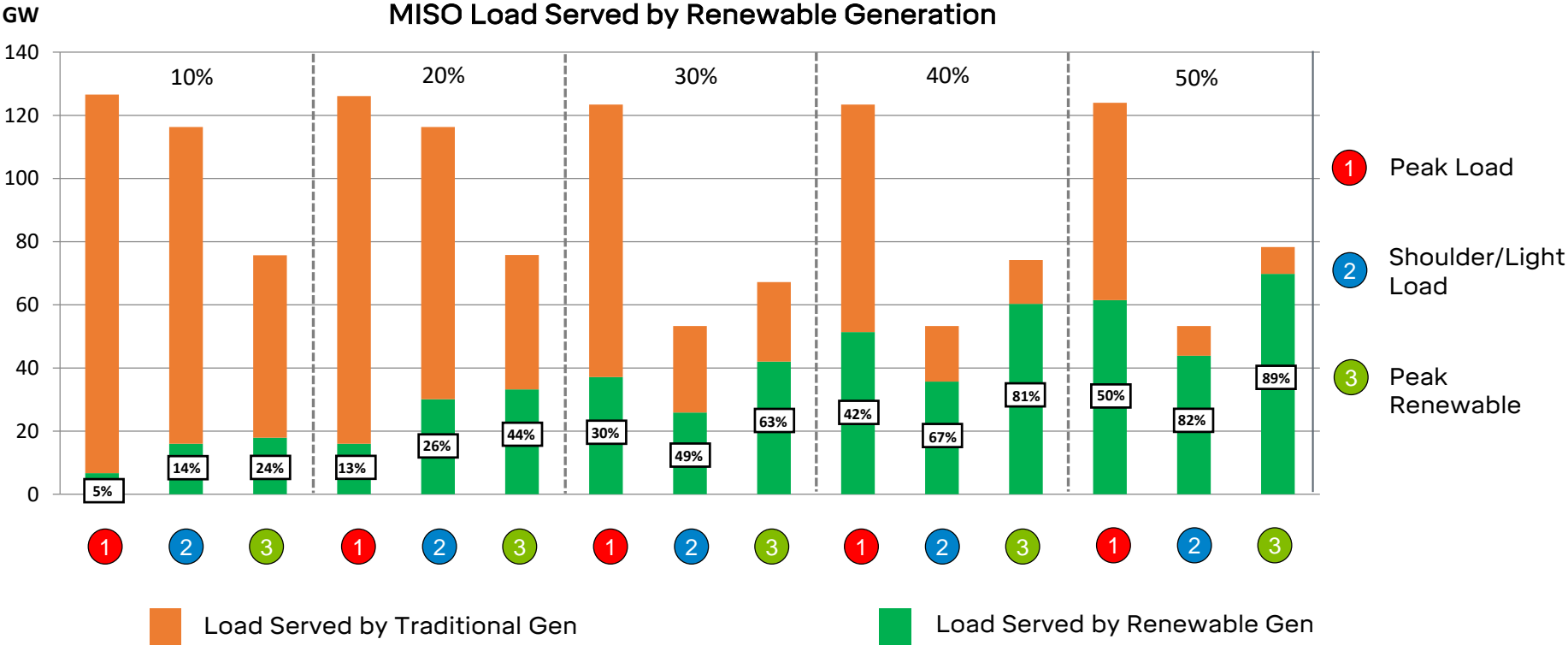
Ability to withstand unanticipated component losses or disturbances

