What condition is being studied and with what tools? – Towards More Holistic Planning

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ESIG
ENERGY SYSTEMS INTEGRATION GROUP

Integrated Planning: Assuring Stability in Modern Systems

Day 2: Session 7

Tuesday September 16, 2025

encoord

Plan the Energy Future

ESIG

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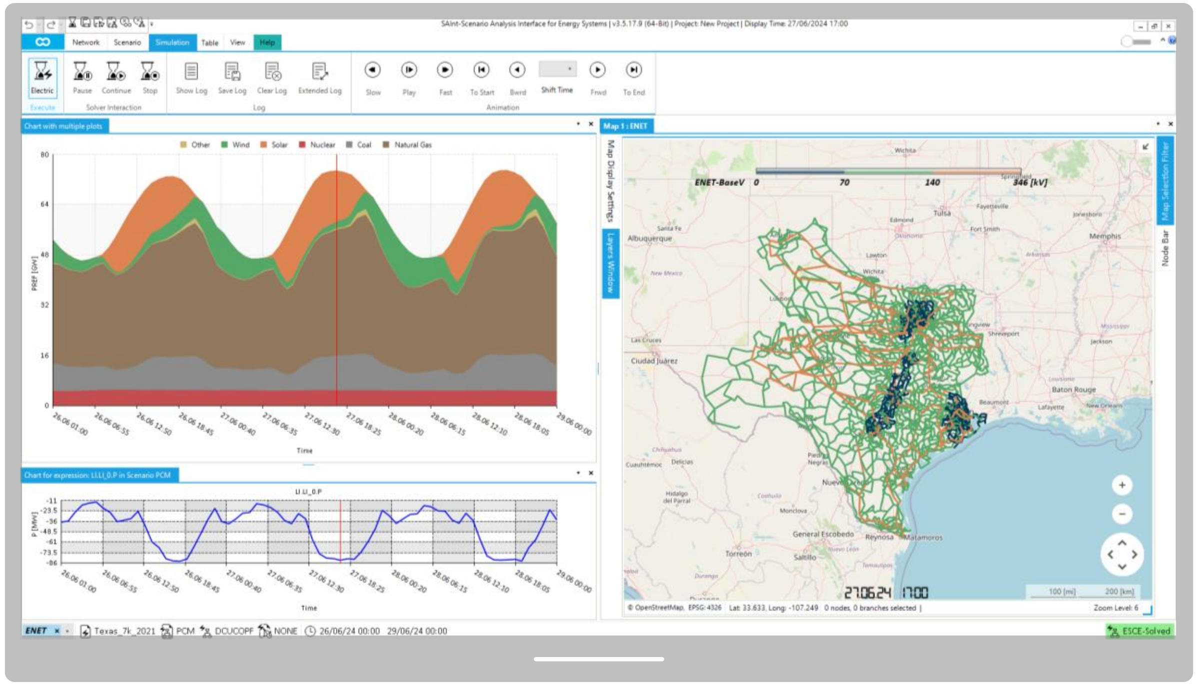


We help utilities and asset developers deliver reliable, affordable, and cleaner power — with a breakthrough solution that **integrates economics and reliability planning** across generation, transmission, and distribution.

Main Takeaways

Yesterday, we learned about:

- The importance of including stability as an integral part of planning (not as an afterthought)
- Fundamentals of power system dynamics: voltage and frequency stability

Today, we just explored:

- How wind, solar, and batteries reshape operational reliability
- Ways to model and plan power systems with large penetrations of these technologies (IBRs)

Next, we will gain insights on:

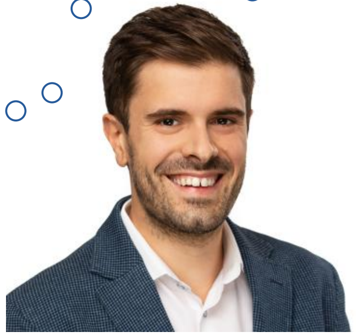
- Linking economic and reliability planning
- Testing if economic solutions are operationally stable

Meet the Planners

Economics

8760

Energy
Active Power



Resource Planner

(i.e., generation/system planner)

Reliability

Snapshots

Voltage
Frequency

Transmission Planner

(i.e., planning engineer)

Resource (Generation) Planning

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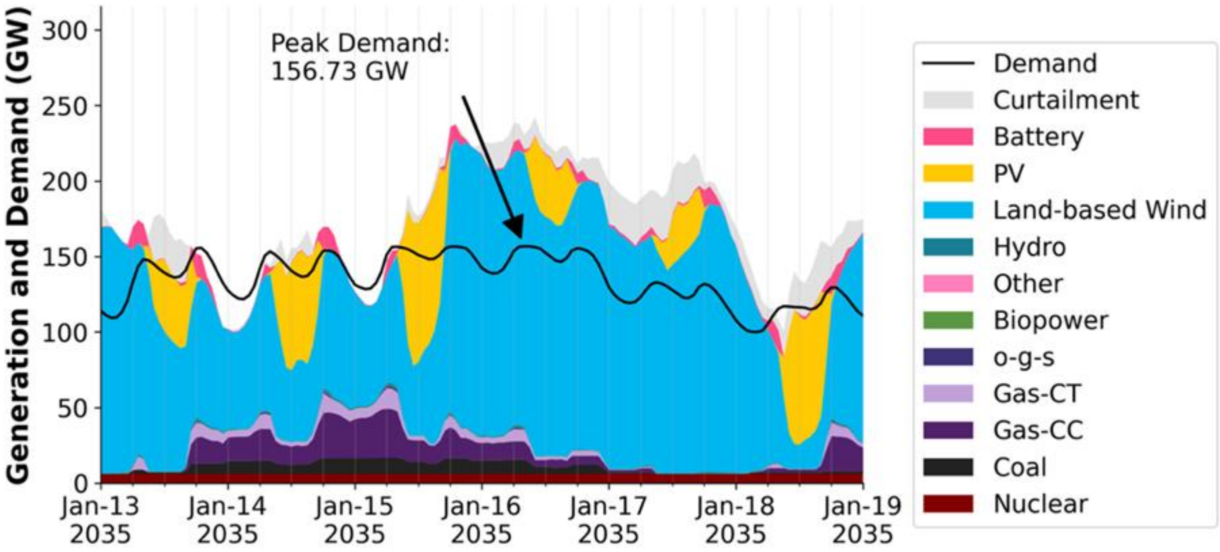
Objective: development of generation and storage assets to ensure an adequate, reliable, and least-cost electricity supply.

Scenarios:
- Multi-year, 8760
- Projections for demand growth, technology & fuel costs, and weather variability

Modeling tools:
- Capacity expansion modeling
- Probabilistic resource adequacy assessment
- Production cost modeling

Challenges:
- Resource availability
- Transmission constraints
- Ancillary service provision

How do we think about Transmission Planning:
- They define transmission and stability constraints as inputs to our models (e.g., mon/con pairs, ancillary service requirements, must-run units, min. synchronous generation, etc.)
- They'll make sure the system can operate reliably during all operating conditions



Source: https://www.energy.gov/gdo/national-transmission-planning-study

Transmission Planning

Objective: ensure the reliability and stability of the high-voltage bulk power system through current, and future, infrastructure assessments.

