Introduction to PSCAD/EMTDC for Wide Area Modelling

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Introduction/Context

- Historical need for EMT type tool capable of accurately modelling behavior of HVDC lines and controllers identified by Manitoba Hydro (provincial utility) in the early 1970's
- First version of EMTDC engine developed in the mid 1970's
  - Command Line Utility
- Graphical User Interface for EMTDC begins development circa 1988. This would later become known as PSCAD (Power Systems Computer Aided Design)
- PSCAD/EMTDC have continuously developed since then and are currently in version 5.0.2 (released March 1st, 2023)

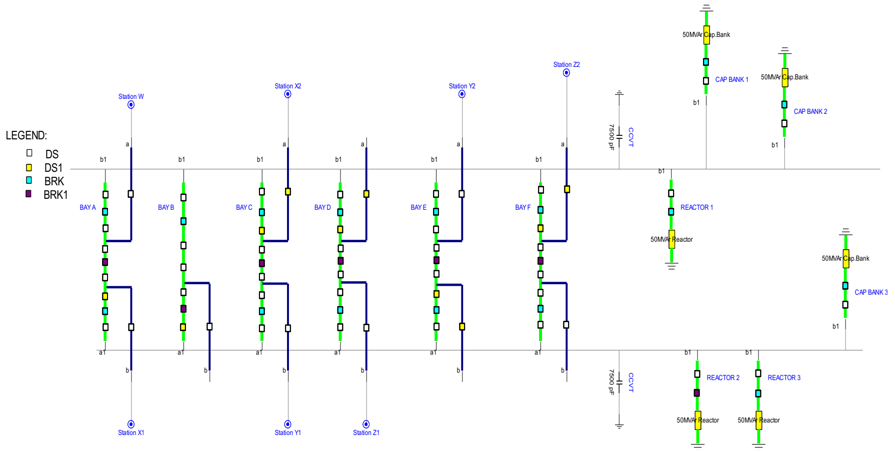
Some Common Applications

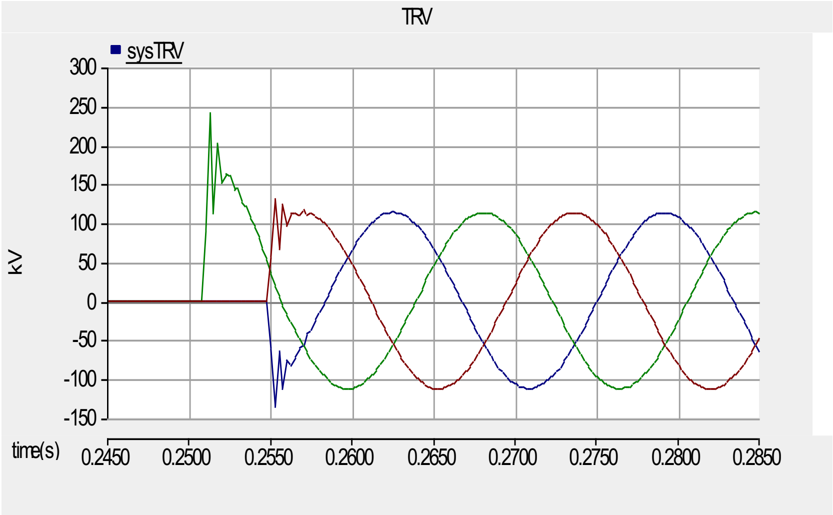
- IBR Studies
  - HVDC system design and operation studies
  - Accurate modeling of FACTS and Power Electronics applications
  - Wind power and other renewable energy systems
  - Distributed Generation Studies – wind power, solar, fuel cell, diesel…
- Insulation Coordination
  - Switching Over-Voltage studies – arrester ratings
  - Power System Lightning performance – BIL
  - Breaker Transient Recovery Voltage – restrike
- System Level Studies
  - Sub-Synchronous Resonance
  - Protection System modeling and testing
  - Dynamic/Transient Power System response
  - Harmonic System response