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

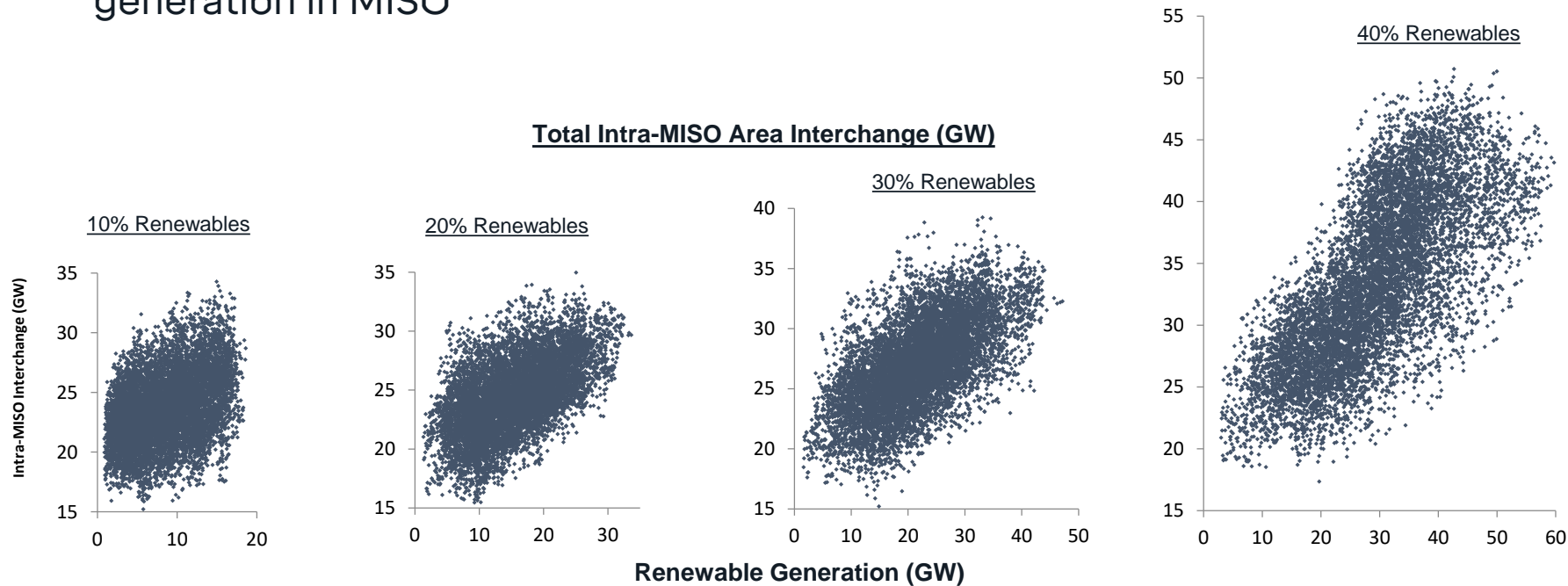


Operating reliability analysis was conducted on instantaneous renewable penetration snapshots from 5% to 89%

