Introduction to Electromagnetic Transient Simulations

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ENERGY SYSTEMS INTEGRATION GROUP

Acknowledgement of Multiple Software Tools

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There are multiple commercially available Electromagnetic Transient (EMT) Software available currently

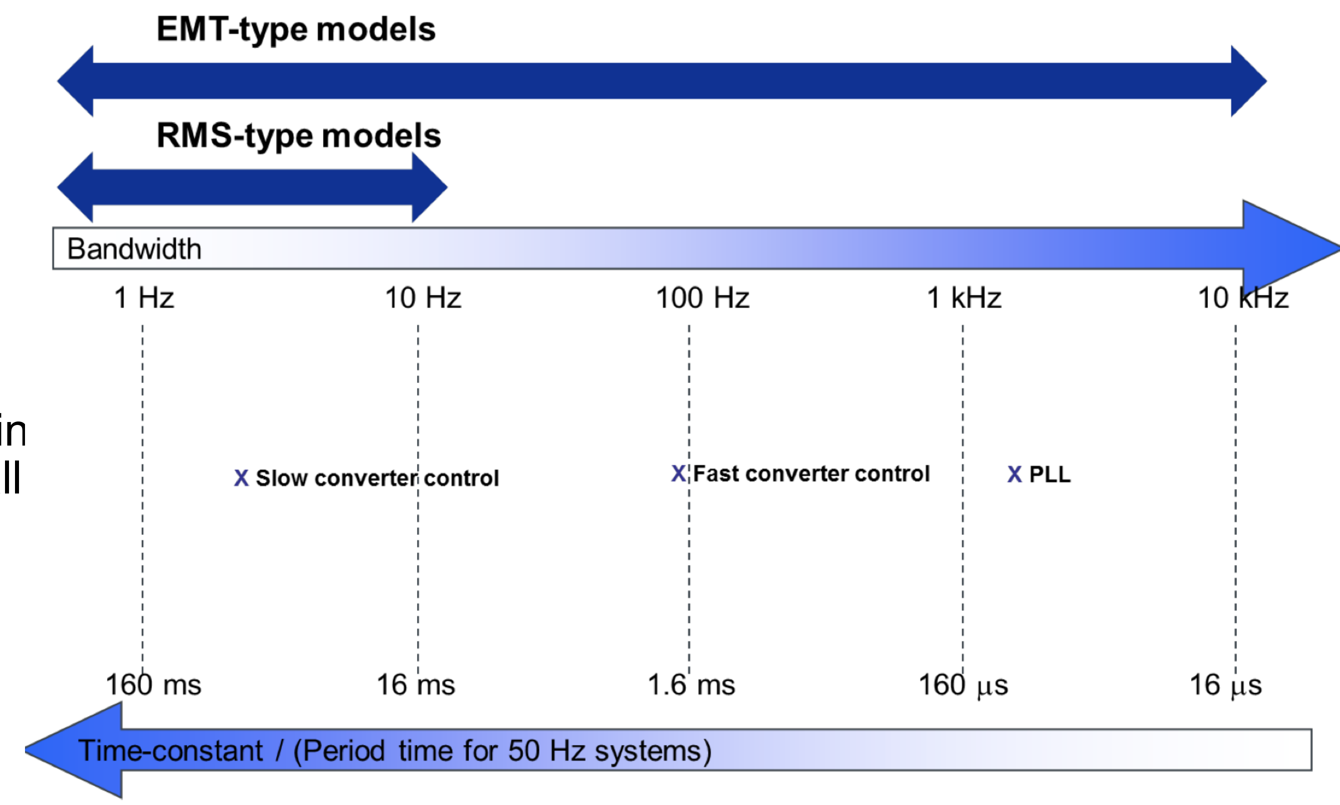
Wednesday and Thursday will include demonstrations in one EMT software but this is not an endorsement of this software, please use the software tool that best aligns with your needs

Throughout this week (and in general in public discussions) please refer to any EMT software tools as ”EMT” or similar and try to refrain from using brand names in any discussions

PSPD vs EMT Basics

Both PSPD and EMT have great use cases and limitations

- **PSPD:**
  - Solution is based on phasor calculations
    - Quick simulation time to provide insight into power flow, voltage, and current
  - Assumes a quasi-steady state and sinusoidal balance
- **EMT:**
  - Solves differential equations in the time domain and resolves the actual waveform at very small time intervals
  - Does not assume sinusoidal balance and captures:
    - Unbalanced faults
    - Very fast control behavior
    - Resonances



Source: AEMO

PSPD vs EMT Generally

PSPD

- Short simulation times
- Less detailed and accurate*
- “Sledgehammer” of current study paradigm
- More Generic/Standard Library than Manufacturer-specific
- Can be difficult to map to real-world parameters
- Limitations at low “system strength”

EMT

- Significantly longer simulation times
- More detailed and accurate*
- “Scalpel” of current study paradigm
- Most often Manufacturer-specific
- Often easier to map to real-world parameters
- Fewer limitations at low “system strength”
- Can be used to study harmonics, SSCI/SSR

How Is The Power System Changing?

- **System inertia or “system strength” is reducing**
  - ***All assumptions must change***
- Frequency perturbations will be larger and happen faster (Rate of change of Frequency (ROCOF) increase)
  - Higher ROCOF means its harder to establish and remain within limits
- System voltages will be “less firm”
  - With lower system strength, each change in reactive power will cause a larger change in voltage
- **More complex resources are interconnecting**
  - Hybrid, mixed manufacturer, supplementary controls and devices
- **EMT simulations (and PSPD simulations**) are paramount represent increasingly complex resources on “weakening” system**

