PSLF User's Group Meeting

Developing Open Form User Models for Rotating Machines and Static Devices in PSLF

April 26, 2007

Pterra, LLC

Chicago, Illinois

- **Introduction**

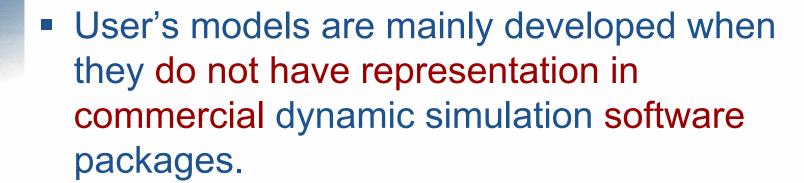- **Overview**

- **Development process**

- **Data Collection**

- **Developed Models**

- User's models are mainly developed when they do not have representation in commercial dynamic simulation software packages.

- From time to time user's models are developed, even if they can be replaced or approximated by models already available, for particular purposes, i.e., research, training or code accessibility.

Consulting and
Training Services

- Developing User models requires:

  o Knowledge of equipment performance characteristics (Manufacturer knowledge).

  o Understanding of the overall response characteristics of the network where the equipment is connected (Transmission provider or operator).

  o Ability to convert the equipment and associated network response characteristics into a usable model for simulation (Model writer).

- The success of a user model development depends on the collaborative effort of the:

    - Equipment specialist (**manufacturer**)
    - Power system specialist (**transmission owner**)
    - Model code **specialist**

- Given a good understanding of the control process and software interactions, a close coordination with the equipment manufacturer could help in tuning the simulation response of the user model.

- Writing a user's model is **an exercise in practical modeling** rather than theoretical.

  - The proper **selection of controls and interactions** to be included in the model is very important.

  - **Higher order frequency effects do not have impact** on stability performance.

  - **An overly complicated model** that captures all frequencies is not better than a **simplified model** that captures the essential response.

  - **Robustness response within the time step size** is also a very **important factor**. High frequency effects and voltage-sensitive models can lead to error propagation and numerical problems.
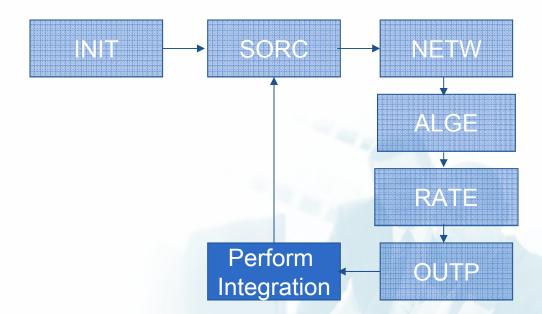
- Power System Equipment is **modeled by a set of non-linear algebraic-differential equations**.

- **Dynamic performance** under disturbances is **analyzed by solving this equation set**.

- Dynamic simulation of a power system **implies two processes**:

  - Simulation of dynamic models represented by **differential equations** (**generators, exciters, governors**, etc.)

  - Solution of the electrical network represented by **algebraic equations** (**Voltage & Current**).

Consulting and
Training Services

```
┌─────────────────┐      ┌─────────────────┐      ┌─────────────────┐
│ Initialize State│ ───▶ │ Calculate Source│ ───▶ │  Solve Network  │
│    Variables    │      │    Currents     │      │                 │
└─────────────────┘      └─────────────────┘      └─────────────────┘
                                  ▲                         │
                                  │                         ▼
                                  │                ┌─────────────────┐
                                  │                │    Calculate    │
                                  │                │    Algebraic    │
        Process for Dynamic Simulation            │    Variables    │
                                  │                └─────────────────┘
                                  │                         │
                                  │                         ▼
                                  │                ┌─────────────────┐
                                  │                │    Calculate    │
                                  │                │   Derivatives   │
                                  │                └─────────────────┘
                                  │                         │
                                  │                         ▼
                         ┌─────────────────┐      ┌─────────────────┐
                         │    Perform      │ ◀─── │  Save Output    │
                         │   Integration   │      │   Variables     │
                         └─────────────────┘      └─────────────────┘
```

- Any user's model contains all or some of the following modes:
  - INIT
  - SORC
  - ALGE
  - RATE
  - OUTP
  - NETW

- INIT Mode: **State Variables and Output Variables** are initialized.

- SORC Mode: Calculates **nodal injection currents**; i.e., generator **network boundary source conditions**. Not needed if the model is not connected directly to the network; i.e., exciter or governor models.

- ALGE Mode: Calculates **secondary variables** (not state variables); i.e., internal signals. Network events are initiated in this mode; such as, load shedding, capacitor switching.

- **RATE Mode:** State variable derivatives are calculated.

- **OUTP Mode:** Output variables should be set either in OUTP or ALGE MODE.

- Optionally, the name and scale range for the output channels can be modified in INIT MODE.

