Transient Stability Analysis with PowerWorld Simulator

T1: Transient Stability Overview, Models and Relationships

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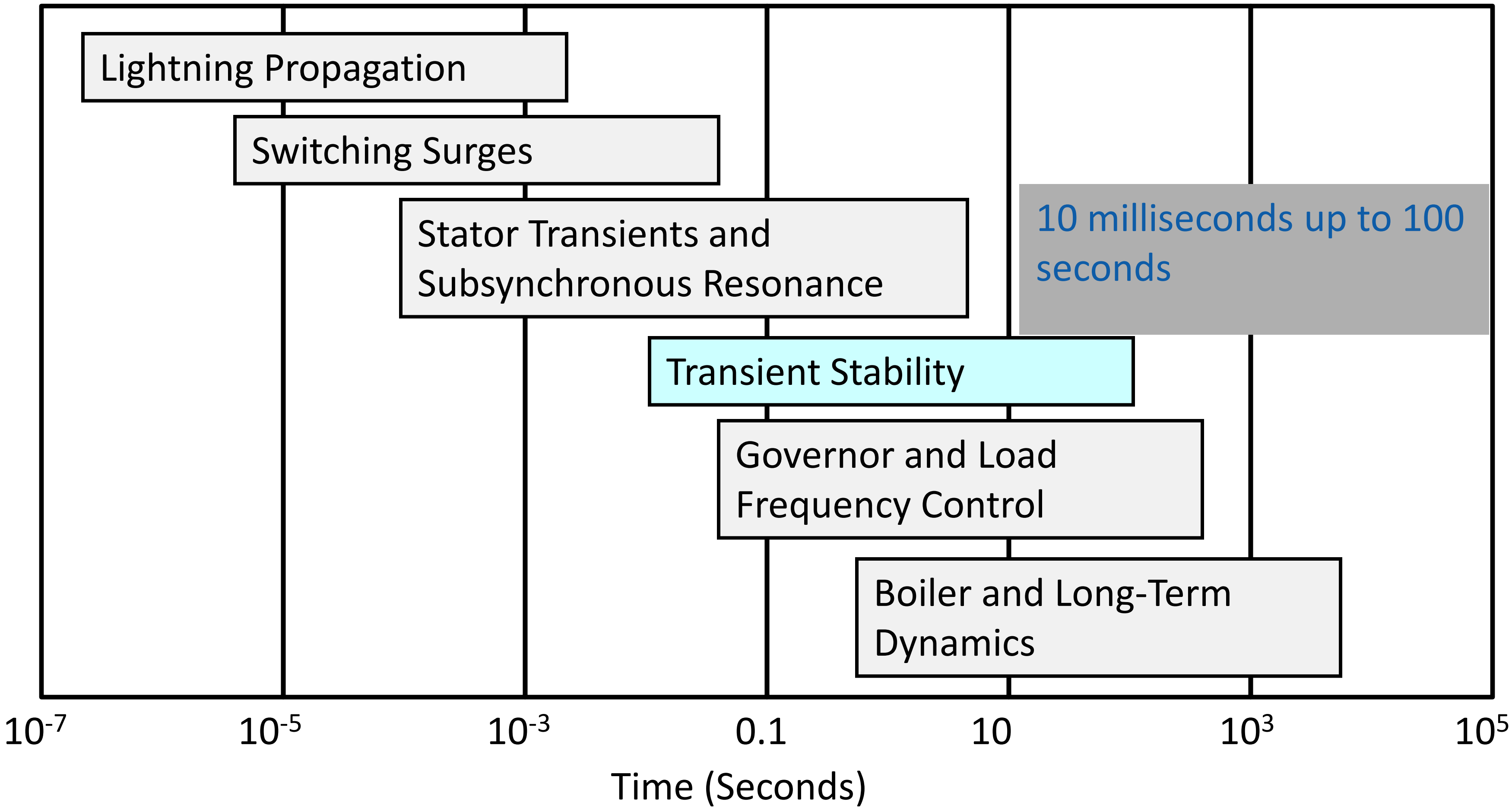
PowerWorld and Transient Stability

- PowerWorld has been working on transient stability since 2006, with a very simple implementation appearing in Version 12.5 (Glover/Sarma/Overbye book release).
- Some reasons for adding transient stability to PowerWorld
  - Growing need to perform transient stability/short-term voltage stability studies
  - There is a natural fit with PowerWorld – we have good expertise in power system information management and visualization and transient stability creates lots of data
  - Fills out PowerWorld's product line

Models and Model Relationships

- Overview of power system modeling in general
- Overview of the different model types supported by Simulator
  - Generator Models
    - Relationships between the different types of generator models
  - Wind Generator Models
    - Relationships for them
  - Also some discussion of Load Models

Time Scale of Dynamic Phenomena



P. Sauer and M. Pai, *Power System Dynamics and Stability*, Stipes Publishing, 2006.

Power Flow vs. Transient Stability

- The power flow is used to determine a quasi steady-state operating condition for a power system
  - Goal is to solve a set of algebraic equations
    - $\mathbf{g(y)} = \mathbf{0}$ [**y** variables are bus voltage and angle]
  - Models employed reflect the steady-state assumption, such as generator PV buses, constant power loads, LTC transformers.