Power System is Changing: Timeframe

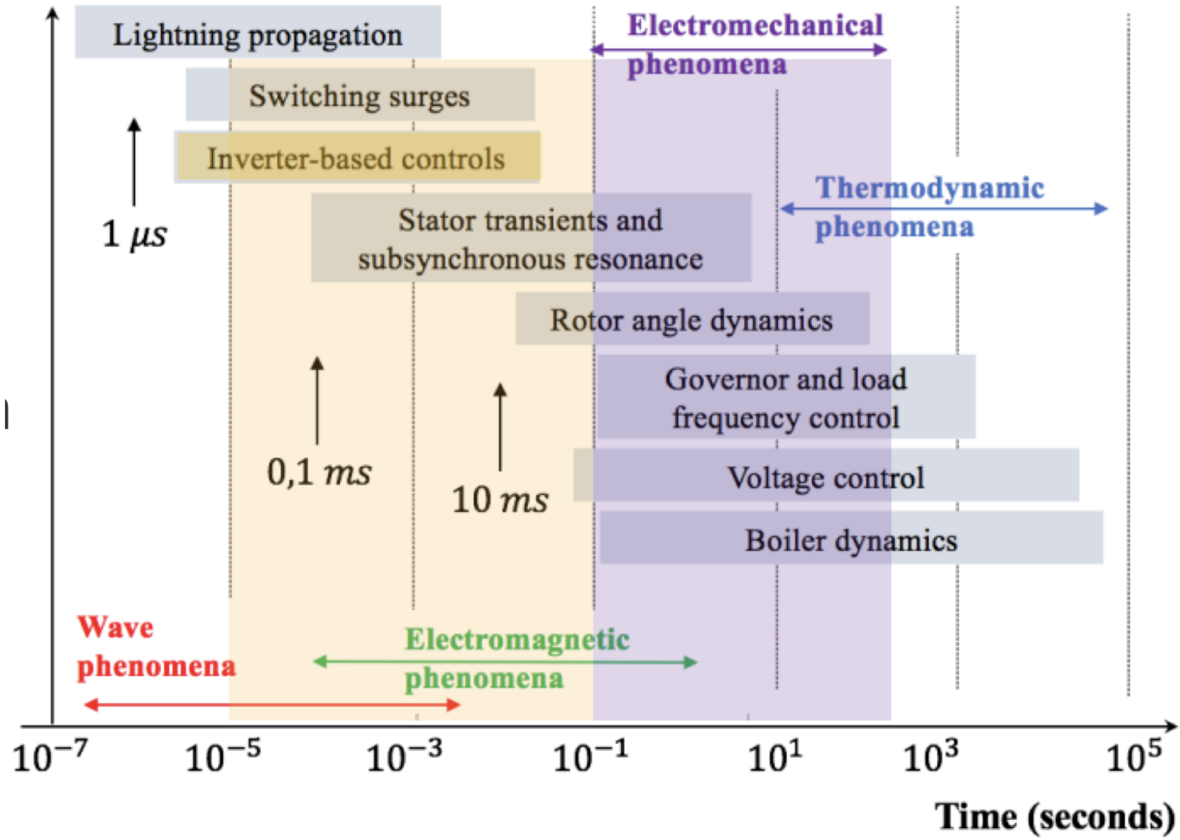
- **IBR bring extremely fast controls driven by power electronics and software**
  - Performance is significantly more decoupled from physical behaviors when compared to synchronous machines
  - Software-based controls and power electronics significantly increase the speeds and magnitudes of response
- **IBR controls will get even faster**
  - With increased penetrations of grid forming inverters, overall timeframe will become faster

Differences between Inverter-Based Resources and Synchronous Generation

Inverter-Based Resources	Synchronous Generation
• Driven by power electronics and software	• Driven by physical machine properties
• No (or little) inertia	• Large rotating inertia
• Very low fault current	• High fault current
• Sensitive power electronic switches	• Rugged equipment tolerant to extremes
• Very fast and flexible ramping	• Slower ramping
• Very fast frequency control	• Inherent inertial response
• Minimal plant auxiliary equipment prone to tripping	• Sensitive auxiliary plant equipment
• Dispatchable based on available power	• Fully dispatchable
• Can provide essential reliability services	• Can provide essential reliability services

Power System is Changing: Timeframe

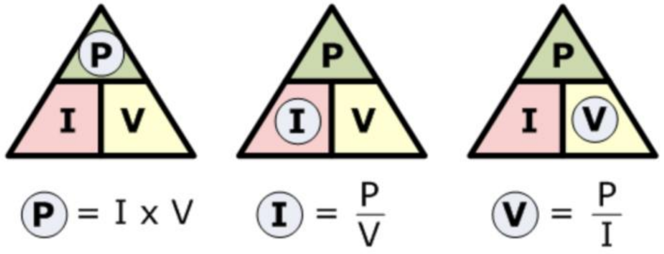
- Relevant control and time constants in a synchronous generator-dominated system fall within the electromechanical window
- Relevant controls and time constants for IBR are significantly faster and encompass the **electromagnetic** window
- **As more IBR integrate with the system:**
  - System stability becomes more dependent on faster controls
  - Fast transients and responses to those transients play larger roles in reliability
  - The system response overall becomes faster



Source: GPST

Power System is Changing: System Strength

- **Synchronous machines provide inertia to the power system**
  - Large spinning masses have momentum and resist changes
  - Power-electronics resources decouple the mechanics from power injection (type 1-3 wind need consideration)
- **Fault current is provided by this momentum**
  - During system disturbances voltage drops
  - Synchronous generator inertia continues to provide power



