Composite Load Model Development and Implementation

2015 NERC-DOE FIDVR Conference

Presented by

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History Of Load Modeling

1980’s – Constant current real, constant impedance reactive models connected to a transmission bus

Reflected the limitation of computing technologies of that time

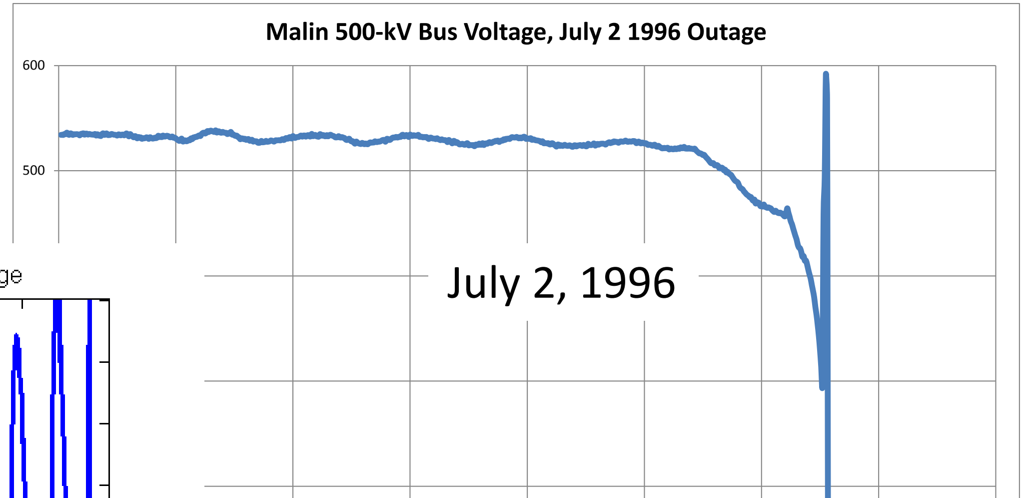
1990’s – EPRI Loadsyn effort

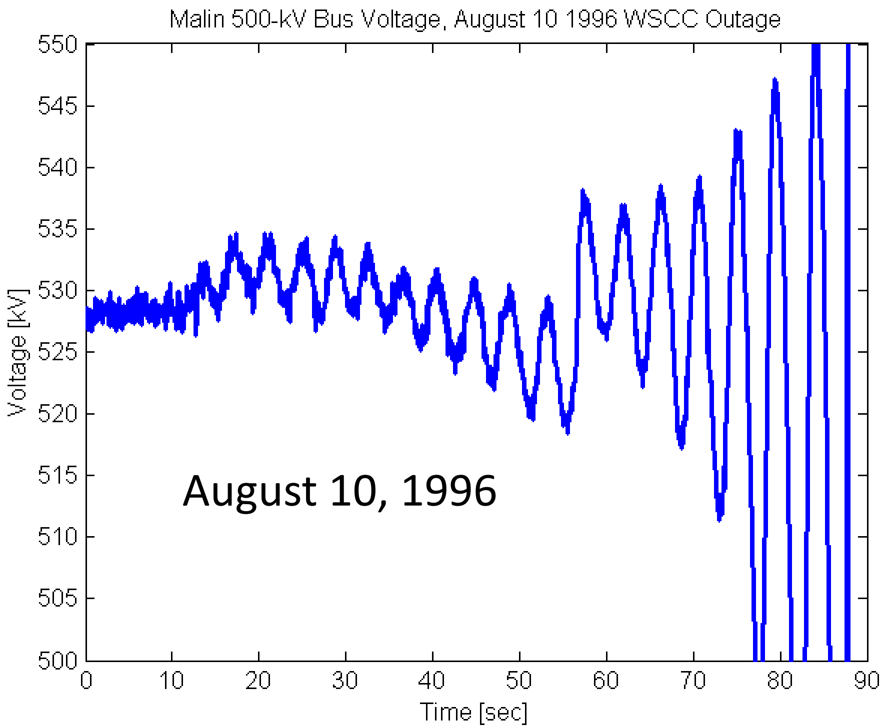
Several utilities use static polynomial characteristics for load representation

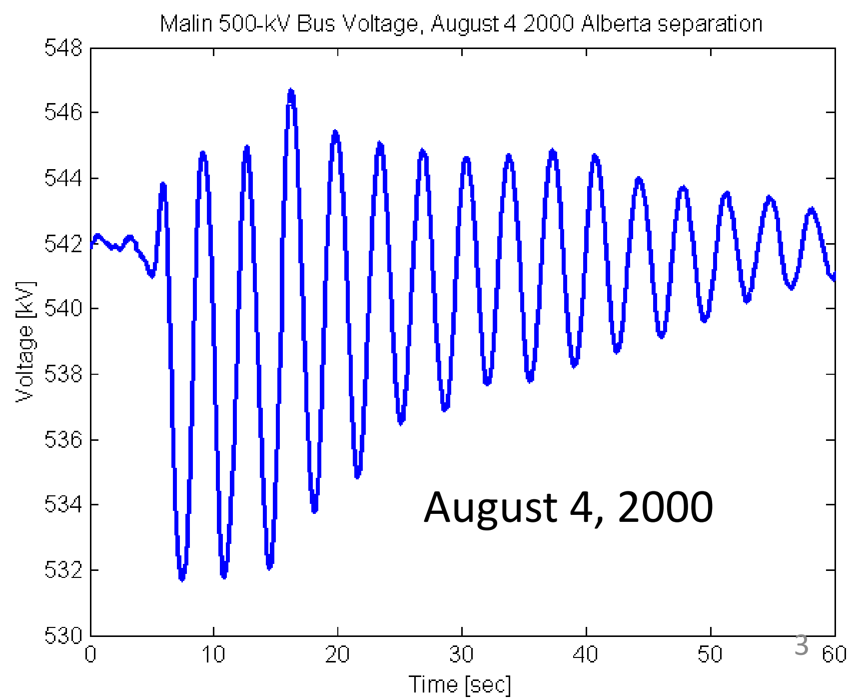
1990’s – IEEE Task Force recommends dynamic load modeling

The recommendation does not get much traction in the industry

1996 Large-Scale Outages in the West







2001 “Interim” Load Model

2001 – WECC “Interim” Load Model:

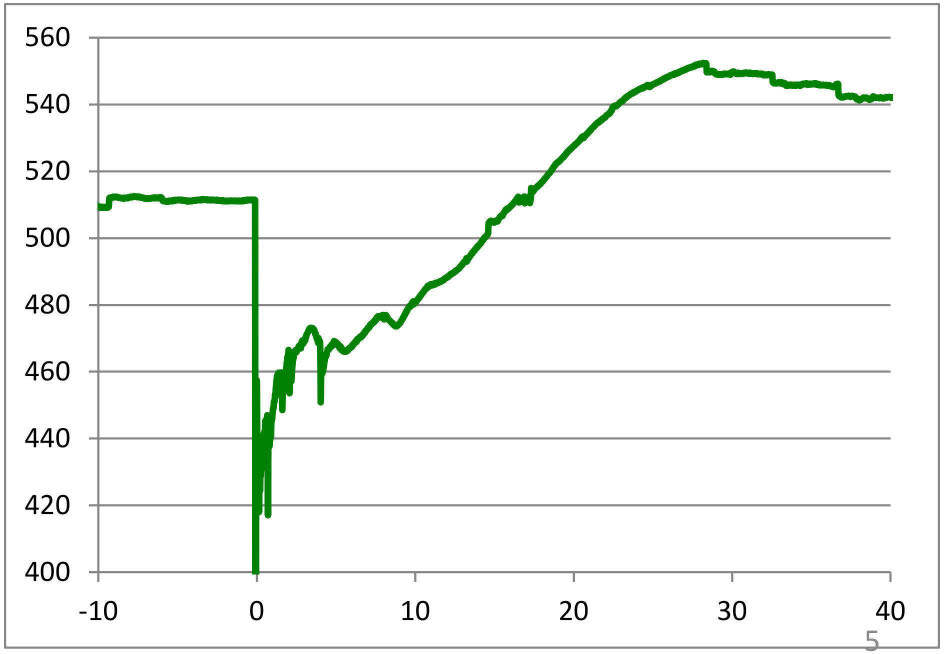
- 20% of load is represented with induction motors, the remaining load is static, mainly constant current active, constant impedance reactive components
- Motors were connected at high voltage bus, data representative of large fan motors (source John Undrill)
- Same percentage was applied to all areas in WECC
- Was the only practical option available in 2001
- “Interim” load model was intended as a temporary solution to address oscillation issues observed at California – Oregon Intertie
- Was in use until 2014 when superseded with composite load model

Events of Delayed Voltage Recovery in Southern California

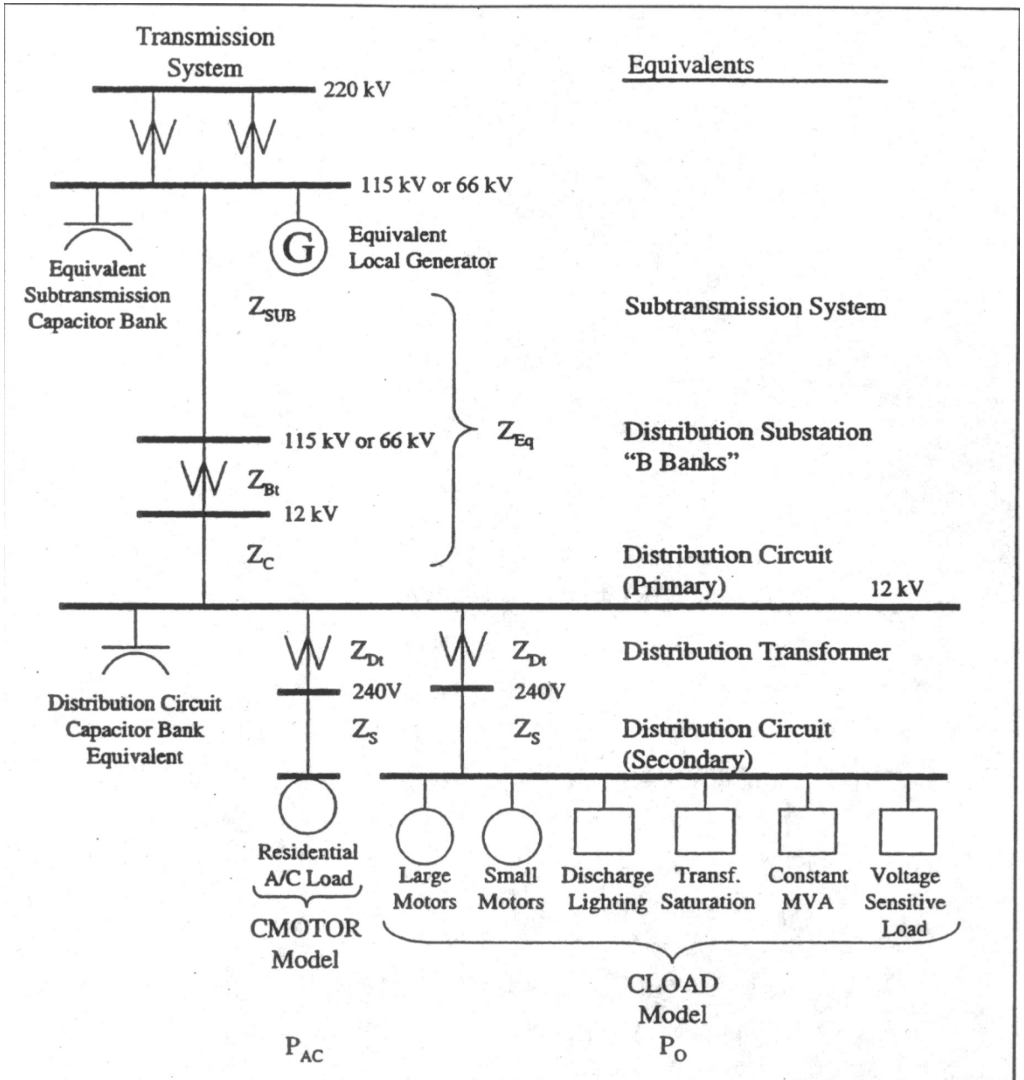
- 1980's – Southern California Edison observed events of delayed voltage recovery attributed to stalling of residential air-conditioners
  - Tested residential air-conditioners, developed empirical AC models

- 1997 – SCE model validation study of Lugo event.

