

An aerial view of a city at dusk, with a blue network overlay of glowing nodes and lines connecting various points across the cityscape. The text "POWERED BY Sienna" is overlaid on the left side of the image.

POWERED BY
Sienna

Sienna Modeling Framework

Clayton Barrows

National Renewable Energy Laboratory

June 11, 2024

NREL Sienna Team: Sourabh Dalvi, Surya Dhulipala, Kate Doubleday, Rodrigo Henriquez Auba, Gabriel Konar-Steenberg, José Daniel Lara, Pedro Sanchez Perez, Daniel Thom

The Power System Is Changing



Electricity Demand

Is Growing

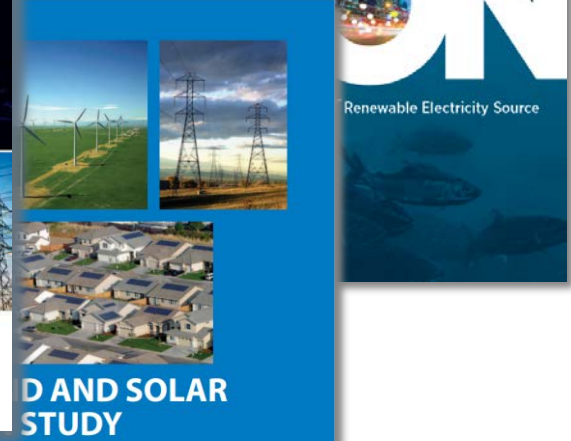
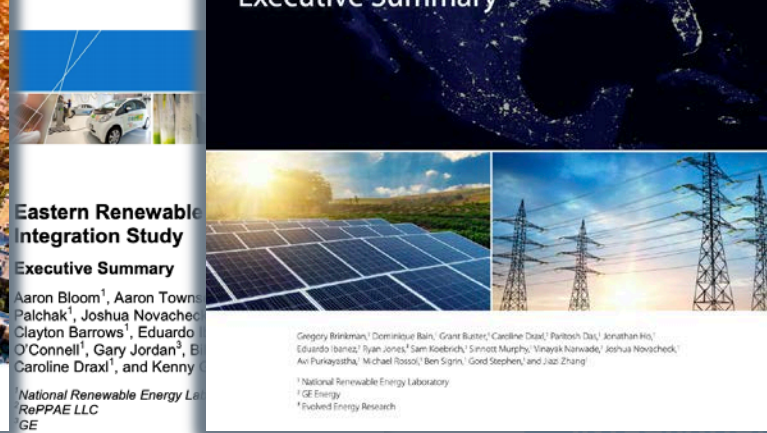
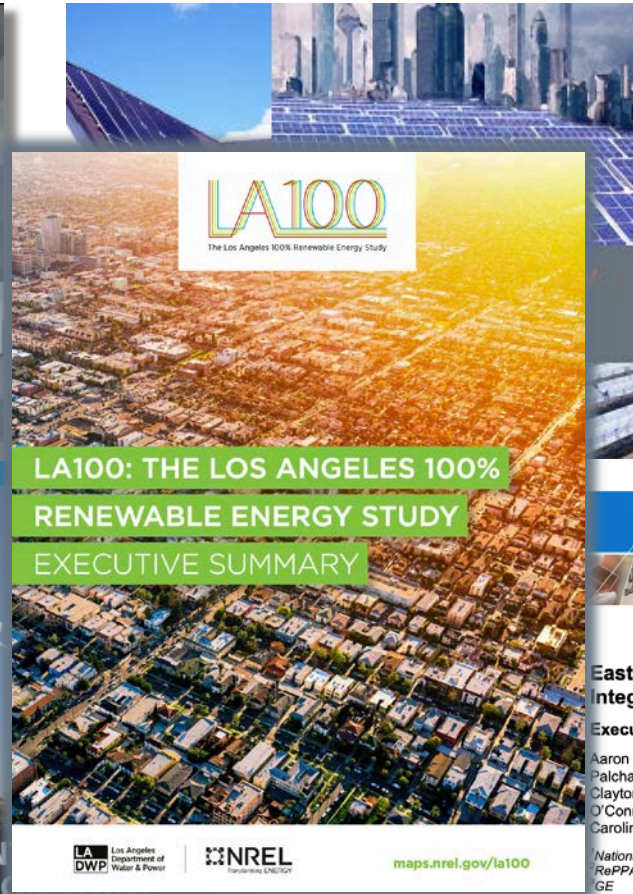
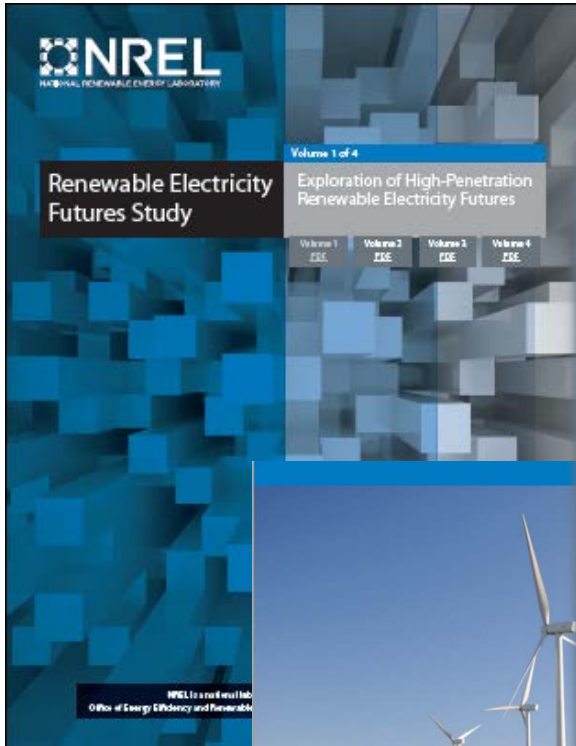




Reliability and Resilience

Are Even More Paramount

A learning process



PREPARED FOR:
The National Renewable Energy Laboratory
A national laboratory of the U.S. Department of Energy

PREPARED BY:
EnerNex Corporation

REVISED FEBRUARY 2011

[Main Report](#)

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC
This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-6A20-64472-ES
August 2016

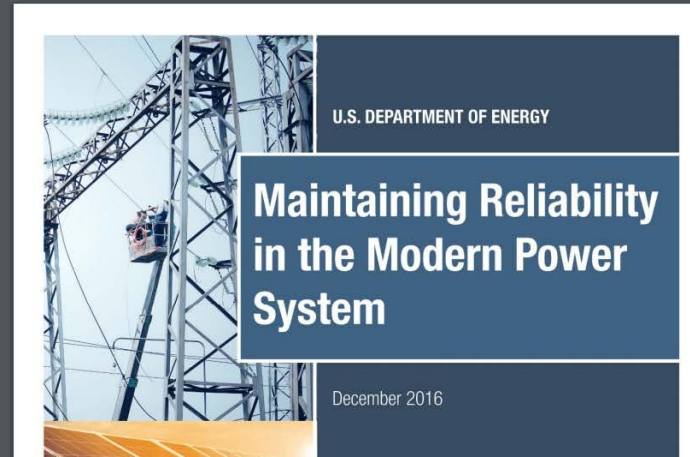
Contract No. DE-AC36-08GO28308

PREPARED FOR:
The National Renewable Energy Laboratory
A national laboratory of the U.S. Department of Energy

PREPARED BY:
GE Energy

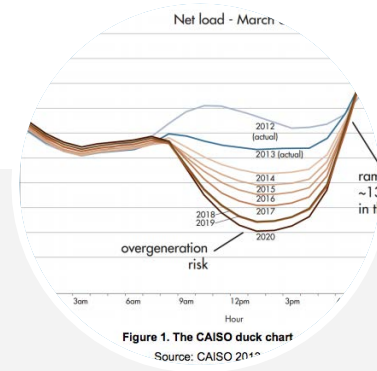
MAY 2010

Four Pillars of Power System Reliability



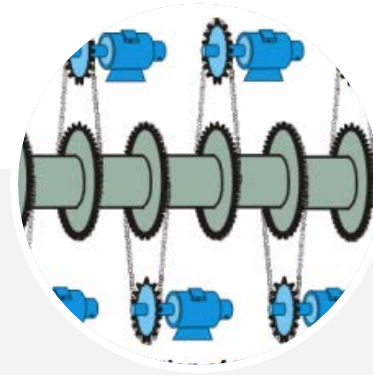
Capacity

Power generation and transmission capacity must be sufficient to meet peak demand for electricity.



Flexibility

Power systems must have adequate flexibility to address variability and uncertainty in demand (load) and generation resources.



Frequency

Power systems must be able to maintain steady frequency.

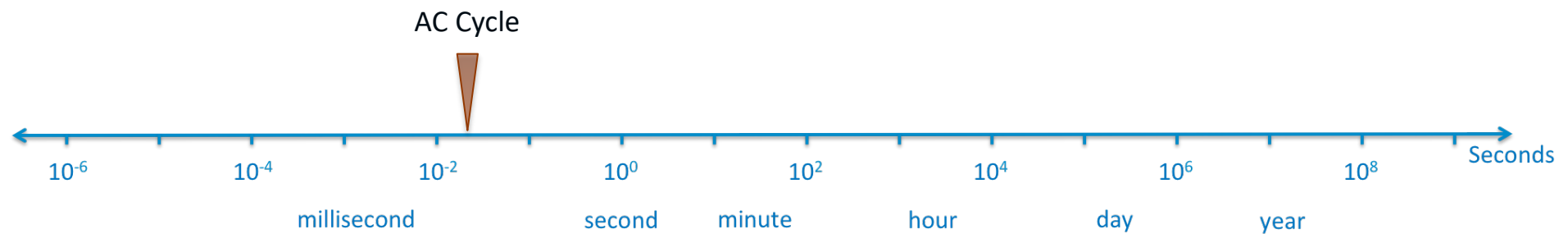


Voltage

Power systems must be able to maintain voltage within an acceptable range.