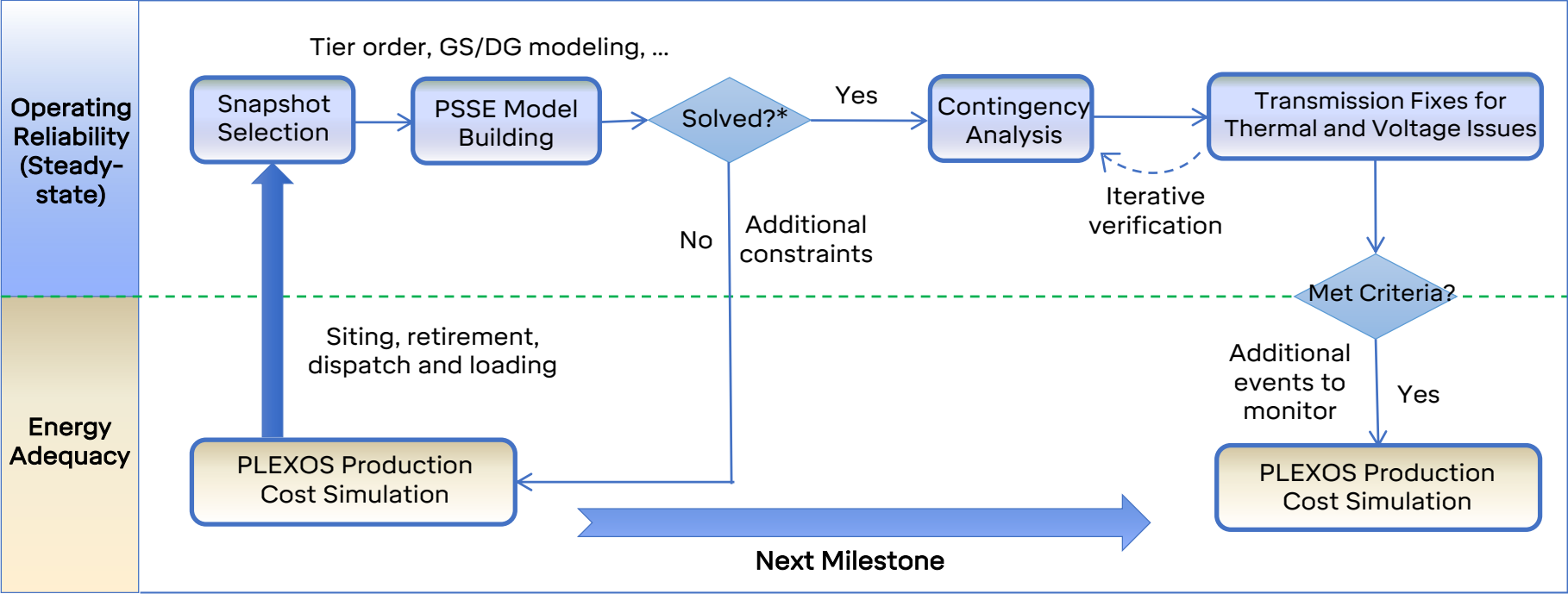


Intra-MISO interchange increases as renewable penetration grows

- 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



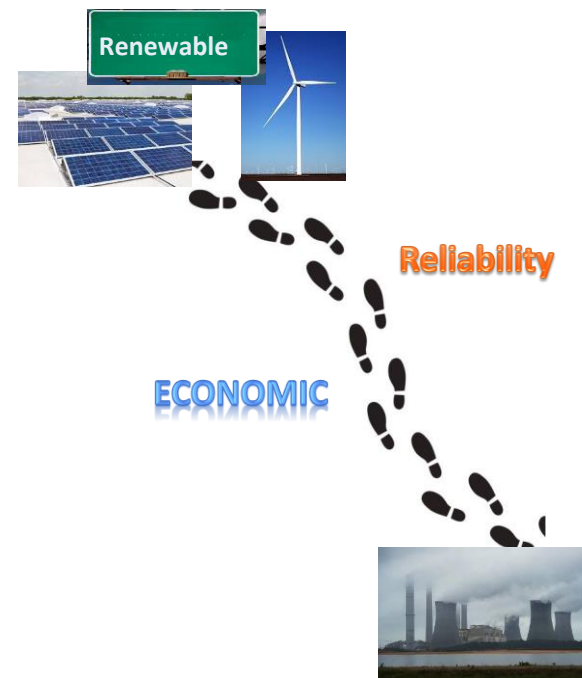
Integrated production cost and operating reliability analysis framework



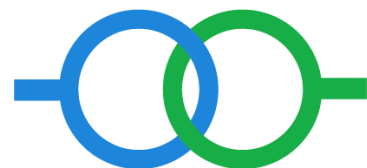
* Solutions from DC models with linearized losses are generally “tighter” than AC solutions thus may introduce infeasibilities.

