Sienna Modeling Framework

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National Renewable Energy Laboratory

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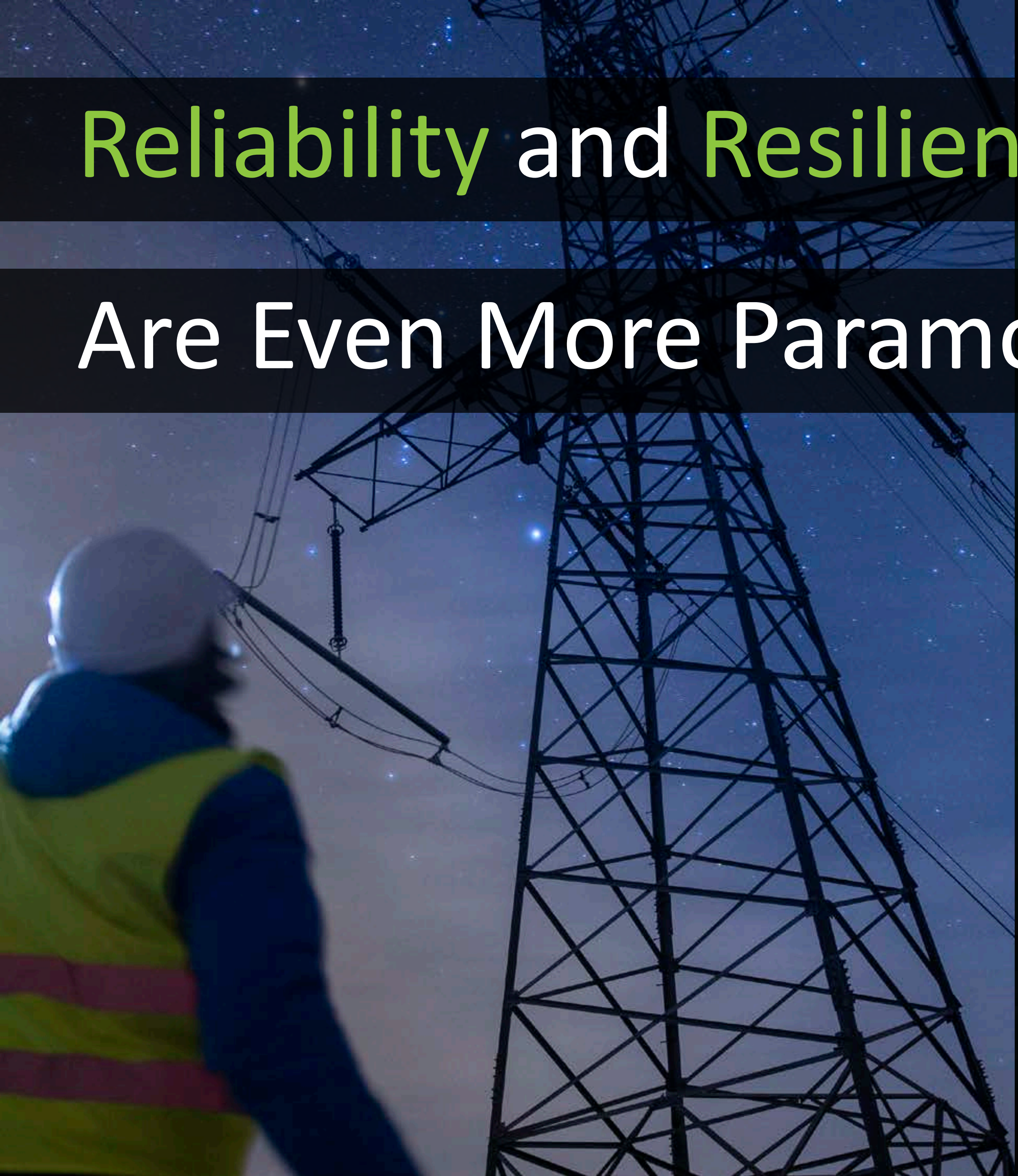
The Power System Is Changing

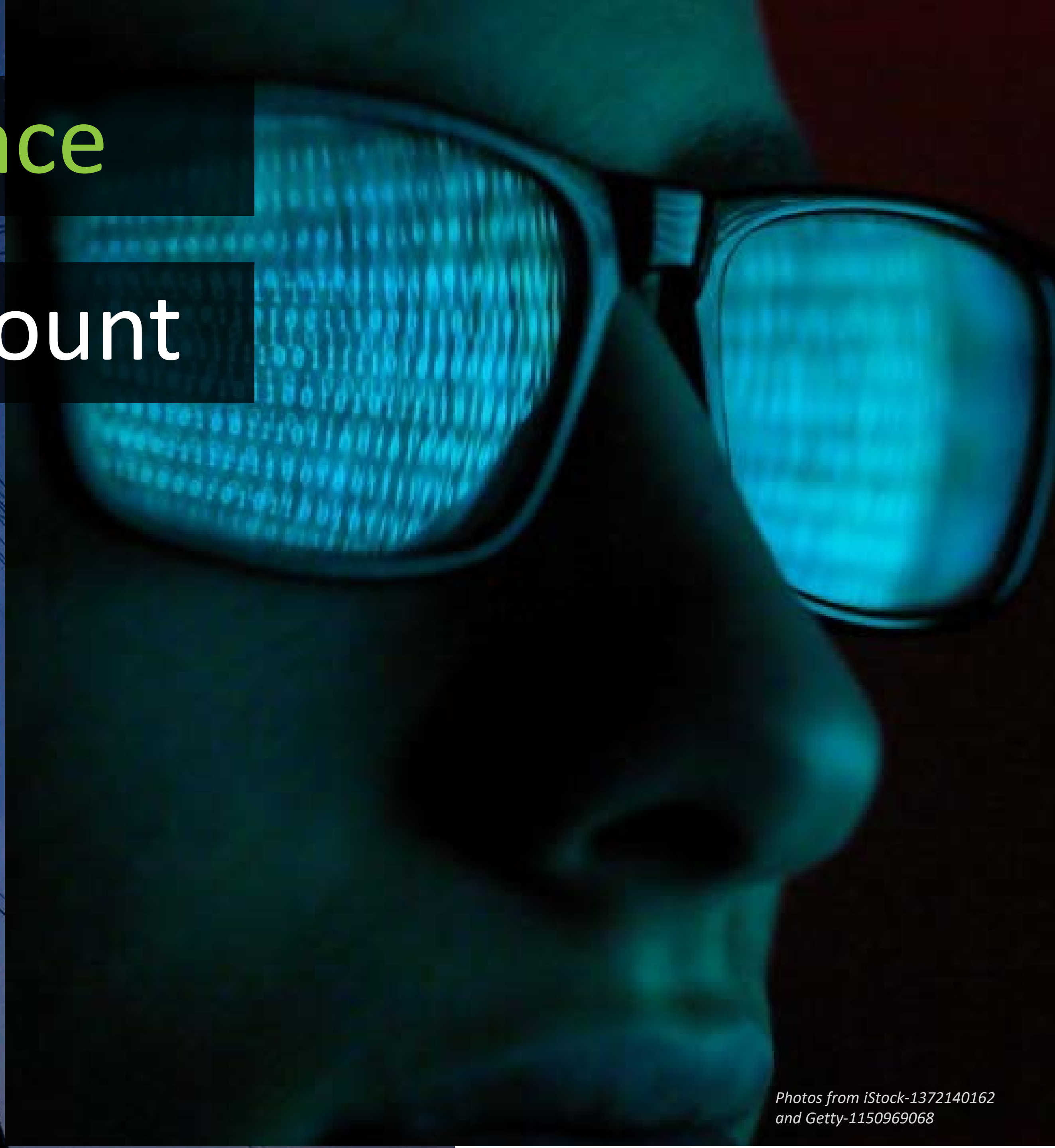
Video from iStock-639464770

Electricity Demand Is Growing

Photo from iStock-635716108

Reliability and Resilience Are Even More Paramount

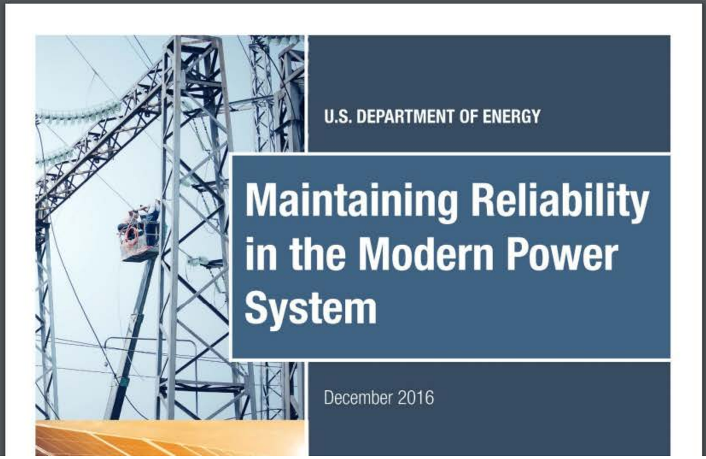




Photos from iStock-1372140162 and Getty-1150969068

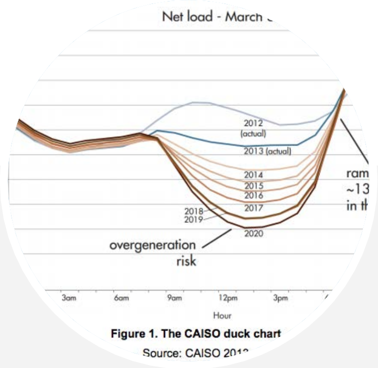
A learning process

Four Pillars of Power System Reliability



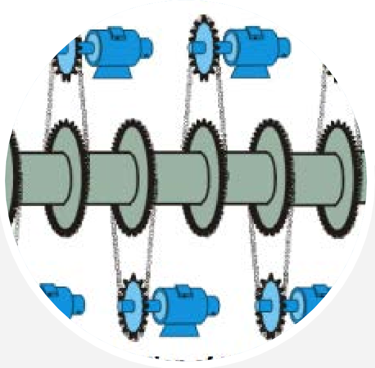
Capacity

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.



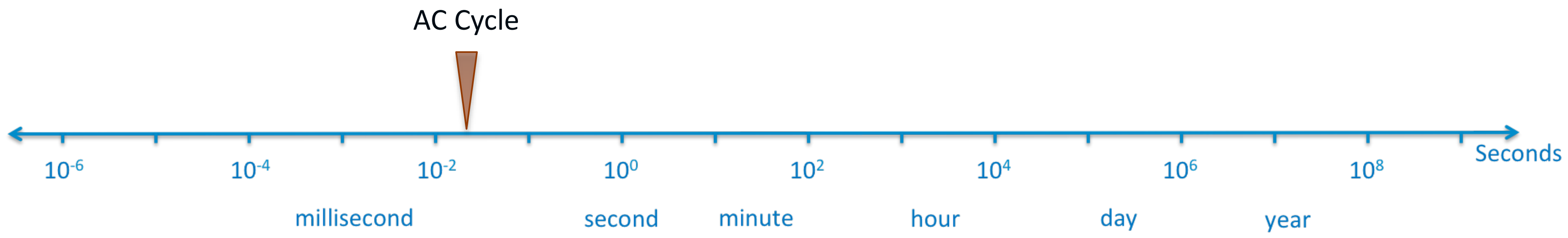
Frequency

Power systems must be able to maintain steady frequency.

Voltage

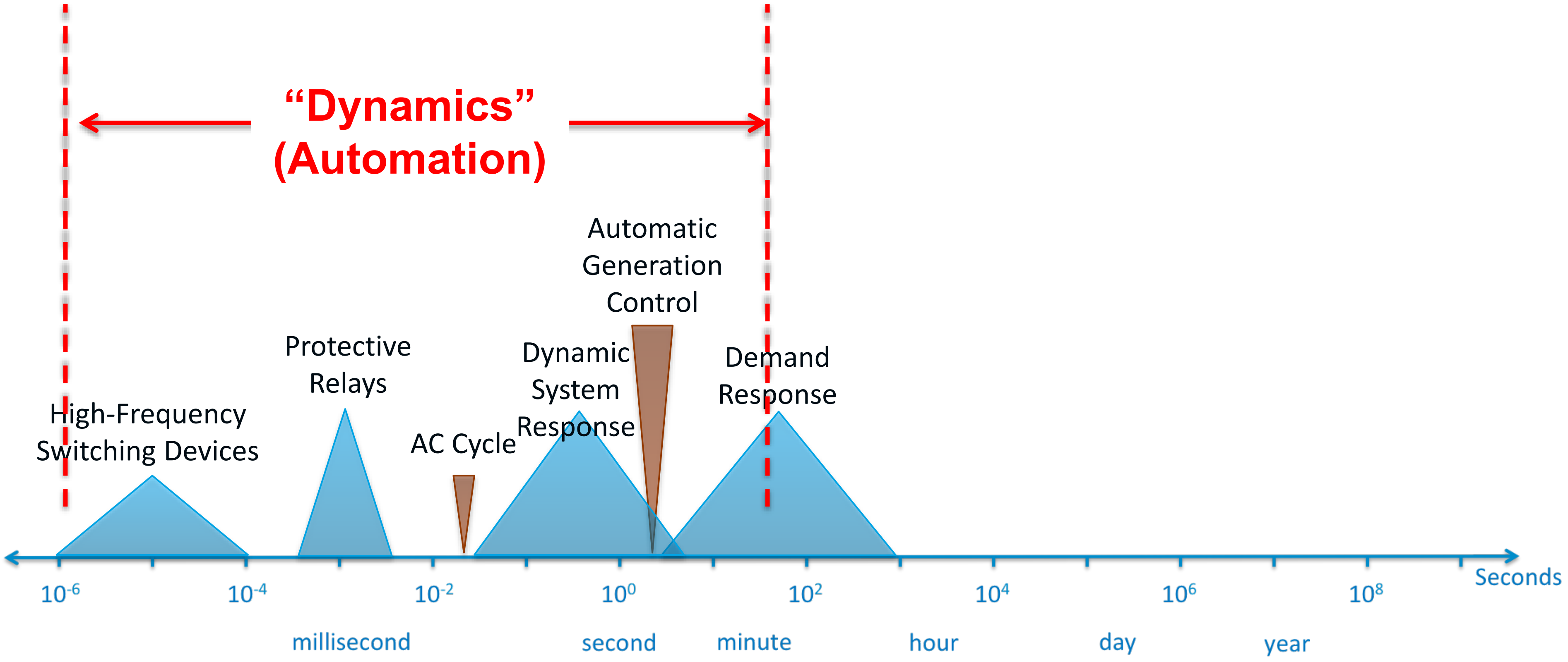
Power systems must be able to maintain voltage within an acceptable range.