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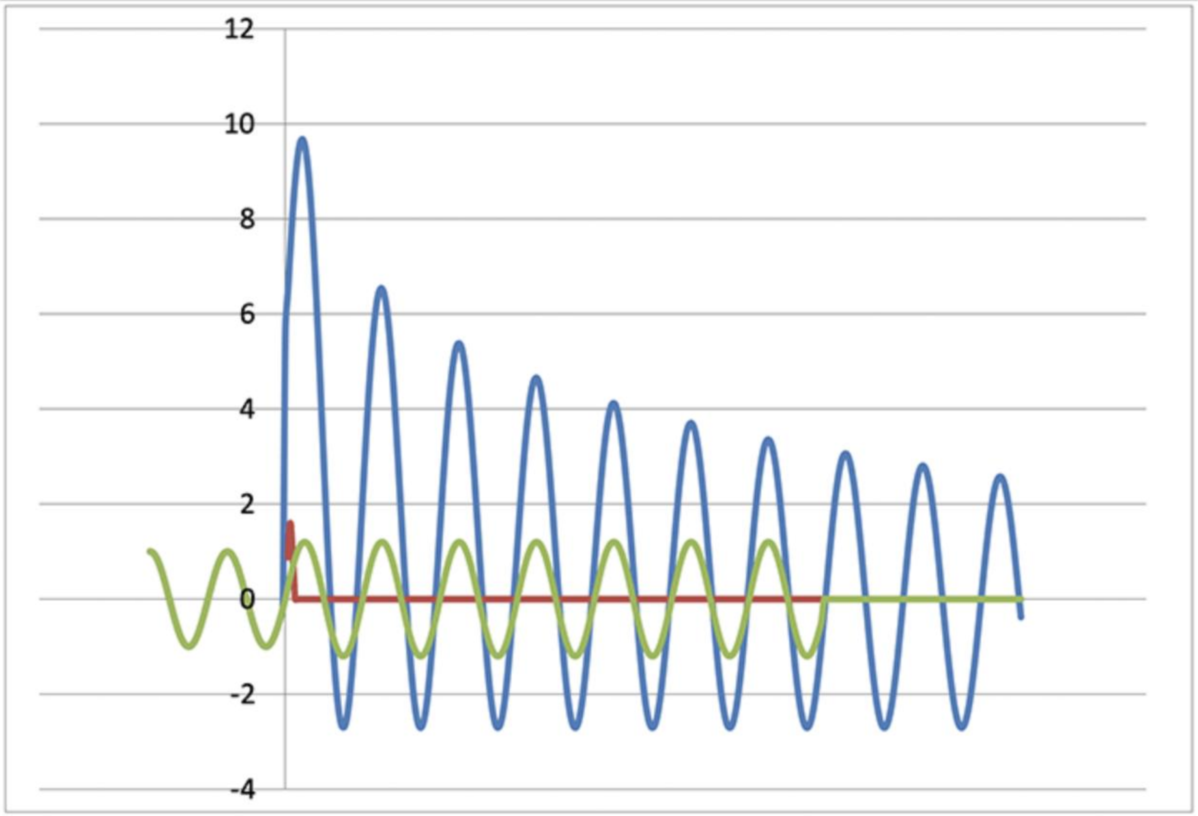
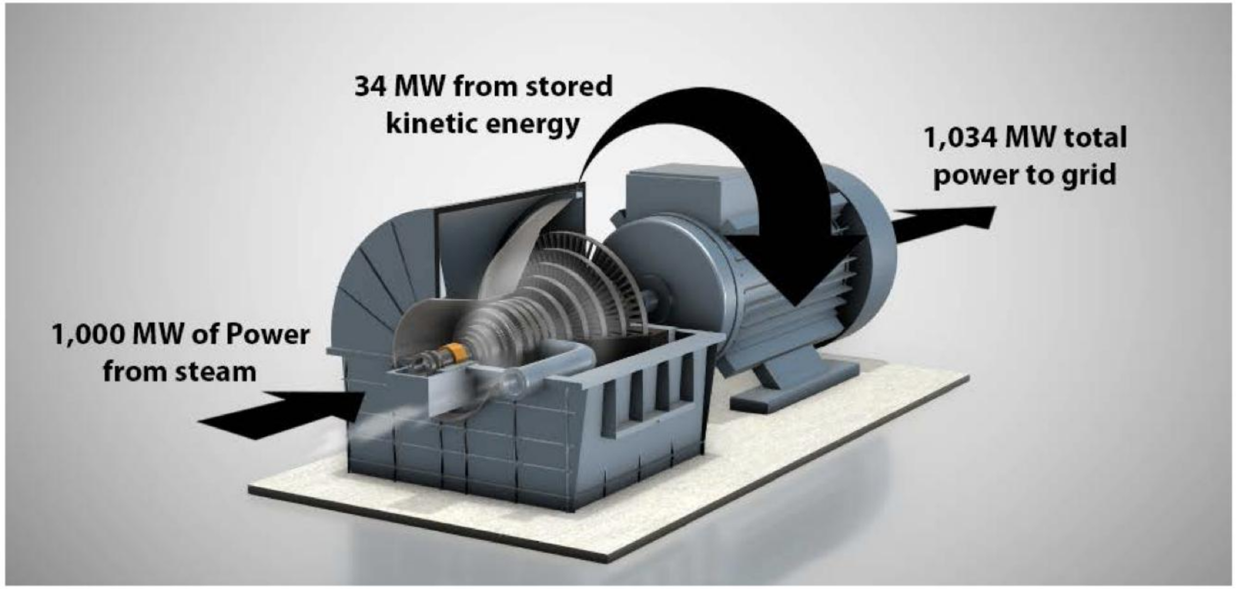
Source: ElectronicsTutorials

Short Detour to System Protection



Fault currents for a synchronous generator (blue), an inverter with rapid disconnect (red), and an inverter with ride-through capability (green).

- **Detailed and high quality EMT protection models and studies have the potential to help solve this problem**



Source: NREL

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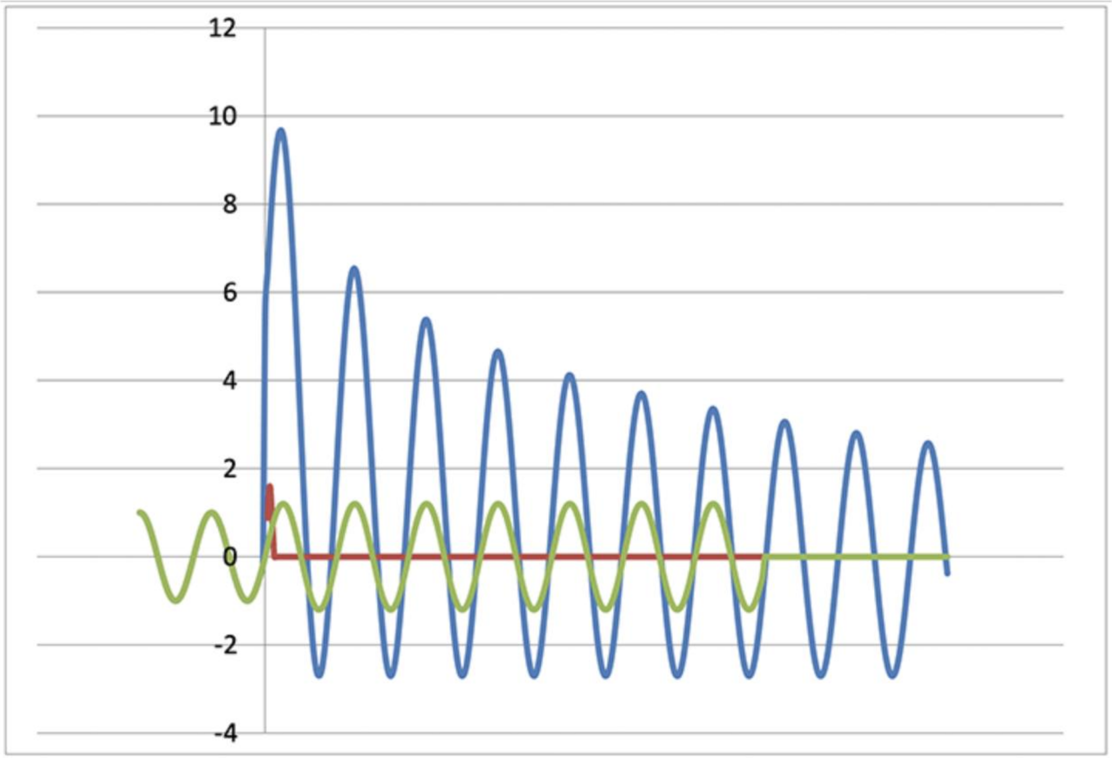
Short Detour to System Protection

