Real-time Dynamic Path Limit Computation for Market Efficiency and Grid Reliability

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Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software

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Background

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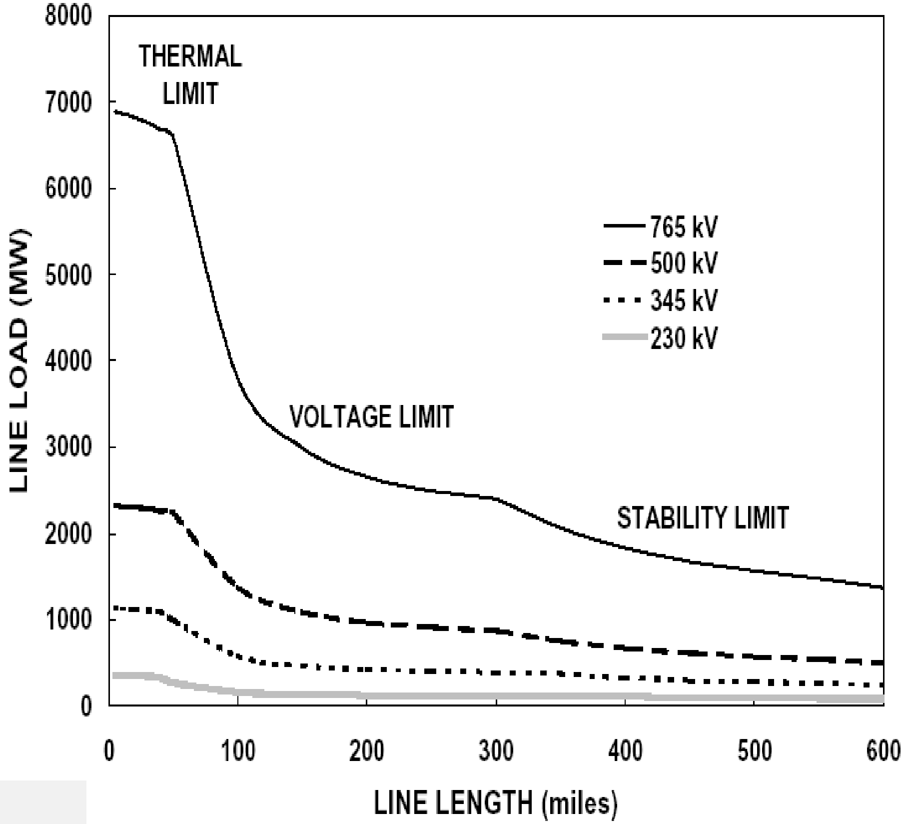
Different Limits in Transmission Lines



- Short: Thermal limit
- Medium: Voltage limit
- Long: Stability limit

Current Practice

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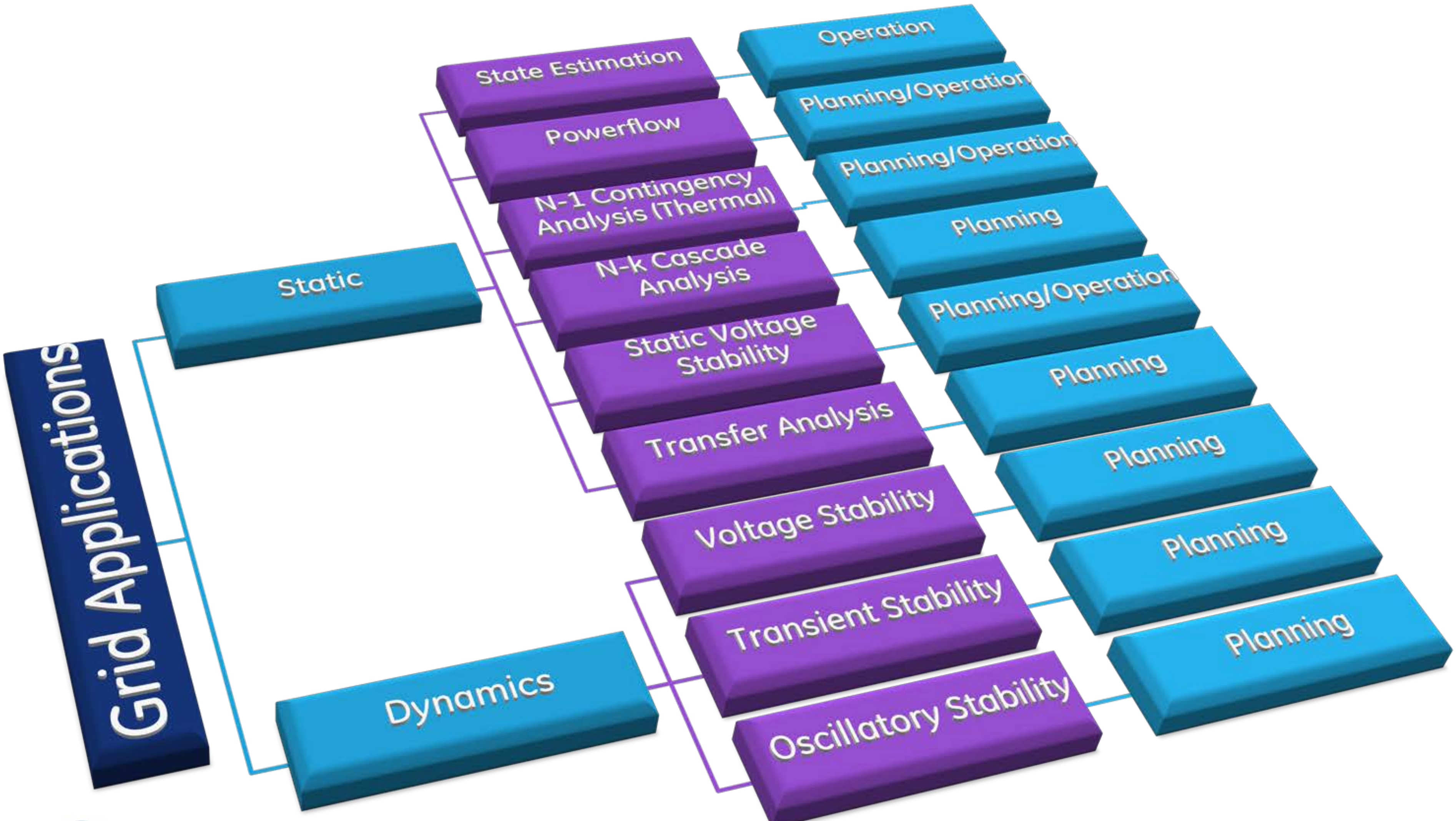
Typical Grid Applications