Scenarios:

- Operational and future scenarios' snapshots
- Coincident loading; peak, shoulder, at-risk operational periods

Modeling tools:

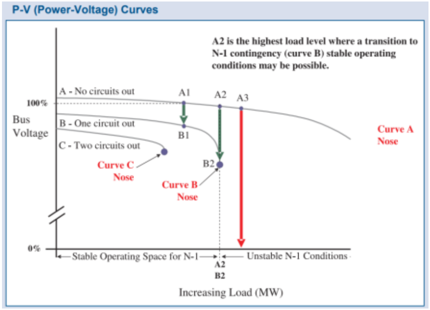
- Power Flow Assessments (steady state, transfer capability)
- Analytic Stability (short circuit, eigenvalue)
- Time-domain Assessments (phasor, waveform domain)

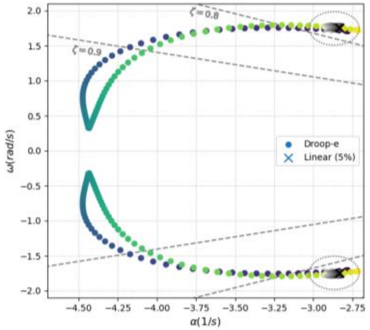
Challenges:

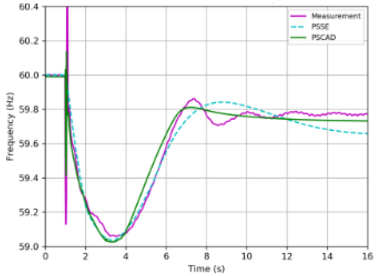
- Building / handling high-fidelity models
- Developing / conditioning representative cases

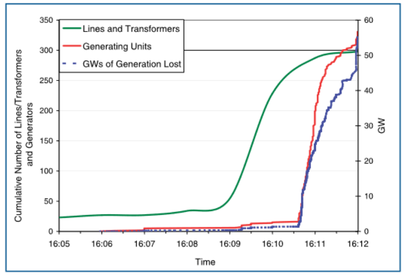
How do we think about Resource Planning:

- Configure the economic operation of generation resources with minimal physical considerations
- Take snapshot derived constraints and apply them to all hours of the year

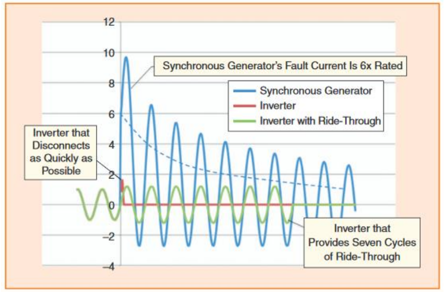




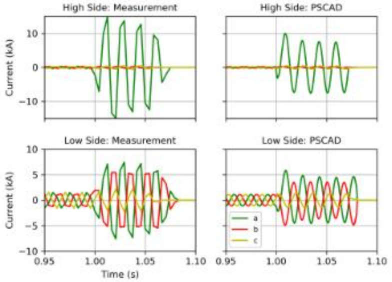




U.S.-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada," Apr. 2004.

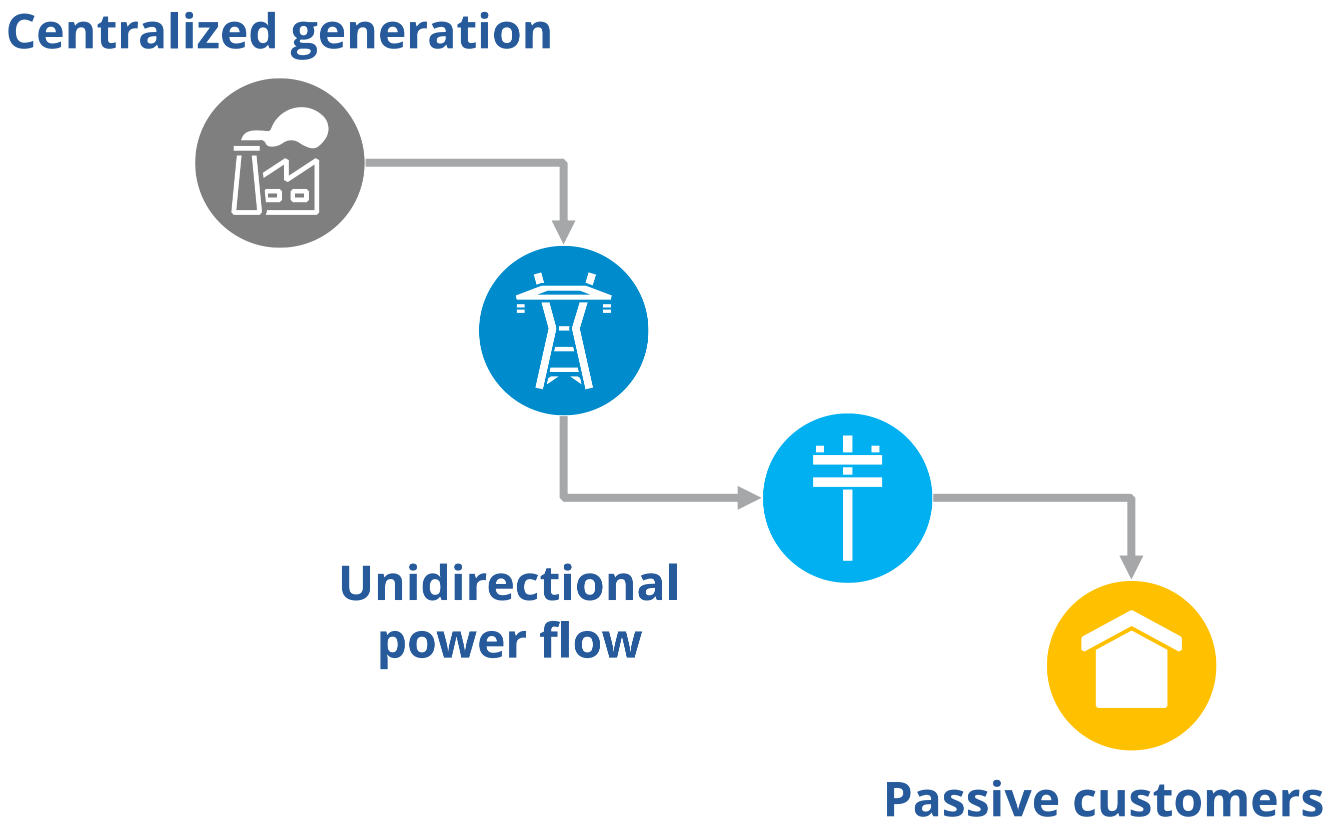


B. Kroposki *et al.*, "Achieving a 100% Renewable Grid: Operating Electric Power Systems with Extremely High Levels of Variable Renewable Energy," *IEEE Power and Energy Magazine*, vol. 15, no. 2, pp. 61–73, Mar. 2017.



