GRID EMT
SIMULATION INITIATIVE



Overview of the EMT Initiative

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*Oak Ridge National Laboratory

08/18/2026

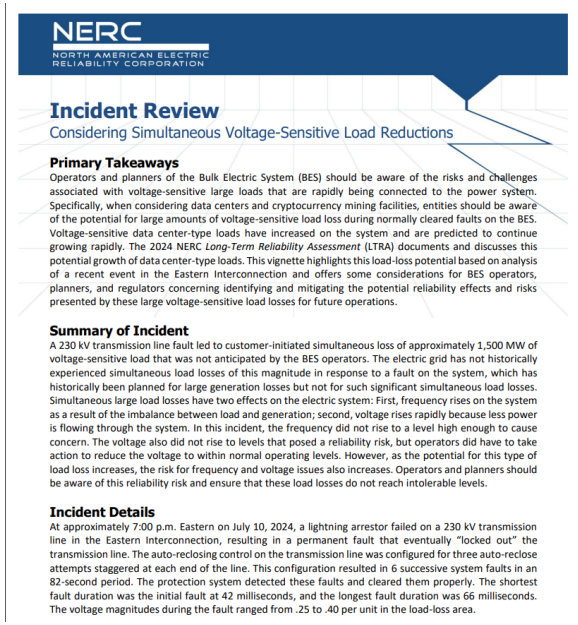
U.S. DEPARTMENT of ENERGY | Office of Electricity

Motivation

Needs Identified by NERC:
1. EMT simulations as more power electronics are integrated
2. Higher fidelity-models of connected devices in power grid



Courtesy: NERC

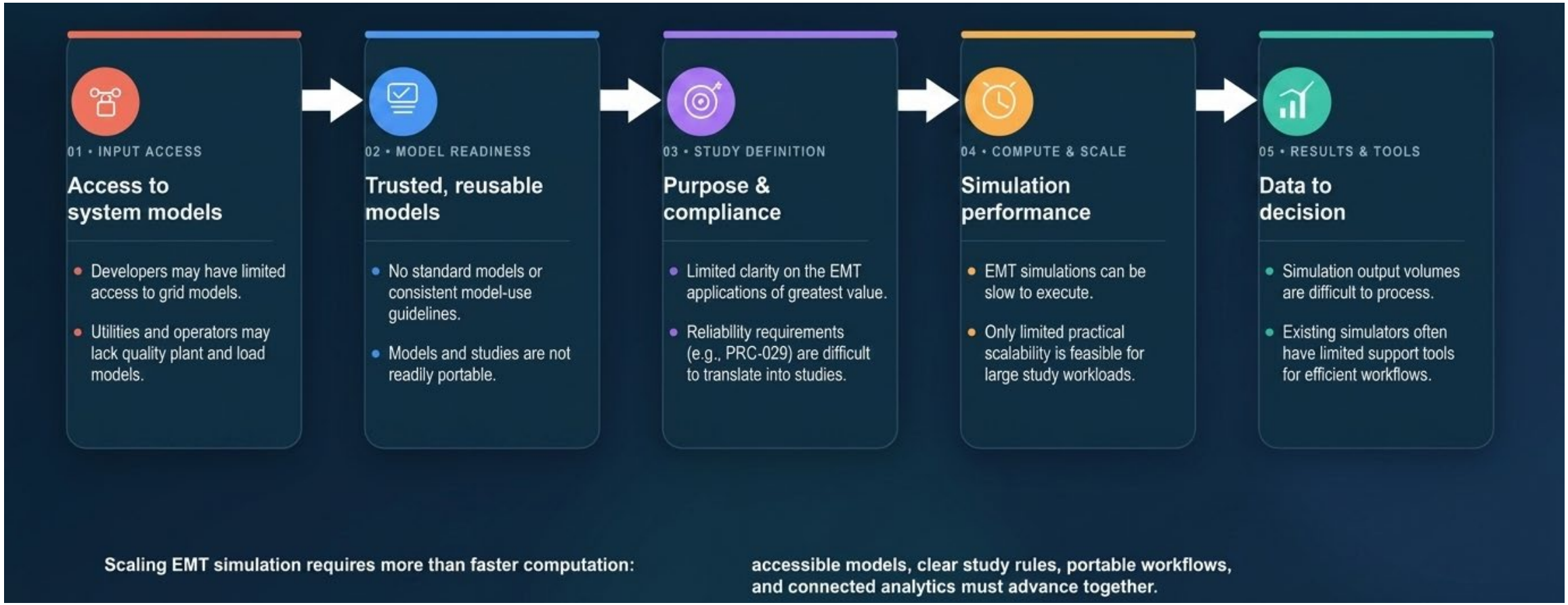


2025

Do not want to make the same mistakes with large loads (that were observed with generation plants – trips, oscillations)! – EMT simulations are needed for power electronics (large loads, HVdc, generation plants)!

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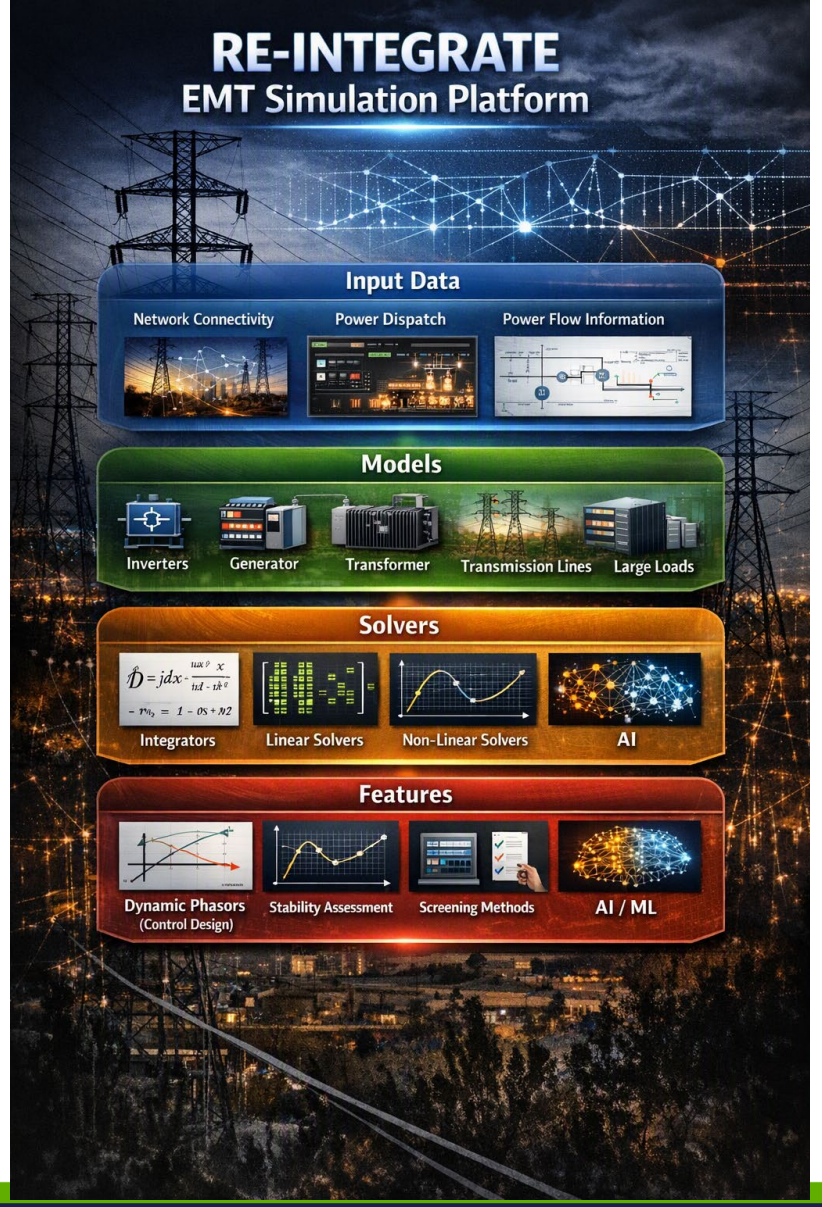
EMT Simulation – Challenges