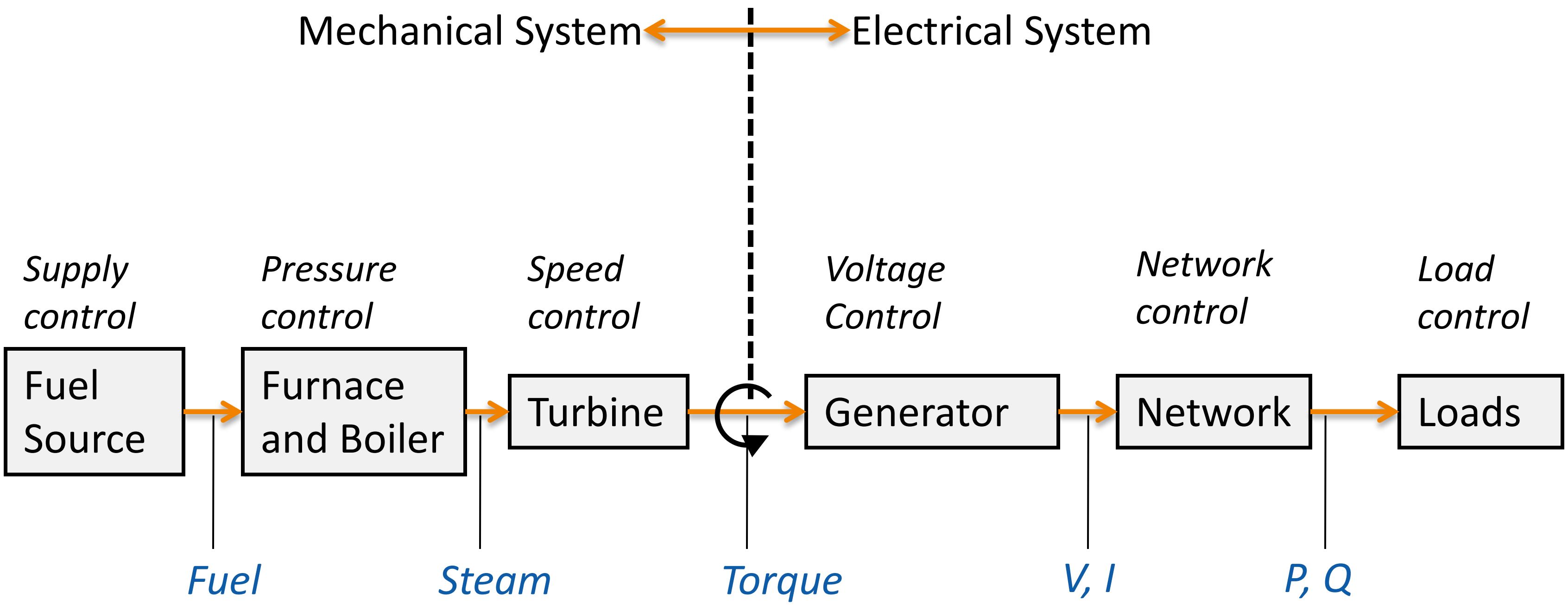
Power Flow vs. Transient Stability

- Transient stability is used to determine whether following a contingency the power system returns to a steady-state operating point
  - Goal is to solve a set of differential and algebraic equations,
    - $d\mathbf{x}/dt = \mathbf{f}(\mathbf{x},\mathbf{y})$ [**y** variables are bus voltage and angle]
    - $\mathbf{g}(\mathbf{x},\mathbf{y}) = \mathbf{0}$ [**x** variables are dynamic state variables]
  - Starts in steady-state, and hopefully returns to a new steady-state.
  - Models reflect the transient stability time frame (up to dozens of seconds)
    - Some values assumed to be slow enough to hold constant (LTC tap changing)
    - Others are still fast enough to treat as algebraic (synchronous machine stator dynamics, voltage source converter dynamics)

PowerWorld Transient Stability Training Philosophy

- In teaching transient stability there are three main areas in which we could focus
  - Theory
    - The theory underlying transient stability, including the models
  - Practice
    - The practical application of transient stability tools
  - Mechanics
    - The mechanics of using the PowerWorld Simulator Transient Stability Add-on
- Obviously some knowledge is needed in all of these areas, but the focus of this training is on the third, then somewhat on the second, with a small amount of coverage of the first.

Physical Structure
Power System Components



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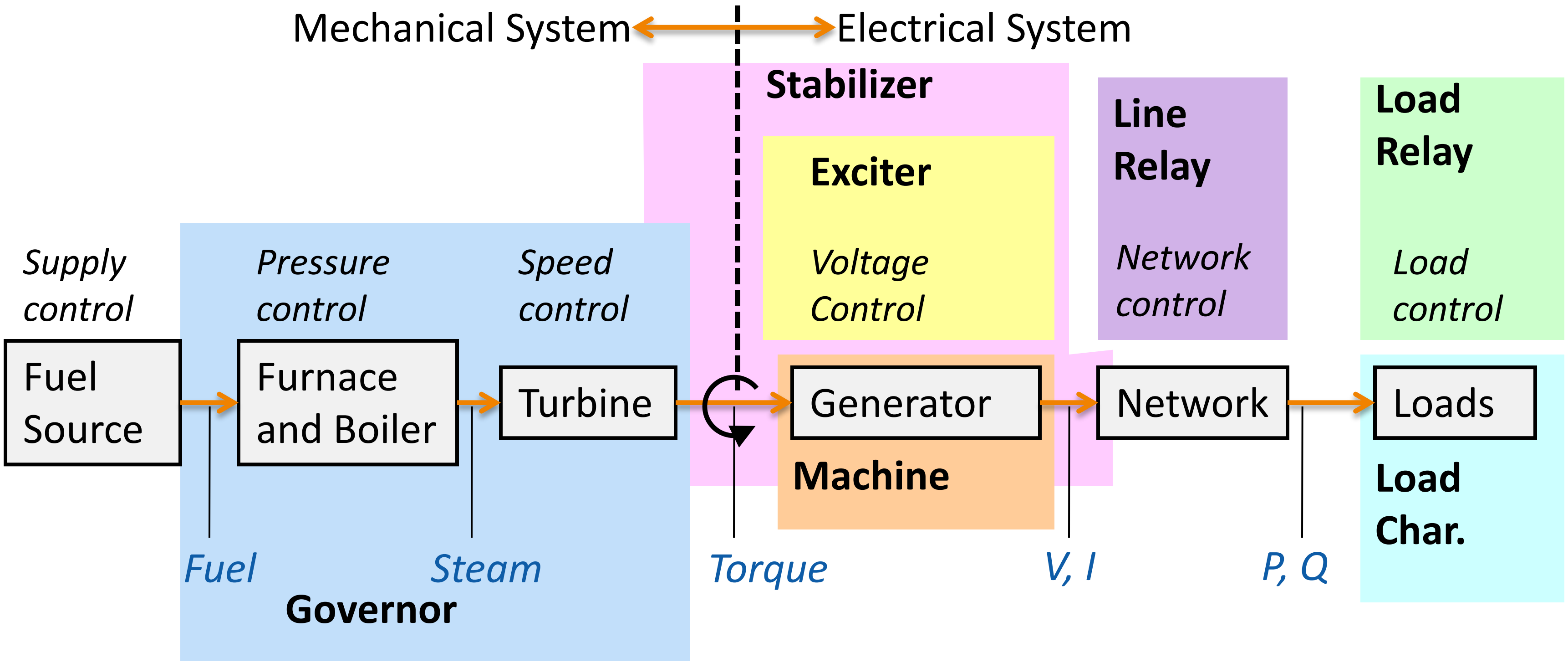
Transient Stability Models in the Physical Structure