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>



Pearl Street

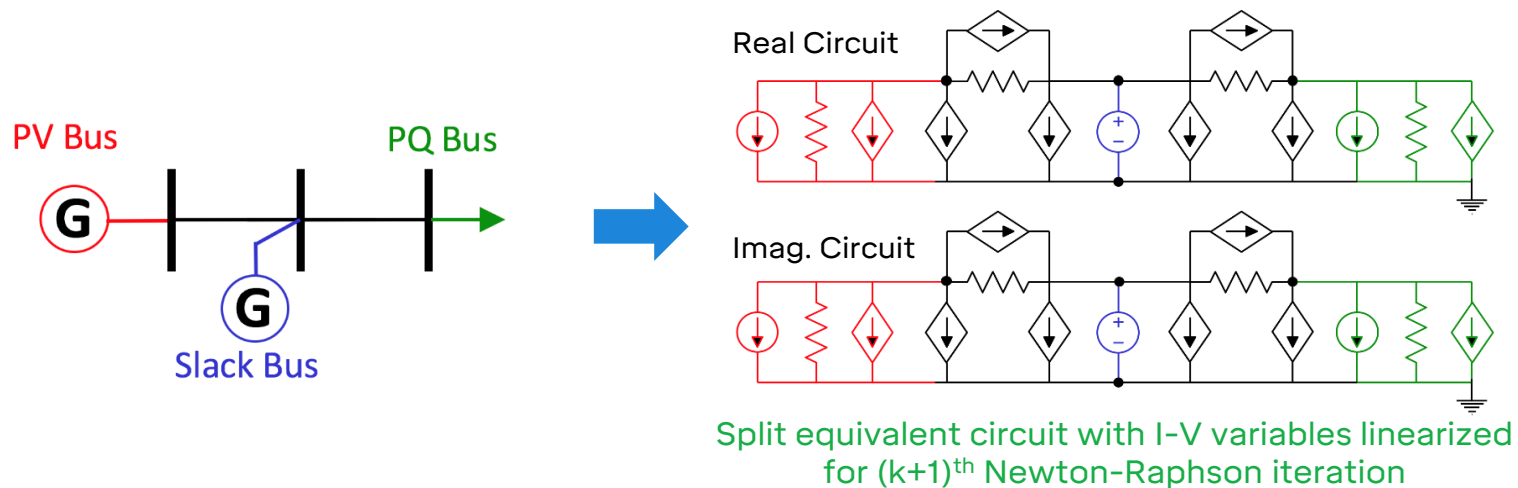
TECHNOLOGIES

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



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](#)