- 2004-06 FIDVR events in Valley area



Southern California Edison



Need to represent a distribution equivalent

Need to capture diversity of end-uses

Need to have special models for air-conditioning load

Early Load Modeling Efforts in the East

1994 – Florida Power published an IEEE paper, used a similar load model

1998 – Events of delayed voltage recovery were observed in Atlanta area by Southern Company, the events are analyzed and modeled

Southern Company and Florida Power used approaches similar to SCE's.

The approach was later adopted by WECC in the development of the composite load model…

WECC Load Modeling Task Force

2005 – WECC developed “explicit” load model:

- Adding distribution equivalent to powerflow case WECC-wide
- Modeling load with induction motors and static loads
- Numerically stable in WECC-wide studies !

2007 – PSLF has the first version of the composite load model (three-phase motor models only)

2006-2009 – SCE-BPA-EPRI testing residential air-conditioners and developing models

2009 – residential air-conditioner model is added to the composite load model

Implementation Plan for Composite Load Model

A. Model Structure

Model structure must be implemented in production programs, validated and must be robust and numerically stable in large scale simulations

B. Data

Tools for data management are available

Processes for providing data are established

Default data sets are available

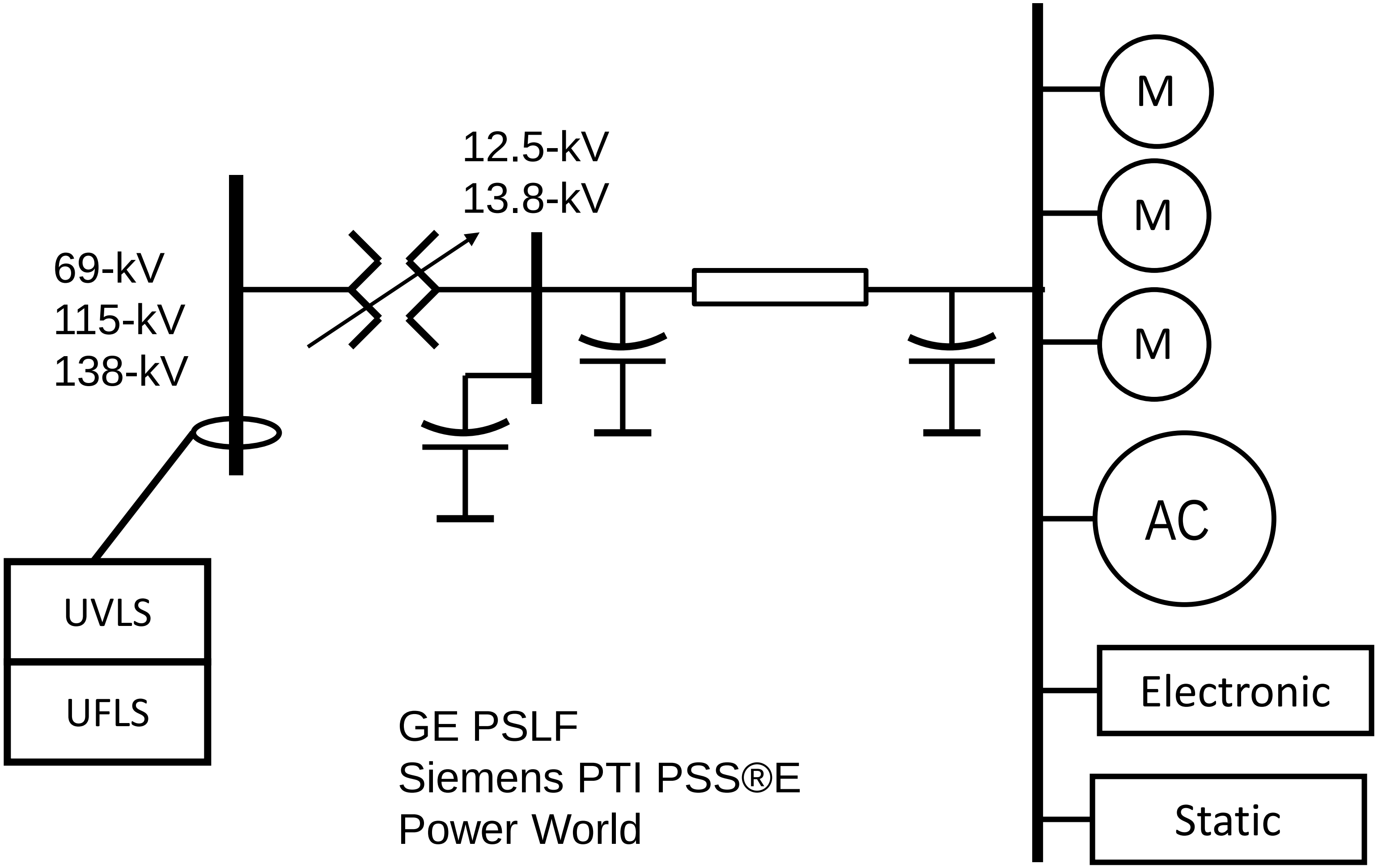
C. Studies

Model validation studies

System impact and sensitivity studies

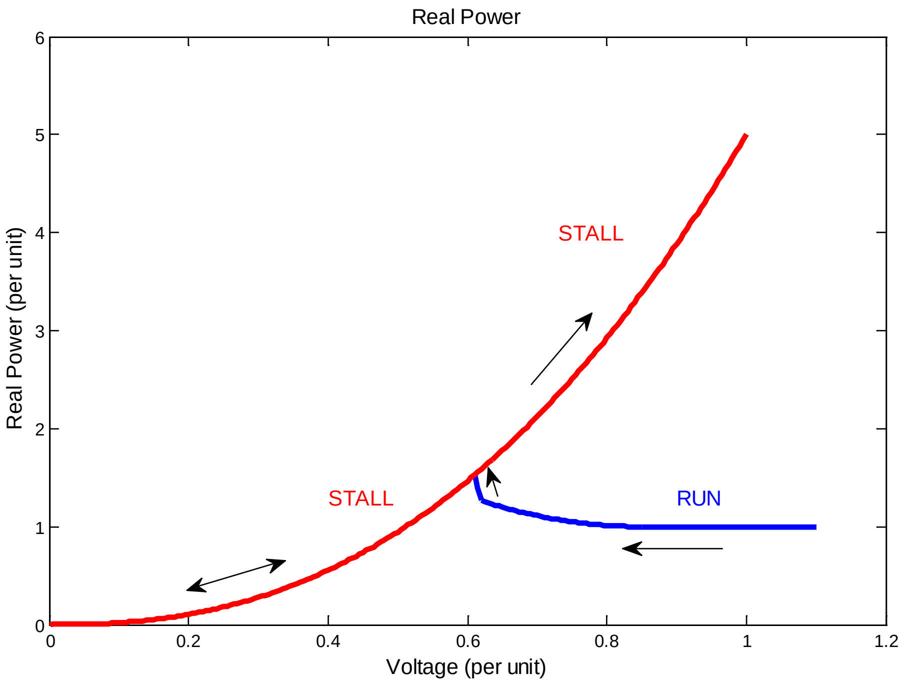
Composite Load Model Structure

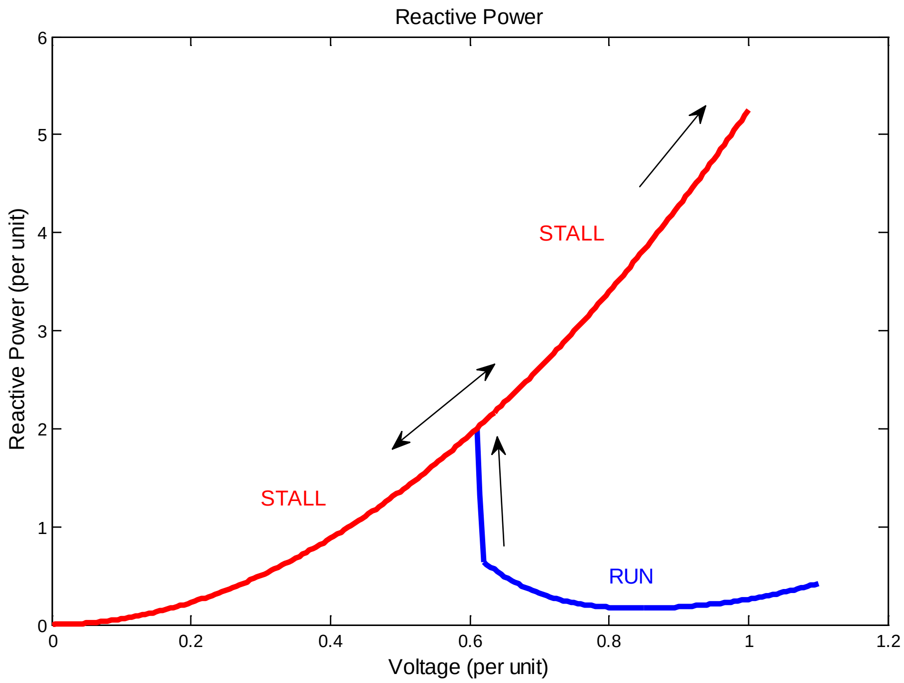
Composite Load Model Structure



GE PSLF
Siemens PTI PSS®E
Power World

“Performance Model” for Air-Conditioners





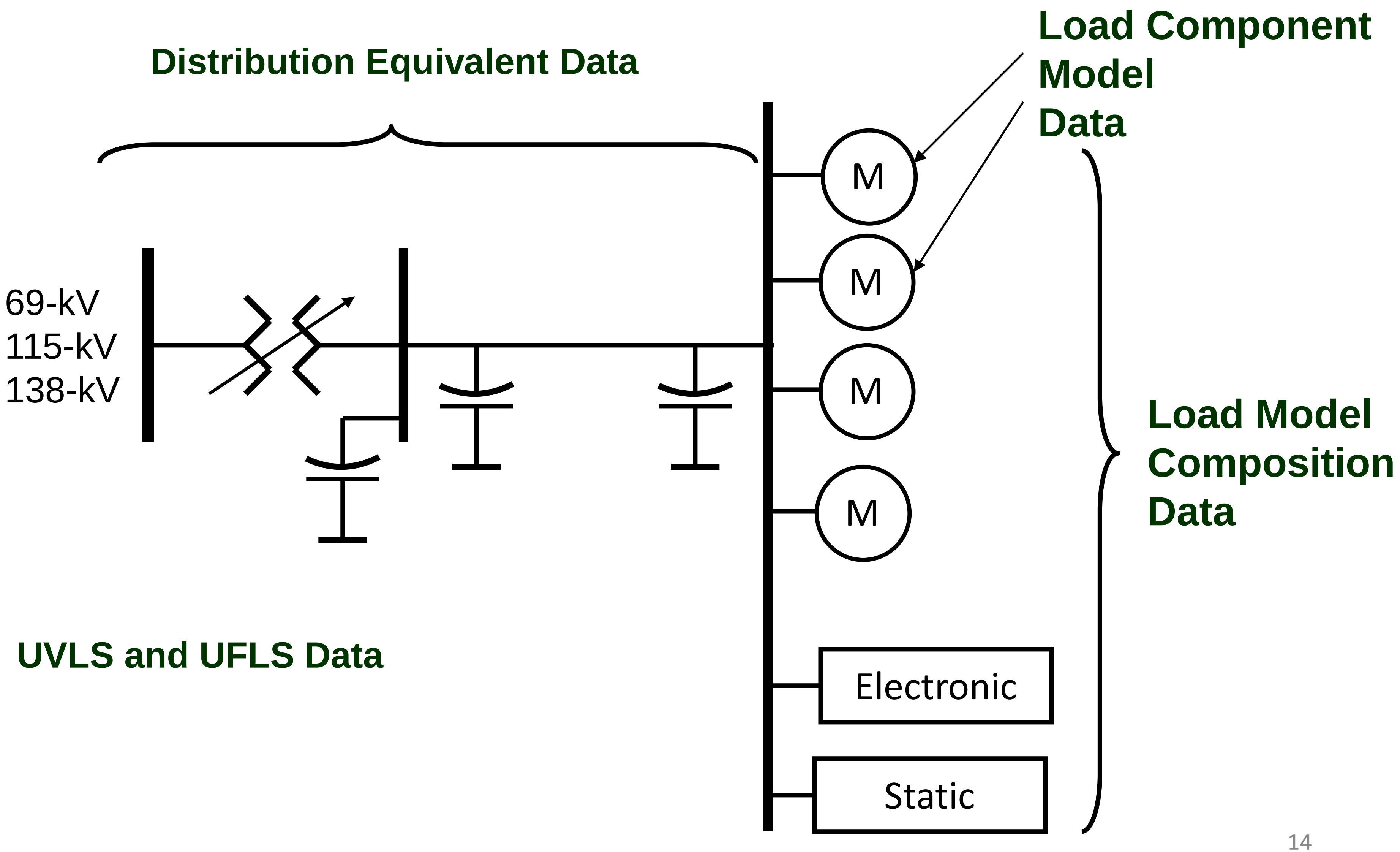
Motors stall when voltage drops below Vstall for duration Tstall