EMT Initiative

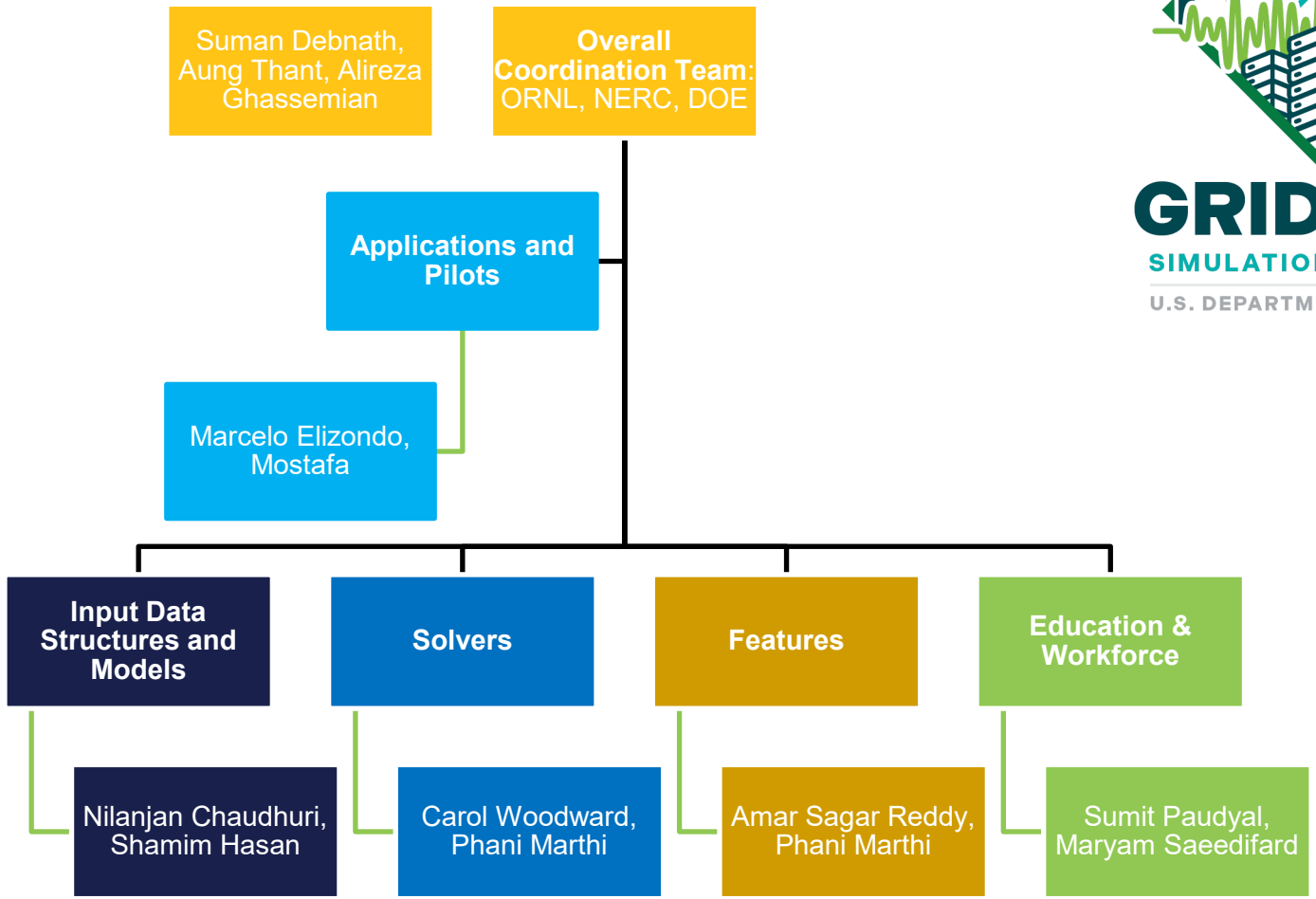
Bring together national labs, academia, and industry partners under one platform to accelerate the development and use of electromagnetic transient (EMT) simulation software.

- **Vision**
  - Enable **industry's transition** to EMT simulation for a secure, reliable future grid through an ecosystem.
- **Overall Goal**
  - Integrate models, data, validation, standards, and workforce training.
- **Impact (Near-Term)**
  - **Faster** interconnection studies
  - **Reliable** deployment of large loads and new generation
  - Higher **return** on **capital** and **lower capital** expenditure



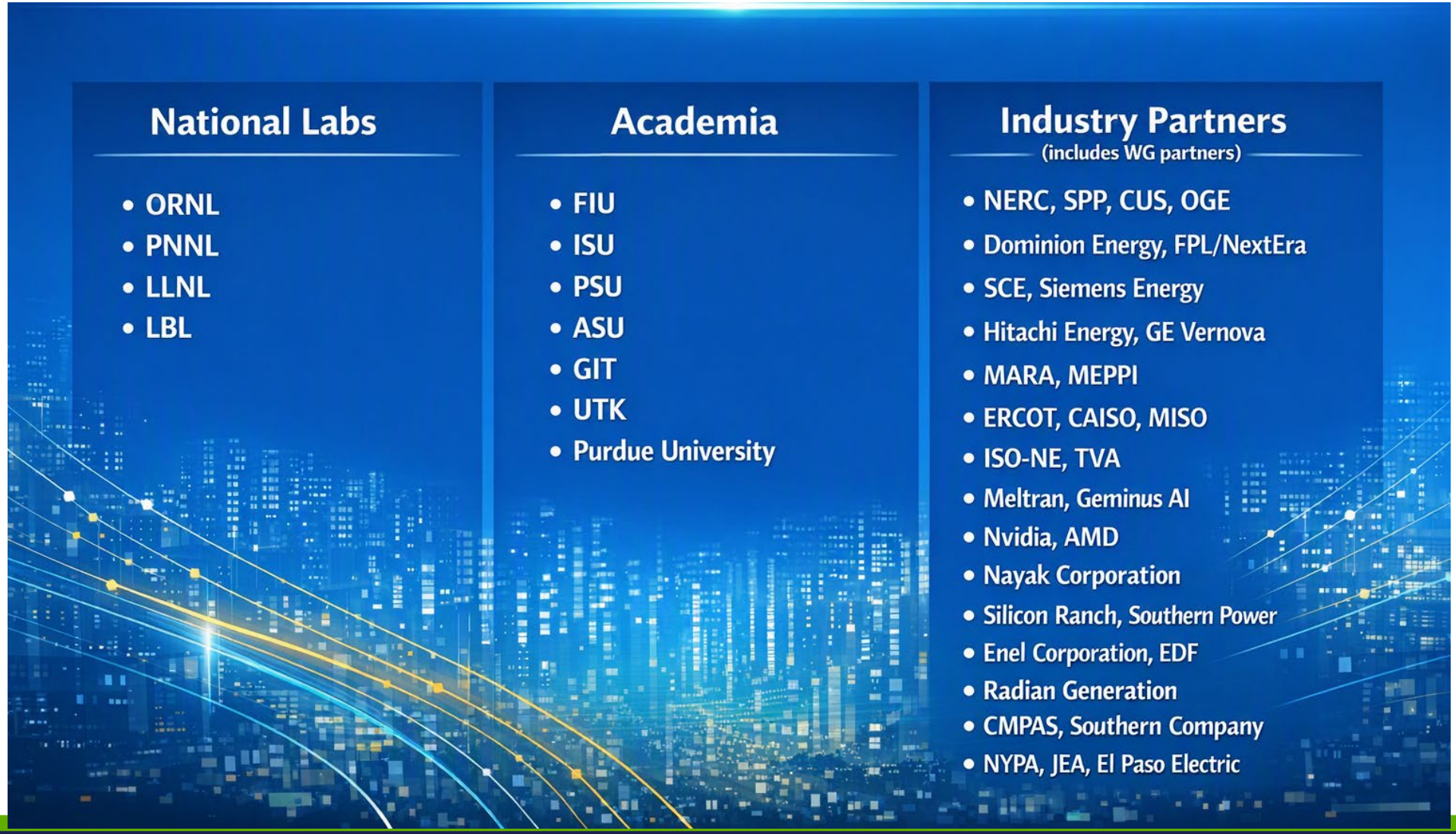
EMT Initiative: Working Groups

- Working groups created to work on problems identified with EMT simulations and provide solutions to the community!



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EMT Initiative: Team



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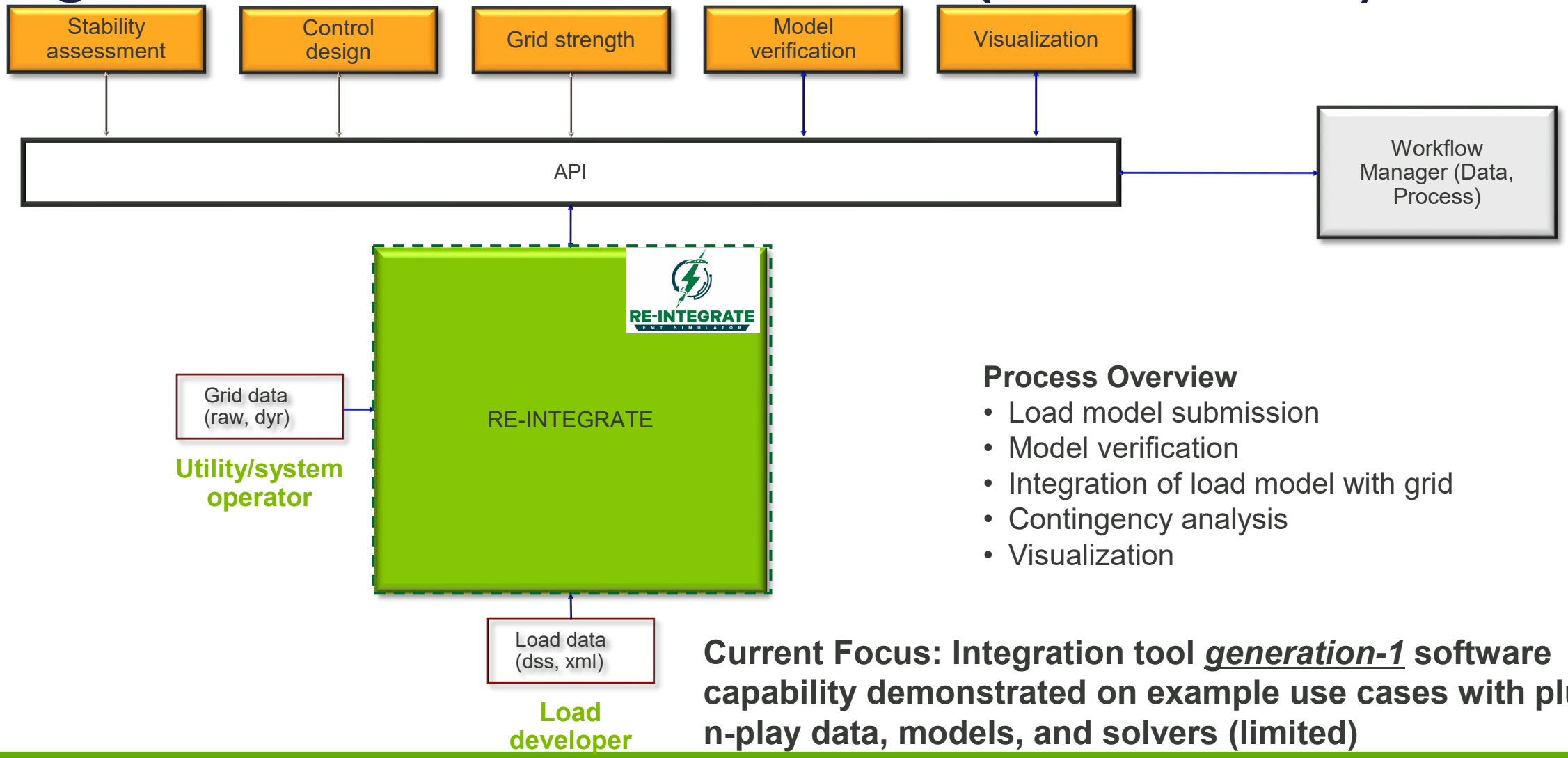
Applications

Applications: Challenges, Roadmap, & Ongoing Work

Challenge: Limited understanding of usage of EMT simulations – what applications are of interest?