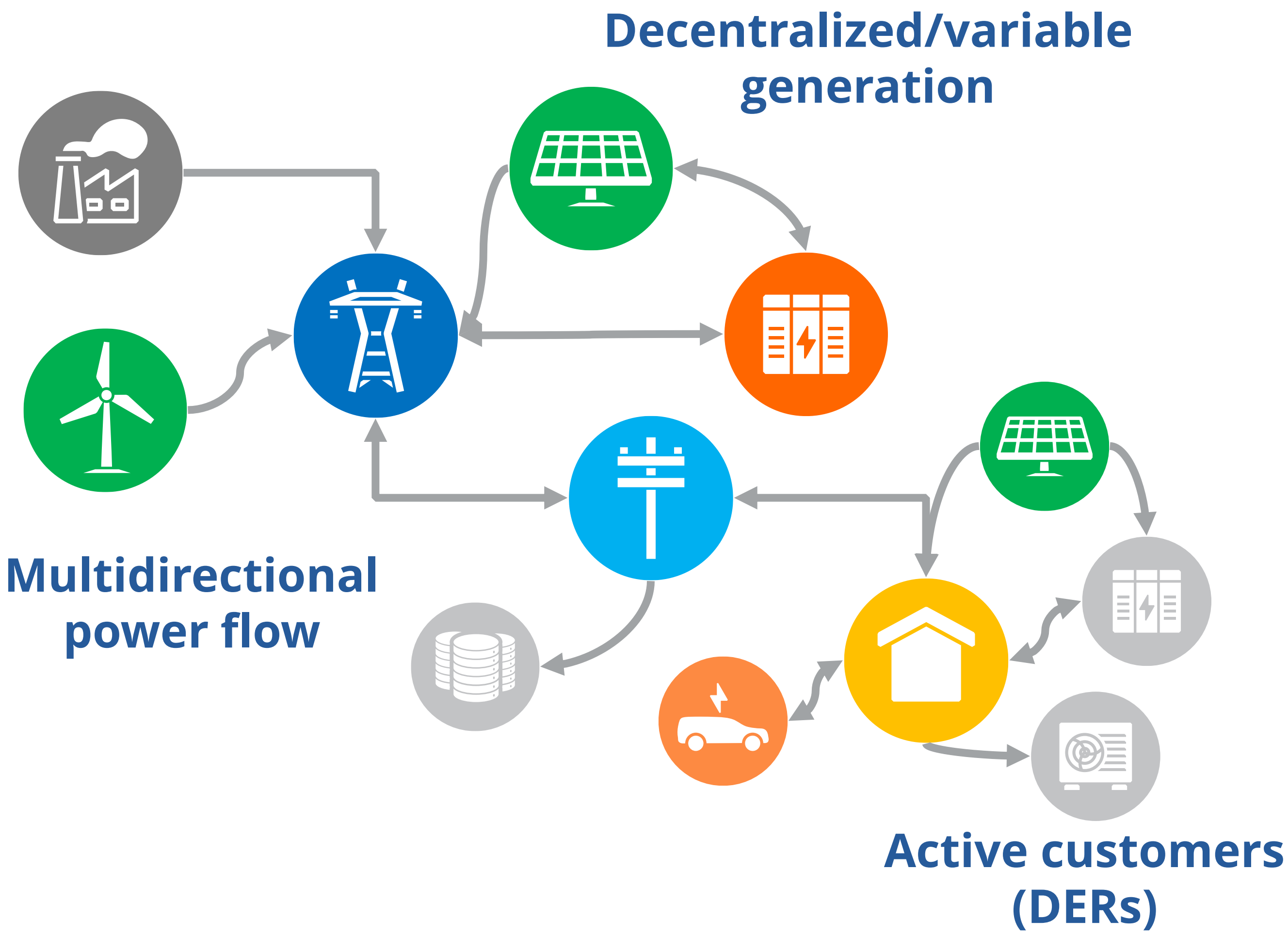
R. W. Kenyon, B. Wang, A. Hoke, J. Tan, C. Antonio, and B.-M. Hodge, "Validation of Maui PSCAD Model: Motivation, Methodology, and Lessons Learned," in *2020 52nd North American Power Symposium (NAPS)*, Apr. 2021, pp. 1–6.

Siloed planning worked for traditional power systems



Transmission planning followed resource (generation) planning to ensure that the economic solution would be operationally stable (by defining transmission upgrades and operational constraints).

Siloed planning is inadequate for modern power systems



Costs of silos are significant:

- Major unforeseen reliability risks if we don't consider a wider range of operational snapshots.
- Transmission constraints have a significant impact on the economics of renewable generation and storage.

As the grid transforms, **integrated planning** is key to delivering reliable, affordable power under increasingly complex conditions.

Modern Power System – Transmission Planner

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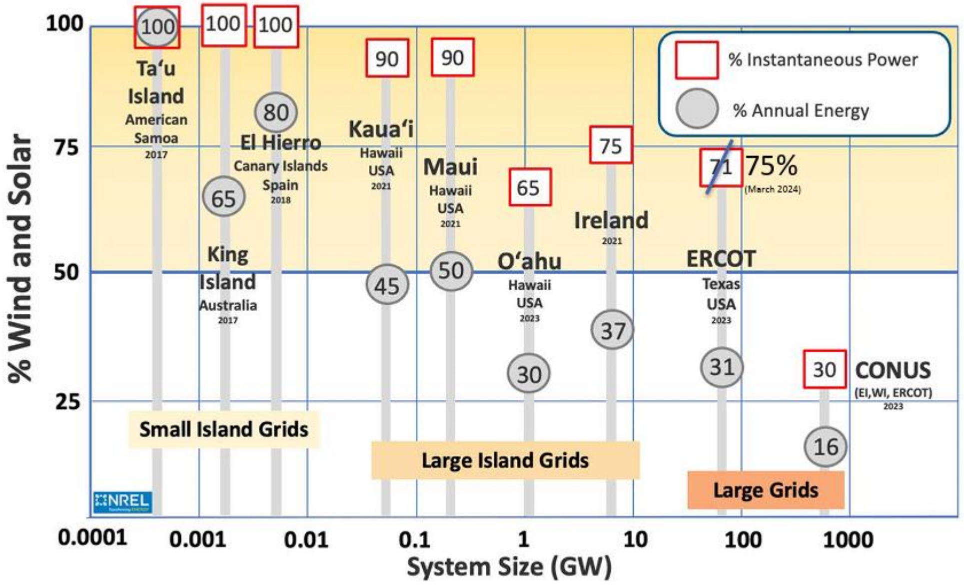
Challenges:

- Changing technology types (IBRs)
- Increased quantity of generation sources (more, smaller assets)
- Different system needs requiring attention (voltage forming, inertia, etc.)
- Accurate and effective models (complexity / proprietary nature of IBRs)
- Device configurations (ride through, response)
- Adapting existing workhorse tools to meet the current needs (assessing capabilities/deficits of simulation engines)
- Compliance

