<Public>

Update on Inverter-Based Resource (IBR) Modeling and Simulation in OneLiner

ASPEN Update for WECC SCMS
November 14, 2024

Topics covered

Overview of IBR Models in OneLiner

Phasor Domain IBR Model Limitations

IBR Short-Circuit Simulation Primer

DLL Framework for IBR Models (R&D)

Overview of IBR Models in OneLiner

History

2010

Current Limited Generator

Ability to constrain generator output to a specific value

2016

VCCS
(Voltage Controlled Current Source)

Tabular Voltage-Current curve for positive sequence

2021

CIR (Converter Interfaced Resource)
K-Factor control for positive and negative sequence

Type-3 Wind Plant

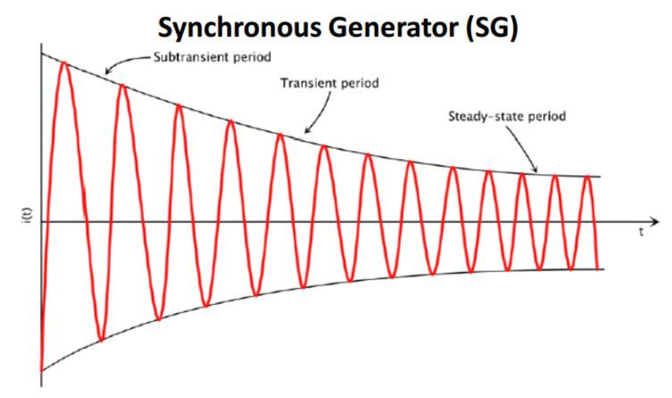
Future

Additional Generic IBR Models
Vendor Specific DLL Models

Overview of IBR Models in OneLiner

Conventional Generator

Phasor-domain Solution based on specific time periods

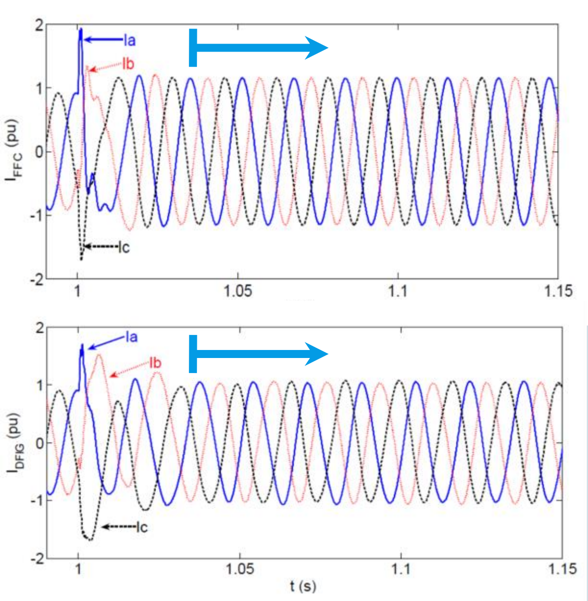


IBR Generator

Phasor-domain Solution based on post-transient period

Type-4

Type-3



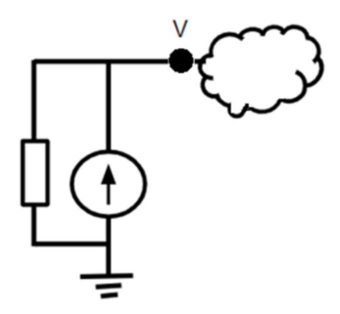
Type-3 and Type-4 Diagram Reference: EPRI

Overview of IBR Models in OneLiner

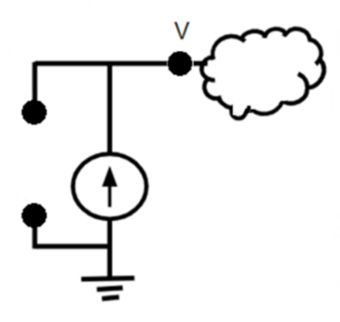
- Ideal voltage-dependent current source
  - Impedance (current-limited generator only)
- Iterative solution

  (more details later)

