ESIG SPRING TECHNICAL WORKSHOP

MARCH 19, 2025

RESOURCE ADEQUACY UNDER SYSTEM TRANSFORMATION

ENERGY STORAGE, CAPACITY MARKETS, AND SCARCITY PRICING

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ARGONNE MARKET WORKSTREAMS

Market design to ensure revenue sufficiency and resource adequacy

- Three key research questions:

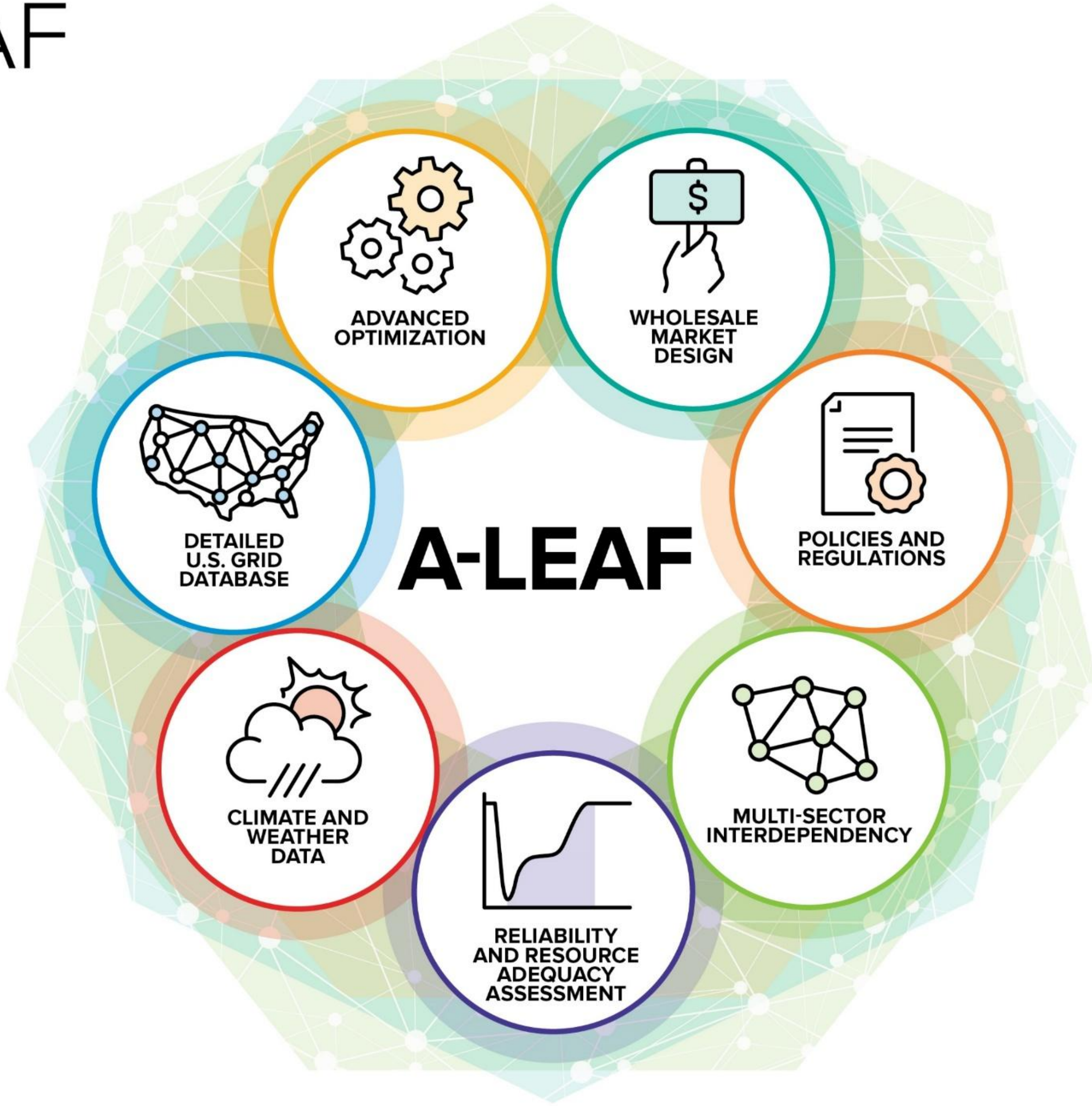
1. How do system modeling assumptions impact reliability metrics?
2. How do energy storage dispatch assumptions impact reliability and capacity accreditation?
3. How can ORDC and CDC design be coordinated to mitigate missing money and improve resource adequacy?

POWER SYSTEM MODELING
WITH A-LEAF

ADVANCED OPTIMIZATION
- System least-cost planning and operations
- Strategic investments
- Sub-hourly dispatch
- Multiday representative periods
- Simultaneous generation and transmission, and storage expansion planning

DETAILED U.S. GRID DATABASE
- Extensive database of 9000+ U.S. generation resources
- Hourly load profiles for 130+ balancing authorities
- User-defined transmission zones at any scale
- 200+ zone county-level Texas system

CLIMATE AND WEATHER DATA
- Future weather years derived from climate models
- Extreme weather events
- Hourly wind and solar availability for current and future scenarios
- Temperature dependent thermal outages



WHOLESALE MARKET DESIGN
- Multi-stage market settlement
- Scarcity pricing mechanisms
- Forward market modeling

POLICIES AND REGULATIONS
- National and local policies and incentives
- Customizable critical material constraints
- Land use restrictions and resource availability

MULTI-SECTOR INTERDEPENDENCY
- Coupling with a global energy systems model (TIMES)
- Water-energy nexus
- Transportation systems
- Natural gas infrastructure

RELIABILITY AND RESOURCE ADEQUACY ASSESSMENT
- Probabilistic reliability assessment
- Capacity accreditation using ELCC
- System inertia requirements