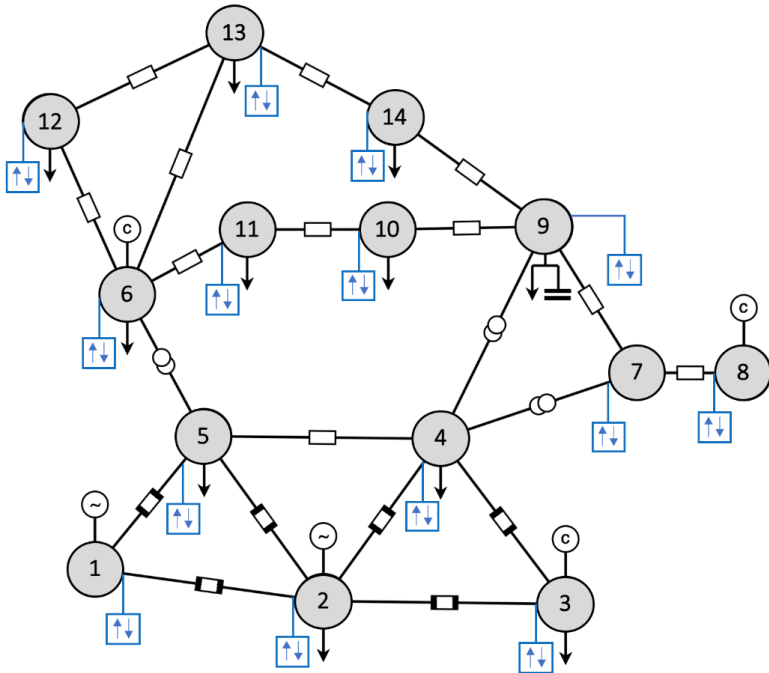
Extreme Contingency Operation

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

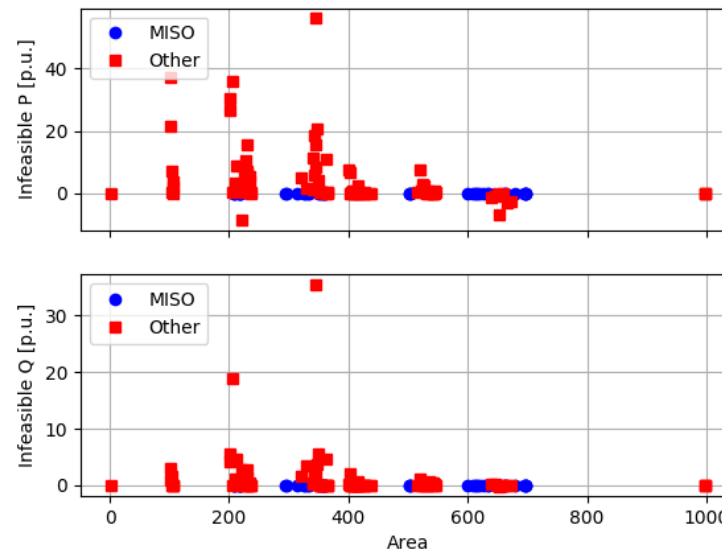
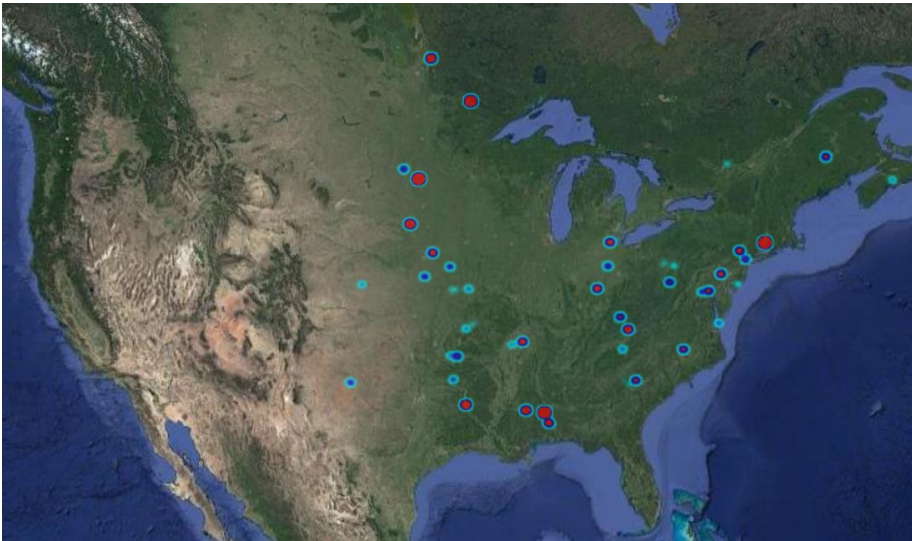
Source values are zero, power flow solution unchanged

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

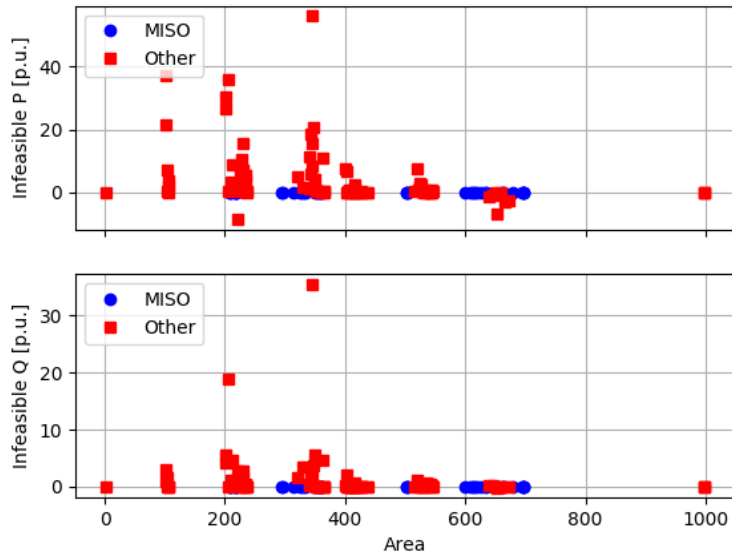
1. Solve the unsolved case with feasibility sources on all buses outside MISO
2. Given the infeasible real power computed at each bus:
 - Aggregate all the infeasible real power on an area-by-area basis
 - Redistribute the area’s infeasible real power among available generators in the area “greedily”
 - 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