Relevant grid decision timescales span 15 orders of magnitude



Adapted from A. Von Meier

Relevant grid decision timescales span 15 orders of magnitude



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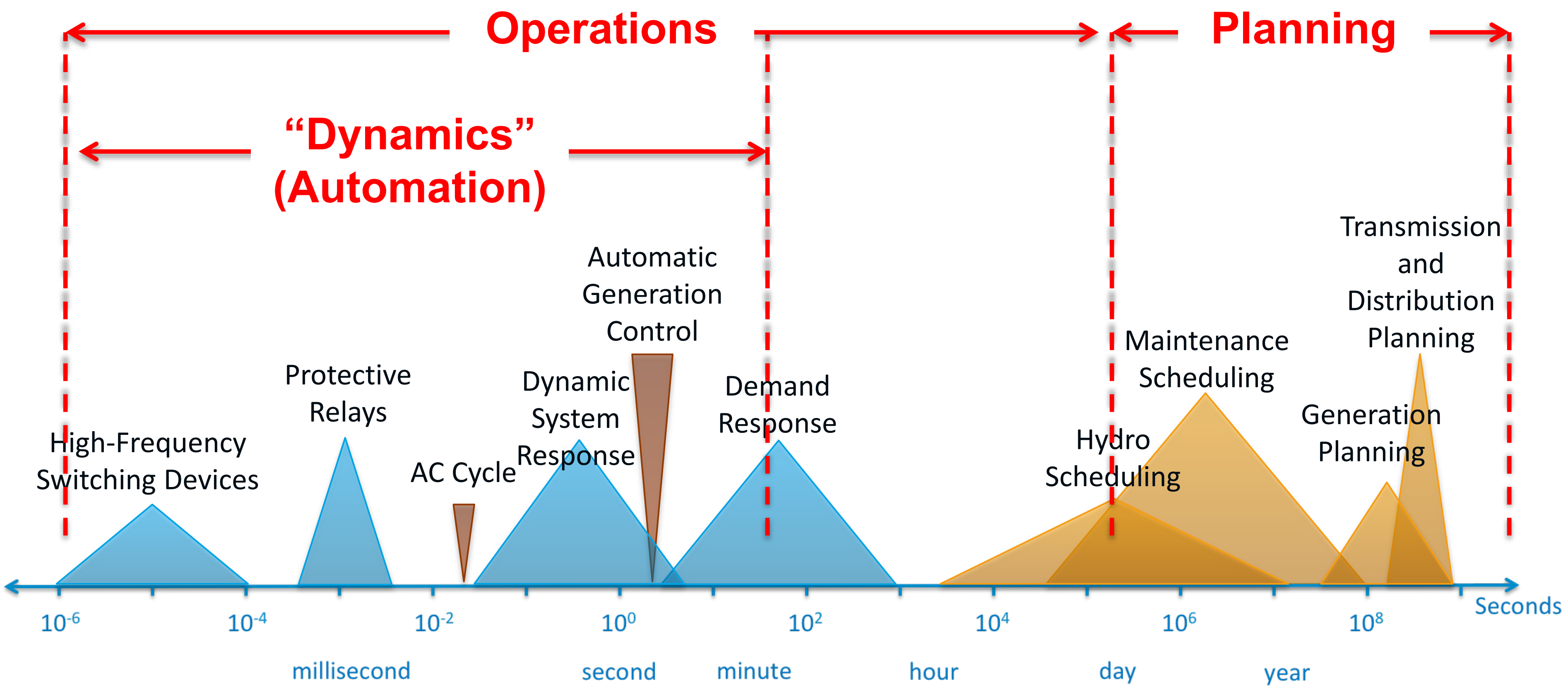

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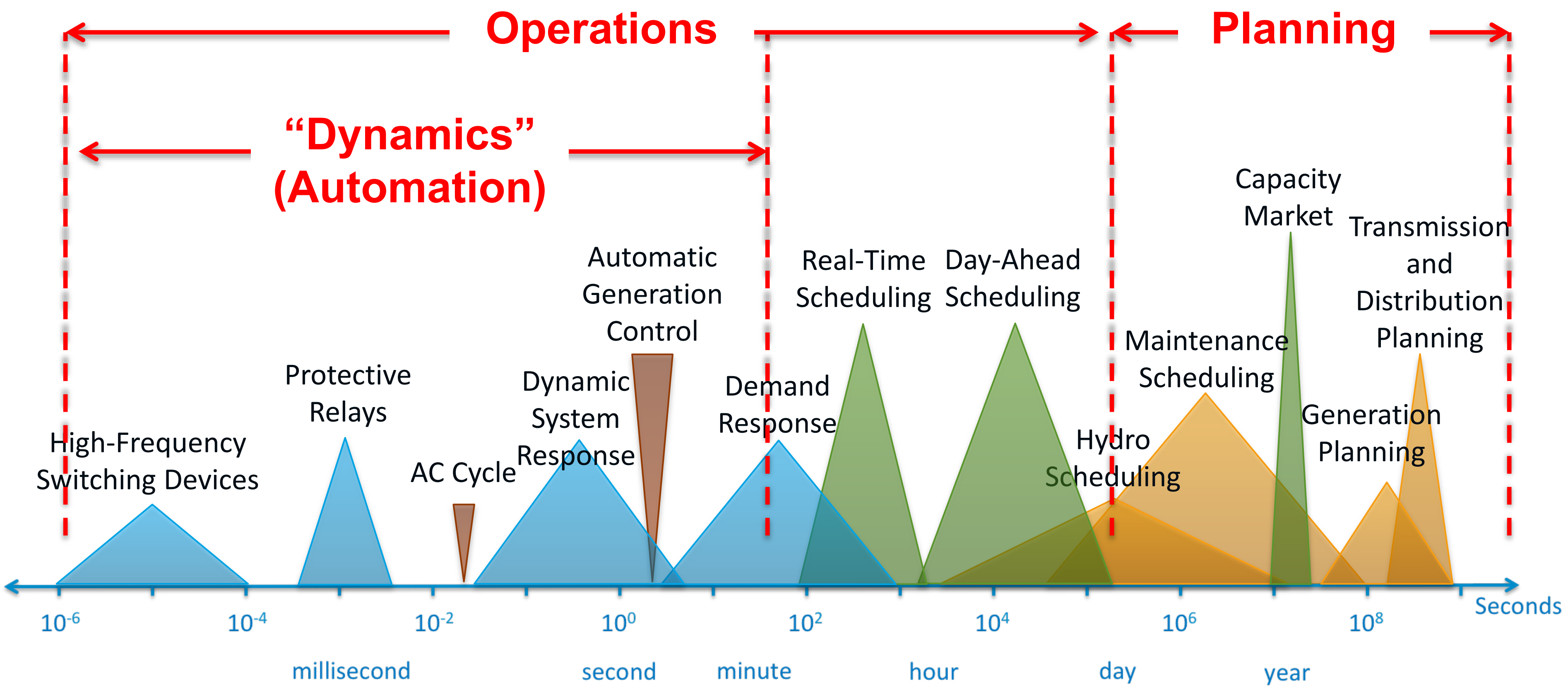

Adapted from A. Von Meier

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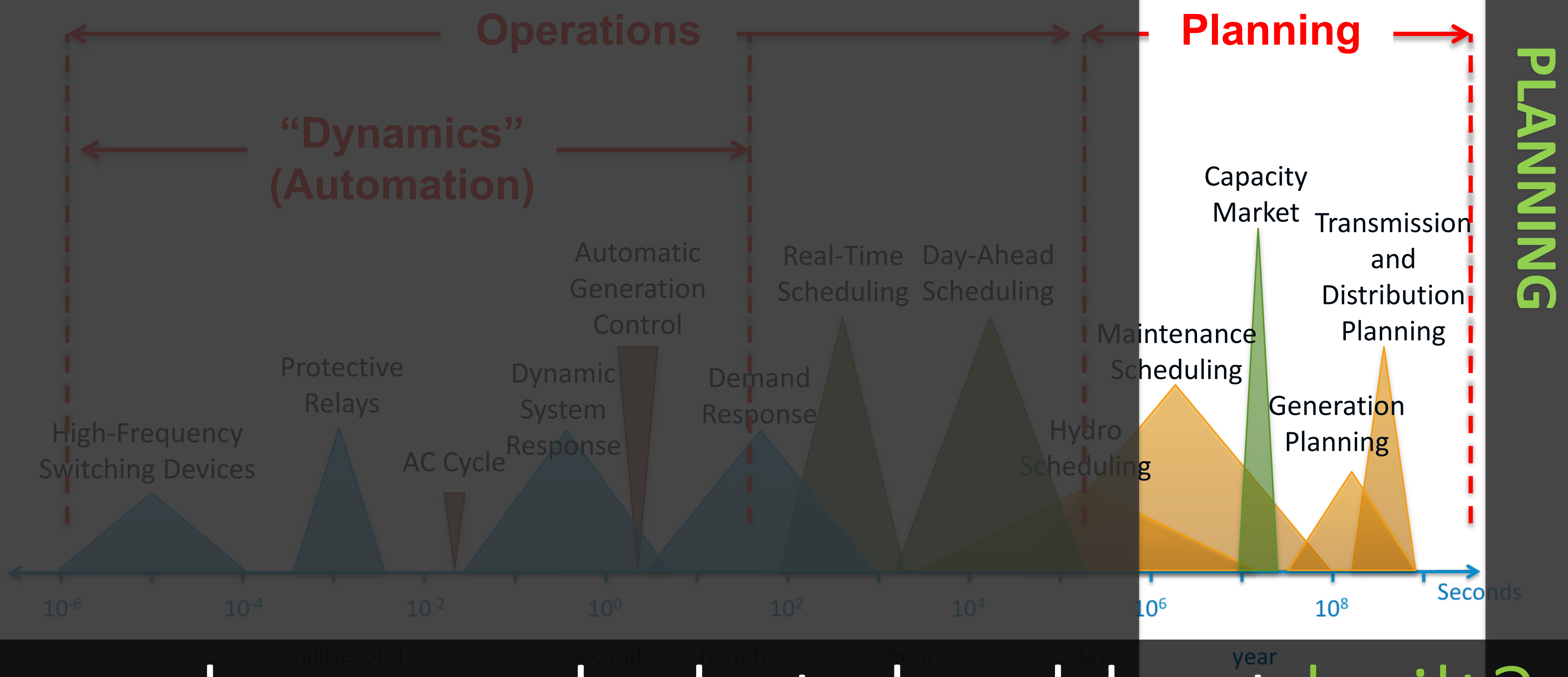
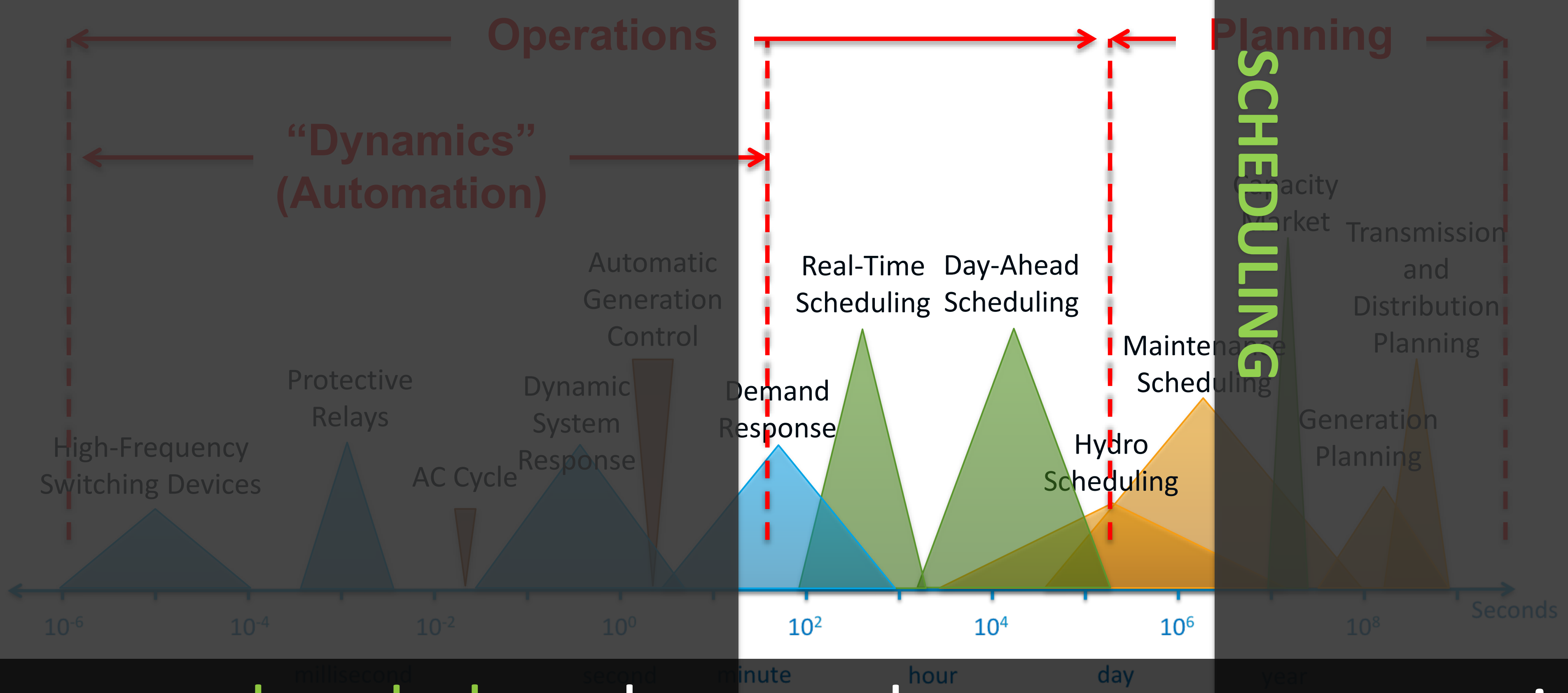


