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SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

Improving the modeling accuracy and performance of analysis of transient dynamics of large-scale power grids with extensive IBRs

DOE SETO Workshop on Dynamics and Transients

11/16/2021

Period of performance
Oct. 2021 - Sept. 2023

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NREL Transforming ENERGY
THE UNIVERSITY OF TENNESSEE KNOXVILLE
EPRI ELECTRIC POWER RESEARCH INSTITUTE
Pacific Northwest NATIONAL LABORATORY
ASU

I-PEP Project

- Title: **Intelligent Phasor-EMT Partitioning (I-PEP) for Accelerated Large-scale IBR Integration Studies**
- 2-year project
- Started October 2021
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- DOE Project Manager: Tommy Rueckert
- Overall PI: Andy Hoke, Andy.Hoke@nrel.gov; Co-PI Jin Tan, Jin.Tan@nrel.gov
  - EMT solver lead: Bin Wang
  - HPC lead: Matthew Reynolds
- PNNL: Qiuhua Huang, Bruce Palmer
- UTK: Professor Kai Sun
- EPRI: Deepak Ramasubramanian, Wes Baker
- ASU: Professor Vijay Vittal

Context

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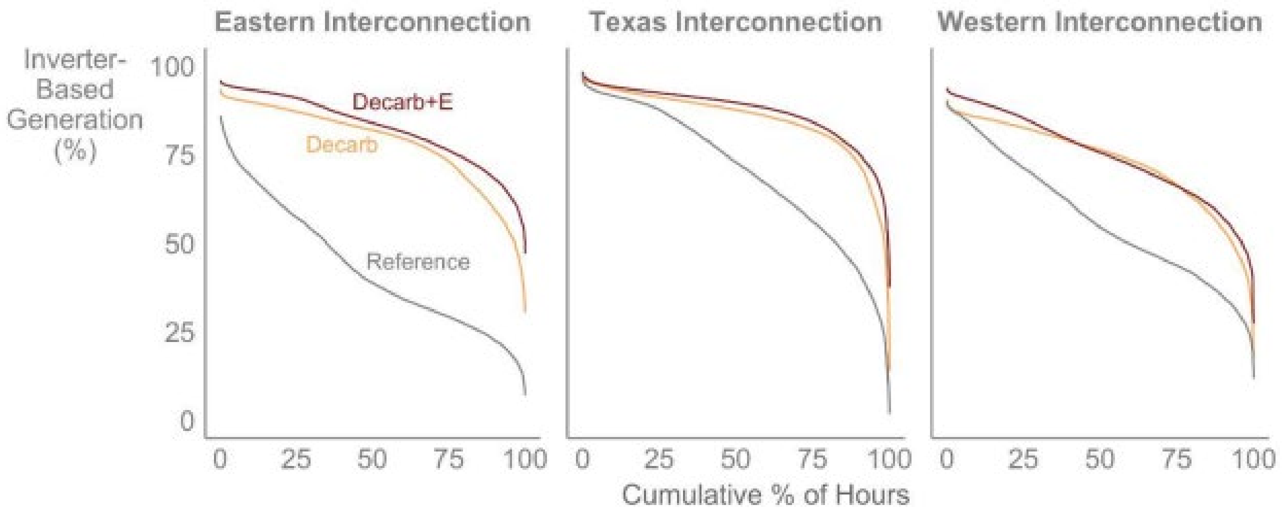
- Power systems are moving rapidly towards very high levels of inverter-based resources (IBRs)

Excerpt from 2021 DOE Solar Futures Study

https://www.energy.gov/eere/solar/solar-futures-study



- Conventional phasor-domain dynamic modeling tools can miss important IBR-related interactions that can destabilize the system

