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
Validation of Models…

- Graphical user interfaces have made transients programs much easier to use
- It is very easy to get simulation results
  - But it is critical to be able to verify that the results are correct
- First step is validating the system model

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 with power converters in the circuit 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

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
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
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

The Electromagnetic Transients Program-EMTP

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

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\(\rightarrow\)astable
  - Stable results if transient response modeled is stable
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

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/](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