U.S. DEPARTMENT OF ENERGY
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A-LEAF APPLICATIONS

Argonne NATIONAL LABORATORY

ELECTRICITY SYSTEM MODERNIZATION

- Identify system least-cost electricity system modernization pathways
- Establish the role of transmission expansion in different system portfolios
- Establish the role of energy storage in different system portfolios

WHOLESALE MARKET ANALYSIS

- Compare the price and portfolio implications of enhanced scarcity pricing mechanisms
- Explore the implications market designs and incentives

LONG-TERM PLANNING

- Conduct high-fidelity capacity expansion analysis with up to 5-minute dispatch intervals
- Establish highly-customized multi-day periods to capture LDES value
- Evaluate storage value as a transmission asset
- Customize spatial representation to improve computational performance

SHORT-TERM OPERATIONS AND RELIABILITY ASSESSMENT

- Conduct full direct current optimal power flow modeling
- Simulate stochastic resource outages to determine reliability metrics
- Determine system-wide and regional reliability metrics
- Calculate technology resource adequacy contributions (i.e., effective load carrying capabilities)

TECHNOECONOMIC VALUATION

- Assess optimal investment decisions from multiple perspectives: owner/operator, system, society
- Analyze resource revenues from providing capacity, energy, and reserves

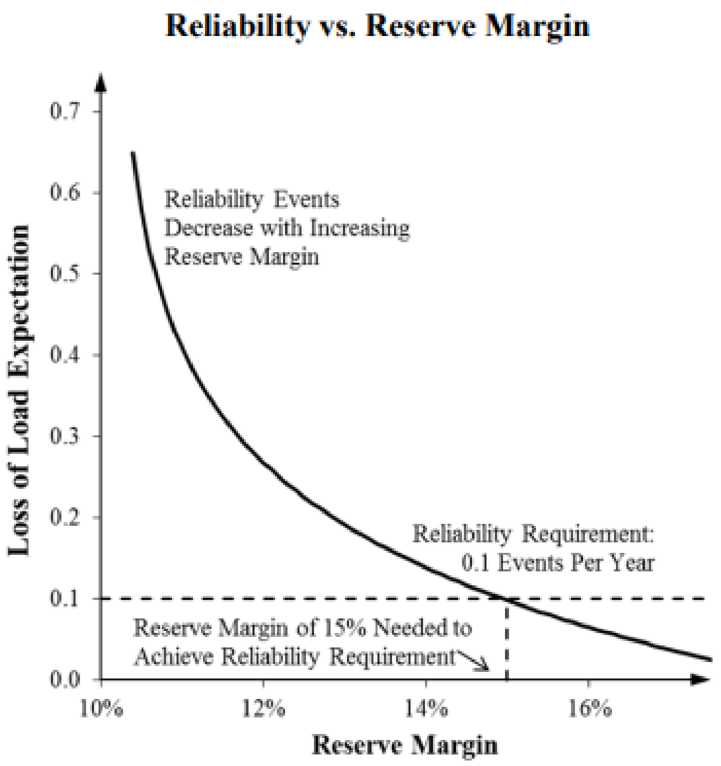
EXTREME WEATHER RESILIENCE

- Consider 60+ future weather years with downscaled projections from global climate models
- Identify and analyze extreme weather events and periods of stressed operating conditions

TWO-STAGE PROBABILISTIC RELIABILITY ASSESSMENT WITH EFFICIENT FILTERING AND IMPERFECT FORESIGHT

LONG-TERM SYSTEM RELIABILITY

- System reliability metrics (EUE, LOLP, and LOLE) inform system planning and market designs.
  - Planning reserve margins
  - Capacity market demand curves
  - Operating reserve demand curves
- Capacity accreditation determines resource contributions
  - Historical performance
  - ELCC
  - DLOL



Reliability assessment isn't just a modeling exercise, it plays a crucial role in establishing these parameters, which in turn impacts investments and system portfolios

Loss of Load Expectation (LOLE) *expected loss of load over a duration (1 year, 10 years)*
Loss of Load Probability (LOLP) *the proportion of days with insufficient generation to meet demand*

J. P. Pfeifenberger, K. Spees, et al "Resource Adequacy Requirements: Reliability and Economic Implications," available at: https://www.ferc.gov/sites/default/files/2020-05/02-07-14-consultant-report.pdf

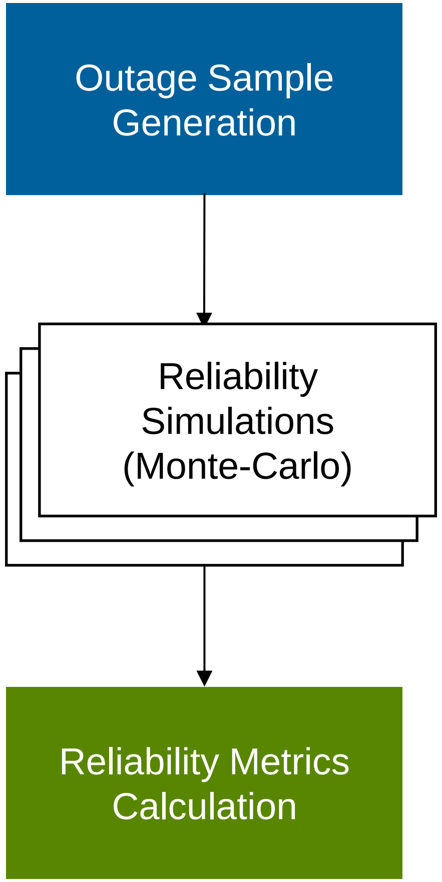
RELIABILITY ASSESSMENT MODELS

- **Industry Status Quo**
  - —PJM: Probability Reliability Index Model (PRISM), Multi-Area Reliability Simulation (MARS)
  - —NYISO, ISO-NE: MARS
  - —MISO: MARS, Strategic Energy & Risk Valuation Model (SERVM)
  - —ERCOT: SERVM
- **Challenge**:
  - —It is important to achieve a balance between detail and computational tractability.
  - —Limited attention has been given to understanding how different modeling assumptions and methods affect quantification reliability metrics.
    - Risk sample size
    - Filtering methods
    - Post-contingency scheduling algorithm

CONTRIBUTIONS

- **Sample size**
  - We analyze how the number of considered outage scenarios influences the accuracy and robustness of the model's reliability estimates.
- **Risk sample filtering**
  - We evaluate the performance of three different risk sample filtering methods, which reduce computational demands while attempting to preserving assessment accuracy.
- **Imperfect foresight**
  - We introduce and assess a two-stage post-contingency dispatch algorithm that captures imperfect foresight and assess the implications for modeled RA metrics.