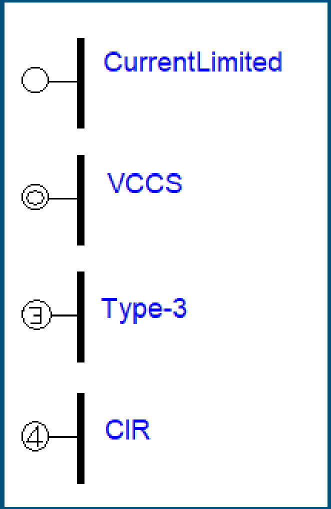
Current Limited Generator



CIR Type-3 VCCS



OneLiner Models Currently Available



Reference: Modification of Commercial Fault Calculation Programs for Wind Turbine Generators (PES-TR78)

Phasor Domain IBR Model Limitations

- Important modeling concept:
  - All models are wrong, therefore: *
    - a "correct" model cannot be obtained with excessive detail
    - we must be aware of where a model is "importantly wrong"
- Modeling and simulation has always required judgment, the same is true with these new models
- Examples where the phasor-domain model of grid-following IBRs can be importantly wrong:
  - 3LG POI fault - because the grid-following IBR model loses its reference angle
  - When the actual IBR plant has different control objectives than the IBR model

*George E. P. Box, "Science and Statistics", 1976 (paraphrased)

Phasor Domain IBR Model Limitations

- CIR, Type-3, and VCCS are Functional Models
  - The internal device topology and circuit physics are not simulated directly in OneLiner
  - Simulation represents the post-transient period of IBR fault ride through based on functional requirements
  - The model is grid-following - it needs a reference from the grid
  - Low Short-Circuit Ratio can result in unstable solution because of hunting

- Large number of IBR models will slow down the network solution
  - We are actively enhancing the solution algorithm to improve network solution time

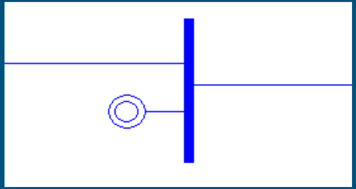
Phasor Domain IBR Model Limitations

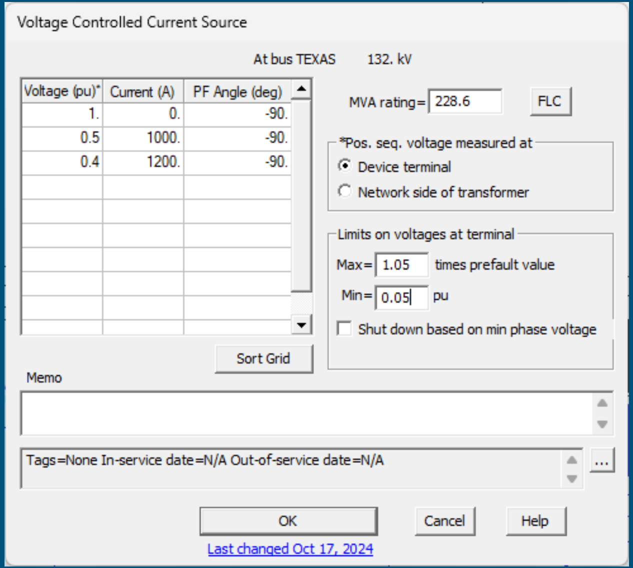
- The Thevenin equivalent theorems apply to linear circuits
  - The OneLiner Thevenin calculation only account for the linear circuit elements
  - TTY and other Thevenin reports in OneLiner are linear only
  - As IBR models increase within your network, you must take into account that the nonlinear elements are ignored in the Thevenin values

Phasor Domain IBR Model Limitations

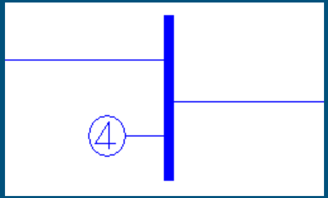
Voltage Controlled Current Source (VCCS) Model

- Table based model
- Positive Sequence Only
- Limited number of rows
  - Linear interpolation between rows
- Modeling active power requires table update



