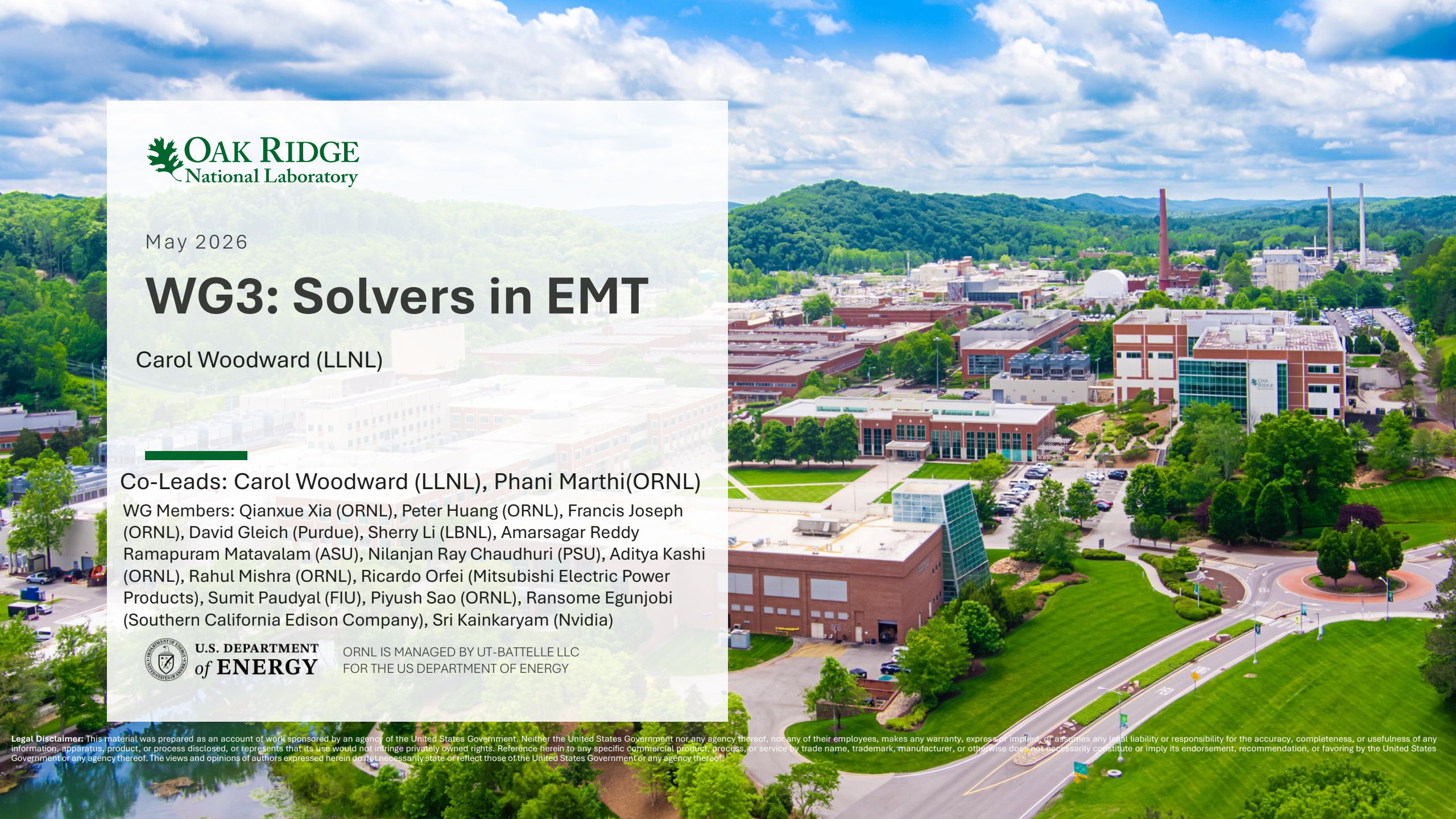

OAK RIDGE National Laboratory

May 2026

# WG3: Solvers in EMT

Carol Woodward (LLNL)