Relevant grid decision timescales

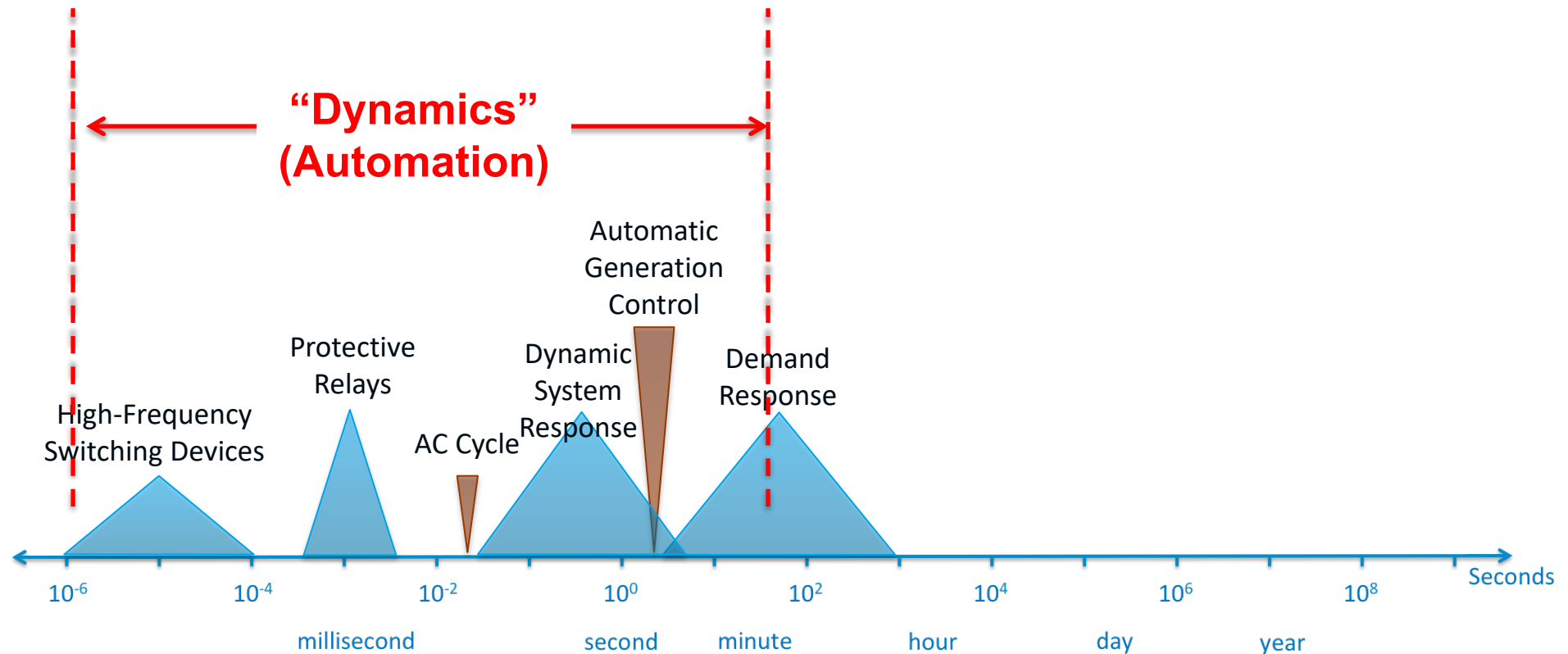
span 15 orders of magnitude



Adapted from A. Von Meier

Relevant grid decision timescales

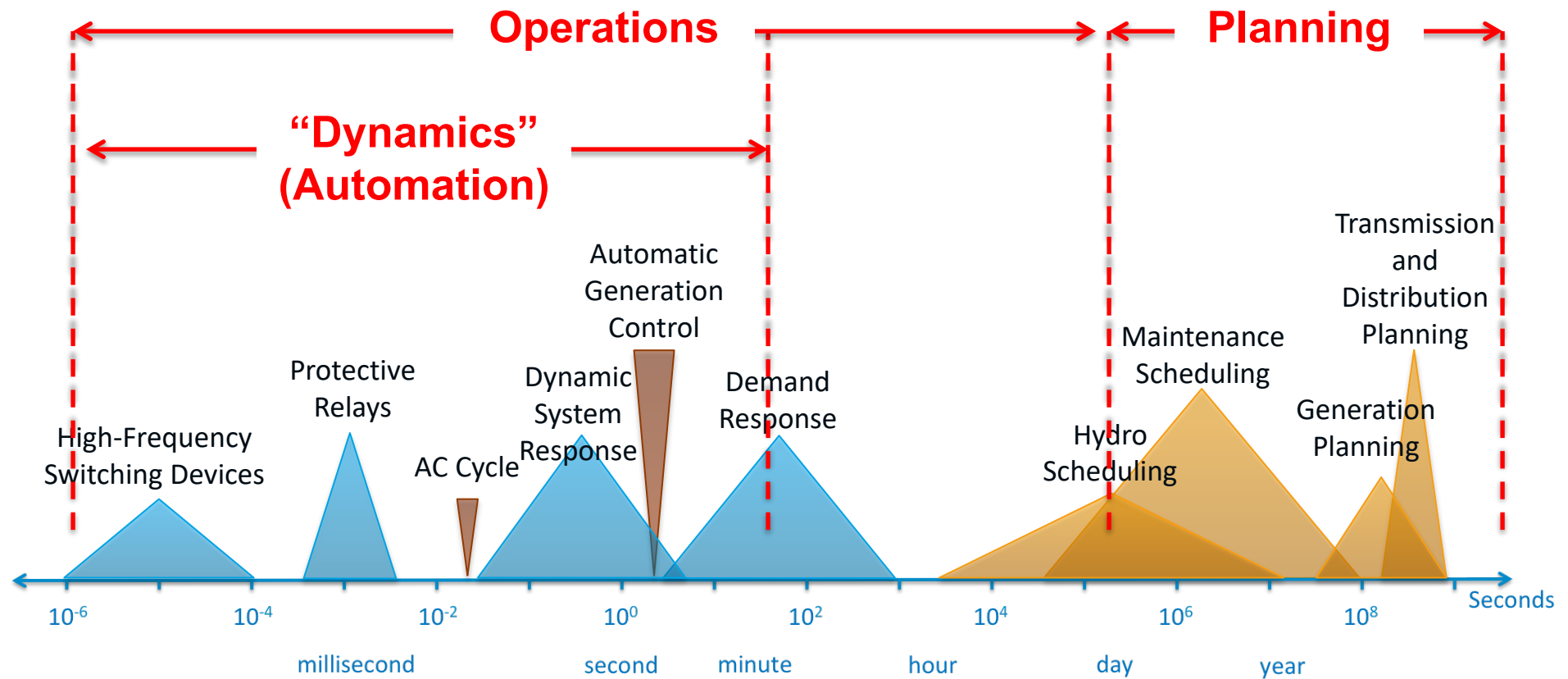
span 15 orders of magnitude



Adapted from A. Von Meier

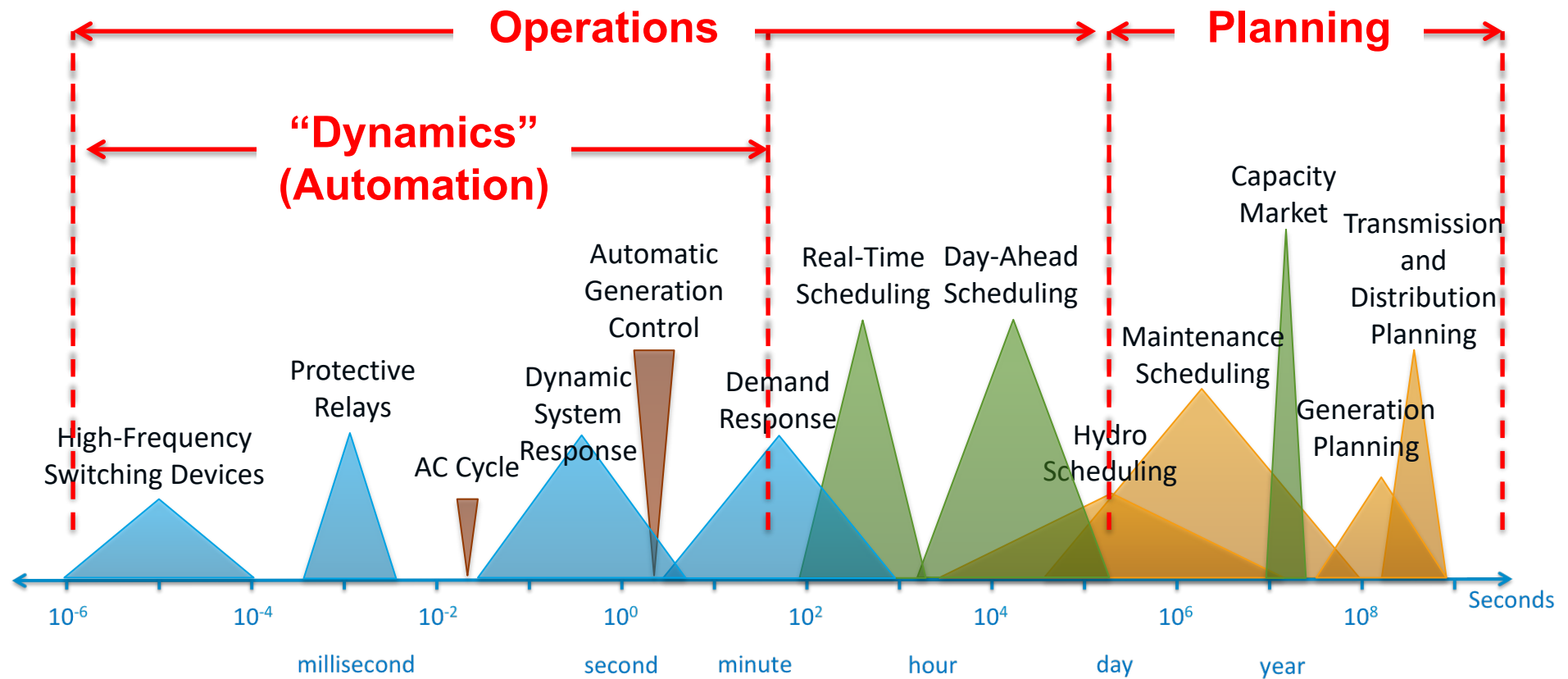
Relevant grid decision timescales

span 15 orders of magnitude



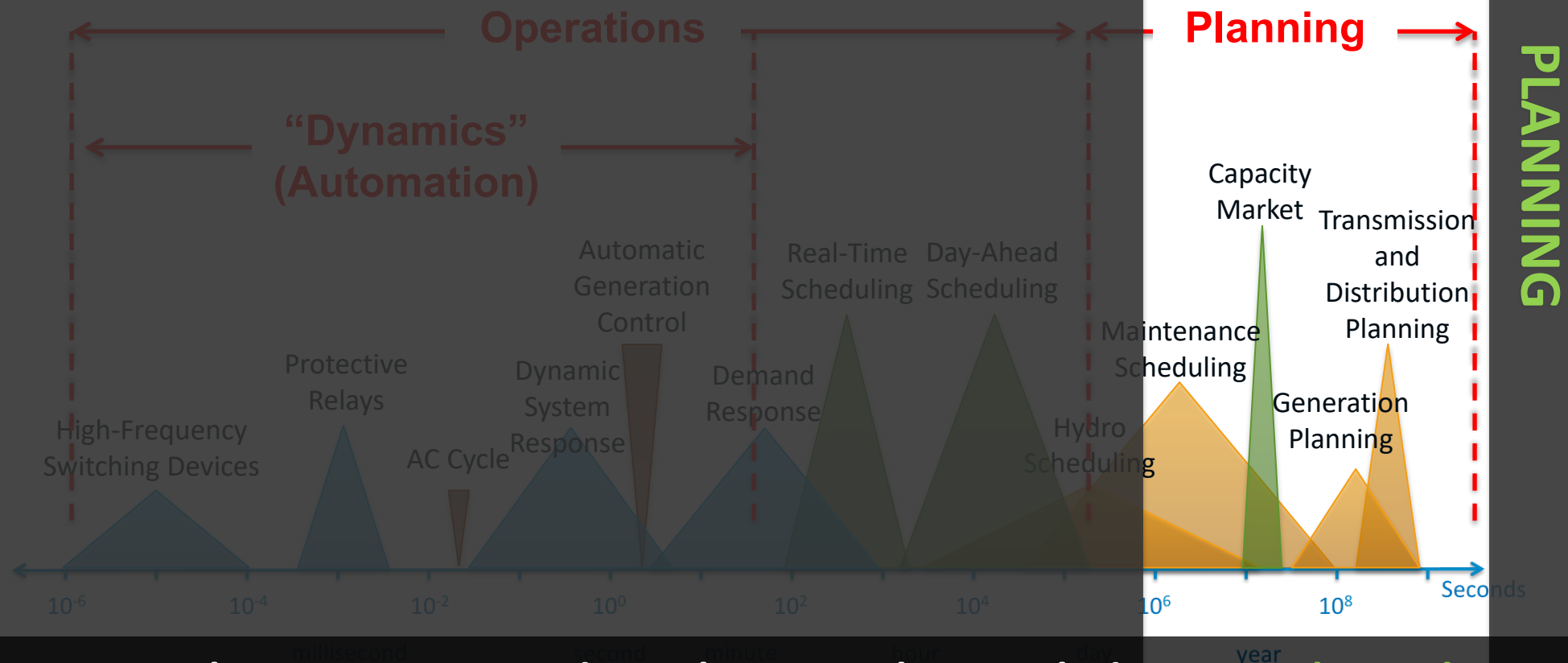
Relevant grid decision timescales

span 15 orders of magnitude



Relevant grid decision timescales

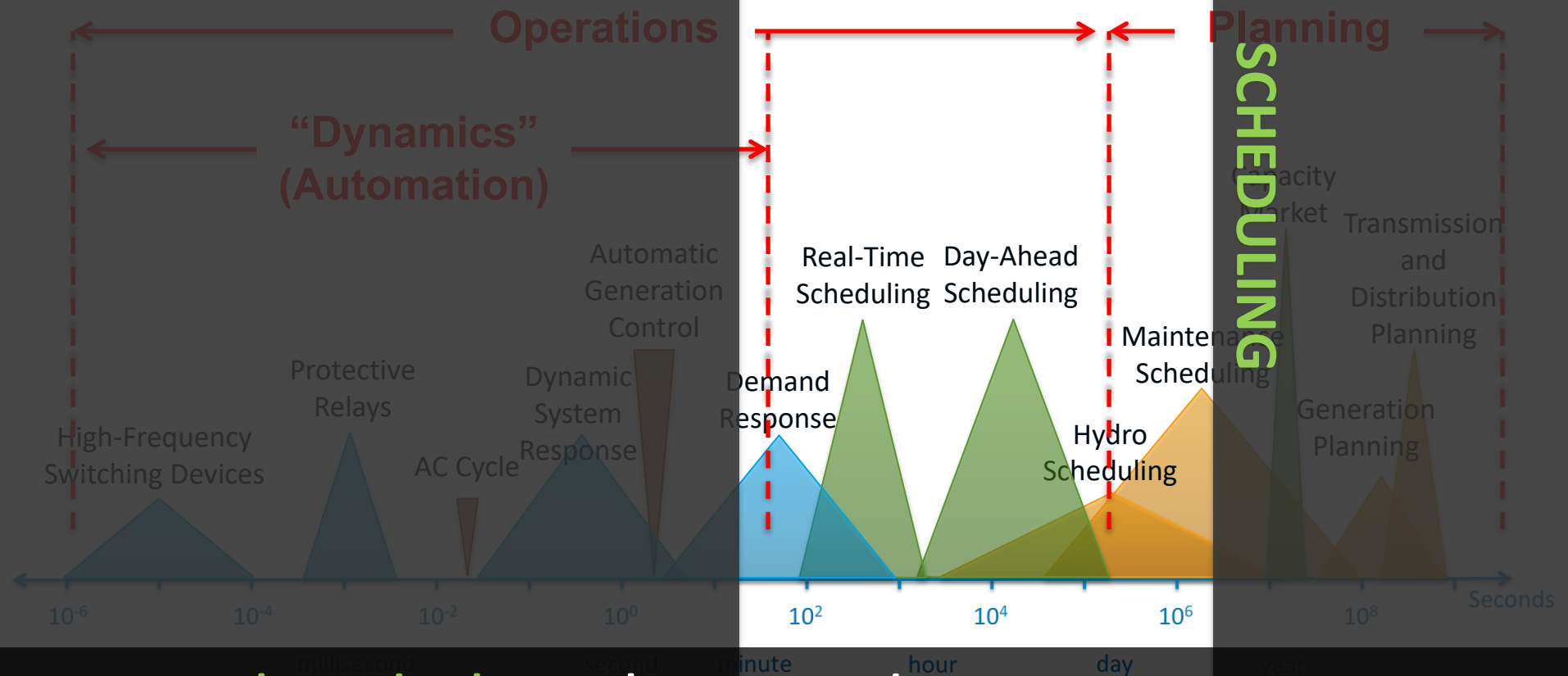
span 15 orders of magnitude



When, where, and what should get built?

Relevant grid decision timescales

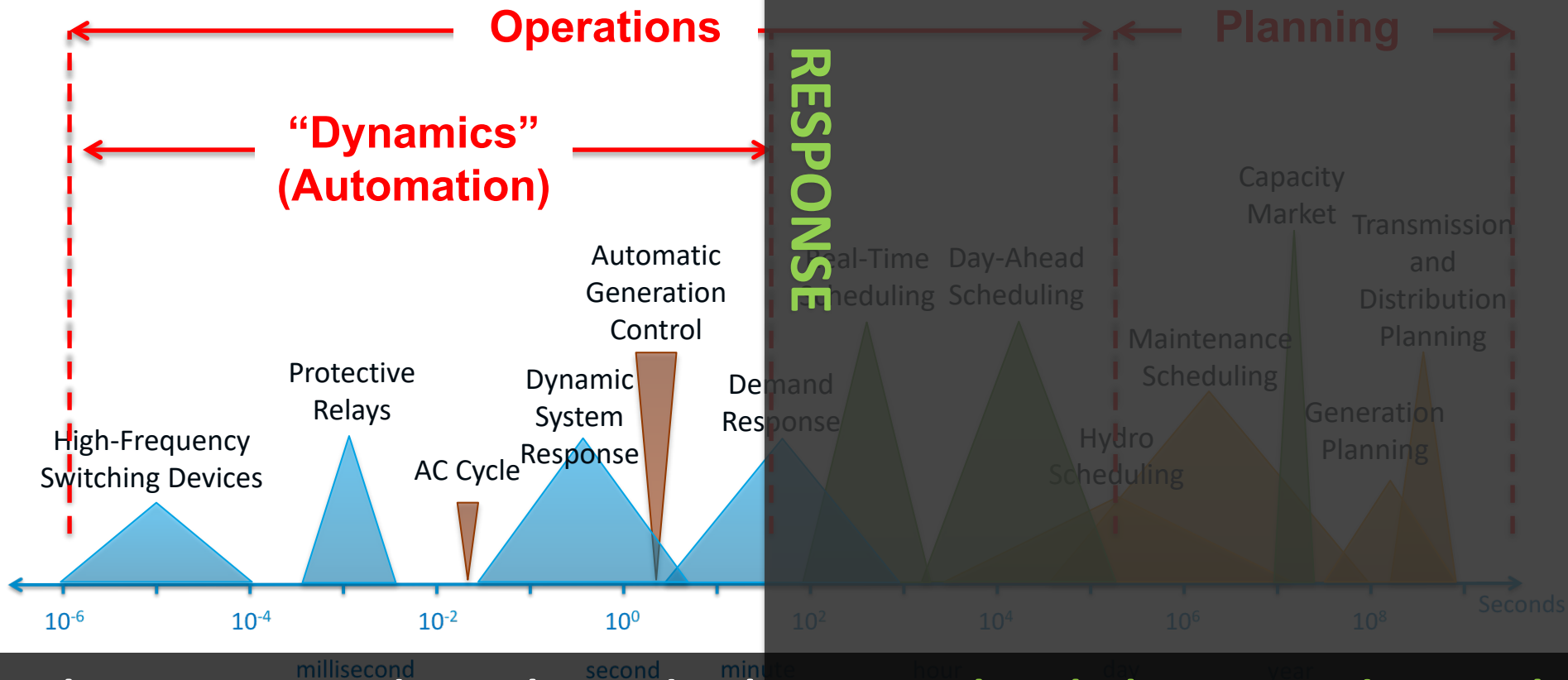
span 15 orders of magnitude



How to **schedule** planned system operations?

Relevant grid decision timescales

span 15 orders of magnitude



Are plans and schedules reliable and stable?

GPAC Integration Studies Rely on Multiple Linked Modeling Exercises

