- Some cases too complicated to adequately model using phase-based techniques.

- Simultaneous fault

- Control behavior during response to fault

⇒ Power converters
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) Also Opal-RT
  - SimPowerSystems blockset for Matlab

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
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 6.2
  [http://www.ece.uidaho.edu/ee/power/ECE529/Lectures/L5/lect5.pdf](http://www.ece.uidaho.edu/ee/power/ECE529/Lectures/L5/lect5.pdf)
  » PSCAD/EMTDC version 4.2
  [http://www.ece.uidaho.edu/ee/power/ECE524/Lectures/L5/L5_emtdc.pdf](http://www.ece.uidaho.edu/ee/power/ECE524/Lectures/L5/L5_emtdc.pdf)

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

with ATPDraw -variable/node names should be in upper case letters or numbers (BUSI)
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
Simultaneous faults
- vast majority of faults are a single event
- some situations with multiple faults present
- one may cause the second or completely unrelated
1) SLG evolving

**Case A:**

\[ N = G \]
\[ CN = VG \]
\[ \text{SLG} \]
\[ \text{DLG} \]

**Case B:**

\[ A_6 \]
\[ LG \]
\[ Li \]
\[ CG \]

So may need to treat as simultaneous fault.
(2) phase-to-ground fault with a broken conductor

(3) Unrelated faults
Analysis of simultaneous faults

- 2 port equivalent between the fault location
- we cross symmetrical components
- we cross references
- phase A referred components
- $AG \rightarrow (5 \, \text{BC})$
- at the same time
- $ABG \rightarrow B \, \text{of components}$

Corrections for this problem.
2 Port Network Equivalents

Two Port Network

Fault location $x$

Fault location $y$

Positive negative zero

Phase B open

Created connections for fault types
Three Types of Two Port Networks (Section 9.1 & 9.2 in Anderson)

I. $Z$-Type (Impedance relationship)

\[
\begin{bmatrix}
V_x \\
V_y
\end{bmatrix} =
\begin{bmatrix}
Z_{xx} & Z_{xy} \\
Z_{yx} & Z_{yy}
\end{bmatrix}
\begin{bmatrix}
I_x \\
I_y
\end{bmatrix}
\]

II. Admittance ($Y$-type)

\[
\begin{bmatrix}
I_x \\
I_y
\end{bmatrix} =
\begin{bmatrix}
Y_{xx} & Y_{xy} \\
Y_{yx} & Y_{yy}
\end{bmatrix}
\begin{bmatrix}
V_x \\
V_y
\end{bmatrix}
\]
Hybrid type (H-parameters)

\[
\begin{bmatrix}
U_x \\
I_y
\end{bmatrix} =
\begin{bmatrix}
H_{xx} & H_{xy} \\
H_{yx} & H_{yy}
\end{bmatrix}
\begin{bmatrix}
I_x \\
U_y
\end{bmatrix}
\]

- Choose appropriate type for fault types involved
  - Partly how sources modeled
Example

Fault X: SLG on phase A

- Connect pos, negative & zero in series ($I_0 = I_1 = I_2$, $V_0 + V_1 + V_2 = 3R_f \cdot I_0$
- phase A ref

Fault Y: BC

- If $R_f = 0$, $V_1 = V_2$, $I_1 = -I_2$
- no $I_0$
- phase A ref
Suppose LL fault was AB not BC

C reference components

Ideal Xfmr.
Example - simultaneous faults at same location

ABC constraints

SLG: $V_{AG} = R_G \cdot I_{af}$

LL: $I_{bf} = -I_{cf}$

$V_{BG} = V_{GS} + R_{BC} \cdot I_{bf}$