Limited only by the imagination

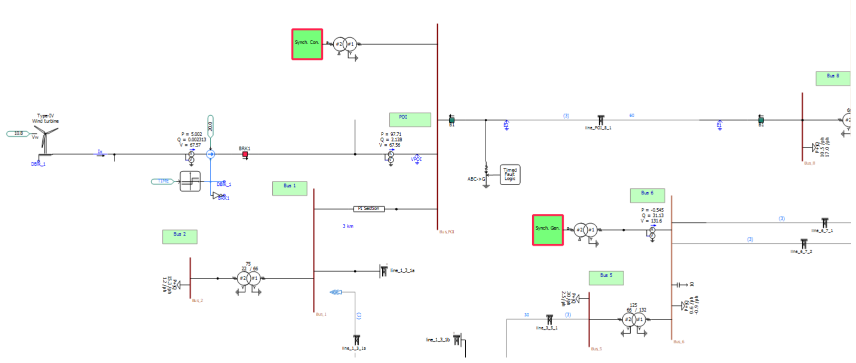
Some Common Applications

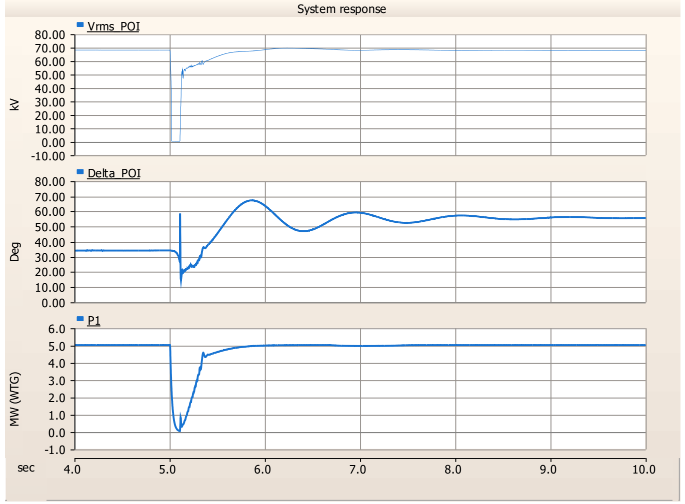
Fasts Transients – Breaker TRV Study





IBR Response – Wide Area studies

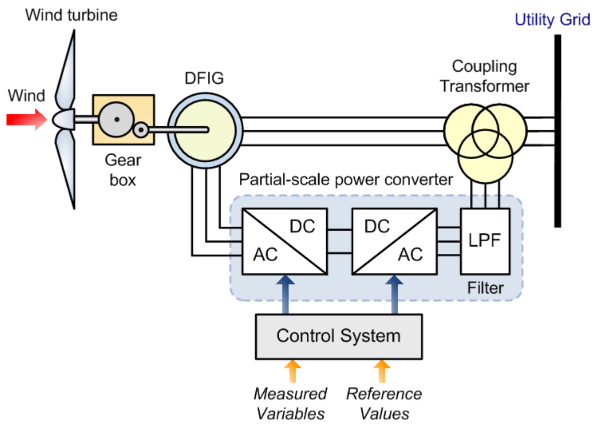


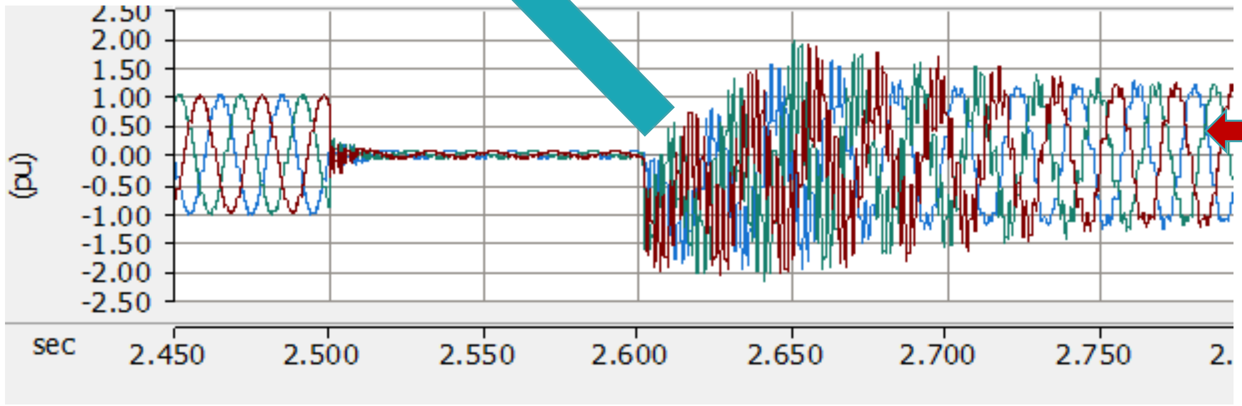


IBR Studies

- Electromagnetic Transient simulation plays an important role during integration of wind and other renewable energy-based generation to transmission networks. This is mostly because renewable generation is connected to grids through **power electronic inverters**.
- Dynamic response issues can arise, especially when inverter-based resources are connected 'weak' (low short circuit level) locations on the transmission network.
  - The voltage (specially the phase angle) at weak grid locations show pronounced variations following a system disturbance such as fault clearing. The '**GRID Following**' inverter response is critically dependent on measuring such phase angle changes (instantaneous response as opposed to rms) accurately through the Phase Locked Loop (PLL) and other signal measurements at the connection point. Inability of PLL to correctly track the voltage changes has resulted on poor fault recover response of the inverter or tripping of the unit in violation of grid codes.
  - The voltage control at weak locations is challenging. When multiple inverter-based devices are located in close vicinity in a weak grid area, there is a risk of these fast acting (fast reactive current control) devices interacting in an unstable manner and leading to a multitude of issues, generally classified as 'control interaction'.