Integration Tool: Current Year Effort (Generation-1)

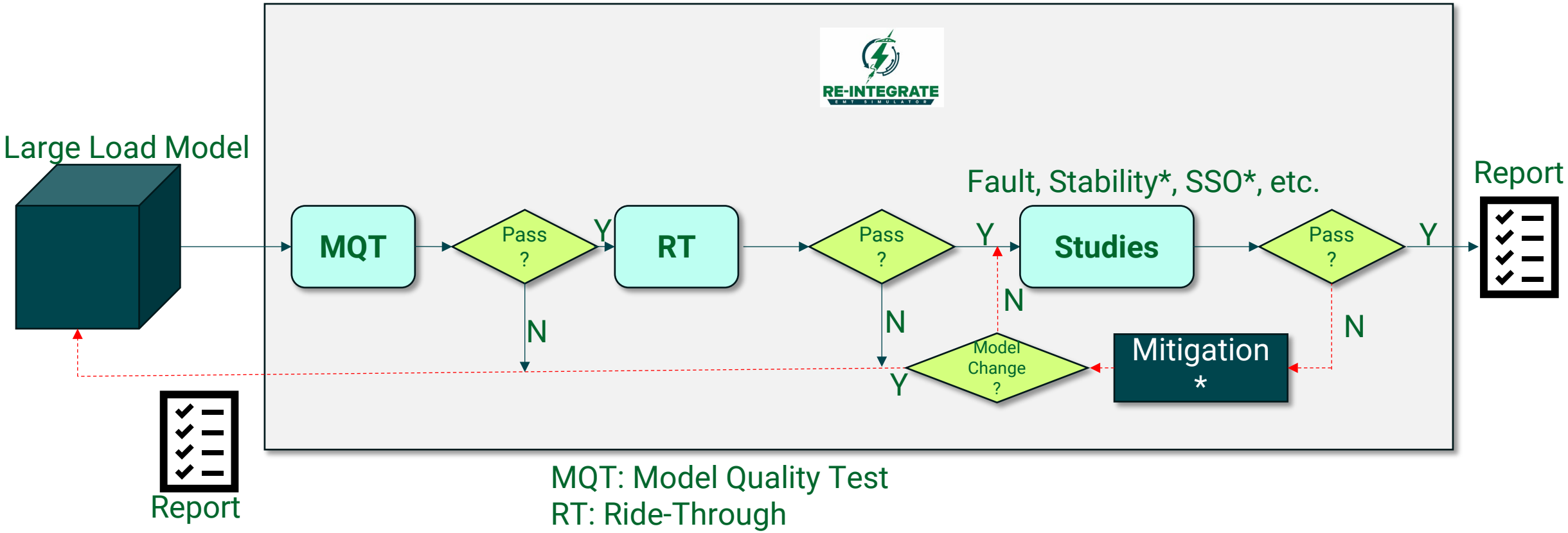


Process Overview

- Load model submission
- Model verification
- Integration of load model with grid
- Contingency analysis
- Visualization

Current Focus: Integration tool *generation-1* software capability demonstrated on example use cases with plug-n-play data, models, and solvers (limited)

Large Load Integration Process

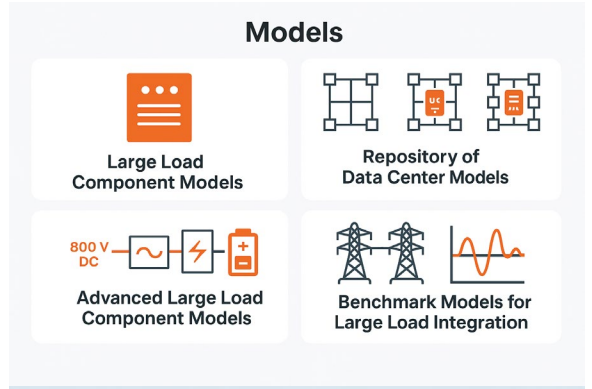


MQT: Model Quality Test
RT: Ride-Through
SSO: Sub-synchronous Oscillation
*SSO/Stability/Mitigation: Under R&D

v0.1 MQT, RT, and integration tool to be demonstrated on Wednesday (08/19)

Integration Tool: Needs

- **Input Data Structures & Models** – large load models, generation plant models, model quality needs, ride-through needs, commonly used data structures, common benchmarks
- **Solvers** – structure-aware solvers, solver intelligence, approximate solvers, performance characterization and optimization, integrators and characteristics enhancement – focus on speed-up
- **Features** – grid strength, control design, chatbot-assisted interpretation, visualization, contingency selection, event detection





Models & Input Data Structures

Models: Challenges, Roadmap, & Ongoing Work

Some of the challenges (models)

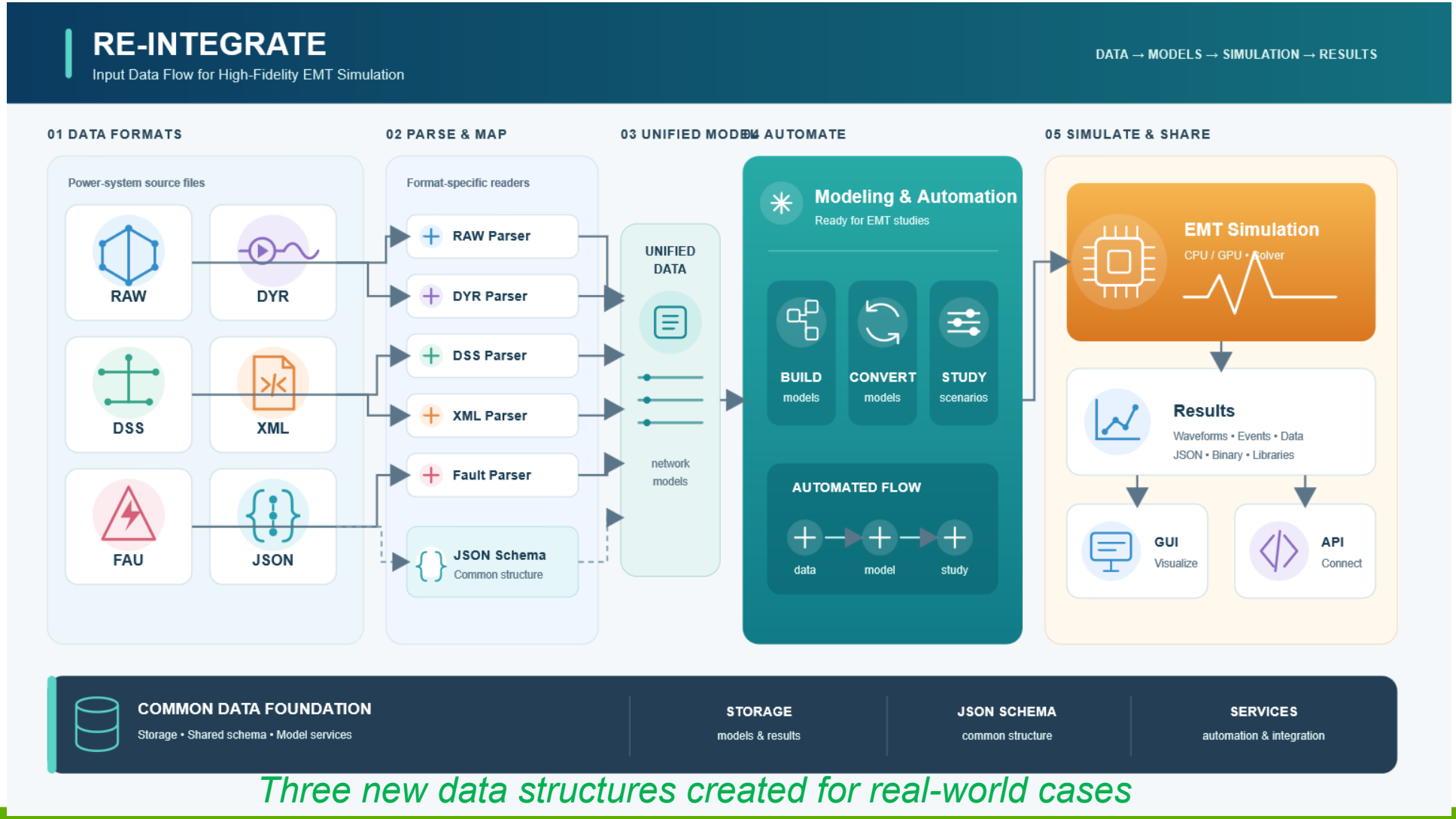
- No standard models are available or no guidelines on model usage (and no models in some cases)
- No standard benchmark models to evaluate EMT solvers and/or post-processing (features) capabilities
- Simulation is not portable – not transferable
- Translating reliability to EMT simulation studies (e.g., PRC-029 standard) – how to do it?

