

ECEN 667

Power System Stability

Lecture 19: Load Models

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Announcements



- Read Chapter 7
- Homework 6 is due on Nov 9
- Final is as per TAMU schedule. That is, Friday Dec 8 from 3 to 5pm

Calculating the Initial Slip



- One way to calculate the initial slip is to just solve the below five equations for five unknowns (s , I_D , I_Q , E'_D, E'_Q) with P_E , V_D and V_Q inputs

$$P_E = V_D I_D + V_Q I_Q$$

$$V_D = E'_D + R_s I_D - X' I_Q$$

$$V_Q = E'_Q + R_s I_Q + X' I_D$$

$$\frac{dE'_D}{dt} = 0 = \omega_s s E'_Q - \frac{1}{T'_D} (E'_D + (X - X') I_Q)$$

$$\frac{dE'_Q}{dt} = 0 = \omega_s s E'_D - \frac{1}{T'_Q} (E'_Q - (X - X') I_D)$$

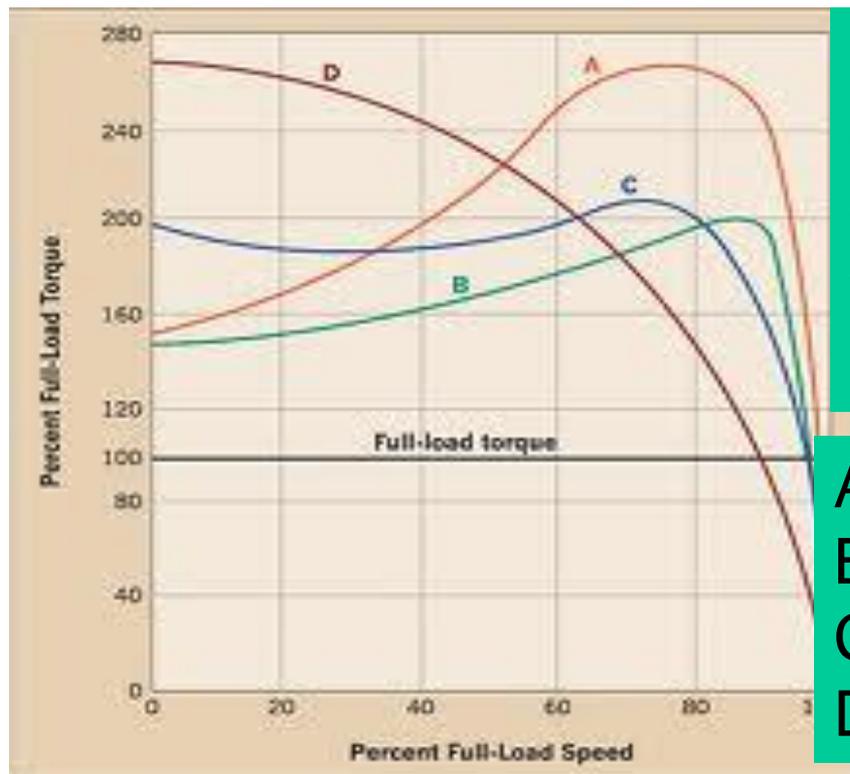
These are nonlinear equations that can have multiple solutions so use Newton's method, with an initial guess of s small (say 0.01)

Initial slip in example is 0.0251

Induction Motor Classes



- Four major classes of induction motors, based on application. Key values are starting torque, pull-out torque, full-load torque, and starting current



In steady-state the motor will operate on the right side of the curve at the point at which the electrical torque matches the mechanical torque

- A: Fans, pumps machine tools
- B: Similar to A
- C: Compressors, conveyors
- D: High inertia such as hoists

Induction Motor Stalling

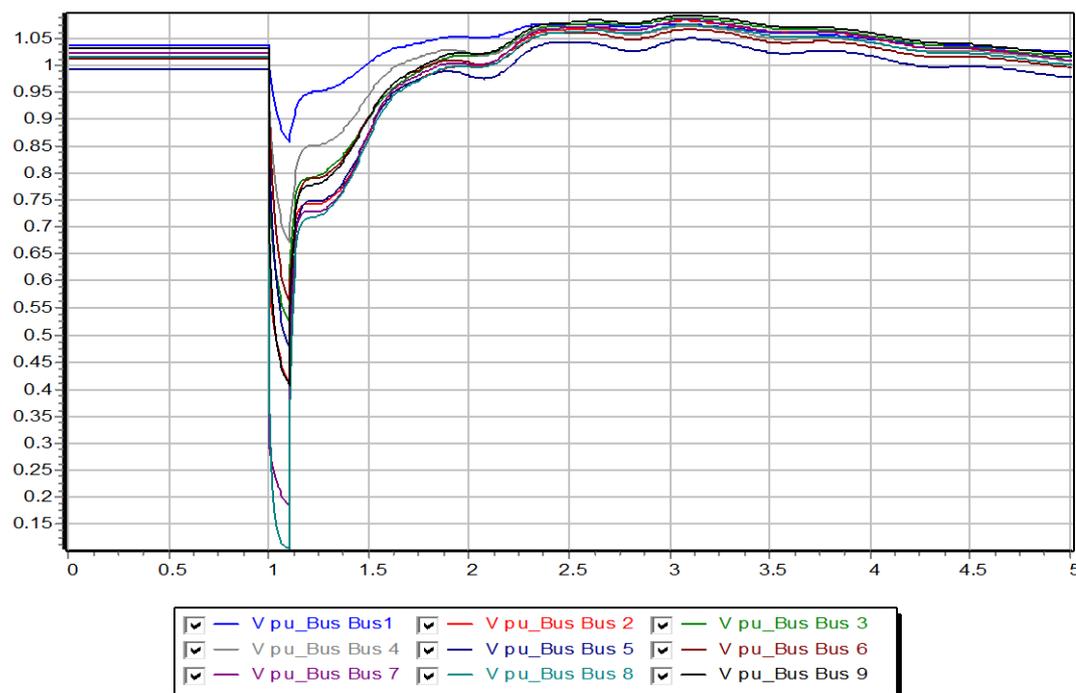


- Height of the torque-speed curve varies with the square of the terminal voltage
- When the terminal voltage decreases, such as during a fault, the mechanical torque can exceed the electrical torque
 - This causes the motor to decelerate, perhaps quite quickly, with the rate proportional to its inertia
 - This deceleration causing the slip to increase, perhaps causing the motor to stall with $s=1$, resulting in a high reactive current draw
 - Too many stalled motors can prevent the voltage from recovering

