Transmission System Transient Models from the CIM

Panel: Application of CIM Standards in Enhancing Power System Interoperability
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Electromagnetic transient (EMT) model management is a new utility workflow requirement, and CIM can help.

- North American Electric Reliability Corporation (NERC) requires EMT modeling of inverter-based resources (IBR) to maintain grid reliability.
- Interconnection queues for new solar, wind, and storage IBR are years long in many regions; new EMT studies will only worsen this problem.
- EMT is still a niche specialty at most utilities; there is a shortage of staff trained to build, validate, maintain, and run EMT network and IBR models.
- Existing network models may have baked-in deficiencies for EMT usage, e.g., artificial two-winding transformer equivalents, no zero sequence.
- <u>**CIM is the only option**</u> for standards-based, multi-vendor, multi-simulator management of EMT network and IBR models.
- CIM already works for unbalanced distribution network model management.
- CIM-based Common Grid Model Exchange Standard (CGMES) already works for transmission dynamics network and machine model management in Europe.

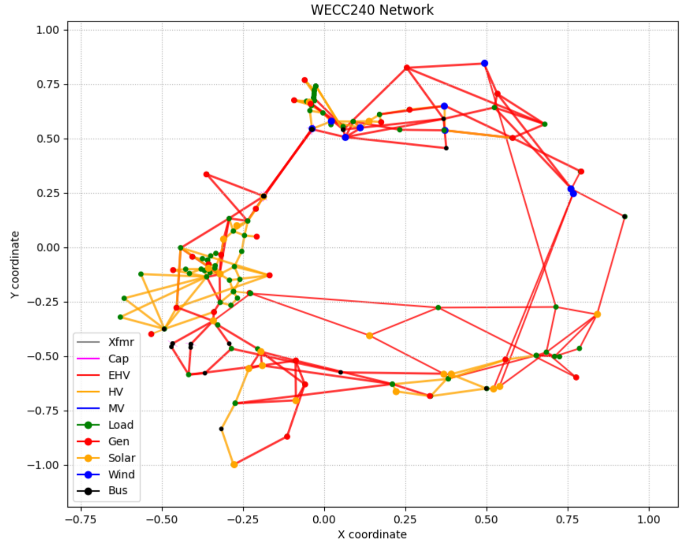
Bulk electric system test cases are medium-scale, generally representing WECC, the Midwest, and New England.

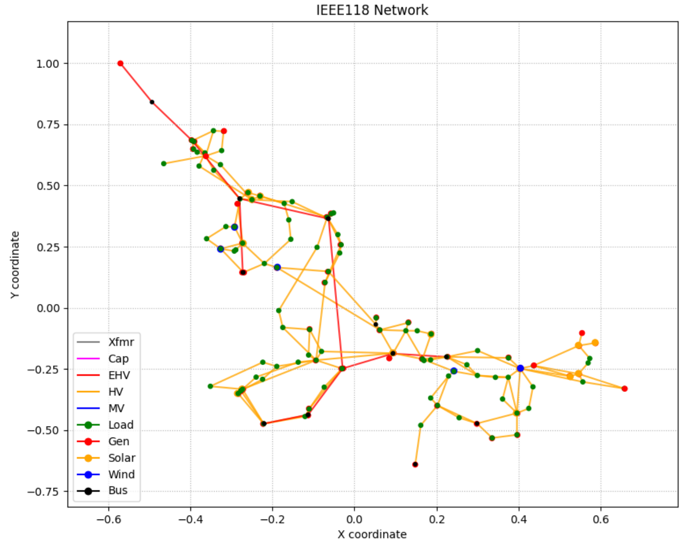
Medium-Scale Test Systems Augmented with IBR

	WECC 240	IEEE 118	IEEE 39
Buses	243	193 *	39
Machines	49 **	56 **	10
Solar	25	14	1
Wind	10	5	1
Notes	w/ Series Capacitors 2 aggregate DER By NREL, circa 2020	AEP System circa 1962	New England circa 1979

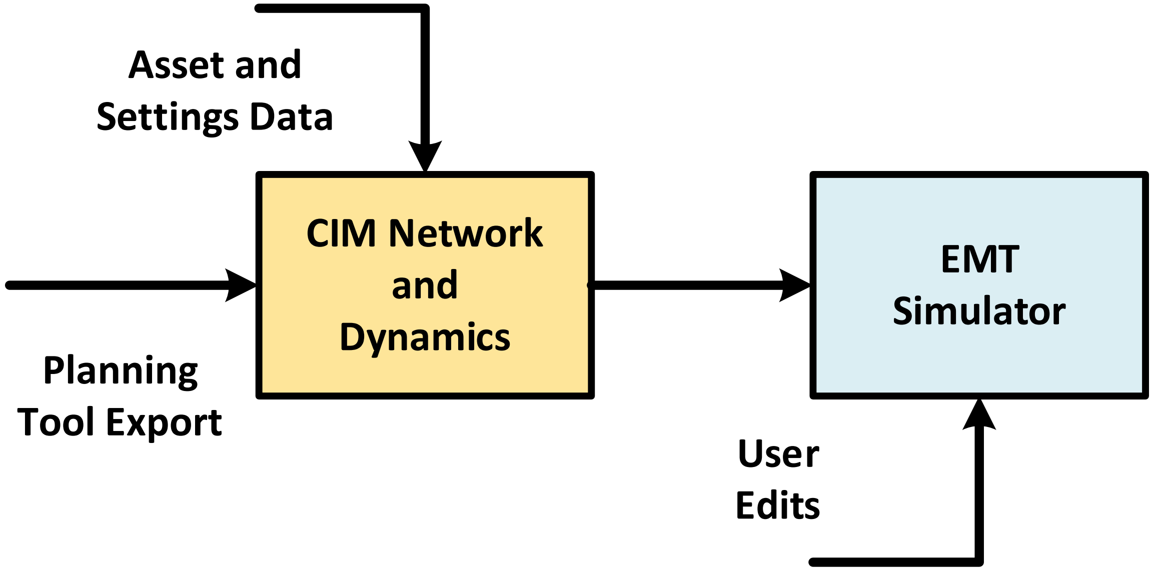
* Extra buses for generator step-up (GSU) transformers.