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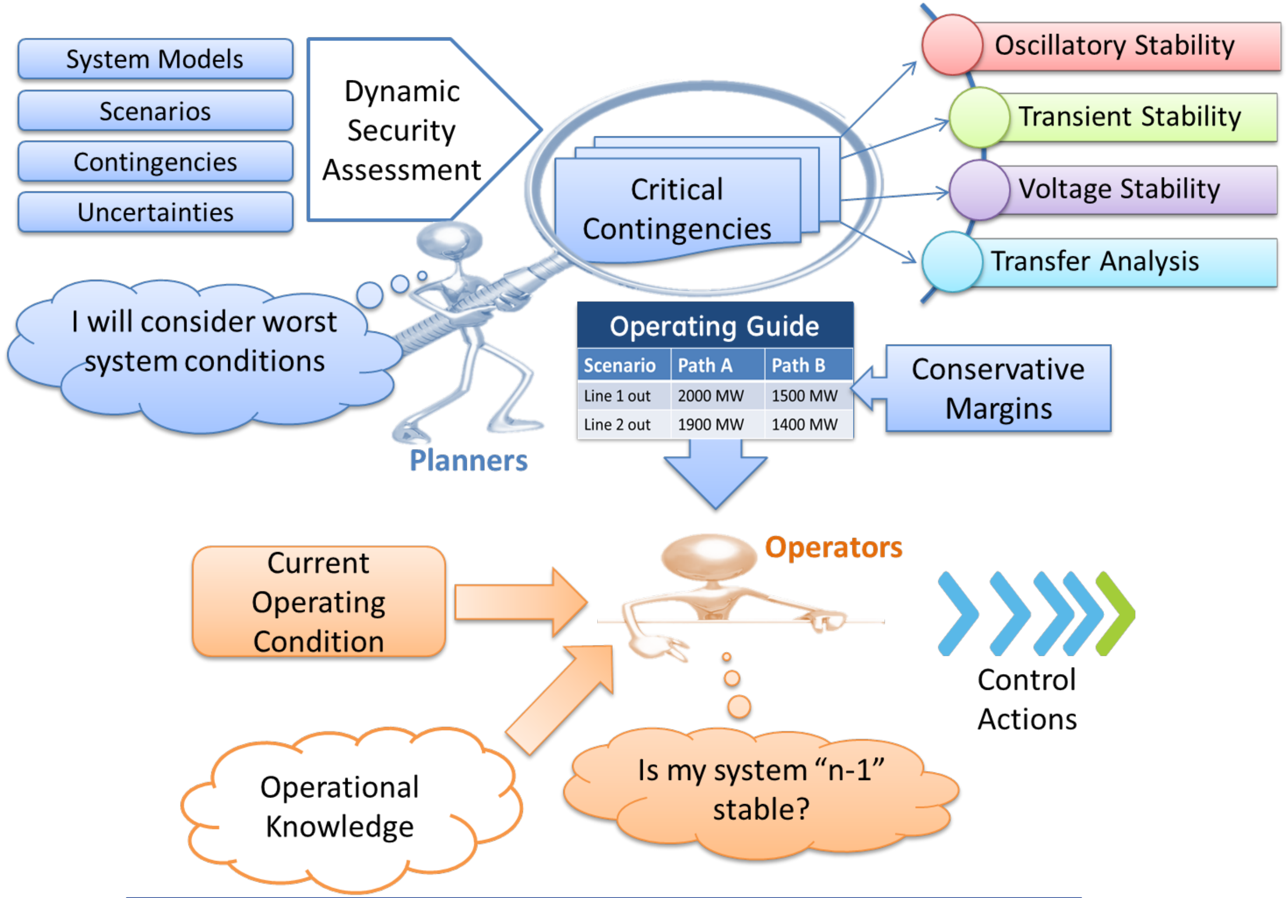
Current Practice