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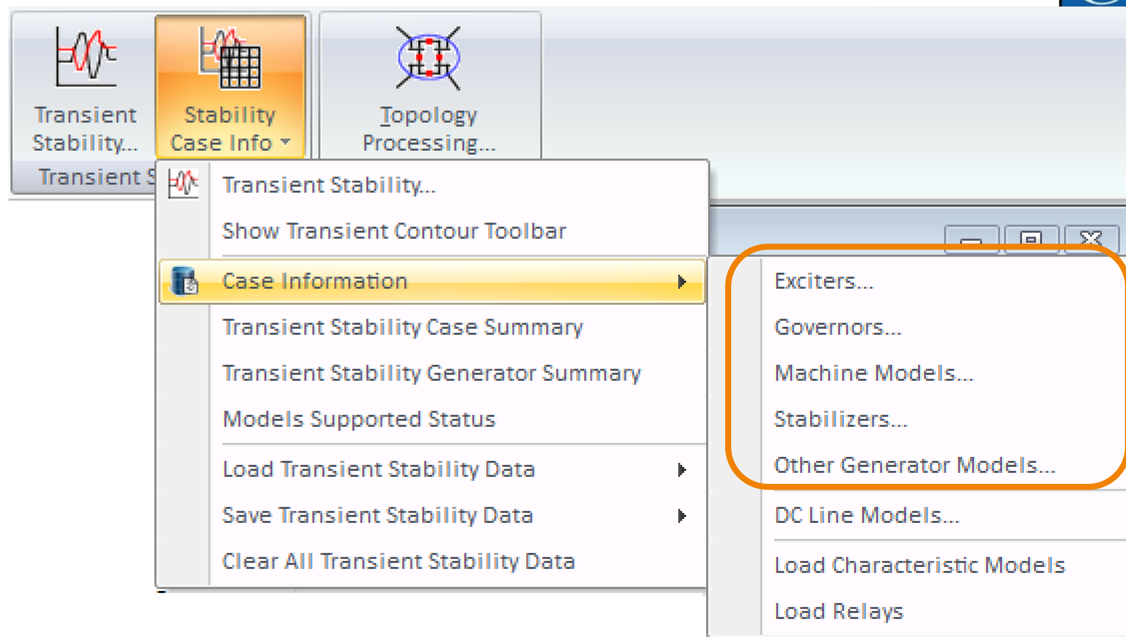
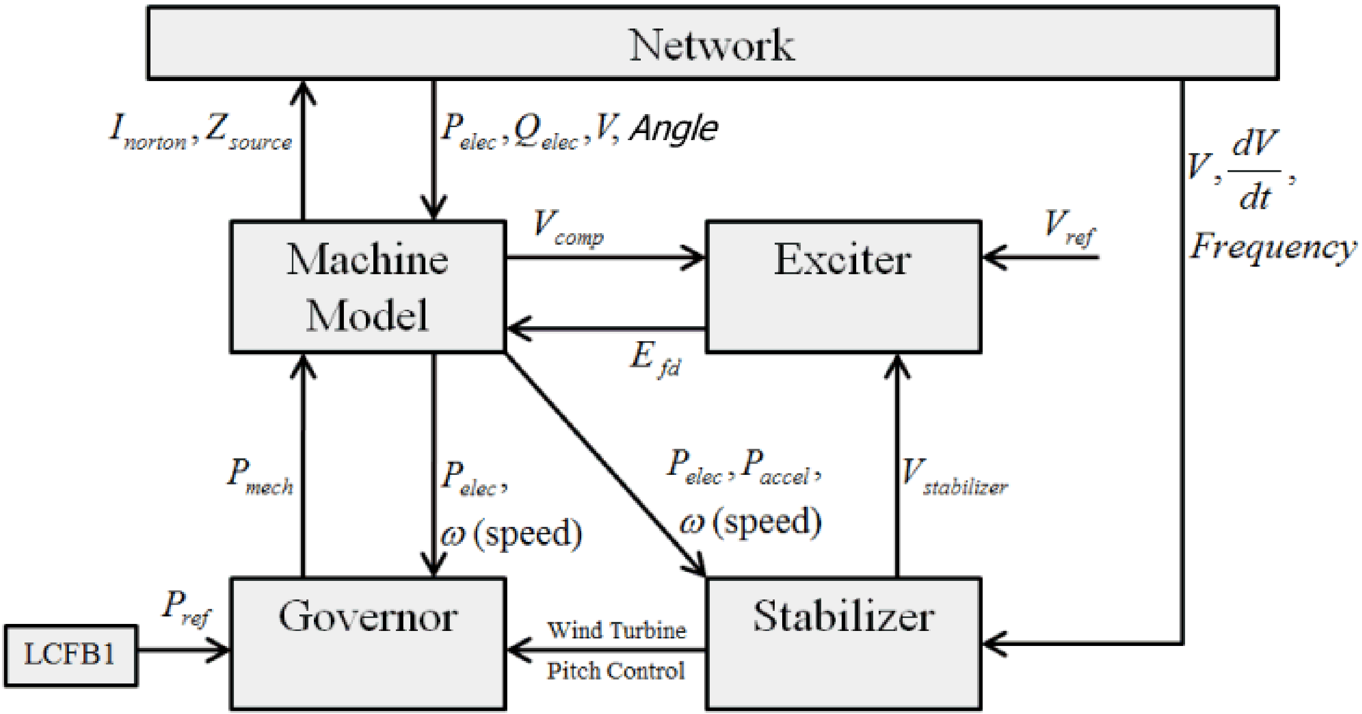
Generator Models

- Generators can have several classes of models assigned to them
  - Machine Models
  - Exciter
  - Governors
  - Stabilizers
- Others also available
  - Excitation limiters, voltage compensation, turbine load controllers, and generator relay model



Generator Models



P_{elec} = Electrical Power

Q_{elec} = Electrical Reactive Power

V = Voltage at Terminal Bus

$\frac{dV}{dt}$ = Derivate of Voltage

V_{comp} = Compensated Voltage

P_{mech} = Mechanical Power

ω(speed) = Rotor Speed (often it's deviation from nominal speed)

P_{accel} = Accelerating Power

$V_{stabilizer}$ = Output of Stabilizer

V_{ref} = Exciter Control Setpoint (determined during initialization)