Motor Stalling Example



- Using case WSCC_CIM5, which models the WSCC 9 bus case with 100% induction motor load
- Change the fault scenario to say a fault midway between buses 5 and 7, cleared by opening the line



Results are for a 0.1 second fault

Usually motor load is much less than 100%

Impact of Model Protection Parameters



- Some load models, such as the CIM5, have built-in protection system models. For CIM5 the V_i and T_i fields are used to disconnect the load when its voltage is less than V_i for T_i cycles
 - When running simulations you need to check for such events

Load Characteristic Information

Specify a load characteristic which is the default for all loads in the system

Element Type

- System
- Area
- Zone
- Owner
- Bus
- Model Group
- Load

Load Characteristics | Load Relays | Distributed Gen

Insert Delete Show Block Diagram

Type: Active - CIM5 Active (Only One Active, Except for Supplementary Models)

Parameters

IT	1	E1	0.0000	Ti	240.0000
Ra	0.0120	SE1	0.0000	Tb	0.0000
Xa	0.0600	E2	0.0000	D	2.0000
Xm	4.0000	SE2	0.0000	Tnom	0.0000
R1	0.0300	Mbase	0.0000		
X1	0.0400	Pmult	1.2500		
R2	0.0000	H	1.0000		
X2	0.0000	Vi	0.8000		

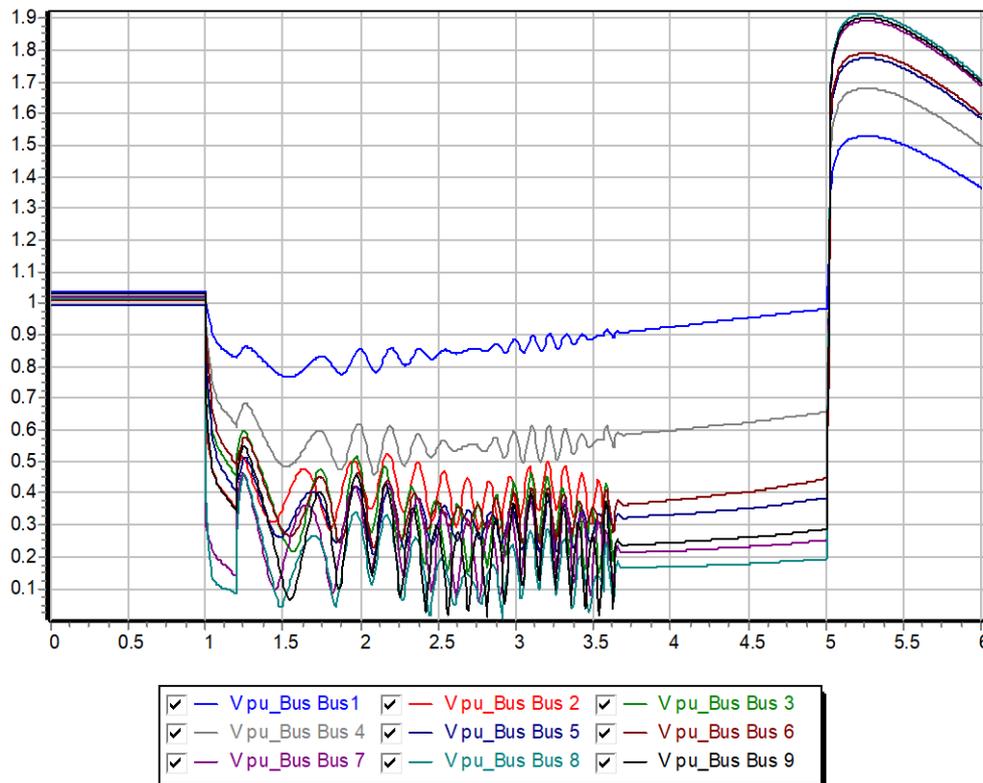
Show Torque Speed Dialog

OK Save Cancel

Motor Stalling With Longer Fault



- The below image shows the WECC_CIM5 system with the fault clearing extended to 0.2 seconds