A-LEAF PROBABILISTIC RELIABILITY ASSESSMENT MODEL

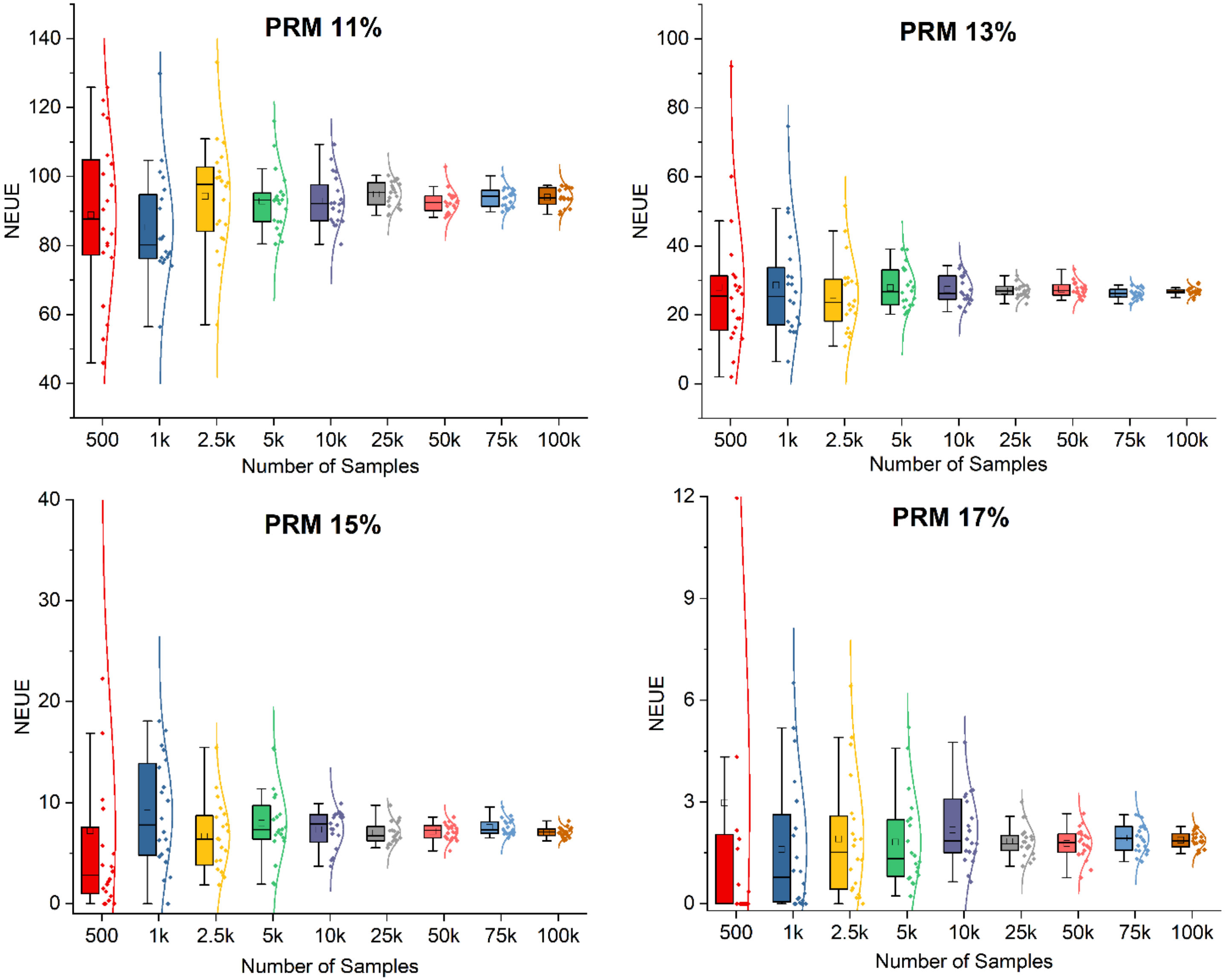


- Temperature-dependent generator outage sampling that utilizes a Markov chain approach to model generator state transitions
  - Sampled hourly over a full year
- Efficient sample filtering method to reduce the number of risk samples requiring dispatch simulations while maintaining the accuracy of resulting reliability metrics

- Two-stage system dispatch simulations with and without perfect foresight
  - First stage: Steady-state system operations
  - Second stage: Realization of system risks and post-contingency system redispatch