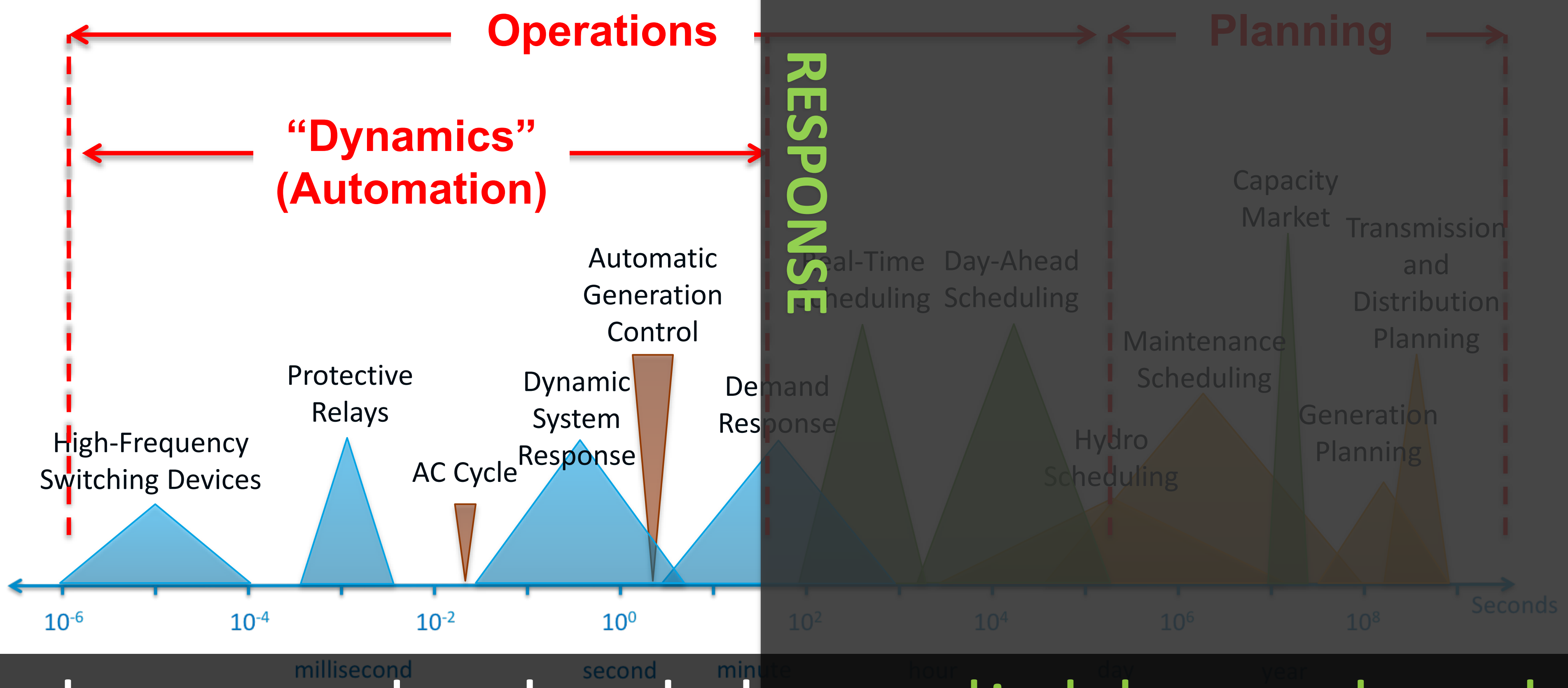
When, where, and what should get built?

Relevant grid decision timescales span 15 orders of magnitude



How to schedule planned system operations?

Relevant grid decision timescales span 15 orders of magnitude

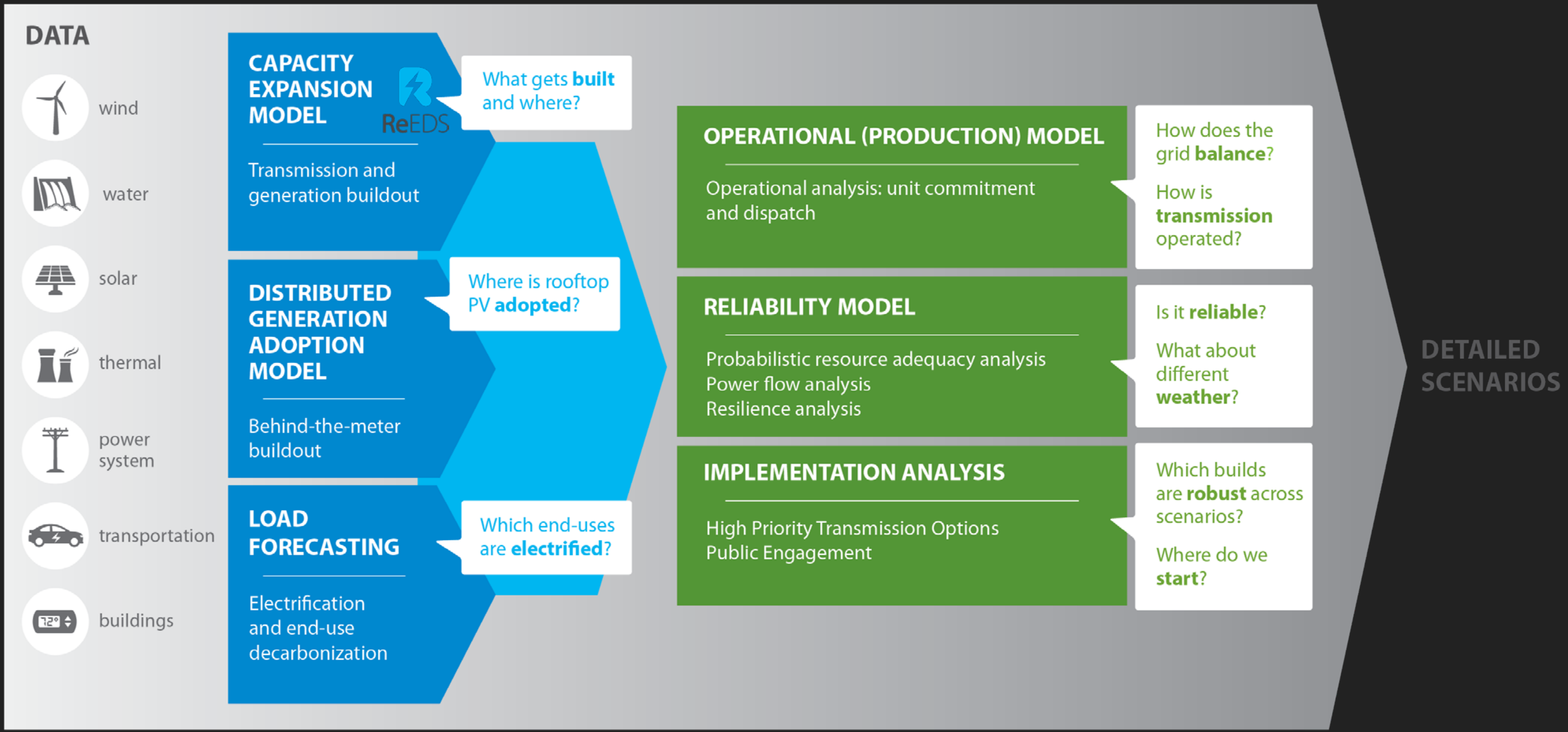


Are plans and schedules reliable and stable?

GPAC Integration Studies Rely on Multiple Linked Modeling Exercises

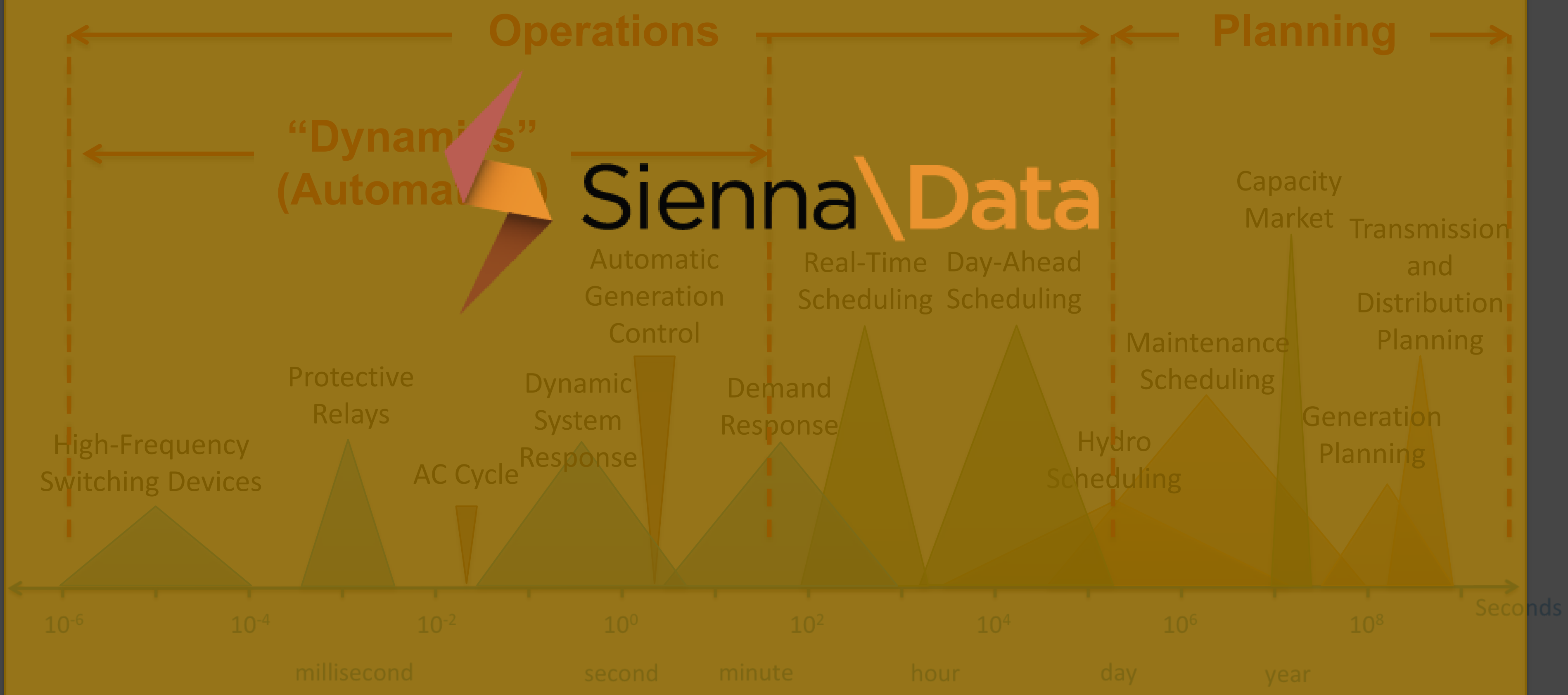
Scenario Refinement and Detailed Reliability Evaluations