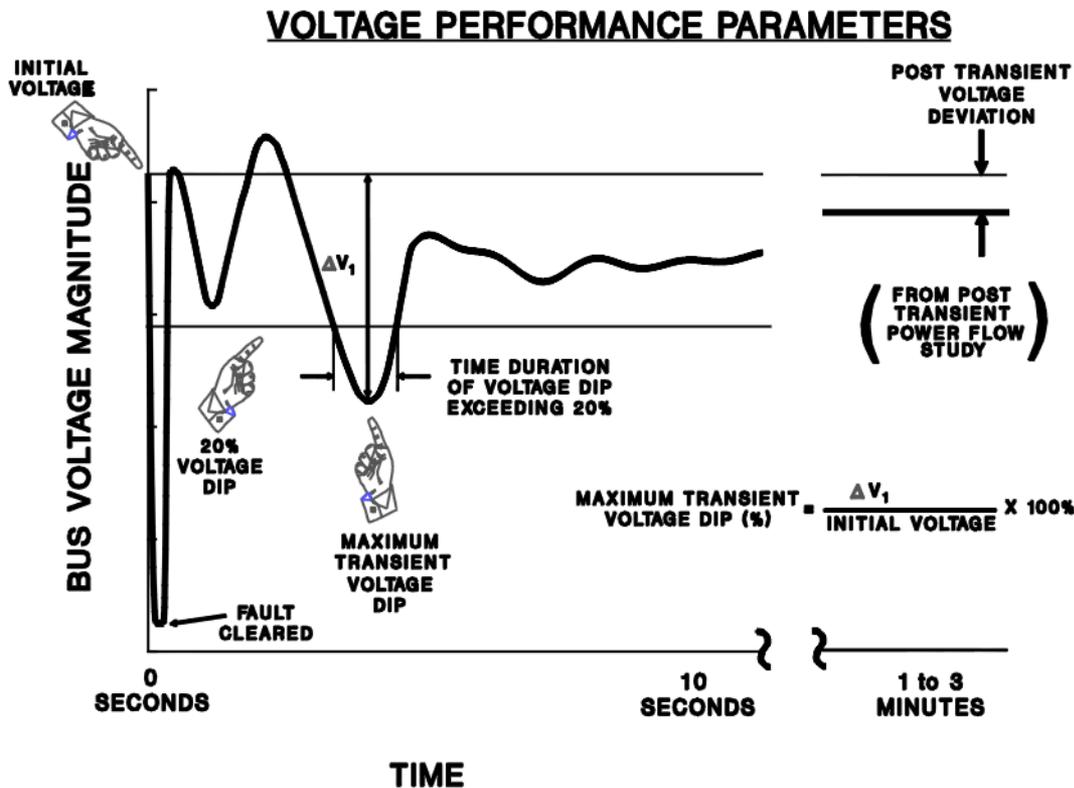


The models are no longer giving realistic results; two generators trip on over speed; then the load trips after 4 seconds.

Transient Limit Monitors



- There are different performance criteria that need to be met for a scenario



Similar performance criteria exist for frequency deviations

Motor Starting



- Motor starting analysis looks at the impacts of starting a motor or a series of motors (usually quite large motors) on the power grid
 - Examples are new load or black start plans
- While not all transient stability motor load models allow the motor to start, some do
- When energized, the initial condition for the motor is slip of 1.0
- Motor starting can generate very small time constants

Motor Starting Example

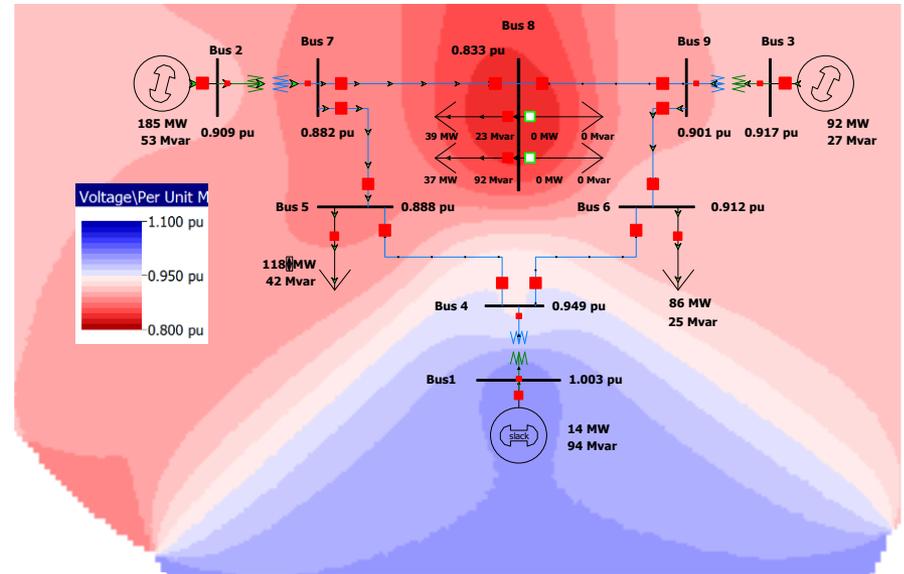
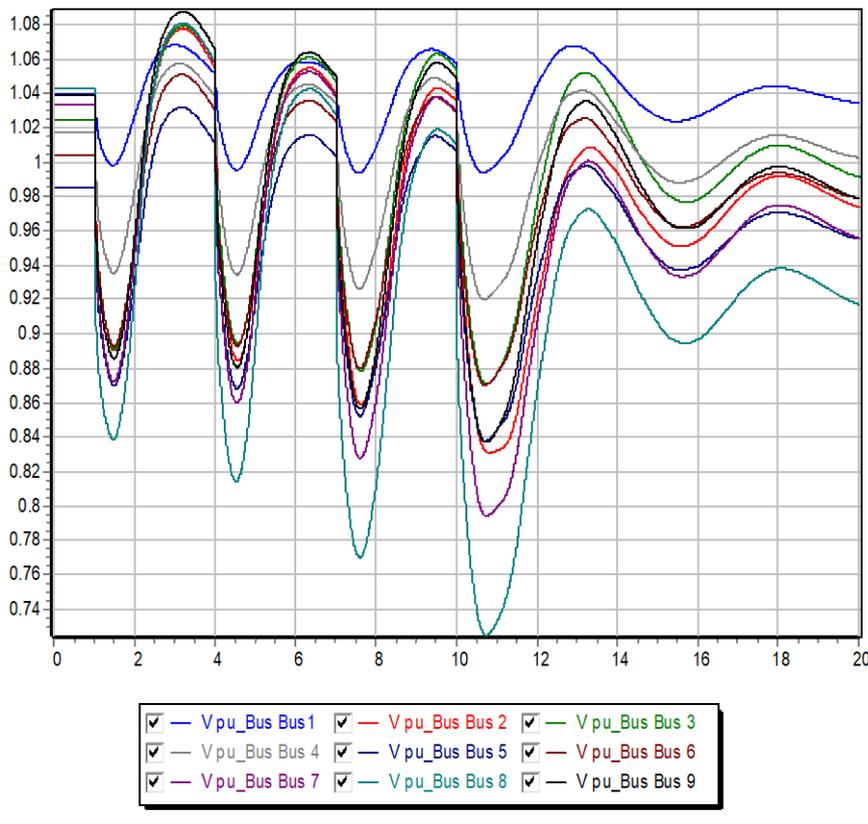