A fraction Frst of the aggregated motor can restart when the voltage exceeds Vrst for duration Trst

Motor thermal protection is modeled

Data

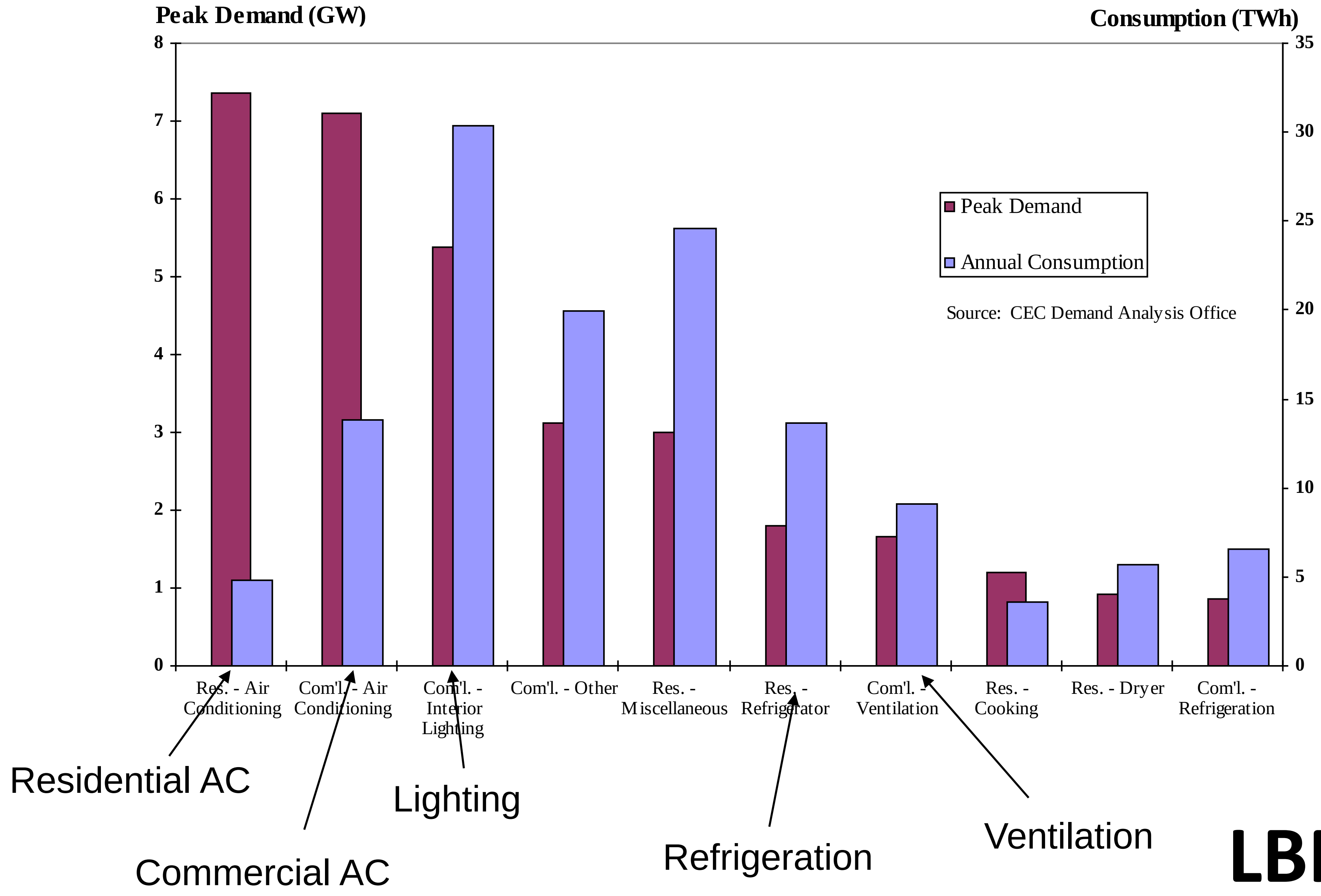
Load Model Data



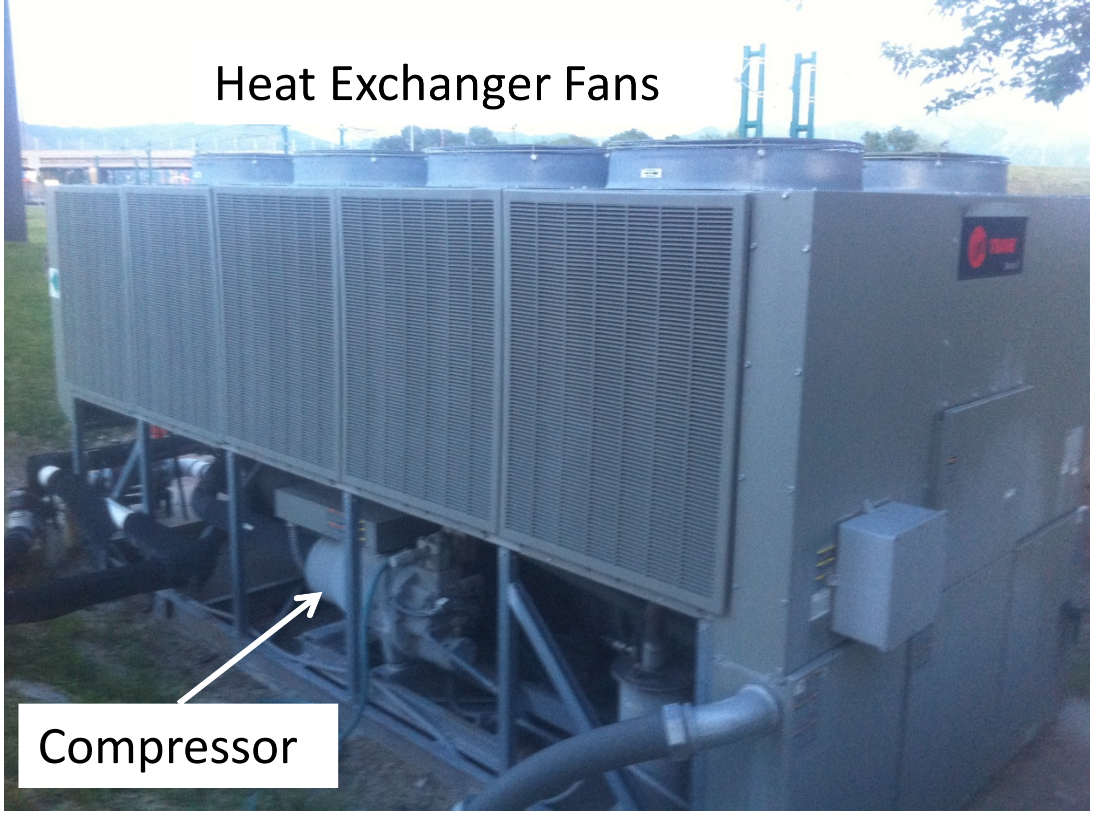
Load Model Data

- Develop understanding of electrical end uses in various buildings, do not rely solely on consultants with elaborate building models
  - Building models can help develop understanding, but should not be used as the primary source
- When you walk in Whole Foods on hot summer day, do you know how much load is refrigeration / AC / lighting / fans / cooking? Do you know expected size and type of compressor motors? Do you know what building EMS system will possibly do during a fault?
- We need to develop this expertise