Roadmap: Models

Timeline	Activities
2 years	Standardized model architecture & performance
3 years	Repository of models (components, benchmarks)
3 years	Automated benchmarking capability and identification of misrepresentation of parameters

Goal: Input data structure and models that help with portability, standardization, details, and ease of usage

Input Data Structures



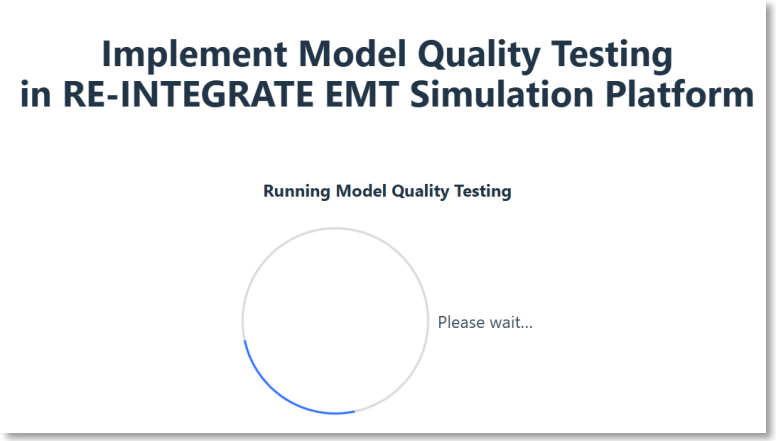
Three new data structures created for real-world cases

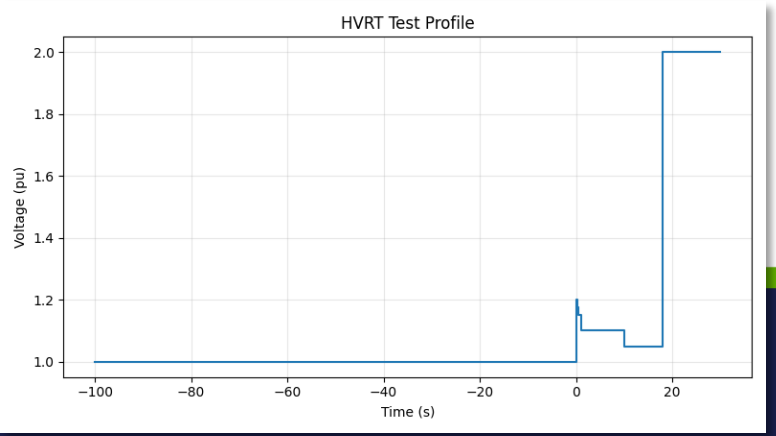
Models: Performance

- **Model Quality Test:**
  - Component Parameter Test
  - Functional Tests
    - Flat start
    - Small voltage disturbance
    - Phase jump angle
    - Grid strength
- **Ride-through Test**
  - Voltage ride-through
  - Frequence ride-through

The process is fully automated, and the user can change the ride-through curve, MQT needs.

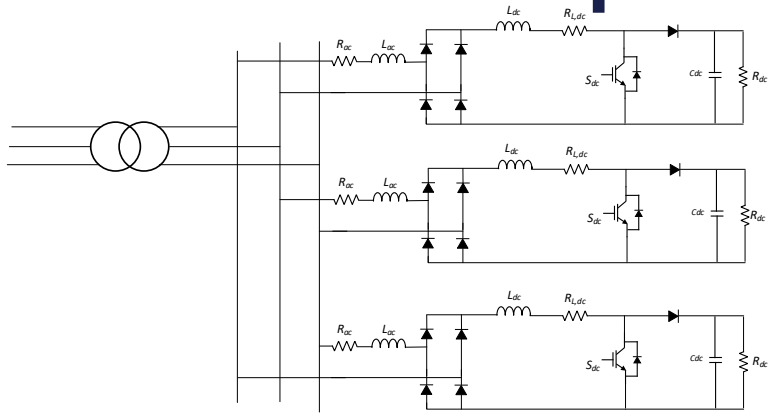
```
"Ride-through" :
{
    "Voltage ride through" :
    {
        "profile" : ["/host/input_files/Interconnection/profile_LVRT.txt",
                     "/host/input_files/Interconnection/profile_HVRT.txt"
                     ]
    },
    "Frequency ride through" :
    {
        "profile" : ["/host/input_files/Interconnection/profile_HzUP.txt"]
    }
},
```



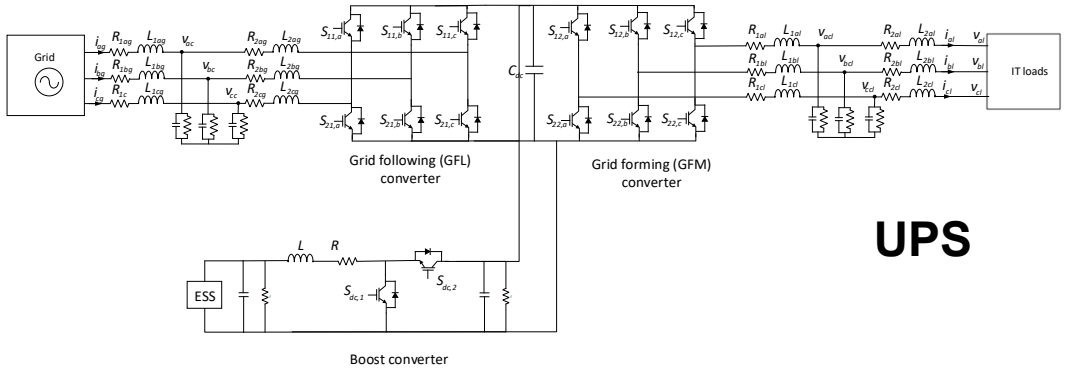



```
"MQT" :
{
    "Individual" :
    {
        "Component1" :
        {
            "ModelPath" : "/host/input_files/Interconnection/IBLParams.xml",
            "Parameters" :
            {
                "IBLConverter:IBL_hardware:R2ac_Ohm" :   [1.0e-3,2.0e-3],
                "IBLConverter:IBL_software:Kp_Q"     :   [0.3, 0.1]
            }
        }
    },
    "Functional" :
    {
        "Model" :
        {
            "Plant" : "/host/input_files/Interconnection/components12Feeders.dss",
            "Generic" :
            {
                "IBLConverter" : "/host/input_files/Interconnection/IBLParams.xml"
            },
            "OEM" :
            {
                "IBL1" : "/host/input_files/Interconnection/IBLParams.xml"
            }
        },
        "Test":
        {
            "Flat Start" :
            {
                "vmag"      : 1.0,
                "phase"     : 0,
                "frequency" : 60,
                "duration"  : 5
            },
            "Small voltage disturbance" :
            {
                "increase" :
                {
                    "at"        : 1,
                    "percent"   : 3,
                    "duration"  : 5
                },
                "decrease" :
                {
                    "at"        : 1,
                    "percent"   : 3,
                    "duration"  : 5
                }
            },
            "Phase angle jump test" :
            {
                "origin"    : 1,
                "jump"      : 1,
                "at"        : 1,
                "duration"  : 5
            },
            "Grid strength" :
            {
                "SCR" : [10,8,7,3,1],
                "duration"  : 5
            }
        }
    }
},
```