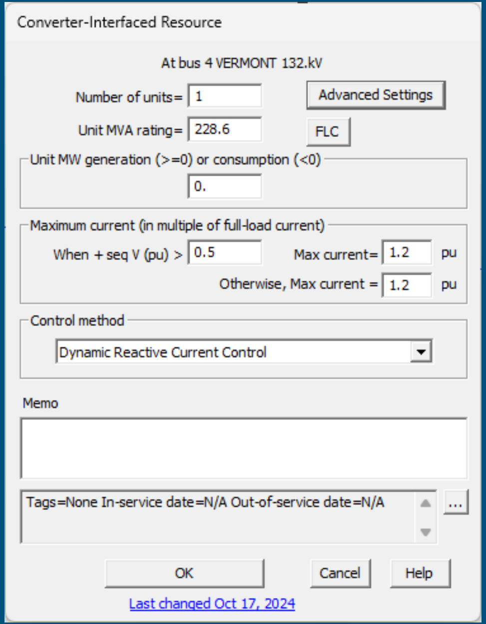


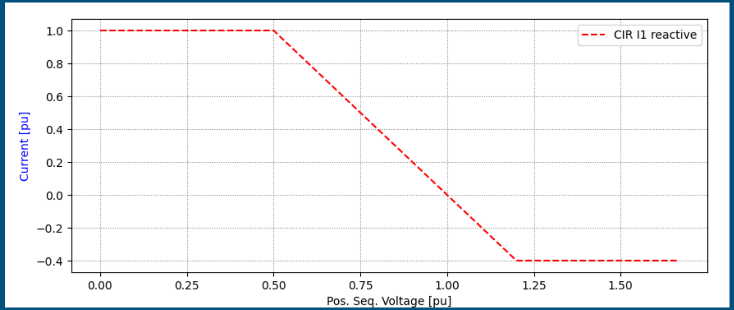
Phasor Domain IBR Model Limitations

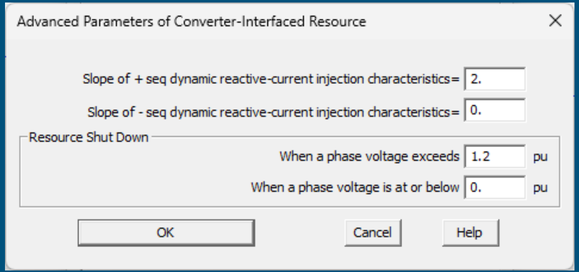


Converter Interfaced Resource (CIR) Model

- Equation based model
- Positive and Negative Sequence slope settings
- Some slope based IBR may have different:
    - Current limiting and prioritization
    - Deadband type and settings







IBR Short-Circuit Simulation Primer

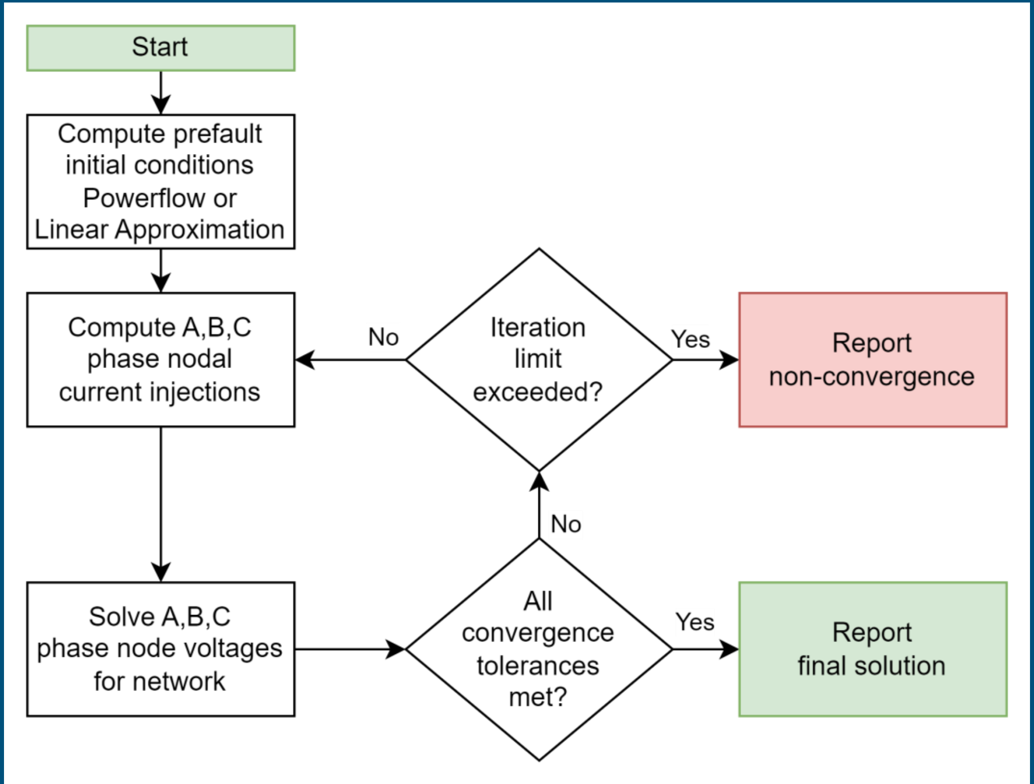
- Network model preparation
  - An important first step is tuning the network prefault condition, which can help resolve non-convergence in fault simulations
  - Significant factors that can affect the prefault network condition
    - Phase shift anomalies - Generators and Transformers
    - Off-nominal transformer taps
    - Generator REFV settings
    - Generation/Load balance
    - Nonlinear participation in linear prefault solution