Scenario	Path A	Path B
Line 1 out	2000 MW	1500 MW
Line 2 out	1900 MW	1400 MW

Limitations

- Model accuracy
- Does not reflect present condition
- Variability in generating resources

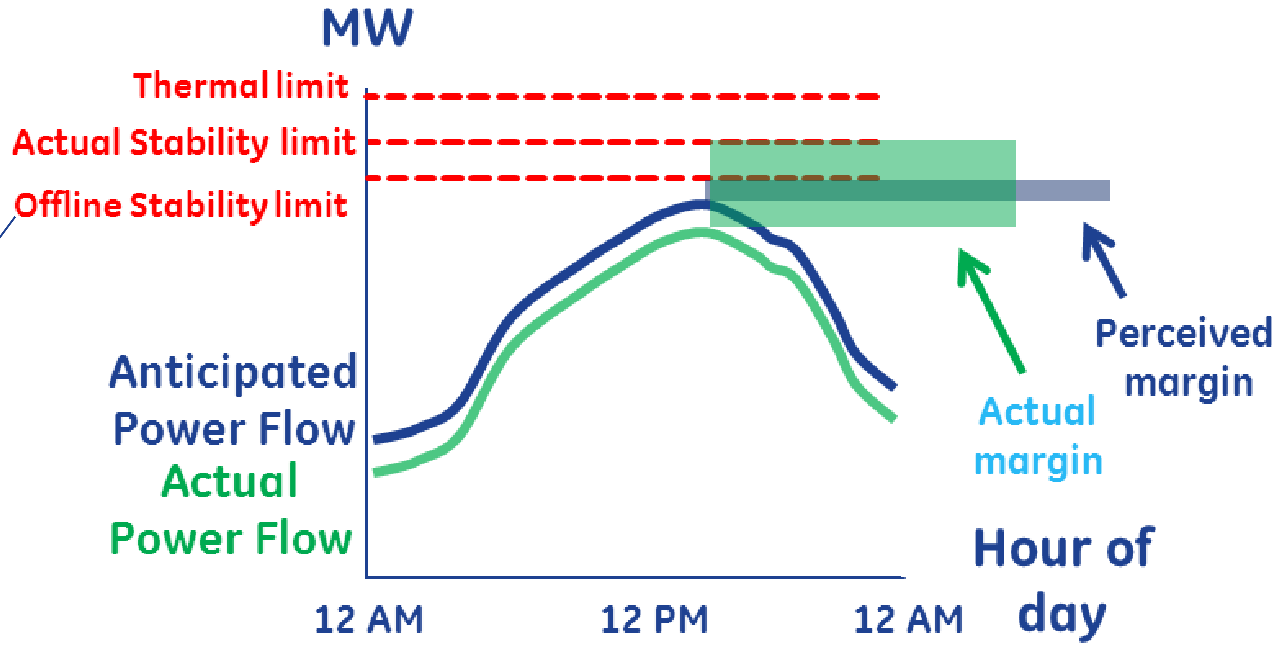
Economic Motivation: Value of Real-Time Transmission Controls

Time variant

- depends on operating conditions

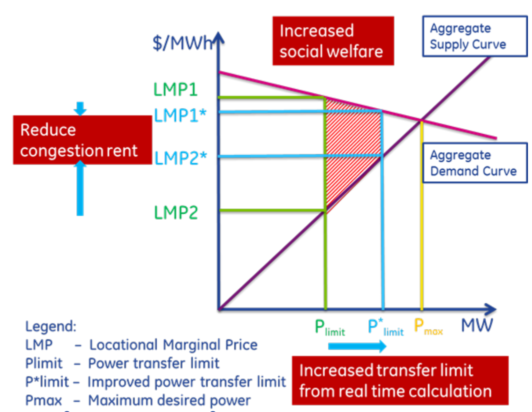
Static

- set by utility periodically



Est. 5-30% reserve stability margin based on worst-case conditions*

*Taylor, C.W.; Erickson, D.C.; Martin, K.E.; Wilson, R.E.; Venkatasubramanian, V., "WACS Wide-Area Stability and Voltage Control System: R&D and Online Demonstration," Proceedingsof the IEEE, vol.93, no.5, pp.892-906, May 2005.; D. Guido, "ISO, NERC Pact Aims to LowerBlackout Threat," *Megawatt Daily*, April 16, 2010.