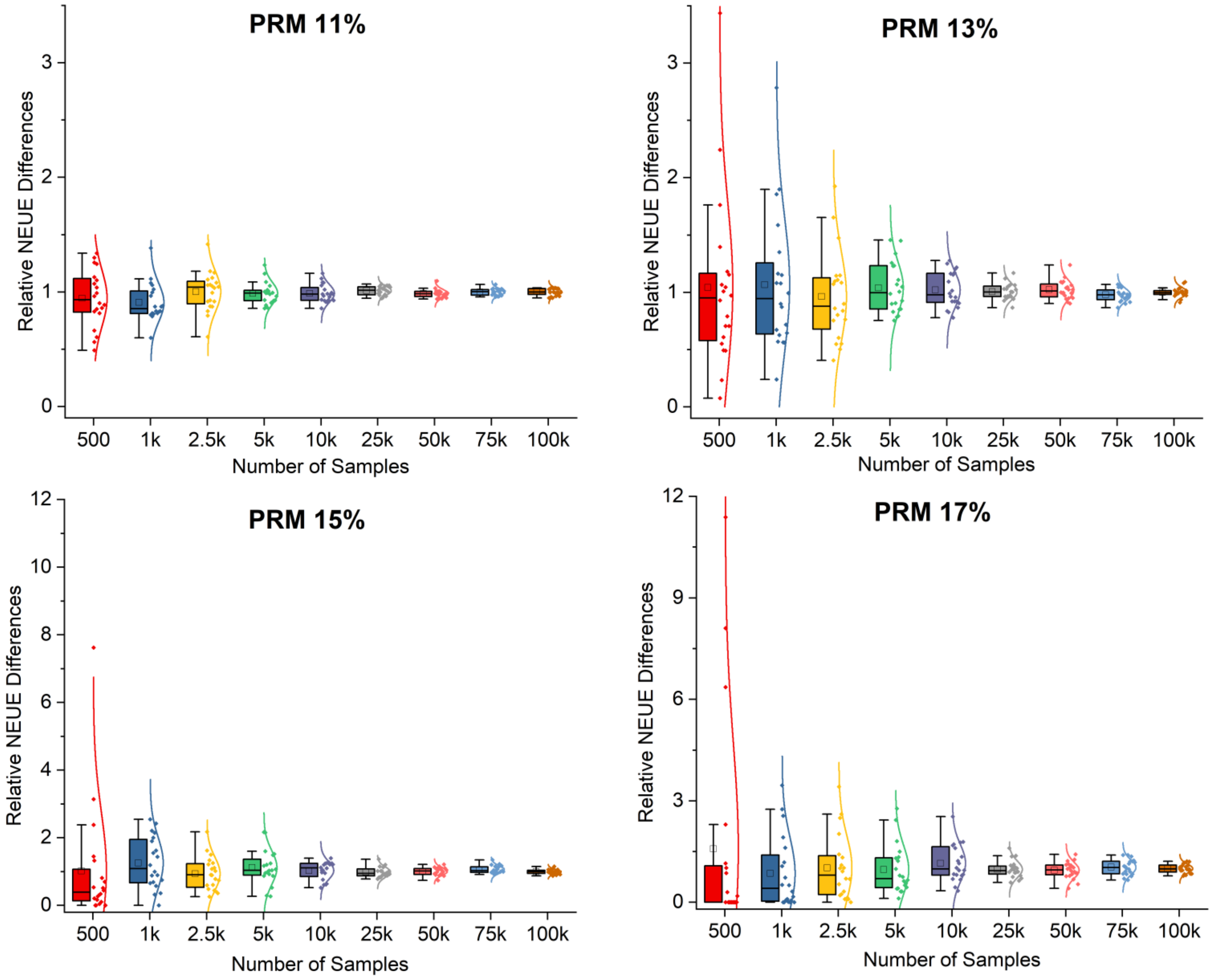
- Determines a range of metrics to evaluate system performance.
  - EUE, NEUE, LOLH, LOLP, and LOLE.
  - Indicators of outage severity (e.g., the maximum consecutive hours with load shedding, and the maximum load-shedding capacity in MW and MWh).

THE IMPACT OF SAMPLE SIZE ON RA METRICS



- We assess
  - 4 different PRM levels
  - 20 independent simulations for each sample size
  - Sampling peak day
  - No filtering
  - Applied to “ERCOT-like” system
- Across all PRM levels, the variability of NEUE decreases across batches as the number of samples increases.
- Smaller sample sizes cause high variability in absolute EUE values
  - Especially at lower PRMs.

THE IMPACT OF SAMPLE SIZE ON RA METRICS

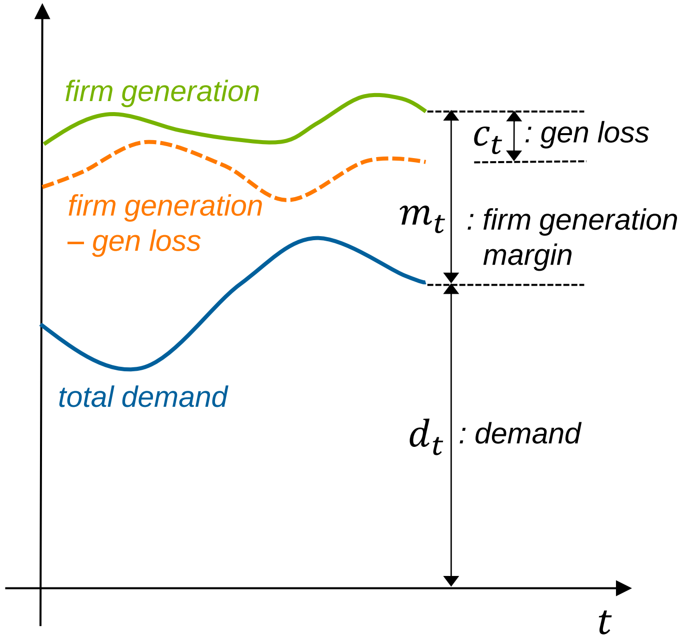


- Systems with high PRMs have low NEUE in absolute terms the variation
- But the relative deviation from low to high sample size is much greater.
- Results seem to converge around ~25k samples

System-specific sensitivity analyses are essential to establish robust results and determine the appropriate sample size