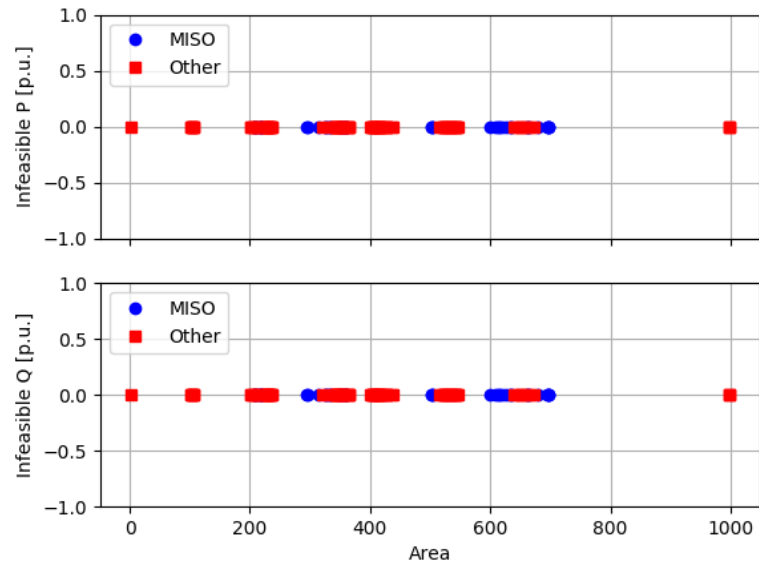
Original case

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

The screenshot displays the SUGAR web application interface. At the top, there is a navigation bar with a logo on the left and links for 'Cases', 'Files', 'Solver settings', and 'Account' on the right. Below the navigation bar, a green link reads 'Return to case case_2019-06-03T14:35:01.115815'. The main content area is divided into two panels. The left panel, titled 'Simulation settings', contains a text input field with the value 'simulation_2019-06-03T14:35:14.173612'. Below this, it lists 'System file: ACTIVSg10k_DG.raw', 'Redispatchable generators file: sortedGens.csv', and 'Solver settings: Pearl Street defaults'. There are two expandable sections: '+ Change simulation options' and '+ Change solver settings'. At the bottom of this panel is a green button labeled 'Run model builder'. The right panel, titled 'Results summary', shows 'Simulation status: complete' and a blue button labeled 'View Results'. Below this are four buttons: 'Simulation log', '.raw file', 'Bus data', and 'Change log'. A large text area displays the simulation log output, which includes information about the SUGAR version (0.9.1), machine details, command-line options, and the loading of the system file.

Simulation settings

simulation_2019-06-03T14:35:14.173612

System file: ACTIVSg10k_DG.raw
Redispatchable generators file: sortedGens.csv
Solver settings: Pearl Street defaults

+ Change simulation options

+ Change solver settings

Run model builder

Results summary

Simulation status: complete

View Results

Simulation log .raw file Bus data Change log

```
[info] -----  
[info] SUGAR(TM), by Pearl Street Technologies, LLC  
[info] Version: 0.9.1  
[info] Machine: worker-794659b898-jbkfh; Kernel version: 4.14.91+; Architecture: x86_64  
[info] Mon Jun  3 14:35:15 2019  
[info] Command-line options: --log-file=/workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/log_107ce896-256d-4ee0-825f-6f02a1d36b6a.txt --write-raw-file=/workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/simulation_2019-06-03T14:35:14.173612.raw --write-sug-file=/workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/simulation_2019-06-03T14:35:14.173612.sug-o  
/workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/simulation_2019-06-03T14:35:14.173612.csv --write-change-log=/workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/simulation_2019-06-03T14:35:14.173612.changelog -e 0.0001 --tx-step-tol=0.001 --tx-step-G=40.0 --zbr-cutoff=0.00025 --run-feasibility --feas-src-loc=everywhere --enable-gen-conv=all --loading-factor=1.0 --disable-discrete-shunt-control --disable-tap-control --verbose --limit-vm-hi=1.2 --limit-vm-lo=0.7 --feas-redispatch --skip-dev-ctrl --feas-type=pq --fast-homotopy --adjustable-gens-file=/workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/files/b80794d7-ae0-41a1-9c86-85f8f0a1ee76/sortedGens.csv /workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/files/b80794d7-ae0-41a1-9c86-85f8f0a1ee76/ACTIVSg10k_DG.raw  
[info] Loading system file: /workdir/107ce896-256d-4ee0-825f-6f02a1d36b6a/2019-06-03T14:35:14.859104/files/b80794d7-ae0-41a1-9c86-85f8f0a1ee76/ACTIVSg10k_DG.raw
```

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