Reduced congestion

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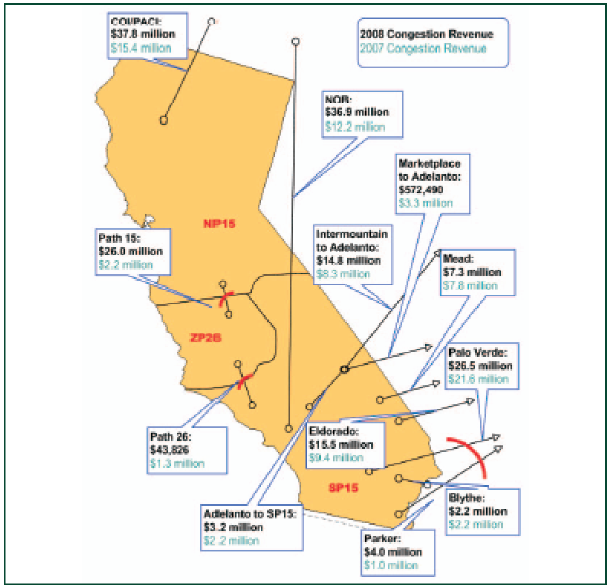
Cost of Congestion …

Reported congestion cost examples:

CA ISO

(most stability constrained)



Source: CAISO (2009c). *Market Issues & Performance: 2008 Annual Report*, at http://www.caiso.com/2390/239087966e450.pdf, Figure E-12, p. 18.

2004: $1.1B
2005: $670M
2006: $467M

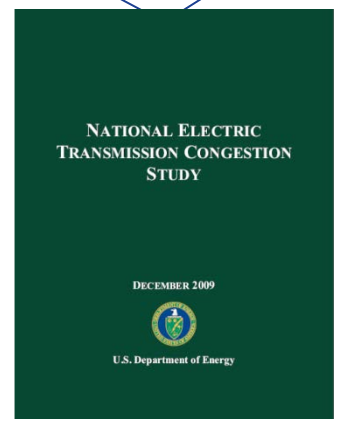
PJM

(largest ISO in US)

PJM Congestion Cost Summary, 2008 ($M)

	Day Ahead				Balancing				
Control Zone	Load Payments	Generation Credits	Explicit	Total	Load Payments	Generation Credits	Explicit	Total	Grand Total
Total	$1,286.1	($1,166.7)	$208.4	$2,661.2	($225.9)	$79.2	($239.5)	($544.6)	$2,116.6

2004: $750M
2005: $2B
2006: $1.6B



PJM Reports that congestion costs are annually 7-10% of total billings

FERC is mandated to reduce the cost of congestion to society

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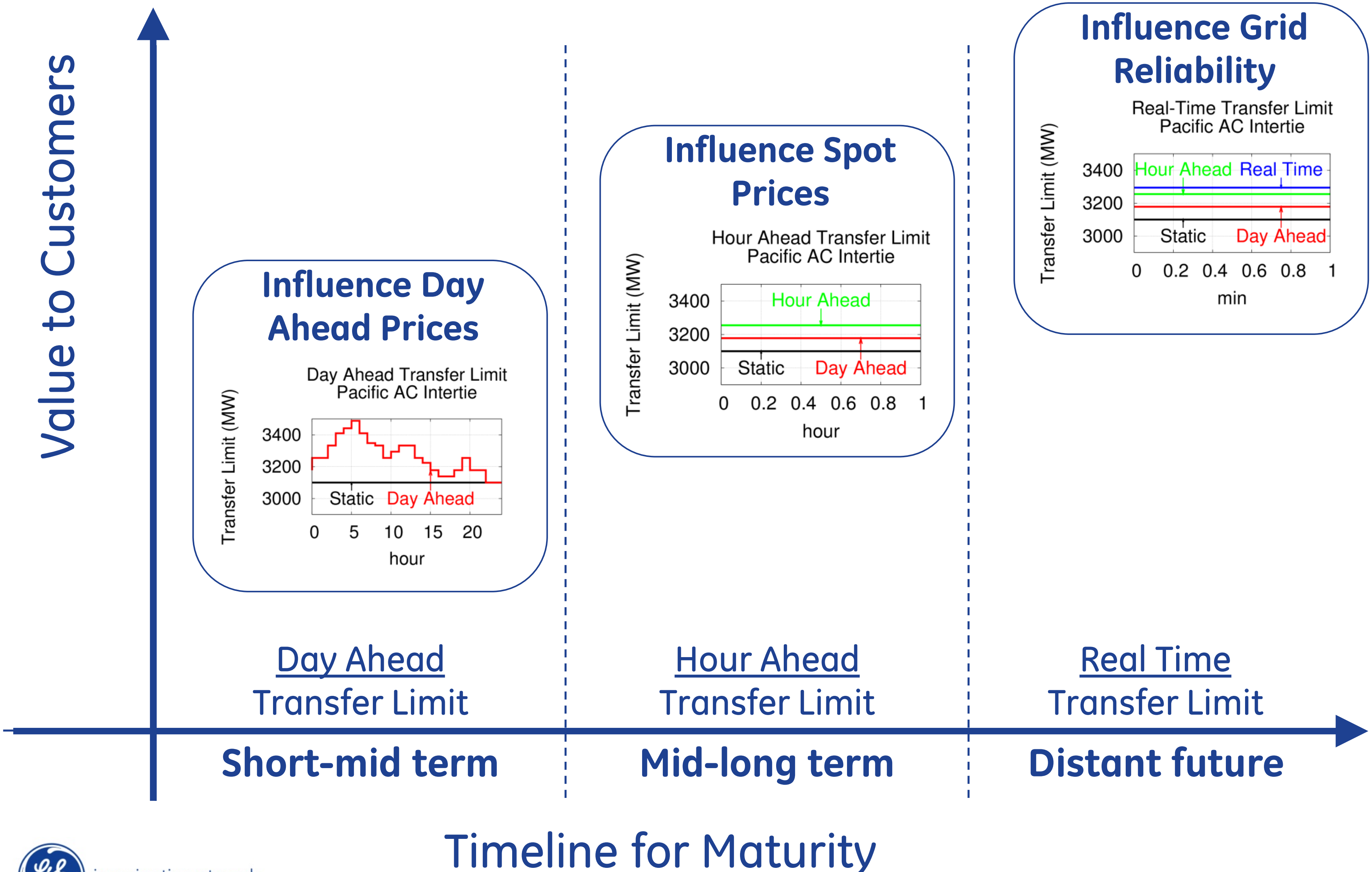
Benefits at Different Timescales