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WG Members: Qianxue Xia (ORNL), Peter Huang (ORNL), Francis Joseph (ORNL), David Gleich (Purdue), Sherry Li (LBNL), Amarsagar Reddy Ramapuram Matavalam (ASU), Nilanjan Ray Chaudhuri (PSU), Aditya Kashi (ORNL), Rahul Mishra (ORNL), Ricardo Orfei (Mitsubishi Electric Power Products), Sumit Paudyal (FIU), Piyush Sao (ORNL), Ransome Egunjobi (Southern California Edison Company), Sri Kainkaryam (Nvidia)

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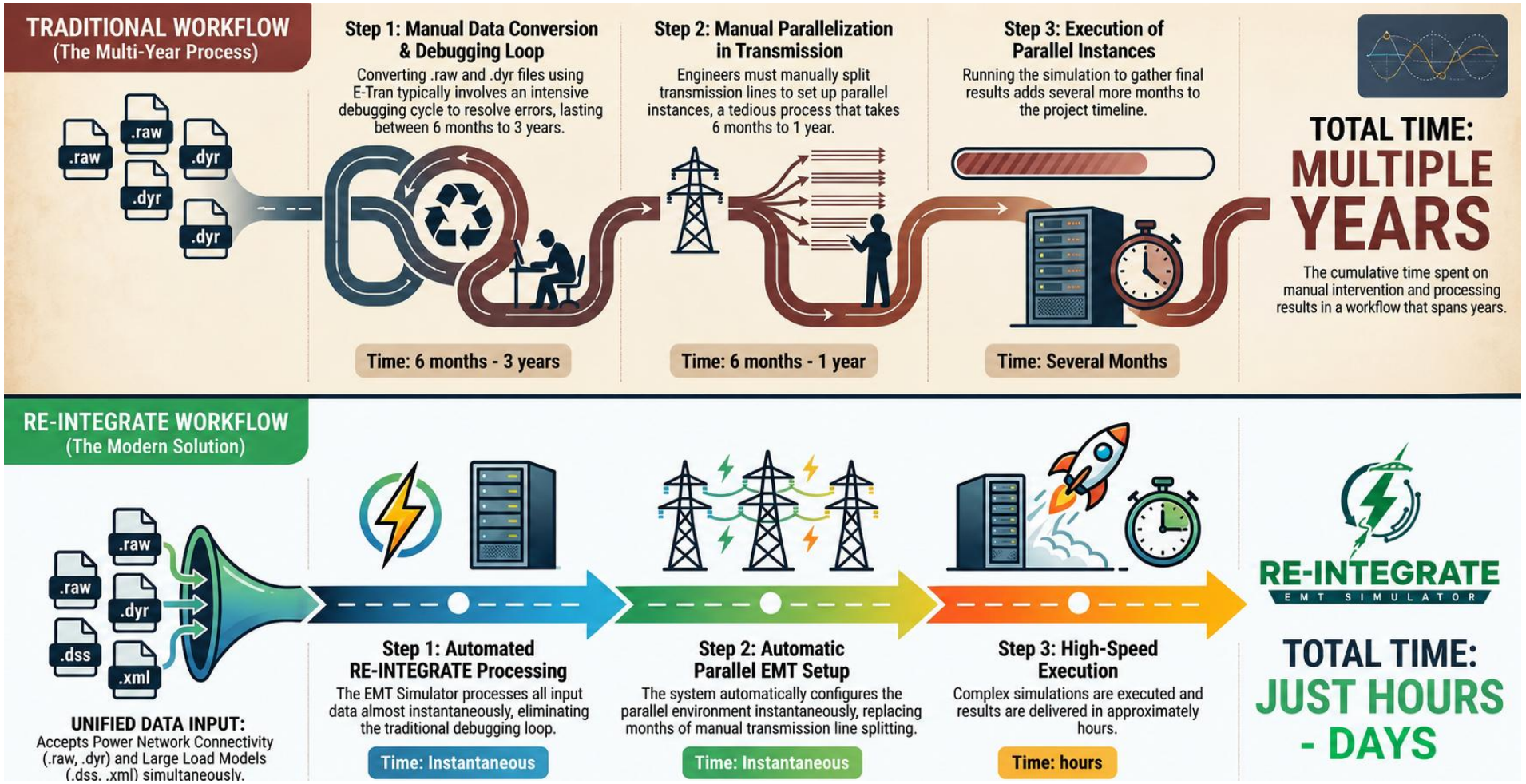
# Grand Challenge



# The Solvers Working Group scope focuses on the mathematical and computational aspects of the main time integration and algebraic solvers in EMT simulation

## Goal

Advance solver technologies and architectures for EMT simulation to address **slowness** of simulations and **limited scalability** of such simulations, with emphasis on **near real-time** studies of large-scale power grids comprising **tens of millions of nodes** and **millions of inverters**.