- **~6x fault current injection from synchronous machine**
- **System protections currently use fault current as a primary trigger**
  - What happens when protection expects 6x fault current?
  - How can detailed EMT modeling of test systems and protection devices help new solutions?
- **Challenges to overcome**
  - IBR ***do*** provide some fault current
  - Fault current injection changes with control changes
  - There is no "one size fits all" for fault current
  - Cannot fit a IBR-sized peg into a synchronous machine-sized hole



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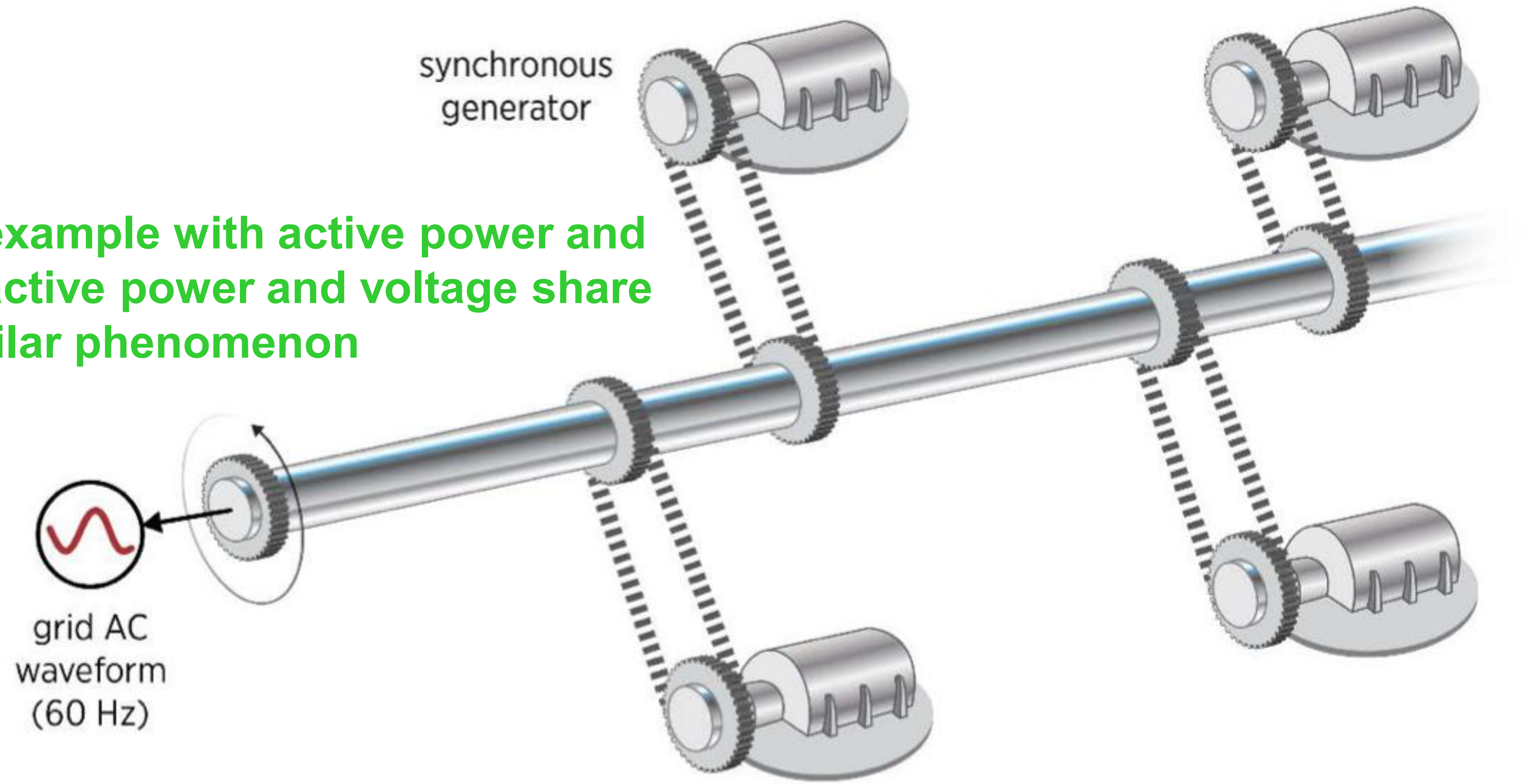
Inertia and System Strength: High Level