Example: Type 3 Wind Farm in Weak Grid Condition



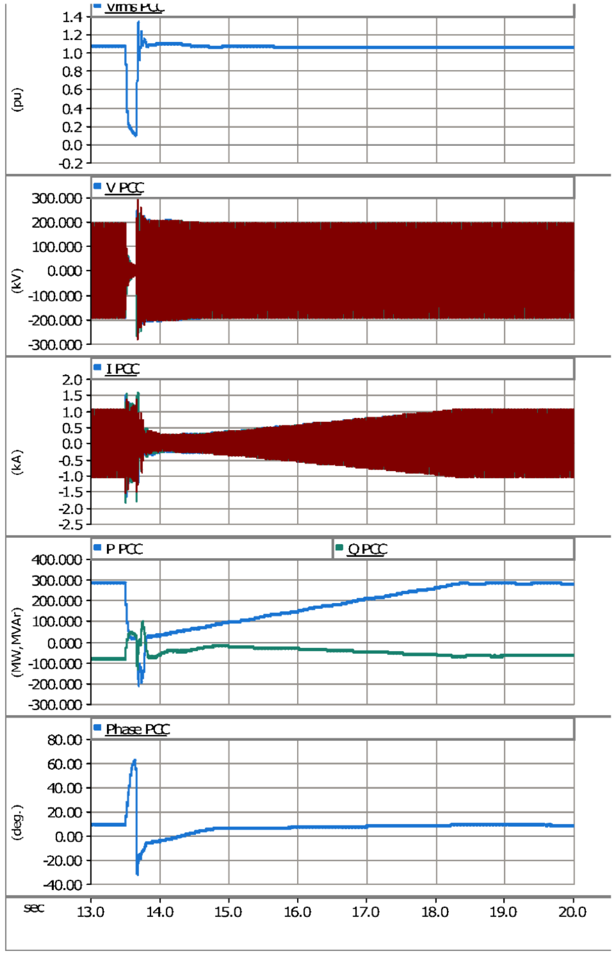


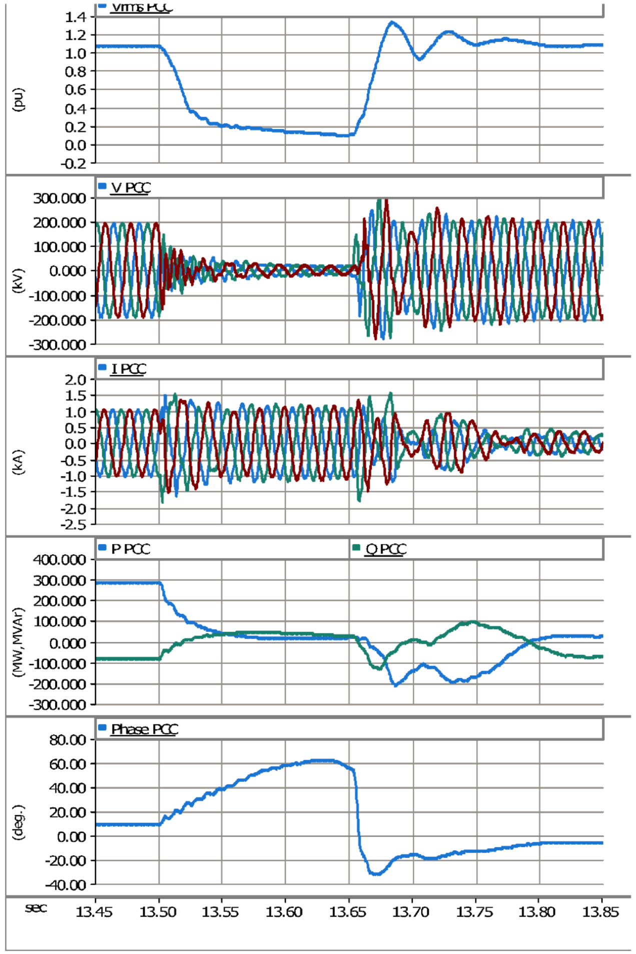
Bus voltage following a fault

This voltage must be tracked and phase angle shifts estimated accurately and fast to ensure stable operation

Example: Type 4 Wind Farm Power Reversal

Power reversal is observed in an offshore windfarm during a fault recovery due to temporary loss of PLL lock.





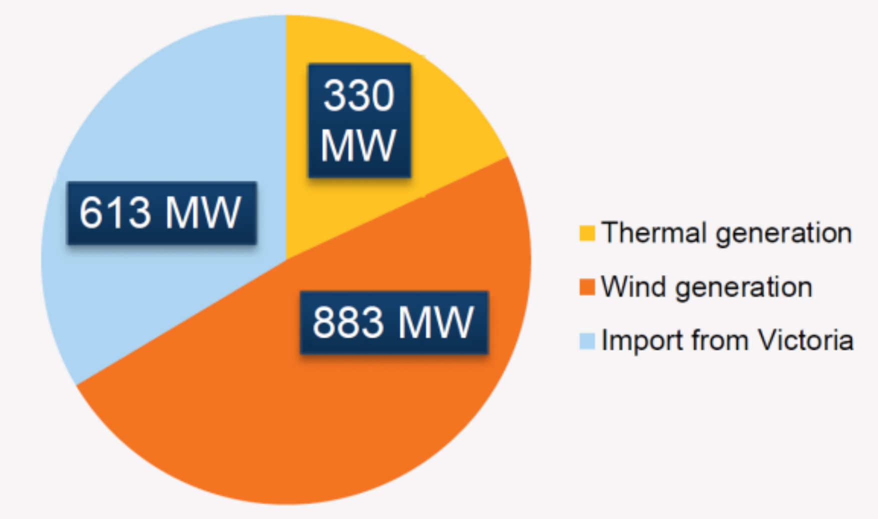
IBR Studies → Wide Area EMT Studies

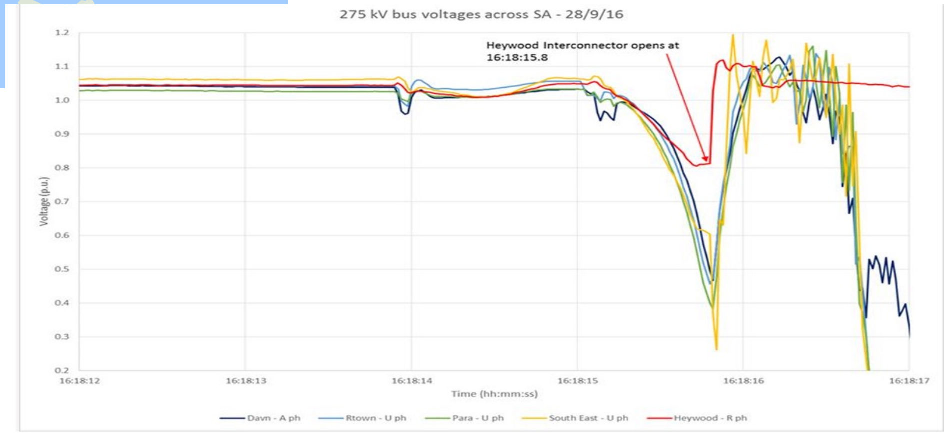
- EMT analysis is essential to verify the design and stable operation of IBRs, especially when connecting to ‘weak’ grid locations.

- Most design verification studies (previous examples) can be performed with a small area of the transmission network captured in the EMT circuit formulation.

- However, there have been industry experience where a wider network had to be implemented to capture the overall system response accurately. This has led to a strong interest in ‘Wide Area EMT Simulations’.

Example: South Australia Blackout 2016





OAK RIDGE National Laboratory

Example: South Australia Blackout 2016

Event Description

1. Extreme weather conditions resulted in five system faults on the SA transmission system in the 87 seconds between 16:16:46 and 16:18:13, with three transmission lines ultimately brought down.

2. In response to these faults, and the resulting six voltage disturbances, there was a sustained reduction of 456 MW of wind generation to the north of Adelaide.

3. Increased flows on the Heywood Interconnector counteracted this loss of local generation by increasing flows from Victoria to SA.

4. This reduction in generation and increase of imports on the Interconnector resulted in the activation of Heywood Interconnector's automatic loss of synchronism protection, leading to the 'tripping' (disconnection) of both of the transmission circuits of the Interconnector. As a result, approximately 900 MW of supply from Victoria over the Interconnector was immediately lost.

5. This sudden and large deficit of supply caused the system frequency to collapse more quickly than the SA Under-Frequency Load Shedding (UFLS) scheme was able to act.

6. Without any significant load shedding, the large mismatch between the remaining generation and connected load led to the system frequency collapse, and consequent Black System.

A full description of the event can be found at:
https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2017/integrated-final-report-sa-black-system-28-september-2016.pdf

Example: South Australia Blackout 2016

Lessons Learned

1. The system inertia on the SA side was not sufficient to maintain the frequency drop (once the Haywood interconnector tripped) and to make the under frequency load shedding (UFLS) effective.