EMT: Electromagnetic Transient; DAE: Differential Algebraic Equations; CPU: Central Processing Unit; GPU: Graphical Processing Unit; AI: Artificial Intelligence

# We identified several gaps and challenges in integration and solvers for EMT simulation

Gaps

- Absence of automated parallelism in EMT
- Use of general-purpose solvers
- Use of general-purpose integrators (usually codes have these hard-coded in)
- Limited multi-node capabilities (including GPU, CPU-GPU, etc.)
- No standardized EMT benchmarks with reference solutions and defined Quantities of Interest (QoIs)
- Commercial tools lack extensibility for rapid algorithm integration
- Limited use of automation and intelligence

# Our research focuses on addressing these gaps

## Research Focus

1. Structure-aware solvers to optimize solve
2. DAE properties-based optimization of integration
3. CPU, GPU, and multi-node parallelism
4. Approximate solves
5. Multi-timestep solves
6. AI-based methods

## Impact

Speedup; Automation; Parallelism; Extensibility; Scalability; Intelligence



EMT: Electromagnetic Transient; DAE: Differential Algebraic Equations; CPU: Central Processing Unit; GPU: Graphical Processing Unit; AI: Artificial Intelligence

# Working Group activities include talks, webinars, and EMT Workshop contributions

- **Minisymposia at the Society for Industrial and Applied Mathematics (SIAM) Annual Meeting in July (Accepted). Will include 4 presentations with goal of engaging the math community**
    - Fundamentals of EMT
    - Mathematics for EMT
    - Ongoing Research in EMT
    - Advanced Solutions for EMT
- **Webinars**
    - May 2026: “Introduction to WG3”; "RE-INTEGRATE Fast Simulations"; “GPU-Based Power System Simulations”
    - Oct. 2026 - TBA
- **EMT Workshop Session**
    - Several topics related to integration, algebraic solvers, automated methods

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May 2026

# RE-INTEGRATE Fast Simulations

Phani Marthi (ORNL)