Frame and Develop Scenarios



Sienna

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



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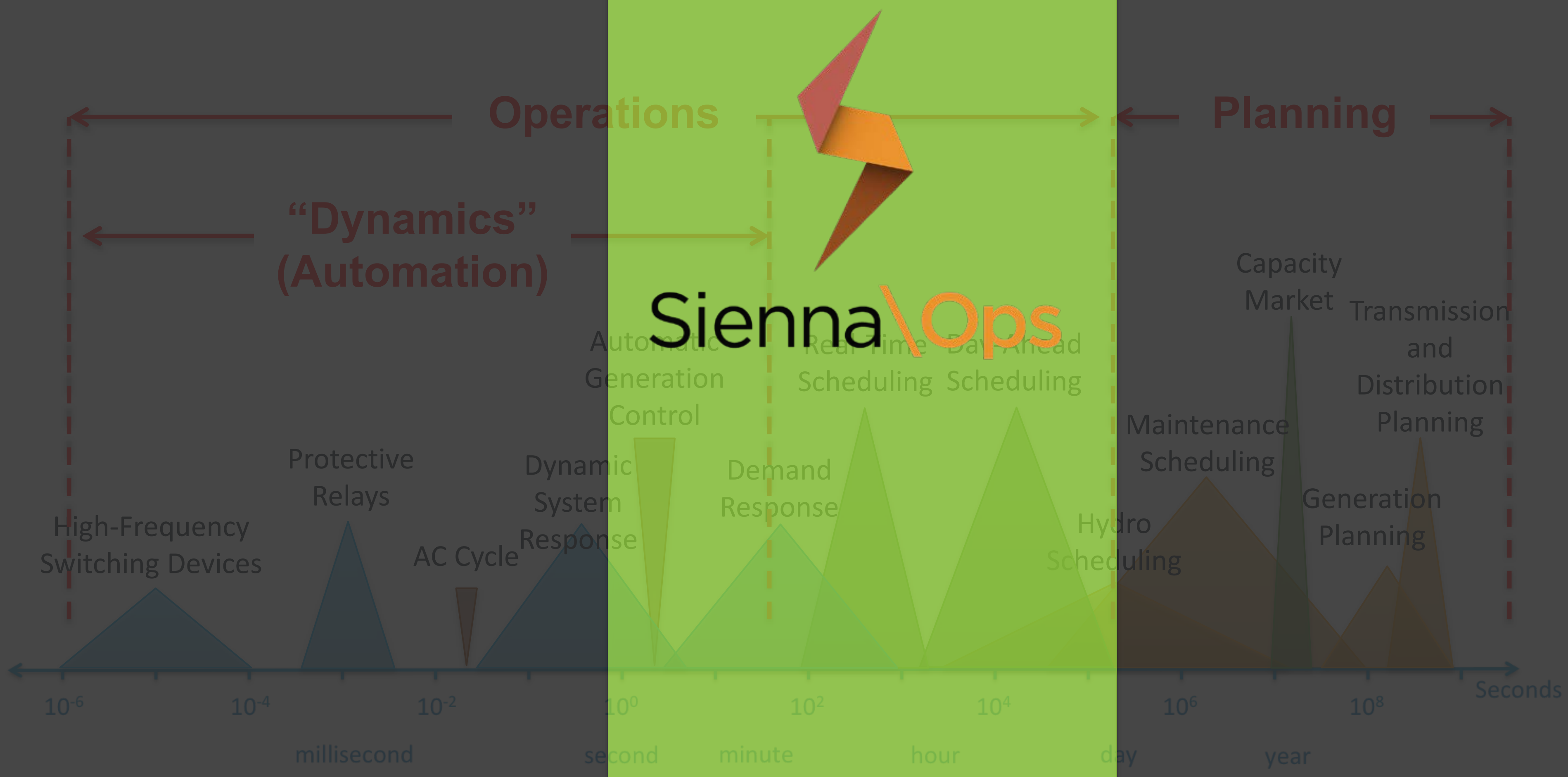
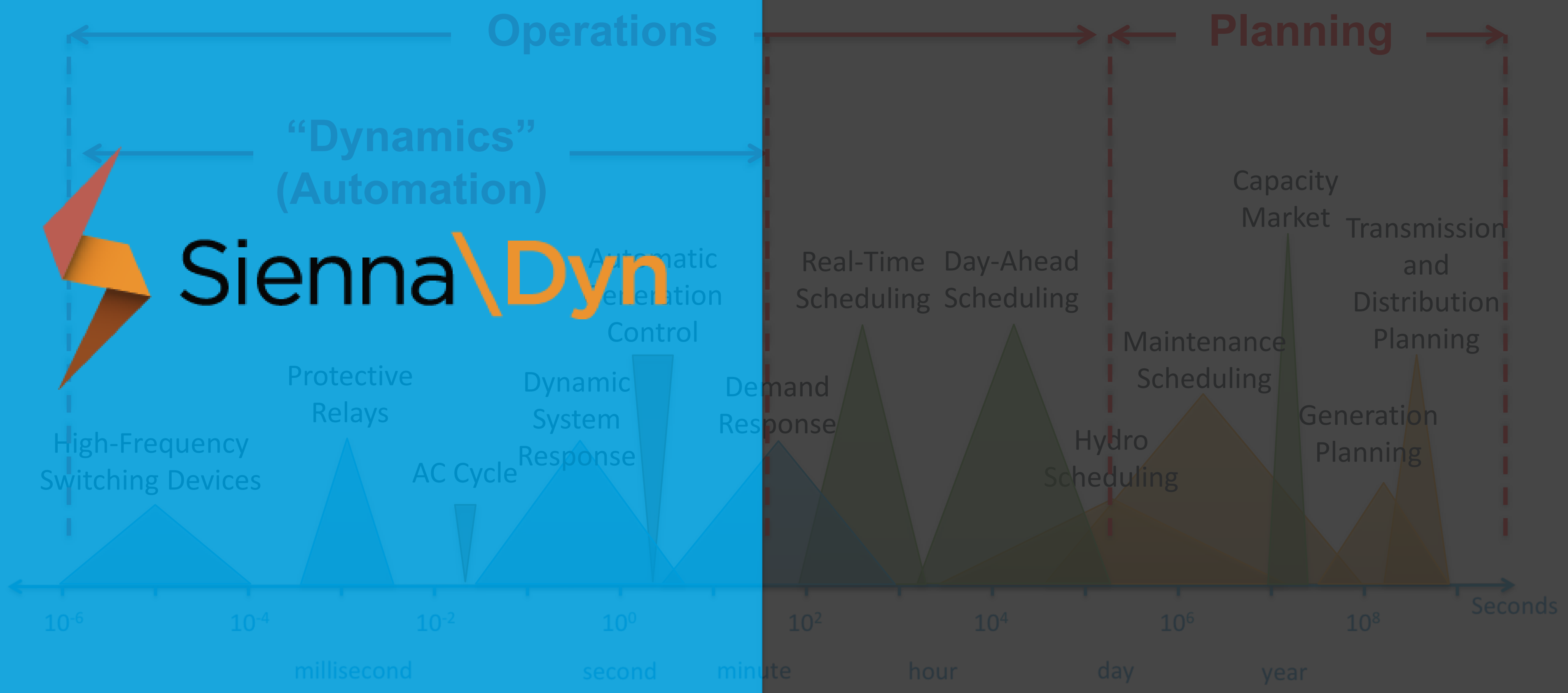


Adapted from A. Von Meier

Sienna\Dyn



Adapted from A. Von Meier

Use Cases

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

PR100

GMLC

Renewable Energy Initiative for Latin America and Caribbean (RELAC)

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

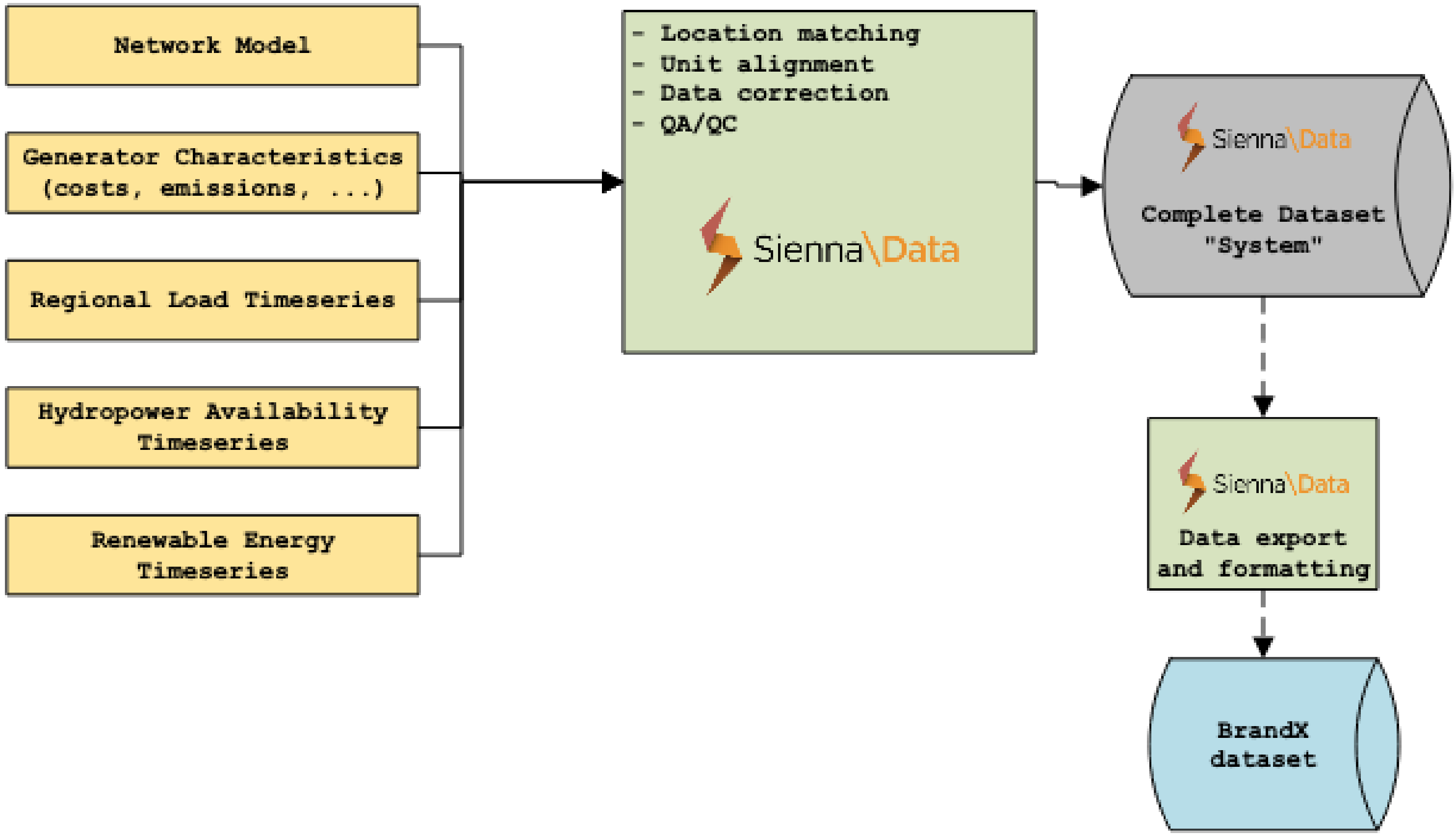
IDB Inter-American Development Bank · olade · NREL Transforming ENERGY · iea International Energy Agency · United Nations · IRENA International Renewable Energy Agency · LEDS LAC · giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH · WWF · JICA