** Reflects aggregation of steam and hydro units at same bus.





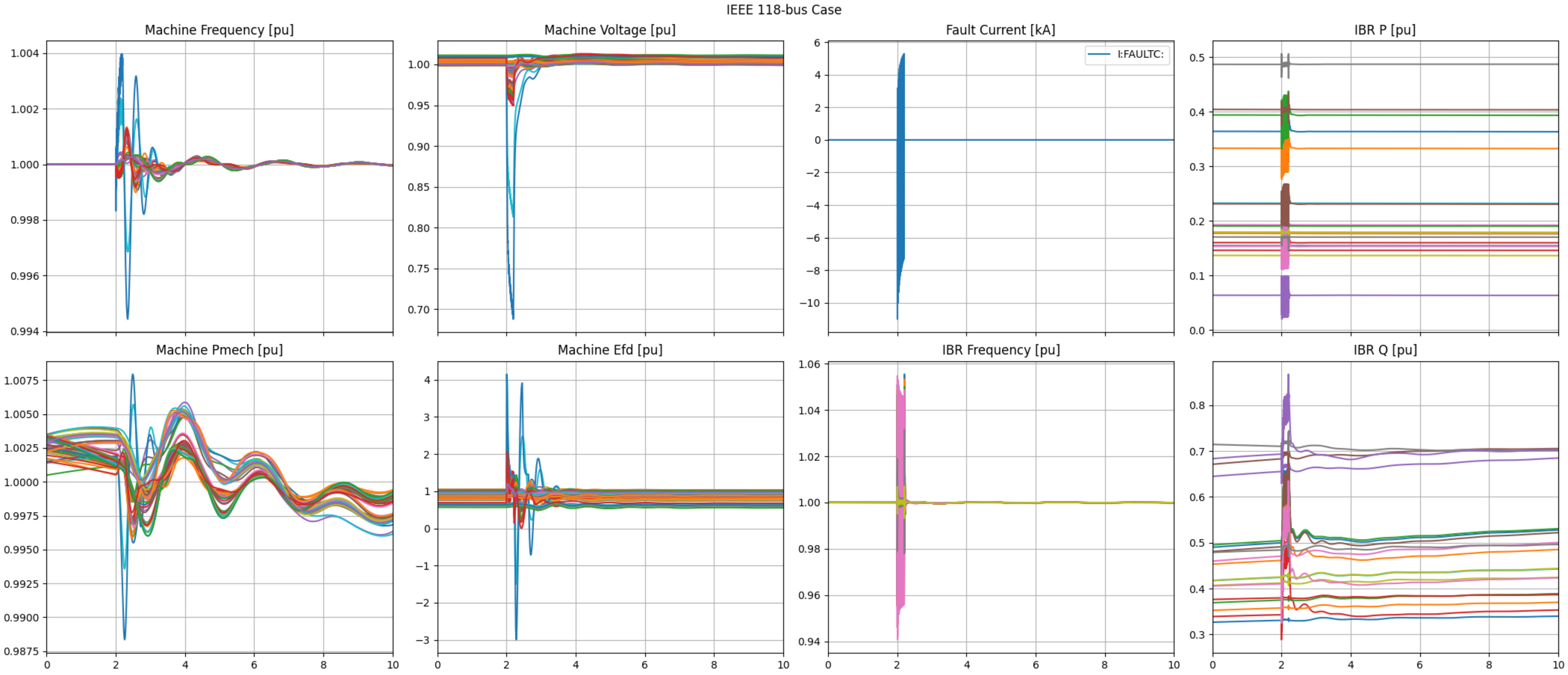
Model conversion process starts with PSSE models, adding some heuristics for CIM, then exporting to ATP netlists.