IBR Power / Energy Shares

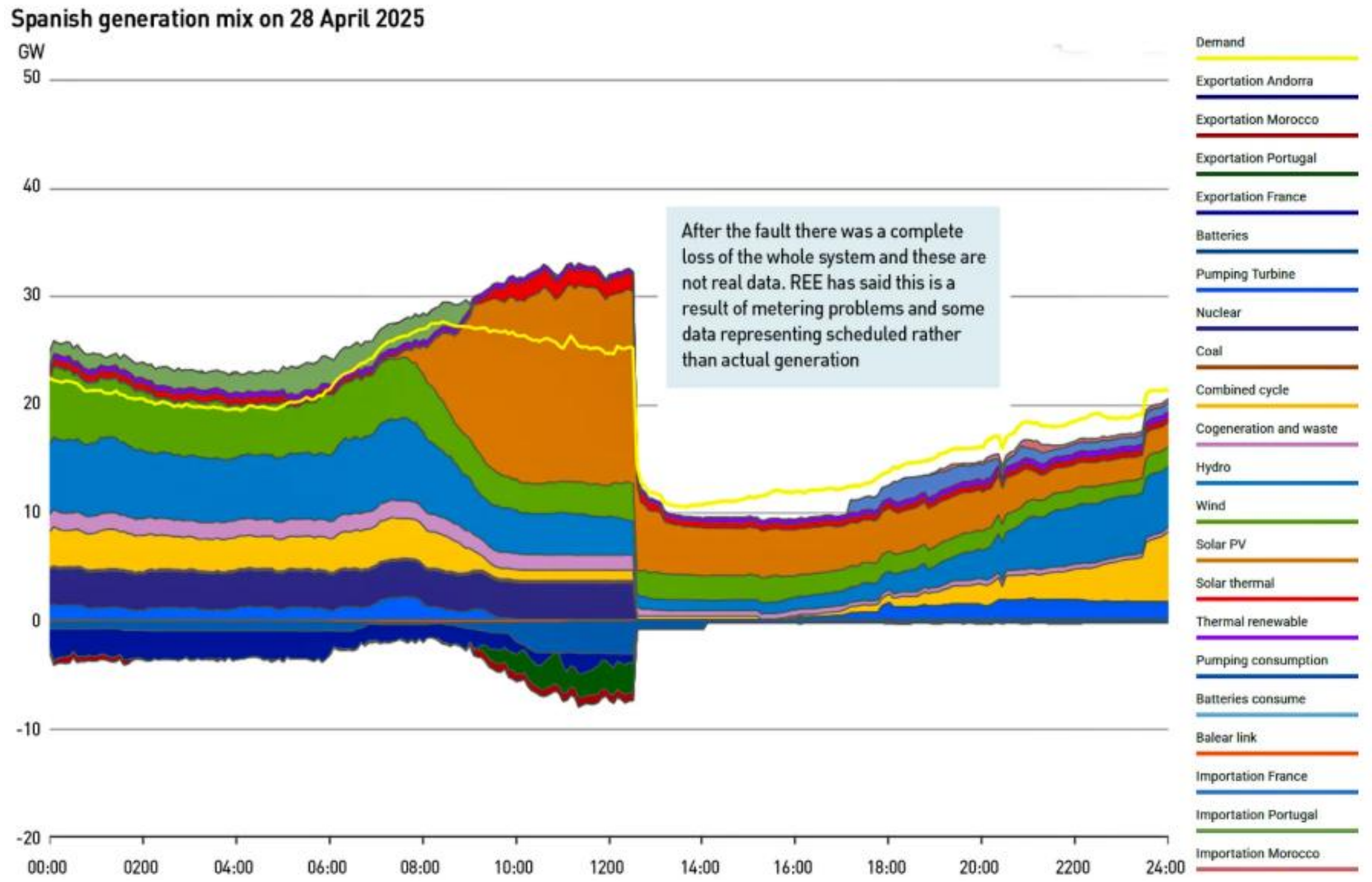


Introduction to Grid Forming Inverters – a Key to Transforming our Power Grid, Ben Kroposki, NREL, June 2024.

Modern Power Systems – Resource Planner

Challenges:

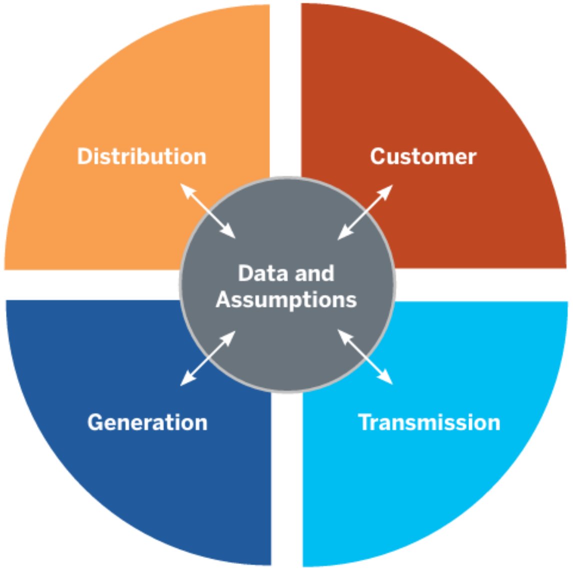
- Generation variability and uncertainty (wind and solar)
- Storage operation
- Distributed generation (and storage) sources
- Demand flexibility (and new large demands)
- Uncertain and changing policy/regulation



Source: https://watt-logic.com/2025/05/09/the-iberian-blackout-shows-the-dangers-of-operating-power-grids-with-low-inertia/

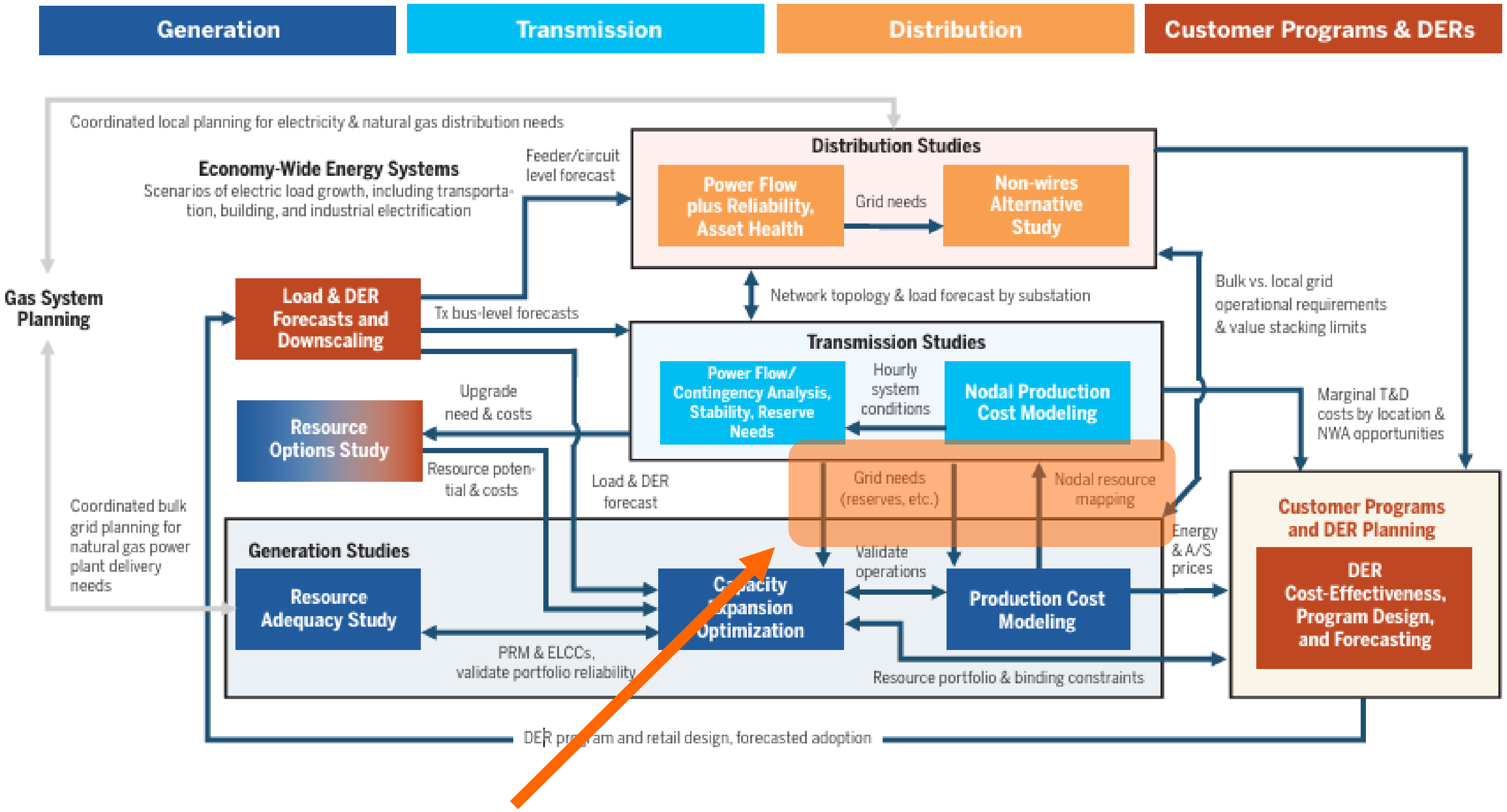
How do we work together?