ENHANCING EFFICIENCY IN RELIABILITY ASSESSMENTS THROUGH SAMPLE FILTERING

Three Sample Filtering Methods



- Simulating a large number of risk samples is challenging even with high-performance computers.
- This study evaluates the performance of three sample filtering methods
- In each case outages are simulated

$$TFGM: \max_t \frac{c_t}{m_t}$$

TFGM: based on total firm generation margin

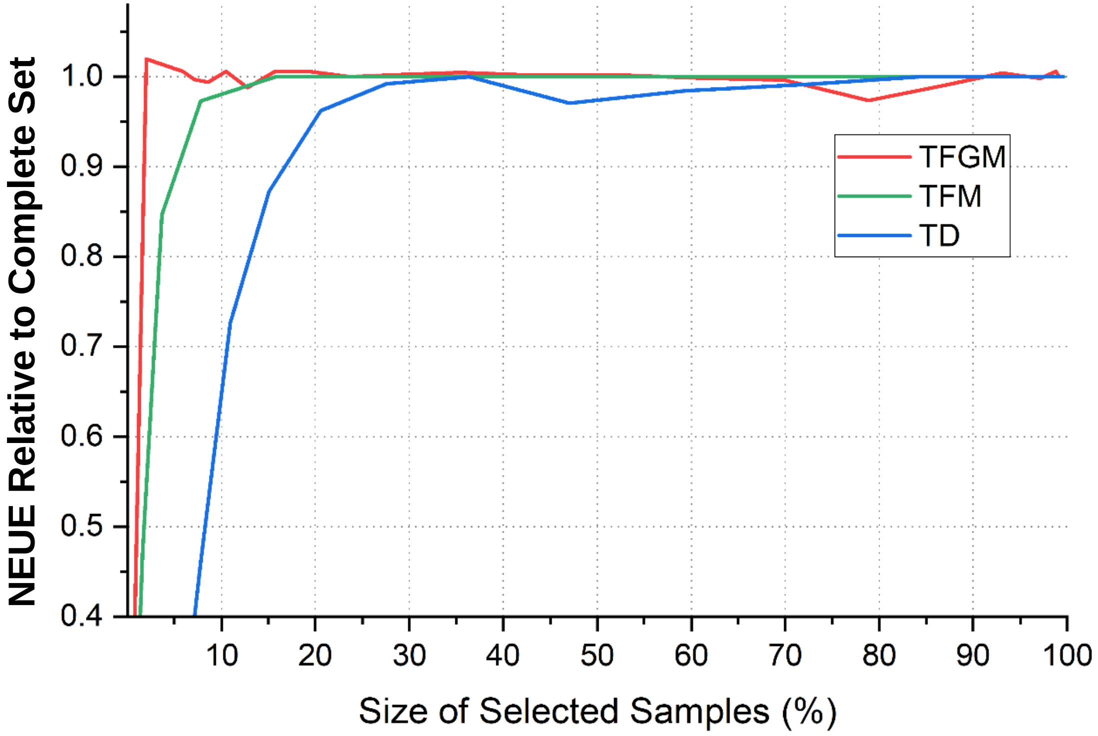
$$TFG: \max_t \frac{c_t}{(d_t + m_t)}$$

TFG: based on total firm generation

$$TD: \max_t \frac{c_t}{(d_t)}$$

TD: based on total demand

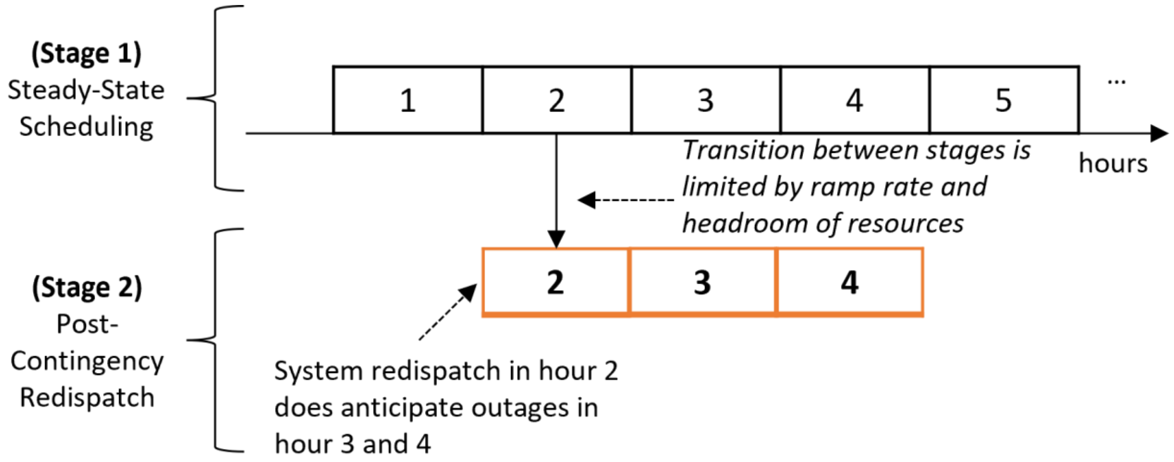
ENHANCING EFFICIENCY IN RELIABILITY ASSESSMENTS THROUGH SAMPLE FILTERING



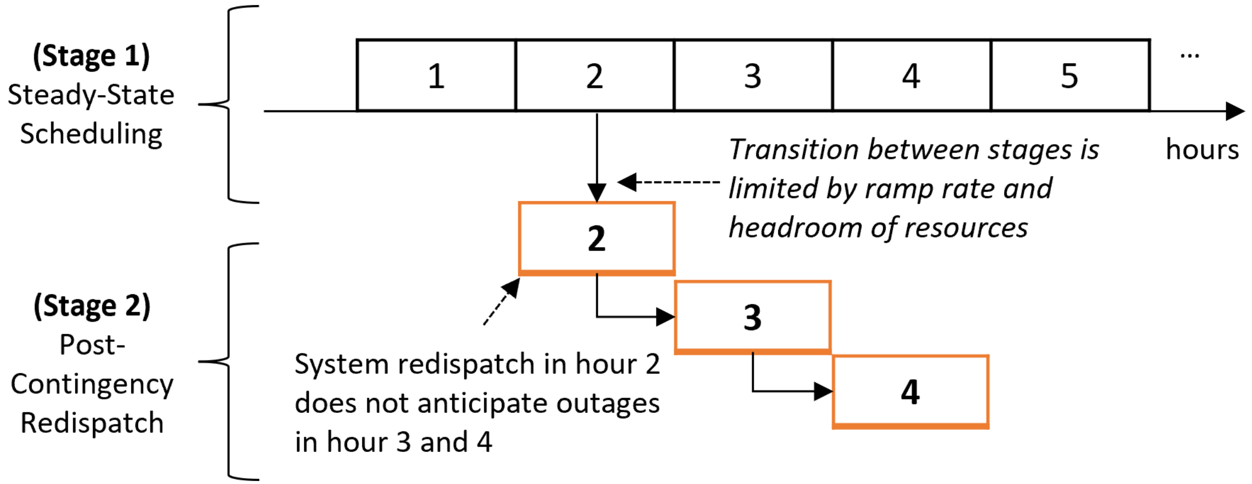
- Three filtering methods are applied to a full year
  - ***TFGM***: based on total firm generation margin
  - ***TFM***: based on total firm generation
  - ***TD***: based on total demand based
- Referencing the firm generation margin captures more relevant information about the systems' reliability margin and outperforms other methods.
- System NEUE was predicted with reasonable accuracy when only simulating ~5% of total outage draws

Sample filtering can improve the efficiency of reliability assessment models while preserving accuracy

IMPERFECT FORESIGHT

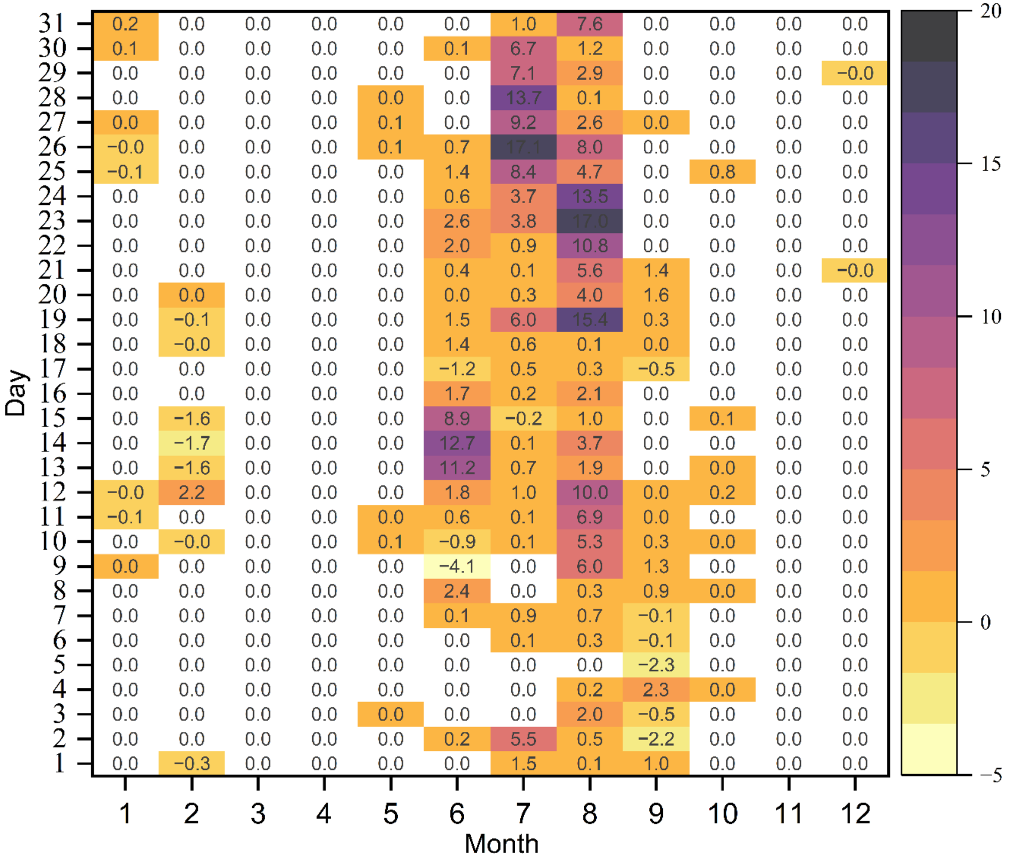


Two-stage structure with perfect foresight



Two-stage structure without perfect foresight