Approach

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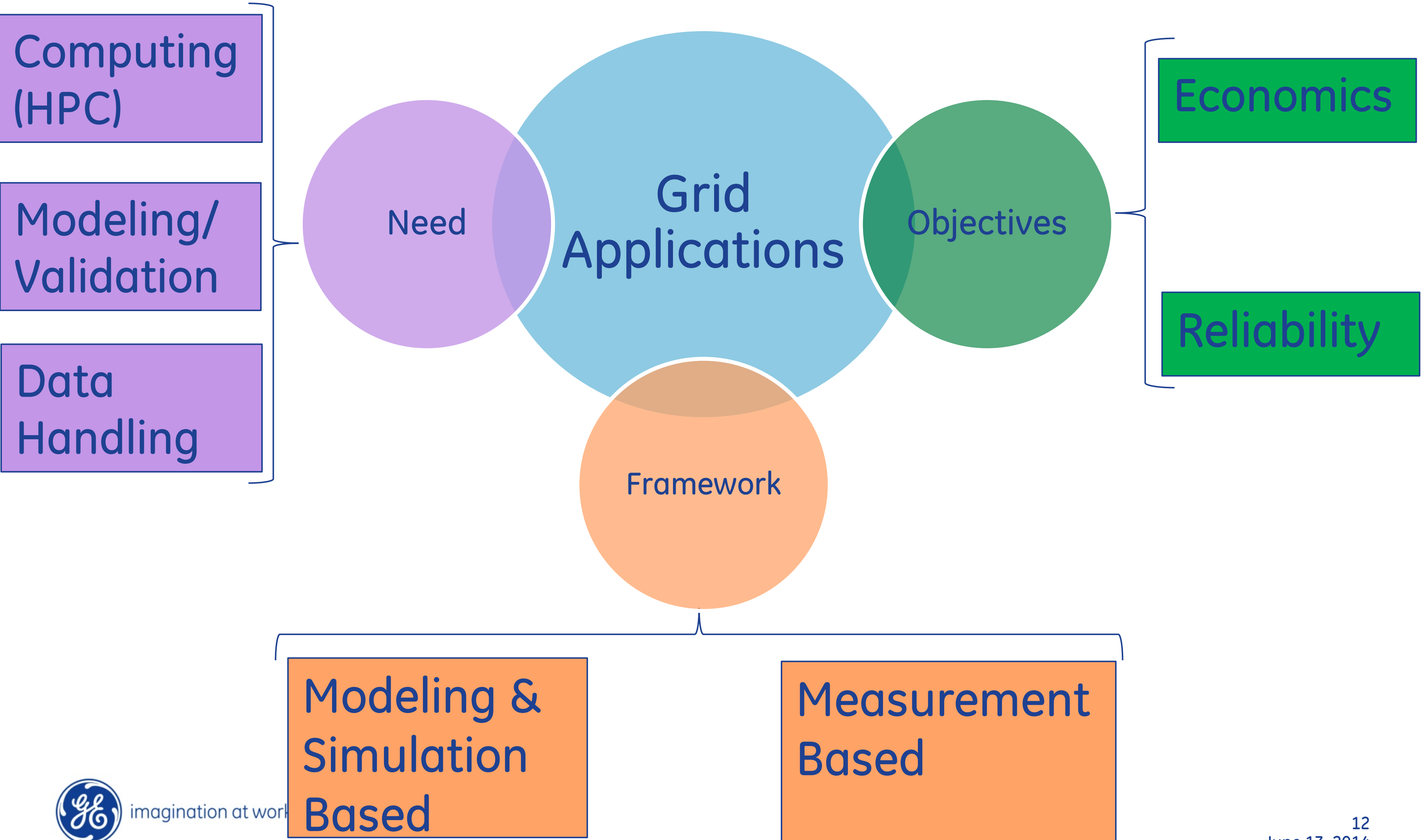
Grid Modeling Overview