IBR Short-Circuit Simulation Primer

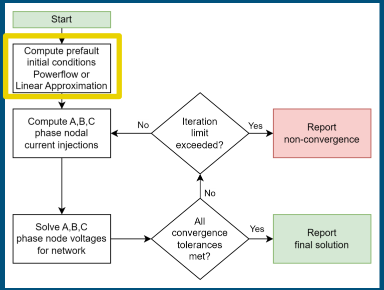
- Network model preparation
- Tools that May Help with Tuning the Network Prefault Condition
  - OneLiner Built-in Tools
    - Transformer phase-shift anomalies
    - Generator reference angle anomalies
    - Transformer tap anomalies
    - IBR Modeling and Simulation FAQ
    - Python OlxAPI Application
      - Network Review Tool
- Coming soon:
  - Python OlxAPI Application
    - Transformer Phase Shift Anomaly Tool

IBR Short-Circuit Simulation Primer

- Basic solution framework



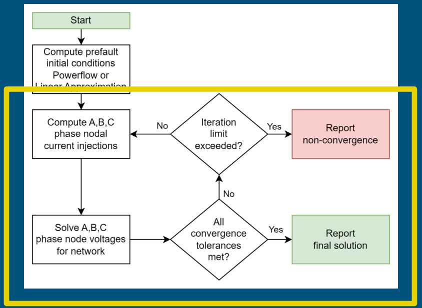
IBR Short-Circuit Simulation Primer

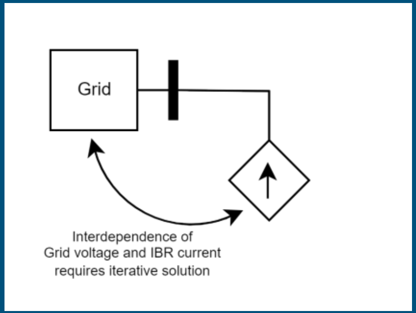


- Prefault solution with IBR
  - Prefault solution must be from:
    - a linear network solution, or
    - a power flow solution
  - VCCS, CIR, and Type-3 Wind Plant models will not be simulated if you choose the "Assumed flat" option.
  - Recent research indicates that in systems with significant IBR, a full power flow prefault solution may become necessary for accurate solutions

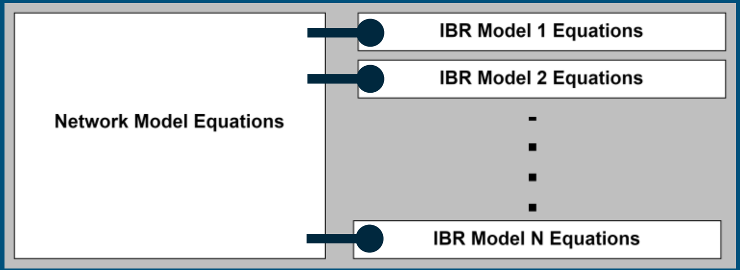
IBR Short-Circuit Simulation Primer

- Fault solution with IBR
  - IBR models are nonlinear
    - Analytic or exact solutions of nonlinear equations is often not possible
  - Iterative methods can be used to solve nonlinear models
    - Continue iterating until each equation is satisfied to within a specified tolerance
    - Non-convergence means that, for at least one nonlinear model, at least one of the specified tolerances was not met
    - Convergence of iterative methods depends on the initial conditions