Scenario Refinement and Detailed Reliability Evaluations

Frame and Develop Scenarios

DATA



wind



water



solar



thermal



power system



transportation



buildings

CAPACITY EXPANSION MODEL



What gets **built** and where?

Transmission and generation buildout

DISTRIBUTED GENERATION ADOPTION MODEL

Where is rooftop PV **adopted**?

Behind-the-meter buildout

LOAD FORECASTING

Which end-uses are **electrified**?

Electrification and end-use decarbonization

OPERATIONAL (PRODUCTION) MODEL

Operational analysis: unit commitment and dispatch

How does the grid **balance**?

How is **transmission** operated?

RELIABILITY MODEL

Probabilistic resource adequacy analysis
Power flow analysis
Resilience analysis

Is it **reliable**?

What about different **weather**?

IMPLEMENTATION ANALYSIS

High Priority Transmission Options
Public Engagement

Which builds are **robust** across scenarios?

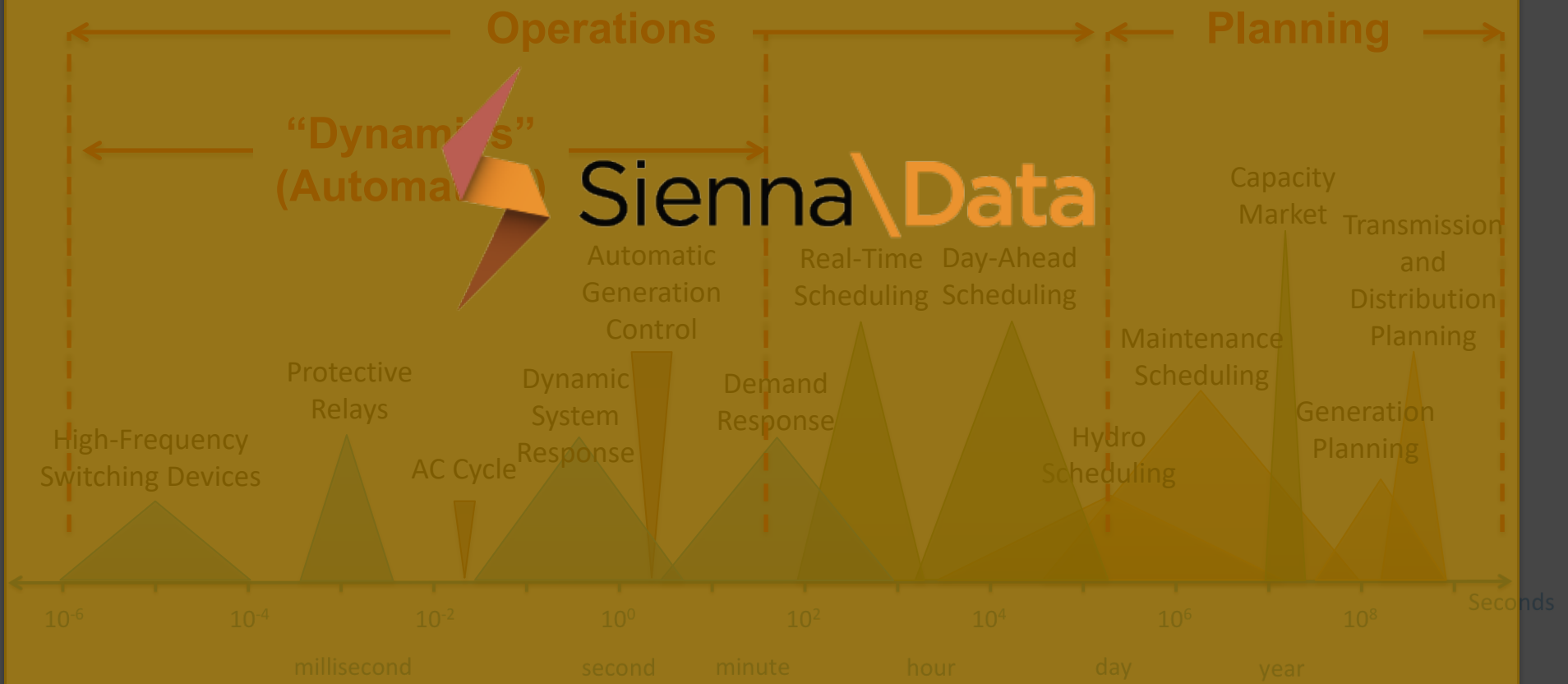
Where do we **start**?