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R&D Opportunities

- Bring "dynamic security assessment" capability closer to operation (real-time)
  - ✓ Numerical approaches
  - ✓ High performance computing (parallel computing) application
  - ✓ Leverage measurement (PMU) to improve model quality
  - ✓ Smart/fast algorithms
- From "analysis" only towards "control" (decision support tool)

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Application Focus

- Different stability limits (e.g., voltage, angle, frequency etc.)
- Focus of the approach: angle stability

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Grid Application Framework

Modeling & Simulation

- ☑ Useful for "what-if" analysis (e.g. real-time dynamic contingency analysis)
- ☒ Model inaccuracies
- ☒ Computing power

Measurement (WAMS)

- ☑ Situational awareness
- ☑ Useful for model validation/calibration
- ☒ Not useful for N-1 secure operation

"Complementary solution"

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Fast Dynamic Simulation

- Model Reduction
- Model Calibration
- Numerical Techniques for Fast Dynamic Simulation
- High Performance Computing (HPC) – Based Dynamic Simulation
- Transfer Limit Computation

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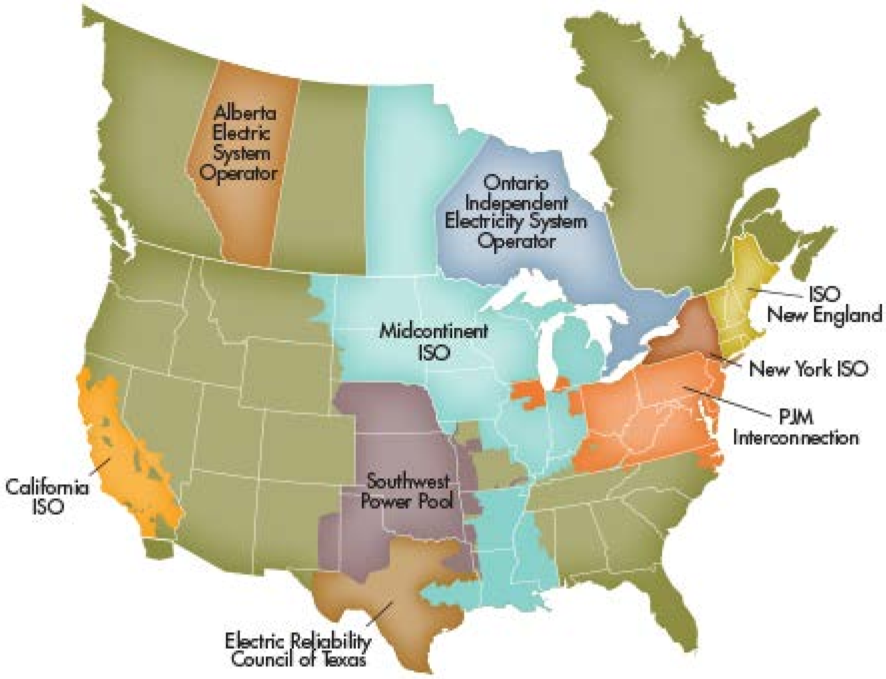
Model Reduction



- EPRI developed a commercial product: DYNRED
- Identify the coherent group of generators
- Aggregate the coherent generators to derive an equivalent generator model
- Network reduction taking advantage of sparsity

- Detailed model within the ISO/utility
- Equivalent representation outside the boundary