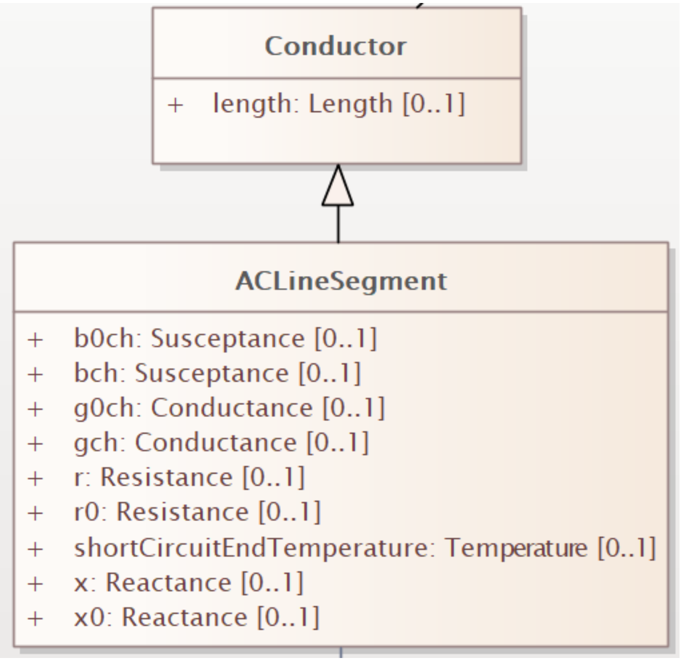
1. Obtain PSSE Raw Files for Test Case
2. Add Controls for Machines and IBR (Solar, Wind)
3. Transform to CIM XML with Python and SPARQL Queries
   a) Use heuristics for line x0, b0
4. Add Bus Locations using length-weighted Networkx package Kamada & Kawaii layout
5. Store CIM XML in Blazegraph Triple Store
6. Export CIM to Matpower to Solve for Initial Conditions
7. Export for Alternative Transients Program (ATP)
   a) Check line travel time vs. Δt
   b) ATP has license requirements, but $0.
8. Solve EMT network in ATP
9. Plot EMT Output Variables and Network Topology with Python and Matplotlib

Ref: https://openei.org/wiki/File:CIM_EMT_Article.pdf

Sample results for the IEEE 118-bus system include machine and IBR responses to a single-phase fault, 12% IBR.



Transmission line zero-sequence data is required for EMT; may use network short-circuit models or heuristics.



Start: $L = x/(length * \omega)$

If $bch > 0$: $C = bch/(length * \omega)$, $Z = \sqrt{L/C}$

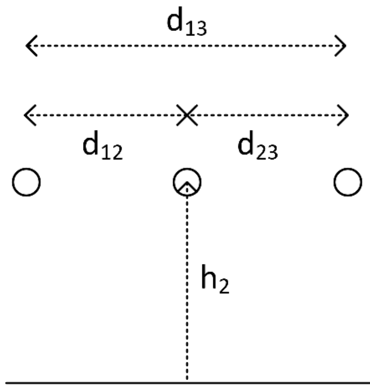
Else: $Z = 400$, $C = L/Z^2$, $bch = C * length * \omega$

Check: $v = 1/\sqrt{LC} \leq 3e8$

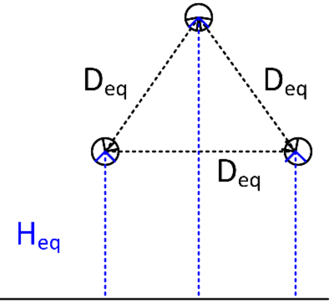
If $Z < 100$: $r0 = r$, $x0 = x$, $b0ch = bch$

Else: $r0 = 2r$, $x0 = 2x$, $b0ch = 0.6 * bch$

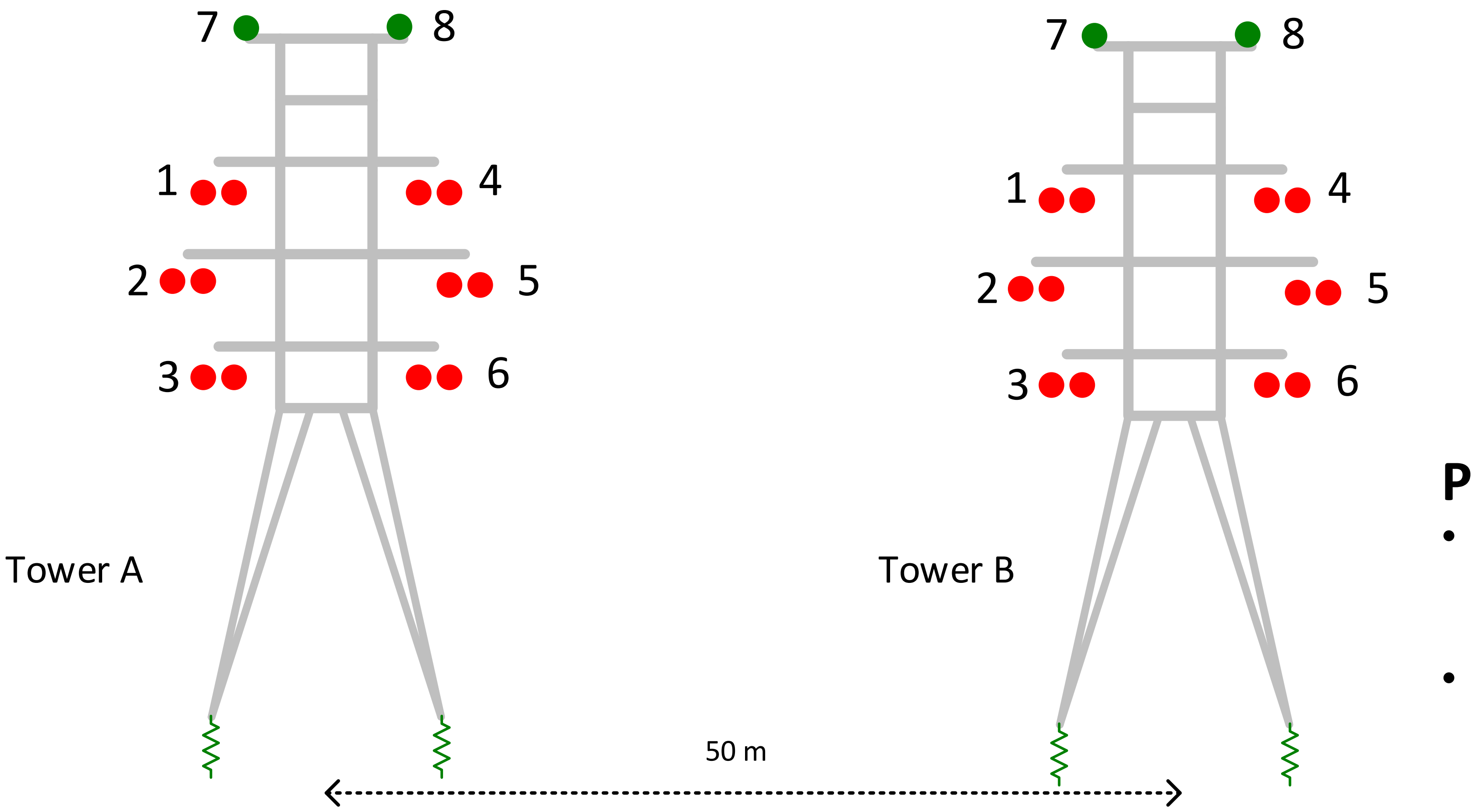
To do the square roots just once, legacy data may retain D_{eq} for positive sequence, losing H_{eq} for zero sequence.