- Case WSCC_MotorStarting takes the previous WSCC case with 100% motor load, and considers starting the motor at bus 8
- In the power flow the load at bus 8 is modeled as zero (open) with a CIM5
- The contingency is closing the load
 - Divided into four loads to stagger the start (we can't start it all at once)
- Since power flow load is zero, the CIM5 load must also specify the size of the motor
 - This is done in the Tnom field and by setting an MVA base value

Motor Starting Example



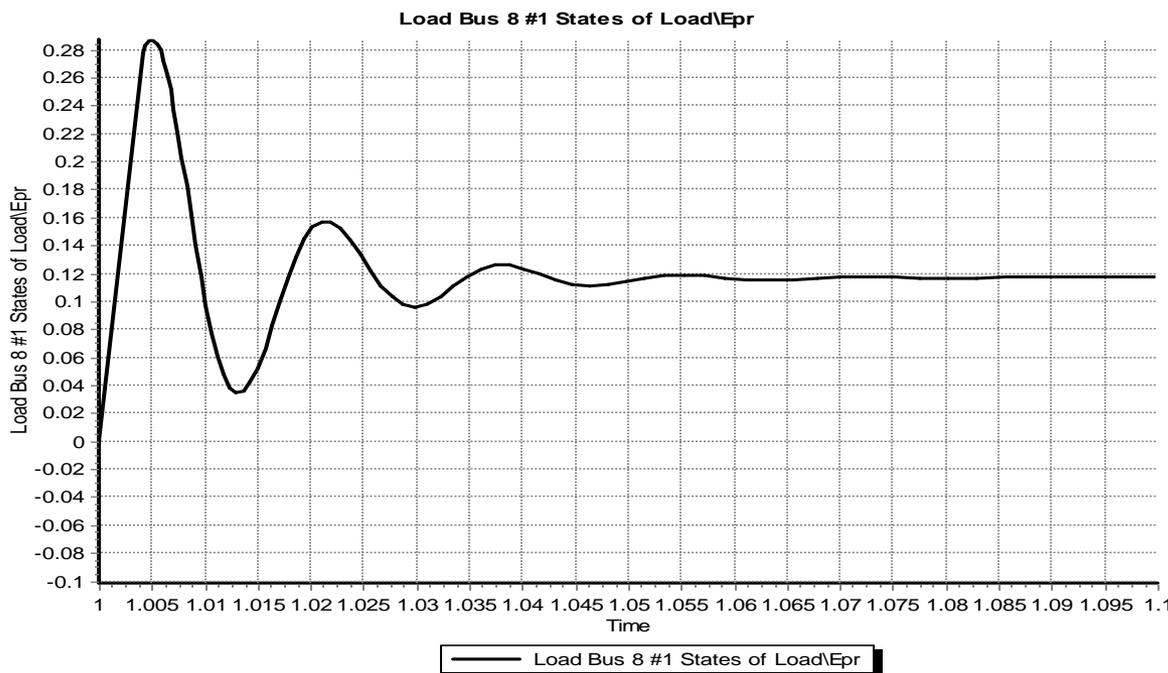
- Below graph shows the bus voltages for starting the four motors three seconds apart



Motor Starting: Fast Dynamics



- One issue with the starting of induction motors is the need to model relatively fast initial electrical dynamics
 - Below graph shows $E'r$ for a motor at bus 8 as it is starting



Time scale
is from
1.0 to 1.1
seconds

Motor Starting: Fast Dynamics



- These fast dynamics can be seen to vary with slip in the $\omega_s s$ term

$$V_D = E'_D + R_s I_D - X' I_Q$$

$$V_Q = E'_Q + R_s I_Q + X' I_D$$

$$\frac{dE'_D}{dt} = \omega_s s E'_Q - \frac{1}{T'_o} (E'_D + (X - X') I_Q)$$

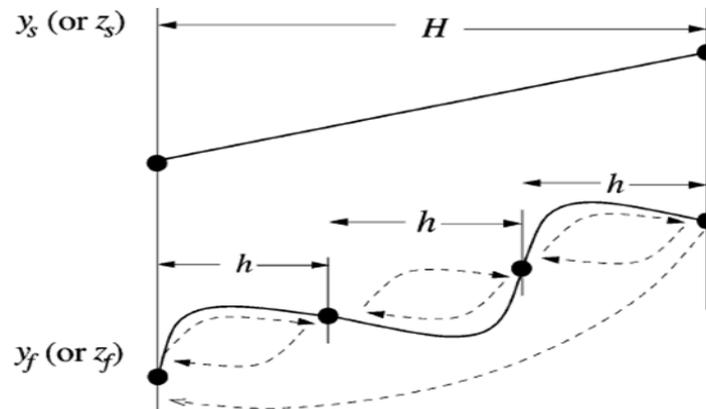
$$\frac{dE'_Q}{dt} = -\omega_s s E'_D - \frac{1}{T'_o} (E'_Q - (X - X') I_D)$$

- Simulating with the explicit method either requires a small overall Δt or the use of multi-rate methods

Multi-Rate Explicit Integration



- Key idea is to integrate some differential equations with a potentially much faster time step than others



- Faster variables are integrated with time step h , slower variable with time step H
 - Slower variables assumed fixed or interpolated during the faster time step integration

Figure from Jingjia Chen and M. L. Crow, "A Variable Partitioning Strategy for the Multirate Method in Power Systems," Power Systems, IEEE Transactions on, vol. 23, pp. 259-266, 2008.

Multi-Rate Explicit Integration



- First proposed by C. Gear in 1974
- Power systems use by M Crow in 1994
- In power systems usually applied to some exciters, stabilizers, and to induction motors when their slip is high
- Subinterval length can be customized for each model based on its parameters (in range of 4 to 128 times the regular time step)
- Tradeoff in computation

C. Gear, Multirate Methods for Ordinary Differential Equations, Univ. Illinois at Urbana-Champaign, Tech. Rep., 1974.

M. Crow and J. G. Chen, "The multirate method for simulation of power system dynamics," *IEEE Trans. Power Syst.*, vol. 9, no. 3, pp.1684–1690, Aug. 1994.