IMPACT OF IMPERFECT FORESIGHT ON RA METRICS



Careful modeling and design of system dispatch algorithms is essential as they can significantly impact reliability outcomes

- We compare two post-contingency redispatch methods 1) with and 2) without perfect foresight.
- Operational uncertainty leads to higher EUE values.
  - Particularly in high-demand periods.
- Perfect foresight post-contingency dispatch models may therefore overestimate system reliability.

Metrics	w/ Perfect Foresight	w/o Perfect Foresight	Difference (%)
EUE (MWh/year)	3,562	3,832	7.6%
NEUE (ppm)	8.0	8.6	7.6%
LOLH (hours)	2.3	2.5	8.5%
LOLE (hours/year)	0.00027	0.00029	8.5%
Max MW Loss	7,945	7,986	0.5%
Max MWh Loss	62,293	62,702	0.7%
Longest Outage (h)	13.0	13.0	0.0%

CONCLUSIONS

- It is important to consider an adequate number of samples in reliability assessment, yet computational limitations remain a challenge.
- Efficient sample filtering can reduce computational requirements while maintaining fidelity of results.
- Perfect foresight post-contingency dispatch models may overestimate system reliability, particularly during high demand periods.

ENERGY STORAGE CAPACITY CREDIT CALCULATION CONSIDERING STATE OF CHARGE DEVIATIONS

ENERGY STORAGE REPRESENTATION IN RA MODELS

Overview

- Past work has shown that different storage dispatch strategies in RA models yield very different results for storage ELCC & system NEUE.