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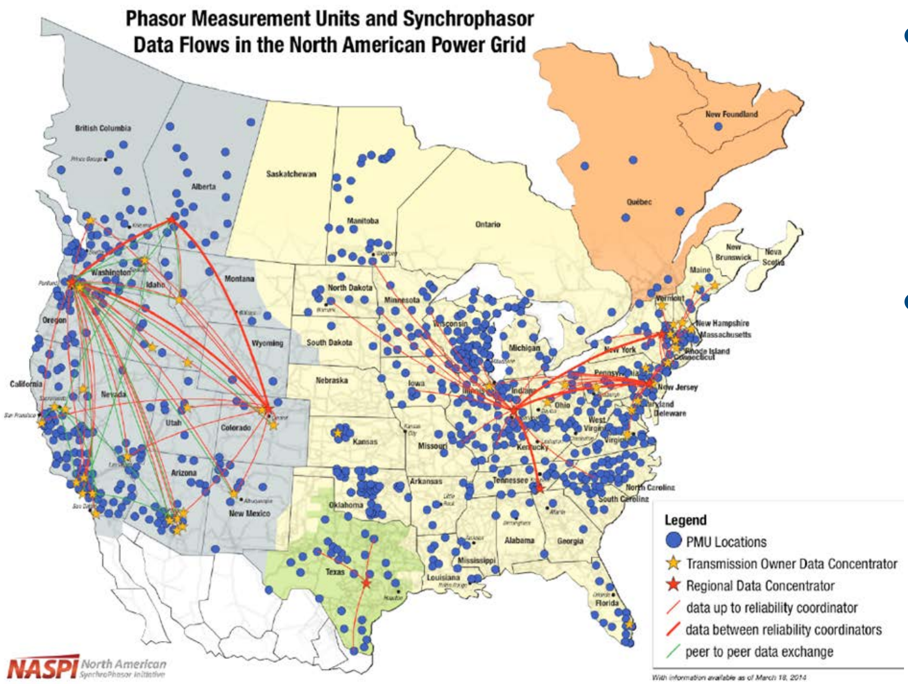
Model Calibration



- More PMUs being installed
- Increasing data exchange among reliability coordinators

- Reduced model – as good as detailed model
- PMUs being installed at the terminal buses of the generators (new NERC standard mandating generator model validation)
- Estimation of model parameters from the terminal voltage and current phasors

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Numerical Techniques for Fast Dynamic Simulation

- Commercial transient simulation software: partitioned approach with explicit integration
- Fast DAE solvers: implicit integration with simultaneously solution of the algebraic equations
- Variable time-step method or ‘theta method’
- Partitioning of stiff and non-stiff portion: parallel computation of DAEs

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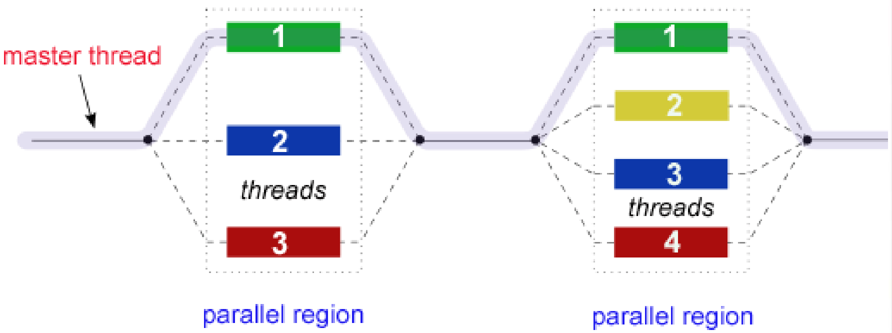
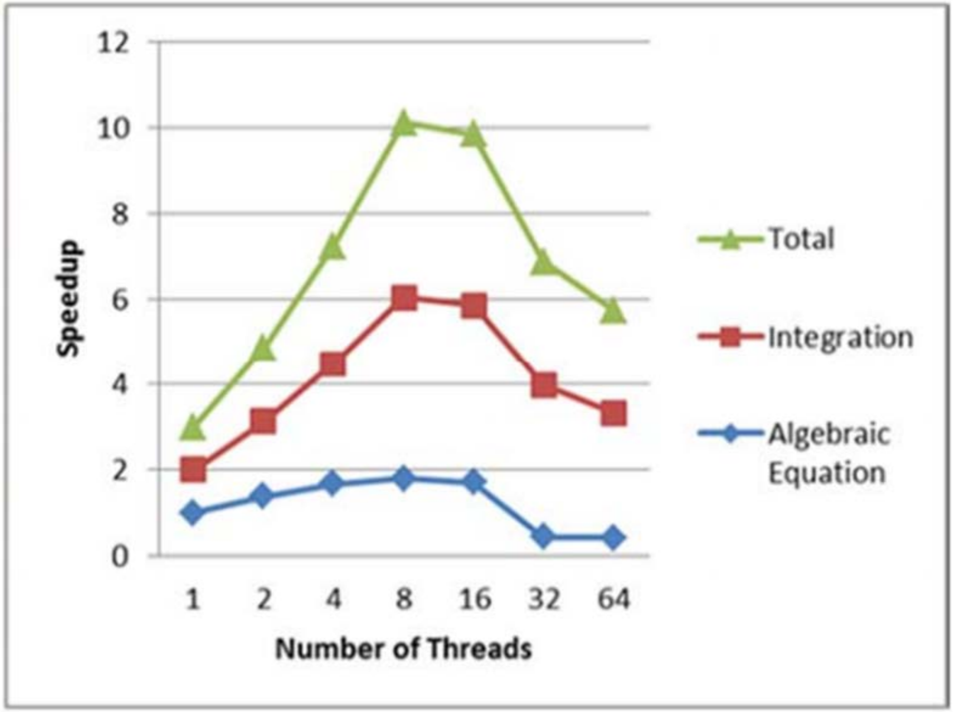
HPC Based Dynamic Simulation