2. 'Must run' thermal generation have to be identified.

3. Synchronous condensers investigated as a potential solution if the thermal generation dispatch is expected to be low under specific load conditions.

4. Load shedding scheme update.

This event lead to the creation of the South Australian wide area model including manufacturer models for all IBRs. The measured results were replicated in PSCAD/EMTDC.

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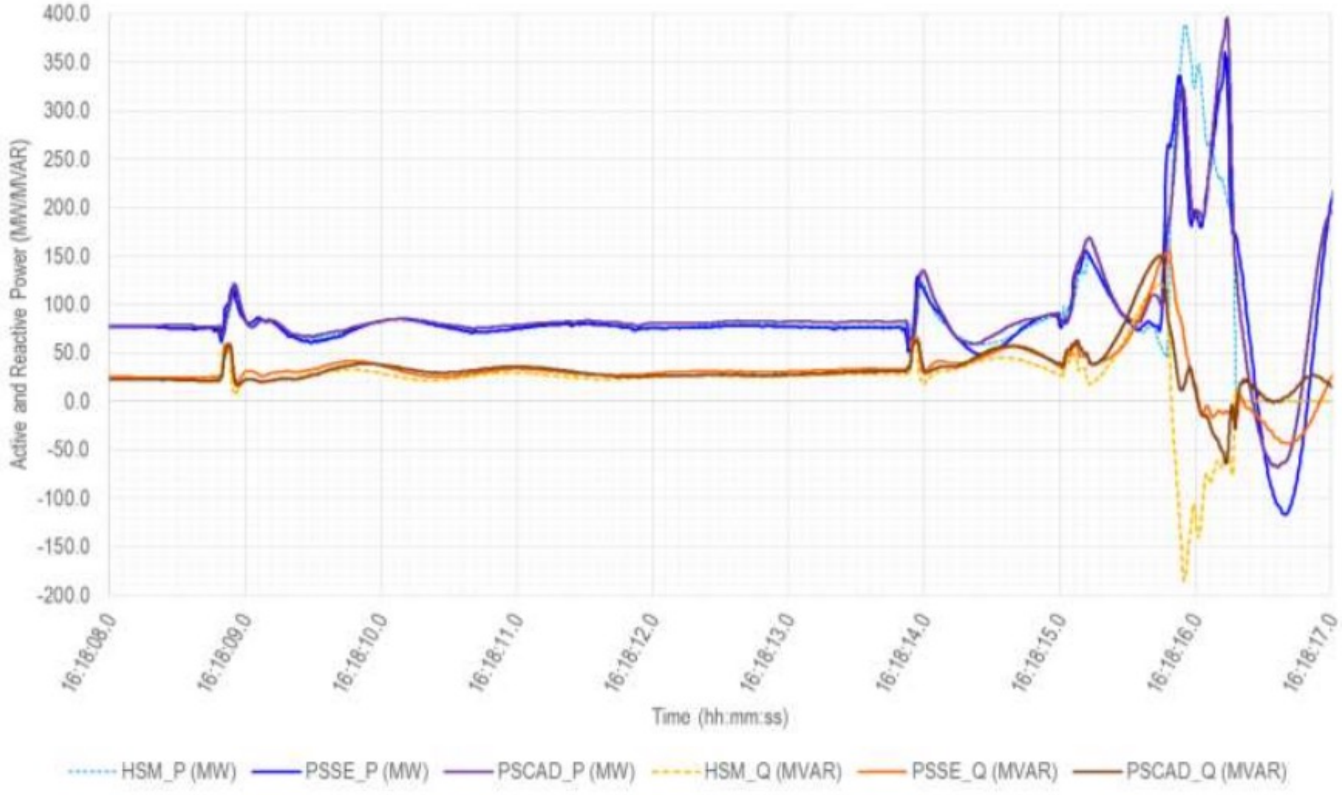
Example: South Australia Blackout 2016

Comparison



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Example: South Australia Blackout 2016

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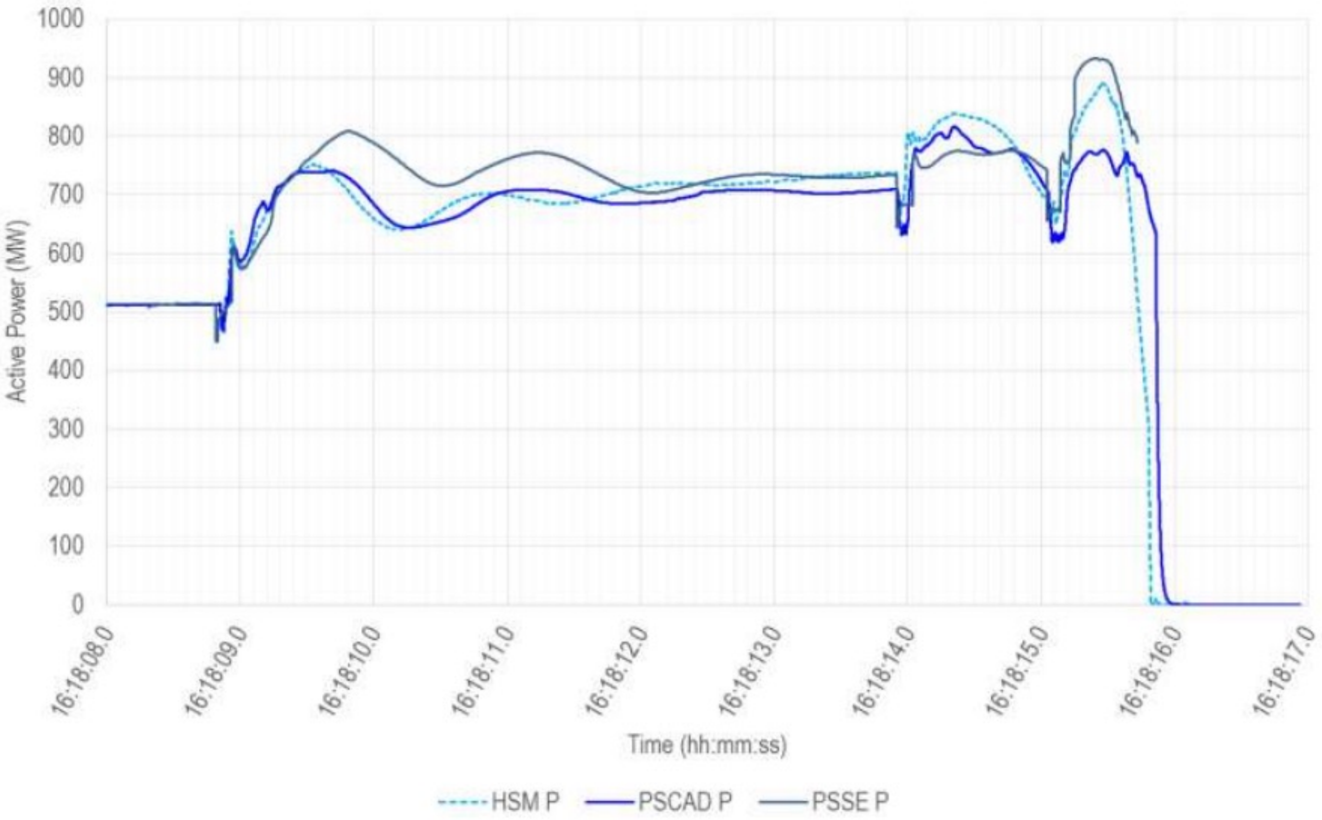