DETAILED SCENARIOS

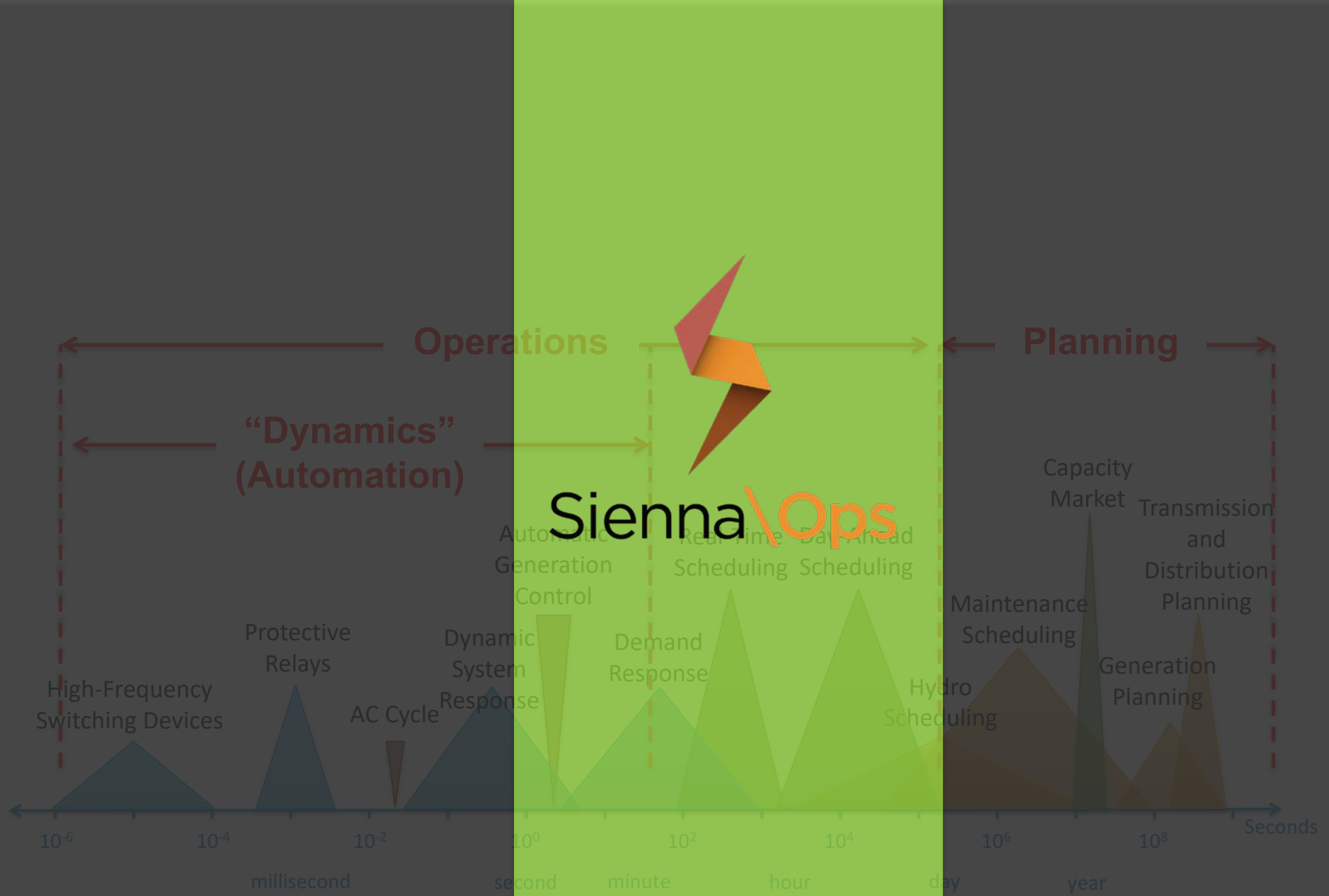


Sienna

Open-Source Ecosystem for Power System Modeling,
Simulation, and Optimization



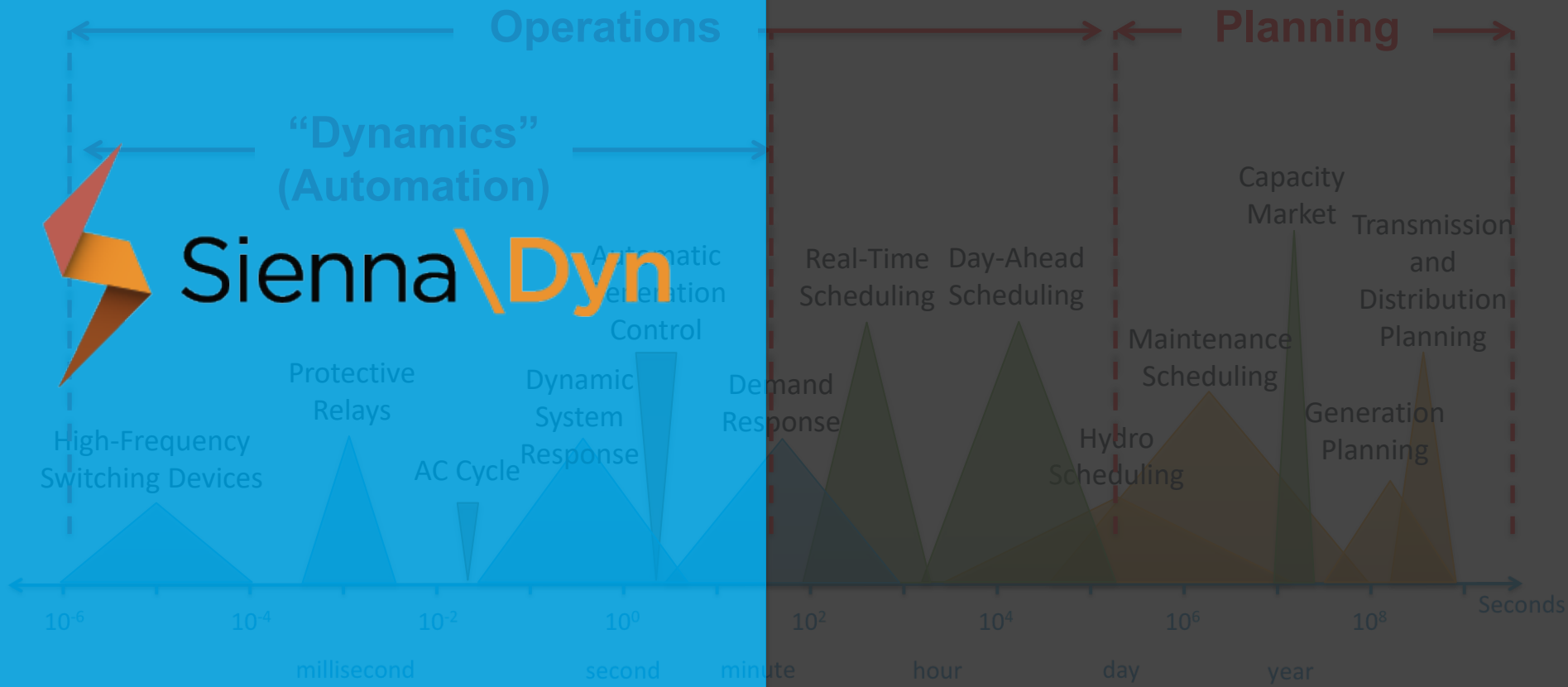
Adapted from A. Von Meier



Adapted from A. Von Meier



Sienna \ Dyn



Adapted from A. Von Meier

Use Cases



U.S. DEPARTMENT OF ENERGY
Building a Better Grid
National Transmission Planning Study



GMMLC

Renewable Energy Initiative for Latin America and Caribbean (RELAC)

GOAL: Achieve at least 70% renewable energy penetration across Latin America and the Caribbean by 2030

RELAC provides 16 partner countries with:

- 1 Support in addressing technical and financial needs to increase renewable energy penetration
- 2 Matchmaking of financial resources to support capacity building needs and implementation of RE expansion plans
- 3 Knowledge exchange and best practices in renewable energy integration to the electrical grid



Partners

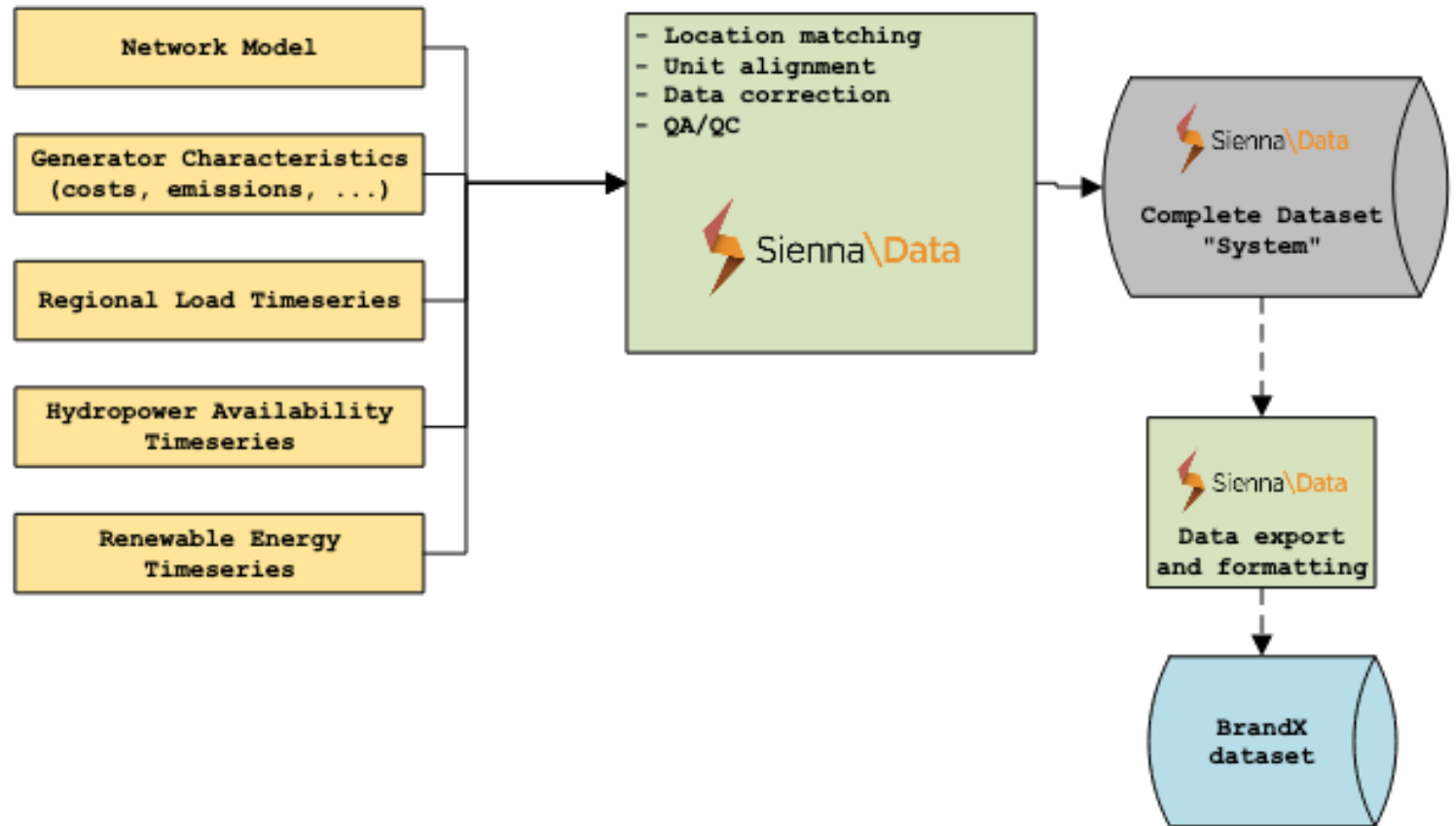




Efficient intake and use of power system data

Scaling Impact With Reproducible Data Management

- Programmatic dataset assembly
- Rapid updates, issue resolution, and scenario creation
- Data version control and cross-project consistency



Interregional Transfer Capability



SYSTEM

System View

Enter the path of a system file

Load System

Loaded system

None

Select units base

- unknown
- device_base
- natural_units
- system_base



Select an
interface

Enforce
generator
limits

- true
- false

Enforce
load
distribution
factors

- true
- false

Enforce
N-1
security

- true
- false

Calculate Transfer Limits

[PowerSystems.jl Docs](#)



**Simulation of system scheduling, including sequential problems
for production cost modeling**



Planning a Reliable Future for Puerto Rico

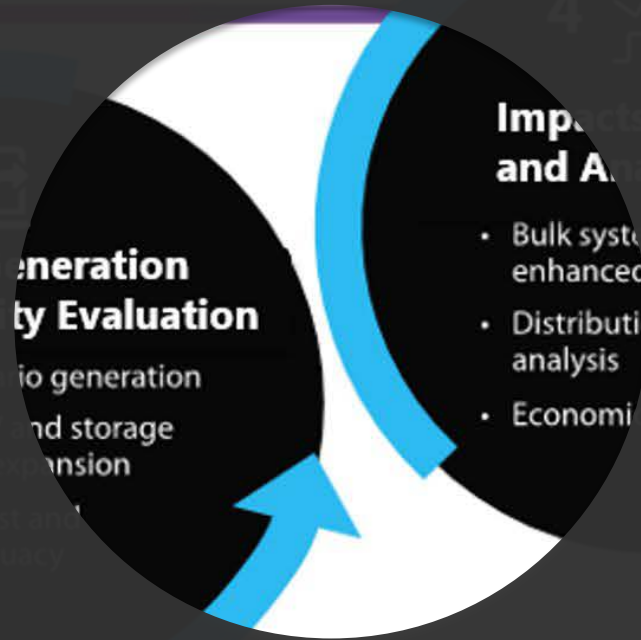


Responsive Stakeholder Engagement and Energy Justice

- Stakeholder engagement inclusive of procedural justice
- Energy justice and climate risk assessment