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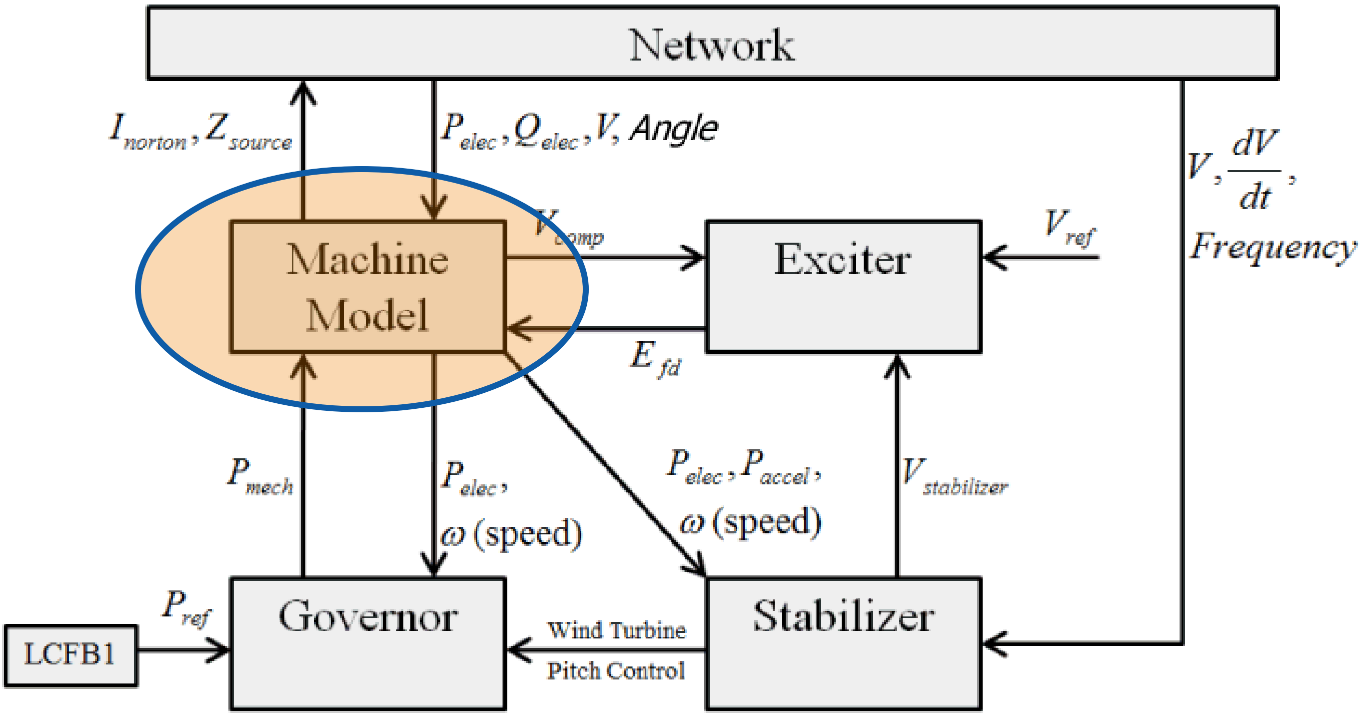
Machine Models



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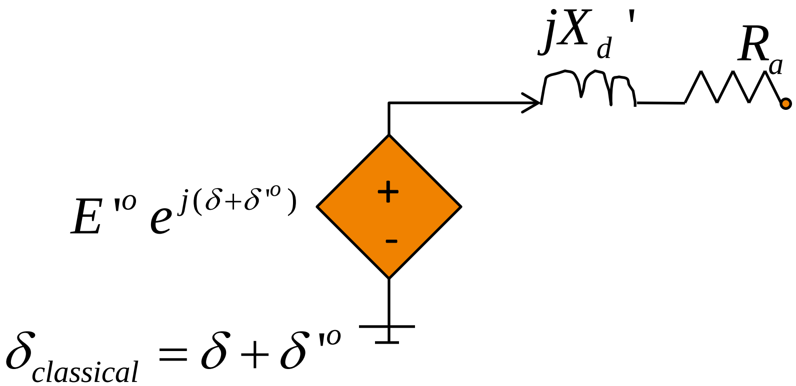
Machine Models

- The Classical Model (GENCLS)- very simplified
- Represents the machine dynamics as a fixed voltage magnitude behind a transient impedance $R_a + jX_d'$.

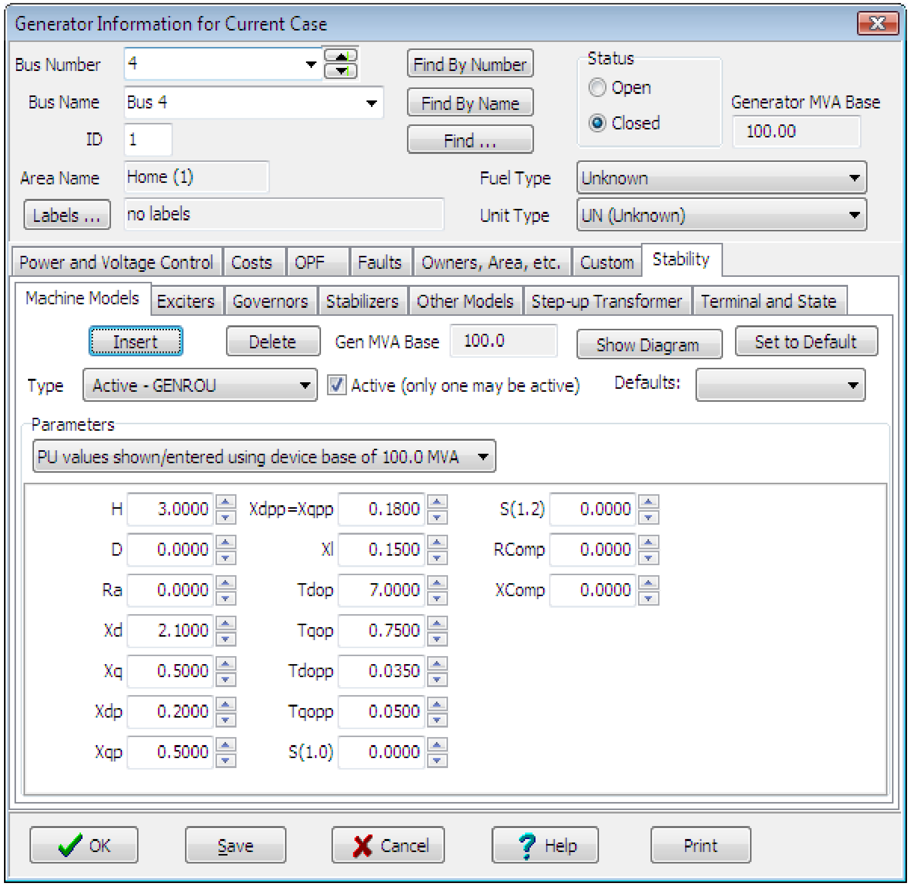


- Used in academic settings because of its simplicity but is not recommended for actual power system studies

More Realistic Models

- PowerWorld Simulator has many more realistic models that can be easily used
  - Many books and papers discuss the details
- Salient pole – GENSAL machine model
- Round rotor – GENROU model
- Generator with Transient Saliency – GENTPF and GENTPJ models
  - These models are becoming required in WECC (Western US and Canada)