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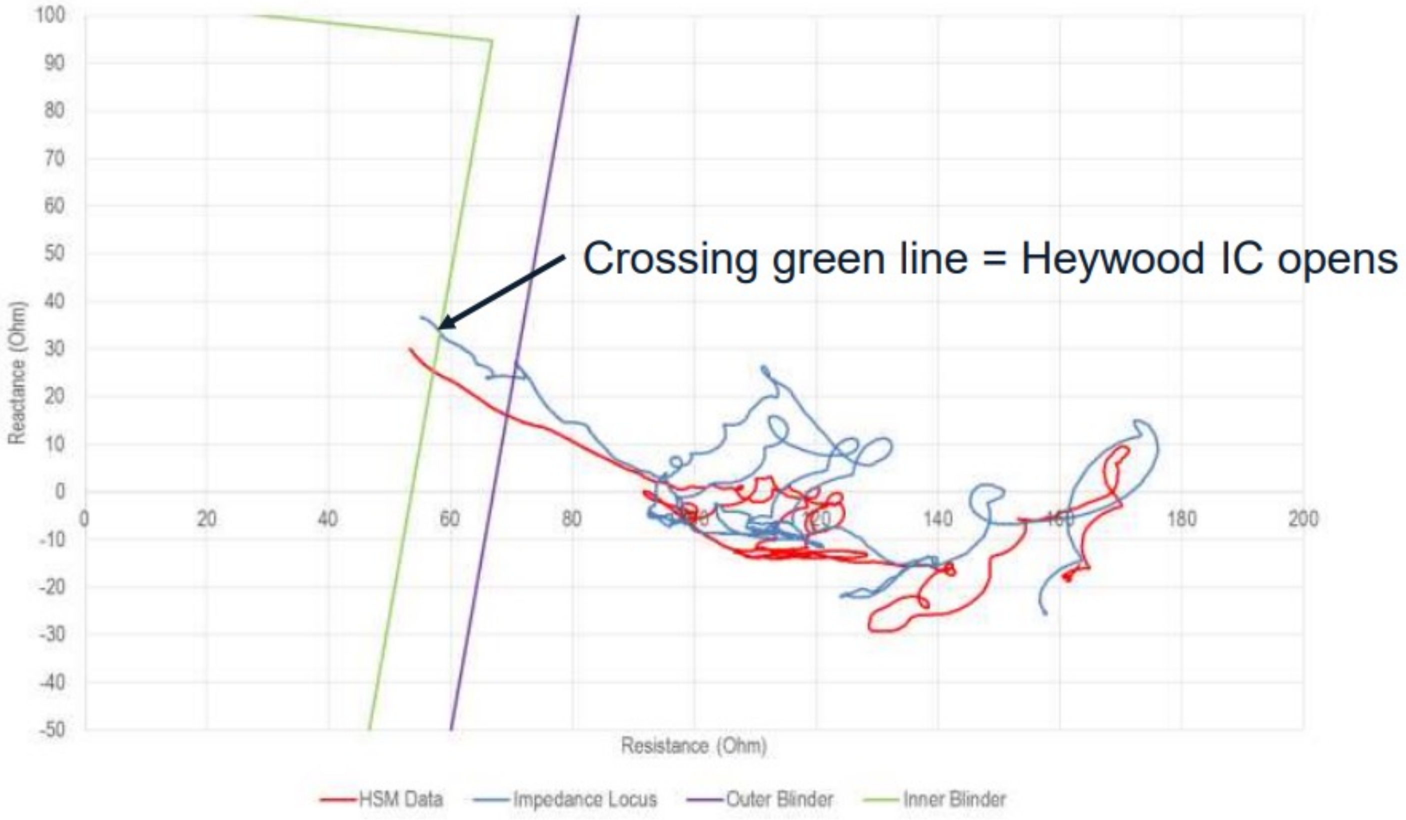