Concept of parallelization

- Preconditioned Conjugate Gradient (PCG) method
- Use of computational libraries: Hypre, PETSc



Speedup due to parallelization of time domain simulation

Source: S. Jin, Z. Huang, R. Diao, D. Wu, Y. Chen, “Parallel Implementation of Power System Dynamic Simulation”, IEEE PES GM 2013

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Transfer Limit Computation

- NERC definition transfer limit: Total Transfer Capability (TTC) = *minimum {Thermal Limit, Voltage Limit,* ***Stability Limit****} for worst N-1 contingency*
- Time-domain simulation for angle stability studies
- Reduction in contingency space (e.g., using artificial intelligence, decision tree etc.)

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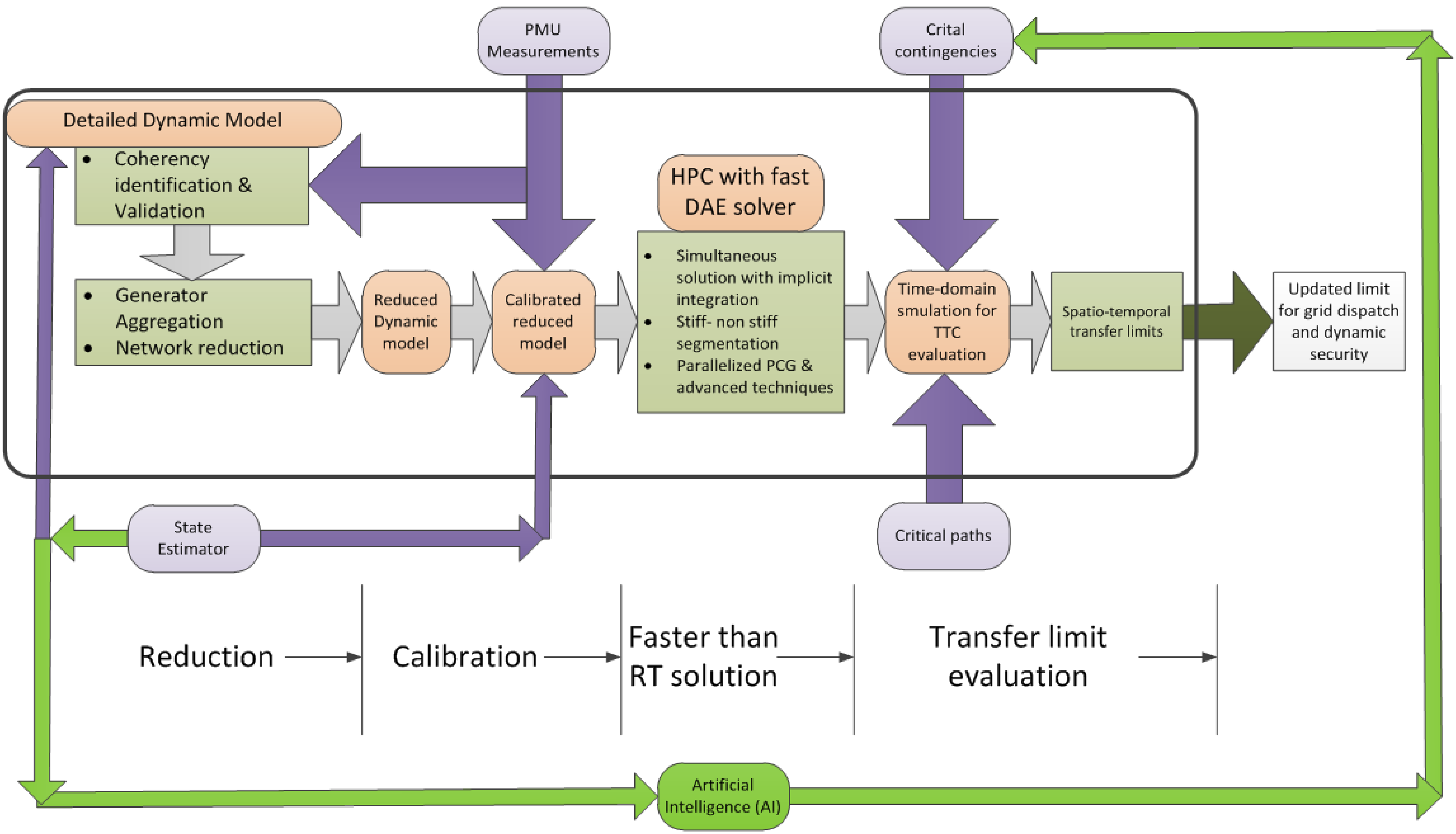
Overall Approach



Questions?

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