GENROU Model

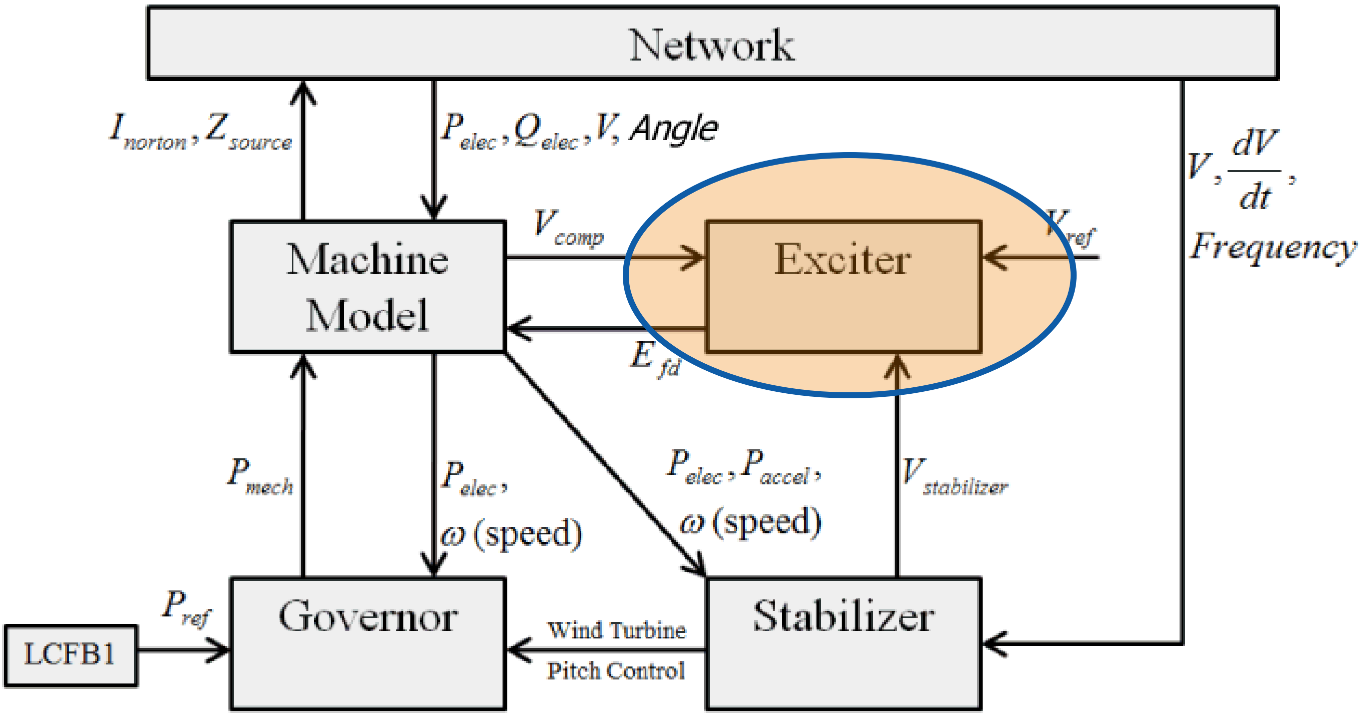


The GENROU model provides a very good approximation for the behavior of a synchronous generator over the dynamics of interest during a transient stability study (up to about 10 Hz).

It is used to represent a solid rotor machine with three damper windings.

More than 2/3 of the machines in the 2006 North American Eastern Interconnect case (MMWG) are represented by GENROU models.

Exciter Models



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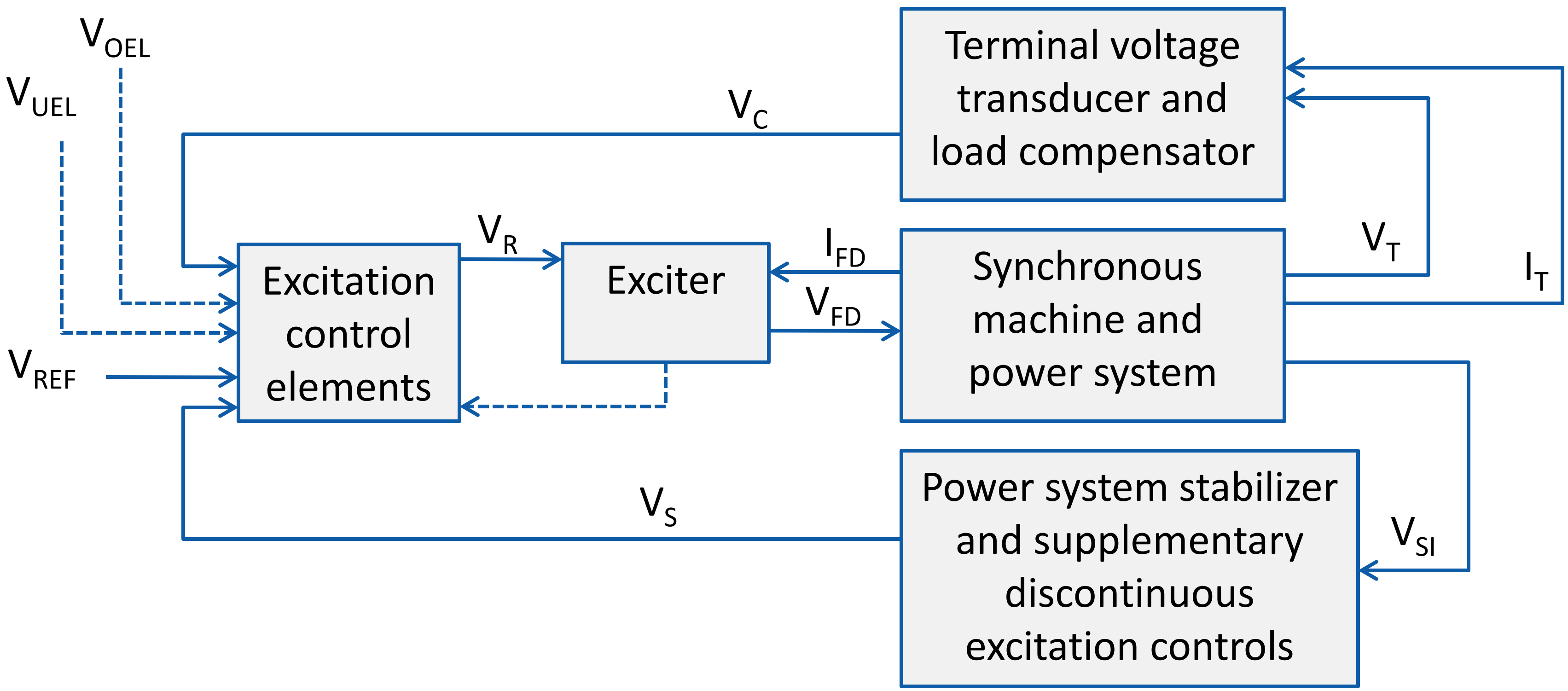
Excitation System Models