$$D_{eq} = \sqrt[3]{d_{12}d_{23}d_{13}}$$



Transmission line data for EMT should come from tower and conductor data to represent unbalance and frequency.



Existing CIM Classes:

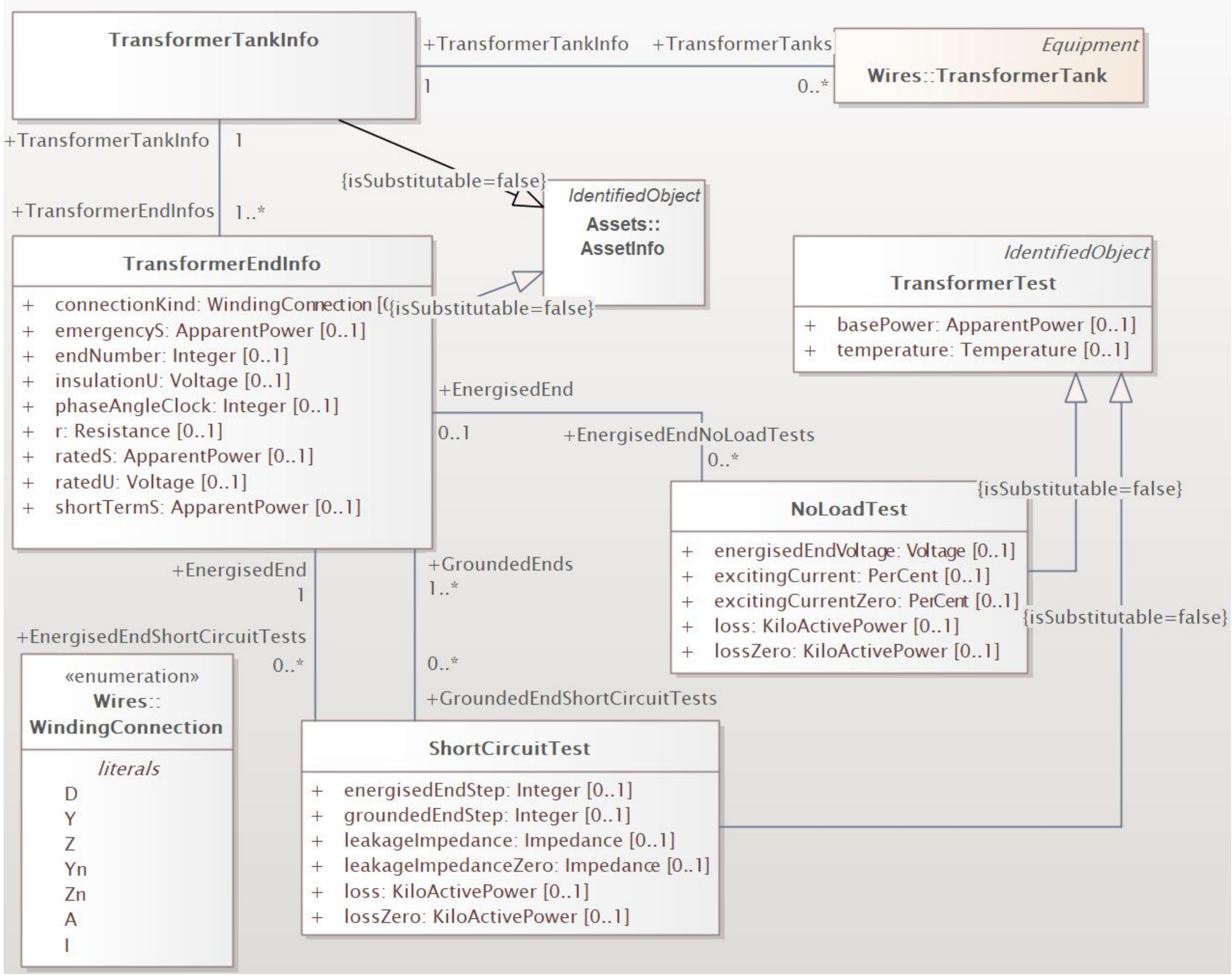
- ACLineSegment
- ACLineSegmentPhase
- WireSpacingInfo
- WireInfo
- WirePosition

Proposed CIM Classes (2021):