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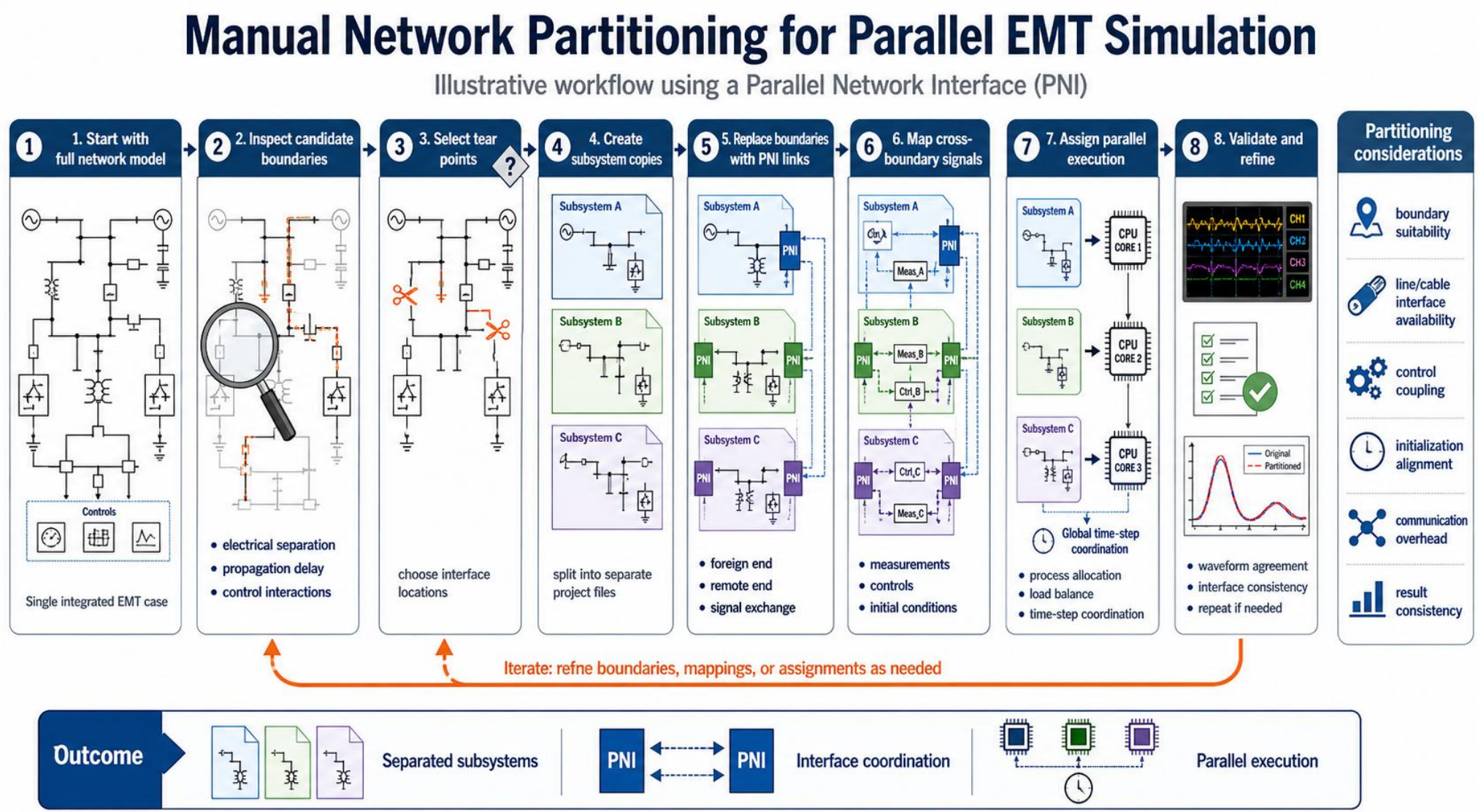