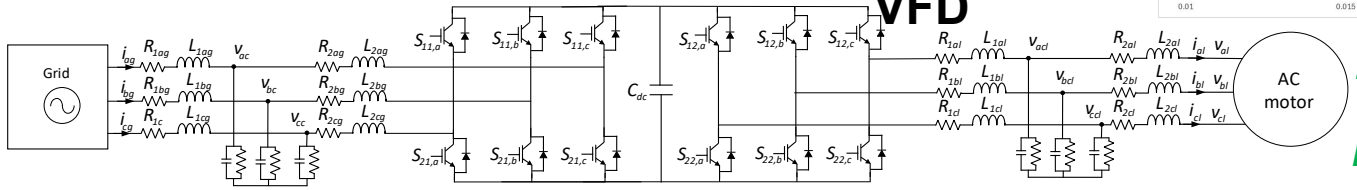
Models: Components & Sub-Systems



PSU

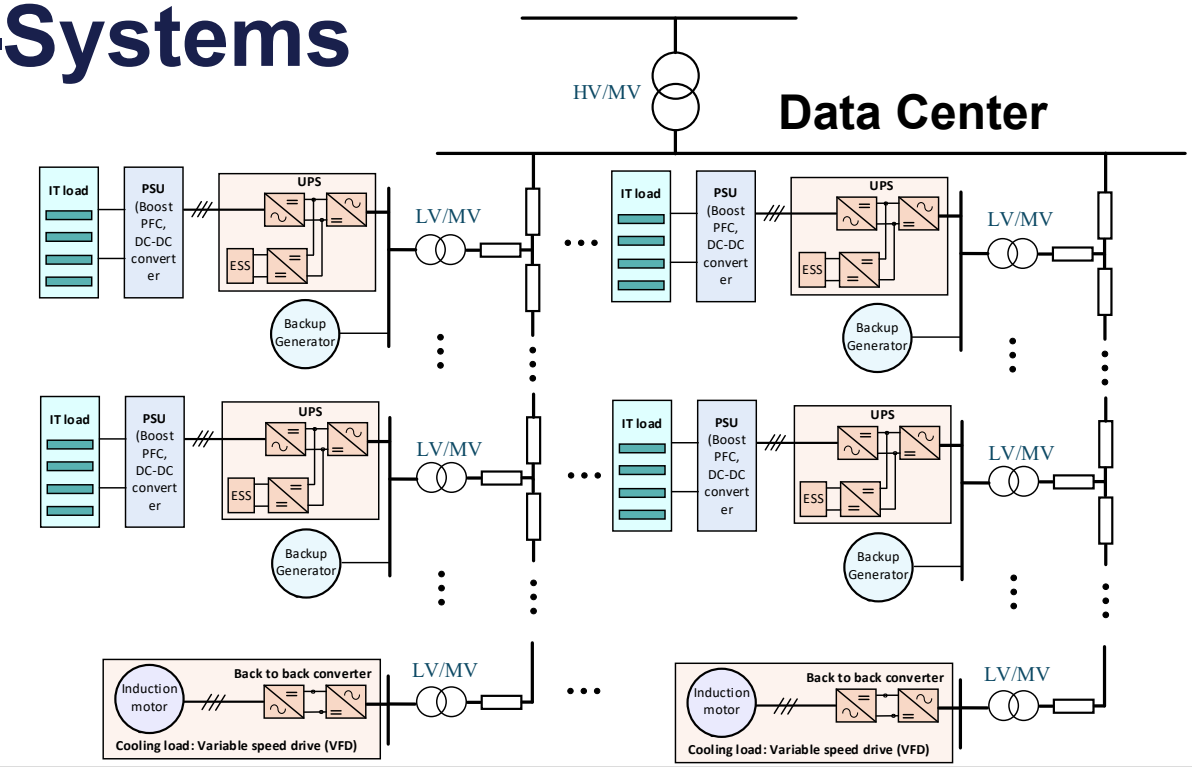


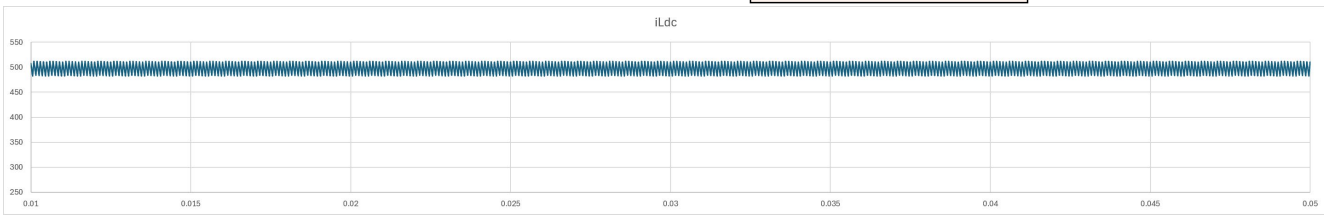
UPS



VFD

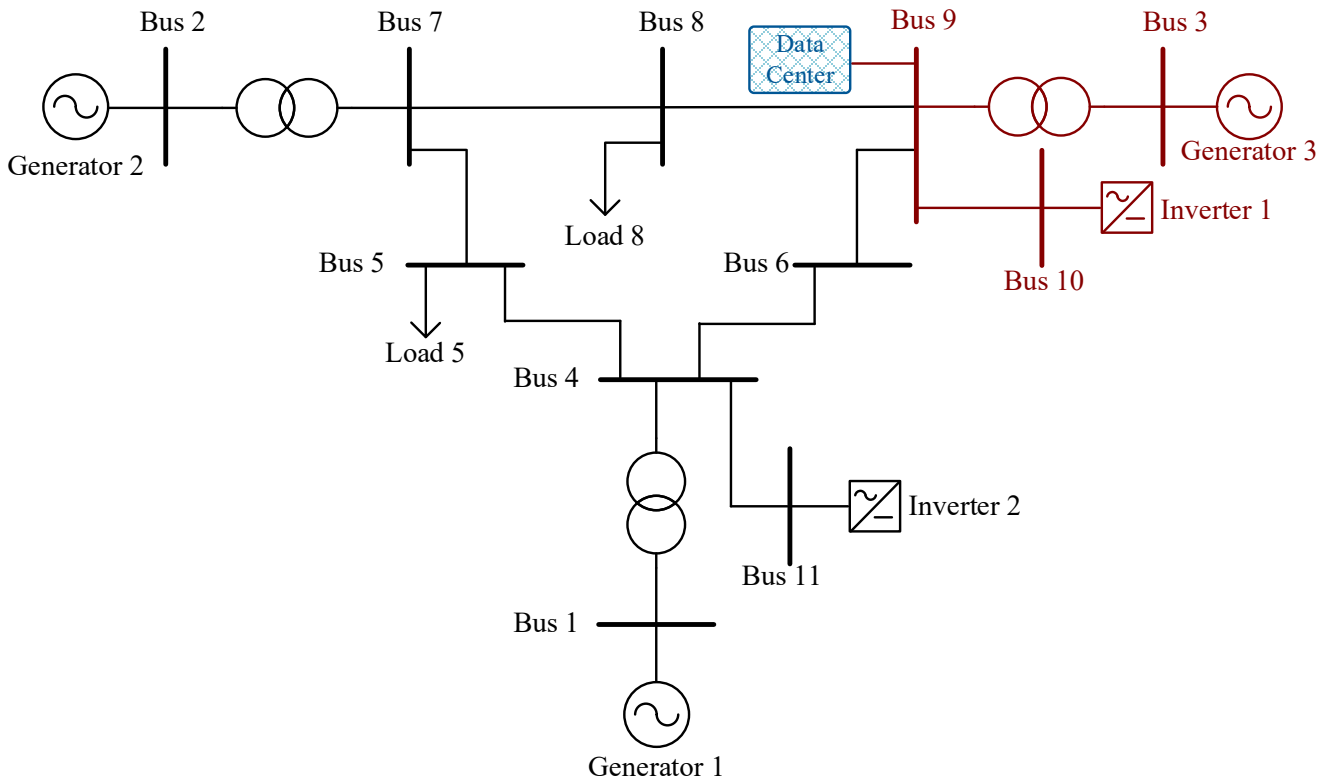
Back-to-back converter





Total of 100+ components present in RE-INTEGRATE library: traditional generators, inverters

Models: Benchmarks



IEEE 9-bus with Large Loads

Category	System	Component information
Small	IEEE 9-bus (WECC)	3 generators, 9 buses, 3 loads, 6 lines, and 3 transformers
Small	IEEE 39-bus (New England)	10 machines, 19 loads, 34 lines, and 12 transformers
Medium	240-bus Reduced WECC	109 machines, 37 renewable. 329 lines, 122 transformers, 139 loads
Medium	Texas 2000-bus synthetic	2751 buses, 1099 generators, 1351 transformers, 2993 lines, 1410 loads (86 GW)
Large	70k-bus EI synthetic	10390 generators, 38181 loads (595 GW), 71353 lines, 10554 transformers, 2100 3-winding transformers

In collaboration with Pacific Northwest National Laboratory

Three new benchmark scenarios created in small use case

Solvers

Solvers: Challenges, Roadmap, & Ongoing Work

Some of the challenges (solvers)

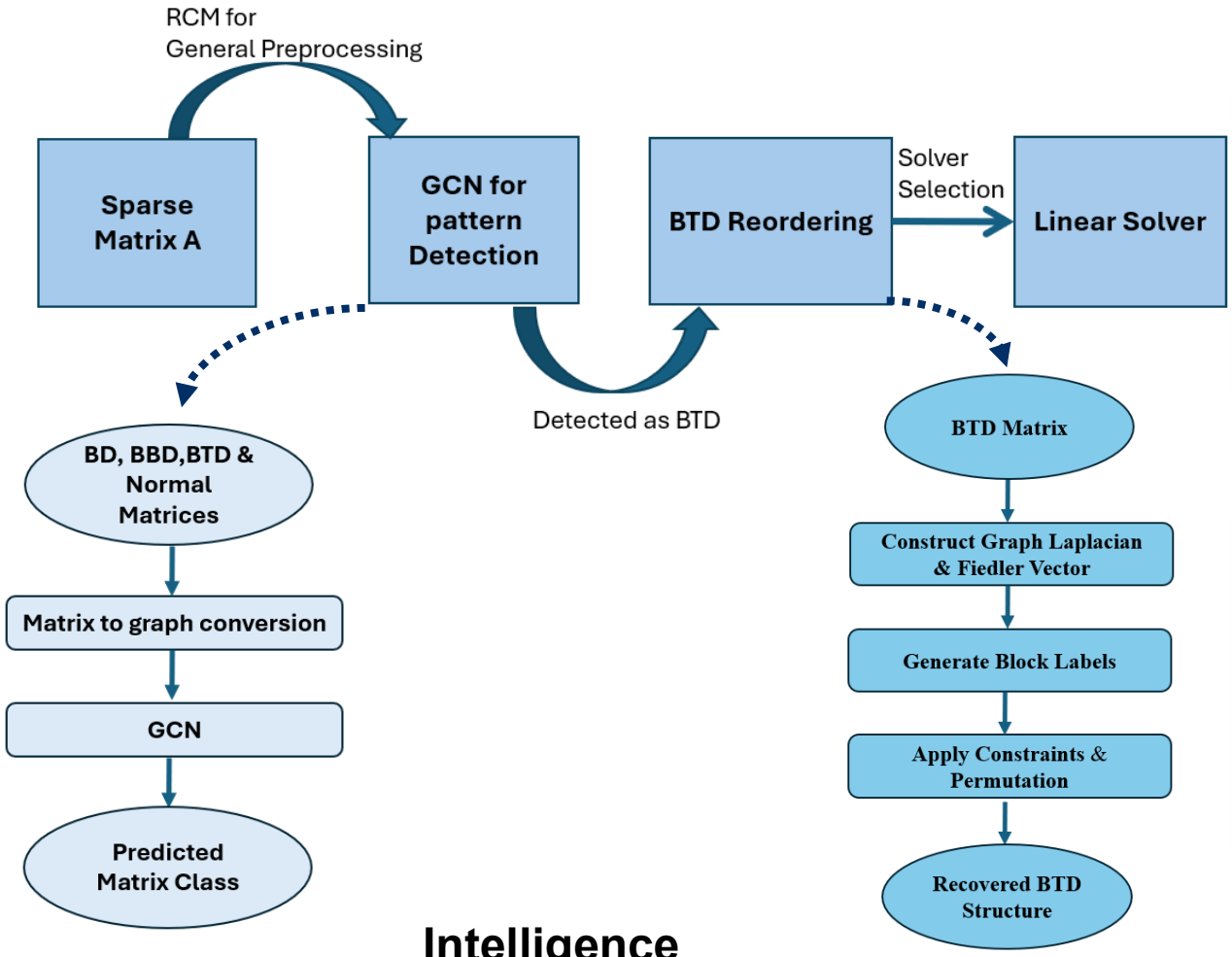
- Slow nature of simulations
- Limited scalability feasible with simulations