- Models must be suitable for modeling severe disturbances as well as large perturbations
- Generally, these are reduced order models that do not represent all of the control loops
- Some model structures were intended to facilitate the use of field test data as a means of obtaining the model parameters
- These models do not generally represent delayed protective and control functions that may come into play in long-term dynamic performance studies

IEEE Standard 421.5, IEEE Recommended Practice for Excitation System Models for Power System Stability Studies, Aug. 1992

Excitation System Models

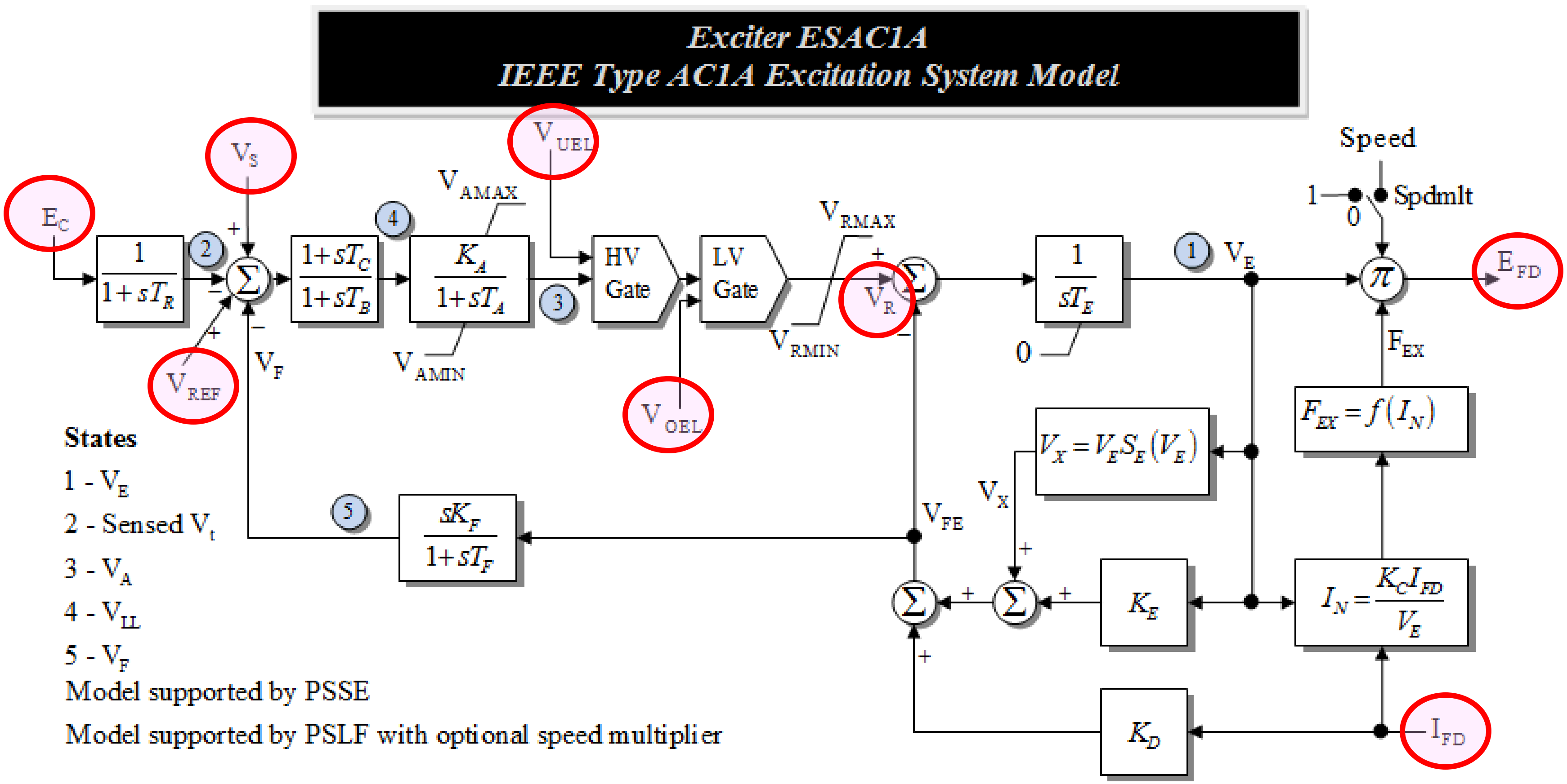
- Excitation subsystems for synchronous machines may include voltage transducer and load compensator, excitation control elements, exciter, and a power system stabilizer



Exciter Models in General

- V_{REF} is the voltage regulator reference signal and is calculated to satisfy the initial operating conditions.
  - In Simulator this will be called the *Exciter Setpoint (Vref)*
- E_{fd} is the field voltage. Adjusting the field voltage changes the field current and thus the terminal voltage.
- If E_{fd} were a constant, the machine would not have voltage control.
- The exciter systematically adjusts E_{fd} in attempt to maintain the terminal voltage equal to the reference signal.