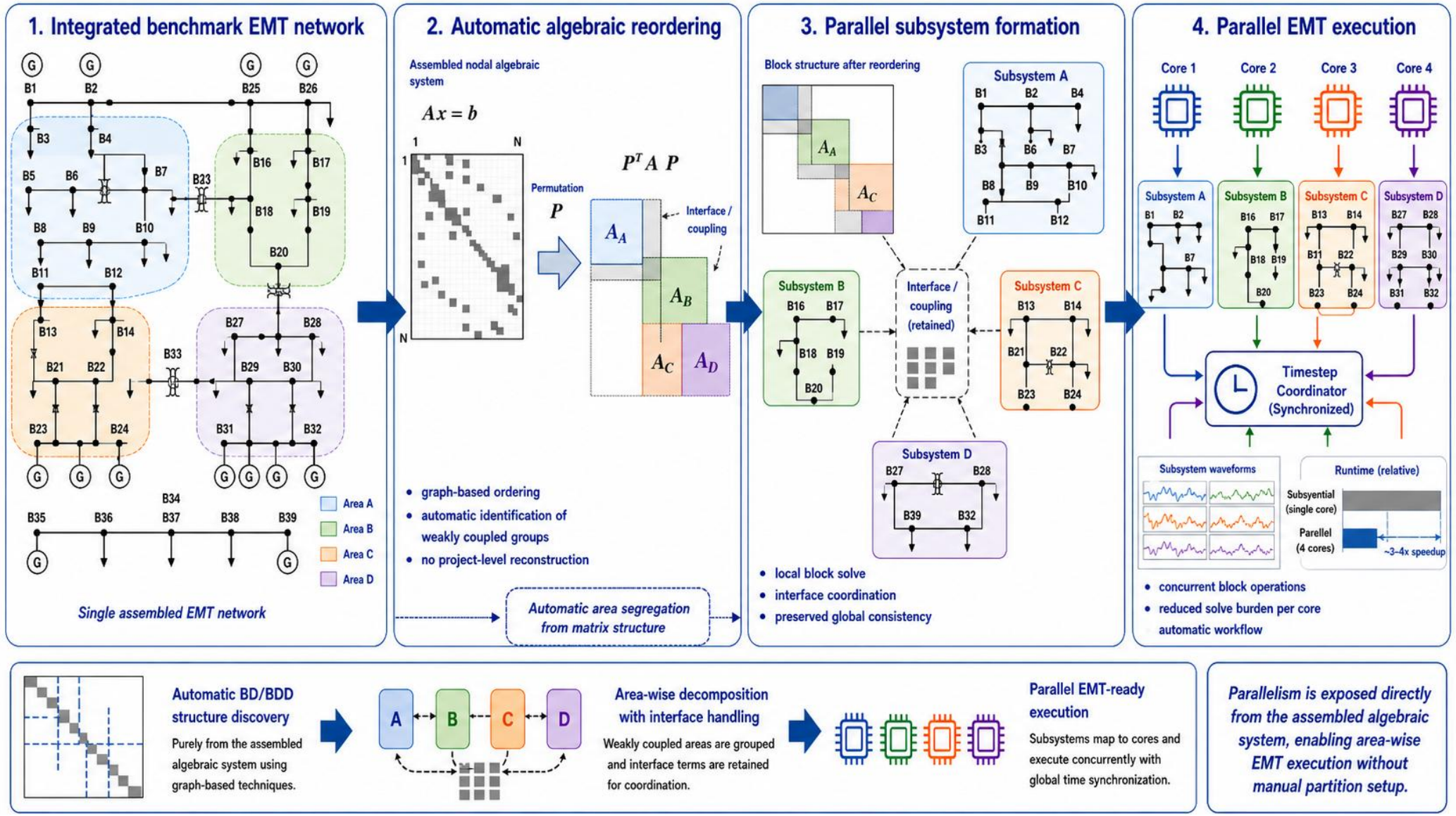
# State-of-the-art Parallelization Methods