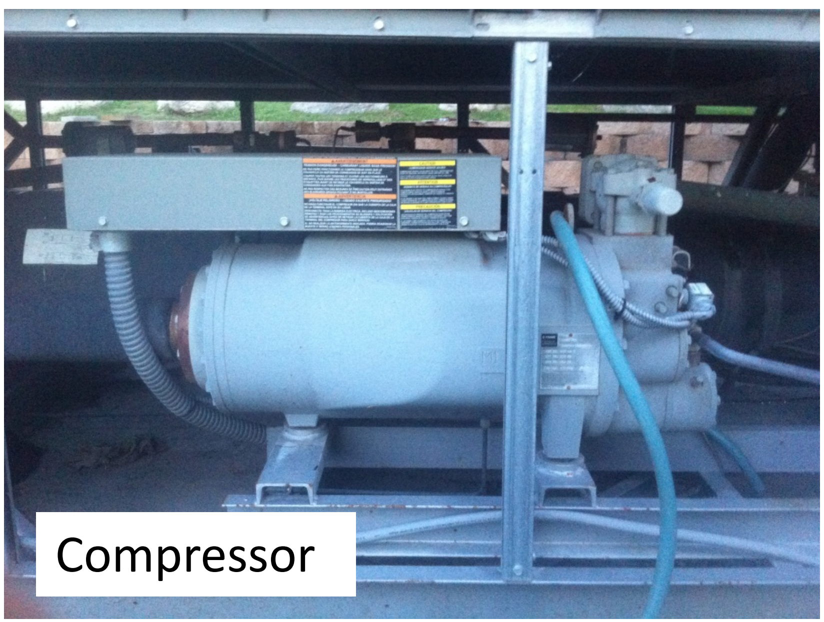
Summer peak demand in California



LBNL



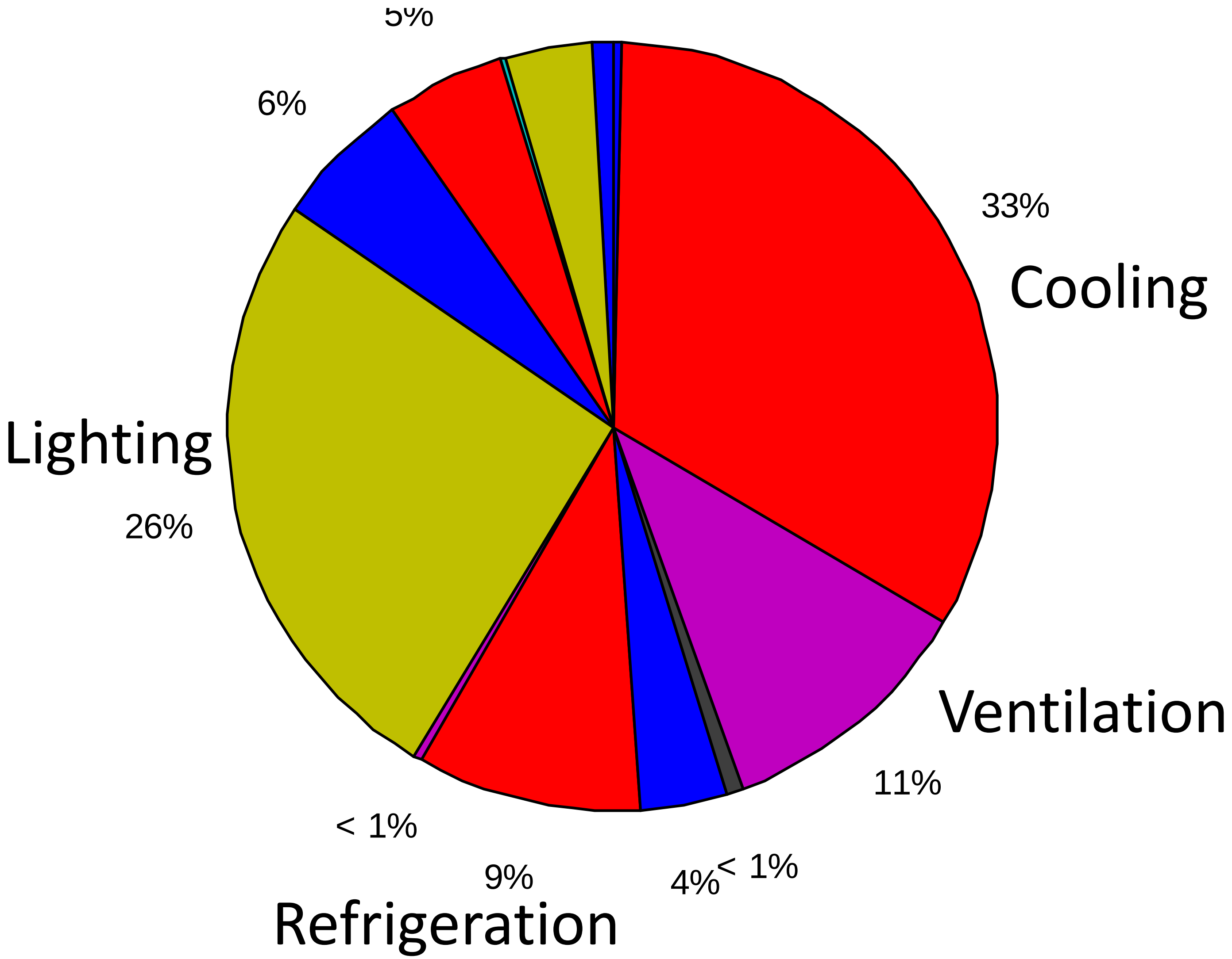
Hotel in Salt Lake City
125 rooms



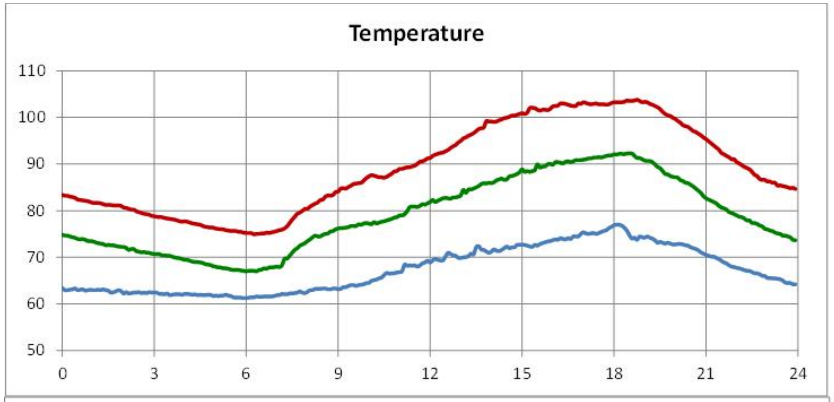
2 Compressor Motors:
A: 3-ph, 460 V, 139 RLA, ~94kW / 70 hp
B: 3-ph, 460 V, 118 RLA, ~80kW / 60 hp

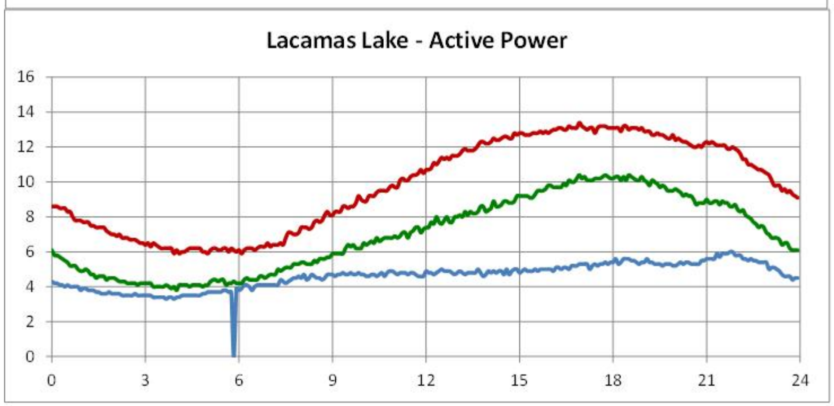
9 Fan Motors:
3-ph, 460V, 1.25 hp each

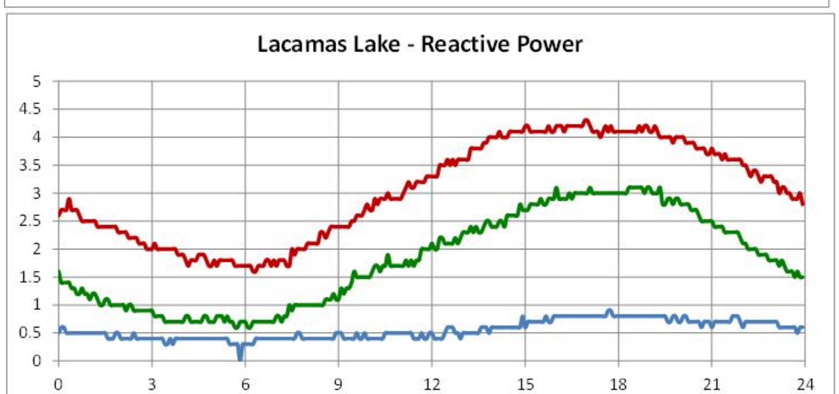
CEC California Commercial End-Use Survey Summer Peak Load



