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
  - » 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

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

Other Applications of Transient Simulation

- Transient simulation tools are now use for non-transient analysis applications
  - » Simulation studies to explore control interactions
  - » Analysis of fault behavior of power electronic converters
    - – Really another control interaction
  - » Harmonic analysis
  - » Hardware-in-the -loop simulations to test protective relays
  - » Hardware-in-the-loop simulation to test control devices
  - » Cybersecurity research on power systems communications and controls

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, EMTP-RV, or PSCAD/EMTDC
  - » EMTP-RV is available on campus and in UI VLAB
    - – http://vlab.uidaho.edu/
  - » In past, most EO students have preferred ATP
  - » 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

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.

ATP Plotting Programs

» 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/ (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 you 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 courses if you want to jump ahead
  - » ATPDraw

http://www.ece.uidaho.edu/ee/power/ECE529/Lectures/L5/lect5.pdf

  - » PSCAD/EMTDC version 4.2

http://www.ece.uidaho.edu/ee/power/ECE404VSC/Lectures/L6/L6.pdf