Sienna\Data

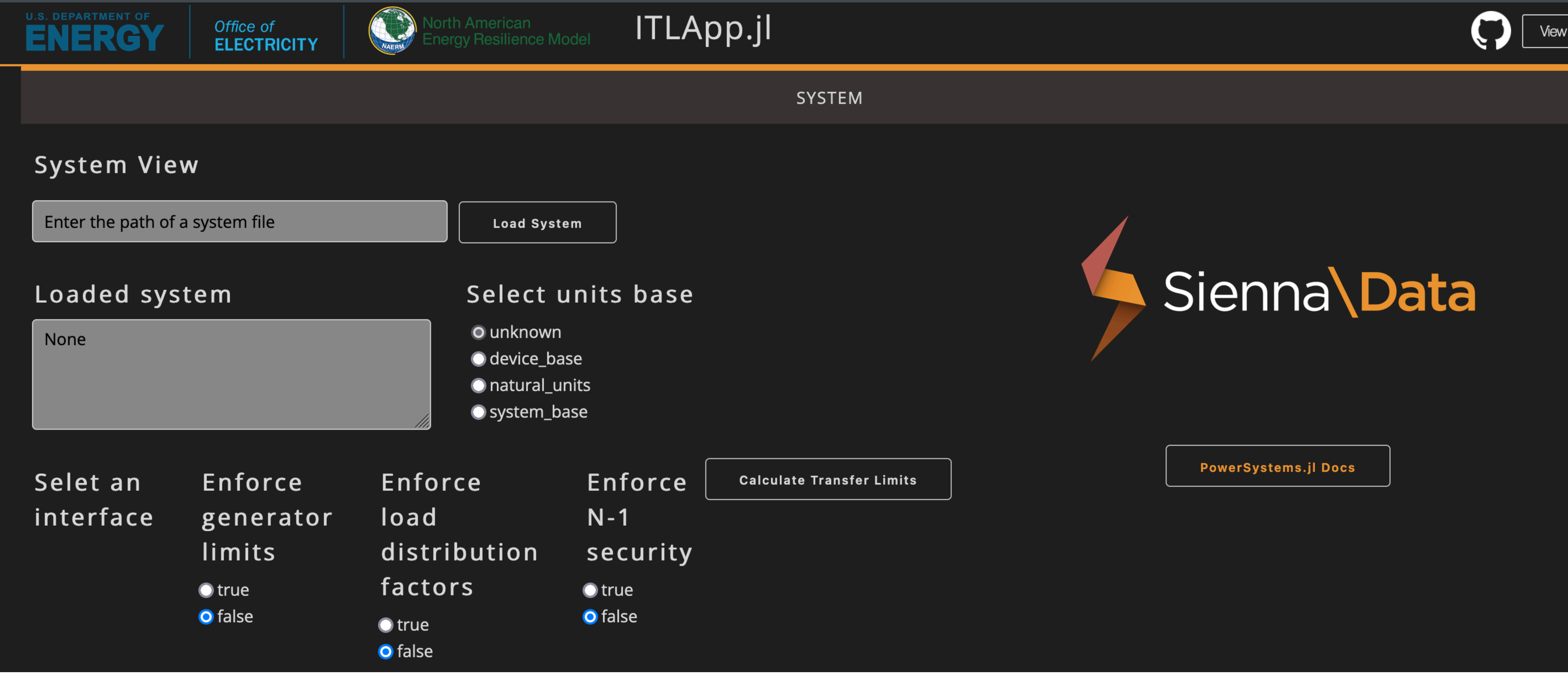
Efficient intake and use of power system data

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



Sienna\Ops

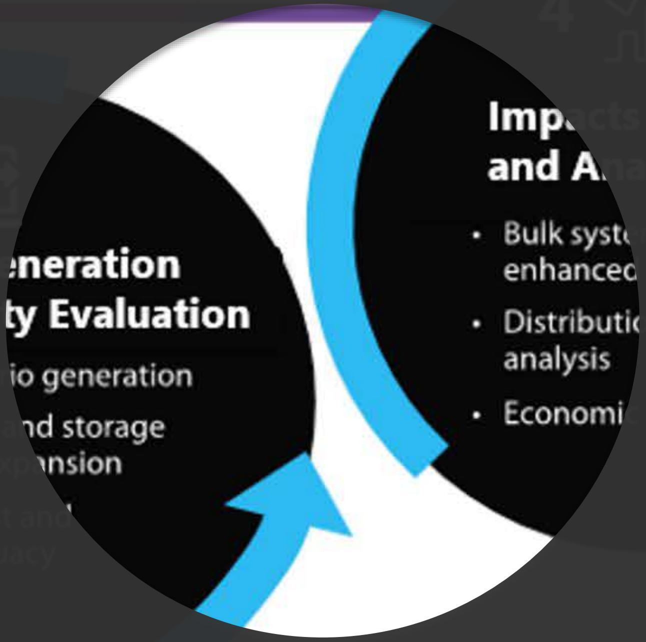
Simulation of system scheduling, including sequential problems for production cost modeling

Planning a Reliable Future for Puerto Rico

1 Responsive Stakeholder Engagement and Energy Justice

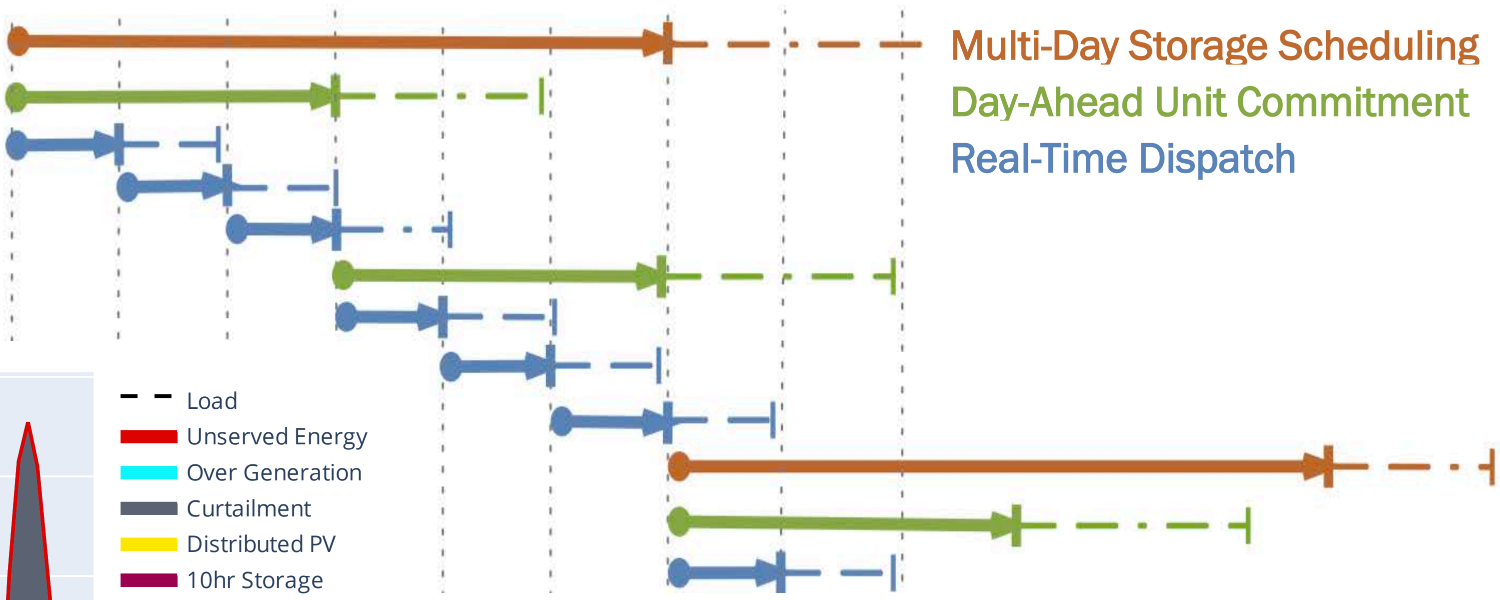
- Stakeholder engagement inclusive of procedural justice
- Energy justice and climate risk assessment

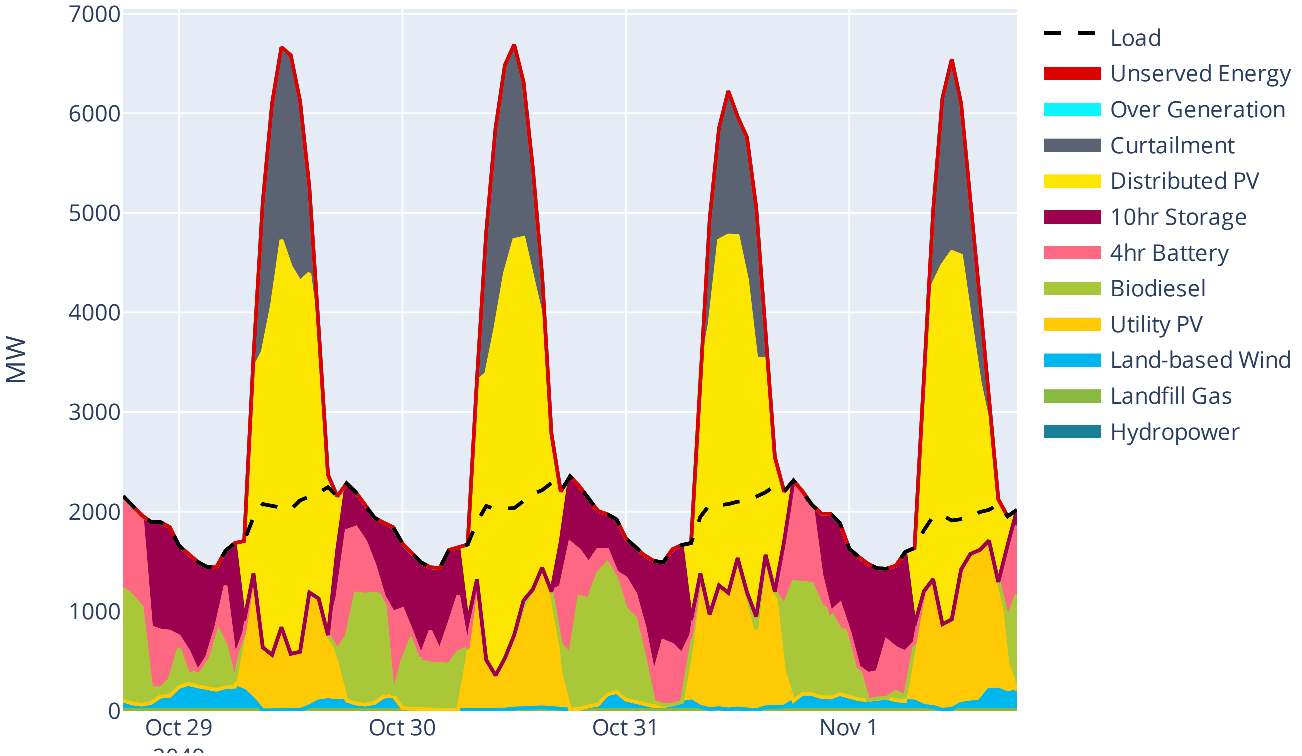
Sienna\Ops



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



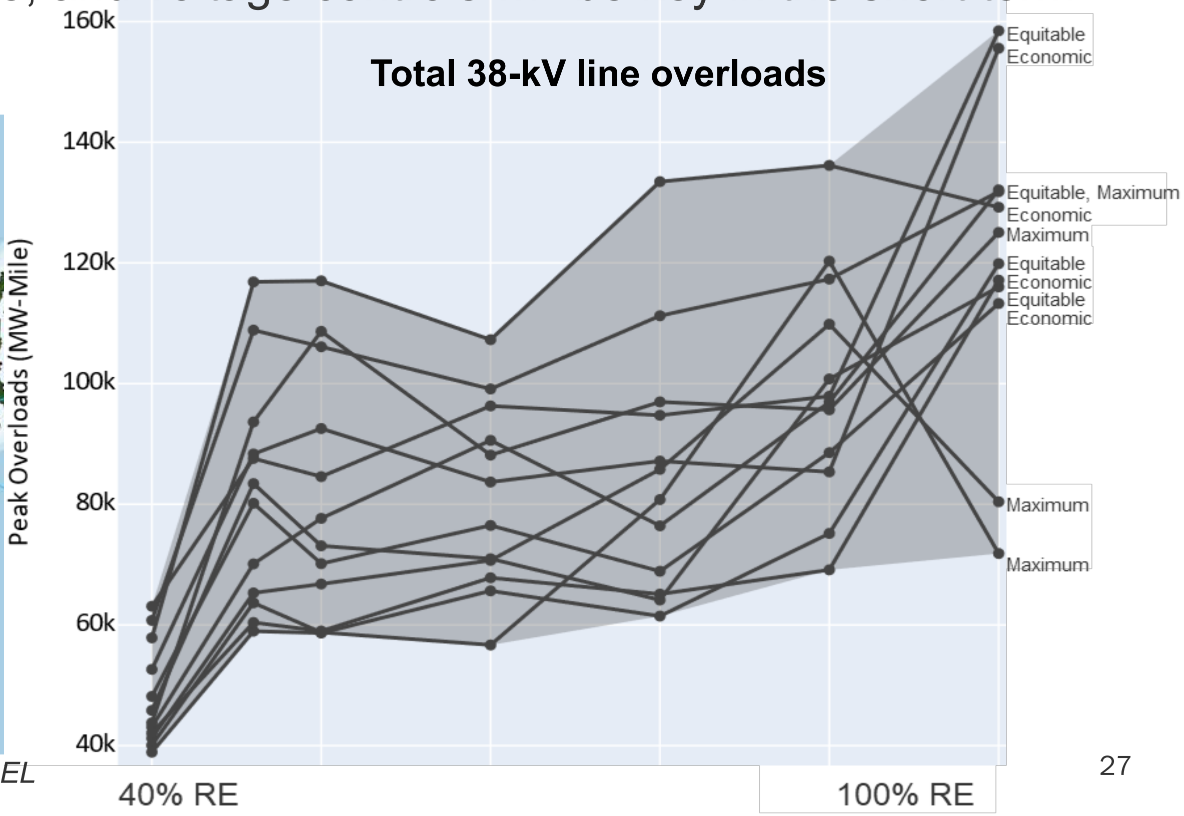


PR100 Simulations:

- 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

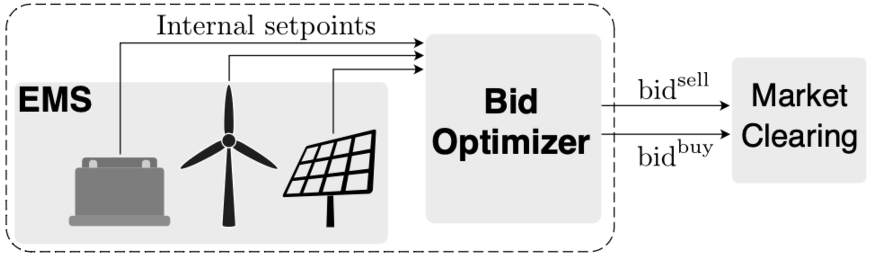
- The current 38-kV network is insufficient to handle the projected system with 40% renewables and is becoming more challenging for 100%.
- The lack of projected resource diversity will require significant operational changes to manage forecast errors.
- To mitigate large frequency deviations and contribute 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.