Sienna\Ops



Generation Capacity Evaluation

- Detailed analysis of generation
- Distributed generation and storage capacity expansion

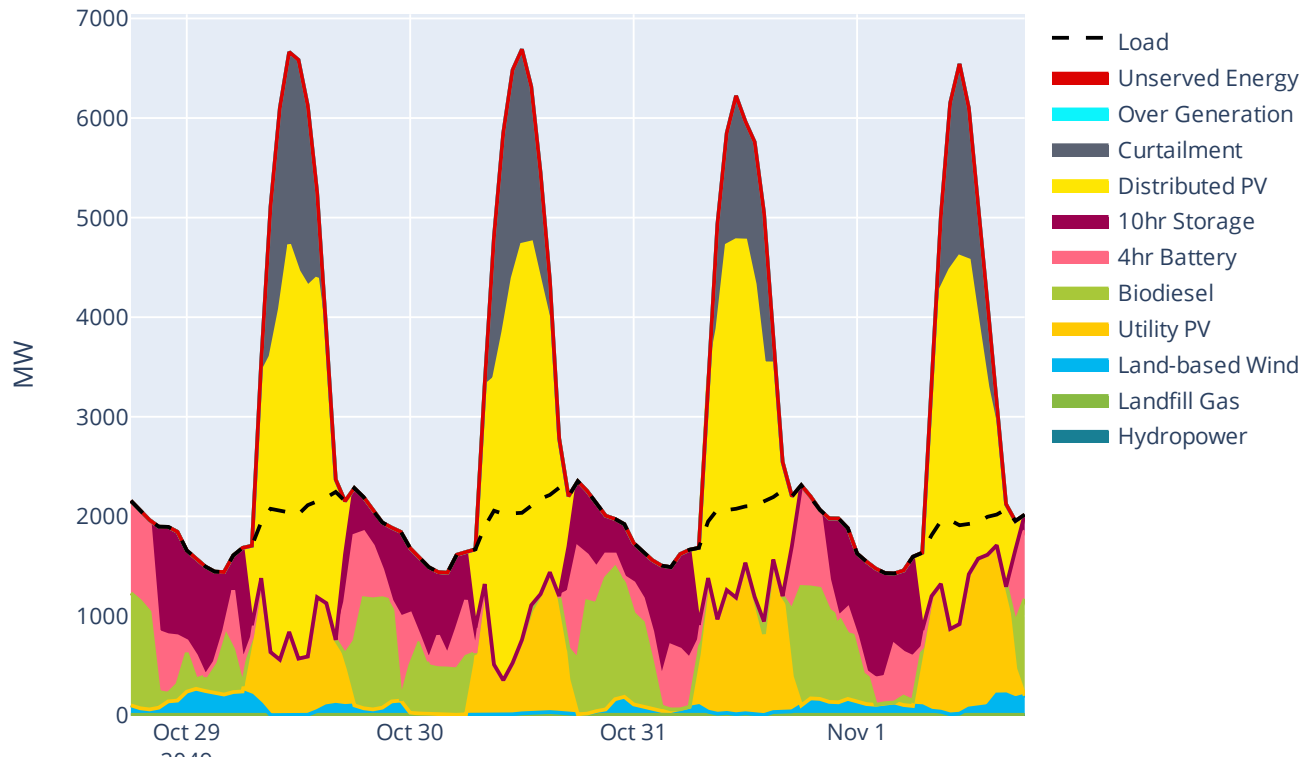
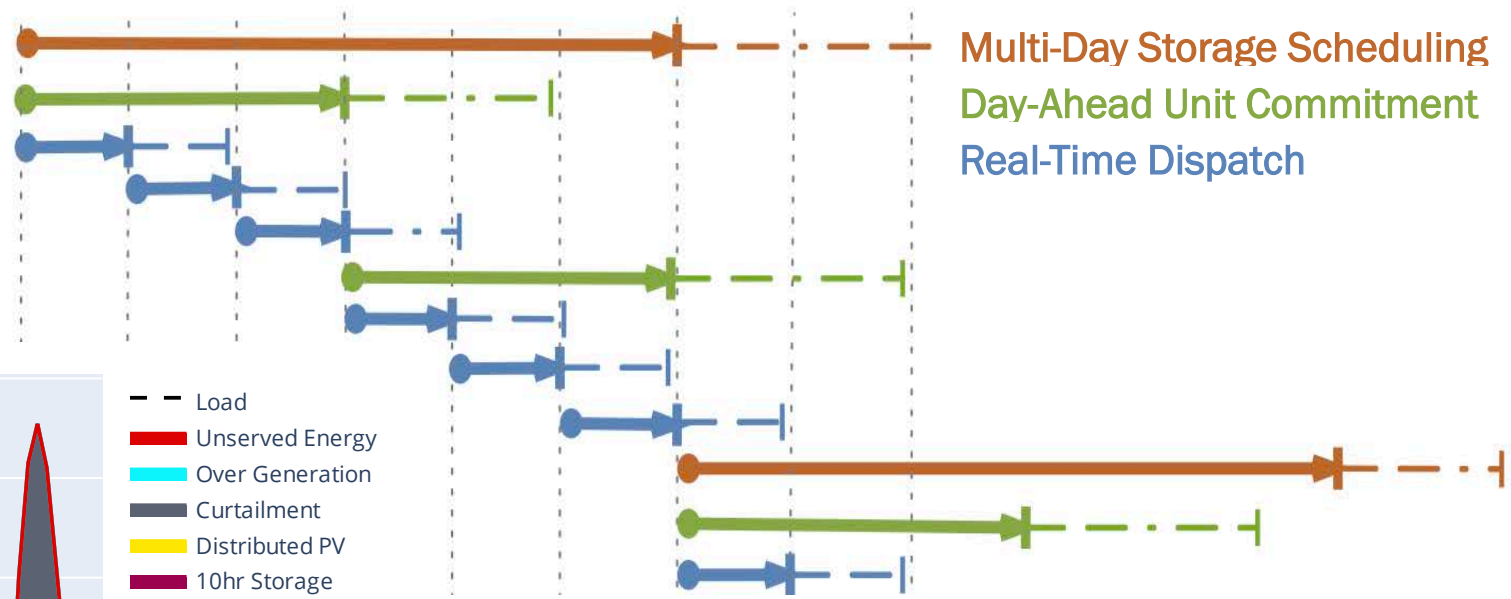
Impacts Modeling and Analysis

- Bulk system analysis for enhanced resilience
- Distribution system analysis
- Economic impacts

Sienna\Ops was used to simulate the ability of the system to balance supply and demand under any expected condition using resource adequacy and production cost models (PCM).



Changing Operations To Support Reliability



PR100 Simulations:

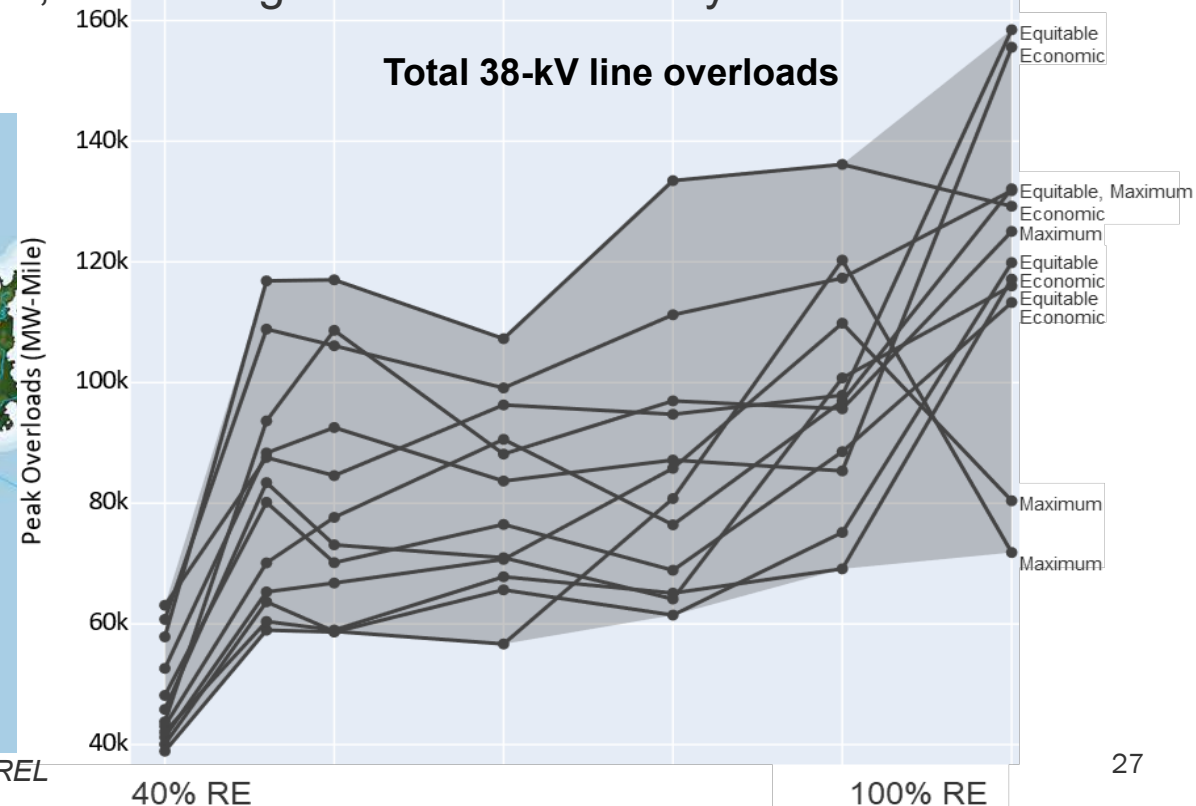
- 3 scenarios x 4 sensitivities x 7 expansion years = 84 annual simulations
- Sienna\Ops on high-performance computing supported execution of all scenarios in 4.5 hours

System Upgrades, Advanced Forecasting, Operating Reserve Management, and Grid Supporting Control Needed for Reliability

- The current 38-kV network is insufficient to handle the projected system with 40% renewables and is becoming more challenging for 100%.
- The lack of projected resource diversity will require significant operational changes to manage forecast errors.
- To mitigate large frequency deviations and contribute to black start and grid recovery, 300 to 800 MW of battery energy storage with grid-forming, fast frequency response, and voltage controls will be key in the short term.



