- Transients programs
  - Time Domain solvers
    - Electrical equations solved
      - Discretized
  - Power converter models
    - Outer control loop \((P, \omega, f)\)
    - Inner current loops (inner controls) \((VSC)\)
    - Synchronization
    - Switching behavior
      - Detailed
      - Simplified switch
      - Average models (neglects switch)
For wind, PV, storage etc → model the resource
-equivalent circuit models
Electromagnetic Transients

- Power systems normally in steady-state
  - Or slowly varying quasi-steady-state
  - Allows use of RMS phasors
- Switching, operations, faults, lightning,
  - Response frequencies from DC to MHz
  - Generally, dies out rapidly (higher freq.)
  - Large voltage and currents are possible
  - RLC response to change in voltage or current

Why Analyze Transients?

- Power systems operate in sinusoidal steady-state majority of time
- Sudden changes cause large voltage and currents
  - Including faults and response to clearing faults
- Protection decisions before transients die out
  - Or even based on transients
- Power converters produce repetitive transient behavior
UI 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

UI Frequency or Frequencies of Interest

- Model detail depends on the frequencies associated with the transient
- Power converter model detail
  » Detailed device turn-on/turn-off
  » Versus ideal-switches
  » Versus non-switching models
- Simulation time step will also vary with classification in time domain simulation

Ton, Toff are the simulation timestep
Circuit Simulation Results

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

Simulation Tools: 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
UI Off-Line Time Domain Simulation

- Digital computer simulation of transients
- General purpose equation solvers: MATLAB, MathCAD
- Analog electronic and integrated circuits: SPICE, Saber
- Not really designed for power system transients

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The Electromagnetic Transients Program-EMTP

- Hermann Dommel, Germany, then BPA
- Numerically solves difference equations
- Fixed versus variable time-step
- EMTP has become and industry standard (verified models)
- Modules in other power systems programs
- Matlab toolbox

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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)
  - EMTDC: student version available free from their web site (http://www.pscad.com/)
  - RTDS: Real time digital simulator
  - OPAL-RT: Real time digital simulator
  - Sim Power Systems block set for Matlab
UI Capabilities and Outputs of EMT Programs

- Outputs are voltage, current, power, and energy versus time
- Control variables are available if controls are modeled
- Can model simple controls using EMTPs control models or can interface to FORTRAN (in some cases C or Matlab too)
  » Programs have internal control modeling
  » Graphical user interface

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UI ECE 529

- This class will have assignments requiring use of an EMTP-like program
- Can use any of programs listed above, but best if use ATP, EMTP-RV, or PSCAD/EMTDC
  » EMTP-RV is available on campus and in UI VLAB
    - http://vlab.uidaho.edu/
  » Student version of PSCAD could be a little small at times
- If your employer has a preferred program you can use that – let me know

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https://pscad.com

emtp.org
Simple Switching Configurations Underlying Power Electronics

Three pole switch: EMTP-RV

[Diagrams of switching configurations with labels and symbols]