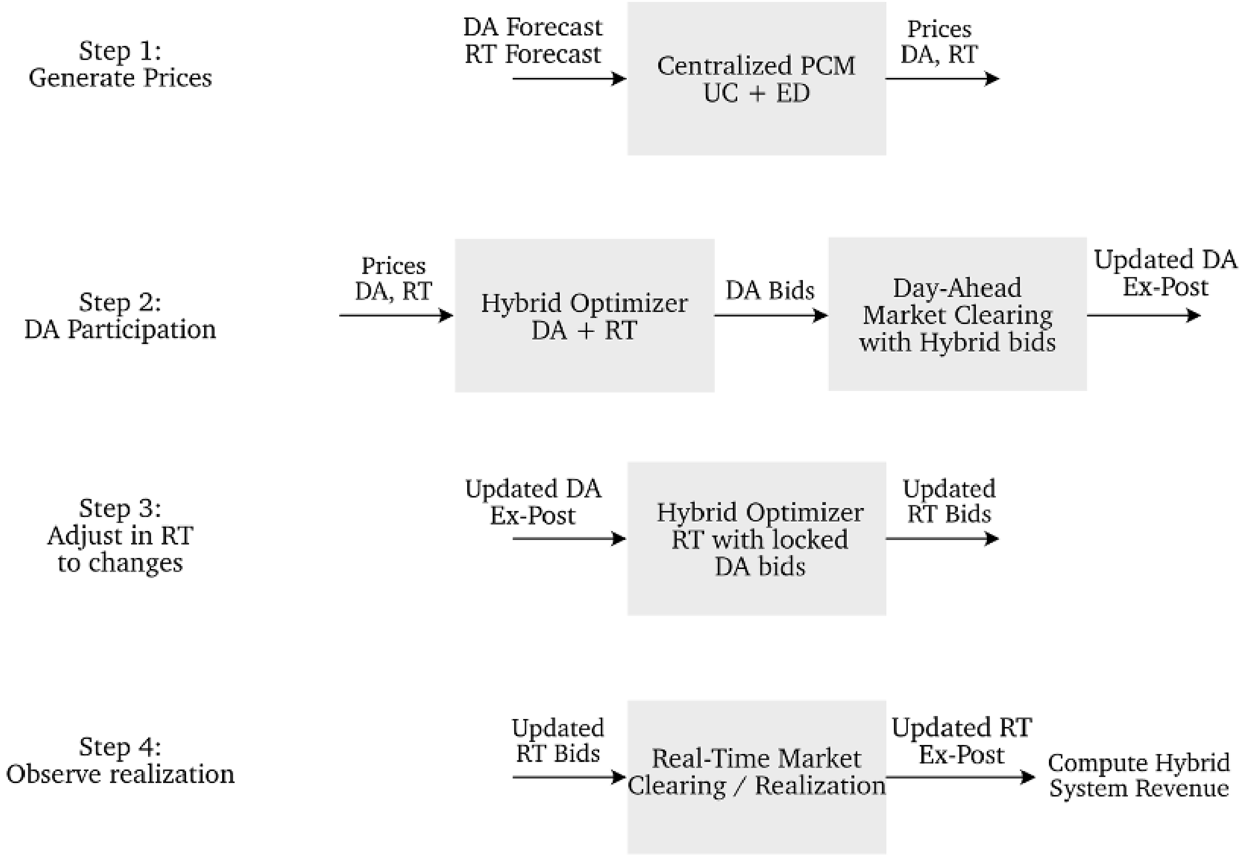


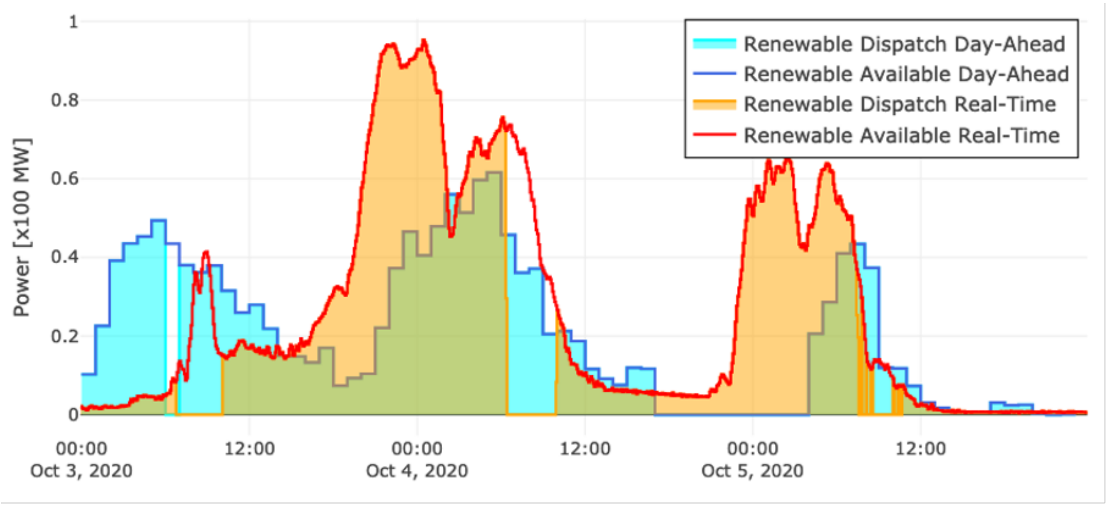
Source: Baggu, Murali, Robin Burton, Nate Blair, et al. (2024a)

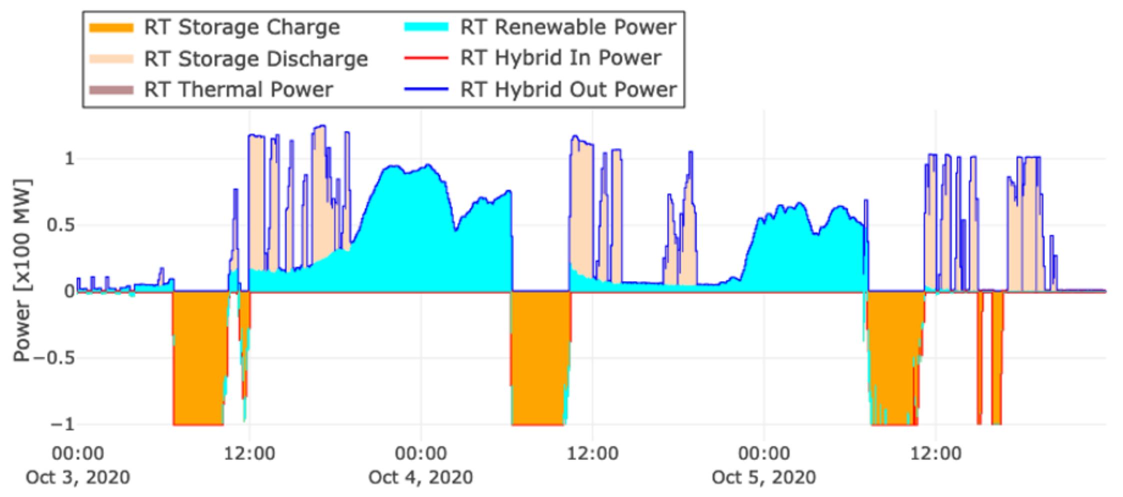
Graphics by NREL

Hybrid Power Plant Merchant Operations









Sienna\Dyn

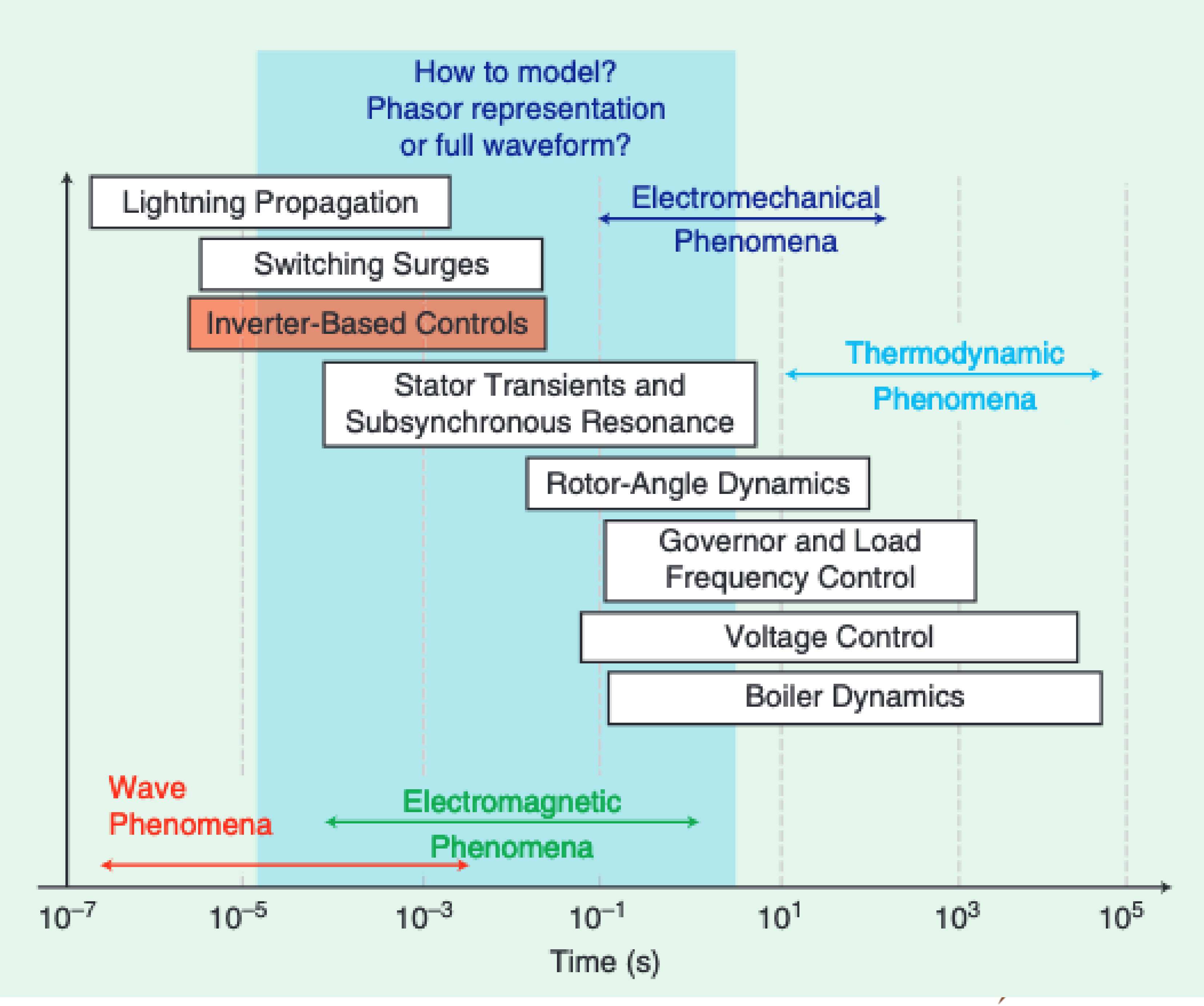
Simulation and modeling of inverter-based resource integration in power systems