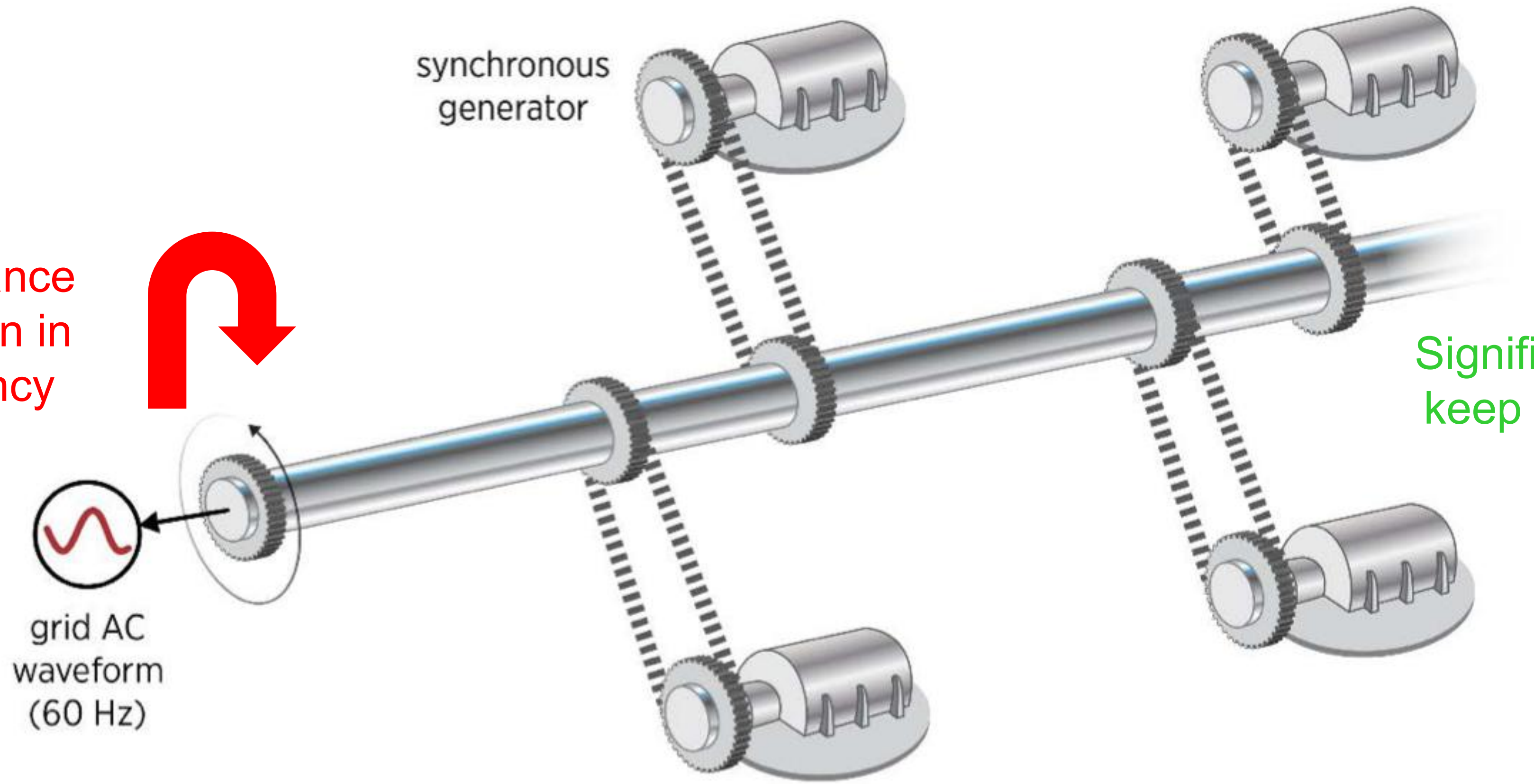


Note: This is an example with active power and frequency but reactive power and voltage share similar phenomenon

Source: NREL

Inertia and System Strength: High Level

System disturbance causes reduction in system frequency



Significant “torque” to keep frequency near nominal

Source: NREL

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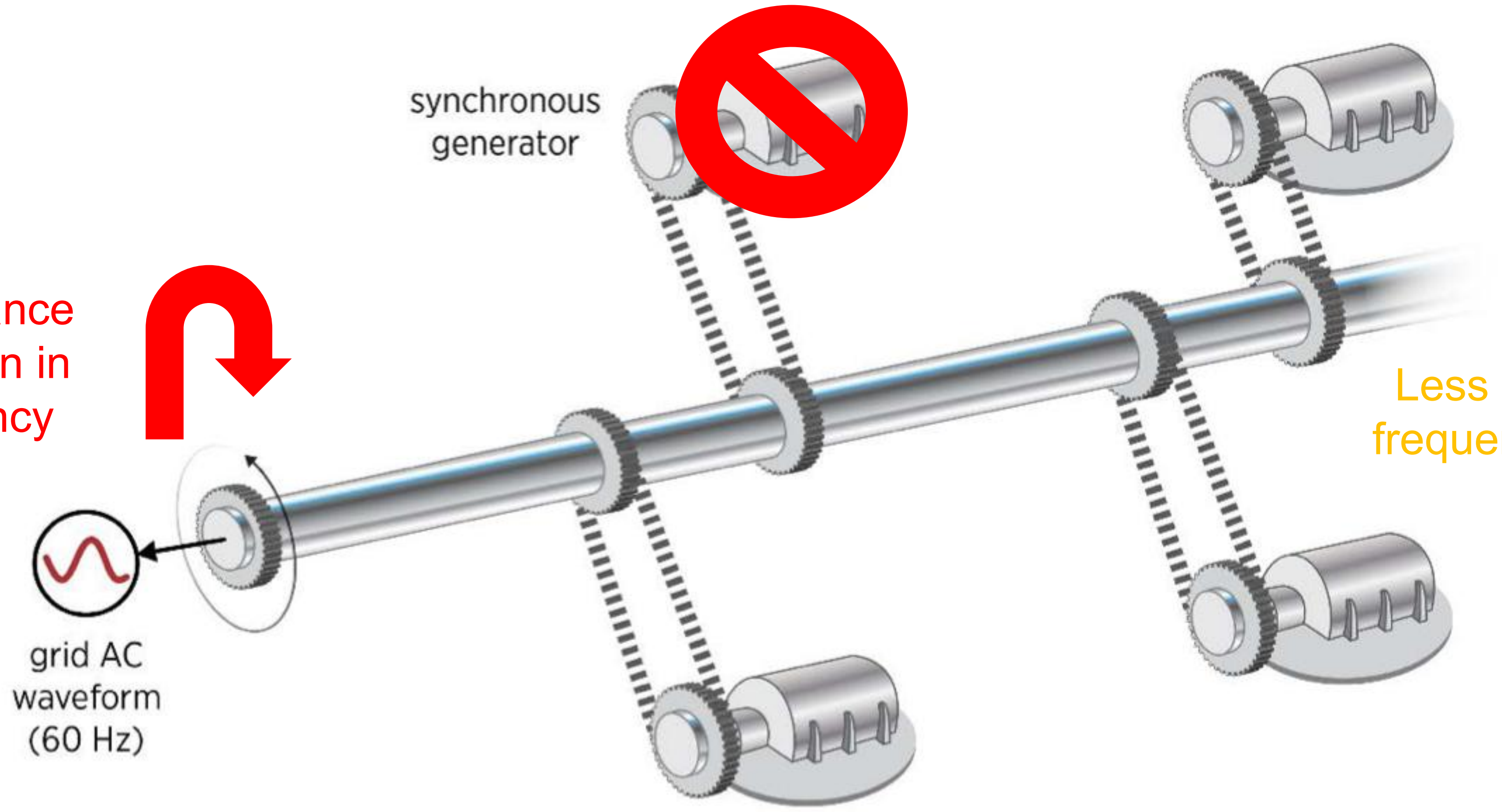