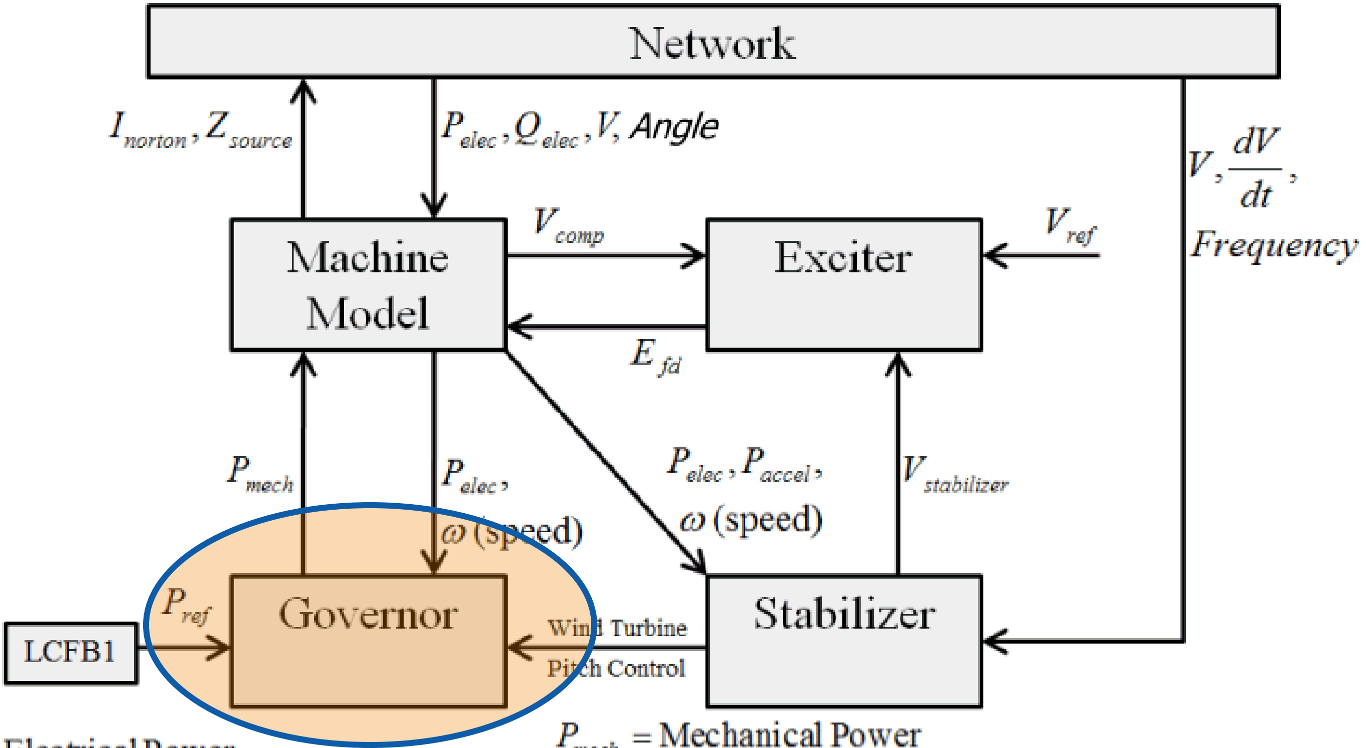
Typical Exciter Block Diagram



Comments on Typical Exciter

- E_c is the "compensated voltage"
  - Typically this is just the generator terminal voltage
  - Could regulate a point some impedance away (such as half way through the stepup transformer)
    - $E_c = V_t - X_{comp} * I_t$
- V_{ref} is the voltage reference
  - Think knob that the generator operator turns to move the voltage higher or lower
- Typical optional feedback signals
  - V_s is from the stabilizer
  - V_{UEL} is from an under excitation limiter
  - V_{OEL} is from an over excitation limiter

Governor Models



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Prime Movers and Turbine Models

- Steady-state speed of a synchronous machine determined by the speed of the prime mover that drives its shaft
- Prime mover thus provides a mechanism for controlling the synchronous speed
  - Diesel engines
  - Gasoline engines
  - Steam turbines
  - Hydroturbines
- Prime mover output affects the mechanical torque to the shaft (T_M)

What is a Governor?

- A governor senses the speed (or load) of a prime mover and controls the fuel (or steam) to the prime mover to maintain its speed (or load) at a desired level
- Essentially, a governor ends up controlling the energy source to a prime mover so that it can be used for a specific purpose
- Consider driving a car → you act as a governor to control the speed under varying driving conditions

Woodward, "Governing Fundamentals and Power Management," Technical Manual 26260, 2004. [Online]. Available: http://www.woodward.com/pubs/pubpage.cfm

Speed Governor Models

- To automatically control speed and hence frequency, need to be able to sense speed or frequency in such a way that it can be compared with a desired value to take a corrective action.
- This is what a speed governor does.
- For example, if a load is removed from the generator, excess power is being supplied to the turbine and the generator will speed up. The steam valve position P_{SV} will decrease and eventually stop the increase in speed.

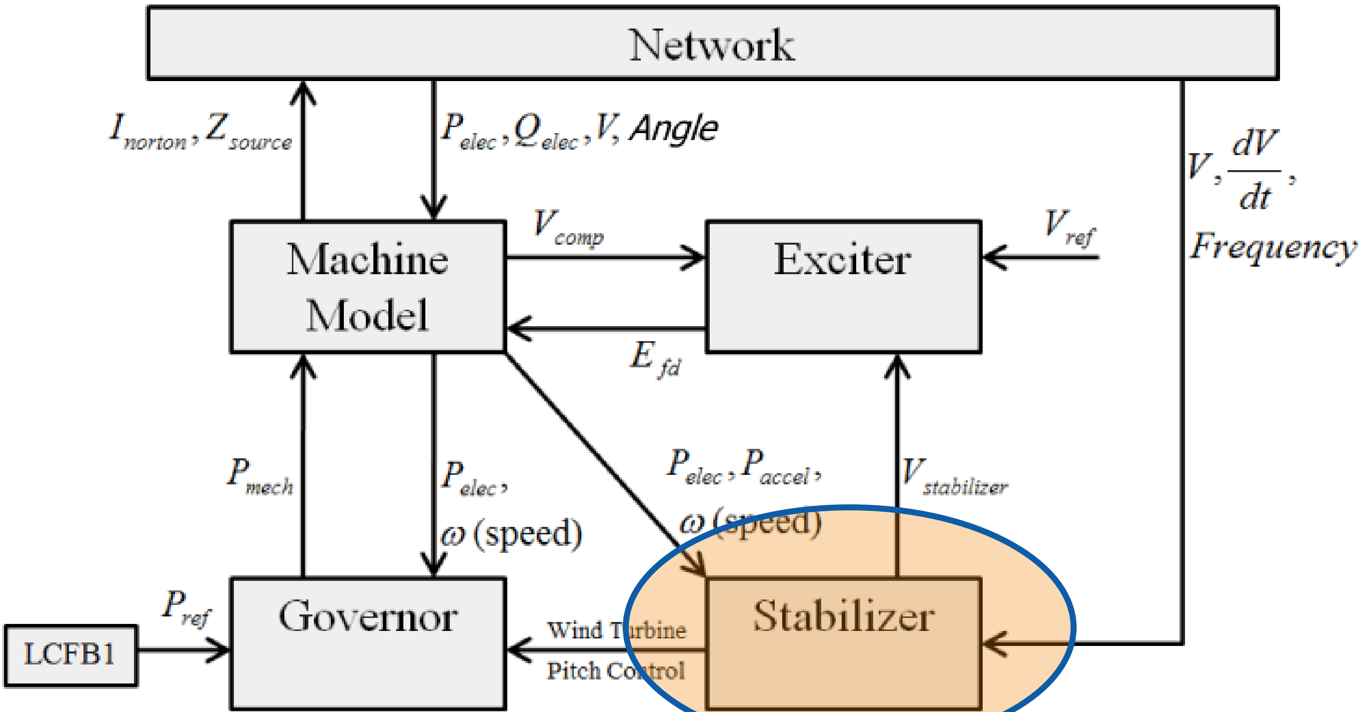
Droop

- Droop is a decrease in speed setting as load increases.
- ***Without droop***, a load increase causes the engine to slow down. The governor will increase its fuel until the speed has recovered.
- However, there will be an overshoot in speed as it corrects. The governor will then respond and decrease the speed.
- This becomes inherently unstable
- Multiple generator operation
  - Can not allow them all to try to maintain a specified frequency.
  - Also unstable