Inverter-connected resources present new control opportunities

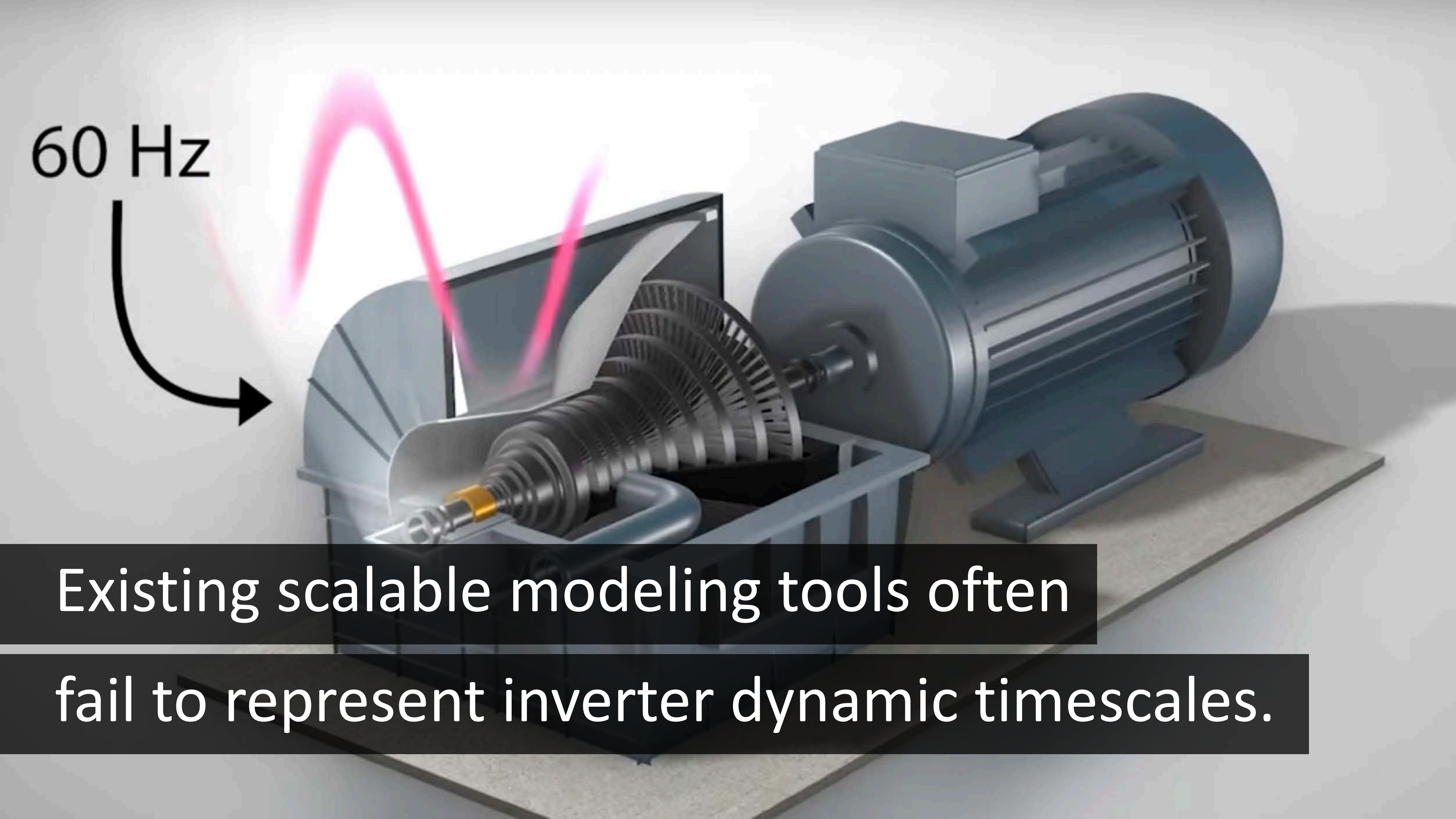
Sienna\Dyn
Dynamic response simulations

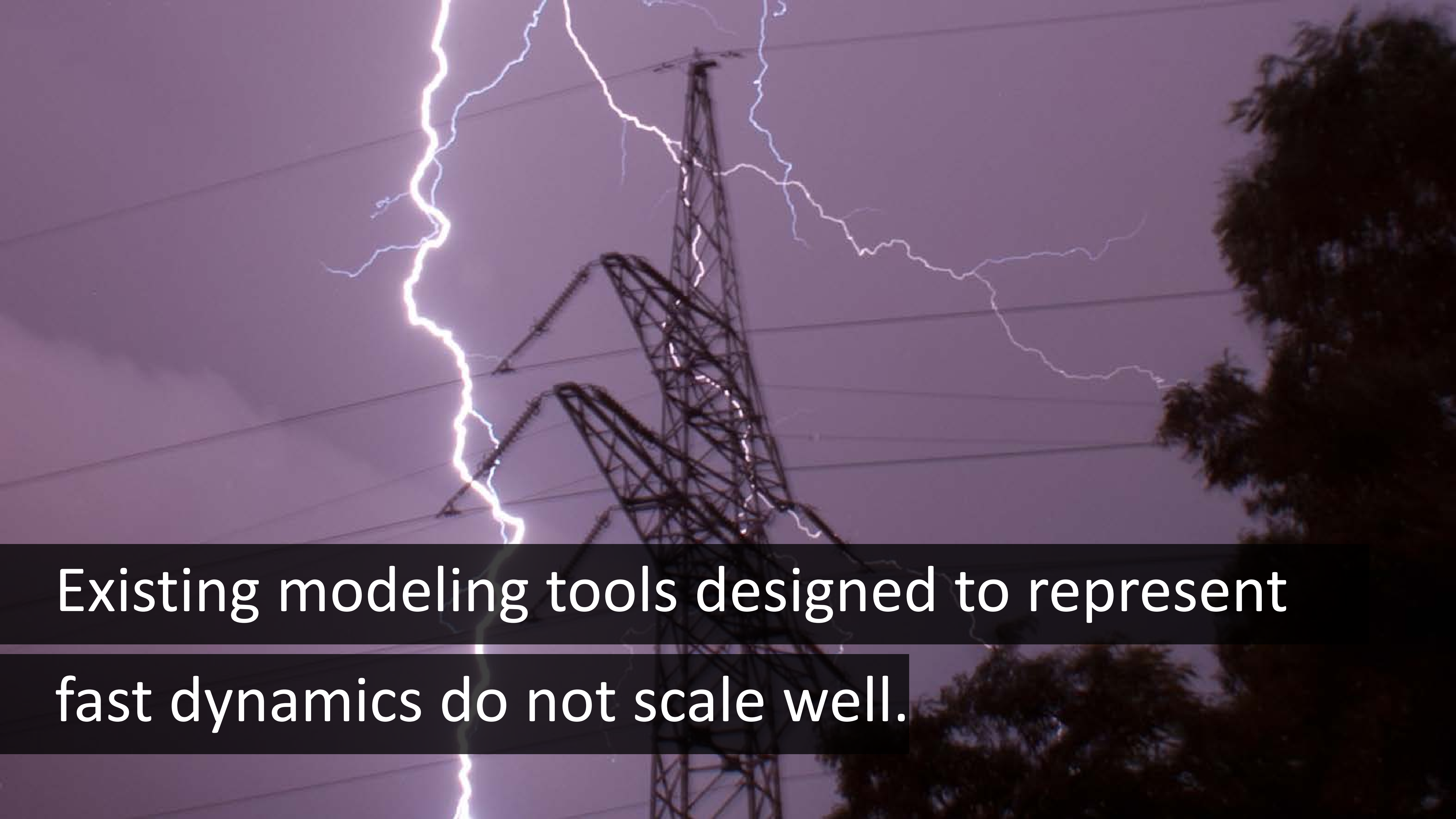
Inverter Connected Resources

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

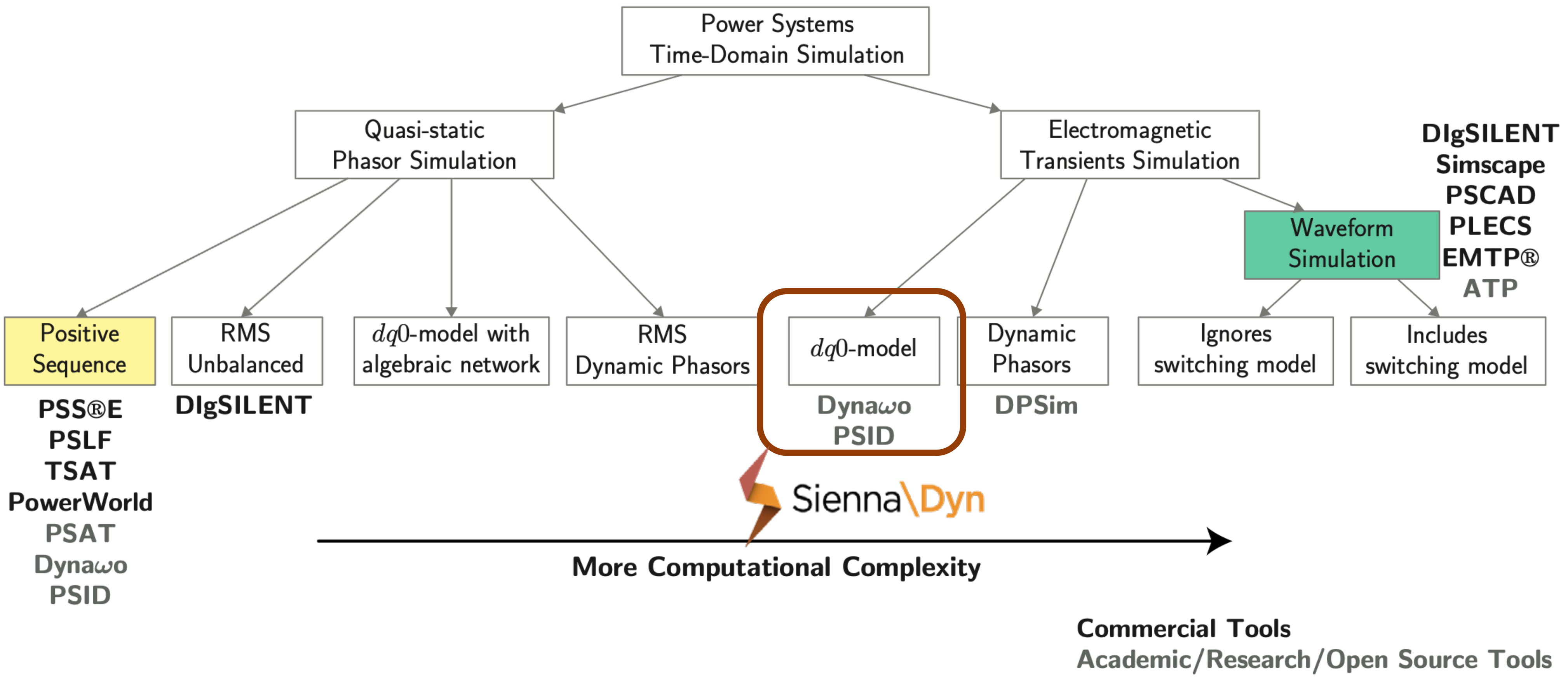


R. Henriquez-Auba, J. D. Lara, D. S. Callaway, and C. Barrows. 2021. "Transient Simulations With a Large Penetration of Converter-Interfaced Generation: Scientific Computing Challenges And Opportunities." *IEEE Electrification Magazine* 9(2): 72-82, June 2021. doi: 10.1109/MELE.2021.3070939.


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



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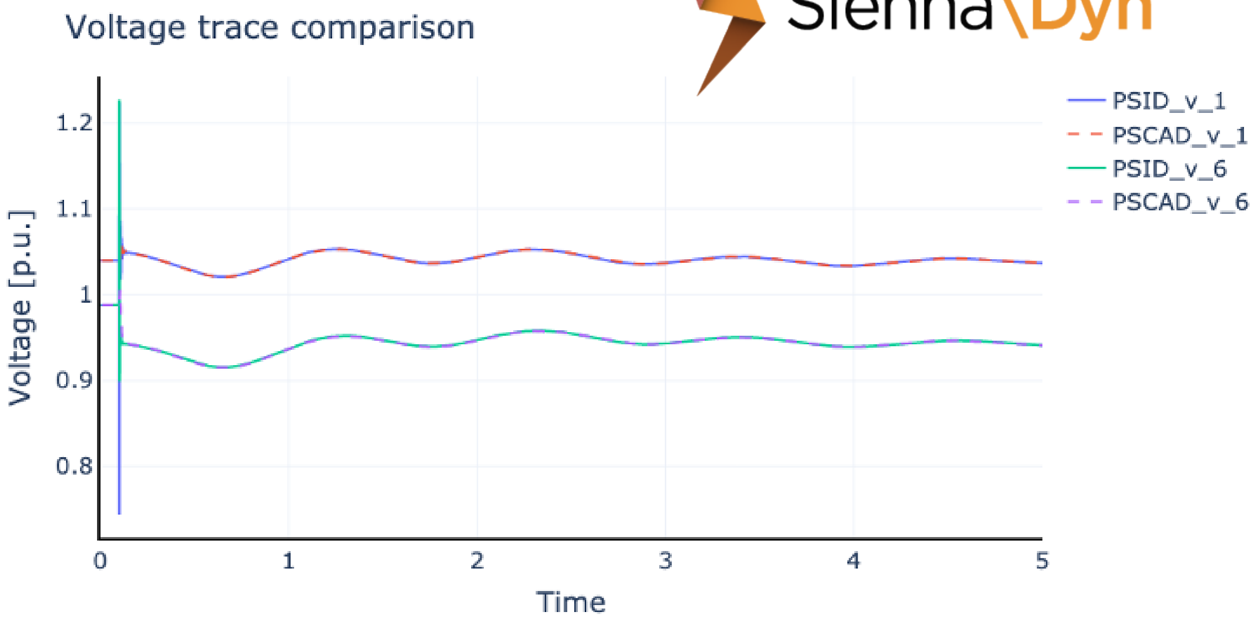
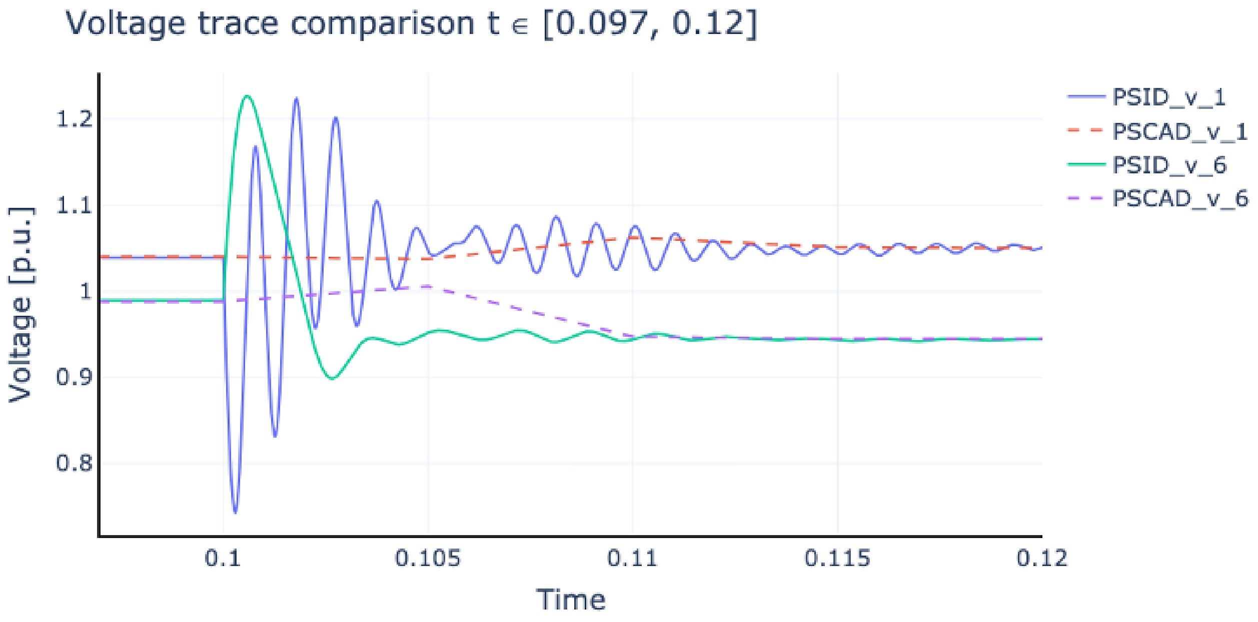
Same Conclusions, But Faster

- 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.