Need for Better Load Modeling: History of Load Modeling in WECC

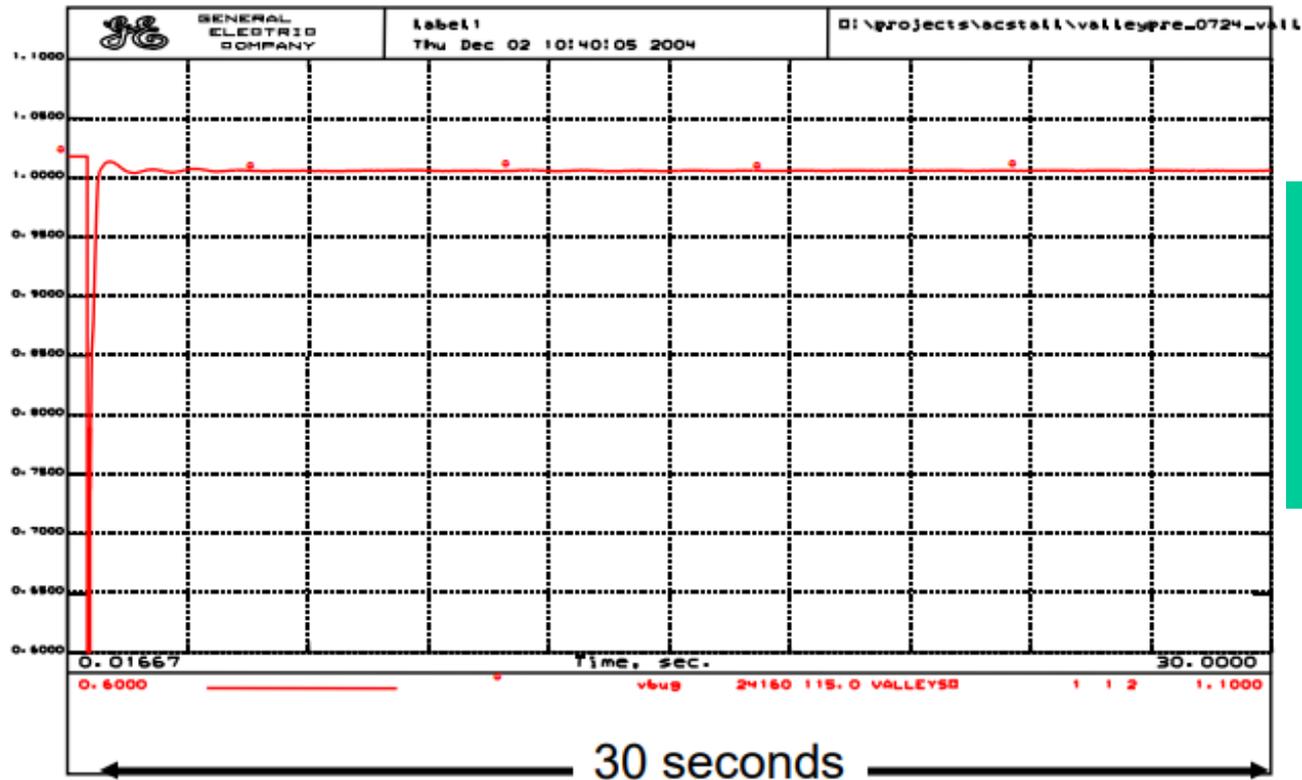


- 1990's – Constant current real, constant impedance reactive models connected to a transmission bus
 - IEEE Task Force recommends dynamic load modeling, however it does not get traction in the industry
- 1996 – Model validation study for July 2 and August 10 system outages:
 - Need for motor load modeling to represent oscillations and voltage decline
- 2000's – WECC “Interim” Load Model: – 20% of load is represented with induction motors
 - Tuned to match inter-area oscillations for August 10 1996 and August 4, 2000 oscillation events ...