Return to Nominal Frequency

- Transient Stability Simulations normally do NOT bring the frequency back to nominal (60 Hz)
- The AGC control which act on the order of minutes normally do this
- LCFB1 model is a special model which can also do this

Stabilizer Models



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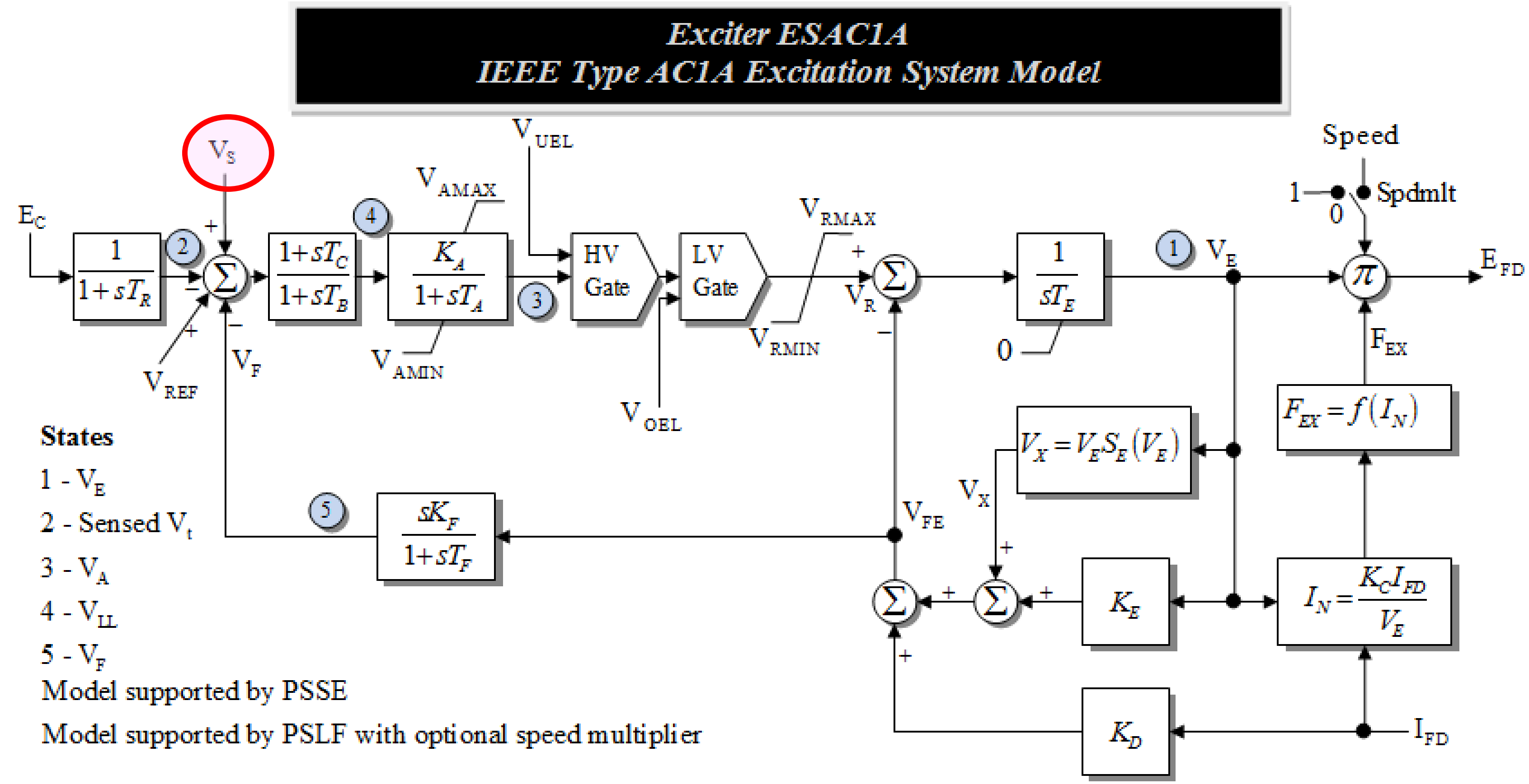
Power System Stabilizers (PSS)

- Stabilizing signals are derived from machine speed, terminal frequency, or power
- Should be activated only when low-frequency oscillations develop
- The design is still done on the basis of a Single Machine Infinite Bus (SMIB) system
- Then, the model parameters are tuned on-line in order to suppress local and inter-area modes
- Output signal goes into exciter

Stabilizer Feedback to Exciter



Wind Generator Models

- Wind Turbines do not have an “exciter”, “governor”, or “stabilizer” built in
- However, modeling is very analogous
  - Wind Machine Model = Machine Model
  - Wind Electrical Model = Exciter
  - Wind Mechanical Model = Governor
  - Wind Pitch Control = Stabilizer
  - Wind Aerodynamic Model = Stabilizer
- Simulator will show wind models listed as though they are Exciters, Governors, and Stabilizers
  - Obviously you should use a synchronous machine exciter in combination with a wind machine model and wind governor!

Load Characteristic Models

- Load fall into two categories in a transient stability
  - Static Load Model
    - Normally a function of voltage and/or frequency

$$P = P_{load}\left(a_1 v^{n_1} + a_2 v^{n_2} + a_3 v^{n_3}\right)\left(1 + a_7 \Delta f\right)$$

$$Q = Q_{load}\left(a_4 v^{n_4} + a_5 v^{n_5} + a_6 v^{n_6}\right)\left(1 + a_8 \Delta f\right)$$

    - Discharge Lighting (Fluorescent Lights)
      - Voltage Dependent.
  - Dynamic Load Models
    - Induction Motors
- Load Characteristic Models end up being combinations of all these
  - "Complex" load models include all of them in various proportions.