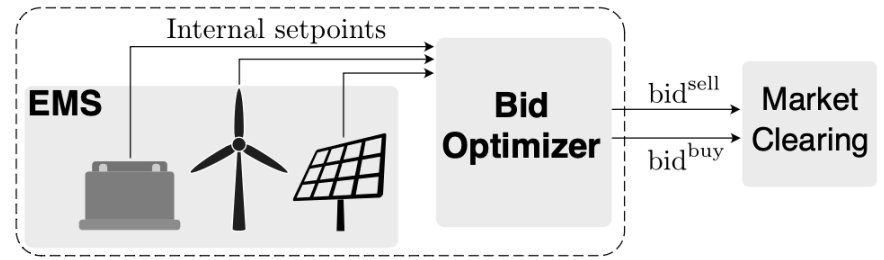
Graphics by NREL



Hybrid Power Plant Merchant Operations



GMLC



Step 1:
Generate Prices



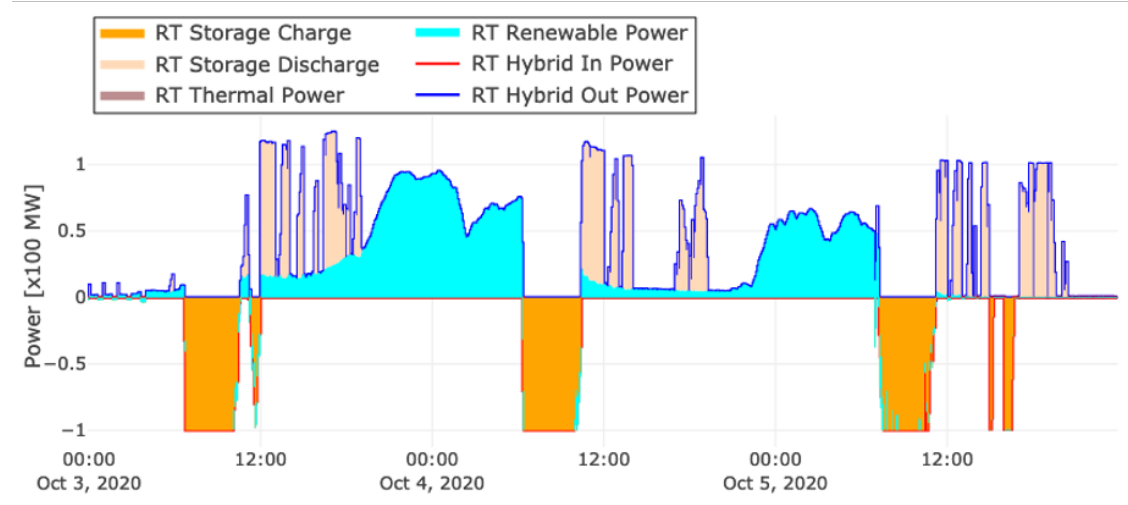
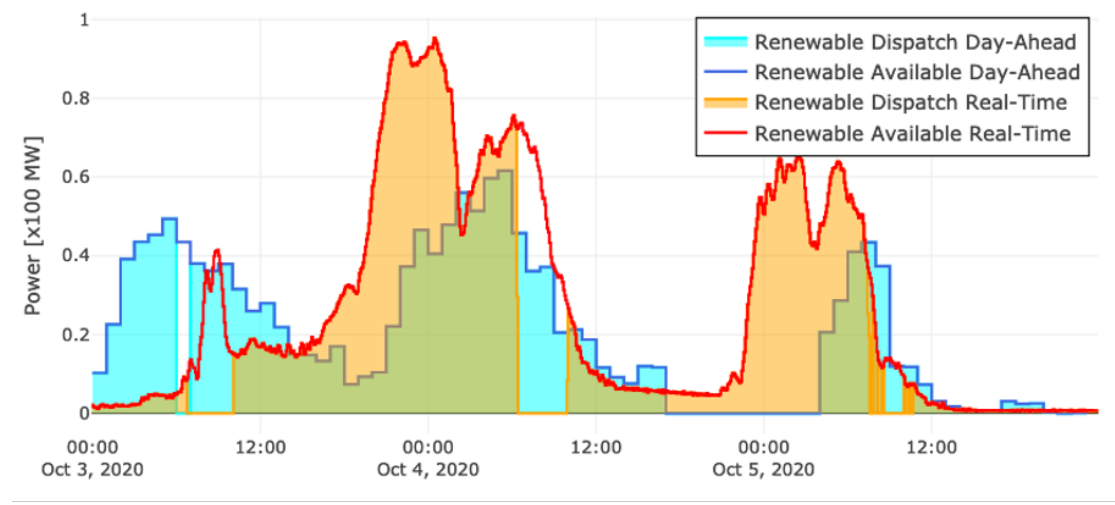
Step 2:
DA Participation



Step 3:
Adjust in RT
to changes



Step 4:
Observe realization





Simulation and modeling of inverter-based resource integration in
power systems

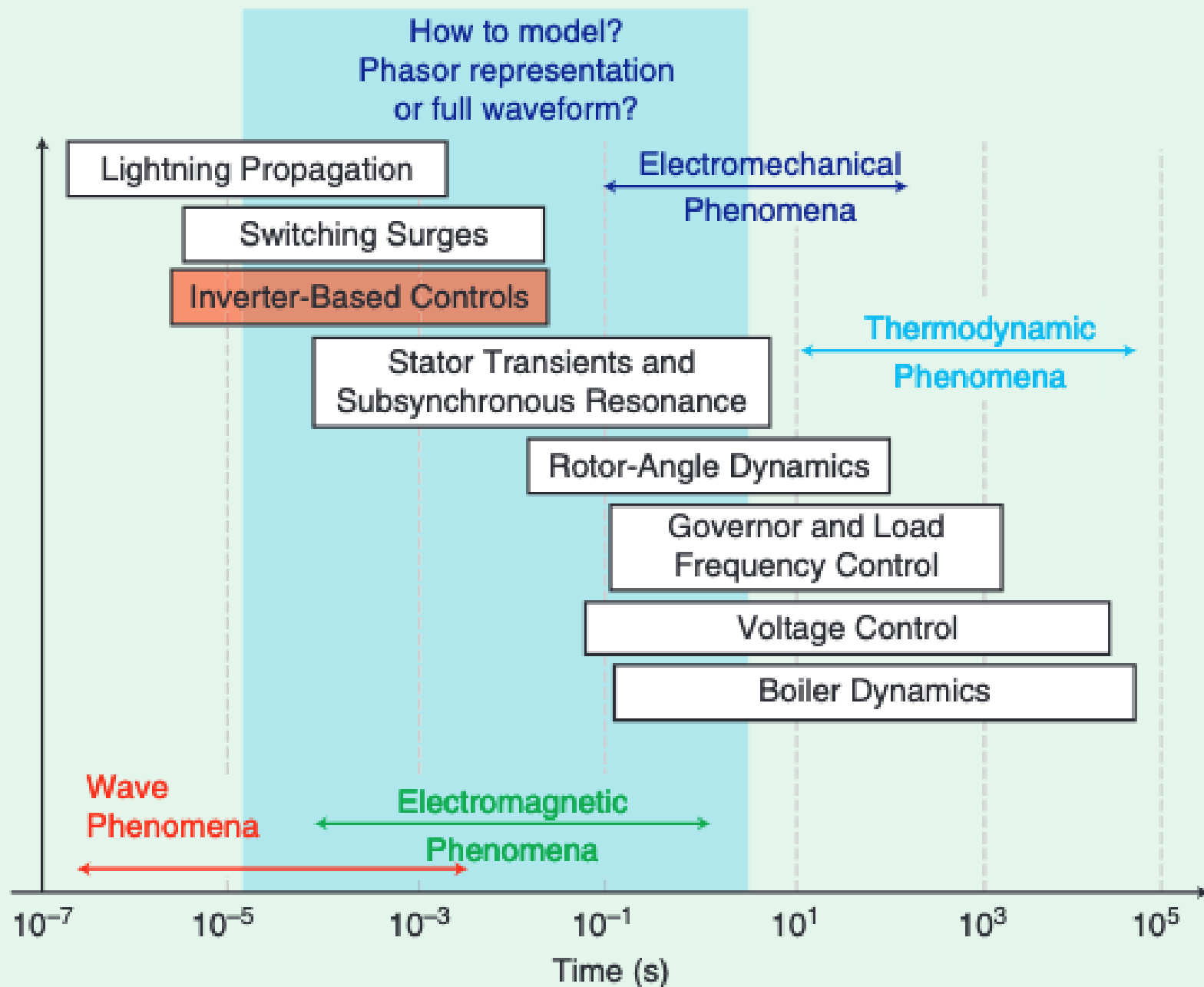


Inverter-connected resources

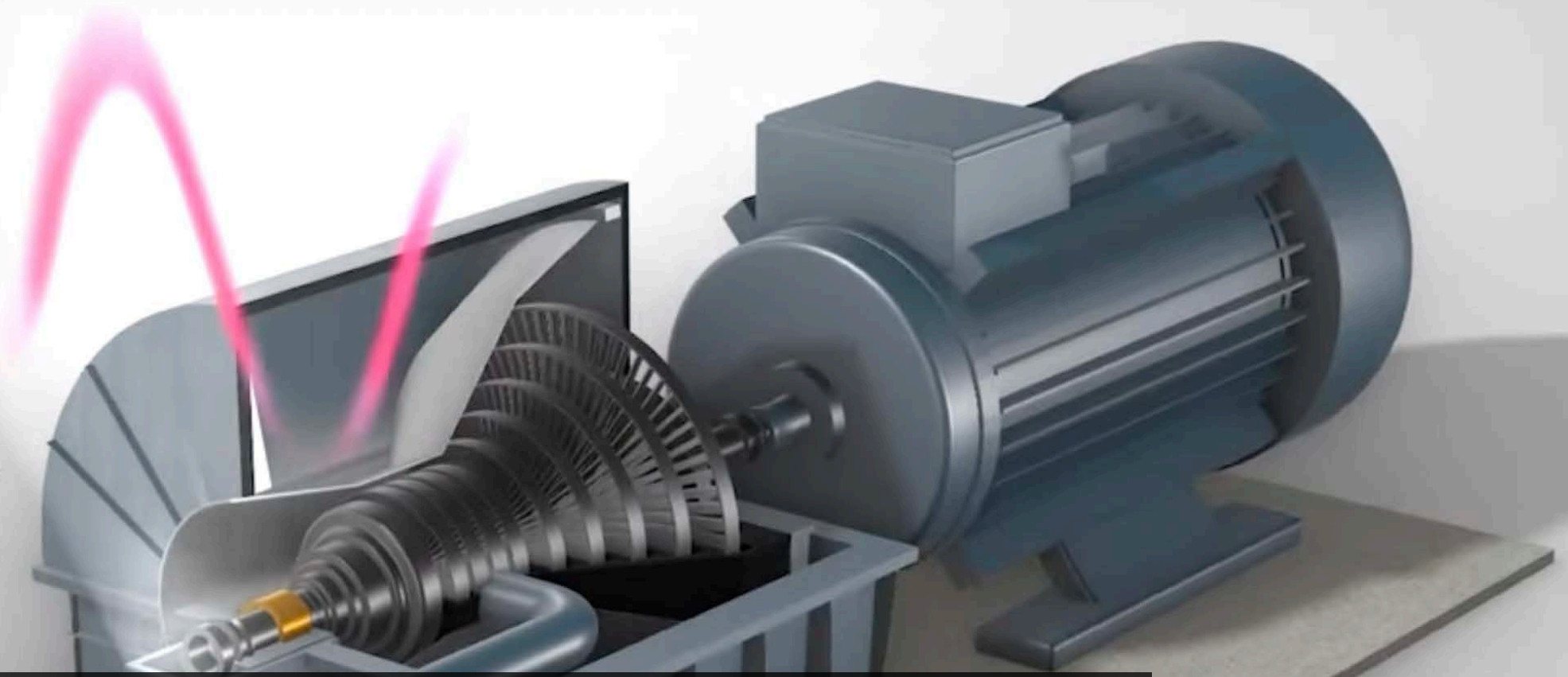
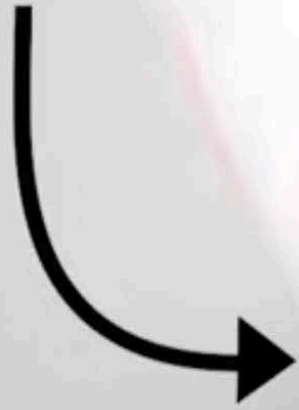
present new control opportunities