***Extremely time-consuming; iterative***

# Next Generation RE-INTEGRATE Fast Simulations




***Extremely fast, Automatic, Optimal, and Accurate***

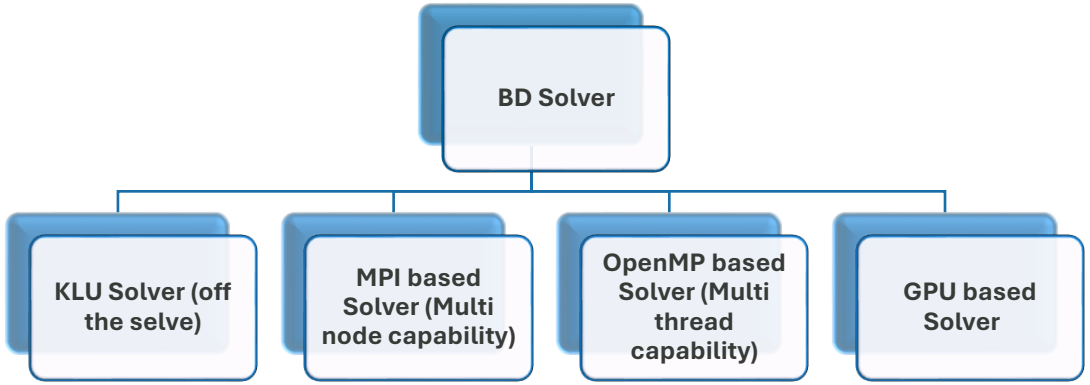
# RE-INTEGRATE EMT Simulation: Demo

## IEEE 3900-bus

# RE-INTEGRATE EMT Simulation: Demo

## IEEE 3900-bus (parallel)

# RE-INTEGRATE: GPU Capability

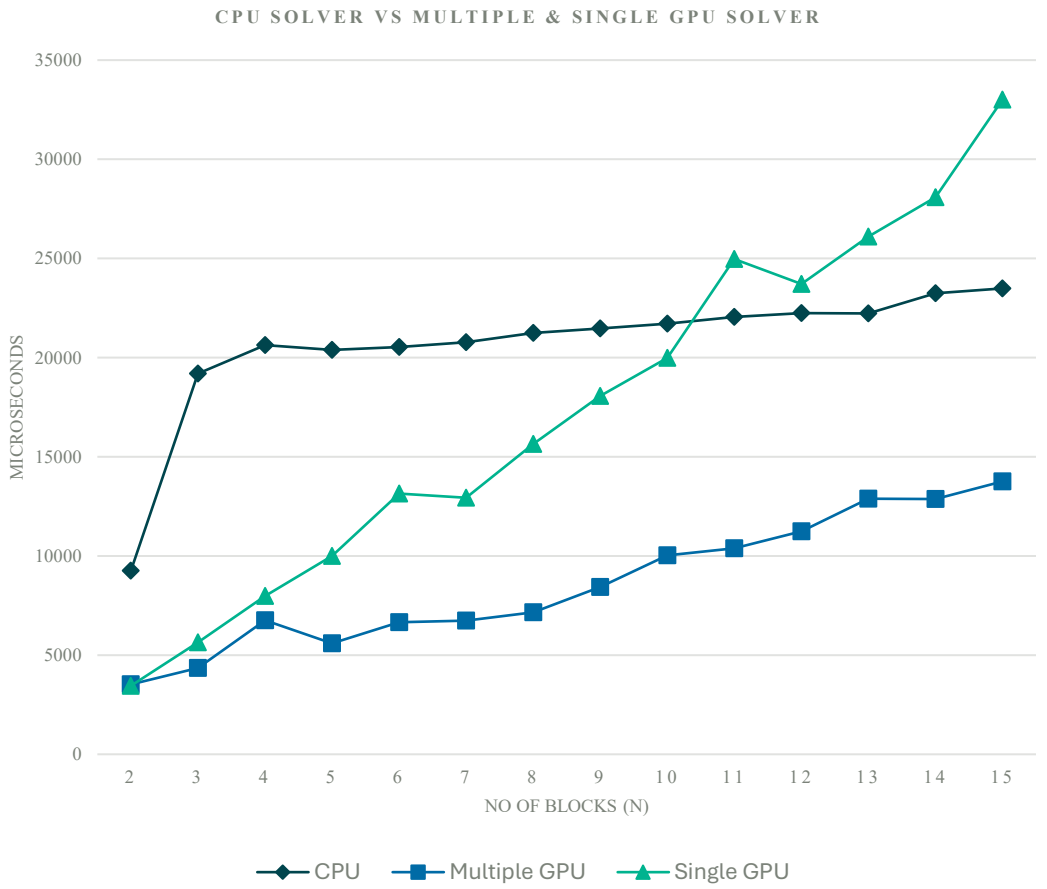



3900 Bus system

| Solver | Time (ms) |
|---|---|
| KLU | 30.05 |
| BD MPI | 21.06 |
| BD OpenMP | 5.70 |
| BD CUDA | 3.70 |

**~9x faster with BD**

- BBD – OpenMP, single-GPU, multi-GPU




**Up to ~1.8x faster with BBD**



*Journal: RE-INTEGRATE GPU Solvers & Use Cases*

# RE-INTEGRATE: AI Capability

| Case | Matrix size | Metis | Framework | Key structural gain | Steady solve impact | Matrix processing time | Solver setup time |
|---|---|---|---|---|---|---|---|
| **IEEE-3900** | 93,700 | BBD | BD | Border 555 → 0 | Solve time -96.2% | +3.4% | -99.9% |
| **IEEE-118 + IBR** | 5,376 | BBD | BD | Border 40 → 0 | Solve time -96.7% | +3.4% | -99.9% |
| **12-Feeder IBL** | 5723 | BBD | BBD | Border 243 → 183 | Solve time -15.1% | -2.0% | **Equal** |

The biggest gains appear when the framework preserves a natural matrix pattern instead of forcing a BBD

**The framework helps for two different reasons:**
**1.smaller separators for BBD cases**
**2. zero-border preservation for BD cases.**



*Journal: "Matrix Detection and Reordering Framework for Accelerating EMT Simulation in RE-INTEGRATE Software" in draft preparation*

BBD: Block Bordered Diagonal; GNN: Graph Neural Network

# Current Capabilities in RE-INTEGRATE

| Solvers | Types |
|---|---|
| Integrators | ImEx (hybrid discretization) |
| Solvers | KLU, SuperLU, BD (MPI, OpenMP, CUDA), BBD (Dense – MPI, OpenMP, CUDA – single GPU, multi-GPU) |
| Intelligence | BD and BDD matrix pattern recognition, BD reordering, BBD reordering (GNN, METIS) |
| Parallelism | OpenMP (COO-to-CSR, matrix/vector creation) |

# Thank you

*Acknowledgement: Thanks to the Office of Electricity's (OE) Advanced Grid Modeling Program for the support.*