Motivation

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- State of the art electromagnetic transient (EMT) tools can capture IBR dynamics, but suffer from intractable computation times for very large models
- Phasor-EMT co-simulation improves speed while capturing fast dynamics of selected regions, but no rigorous method exists for partitioning the system into EMT and phasor domains
    - Representing all IBRs in the EMT domain and the network in the phasor domain can be unnecessarily slow because in most systems there are areas where fast IBR control dynamics are not salient
    - Representing IBRs in the EMT domain when the short-circuit ratio (SCR) at their location is below a predetermined level is an imperfect tool, especially for complex systems containing many IBRs
- Existing phasor-EMT interfacing techniques work well for one EMT subsystem and one large phasor-domain subsystem, but neglect higher-frequency mutual coupling between EMT subsystems
- Commercial phasor-domain tools, EMT tools, and interfacing techniques are neither open-source nor HPC-compatible
- **Industry needs a fast, accurate, open-source simulation tool for large, high-IBR systems**

Proposed Solution

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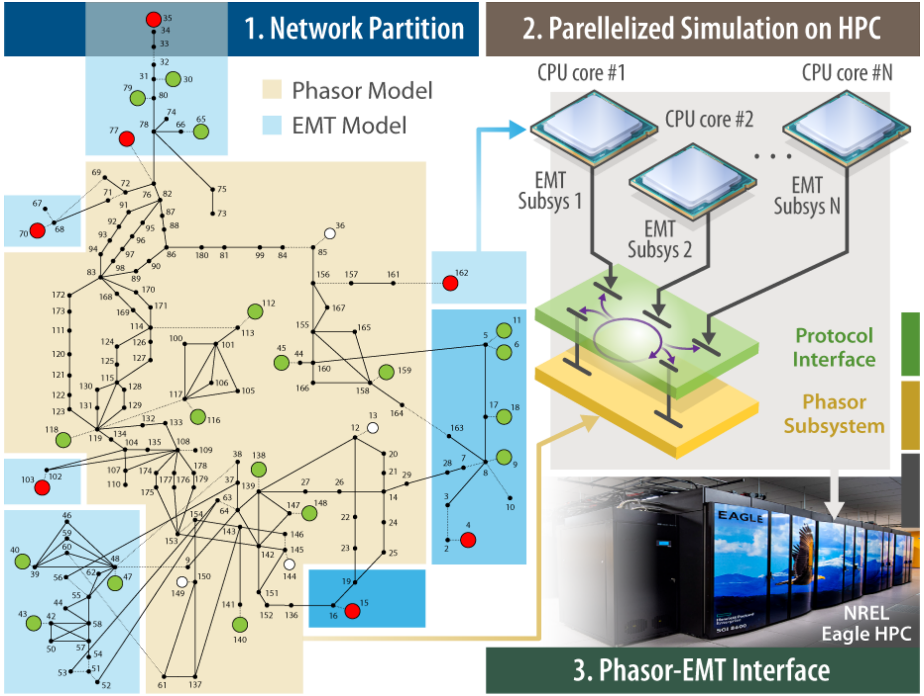
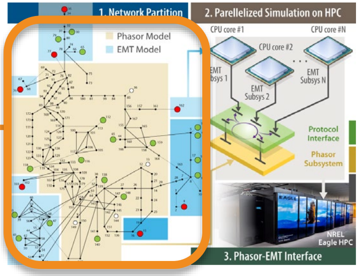
- We aim to develop an adaptive, integrated phasor-EMT simulation framework (I-PEP) for transient dynamic study of large-scale, IBR-dependent power grids
- I-PEP will include
  - A rigorous phasor-EMT partitioning method
  - An accelerated HPC-compatible EMT solver
  - Novel phasor-EMT interface models to ensure modeling accuracy and improve computational speed
- Goal is a technical proof of concept at end of two years



Thrust 1



Region-wise adaptive model partitioning method (UTK)

- Determines boundaries between EMT and phasor zones
- Based on nonlinear participation factors of each generator/region.