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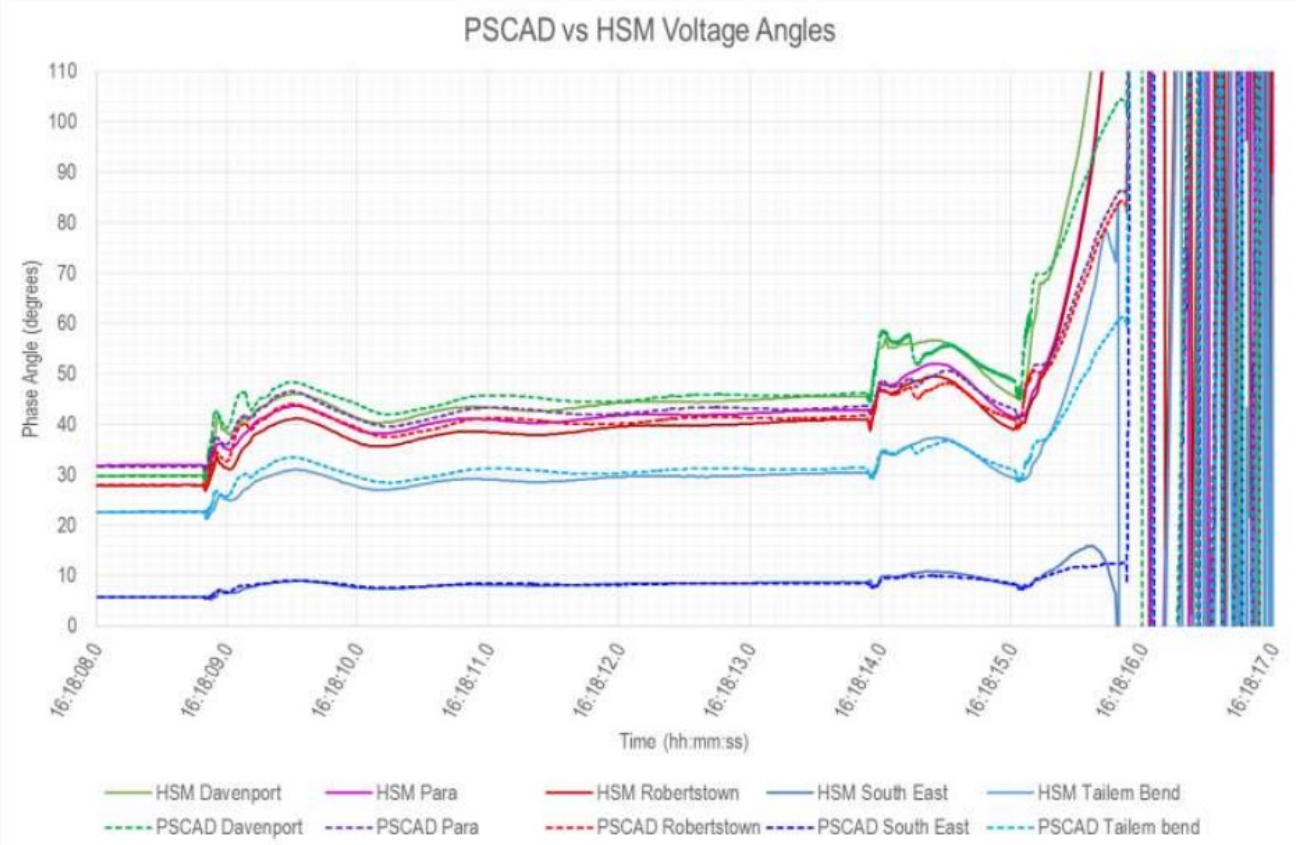

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Challenges and Solutions

EMT type calculations are computationally expensive compared to RMS type calculations:

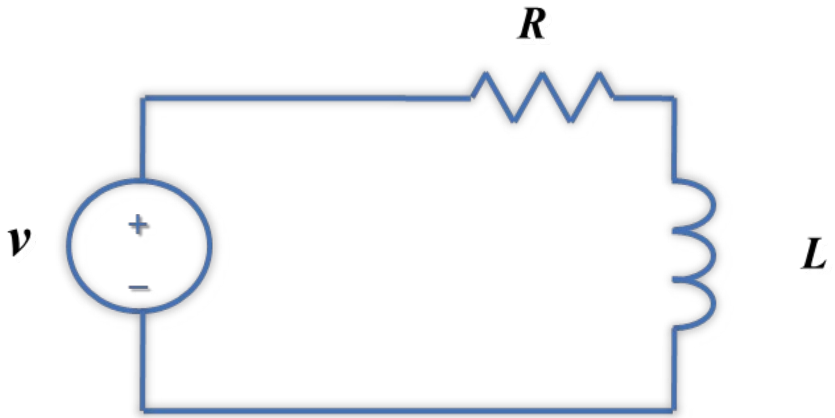
RMS

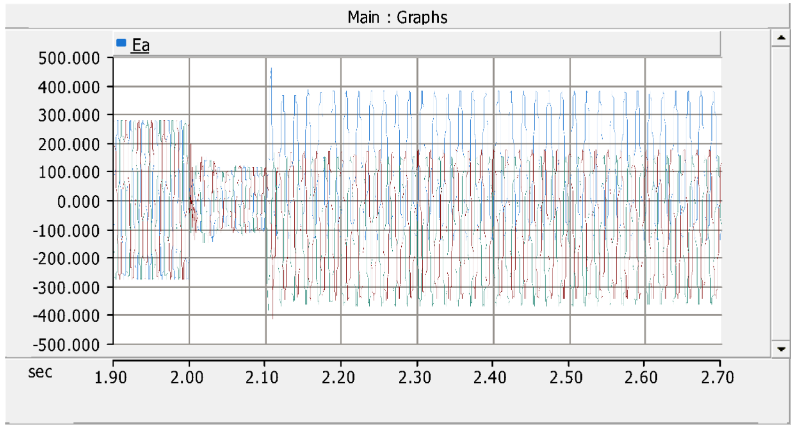
$$V(\omega) = R \cdot I(\omega) + j(L\omega) \cdot I(\omega)$$