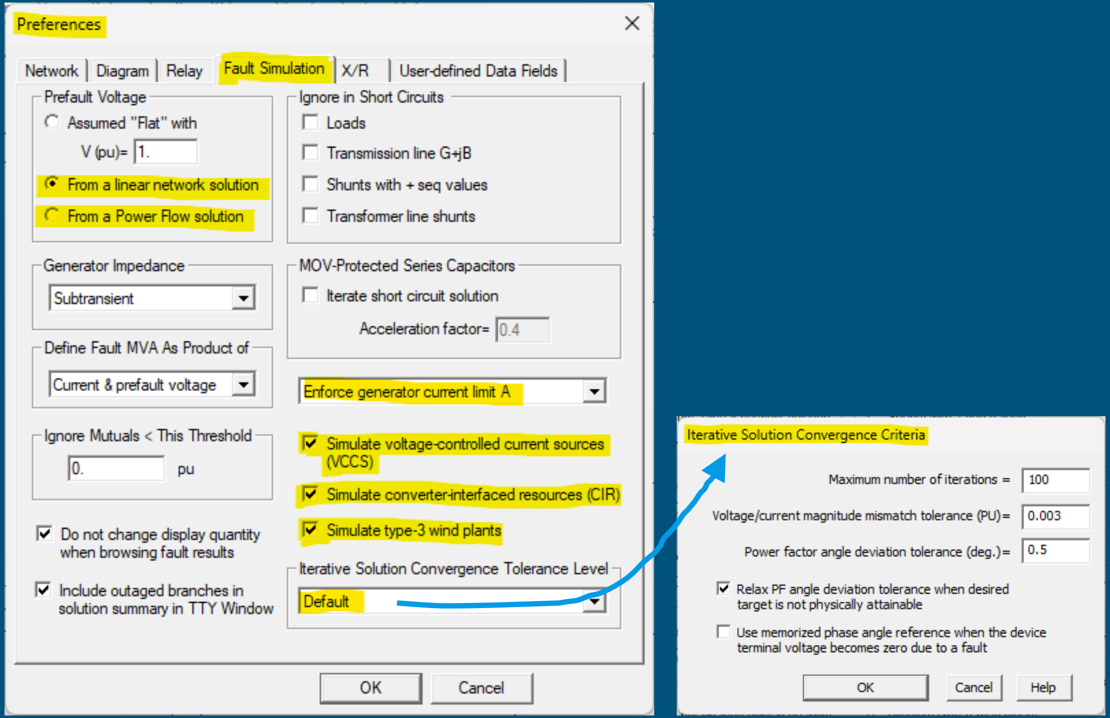


Solution must simultaneously satisfy the Network Equations and the IBR Model equations at every node, to within the specified solution tolerance.