- Other methods may also be examined **(NREL, others)**

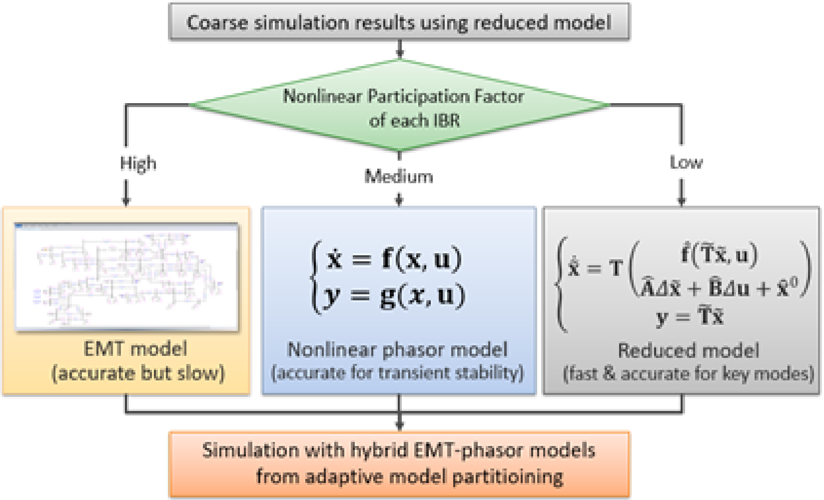
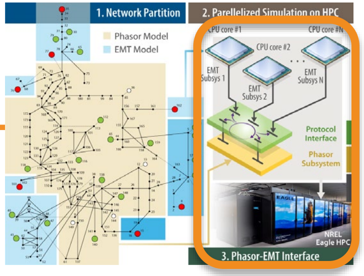


Figure 2. Use of nonlinear participation factors to determine the model detail level

Thrust 2



Accelerated, parallelized, HPC-compatible EMT solver:

A. Develop network decomposition to enable parallelization of network solution **(NREL)**

B. Implement parallelized solver on high-performance computer (HPC) **(NREL)**
   - Goal: Enable but do not require HPC.
   - Goal: Minimize need for user to have specialized computing expertise

C. Develop semi-analytical solvers to shift most computations of model components to offline stage **(UTK)**

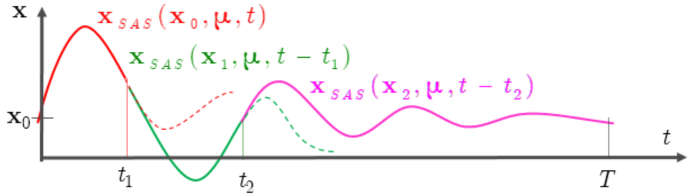
D. Add latest IBR models **(EPRI)**

Semi-analytical solution formulation

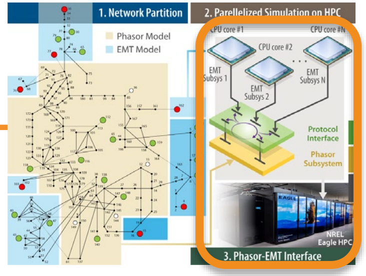
Stage 1 (solution): Find a **semi-analytical solution** symbolizing t, initial state $\mathbf{x}_0$ and selected parameters $\boldsymbol{\mu}$

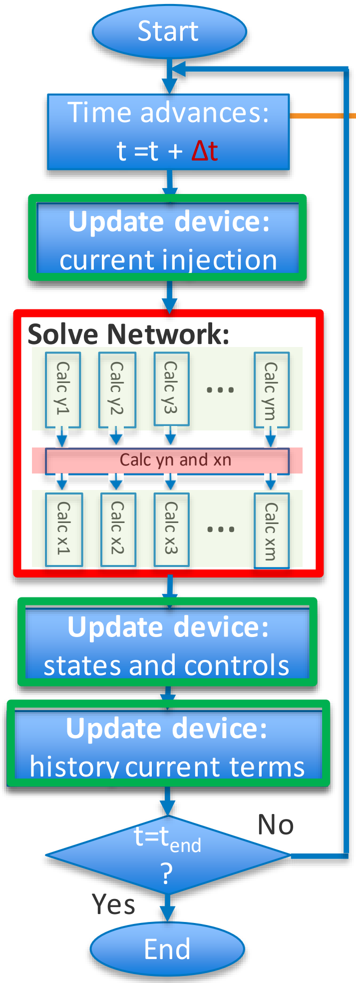
$$\begin{cases} \dot{\mathbf{x}} = \mathbf{g}(\mathbf{x},\mathbf{v}) \\ 0 = \mathbf{h}(\mathbf{x},\mathbf{v}) \end{cases} \Rightarrow \quad \mathbf{x}(\mathbf{x}_0;\boldsymbol{\mu},t) = \sum_{n=0}^{\infty} \mathbf{x}_n(\mathbf{x}_0;\boldsymbol{\mu},t) \approx \sum_{n=0}^{N} \mathbf{x}_n(\mathbf{x}_0;\boldsymbol{\mu},t) \overset{\text{def}}{=} \mathbf{x}_{SAS}(\mathbf{x}_0;\boldsymbol{\mu},t)$$