Need for Better Load Modeling: History of Load Modeling in WECC



- What the simulations down using the interim load model indicated would occur

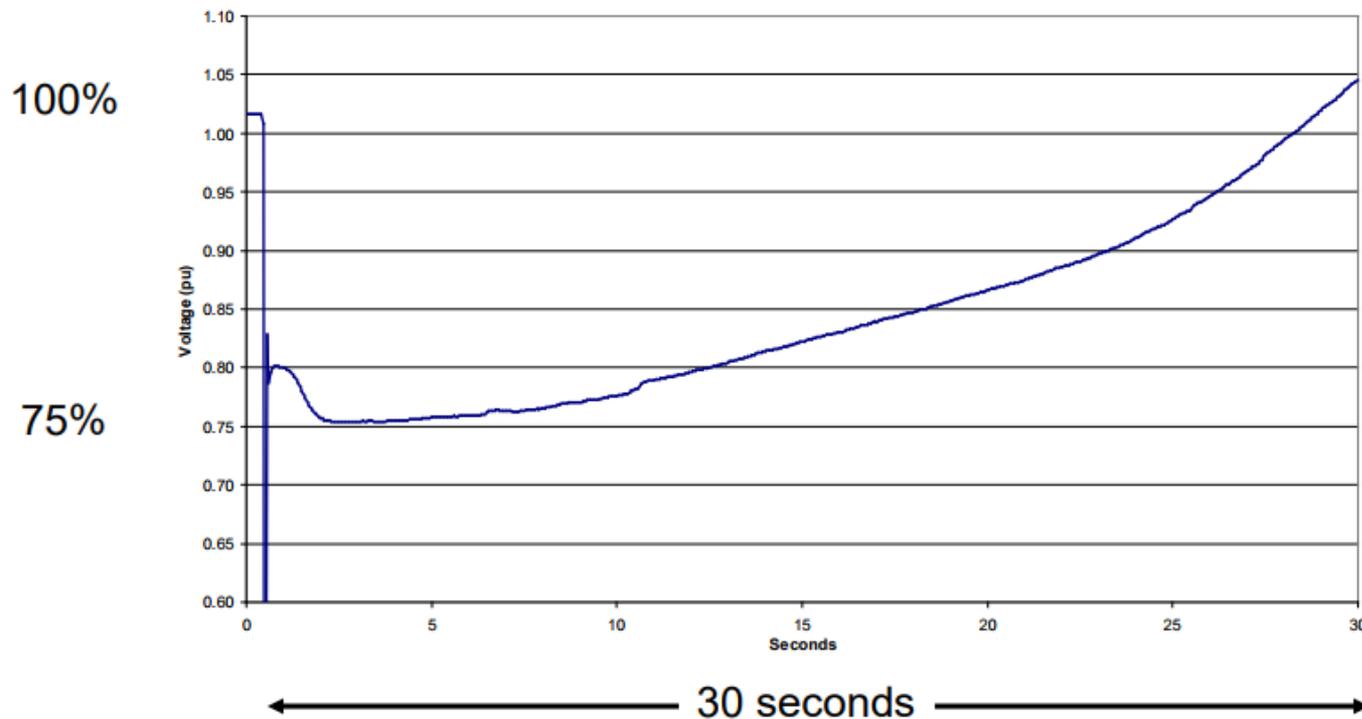


Vertical scale goes down to about 0.6 per unit

Need for Better Load Modeling: History of Load Modeling in WECC



- What was actually sometimes occurring, known as fault induced delayed voltage recovery (FIDVR)
 - Seen in 1980's; traced to stalling air-conditioning load

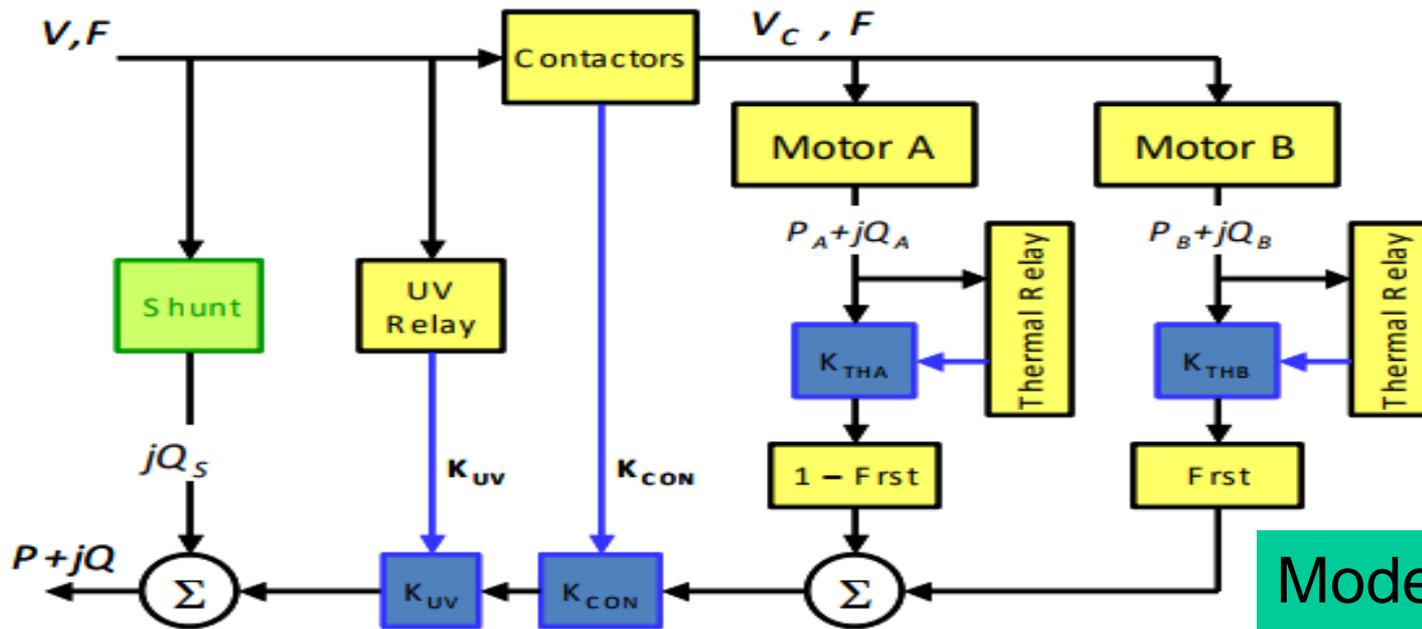


Single Phase Induction Motor Loads



- A new load model is one that explicitly represents the behavior of single phase induction motors, which are quite small and stall very quickly
 - Single phase motors also start slower than an equivalent three phase machine
- New single phase induction motor model (LD1PAC) is a static model (with the assumption that the dynamics are fast), that algebraically transitions between running and stalled behavior based on the magnitude of the terminal voltage

Single Phase Induction Motor Loads



Model is mostly algebraic, but with stalling behavior

The compressor motor model is divided into two parts:

Motor A – Those compressors that can't restart soon after stalling

Motor B – Those compressors that can restart soon after stalling

If $Mbase > 0$ then this value of $MVABase$ is used and the $CompLF = 1.0$

If $Mbase = 0$ then $MVABase = Pinit * Pul$ and $CompLF = 1.0$

If $Mbase < 0$ then $CompLF = abs(Mbase)$ and $MVABase = Pinit * Pul / CompLF$

The values of $Vstall$ and $Vbrk$ are adjusted according to the value of $LFAdj$.