Roadmap: Solvers in RE-INTEGRATE

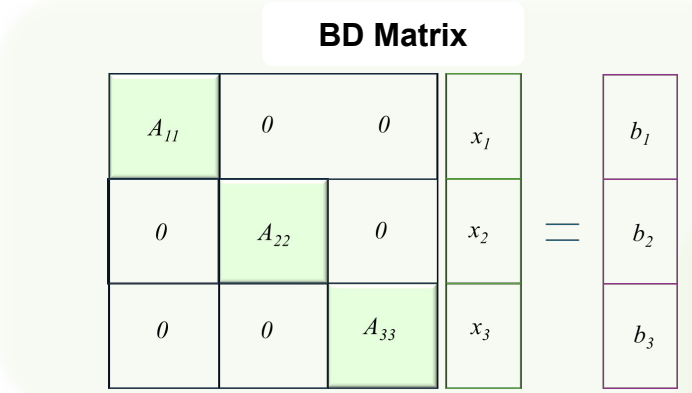
Timeline	Activities
2 years	• Structure-aware solvers with intelligence. • ImEx integrators and detection capabilities. • Preliminarily showcase plug-and-play capability and scalability – GPU usage.
3–5 years	• Mixed-precision solvers and integrators with various special properties of DAEs. • Confirmatory plug-n-play capability with latest solver/integrator capabilities.
10 years	• Enable near–real-time simulation of tens of million-node grids and millions of inverters. • Deploy trustworthy AI-assisted EMT simulations with robust validation.

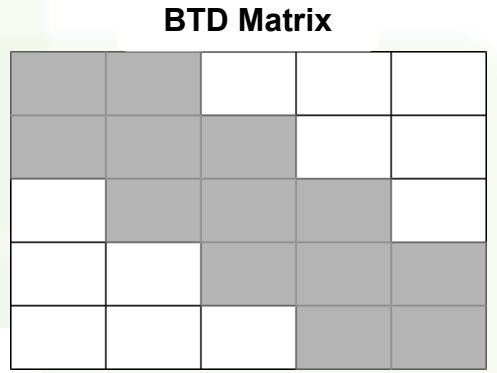
Goal: Integrators and solvers that help with near-real-time simulation for 10 millions of power grid with millions of inverters

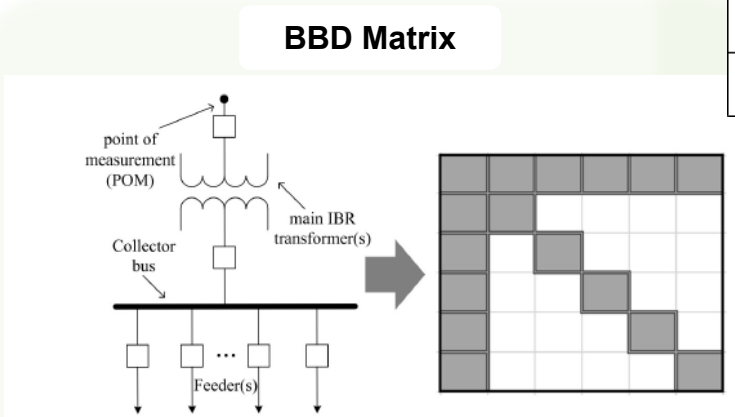
Solvers: Structure-Aware & Intelligence



Intelligence







Matrix Structures

In collaboration with Florida International University

Up to 12x speed-up observed

Solvers: Plug-n-Play

Iterative Solvers

Method	Execution Time (ms)	Speedup vs. KLU	Error Norm
KLU (Circuit-Optimized Direct)	22.330	1	4.478×10^{-7}
GMRES (Left Preconditioned)	10.086	2.2	4.478×10^{-7}
GMRES (Right Preconditioned)	5.352	4	4.478×10^{-7}
BiCGSTAB (Right Preconditioned)	4.198	5	4.478×10^{-7}

In collaboration with Arizona State University, Purdue University, Lawrence Berkeley National Laboratory

Plug-n-play capability observed

Features

Features: Challenges, Roadmap, & Ongoing Work

Some of the challenges (features)

- Difficulty with processing tremendous amount of data from simulations
- Difficulty with using the existing simulators with limited support tools

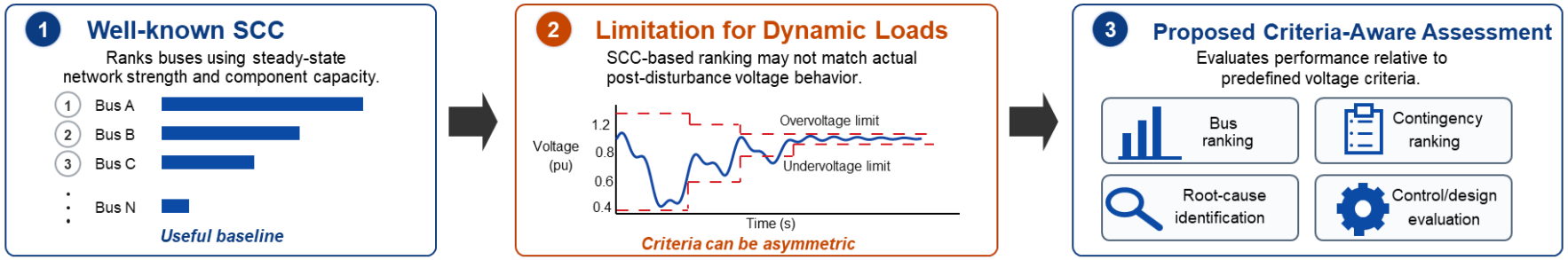
Roadmap: Features in RE-INTEGRATE/Applications

Timeline	Activities
2 years	• Screening methods to identify weak grids • Control design • Automated EMT report generation
3 years	• Data-driven methods to directly quantify instabilities • Geospatial visualization • Automated contingency selection
5 years	• Automated model diagnostics • Automated linear/nonlinear model identification • Generative AI-driven EMT scenario generation
10 years	• Generative AI-driven EMT simulation – automated workflows with chatbox • Implementation of standardized interfaces for EMT simulators

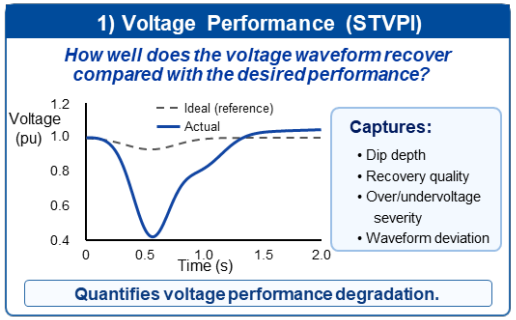
Goal: Enhance ease of usage using tools, automation, and foundational capabilities needed

Features: Grid Strength Metrics Post-Processing (Screening)

New grid strength metrics evaluated for dynamics in the system



Short Term voltage performance index



- STPSI: Short term voltage stability index
- STVTI: tripping caused by short term voltage behavior

New grid strength metric worked on

In collaboration with Iowa State University

Features: Control Design for EMT

New control design processes under exploration with preliminary benefits observed

Get operating point and parameter values (not automated, directly obtained from EMT simulation)

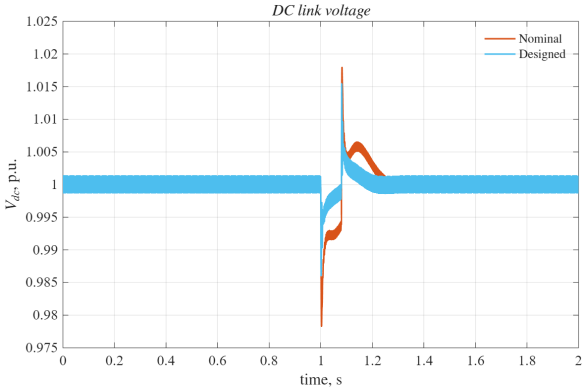
User input: control parameters to be tuned