Stage 2 (simulation): Evaluate the **semi-analytical solution** over consecutive time intervals until making up the simulation period T.



Thrust 2: Initial Progress





EMT simulation flowchart

Device update

+

Network solution

+

Device update

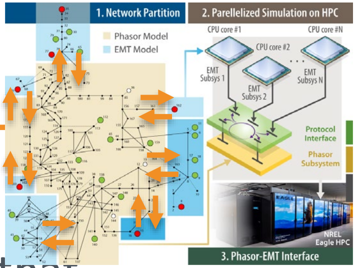
=

Total EMT simulation time

- Parallelized EMT network solver implemented on NREL HPC (Eagle)
- So far, provides 8-10x speed up relative to single-core EMT simulation. (Parallelization only helps so much)
- Speedup depends on:
  - System size
  - Method of partitioning network between cores
  - MPI* group size (number of ranks)
  - Number of nonzero elements in system impedance matrix
  - Other factors

*MPI = Message Passing Interface (for parallel computing)

Thrust 3

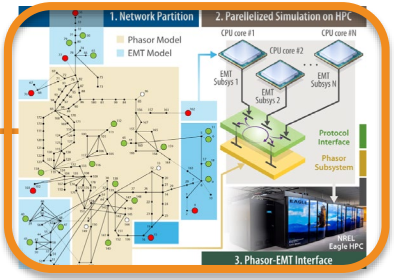


Dynamics-preserving phasor-EMT interface: (PNNL)

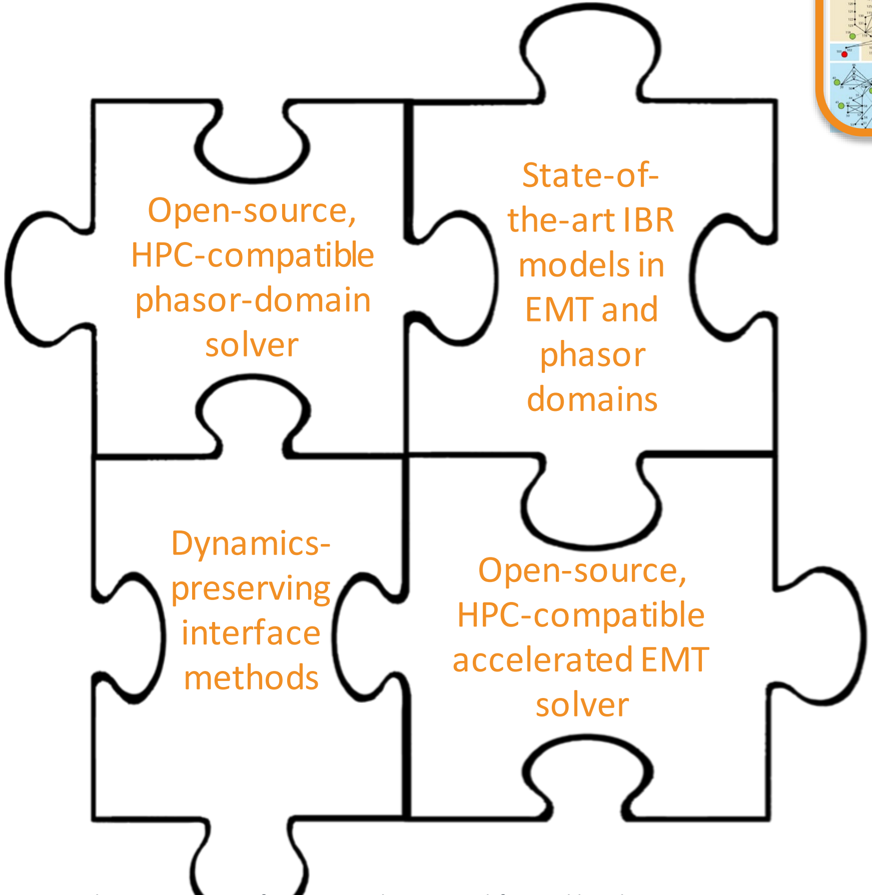
- **Interface model:** Develop distributed phasor-EMT interface model that preserves dynamics between EMT zones
- **Interface protocol:** variables and parameters will be interchanged between phasor-domain and EMT subsystems via a HELICs-compatible communication protocol (TCP or UDP)

