What Are Electromagnetic Transients?

- Power systems normally in steady-state
  - Or 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
Analyzing Transients

- Understand the transient you want to model
- Good data to form detailed models
  » Not trivial to get
- Need mathematical model of the system
  » Appropriate for the transient you are studying
  » Classification of transient important first step

Classifications of Transients

- By Cause
  » Switching transients (all manner of transients)
  » Lightning transients
  » Faults
- Mode of generation of transients
  » Electromechanical
    » Rotating machines mechanical to electrical
  » Electromagnetic
    » Capacitors/Inductors
Classification by Frequency Range (CIGRE WG 33.02)

- Low frequency oscillations
  » 0.1 Hz – 3 kHz
- Slow front surges (most switching)
  » 50/60 Hz – 20 kHz
- Fast front surges (lightning, some classes breakers)
  » 10 kHz – 3 MHz
- Very fast front surges (disconnector restrikes, GIS)
  » 100 kHz – 50 MHz

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 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
- Frequency dependent parameters
- Simulation time step will also vary with classification in time domain simulation

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
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
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 and 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) latest from DCG
  » EMTDC: student version available free from their web site (http://www.pscad.com/)
  » RTDS: Real time digital simulator (cost)
  » 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
EMTP 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

ECE 524

- This class will have assignments requiring use of an EMTP-like program
- Can use any of programs listed above, but best if use ATP or PSCAD/EMTDC
  - Student version of PSCAD will be a little small at times
  - In past, most EO students have preferred ATP
- If your employer has a preferred program you can use that – let me know
The ATP Version

- ATP is essentially free, a license application needs to be filled out
  - http://www.emtp.org/
- The purpose is to limit access to parties that have participated in “EMTP-Commerce”
- Cost only if want materials shipped--can download much of it now, so don’t need to pay for shipping

ATP Versions

- ATP ported several operating system
- Several versions for the PCs
- Run in DOS windows/Command Prompt
  - Ming32: All MS windows variants.
ATP Plotting Programs

- Older versions of EMTP displayed plot on screen at end of the simulation run
- Special purpose plotting programs
  - PlotXY: Simply Windows based plotting program.
    - Export to word processor
    - Recommended for ECE 524
  - TPPLOT: Distributed with Salford ATP
  - PCPLOT (WPCPLOT): Simple plotting program.

GTPPLOT: Build of TPPLOT using GNU Fortran Compiler. Doesn't require Salford Extender, can handle Comtrade

TOP: Electrotek wrote for EPRI-DCG and extended for harmonics programs, ATP
  - Available free: http://www.pqsoft.com/top/
  - Good post processing capabilities.
  - Output to Comtrade

Matlab: Can use “PL42MAT” to convert output from ATP to data file for Matlab.
Graphical Interfaces

- EMTP is written in FORTRAN
  - FORTRAN read statements,
  - Restrictions on input data file
- Several attempts at graphical interfaces
- ATPDraw is best option for ATP
- Use to create circuit and enter parameters
- Program creates the EMTP format data file
- Run ATP and call plot from ATPDRAW

ATPDraw

- Available for download from ATP distribution sites
- Follow link for ATPDraw for information about the program
  - Latest versions are version 6.0
  - File format not backward compatible
  - [http://www.atpdraw.net/](http://www.atpdraw.net/) (ATPDraw only, not ATP itself)
- Get the program and the patch files (update to fix bugs in executable)
- Manual and introduction presentation for download
Capabilities

- Graphical pre-processor for ATP
- MS Windows (old DOS version too)
- Development funded BPA and SINTEF Energy Research
- Automatically fills in the fields, removing a major source of errors in data files
- Still some sources of errors remain

ATP Tools for ECE 524

- If you choose to use ATP:
  - Apply for a license and then contact me
  - Download the following
    - Atpmingw.zip
    - Most recent of ATPDraw6x_install.zip
    - Most recent of PlotXY.zip
PSCAD/EMTDC

• Education version available in ECE labs
• Free Student Edition (15 node limit)
  » Go to: http://www.pscad.com/
  » Create account and get set up to download
    – Download the Program itself
    – Includes free Fortran Compiler
      • Need unless you have compatible one installed

Learning ATPDraw/ATP or PSCAD/EMTDC

• Class will have basic intro for both programs
• Build on this as we go along, with examples
• Program manuals
• Program intros from other recent course if want to jump ahead
  » ATPDraw version 5.7
  http://www.ece.uidaho.edu/ee/power/ECE529/Lectures/L4/IntroToAtp.pdf
  » PSCAD/EMTDC version 4.2
  http://www.ece.uidaho.edu/ee/power/ECE404VSC/Lectures/L6/L6.pdf