- Information of the performance characteristics of the equipment is provided by the manufacturer.
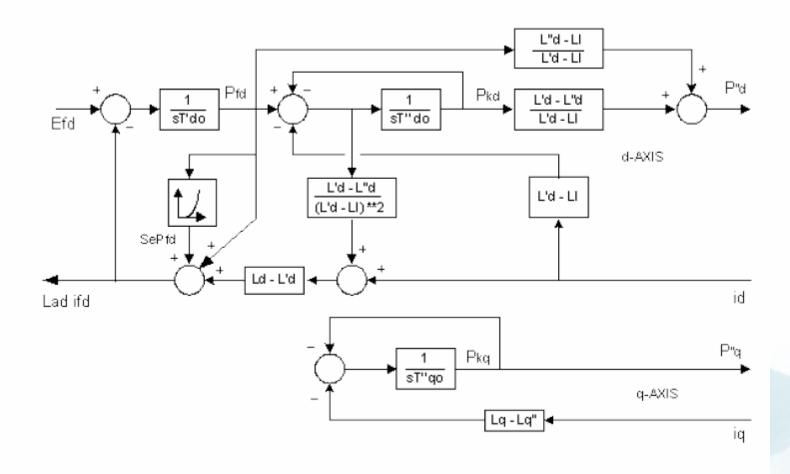
- This information is usually provided in Control Block Diagram form that shows I/O parameters and relationship among equipment components.

- Control Block Diagrams contains **implicitly** the algebraic-differential equations, simply and graphically.
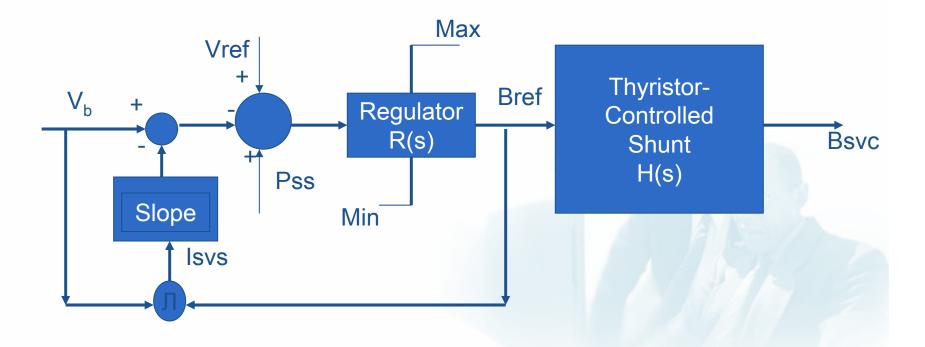
Sample Static Var Device

- SVC Model represents a shunt –connected static (no moving parts) device whose output varies to control specific parameters of the power network.

Development Process

- Control Block Diagram provided by the manufacturer is analyzed according to the simulation objective and the tool for the performance analysis.
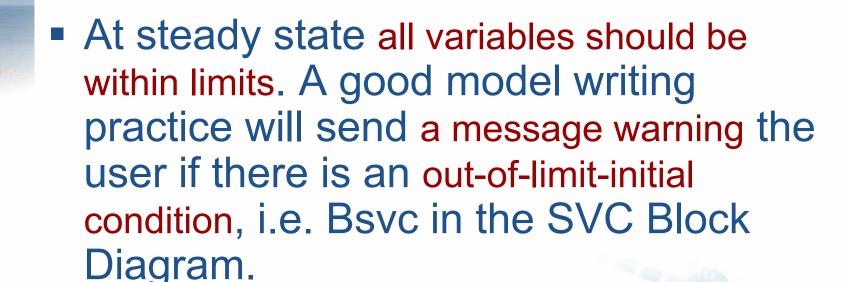
- Higher frequency response is discarded.
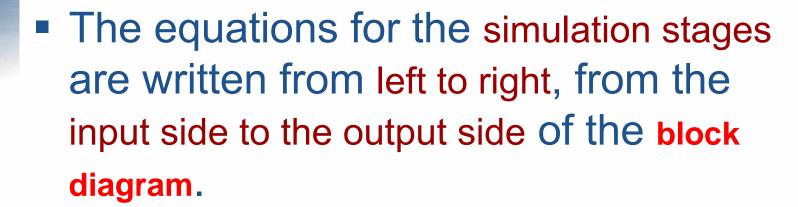
- Initial Conditions (Steady State equations) may be written by proceeding from right to left, from the output side to the input side of the block diagram.

- For instance, the SVC susceptance (Bsvc) at initial condition is calculated from the reactive power source/sink that represents the SVC in the load flow at its terminal voltage.

- At steady state, there is no change or driven variables, all derivatives should be zero.

- At steady state all variables should be within limits. A good model writing practice will send a message warning the user if there is an out-of-limit-initial condition, i.e. Bsvc in the SVC Block Diagram.
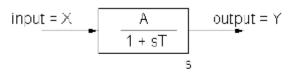
- Equating to zero all state variable derivatives will complete the initial condition algebraic equations.