Inverter Connected Resources

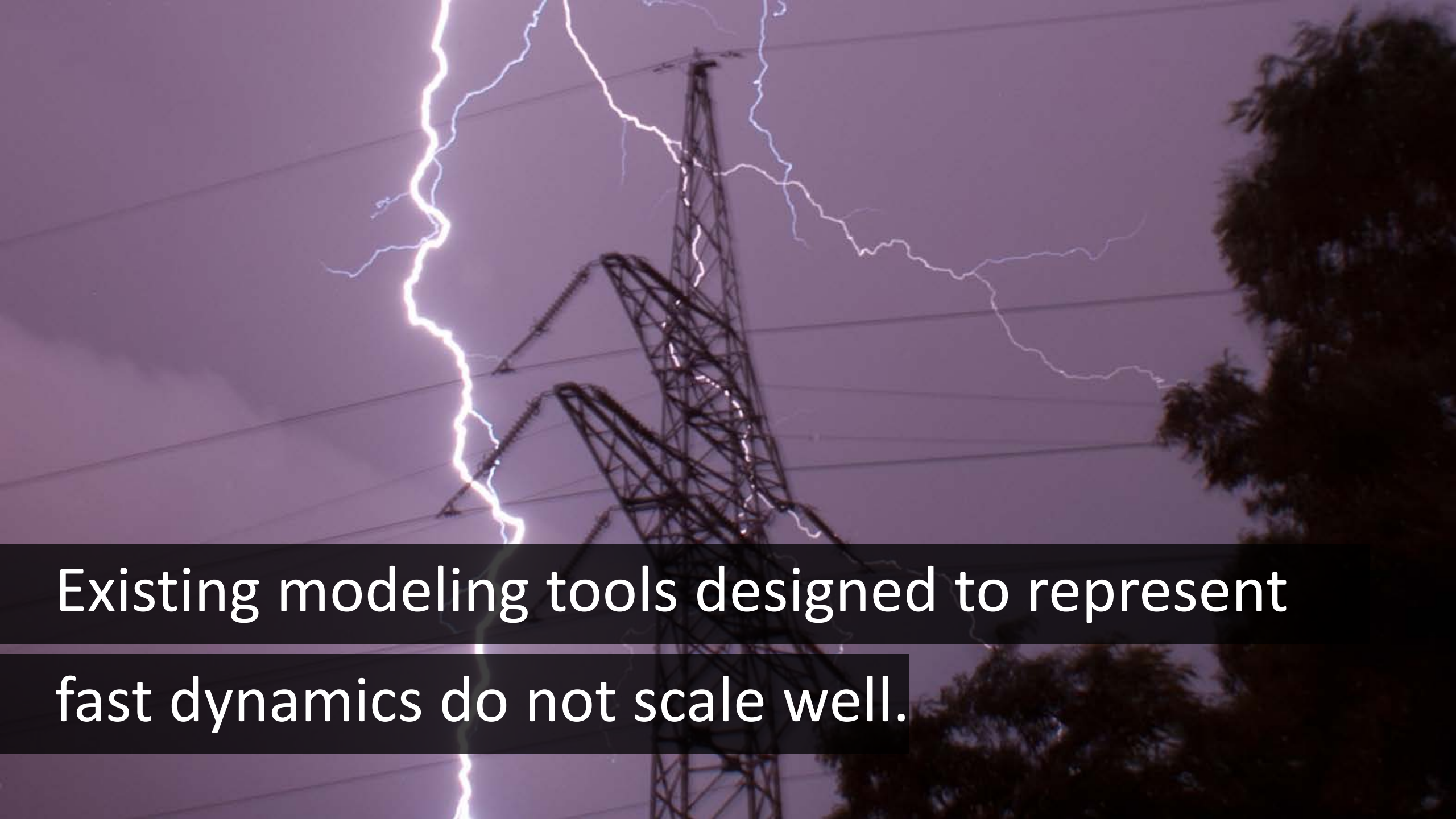
- New control opportunities
- Large numbers of devices
- Fast timescale dynamics



60 Hz

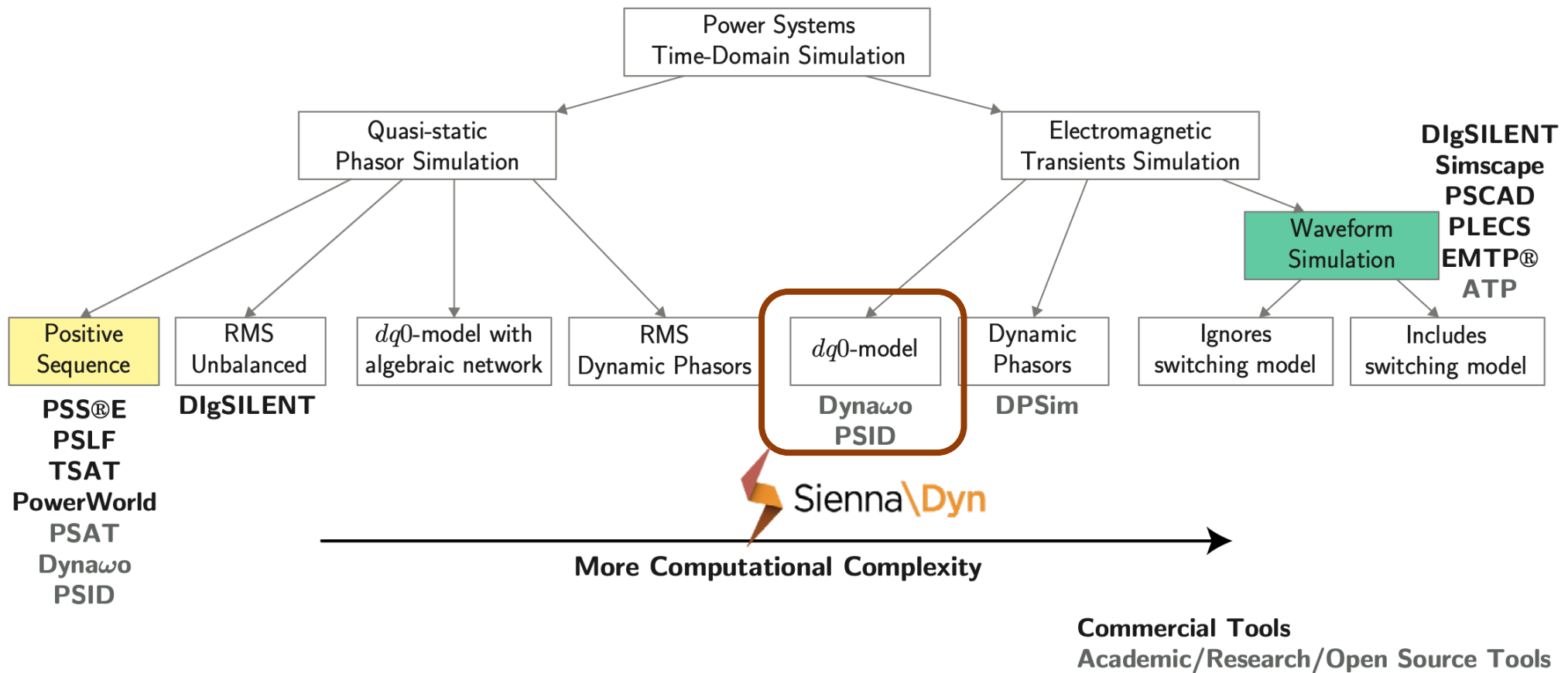


Existing scalable modeling tools often fail to represent inverter dynamic timescales.



Existing modeling tools designed to represent fast dynamics do not scale well.

Dynamic Simulation Taxonomy



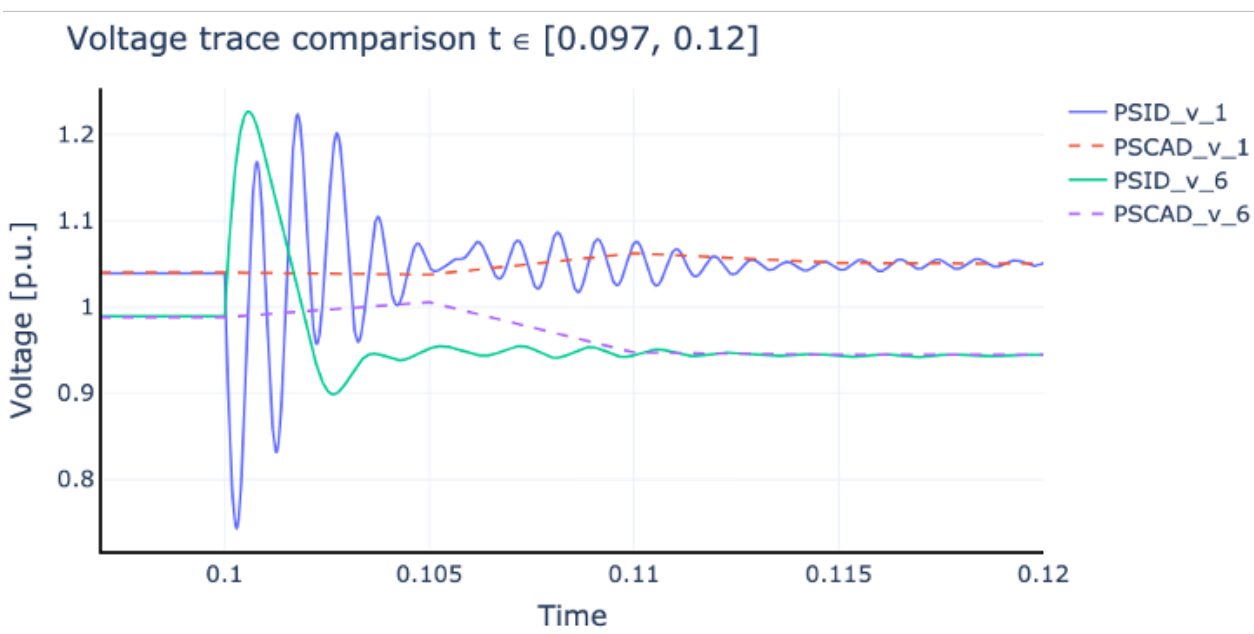
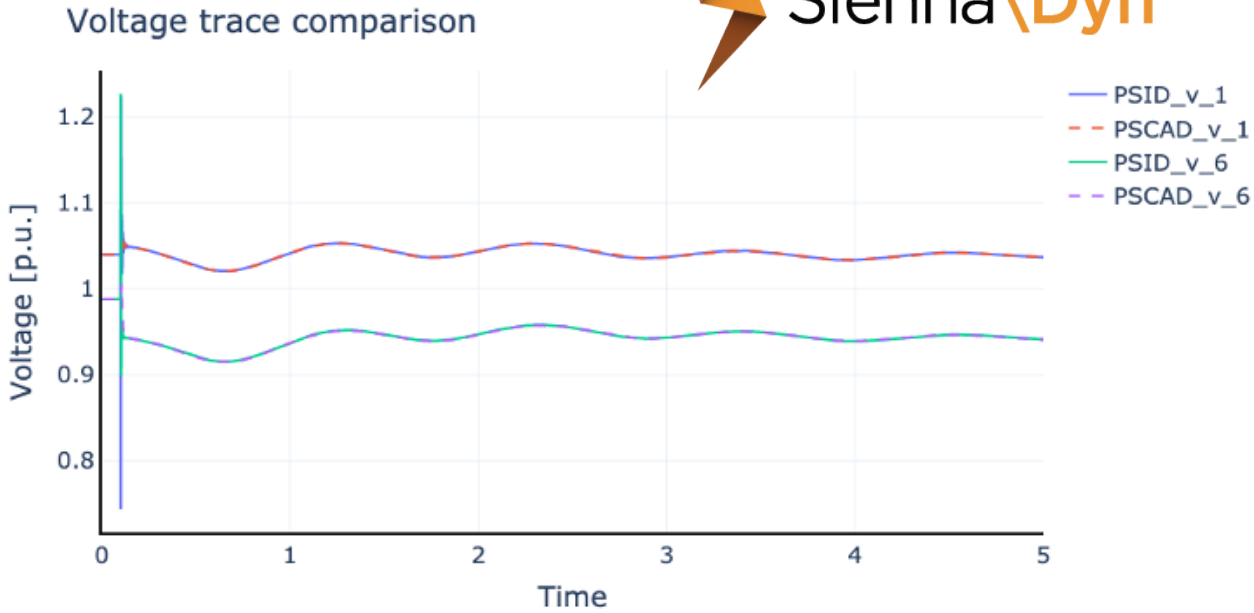
Same Conclusions, But Faster