- WireAssemblyInfo – to support a "catalog" of tower/conductor construction types
- ParallelLineSegment and RightOfWay – to generalize pairwise MutualCouplings

Ref: i2X EMT Bootcamp: https://github.com/pnnl/i2x/tree/master/emt-bootcamp

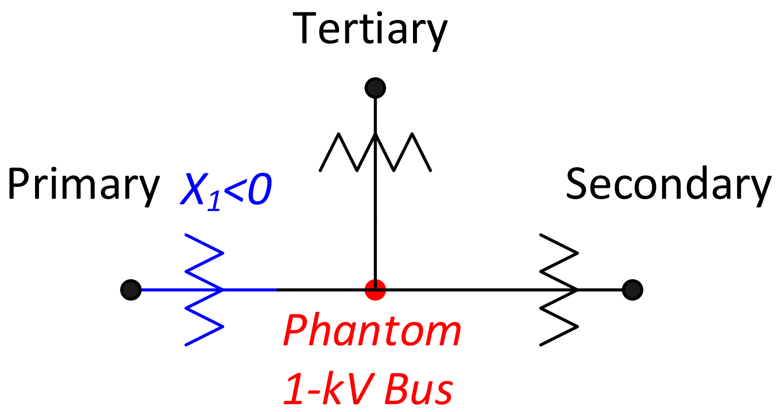
Transformer data for EMT comes from test sheets; if not available, multi-winding connections (YΔ) are required.



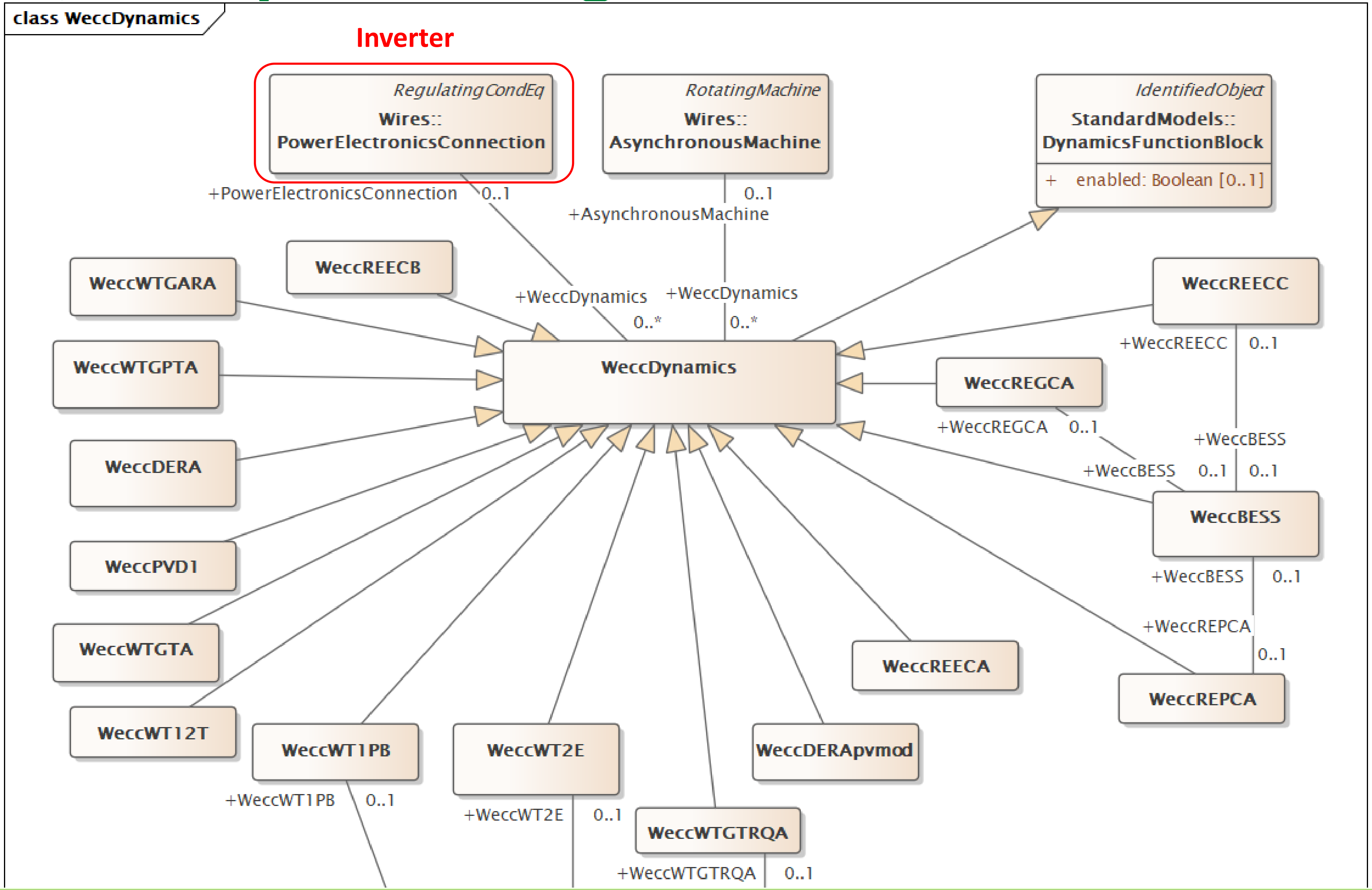
🡐 IEC 61970 Modeling is good for EMT

Include *TransformerTankEnd.OrderedPhases* from the June 2022 EPRI Grid Model Data Management interoperability tests.