- The equations for the simulation stages are written from left to right, from the input side to the output side of the **block diagram**.
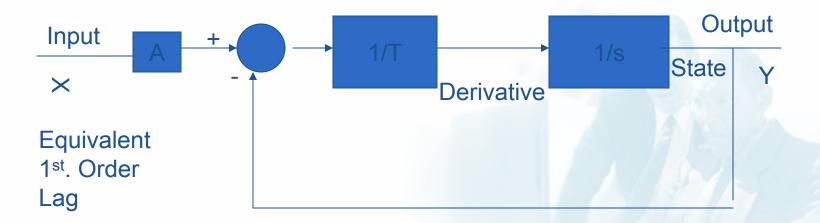
- Auxiliary algebraic variables, state variables and derivatives are formulated as a function of the input parameters to each block.

$$input = X \rightarrow \boxed{\dfrac{A}{1 + sT}} \rightarrow output = Y$$

Block diagram of 1st order lag

Initialization
STATE= Y
X=Y/A

Simulation
Derivative = (AX-STATE)/T
Output= STATE

Input
X

Equivalent
1st. Order
Lag

A → + ⊖ − → 1/T → 1/s

Derivative

Output
State   Y

- Before testing the model, the code should be inspected to avoid inconsistencies, logical or syntax errors.

- Test the code to the limits by changing input variables to their max/min values and check the feasibility of the results.

Summary:

- Revise manufacturer's control block diagram according to the objective and simulation tool.

- Define state variables and assign meaningful names (if possible) to the algebraic variables.

- Understanding the physical meaning of each variable is useful for the code developer.

Consulting and
Training Services

- Define Input/output **format**

- Write **initial condition equations** proceeding from right to left in the block diagram.

- Write **simulation equations**, i.e., state, derivative and auxiliary variables proceeding from left to right in the block diagram.

- Insert initial conditions and simulation equations into the block modes according to the tool language and associated format.

- **Debug** the code from syntax and logical errors.

- It is worthy to revise not only the meaning of each variable but also how each variable **takes a value**, particularly, the initial value.

- None of the above assure a bug-free model. Manufacturer and/or user **testing** are essential to the development process.

- Manufacturer data **collected** (may vary by type of equipment):
  - control block diagram
  - V-curve
  - saturation curve
  - equipment description

Consulting and
Training Services
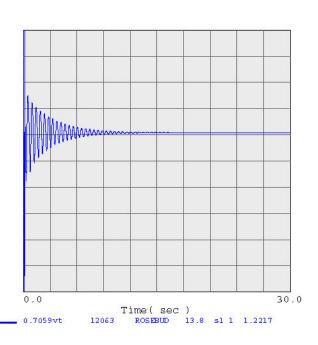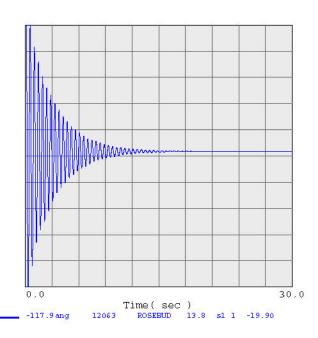
- User's dynamic models for PSLF are written in EPCL under generic model types or software interfaces called **EPCGEN or EPCMOD**.

- EPCMOD interface can represent most power system control functions commonly required for user's models.

- EPCGEN interface is specifically for user's modeling of devices **directly connected** to the network, i.e. **motor, SVC, generator, statcon or current injection models**.

- The user's model for the synchronous motors and the SVC for this project were written by using **EPCGEN** interface.
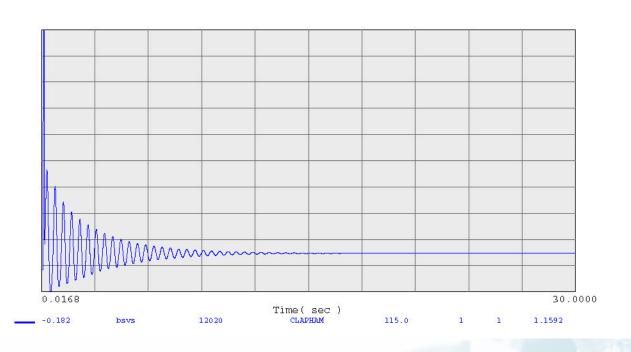
- Close-in fault, cleared normally
- Plot of voltage and angle at salient pole machine

- Same fault
- Response at SVC - Bsvs
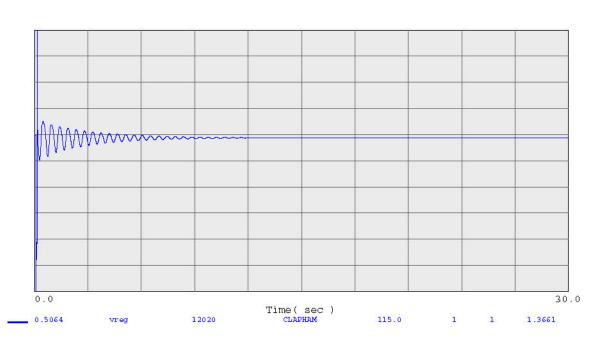
- **Same fault**
- **Response at SVC - Vreg**