Less “torque” to keep frequency near nominal

Source: NREL

Inertia and System Strength: High Level

These grid conditions often need EMT simulations with detailed, accurate, manufacturer- and site-specific models

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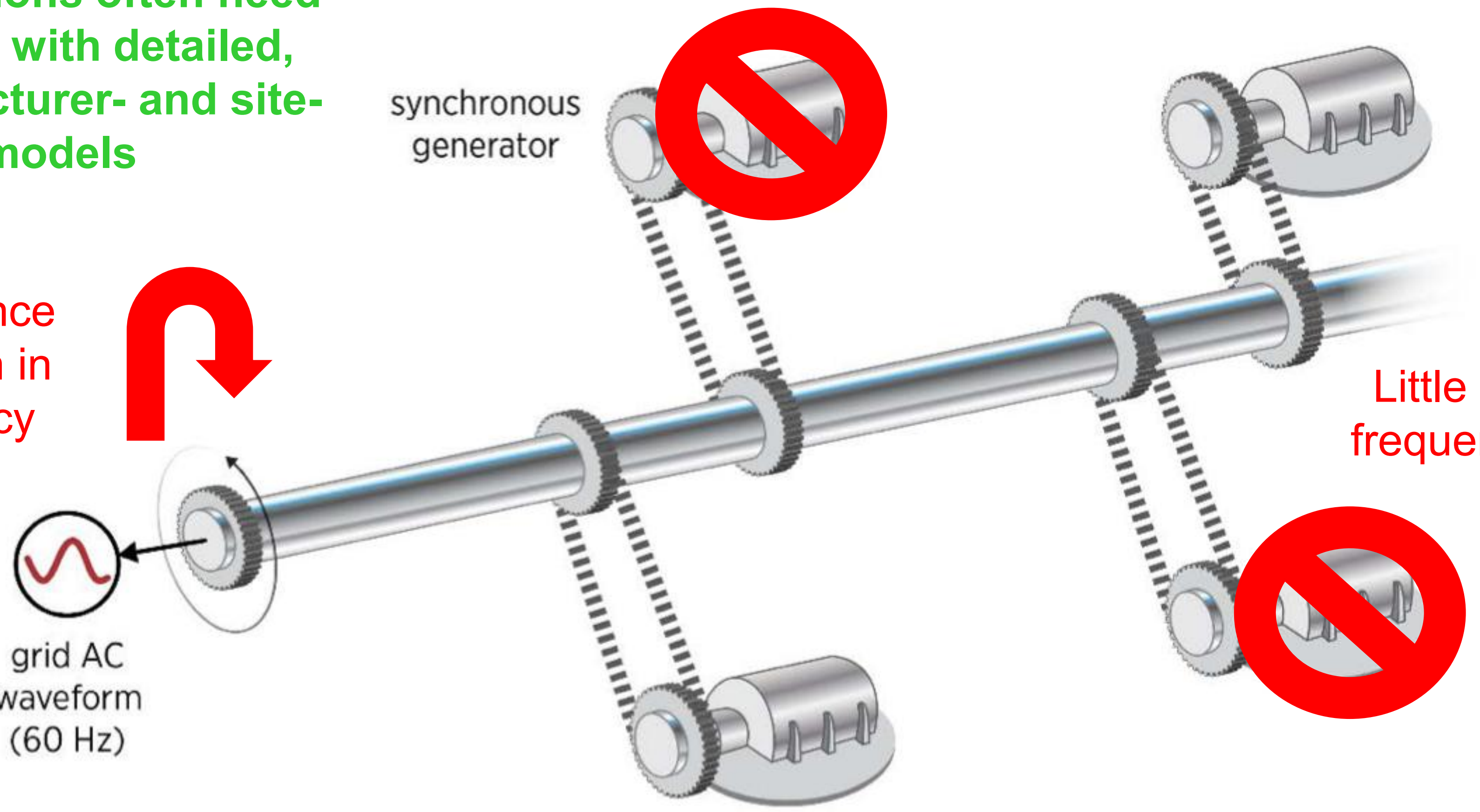

