Detailed simulation studies as a solution to 21\textsuperscript{st} century power system challenges

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Brief introduction to NPPT

*Trustworthy power system engineering services*

Key areas:
- Low-inertia systems (microgrids, islands, remote communities, ≤ 30 MW)
- Distributed Energy Resources (DERs), especially at the distribution level
- “Traditional” EMT-type studies

Primary services:
- System diagnostics/forensics and event analysis
- Control and dynamics
- Protection
- Design
- Test design and result interpretation
- System studies

*moving power forward*
Key challenges to discuss today

- As power systems change, certain key functions do NOT change:
  - Protection
  - Power quality
  - Dynamic performance/stability
  - Reliability
  - Economic optimization

- We’ve been handling all of these, successfully, for over a century.
So, what’s changed?

• Power electronics
  • Much faster time constants
  • Little to no inertia
  • As much software-defined as physics-defined

• Need to study with higher granularity
  • Key approximations/simplifications yield unacceptable error
    • Infinite bus
    • Phase-phase balance
    • Perfect grounding
    • Fixed load types, usually without dynamics
  • Time constants are much shorter (again)
Modeling can have very high value

• The right type of modeling can help us address these challenges.

• Pros
  ✓ Reduces risk
  ✓ Improves fundamental understanding—observability and controllability
  ✓ Shortens development/commissioning times
  ✓ Allows testing that can’t be done experimentally
  ✓ Can significantly decrease overall costs

• Cons
  ✗ Can be expensive
  ✗ Need a lot of data
  ✗ Validation is critical
  ✗ Need someone who knows what they’re doing—easy to build a lying model
The value of modeling

Perceived value
Cost
Understanding gained

0%
Laboratory scale HW
Controls and power HIL
Controls HIL
100%
(pure simulation)

(actual HW on actual system)
What makes a good model?

• The best model is one that includes everything that’s important, and nothing that isn’t.
• Trouble is, you may not know in advance which is which.
  • Go for overkill/accuracy?
  • Go for simplicity/speed?
Key “gotchas” with modeling

• Range of applicability—is the model designed to solve my problem?
  • What are you trying to study?
  • Is the right model being used?
• Input data quality—garbage in, garbage out (GIGO)
• Operator qualifications—does the user understand the model and the system?
• Validation—how do I know the model is telling the truth?
Main model types

- Calculation automators—“macros”
- Models designed for dynamics—“dynamic simulators”
- Models designed for transients—“transient simulators”
- Models designed for “snapshots”—“steady-state simulators”
Simulation tools for power systems—traditional view
Simulation tools for power systems—evolving view
Simulation tools for power systems—low-inertia systems view
Simulation tools for power systems—distribution-connected DER studies

- Generator controls
- Inverter controls
- Protection
- Transient
- Dynamic
- DER-DER interaction
- Voltage fluctuation
- Risk of islanding
- Voltage rise
- Fault current contribution
- LROV
- Harmonics
- Conductor/transformer capacity
- Var/power factor obligations
- Contingency analysis
- Unit commitment
- OPF
- Load flow; “snapshot”
Calculation automators

• User enters inputs; program performs a preset standardized calculation
• Can be thought of as a macro—these are generally NOT simulators
• Sufficient for perhaps 75% of the modeling needed in distribution

• Examples
  • CYME
  • Aspen (?)
  • Synergi
  • SKM

• Things to watch for
  • Powerful and convenient, but limited flexibility
  • Easy to misapply—must be aware of the underlying assumptions and constraints
Calculation automators

A calculation automator can fall anywhere on this chart as long as there’s a standard formula.
Dynamic simulators

- Usually based on phasor and symmetrical component representations
- Also called “electromechanical simulators”
- Designed for machine dynamics and longer-scale transients on large systems
- Solves systems of differential/algebraic equations
- Solvers optimized for speed (modified Euler, simple trapezoidal)
- Typical time step: ¼ cycle
Dynamic simulators

• Examples
  • PSS/E
  • PSLF

• Things to watch for
  • Not well suited for power electronics (time steps too long)
  • Not especially good for distribution (symmetrical component assumptions)
  • Built-in DER models are generic; custom models are not allowed by some jurisdictions
  • Solvers compromise a little on robustness
    • Usually don’t have “backstepping” so may miss switching events
  • Watch out for inaccurate, outdated, or unverified models
Phasor simulators

The range of applicability of phasor simulators is typically here.
Transient simulators

• Based directly on differential equation descriptions of apparatus and components
• Designed to simulate physical phenomenon at “any” time scale, as long as you can represent it with differential equations
• Maximum physical fidelity with minimum assumptions, but also maximum data requirements and computational burden
• Solvers optimized for performance, and may have choices of solvers
  • Back-stepping algorithms or variable-step solvers included to catch switching instants
  • Typical time step: 100 µs (1/160th of a cycle) for averaged models; 1 µs for switching models; sub-microsecond for lightning or other physical models
Transient simulators

• Examples
  • EMTP derivatives (EMTP-RV, PSCAD, ATP)
  • MATLAB/Simulink/SimPowerSystems
  • DigSilent PowerFactory
  • ETAP

• Things to watch for
  • SLOW relative to dynamic simulators
  • Very high input data requirements; GIGO can be a big problem
  • Make sure model user has good physical knowledge ("sanity checks")
  • Control models should be validated
Transient simulators

The range of applicability of transient simulators is typically here. (Depends somewhat on your computer HW.)
Steady-state simulators

- Simulate multiple steady-state snapshots
- Do not simulate dynamics
- Good for “8760” simulations
- Example
  - OpenDSS
  - CYME/Synergi/WindMil have “8760” simulators built-in
  - Load flow solvers with batch mode operation
- Things to watch for
  - Accumulating error—because dynamics not simulated, changes may not propagate correctly from one steady state to another
  - Limits in fundamental math (i.e., Laplace transform)
Steady-state simulators

The range of applicability of steady-state “snapshot” simulators is typically over here.
Switched vs. averaged models of inverters

• Constant-current representations should be avoided, but do averaged models work? Yes, as long as the controls are represented in sufficient detail. Should also have AC/DC filters represented to capture dynamic impacts.

• What you gain with a switching model:
  • MUCH faster simulations due to ability to use longer time steps

• What you lose with an averaged model:
  • Switching harmonics
  • Saturation ("six-stepping")
  • Small differences in GFOV cases—zero-sequence V slightly underestimated
  • Major overestimation of LROV unless you represent antiparallel rectifier
Example inverter model
Validation results

Simulated and experimental inverter terminal voltages, no neutral, with parasitic Z
Feeder modeling

• Usually, sequence impedances used
  • Assumes a symmetrical circuit (not usually true, but not usually important)
  • Loses the identity of the neutral (do you need it?)

• Some transient simulators allow the use of the primitive matrix
  • Use Carson’s equations to get line parameters
  • More physically accurate
  • But higher input data needs (conductor types, segment lengths, and conductor spacings required); GIGO problem
GFOV test feeder
Aggregation

- Often want to model multi-inverter plants using a single aggregated inverter to speed up simulations
- Also often want to “lump” sections of feeders
- When and how can you do this?
Thank you!
Questions?

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