The Iterative Integrated Planning Approach



Source: https://www.esig.energy/wp-content/uploads/2025/06/v2-ESIG-IP-Guidebook-report-2025.pdf

Electricity System Planning Integrations



Let's unpack these arrows!

Source: https://www.esig.energy/wp-content/uploads/2025/06/ESIG-IP-Foundations-Integrated-Planning-report-2025.pdf

Integrated Resource & Transmission Planning Workflow

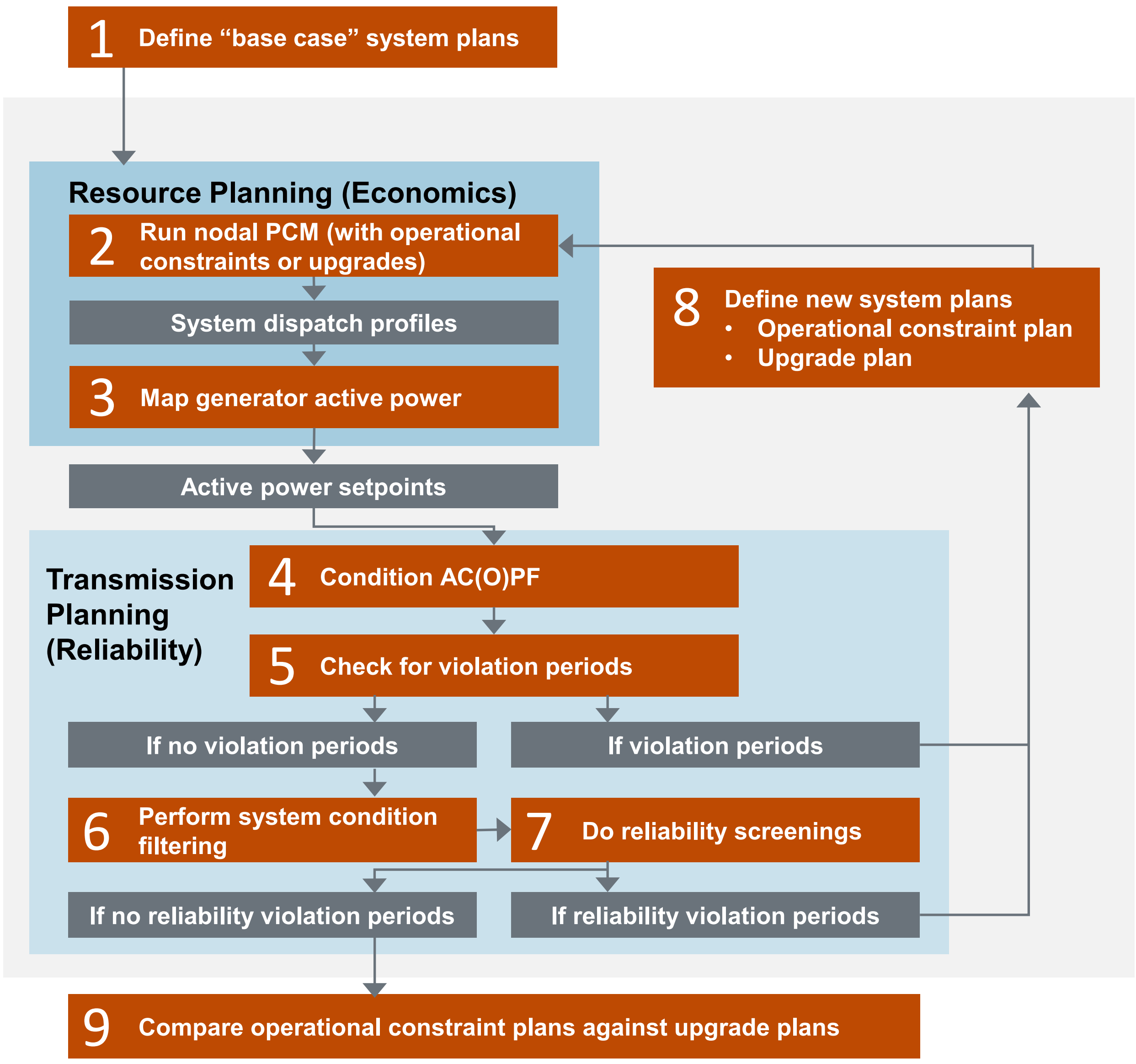
1: Planning case

2–3: Economic

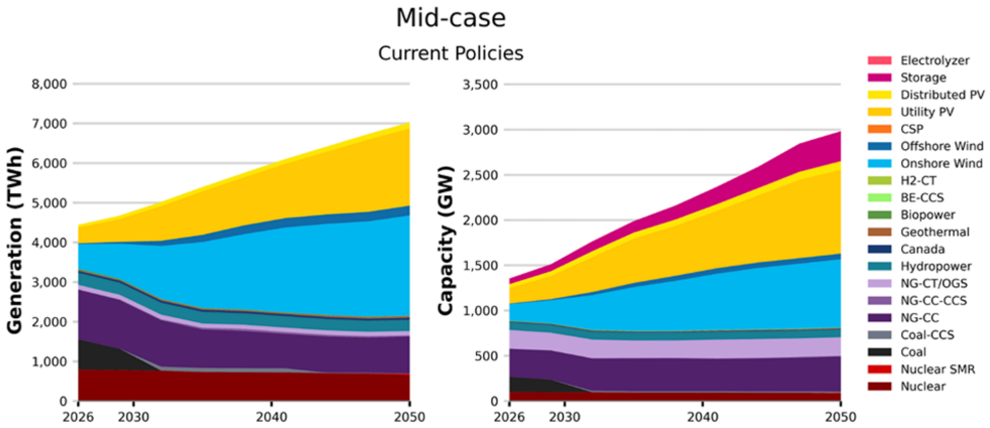
4–7: Reliability

8: Iterate

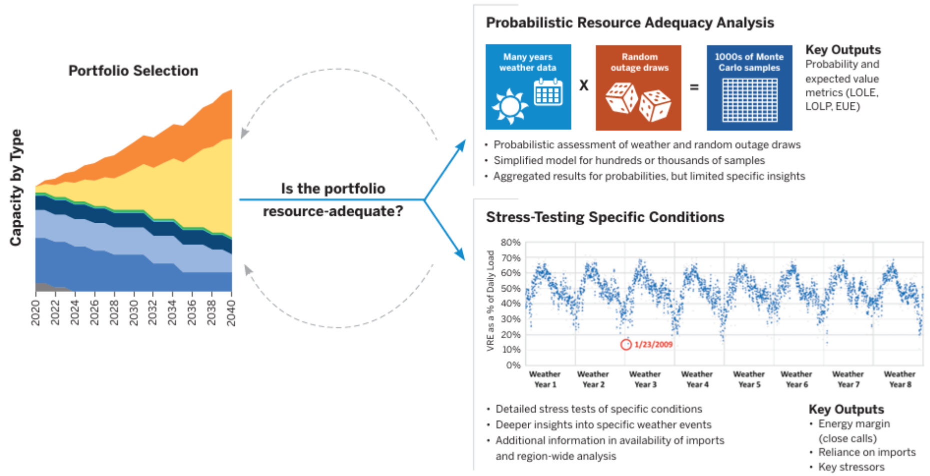