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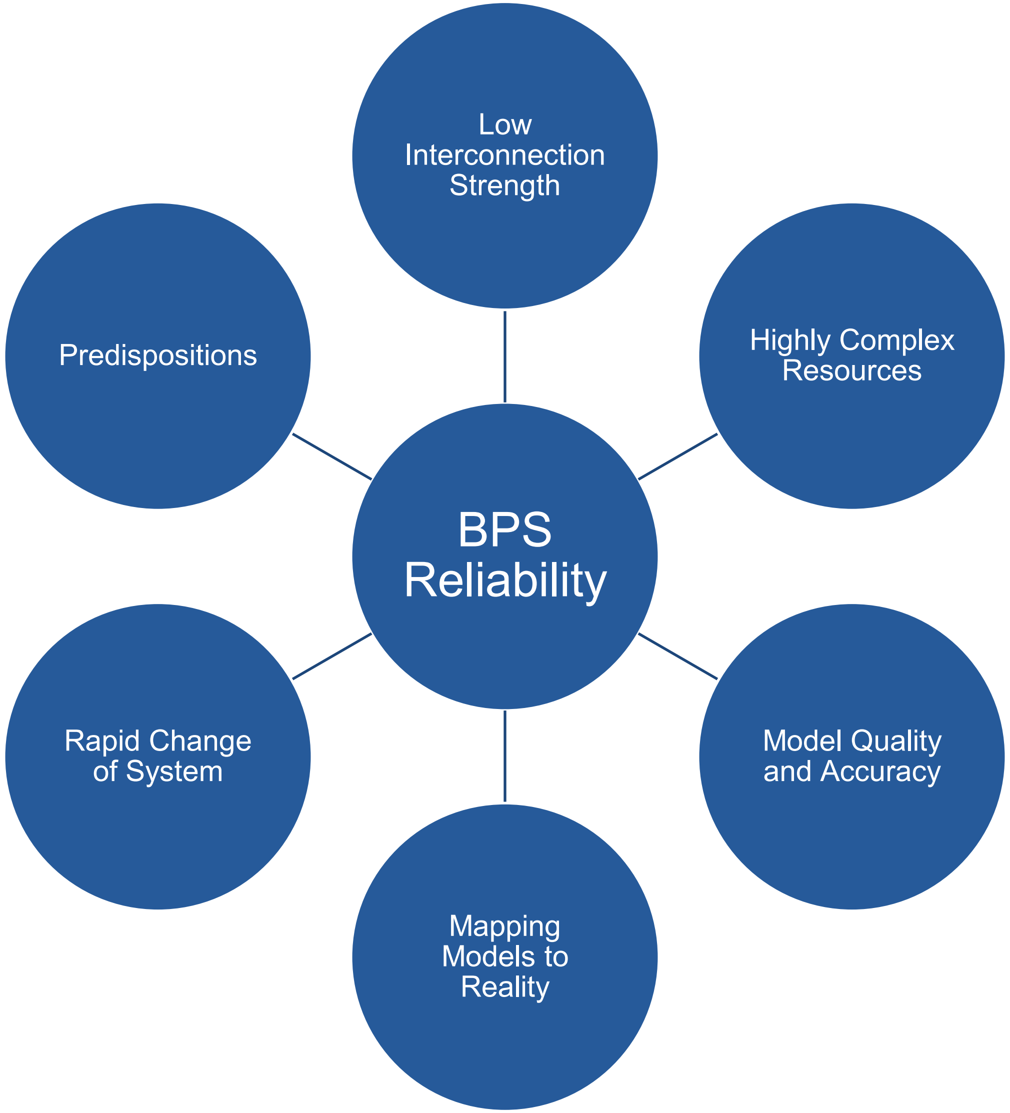
Primary Reliability Gaps



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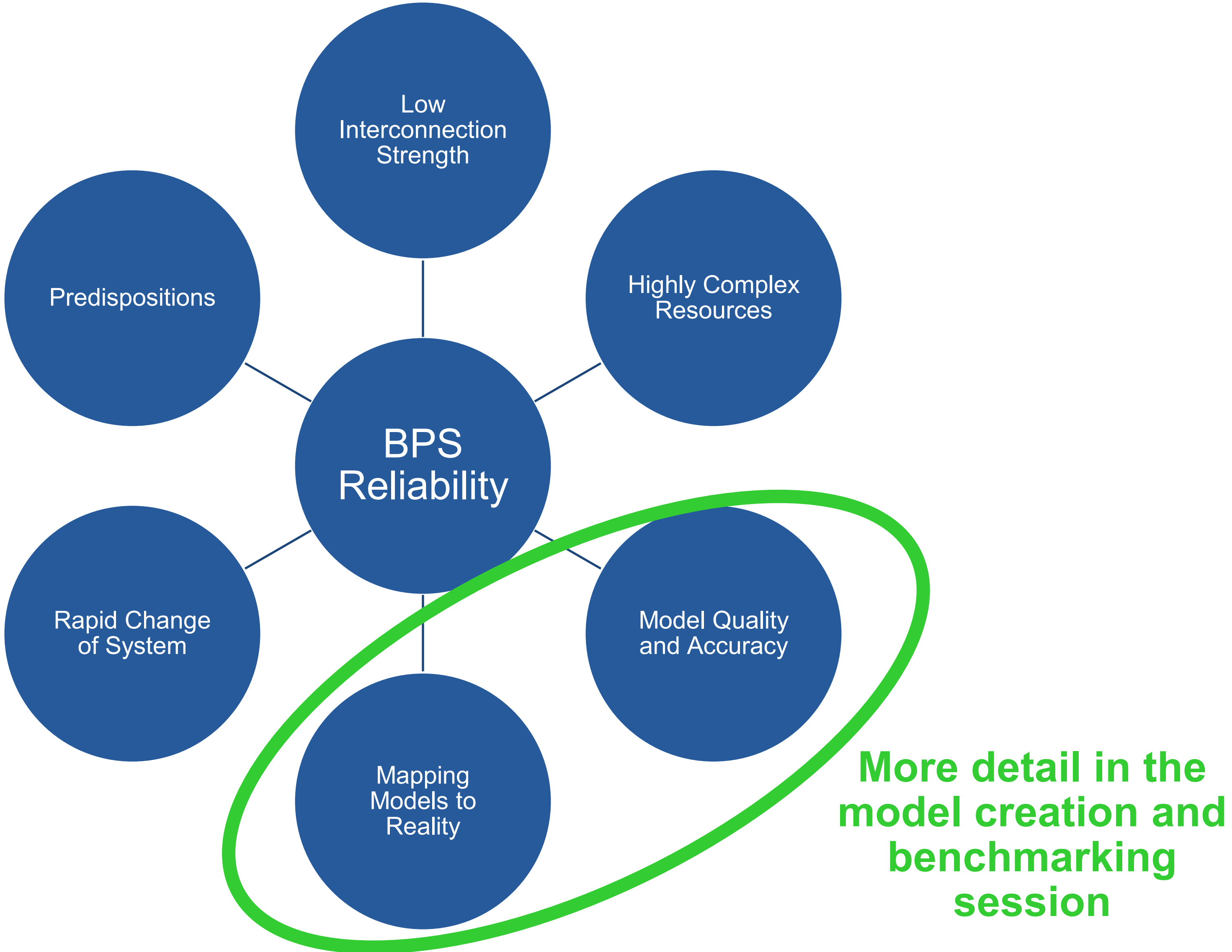