IBR Short-Circuit Simulation Primer

- Example
- Sample30.OLR
  - Ohio IBR

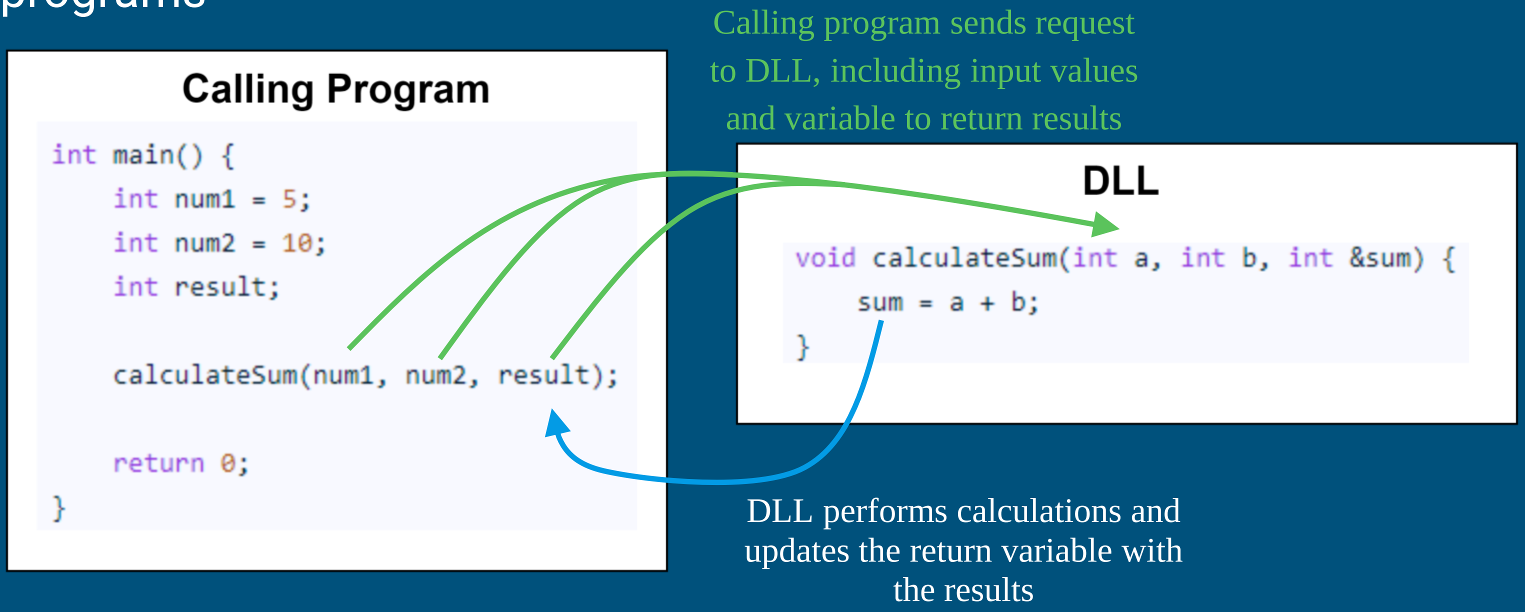


DLL Framework for IBR Models (R&D)

- The DLL framework offers a new way to include IBR models in short-circuit programs
- Vendors can provide phasor domain models of their IBR short-circuit behavior while protecting IP
- The DLL framework is open and not limited to ASPEN software
- Industry collaboration through IEEE PSRC C45 Working Group

DLL Framework for IBR Models (R&D)

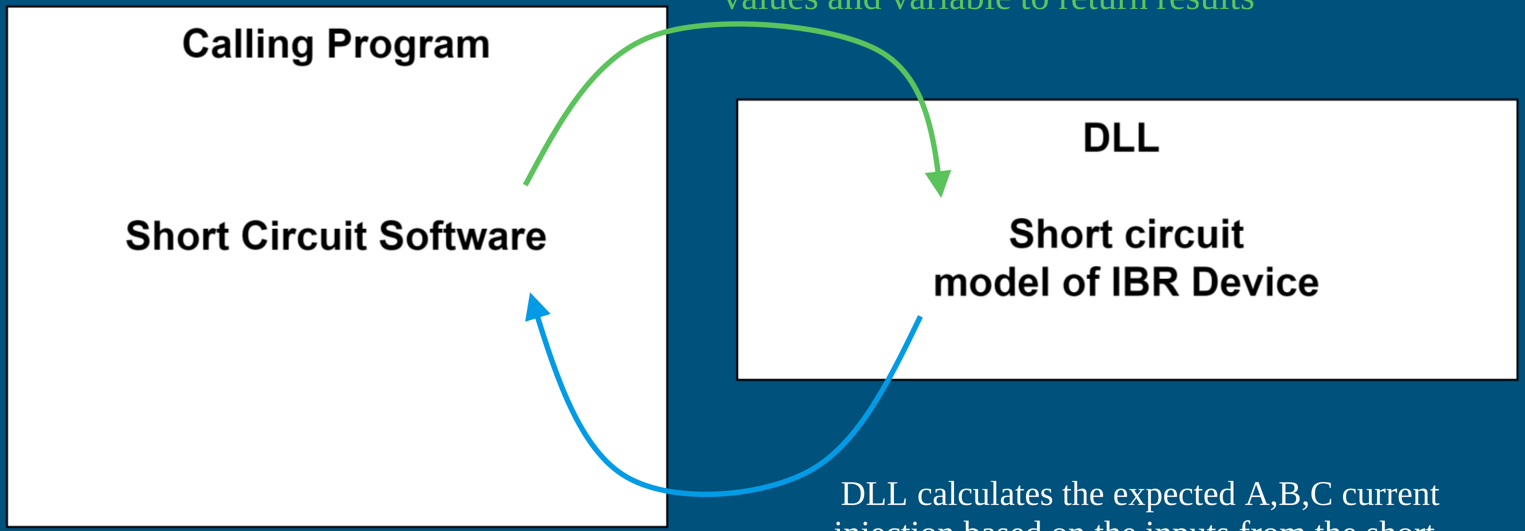
- A DLL is a compiled library containing code that can be called on by other programs



DLL Framework for IBR Models (R&D)