9: Compare plans



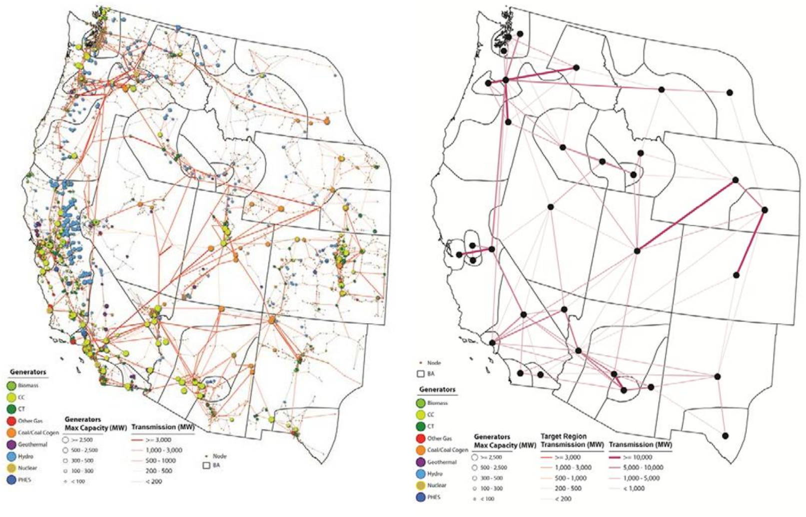
Planning Case (1) & Economic Optimizations (2)



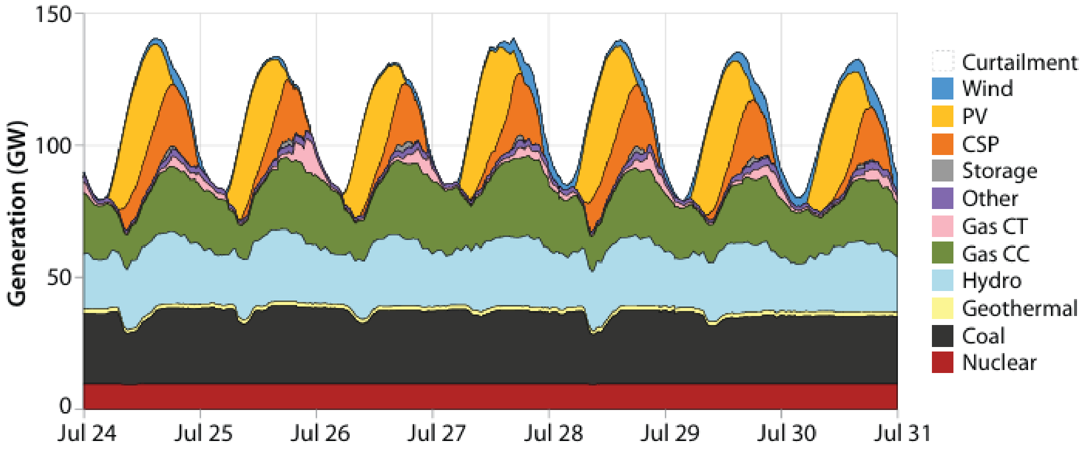
Source: https://docs.nrel.gov/docs/fy25osti/92256.pdf



Source: https://www.esig.energy/wp-content/uploads/2024/03/ESIG-New-Criteria-Resource-Adequacy-report-2024.pdf

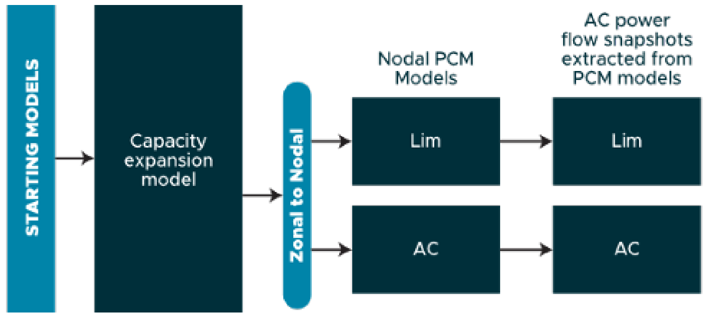


Source: https://docs.nrel.gov/docs/fy14osti/62447.pdf



Source: https://docs.nrel.gov/docs/fy13osti/55588.pdf

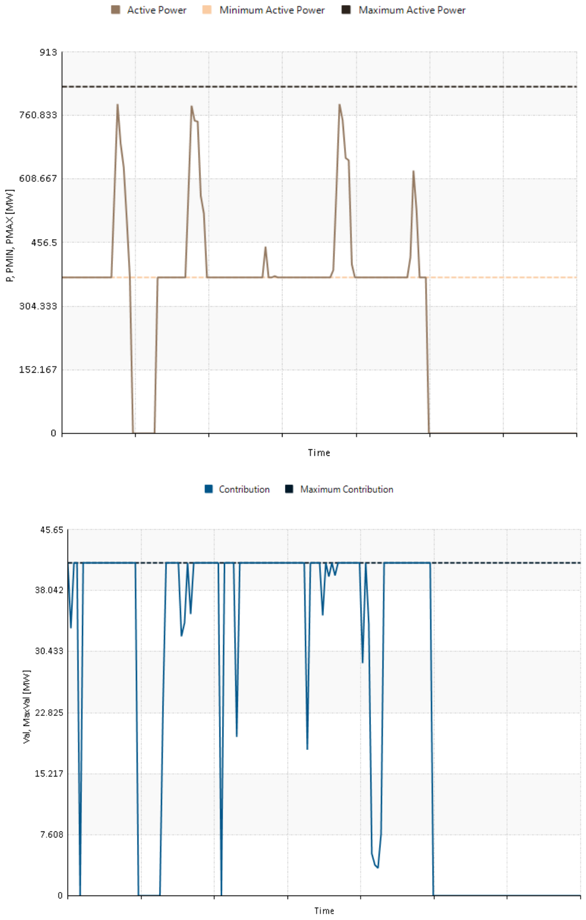
Mapping (3)