Calculate dynamic phasors

User input: desired maximum settling time of all modes

Sweep user-defined control parameters to plot the root locus

Designed values



In collaboration with PSU

Features: LLM-Assisted Post-Processing (Analytics)

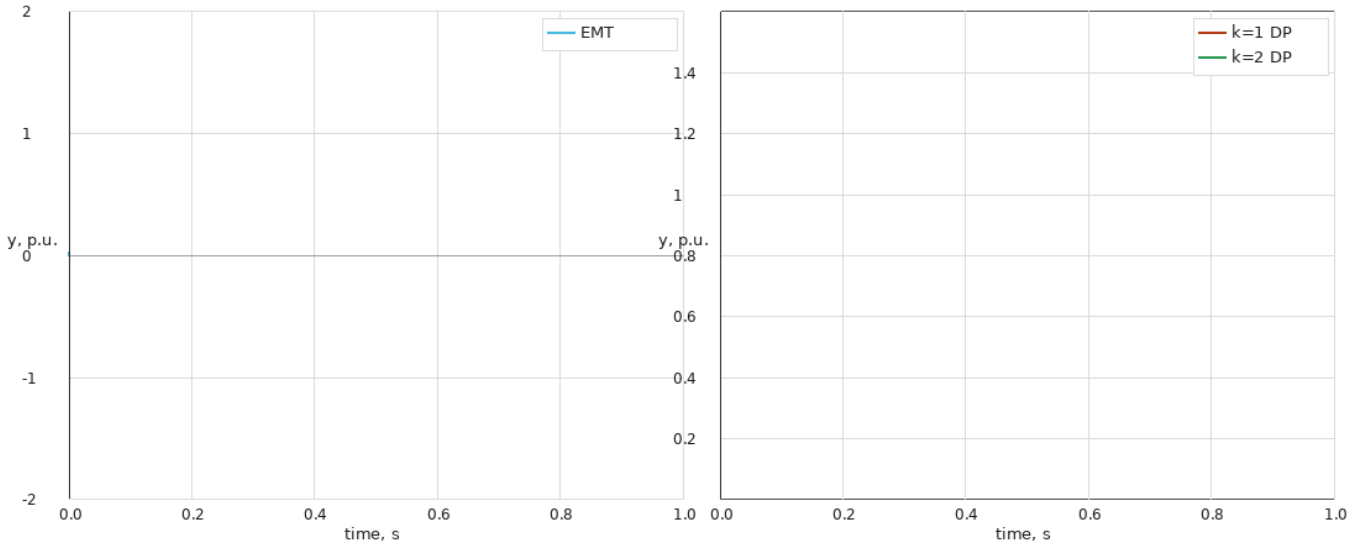
Automated assist for understanding simulations

Metadata Parser → **Selective streaming Loader** → **Feature Extractor** → **Query + Reports**

Avoid loading large data sets

Dip depth, settling, oscillations,

Query engine, automated plots, report



Feature extraction (sample)

In collaboration with PNNL

Features: Contingency Selection

TODAY · BRUTE FORCE

- **Many failures, little data**

  A large candidate set, sparsely labelled.

- **Inefficient analysis**

  EMT spends most of its time on benign cases.

- **Slower decisions**

  Severe cases surface late, or not at all.



PROPOSED · SELECT, THEN SIMULATE

- **Contingency selection**

  Rank every candidate cheaply. Keep the few above the cut-off severity.

- **Focused analysis**

  Full EMT only where it changes the answer.

- **Reliability, sooner**

  The severe cases arrive first, with a defensible reason.

Reduced set of simulations to evaluate contingency on

Applications – Integration Tool: Generation-0.1

Interconnection Tool
RE-INTEGRATE EMT Simulation Platform

RE-INTEGRATE
EMT SIMULATOR

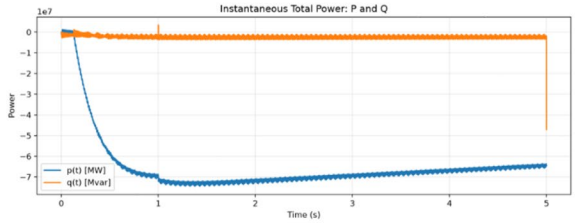
No	Study	Select
1	Model Quality Testing	☐
2	Ride Through Testing	☐
3	Interconnection Study	☐

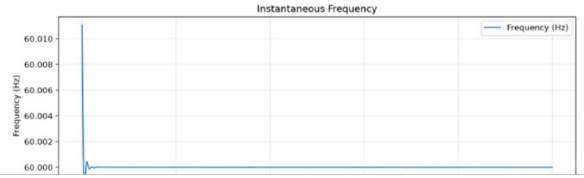
Run Interconnection Tool

Interconnection Study Results
RE-INTEGRATE EMT Simulation Platform

The parameter 'IBLConverterGroup:IBLConverter:IBL_hardware:R2ac_Ohm' has been verified.

The parameter 'IBLConverterGroup:IBLConverter:IBL_software:Kp_Q' has been verified.





Education & Workforce Development

Education & Workforce Development: Challenges, Roadmap, & Ongoing Work

- Some of the challenges (education & workforce development)
  - Limited understanding of usage of EMT simulations – what applications are of interest and what are the requirements and processes that are needed?

Roadmap: Training

Timeline	Activities
<2 years	• Create metrics that define progress in skills in EMT. • Develop course modules on basics and fundamentals of EMT. • Create a repository of resources using open-source tools. • Organize panels and webinars across various communities (power grid, applied mathematics, computing).
5 years	• Develop course modules on applications and advanced features of EMT. • Develop examples and test systems using open-source tools. • Develop and offer new courses on EMT at undergraduate and graduate levels. • Develop and offer tutorials on theory and open-source tools.
10 years	• Develop training resources for continuous learning.

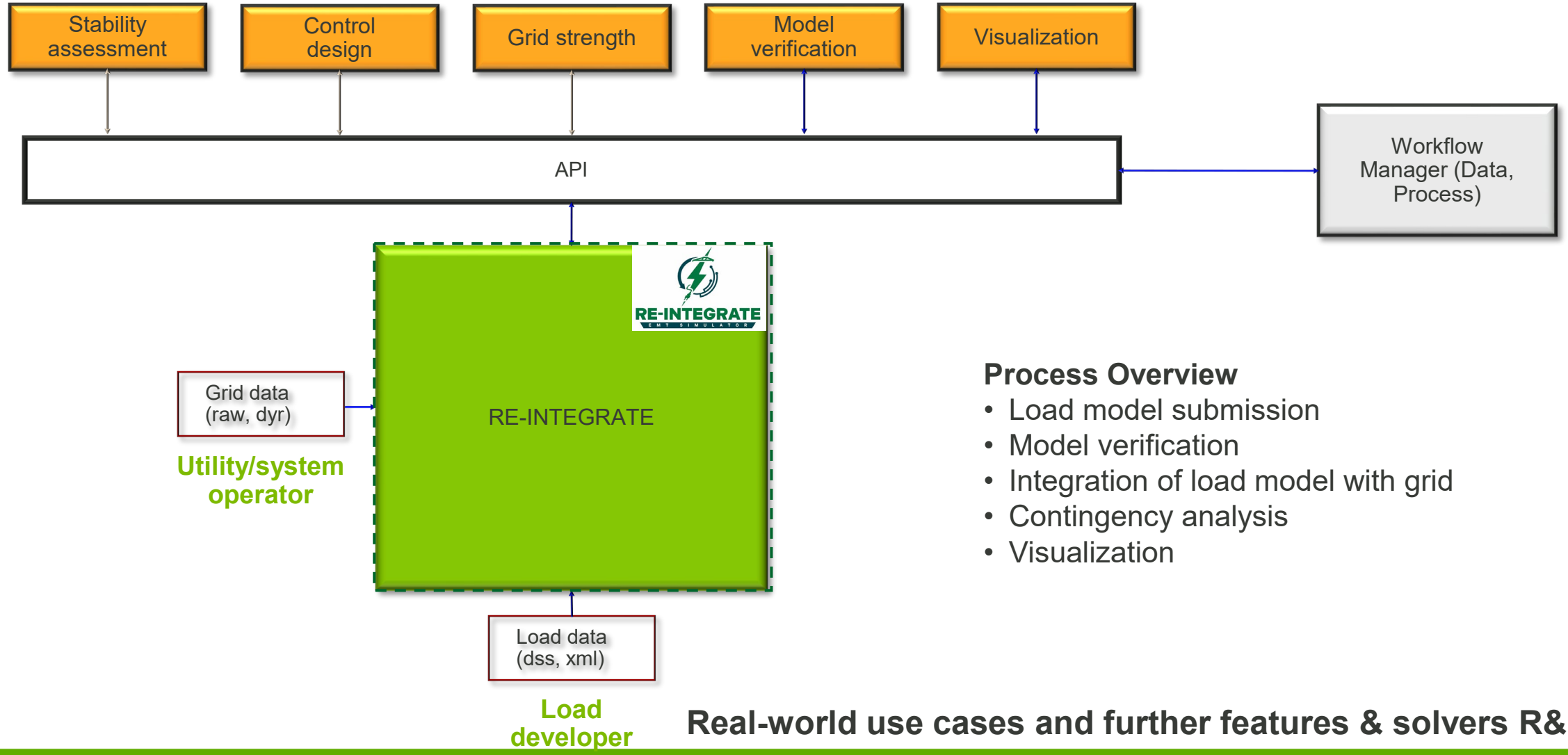
Goal: Educate, train, and create next-generation workforce working with academia and training institutes