- In our case, we have

Short-circuit program sends request to IBR Model DLL, including input values and variable to return results



DLL calculates the expected A,B,C current injection based on the inputs from the short-circuit program, and updates the return variable with the results

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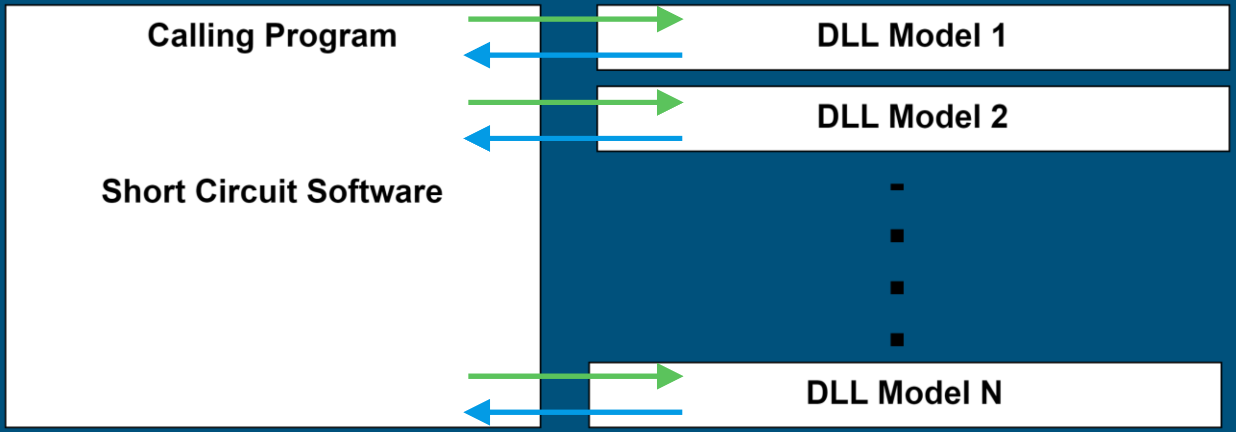
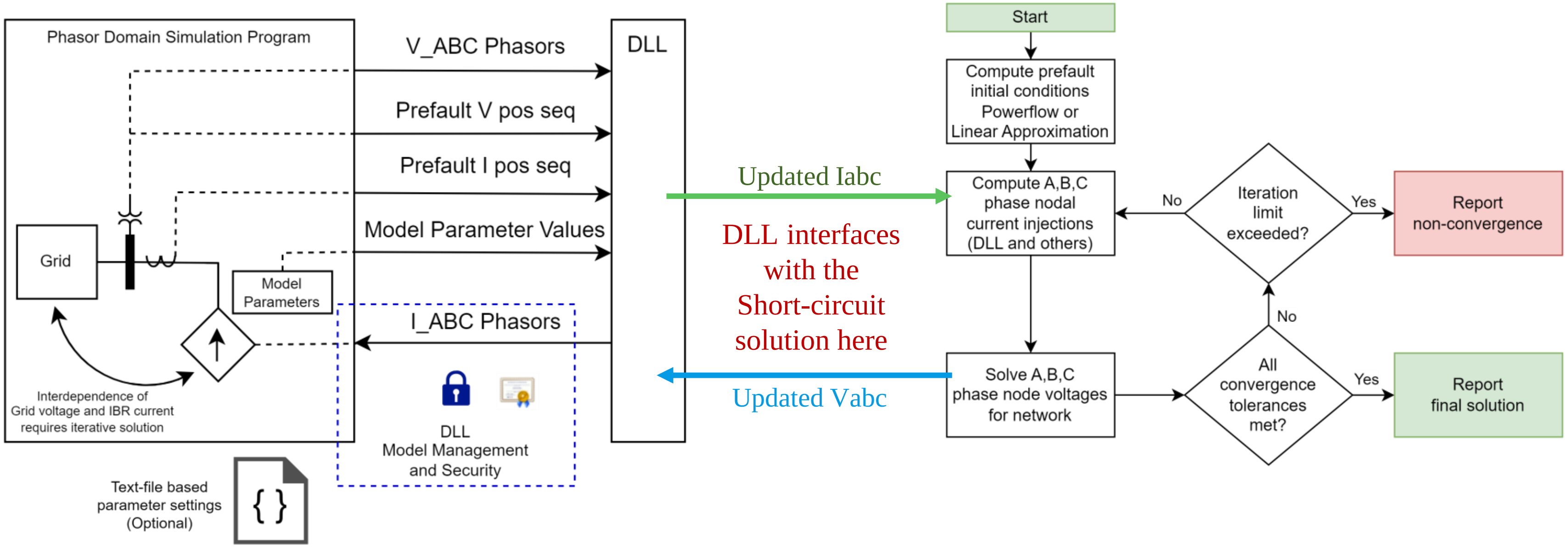
DLL Framework for IBR Models (R&D)