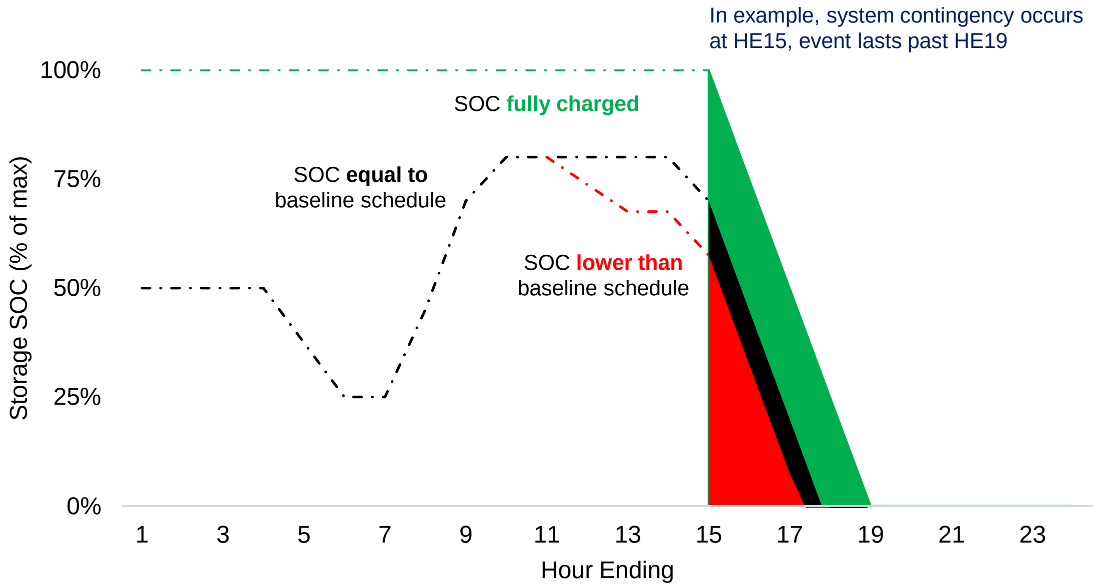
Dispatch type	Detail
Reliability dispatch	SOC assumed to be 100% until storage is needed to relieve lost load
Fixed shape dispatch	SOC shape is fixed for different days
Profit-maximizing dispatch	SOC based on private price-taker profit maximization model
Other methods	Dynamic programming, non-time-sequential methods
DA economic dispatch with RT recourse	**SOC schedule determined via DA economic dispatch, real-time SOC can adapt to prevent lost load**

- Recent academic and industry work has converged to scheduling storage using economic dispatch in a DA stage, followed by updated real-time operations
  - DA stage: similar to real-world market processes
  - RT stage: simplified compared to real-world market process (e.g., discharge only when needed to prevent lost load)
  - Industry: MARS, SERVM
  - Academic papers: Stephen et al., 2022, Leibowicz et al., 2024; Dratsas et al., 2024

ENERGY STORAGE REPRESENTATION IN RA MODELS

Research Objective and Method

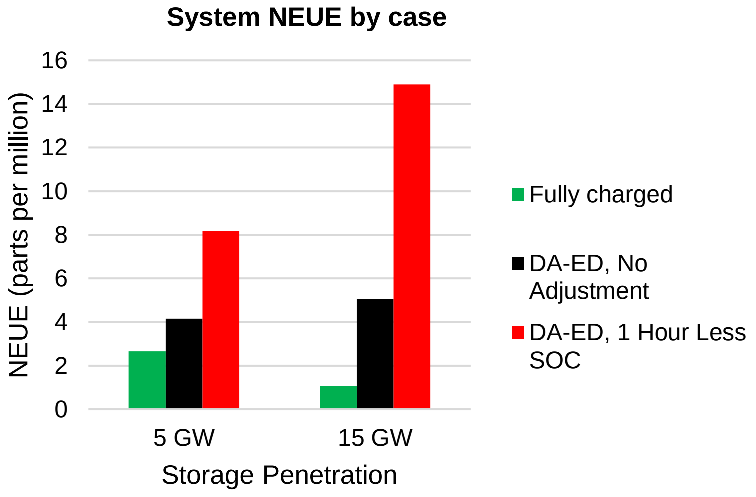
- Goal: investigate impact of different storage scheduling strategies
  - Focus on deviations from widely used “economic dispatch with real-time recourse” method
  - Key outcomes: system NEUE and storage ELCC (marginal)
- Scheduling strategies
  - Reference case (**black**): follow reference schedule that is determined by economic dispatch; deviate only when storage is needed to prevent lost load
  - Deviation cases (**red**): like reference case, but storage SOC decreases by fixed amounts when storage is needed to prevent lost load
  - Fully charged case (**green**): SOC set to 100%
- Two different ERCOT-like systems
  - 5 GW, 15 GW of 4-hr storage ICAP



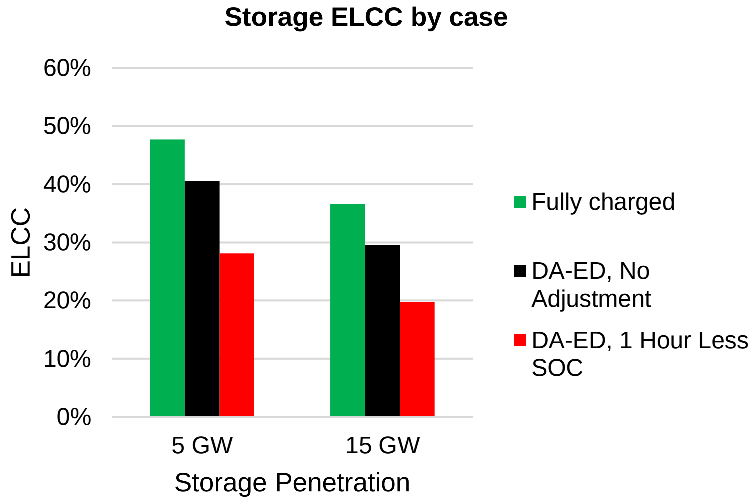
ENERGY STORAGE REPRESENTATION IN RA MODELS

