Building simulation models

- Start from single line diagram for system
  - Power Flow or Fault program

- Reduce model to part of system you need to study
  - Thevenin Equivalent
  
  - Look into boundary buses

- Collect system data at appropriate level of detail

- Build model and test each component

- Build model and test complete model
- Validate
  - against power flow program
    - steady-state - no transients
    - constant impedance load in PF
  - against fault program
    - steady state
- For cases with detailed generation
  models - compare to stabilizer program
  (Exciter, Governor)
- Do simple transients compare to simple calculations
Validation of Models... and Results

- Need to have a basic idea of what the transient response should look like
- Test your system with some very predictable cases
- Start from steady-state operating point
- Understanding behavior will be one of the focuses of this course

Fundamental Principles of Transient Analysis

- The laws of circuit theory still apply
  » Kirchhoff's Laws (KCL, KVL)
  » Energy is conserved
  » You can't change current through an inductor instantaneously
  » You can't change voltage across a capacitor instantaneously
- Oversimplified models can give misleading results

Leave out too much of circuit
\[
I_f = \frac{V_s}{R + jX}\\
I_f = I / \angle 85^\circ
\]

CB opens
### Frequency or frequencies of interest

- Model detail depends on the frequencies associated with the transient
- Frequency dependent parameters
- Simulation time step will also vary with classification in time domain simulation

\[
\text{at least } \frac{1}{10} \text{ to } \frac{1}{20} \text{ of period of fastest response} \]

### Calculations

- Solve coupled differential equations
  - Hand calculations in the LaPlace domain
  - Hand calculations in the time domain
  - Time domain numerical circuit simulation
  - Frequency domain simulation

\[\text{Numerical integration}\]
Circuit Simulation

- Output often as time domain waveforms
- Often want instantaneous peak values of $v(t)$ and $i(t)$
  - Or in some cases energy
  - Peaks missed with RMS or harmonic solutions

Transient Network Analyzer (TNA)

- Predates use of digital computers
  - Analog computer model
  - Hybrid: digital controls
- Real-time digital simulators
- Cost limits to small class of problems
  - Closed loop testing of control hardware
EMTP Variants

- Original version mainly modeled RLC elements switches, ideal sources and lines
- Many extensions and several versions
  - ATP: Alternate transients program (http://www.emtp.org)
  - EMTP-RV (http://www.emtp.com) latest from DCG
  - EMTDC: student version available free from their web site (http://www.pscad.com/)
  - RTDS: Real time digital simulator
  - OPAL-RT: Real time digital simulator
  - SimPowerSystems blockset for Matlab

EMTP-like Programs

- Designed to study transient phenomenon from a few hundred Hertz to hundreds of kHz
- Switching surges, faults studies, insulation coordination, power electronic interactions with power systems
- EMTP can also model dc systems and electromechanical interactions
- Trapezoidal integration scheme → astable
  - Stable results if transient response modeled is stable