$2.\pi.60$

EMT

$$v(t) = R \cdot i(t) + L \frac{d}{dt} i(t)$$

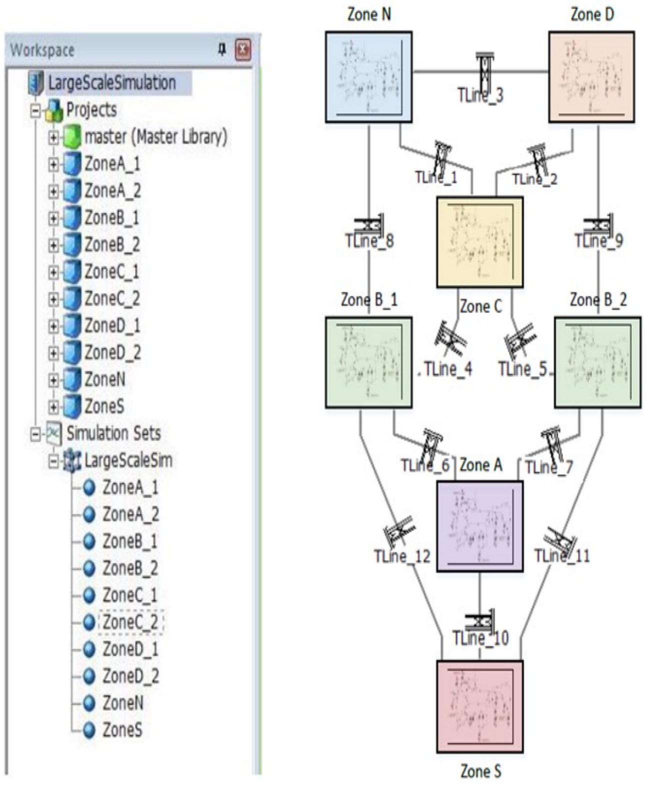




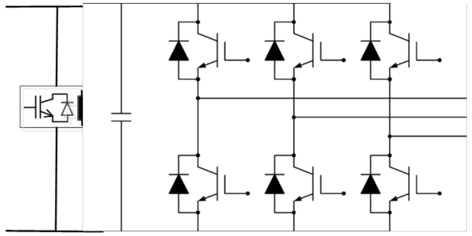
Challenges and Solutions

Solutions provided to overcome the wide area EMT simulation Challenges:

- Improved mathematical algorithms to speed up any one given simulation.
- Parallel simulation of different parts of a network and IBR modules – use the inherent ‘delay feature of a transmission line or cable connection to find a ‘natural’ break point. (Multi-rate PNI line that allows different time steps is also available)
- Non-switching type representation of IBR inverters – if done properly, these models will not impact overall conclusions of a study.



PSCAD Network Workspaces *Network Connected by Parallel EMT*

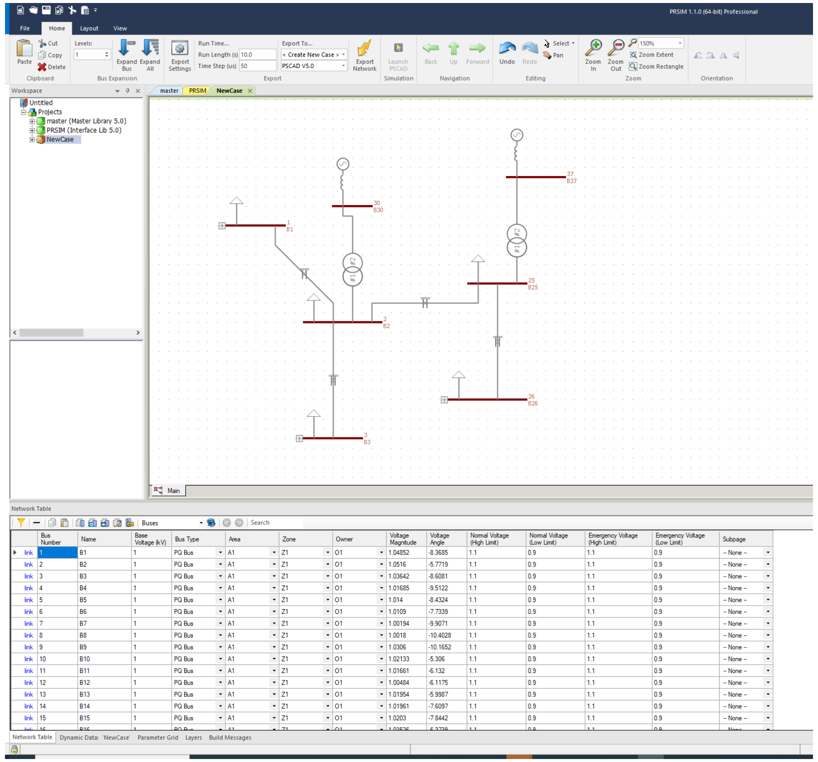


Representing ‘switching devices’ in an EMT simulation further compounds the simulation speed challenge.

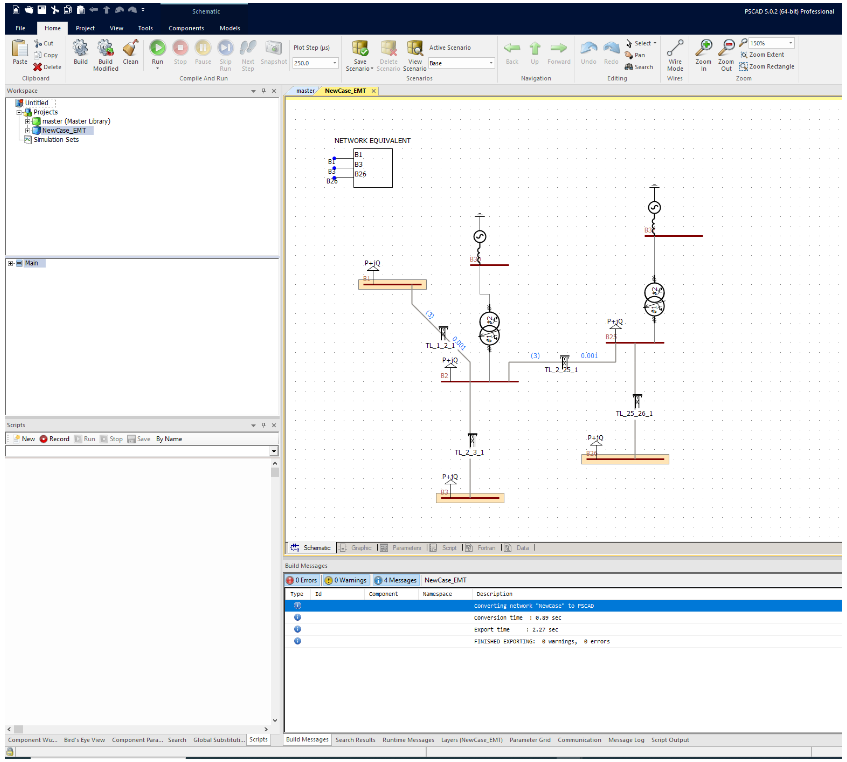
Relatively fast simulation speeds can be achieved

PRSIM

- Translates PSSE and PowerFactory networks into PSCAD
- New addition to tools offered by PSCAD