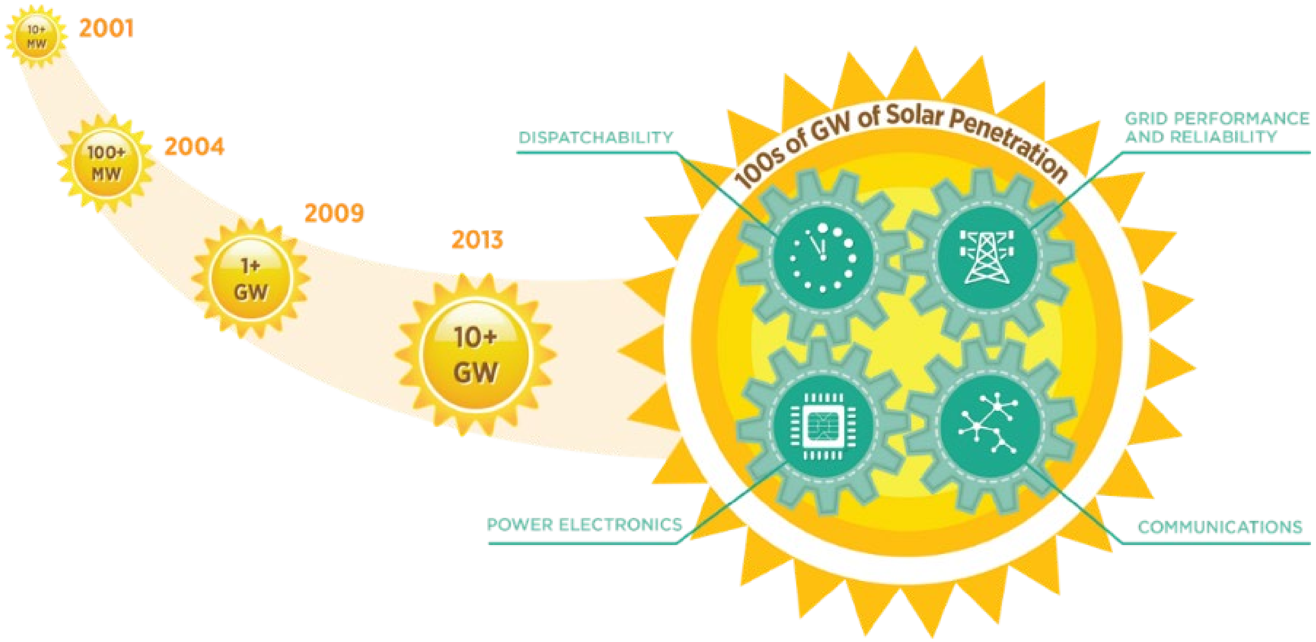
- Leverages existing GridPACK software
  - Includes conv machines, exciters, governors, initial implementation of composite load model, initial IBR models
  - Add latest IBR models **(EPRI)**

Connecting the pieces



- Integrate all the pieces into a functional framework
- **Demonstrate feasibility on test system (>200 buses)**
- Validate preservation of modal dynamics relative to full EMT model
- Quantify speed-up of simulation time relative to state-of-art (>16x target)
- Disseminate findings to industry and academia




10+ MW
2001
100+ MW
2004
1+ GW
2009
10+ GW
2013
100s of GW of Solar Penetration
DISPATCHABILITY
GRID PERFORMANCE AND RELIABILITY
POWER ELECTRONICS
COMMUNICATIONS