***TransformerMeshImpedance* (preferred) and *TransformerStarImpedance* also work. Beware of assumptions made in legacy power flow models.**



WECC generic IBR models and controls have been added to CGMES, on equal footing with machines and controls.



CIM Dynamics extension required for real-code controls (DLL) and plant-level IBR models, to meet NERC guidelines.

Wires:PowerElectronicsConnection

0..1

IEEECigreDLL

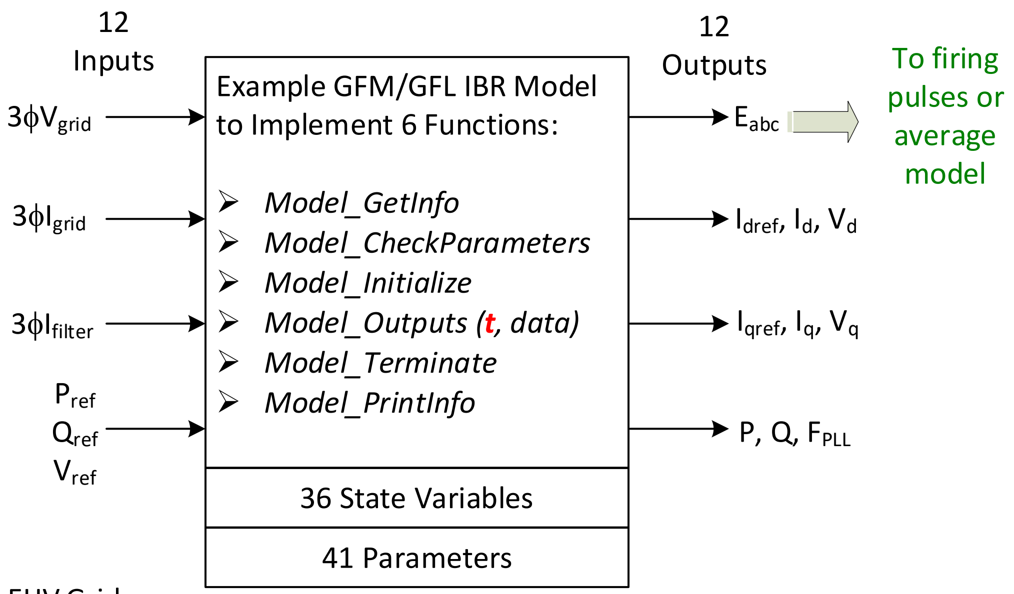
- Name and Vendor
- URI to the Binary DLL
- Firmware Version and Date

0..1

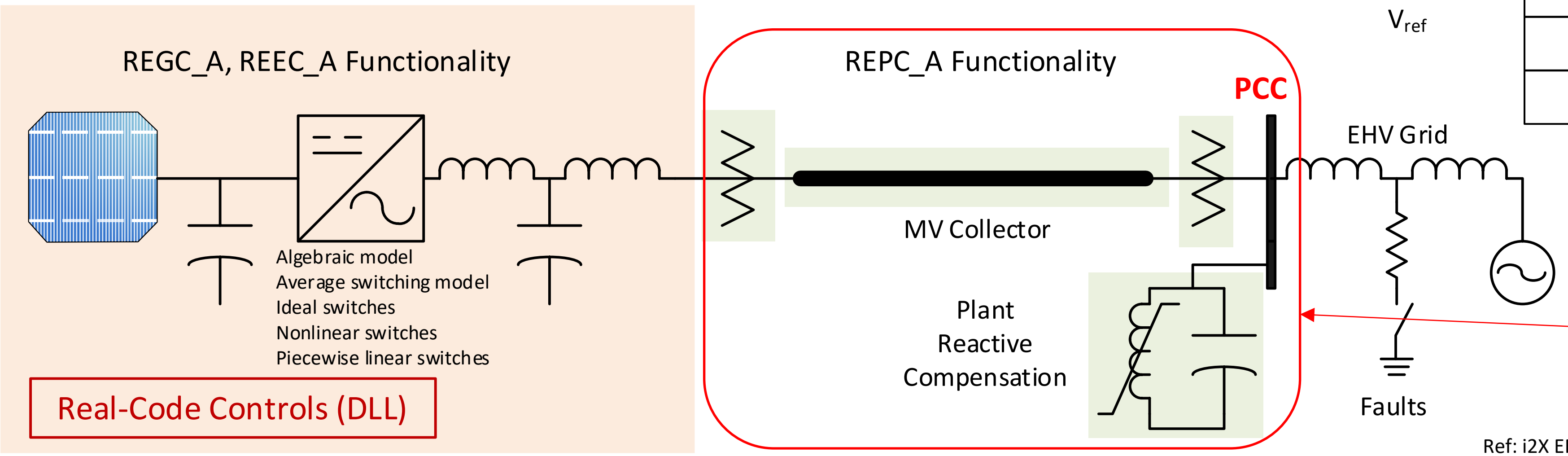
InverterBasedResourcePlant

- LCL Filter Parameters
- Feeder and Transformer Parameters
- Switching Frequency, etc.
- Plant Reactive Compensation?