Key Results

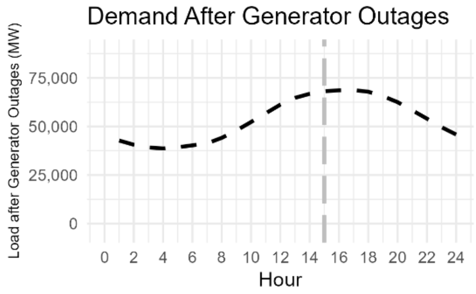
- Deviations from economic dispatch have a large effect on RA metrics.
- A decrease in one hour of SOC results in:
  - ~2-3x increase in NEUE
  - ~8-12% decline in ELCC
- Sensitivity of results highlight the importance of aligning modeling assumptions and actual market outcomes.
  - Some jurisdictions base capacity accreditation on both historical performance and RA modeling outcomes

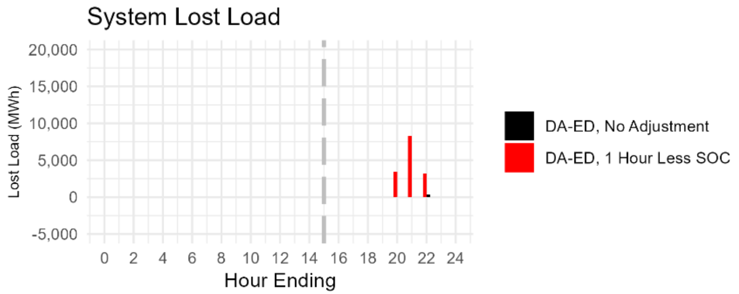


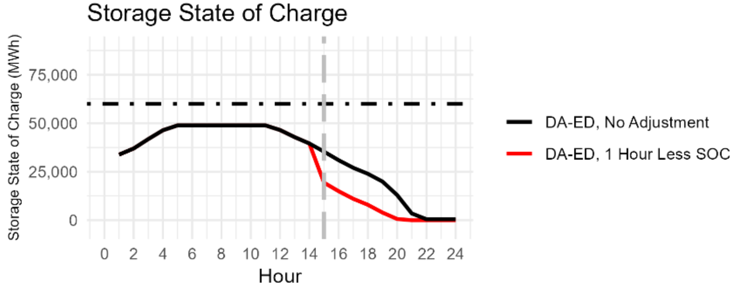
Relative NEUE increase is larger when there is greater reliance on storage for reliability

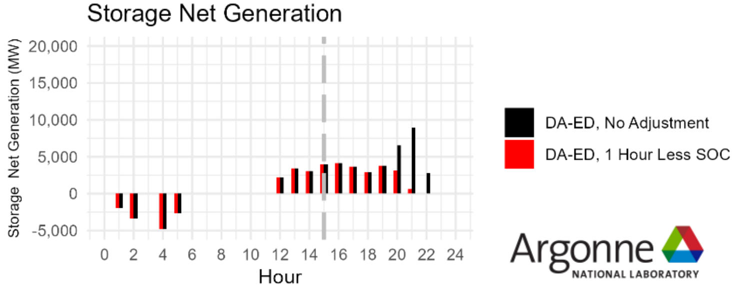


Declining storage ELCCs (aligned with literature)









ENERGY STORAGE REPRESENTATION IN RA MODELS

Conclusions and Future Work

- Modeled system NEUE and storage ELCCs are sensitive to deviations in SOC relative to a reference schedule based on economic dispatch.
  - This work was agnostic to the underlying causes of SOC deviations.
- Future work will explore how modeling storage unit owners as profit-seeking entities affects SOC at time needed to prevent lost load.
  - Impact of storage unit price forecast uncertainty, risk preferences, and different market design elements (e.g., energy price caps).
- Enhanced data on storage SOC would aid future empirical analysis/validation as storage becomes increasingly important to resource adequacy.
  - Each RTO/ISO collects and publishes a different series of storage-related data.

Forthcoming Publications

Kwon, K., Levin, T., Noll, M., Zhou, Z., and Botterud, A. "Two-stage Probabilistic Reliability Assessment with Efficient Filtering and Imperfect Foresight". Under review, IEEE Transactions on Power Systems".

Noll, M. Kwon, J., and Levin, T. "Energy storage capacity credit calculation considering state of charge deviations", in preparation, IEEE Transactions on Energy Markets, Policy and Regulation.

Zhao, D., Zhou, Z., Kwon, J., and Levin, T. "Coordinated Operating Reserve and Capacity Demand Curves for Efficient Missing Money Mitigation". In preparation, IEEE Transactions on Energy Markets, Policy and Regulation.

References

Dratsas, P.A., Psarros, G.N., Papathanassiou, S.A., 2024. A Real-Time Redispatch Method to Evaluate the Contribution of Storage to Capacity Adequacy. IEEE Trans. Power Syst. 39, 1274–1286. https://doi.org/10.1109/TPWRS.2023.3243669

Leibowicz, B.D., Zhang, N., Carvallo, J.P., Larsen, P.H., Carr, T., Baik, S., 2024. The importance of capturing power system operational details in resource adequacy assessments. Electr. Power Syst. Res. 228, 110057. https://doi.org/10.1016/j.epsr.2023.110057

Stephen, G., Joswig-Jones, T., Awara, S., Kirschen, D., 2022. Impact of Storage Dispatch Assumptions on Resource Adequacy and Capacity Credit, in: 2022 17th International Conference on Probabilistic Methods Applied to Power Systems (PMAPS). Presented at the 2022 17th International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), pp. 1–6. https://doi.org/10.1109/PMAPS53380.2022.9810584

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