Source: https://www.energy.gov/sites/default/files/2024-10/NationalTransmissionPlanningStudy-Chapter4.pdf

RESOURCE

- Network Location (if Zonal PCM, to what bus?)
- Active Power Contributions
- Commitment
- Ancillary Services
- Line Topology/ Switching

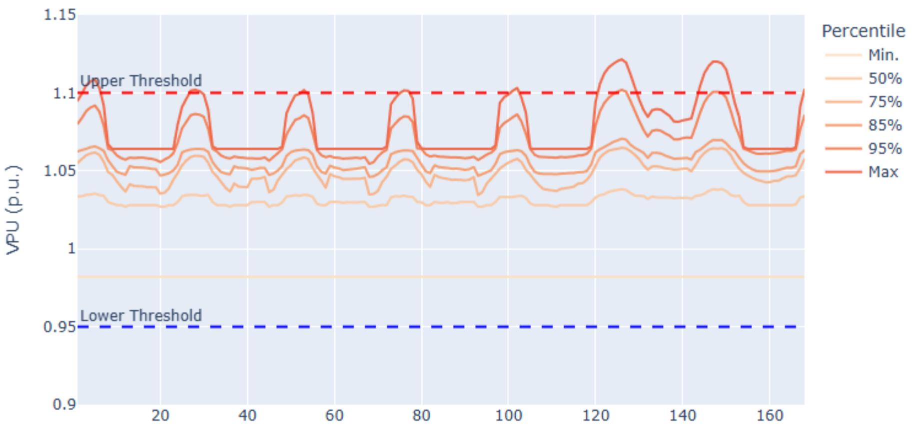


TRANSMISSION

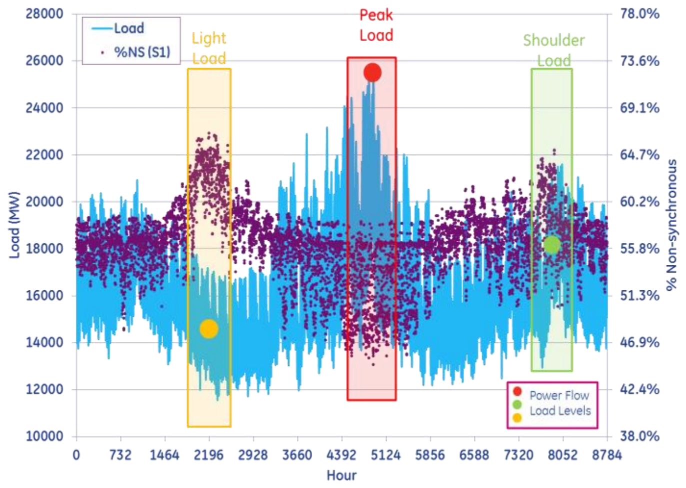
- ACPF Active Power Set Points
- Device Status
- Loading Behavior
- Ancillary Service Provisions

Conditioning (4) – Violations (5) – Filtering (6)

Voltage Conditioning Insights

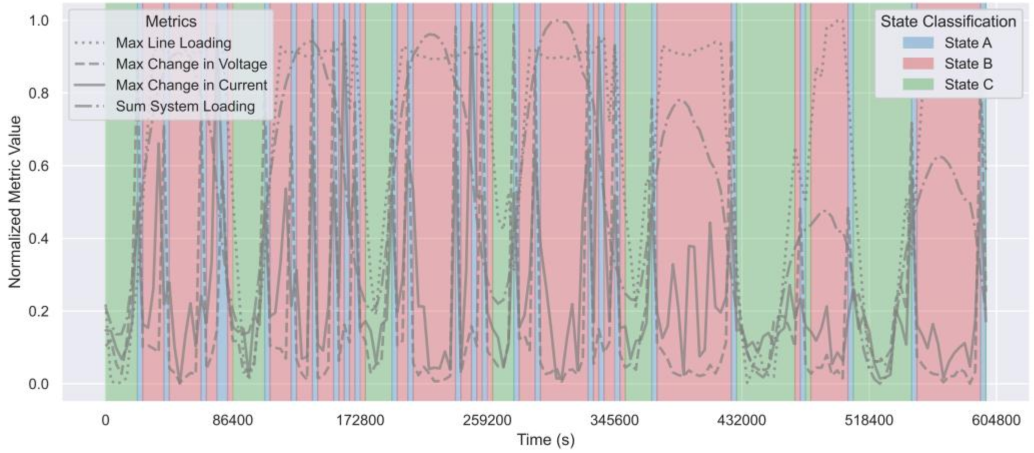


High IBR Share Snapshots



Pushing the envelope: Evolving our study process; Rob D'Aquila, Debbie Lew, Nick Miller; April 12, 2016

Machine Learning Analysis



Quasi-static timeseries conditioning analysis can help uncover other stressed operating conditions:

How to select for additional analysis?
What criteria for which assessments?
How do we ensure we're capturing meaningful periods?

Reliability Screenings (7)

Steady State Contingency Analyses (first pass screening; N-1, N-x, N-k, N-1-1, injection/withdrawal studies)

Transfer Capability Assessments (thermal limiting, voltage limiting, voltage collapse, commitment impacts)

Short-Circuit Assessments (weak grids, stability proxies related with IBR shares)

Small-Signal Stability Analyses (steady state controller/device stability, instability proximities, etc.)

Phasor Domain Analyses (frequency stability, inertial response, critical-clearing times, short term voltage stability, etc.)

Waveform Domain Analyses (physics based, need correlates with IBR shares; SSO analysis, harmonics, etc.)

Iteration (8)

TRANSMISSION

- Conditioning Voltage Procedures
- Steady State Contingency Securitization
- Voltage Stability Loadability Limits
- Reactive Power Support Constraints
- SSO Mitigations
- GFM Requirements