$$Vstall = Vstall[1 + LFAdj(CompLF - 1)]$$

$$Vbrk = Vbrk[1 + LFAdj(CompLF - 1)]$$

Composite Load Models

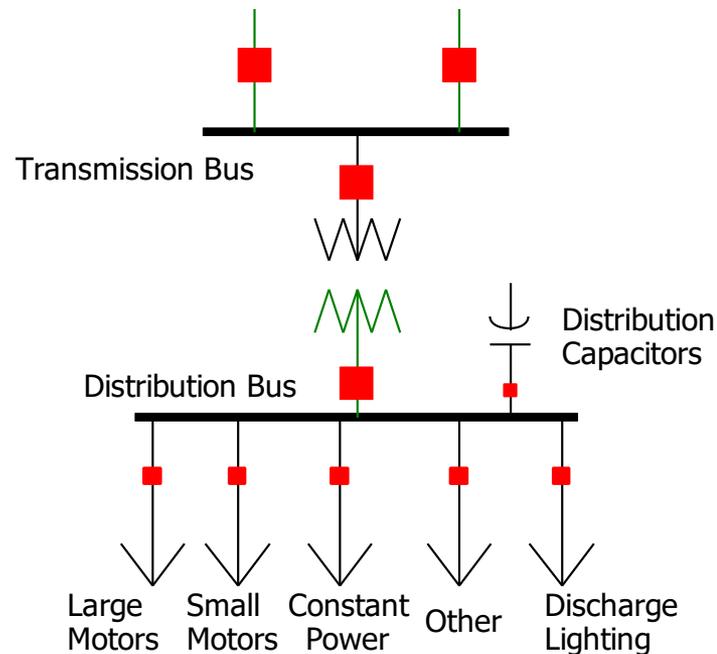


- Many aggregate loads are best represented by a combination of different types of load
 - Known as composite load models
 - Important to keep in mind that the actual load is continually changing, so any aggregate load is at best an approximation
 - Hard to know load behavior to extreme disturbances without actually faulting the load
- Early models included a number of loads at the transmission level buses (with the step-down transformer), with later models including a simple distribution system model

CLOD Model



- The CLOD model represents the load as a combination of large induction motors, small induction motors, constant power, discharge lighting, and other

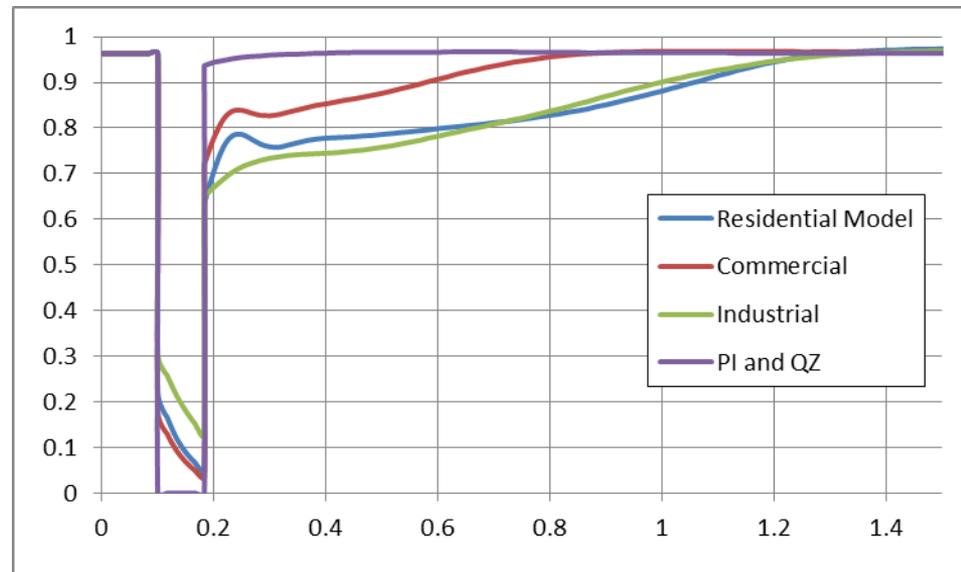


CLOD Model



- Different load classes can be defined

Customer Class	Large Motor	Small Motor	Discharge Lighting	Constant Power	Remaining (PI, QZ)
Residential	0.0	64.4	3.7	4.1	27.8
Agriculture	10.0	45	20	4.5	19.5
Commercial	0.0	46.7	41.5	4.5	7.3
Industrial	65.0	15.0	10.0	5.0	4.0