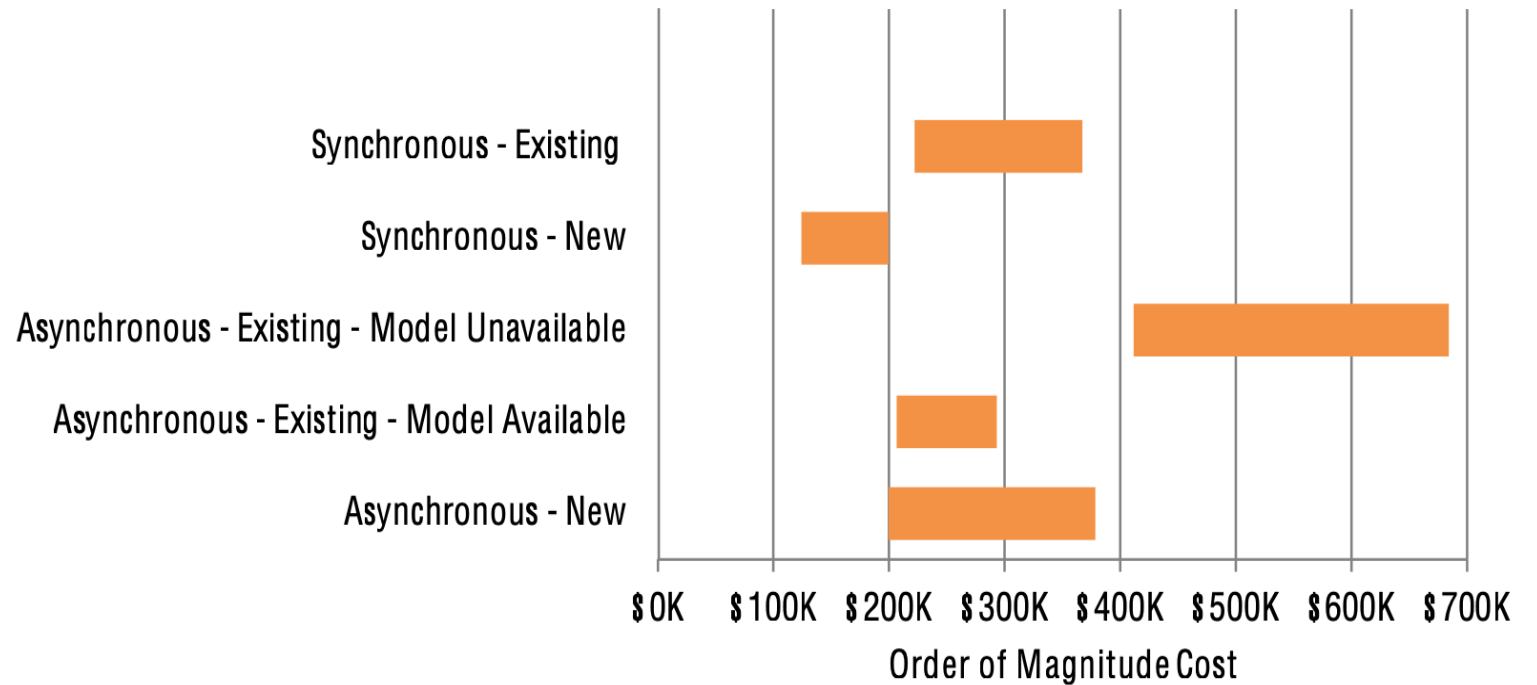
- ▶ Sienna\Dyn adaptive time-stepping can capture fast dynamics with significantly faster solution times.
- ▶ Sienna\Dyn is up to 100x faster in obtaining the solution of a 3-phase balanced EMT simulation considering GFM, GFL, and detailed synchronous machine devices on a 144-bus case for 5 seconds.

PSCAD Init	PSCAD run	FBDF	IDA
37269 (s)	49709 (s)	2665 (s)	69 (s)

*PSCAD: 25us timestep, 500us data collection
 **FBDF(,abstol=1e-9, reltol=1e-9)
 ***IDA(linear_solver = :KLU), abstol=1e-9, reltol=1e-9)



Accelerating the Process of Getting Answers



Source: "EMT and RMS Model requirements." Australian Energy Market Commission, ABN: 49 236 270 144, 16-June-2017.

- Model development:
 - ~40x reduction in development cost
- Modularity:
 - Separation between model specification and solution method creates opportunities to explore new solution methods and algorithms

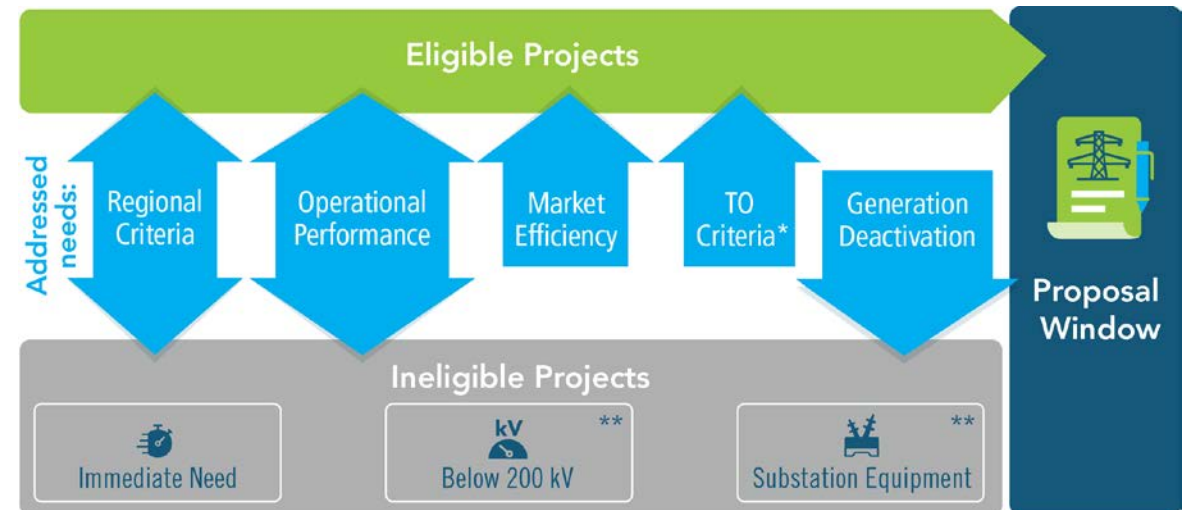
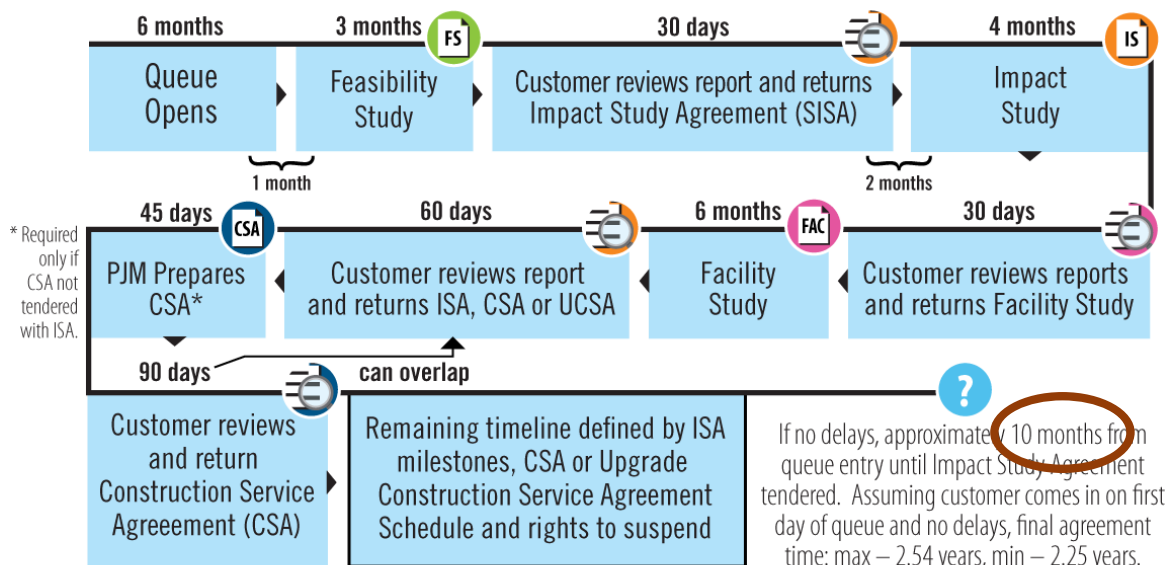


The Interconnection Process Is Broken

- Queue generation (~2.5 years*)
- Delays are common based on modeling/engineer availability
- Adjustments require revision of lengthy modeling processes.

If all goes perfectly:* 4.5 years of "coordinated" G&T approvals

*This never happens. The reality is this process identifies additional system upgrades and costs that delay or cancel many projects.



Note: *TO Criteria Eligible for proposal windows as of Jan. 1, 2020.

**Projects below 200 kV and substation equipment projects could become eligible for competition if multiple needs share common geography/contingency or if the project has multi-zonal cost allocation.

Can We “Automate” the Impact Study Step?

- ▶ Understaffed operators and limited training times for new engineers compound the problem of obtaining results for the interconnection of new generation in time.
- ▶ The problem disproportionately affects small utilities and rural operators.

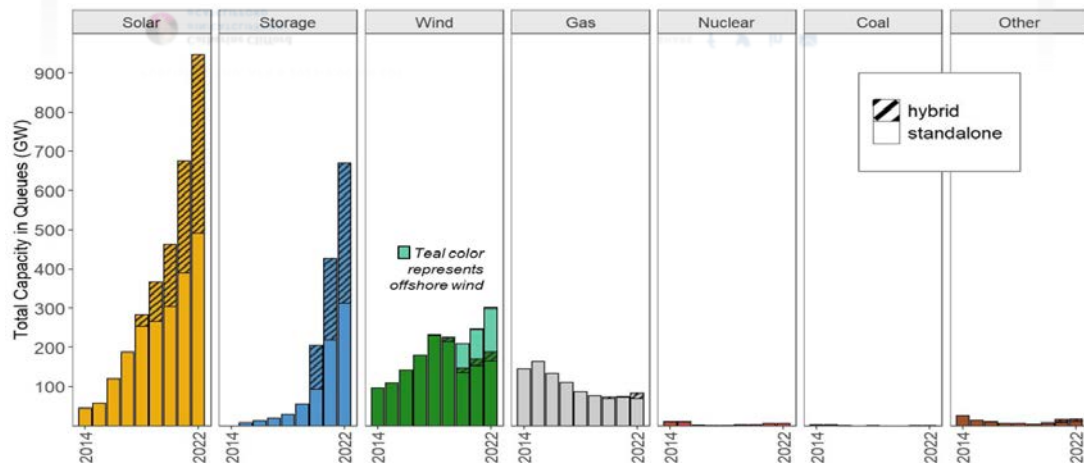
CLEAN ENERGY

Wind and solar power generators wait in yearslong lines to put clean electricity on the grid, then face huge interconnection fees they can't afford

PUBLISHED THU, APR 6 2023-9:00 AM EDT

Catherine Clifford
@IN/CATCLIFFORD/
@CATCLIFFORD

SHARE [f](#) [t](#) [in](#) [e](#)



- Identify costs of maintaining reliability
- The process **relies heavily on simulations** and stress tests
- Historically a sequential process assuming that every new unit added to the system maintains stability
- IBRs challenge these assumptions – more simulations will be needed and with greater detail.

Sienna Index

10,000+ Downloads
25 Packages
12,968,279 Lines of code
22,000 Commits
694 GitHub stars
203 Forks
16 Publications
32 Contributors
200 Datasets
30+ Project usages
400,000 HPC simulation hours

Questions?

www.nrel.gov

NREL/PR-6A40-90227

github.com/nrel-sienna

Clayton.Barrows@nrel.gov

Thanks to José Daniel Lara, Sourabh Dalvi, Surya Dhulipala, Kate Doubleday, Rodrigo Henriquez Auba, Gabriel Konar-Steenberg, Pedro Sanchez Perez, Daniel Thom, and the rest of the Sienna contributors.

This work was authored in part 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. Support for the work was also provided by Sacramento Municipal Utility District (SMUD) under CRD-17-00691. The views expressed within do not necessarily represent the views of the DOE or the U.S. Government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views expressed in the presentation do not necessarily represent the views of the DOE or the U.S. Government or any agency thereof.

