***Panel: Analytical Needs for Composite System Reliability Analysis***
*IEEE PES 2021 General Meeting*

# CSR in the Probabilistic Resource Adequacy Suite (PRAS): Fast interregional transmission models for renewable integration studies

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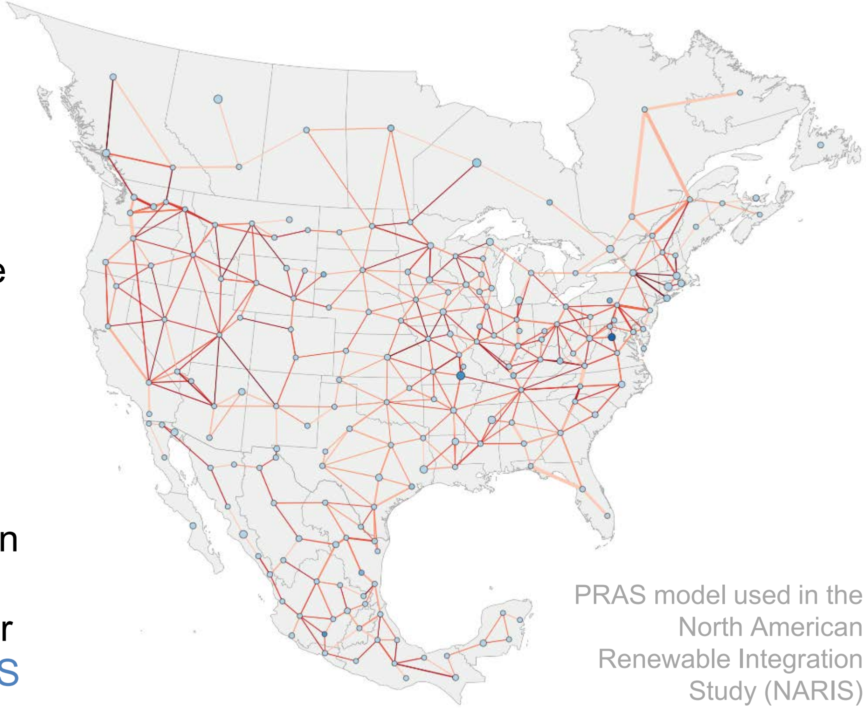
# Probabilistic Resource Adequacy Suite (PRAS)

- NREL's collection of tools for studying unserved energy risk in electric power systems, across space and time
- Designed for studying large-scale renewables integration and potential power transfers over wide geographic areas, across climates and time zones
- Models storage and other energy-limited resources
- Primarily a Monte Carlo model, with other simulation modes available (e.g. HL1 convolution)
- Easy to run on a laptop, scales to a compute cluster
- Free and open-source software: nrel.github.io/PRAS



PRAS model used in the North American Renewable Integration Study (NARIS)

## What PRAS considers:

- ✓ Thermal generators (outage rates, rated capacities)
- ✓ Variable generation and load profiles
- ✓ Interregional lines (outage rates, thermal limits)
- ✓ Interregional interface transfer limits
- ✓ Transport / pipe-and-bubble power flow
- ✓ Time-varying outage rates
- ✓ Storage / energy-limited resources (shortfall-minimizing dispatch)

## What PRAS doesn't consider:

- ✗ Nodal transmission representation
- ✗ Intraregional lines
- ✗ Substation components
- ✗ AC or DC power flow
- ✗ Economic dispatch or unit commitment
- ✗ Demand flexibility