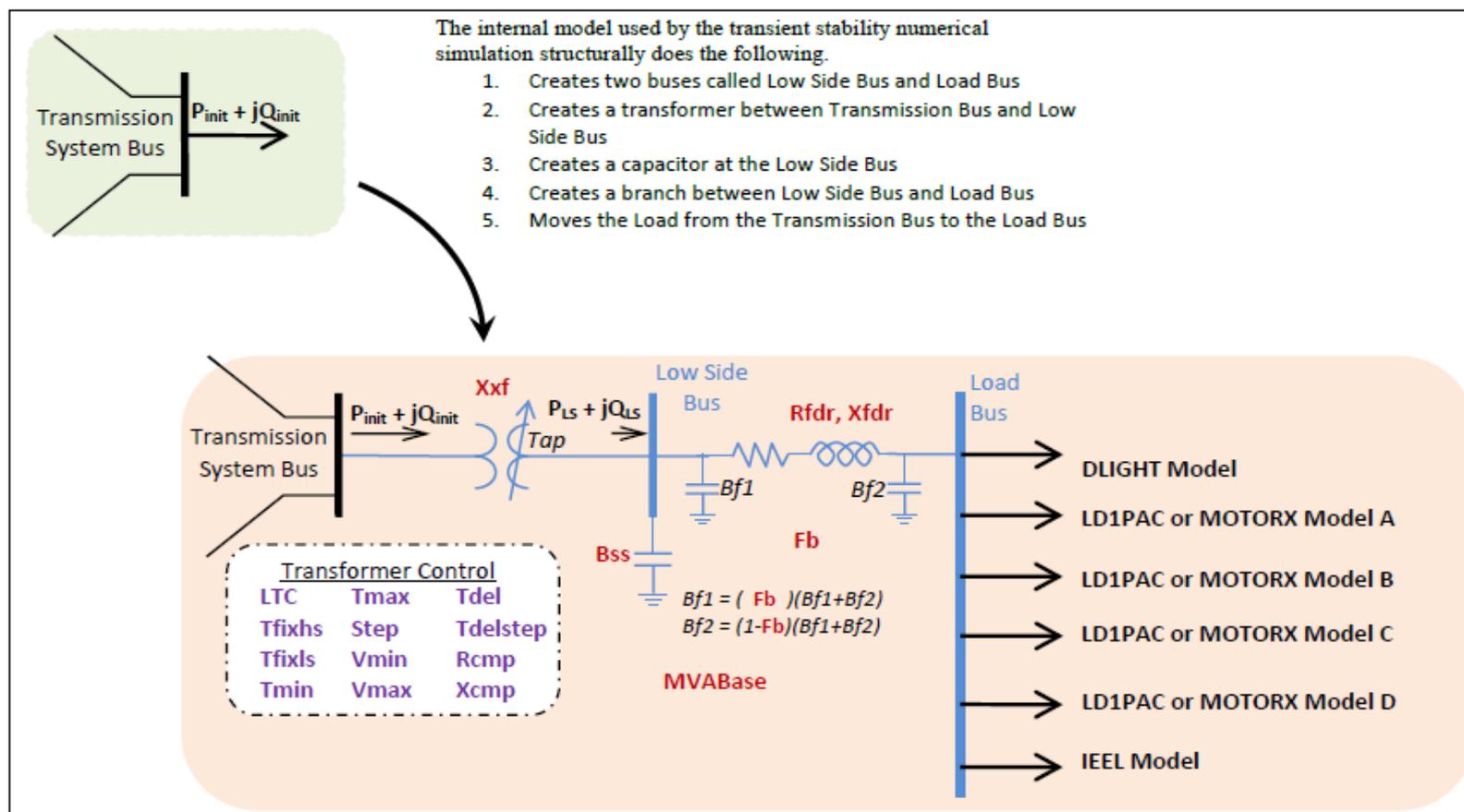


Comparison of voltage recovery for different model types

WECC Composite Load Model



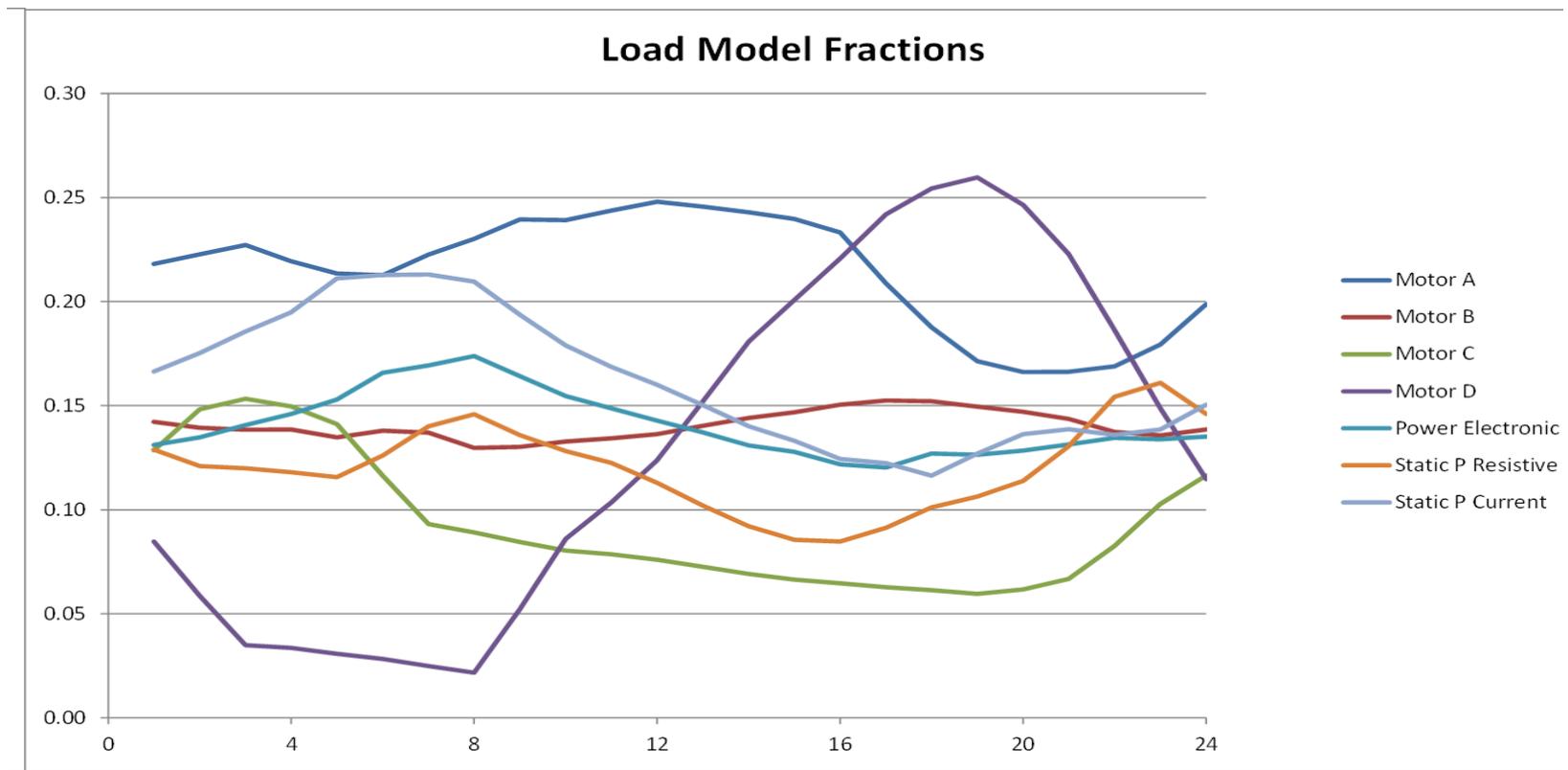
- Contains up to four motors or single phase induction motor models; also includes potential for solar PV



Modeling Time Variation in Load



- Different time varying composite model parameters are now being used



Example of varying composite load percentages over a day₂₆

Current Research



- Current topics for load modeling research include assessment of how much the load model matters
- Another issue is how to determine the load model parameters – which ones are observable under what conditions
 - For example, motor stalling can not be observed except during disturbances that actually cause the motors to stall
 - Not important to precisely determine parameters that ultimately do not have much influence on the final problem solution; of course these parameters would be hard to observe
- Correctly modeling embedded distribution level generation resources, such as PV, is important