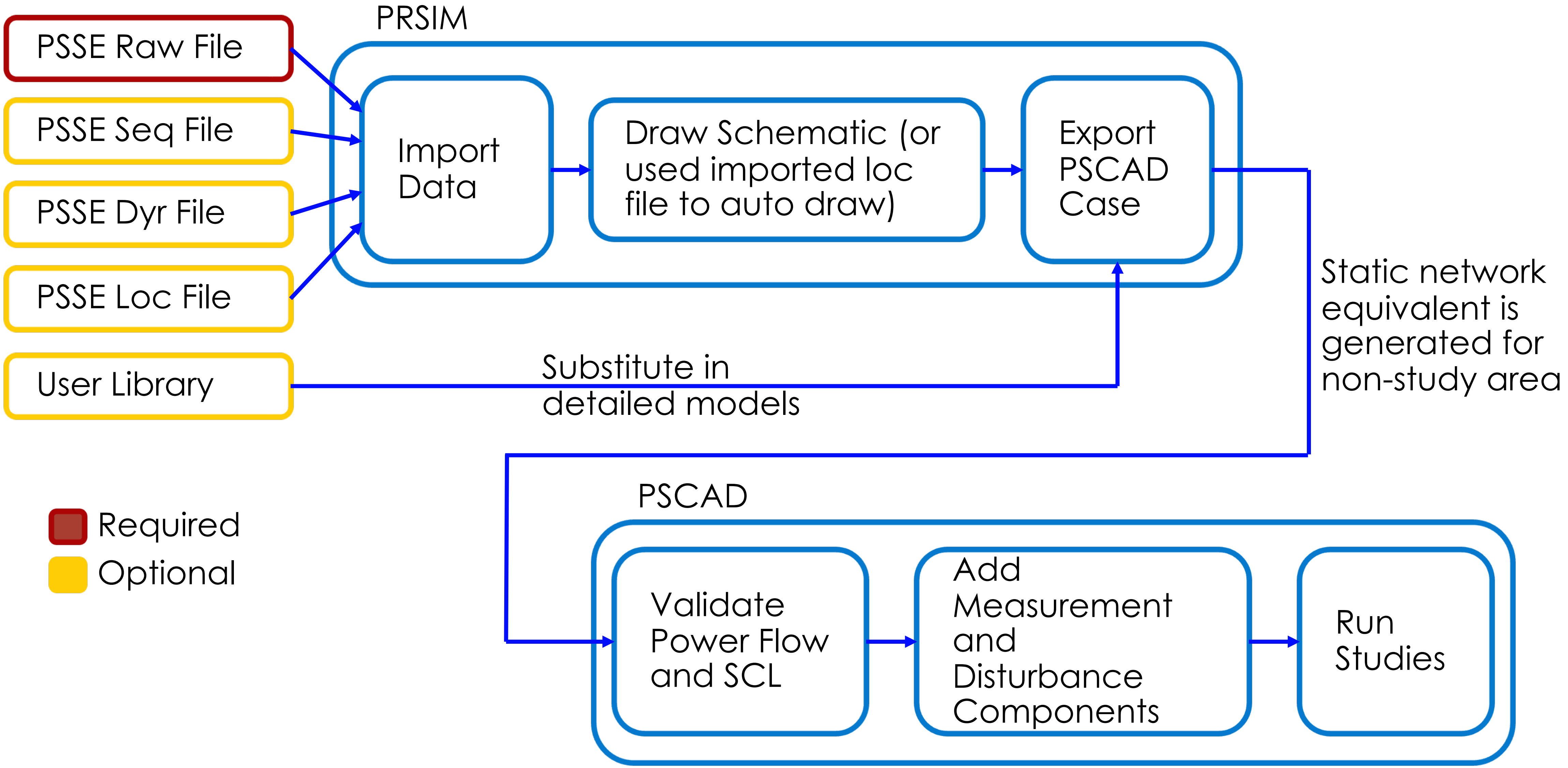


PRSIM



PSCAD

PSSE → PRSIM → PSCAD Workflow



PSCAD Considerations

- **Simulation time-step selection**
  - Fastest dynamic (highest frequency) that is to be simulated
    - e.g. $f_{highest}$ = 2 kHz, Δt = 50 μs (may work for switching transients)
  - TRV - 50 μs is too large. Value of 0.1 μs is typically used
  - Smaller time-step ➔ take longer to complete simulation

- **Plot step selection**
  - Fastest dynamic to be plotted

- **Initialization or how to start a simulation**
  - Use inbuilt loadflow program
  - Directly import dispatch conditions from PSSE or PowerFactory

- **Numerical stability**
  - Chatter removal

- **Interpolation / extrapolation techniques**
  - To match the exact switching instants of power electronic devices

High Performance Computers

- PSCAD/EMTDC runs on all modern Microsoft Windows machines (including Servers).
- Performance of computer should be selected based on system/study requirements. EMTDC solution speed is CPU bound and as such depends on clock speed but splitting the network can also increase speed so core count matters as well.
- We currently run large scale simulations on a variety of Intel and AMD based processors with some server based and some tower based.
- For wide area simulations, most customers are using HPCs with greater than 32 cores.

Example Wide Area Simulation Model

Model	Number
IBR (Manufacturer Model)	~200
Synchronous Machines	~150
HVDC (Manufacturer Model)	~5
Buses	~3500
2-Winding Transformers	~1900
3-Winding Transformers	~150
Loads*	~3000
Transmission Lines	~2500

* While variable, the distribution is often equivalenced at the 66kV or 33kV level

Running this model for 30s of simulation time takes 30-40 minutes on a server based HPC (2x AMD EPYC)

Wide Area Models Developed

PSCAD in partnership with TSOs have developed a variety of Wide Area Models

- South Australia
- Australia (4-State Model)
- Scotland
- National Grid UK
- Spain (Balearic Island)
- Denmark
- Canadian and US Regions

Some Areas of Development

1. A method to parallelize simulations without breaking at one time step T-Line
2. Auto splitting of network models to allow high performance without manual effort
3. New Matrix reduction methods to speed up simulations
4. Creating new libraries of standard models and more complicated modules (WECC Renewable Models, Expanded Protection library, etc.)

While PSCAD/EMTDC are constantly being developed to provide improved performance and convenience, effort will need to be made by researchers and interested parties to develop user friendly standards and models that accurately represent new devices and technologies for EMT simulations.

Trial Licenses and Demonstrations

For access to trial licenses or to arrange a demonstration please contact: sales@pscad.com