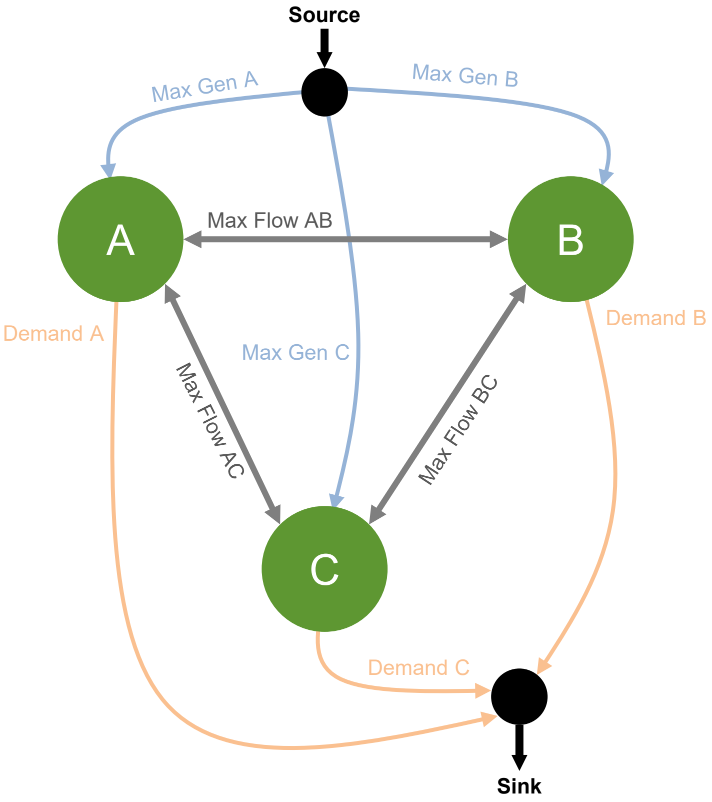
# Transmission in PRAS: simple but fast

Pipe-and-bubble (transport) approach:

- Divide system into regions
- Define interfaces between regions
- Assign interregional lines to interfaces
- Determine interface flow limit based on sum of randomly-available line limits (or use interface transfer limit, whichever is lower)

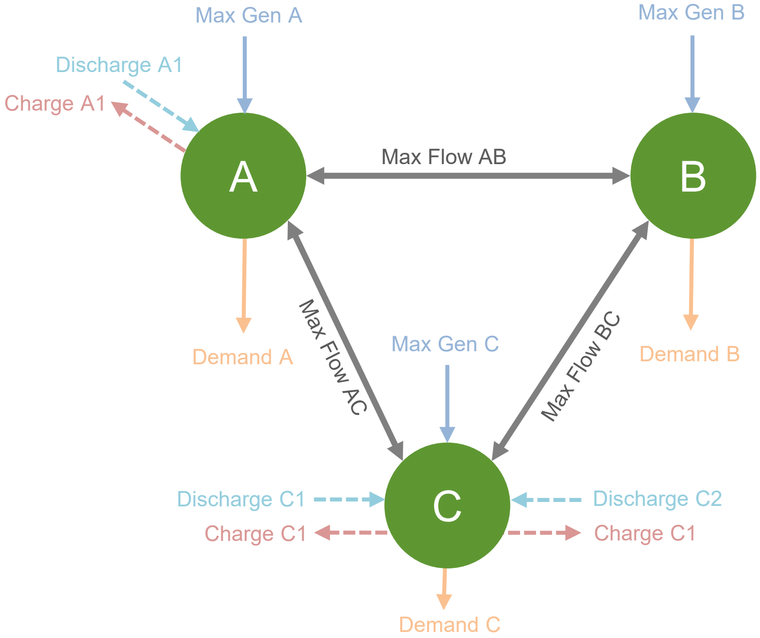
Calculating minimum unserved energy in each timestep:

- Augment network with generation (source) and demand (sink) edges and nodes
- Serving as much demand as possible becomes a max-flow network optimization, with specialized (fast) solution algorithms available
- If demand edges are unsaturated, energy is unserved
- Used in PRAS up to v0.3 – doesn't accommodate storage



# Adding storage: from max-flow to min-cost flow

- Dispatch storage ‘conservatively’ (near-upper bound on RA contribution) without needing to consider future periods
- Charging incurs a negative cost (reward), discharging incurs a higher-magnitude positive cost (prevents cross-charging), always most expensive to drop load
- Charge/discharge costs ordered using ‘time-to-go’ ranking [1] for storage coordination
- Still a network flow problem (but min-cost, not max-flow) with specialized algorithms available – unused capacity / unserved energy channeled through ‘slack node’ to maintain flow balance
- Dual ascent method allows hot-starting one timestep’s solve using solution from previous (similar) timestep
- Used in PRAS since v0.4