- If used in production on today's short-circuit models, the program must call on many different DLLs, and/or the same DLL multiple times, for each iteration of the fault solution



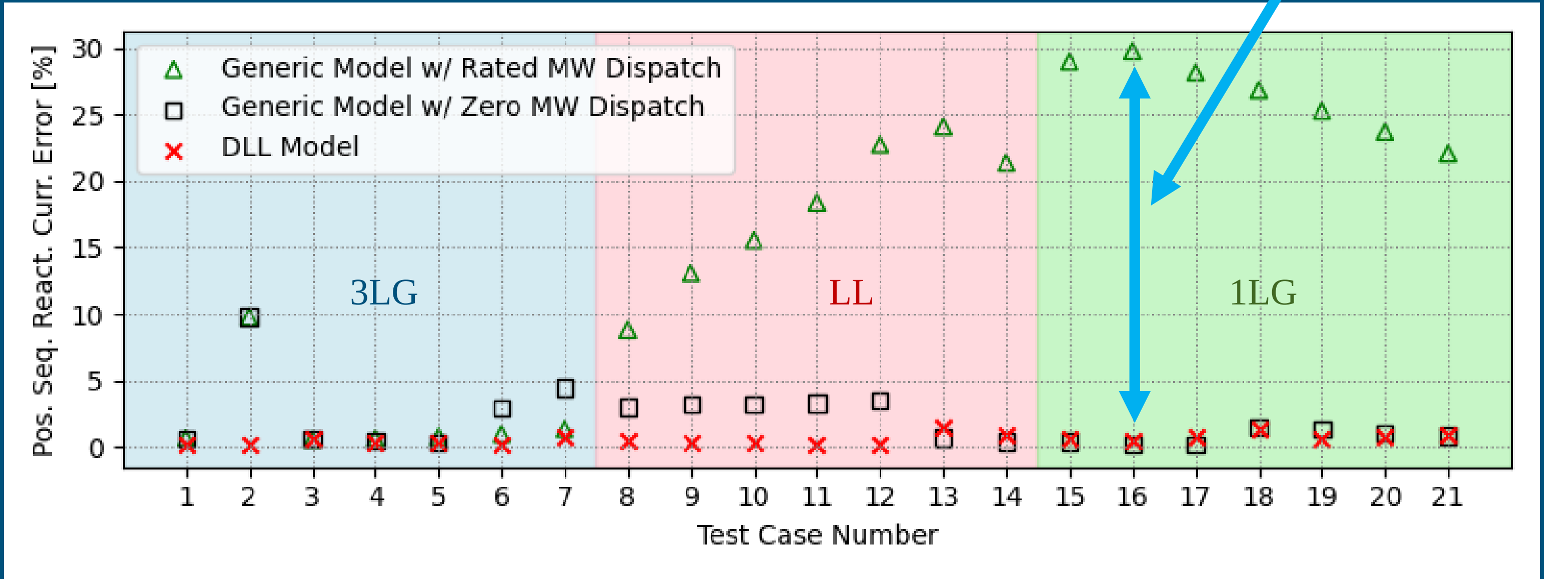
DLL Framework for IBR Models (R&D)



DLL Framework for IBR Models (R&D)

- Error of Generic model and Vendor Developed DLL model
  - Error measured relative to Vendor PSCAD model

Current limiting prioritization method different between generic model and actual IBR



DLL Framework for IBR Models (R&D)

- Working on new Generic Models to represent the observed current limiting and prioritization methods

- Seeking additional OEM collaboration to produce DLL models
  - Framework and Sample Code available on GitHub for:
    - IBR manufacturers
    - Researchers: Universities, EPRI, etc.
  - Reach out to ASPEN if you're interested in participating
    - Chris Weldy <cweldy@aspeninc.com>
    - Thanh Nguyen <tnguyen@aspeninc.com>
    - Phone: +1-650-347-3997

Questions?