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Breaking Predispositions

PSPD:	EMT:
• PSPD is not obsolete • PSPD models can be highly accurate* • PSPD simulations have great use cases	• EMT is not the only “right” tool • EMT models are not accurate just because they are in the EMT domain • Not everything needs an EMT simulation

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System Strength Weakening

PSPD:	EMT:
• Simulation issues at low short circuit ratios (~3-5) • Models may not have advanced control features • Real-world solutions may not map to PSPD models	• Capable of simulating in low short circuit ratios (less than 3) • Models likely include all relevant controls • Often capable of better mapping between real and modeled parameters

Reliability Gaps and Simulation Domains

More Complex Resources

PSPD:	EMT:
• Difficult to model third-party controllers, communication delays, communication protocols, etc.	• High level of detail makes the modeling of highly complex control system feasible

Reliability Gaps and Simulation Domains

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Mitigating Reliability Needs

PSPD:	EMT:

• Can be difficult to represent on-site tuning
  • Often do not include advanced controls
• Lack of direct mapping between model and product
  • No mapping in standard library models
	• Easier to represent on-site tuning
	  • Often include advanced controls
	• More direct mapping ensures on-site solutions can be tested and studied

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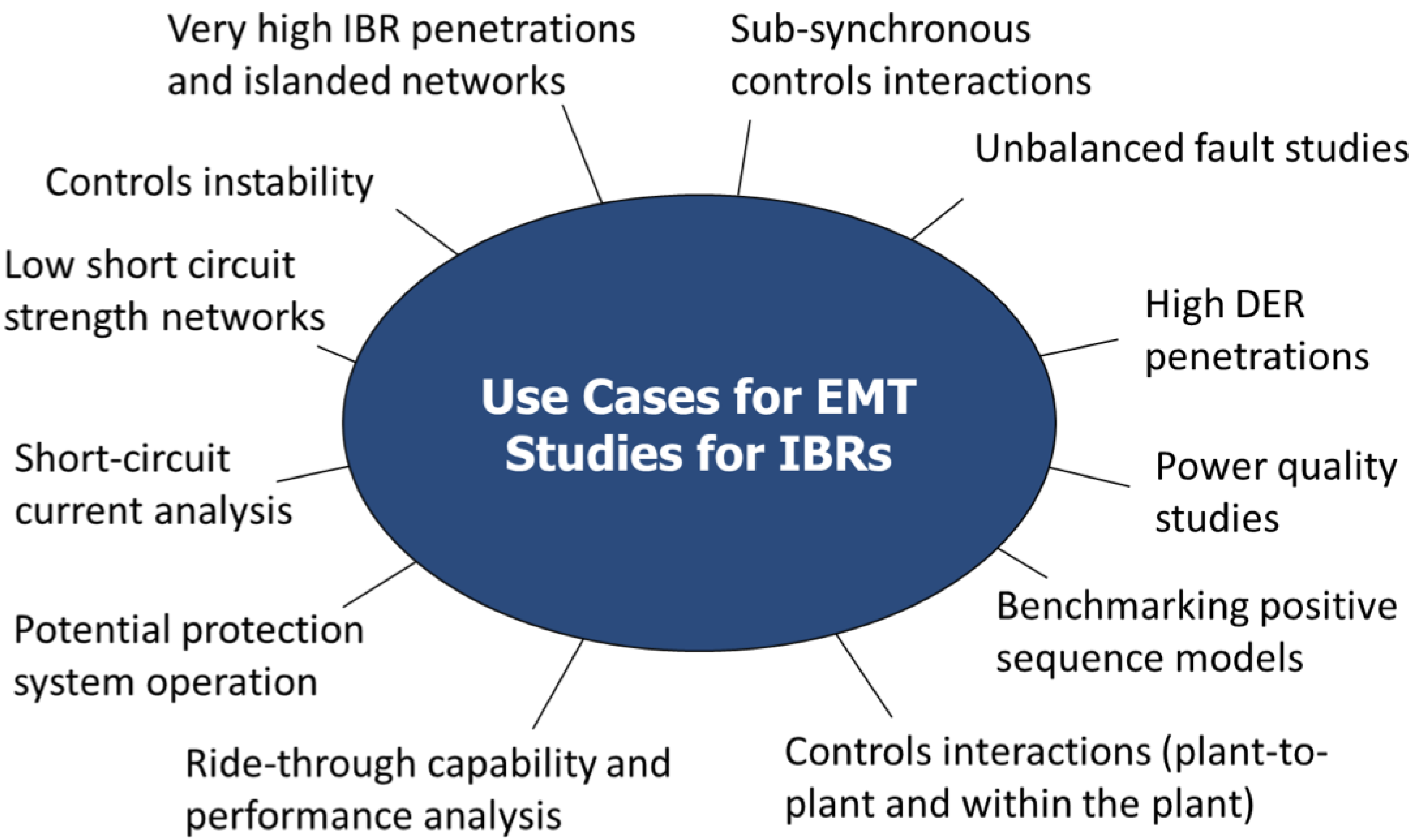
Critical for the efficient use of the power system

Reliability Gaps and Simulation Domains

“New” Grid Issues

PSPD:	EMT:
• Not capable of studying sub-synchronous interactions, unbalanced faults, power quality • Difficulties when studying controller interactions	• Capable of studying sub-synchronous interactions, unbalanced faults, etc. • Added detail helps uncover controller interactions • Studying effects of changing power system on synchronous mechanics

Use Cases for EMT Studies



Source: NERC

Benefits and Limitations of EMT

Benefits

- Very robust solution engine solving the entire waveform in the time domain
- Able to simulate low system strength conditions
- Able to represent mechanical behaviors
- Often contain real code or highly mapped representations
- Needed to study SSCI/SSR, harmonics, etc.

Limitations

- Extremely high computational burden
- Steeper learning curve (both the tools and the problems)
- EMT models are only as good as their parameterization
- EMT models may not exist for a piece of equipment
- Lack of regulatory clarity

Benefits and Limitations of EMT

Extremely capable and important tool

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Even the best tools need to be used with intention