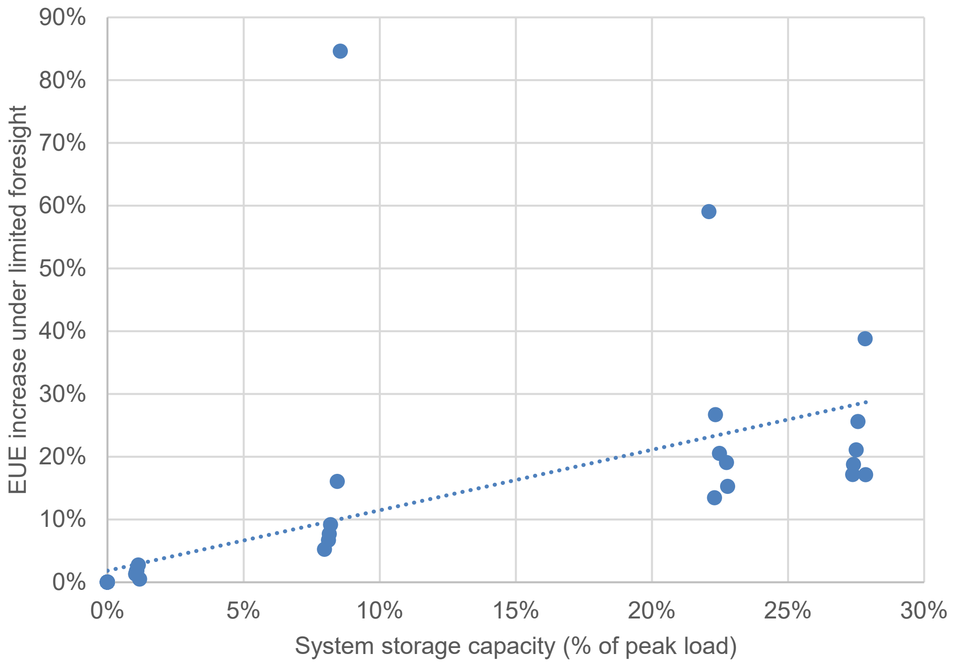



*slack node and edges not pictured

[1] Evans, Tindemans, and Angeli. 2019. “Minimizing Unserved Energy Using Heterogeneous Storage Units”. IEEE Transactions on Power Systems 34(5):3647–3656.

# How realistic is shortfall minimization?

- ‘Real’ limited-horizon economic dispatch / market clearing is susceptible to forecast errors & myopic behavior
- A similar min-cost network flow framework can be applied for efficient <u>intertemporal economic dispatch</u> for use and comparison in probabilistic models (treating storage as transmission through time instead of ranking)
- Dispatch ‘error’ / shortfall suboptimality increases as more storage is required to shift energy over longer periods of time
- May not be a problem for RA assessment of high wind and solar systems (where ‘conservative’ dispatch assumptions could align better with realistic behavior anyways)




Least-cost buildouts of the RTS-GMLC for various reliability constraints and carbon prices. Systems with higher storage dependency typically show a greater performance gap between shortfall-minimizing and 24-hour lookahead economic dispatch.

## Conclusions

- Large-scale integration of renewables often involves long-distance transfers of power and therefore requires CSR analysis
- PRAS uses simplified pipe-and-bubble transmission representations with specialized solution algorithms to simulate operations efficiently for large multi-region systems
- Storage representations are also increasingly important for modeling high-renewable systems
- Network flow optimization models can be adapted in multiple ways for compatibility with storage modeling

# *Thank you - stay in touch!*

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This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office and Wind Energy Technologies Office. The views expressed in this presentation do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting this presentation for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL/PR-5C00-80354