Ongoing: Workshops, webinars, trainings, panels, symposiums, tutorials

Events: https://events.ornl.gov/emt-simulations/

Next Steps

EMT Initiative: Next Steps



Process Overview

- Load model submission
- Model verification
- Integration of load model with grid
- Contingency analysis
- Visualization

Real-world use cases and further features & solvers R&D

EMT Initiative: Next Steps

	Integration	Planning	Operation Assist	Operational Decision-Making
Impact	• ↓ capital expenditure • ↑ speed interconnection studies process (~10×)	• ↑ return on capital • ↑ integration of data centers	• ↑ return on capital • ↓ capital expenditure	• ↑ return on capital • ↓ capital expenditure • 10× reduction in reliability events
Use Cases (Not an exhaustive list)	**(Localized Studies)** • Data center integration • Manufacturing integration • Crypto-currency mining • Generation interconnection	**(Regional Studies)** • HVDC planning • Transmission planning • FACTS	**(Larger Interconnection Studies)** • Automated post-event analysis • Detection of events	**(Larger System Studies)** • Predictive mitigation of events • 10× reduction in reliability events • Real-time state estimator and dynamic stability analysis
Timelines	Near-Term (1–3 Years)	Near-Term (2–4 Years)	Medium-Term (5–7 Years)	Long-Term (~10 Years)
Beneficiaries	**Developers, local utilities, consultants**	**Local utilities, reliability coordinators, consultants**	**Regional utilities, system operators, reliability coordinators**	**Large system operators, utilities, reliability coordinators**

A lot of work is left in R&D of all the applications!!

Acknowledgement

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Questions? debnaths@ornl.gov

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Events: https://events.ornl.gov/emt-simulations/

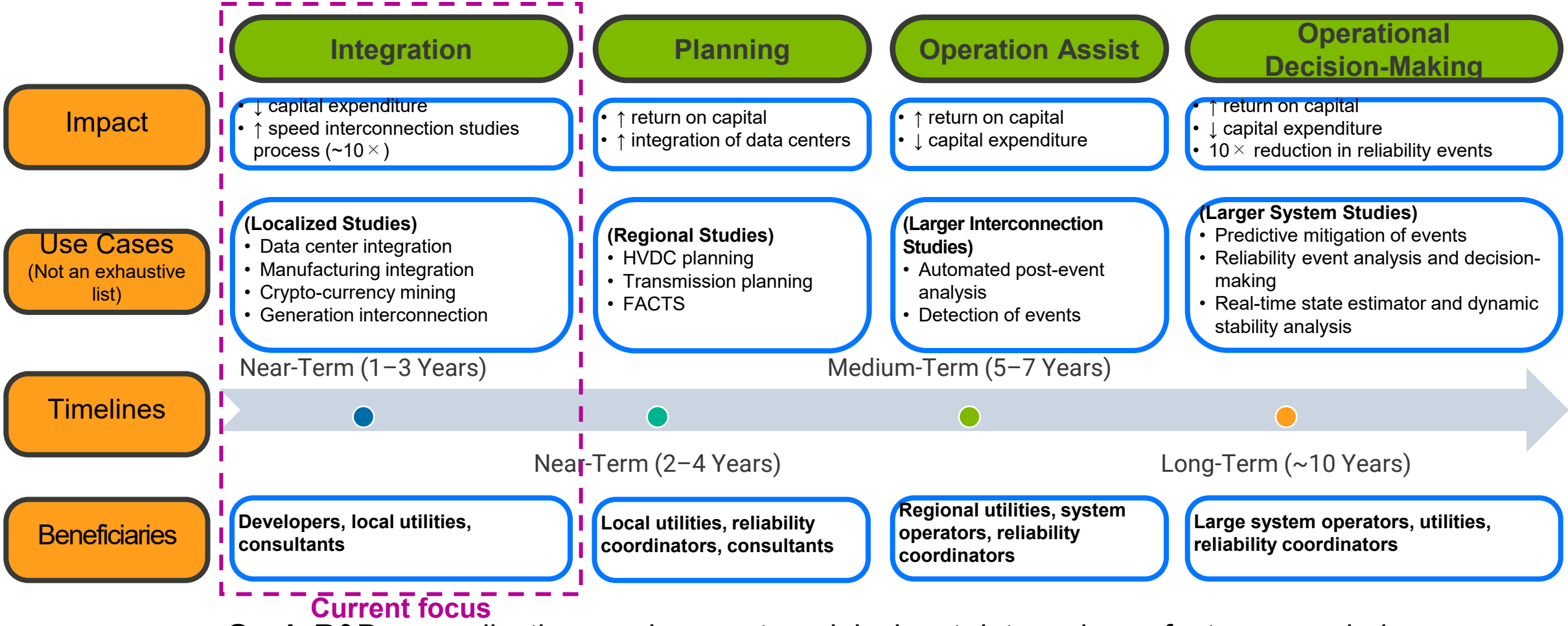


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Applications: Challenges, Roadmap, & Ongoing Work

Challenge: Limited understanding of usage of EMT simulations – what applications are of interest?



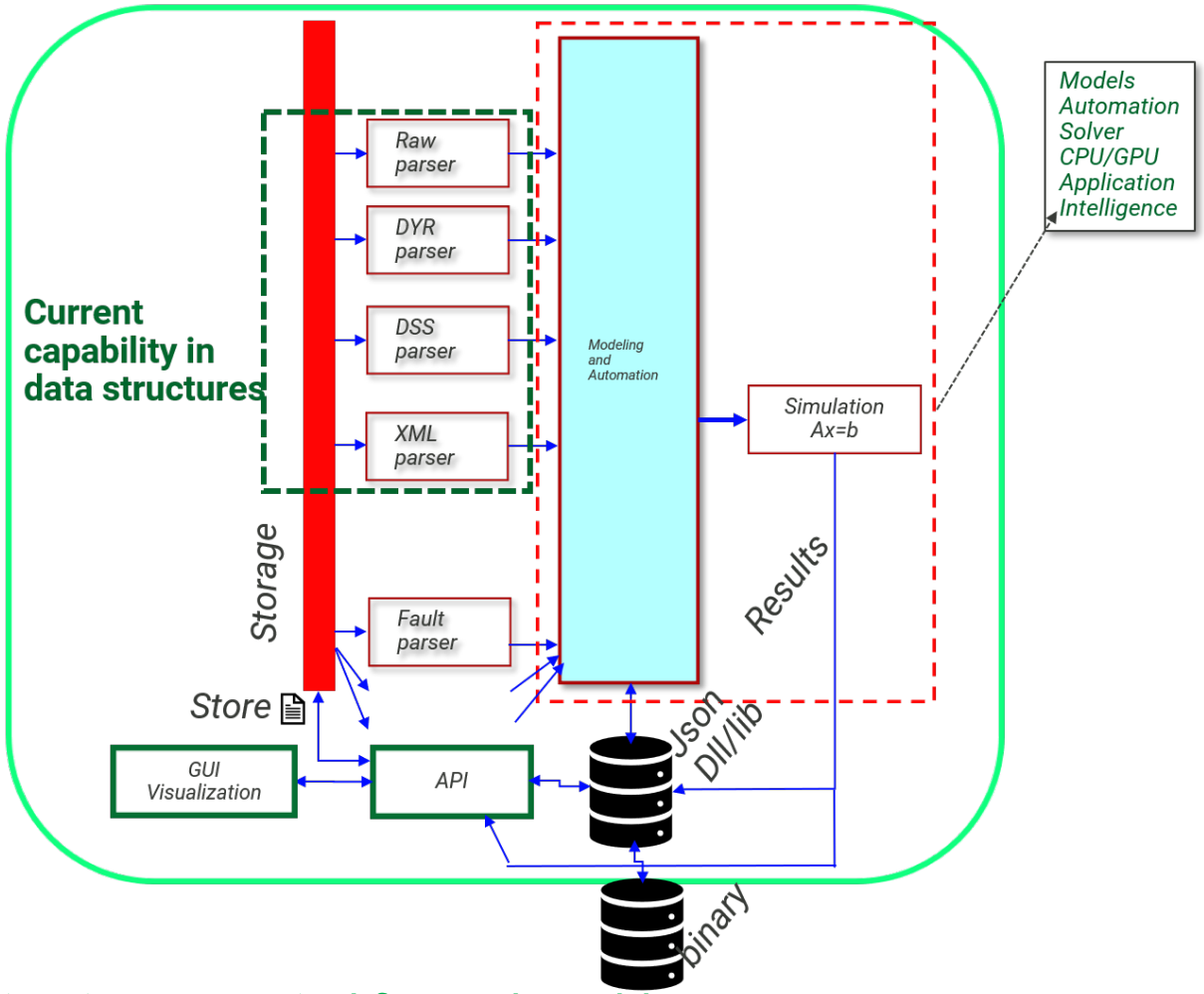
Goal: R&D on applications and support models, input data, solvers, features needed

Input Data Structures

RE-INTEGRATE
Input Data Structure

Multiple data formats and sources are needed for high-fidelity EMT simulations.

- *Raw: Connectivity, branch, transformer*
- *Dyr: Generator dynamics*
- *Dss: Distribution (within generation or load)*
- *Xml: Power electronics data*
- *Json: Common data architecture*
- *Fau: Fault data*



Three new data structures created for real-world cases