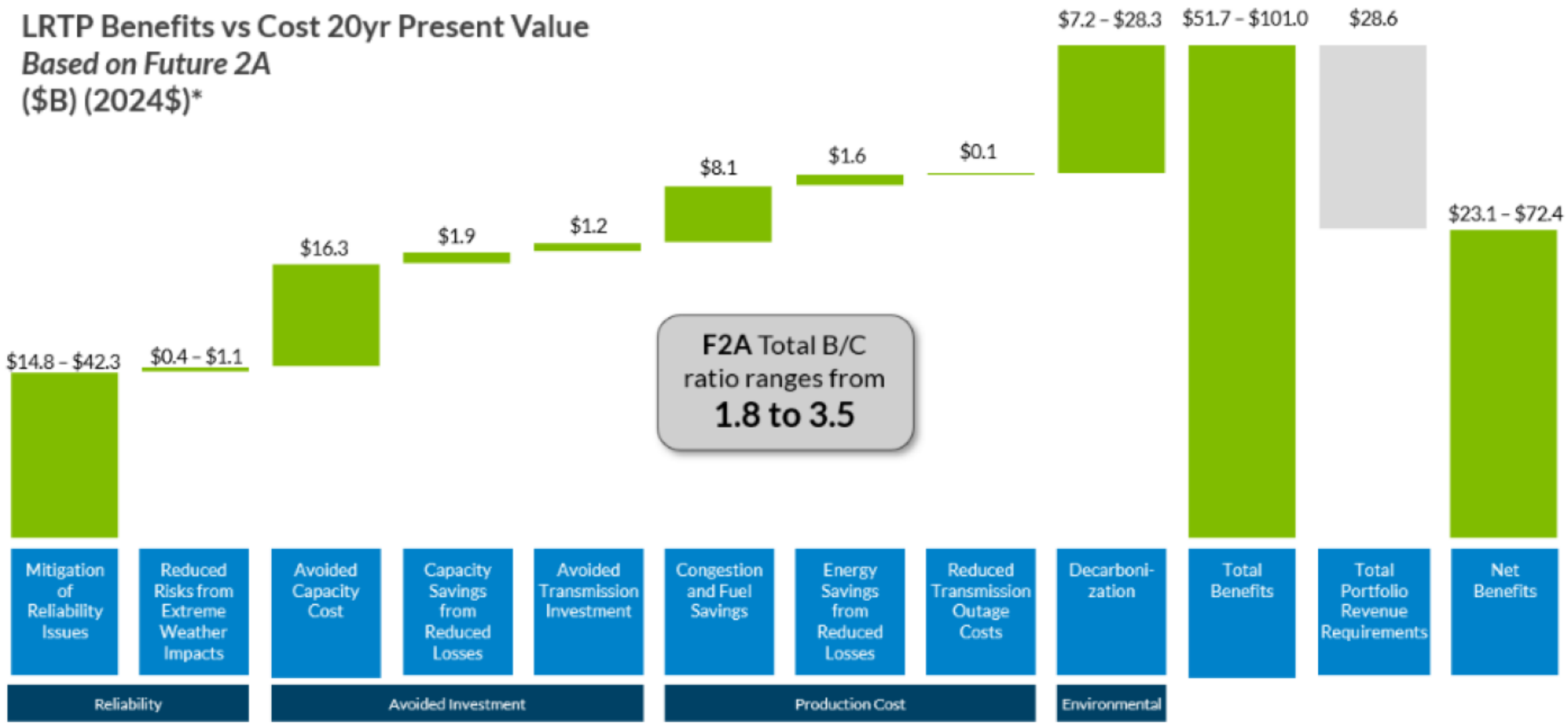
Encapsulating reliability constraints and/or transmission upgrades in economic optimizations →

← Returning updated scenarios for follow-up reliability analysis

GENERATION

- Locational Must-run Constraints
- Mon/Con SCED Enforcements
- Transfer Capability Adjustments
- Voltage Controlling Fleet Commitment
- Constrained Interconnection Type
- Capital Injections for System Build-out

Compare Operational/Capital Solutions (9)



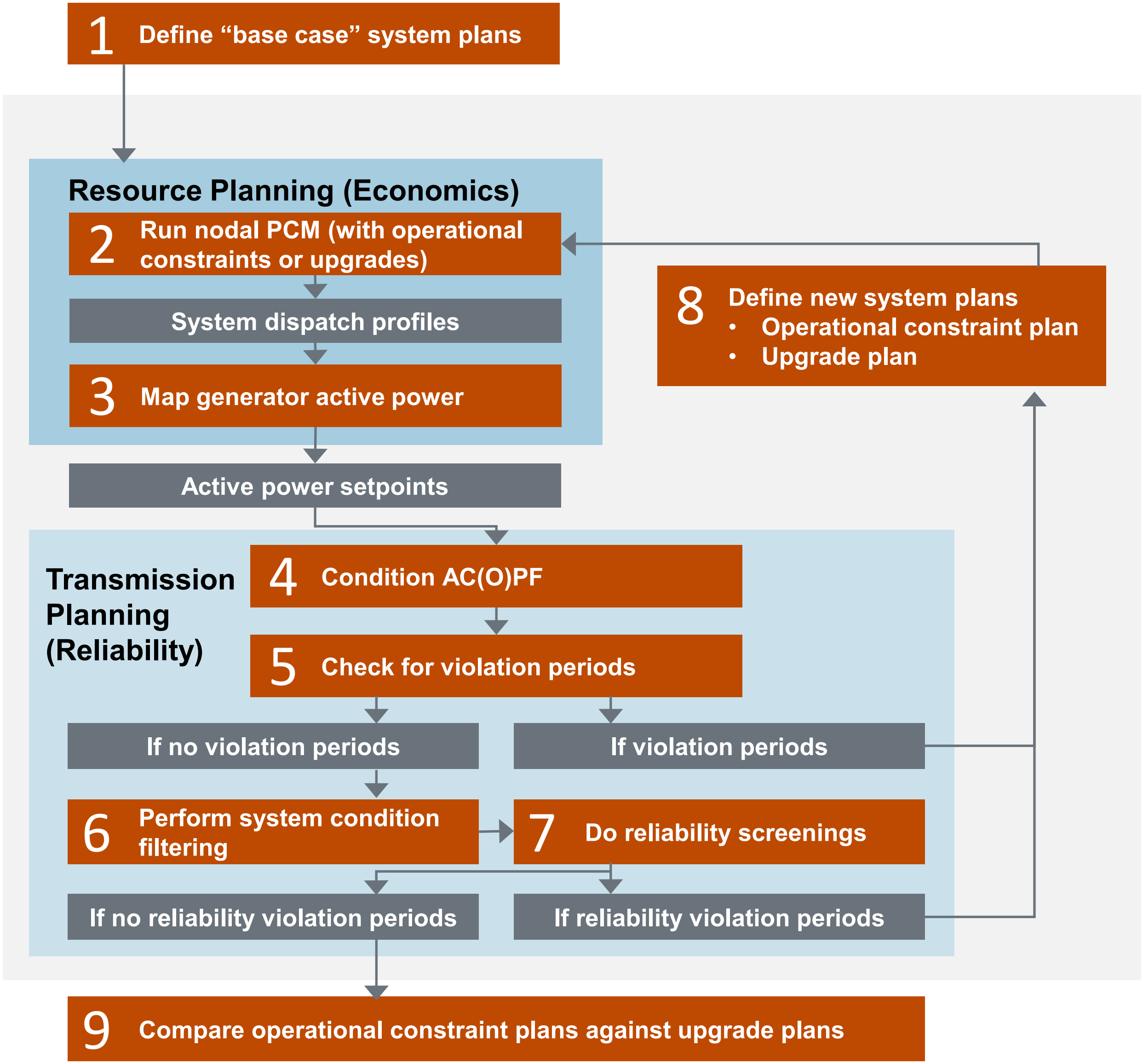
Source: https://cdn.misoenergy.org/MTEP24%20Chapter%202%20-%20Regional%20Long%20Range%20Transmission%20Planning658124.pdf

Conclusions

New frameworks can lay the foundation for meaningful and fruitful coordination and iteration between historically disparate silos.

Benefits:

- Quantify economic and reliability tradeoffs
- Optimize investments across generation and transmission to identify most reliable, cost-effective solutions
- Discover new stress periods and expose hidden reliability risks/constraints



Thank you!

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