IEEE/Cigre B4.82 DLL Specification



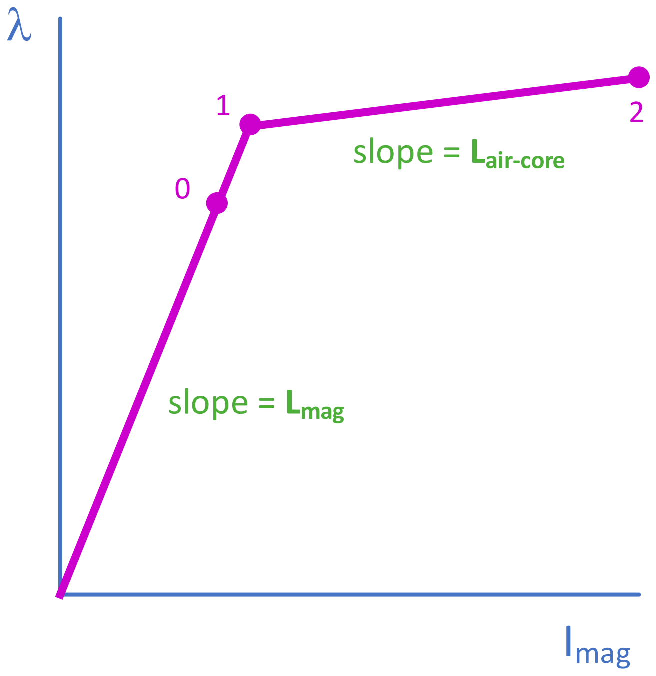
IBR Plant Model Structure



Could use CIM "fragments" or standalone components, e.g., plant reactive compensation.

Ref: i2X EMT Bootcamp: https://github.com/pnnl/i2x/tree/master/emt-bootcamp

CIM extension required for transformer saturation, which influences dynamics in voltage and reactive power.



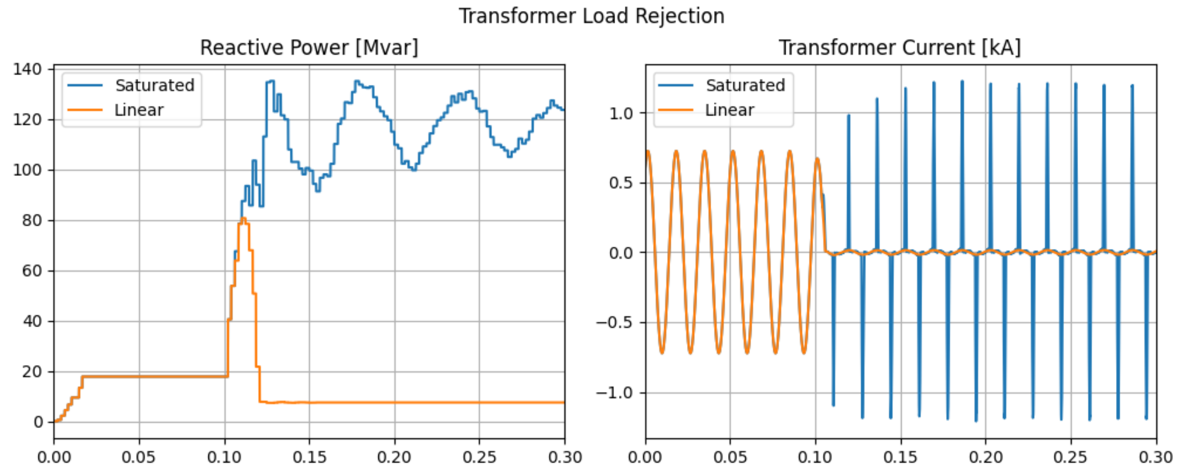
$L_{mag} = b / \omega$

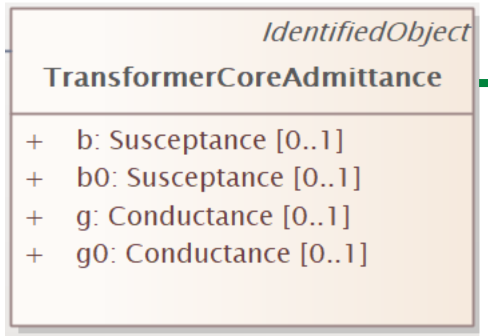
$L_{air\text{-}core} = 2x / \omega$

$\lambda = u / \omega$

Points:

- 0 @ 1 pu voltage
- 1 @ saturation
- 2 by choosing ΔI:
  - $I_2 = I_1 + \Delta I$
  - $I_2 = I_1 + L_{air\text{-}core} * \Delta I$

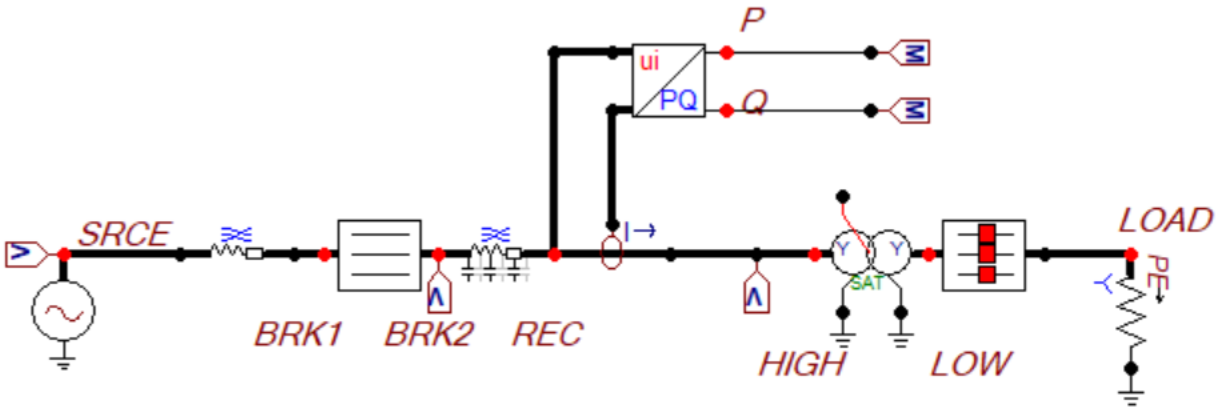




Proposal:

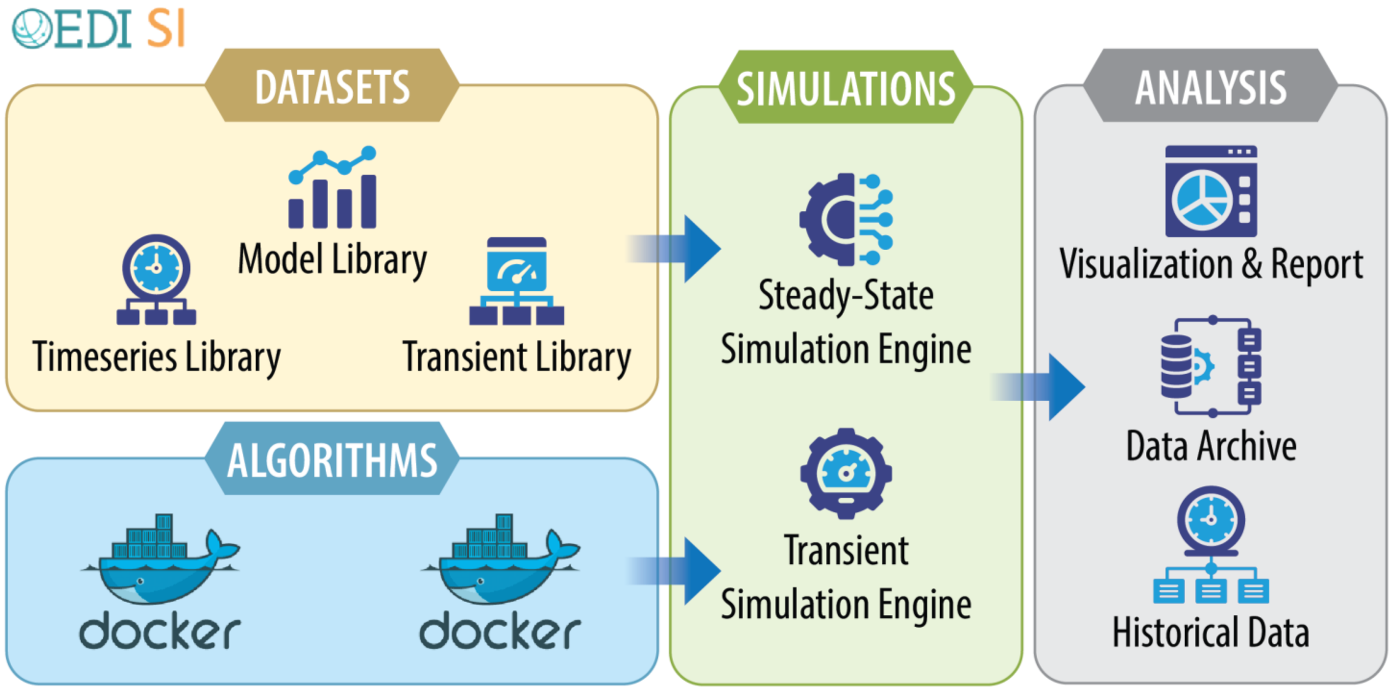
Create *TransformerSaturation*

Use *Curve* and *CurveData*



Open Energy Data Initiative (OEDI)

https://data.openei.org/



1. 5 open-source transient models of the distribution feeders
2. Available in OpenDSS, GridLAB-D, and CIM
3. Feeder models in ATP requires ATP license

1. https://openei.org/wiki/OEDI-SI/Scenarios/Data_Generation_for_CNN_Based_Protection_Zone_Identification
2. https://openei.org/wiki/OEDI-SI/Scenarios/CNN_based_protection_zone_identification
3. https://github.com/pnnl/oedisi_transients

References and Links

- Thapa et. al., “Plug-and-Play Regional Models for Real-Time Electromagnetic Transient Simulations of Large-Scale Power Grids: A Case Study of New York State Power Grid”, https://doi.org/10.1109/ACCESS.2023.3305394
- Martin and Fillion, “Automation of Model Exchange between Planning and EMT Tools,” https://www.ipstconf.org/papers/Proc_IPST2017/17IPST099.pdf
- CGMES Dynamics with WECC Generic IBR Models, https://cgmes.github.io/dynamics/#dynamics-wecc-dynamics
- CIMHub, https://cimhub.readthedocs.io/en/latest/Overview.html
- CIMHub Bulk Electric System Test Cases, https://github.com/GRIDAPPSD/CIMHub/tree/feature/SETO/BES
- Alternative Transients Program (ATP), https://atp-emtp.org
- EMTP®, https://www.emtp.com
- PSCAD®, https://www.pscad.com
- NERC, “Reliability Guideline: Electromagnetic Transient Modeling for BPS-Connected Inverter-Based Resources—Recommended Model Requirements and Verification Practices”, https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline-EMT_Modeling_and_Simulations.pdf
- EPRI Report 3002028322, “Code Based Generic Inverter Based Resource Model”, https://www.epri.com/research/programs/067417/results/3002028322