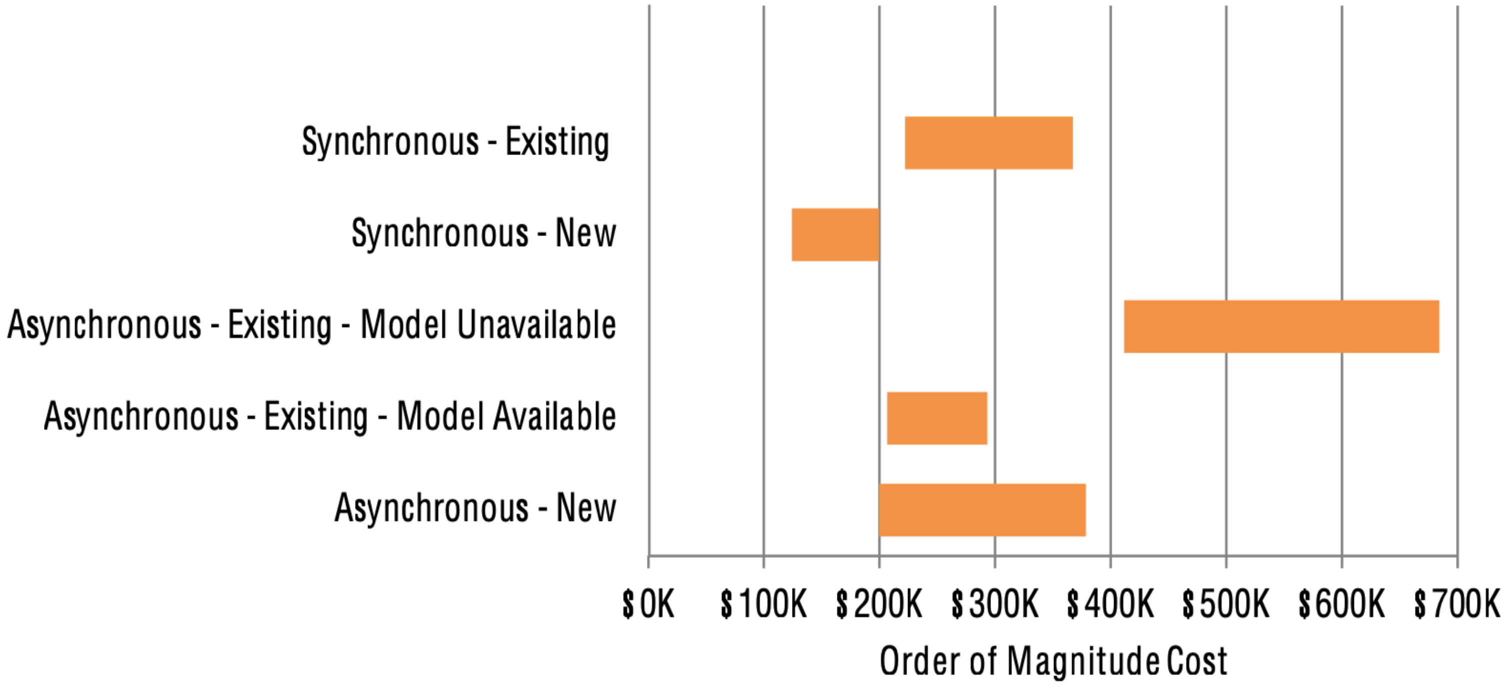
PSCAD Init	PSCAD run	FBDF	IDA
37269 (s)	49709 (s)	2665 (s)	69 (s)

*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

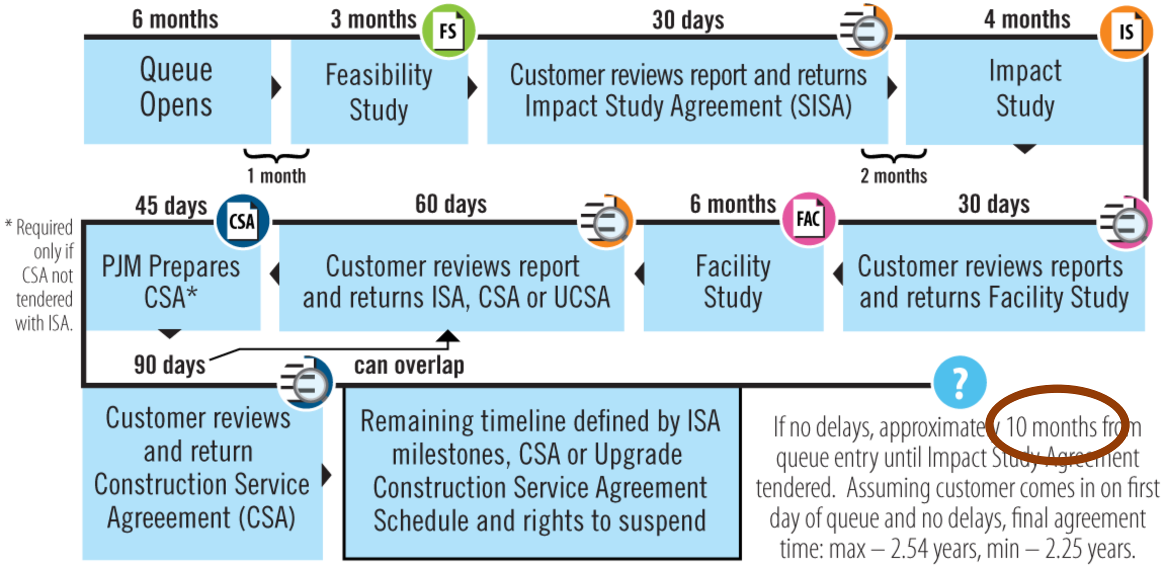
Sienna\Dyn

The Interconnection Process Is Broken

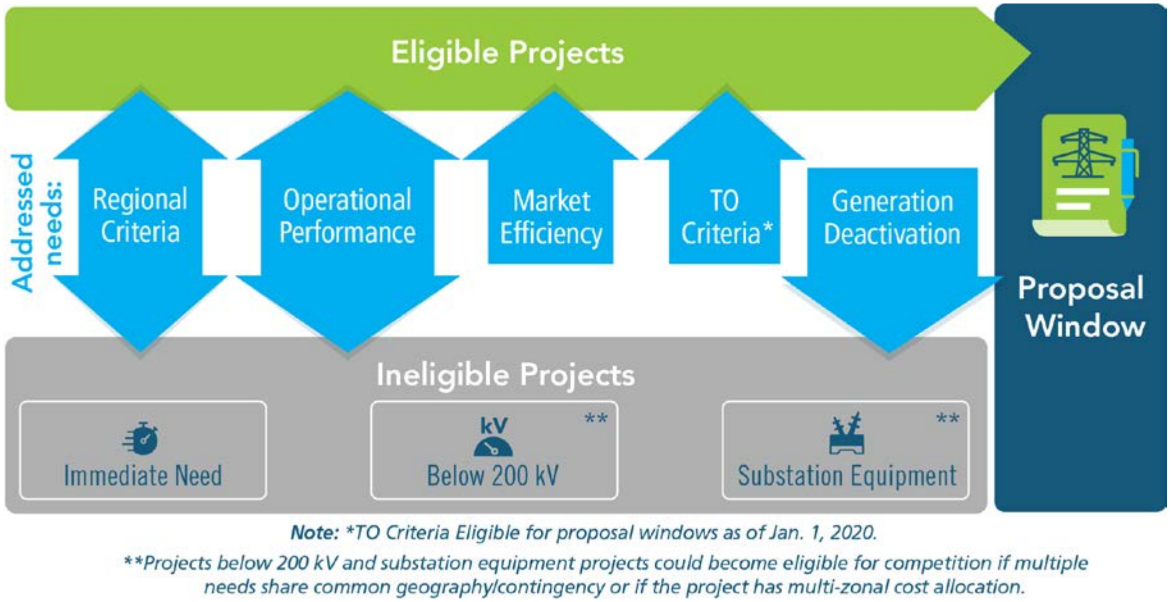
- Queue generation (~2.5 years*)
- Delays are common based on modeling/engineer availability
- Adjustments require revision of lengthy modeling processes.

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.

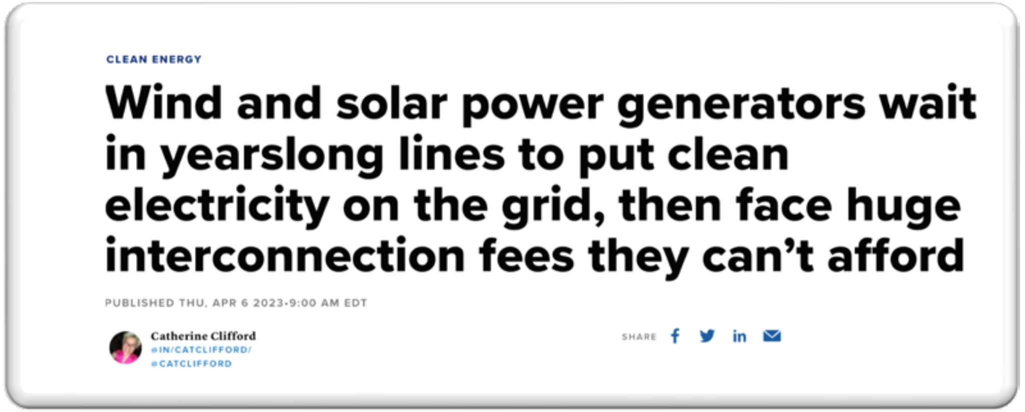


Source: PJM



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 disproportionally 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

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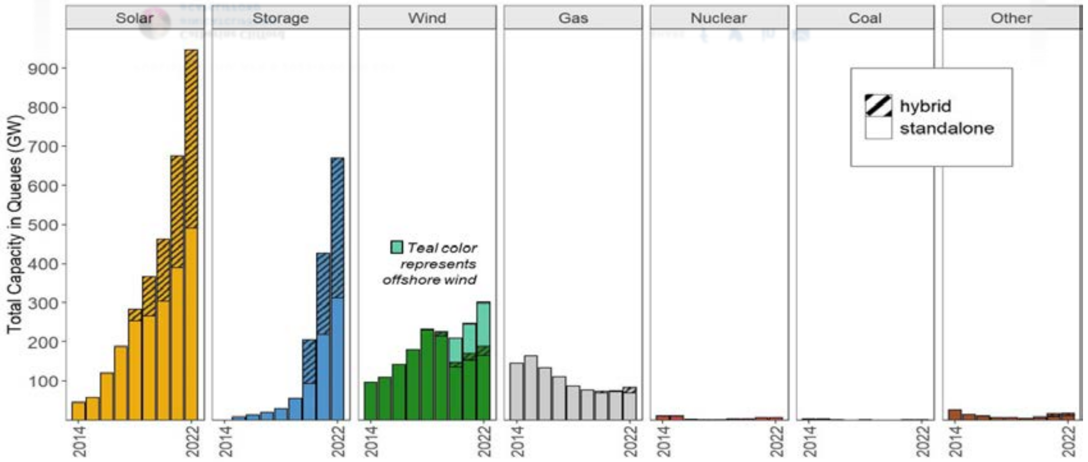

- Identify costs of maintaining reliability
- The process **relies** ***heavily*** **on simulations** and stress tests
- Historically a sequential process assuming that every new unit added to the system maintains stability
- IBRs challenge these assumptions – more simulations will be needed and with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

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