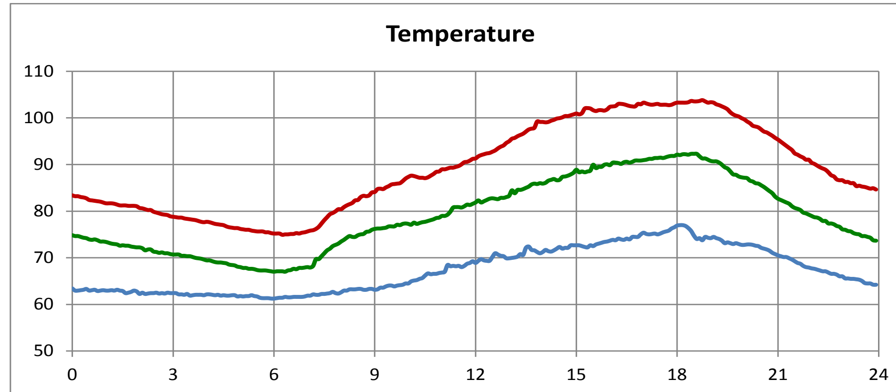
Residential

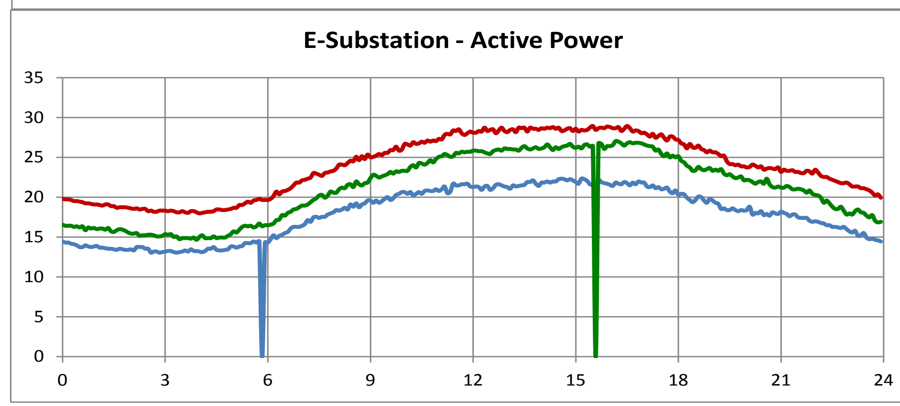


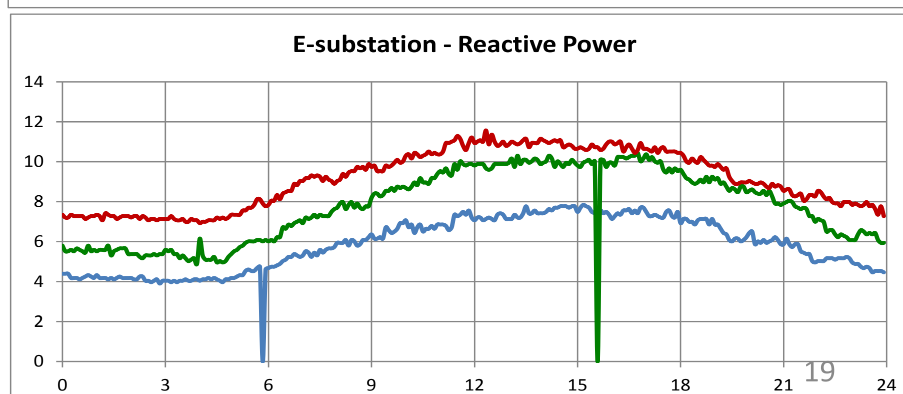




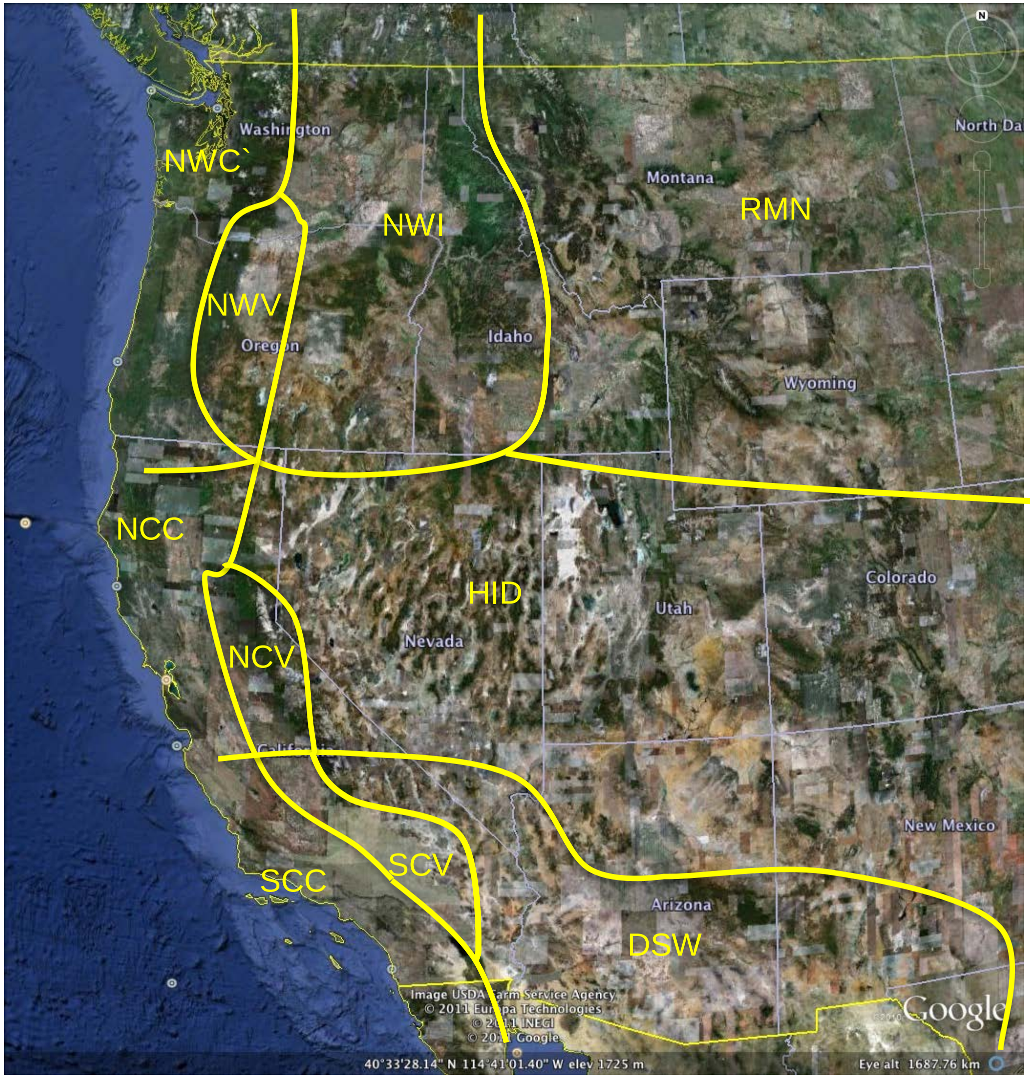
Commercial







Climate Zones



NWC – Northwest coast

NWV – Northwest valley

NWI – Northwest inland

RMN – Rocky mountain

NCC – N. Calif. coast

NCV – N. Calif. Valley

NCI – N. Calif. Inland

HID – High desert

SCC – S. Calif. coast

SCV – S. Calif. Valley

SCI – S. Calif. Inland

DSW – Desert southwest

Substation / Feeder Types

- Residential: typical of your suburban neighborhood
- Commercial: typical of downtown load
- Mixed (default): mix of residential and commercial
- Rural / agricultural
- Several types of industrial loads (petro-chemical, paper mill, steel mill, semiconductor, etc)

Utilities populate base cases with load identifier

(3 characters climate zone)_(3 character type)

Load Composition Model

BPA and WECC developed Load Composition Model:

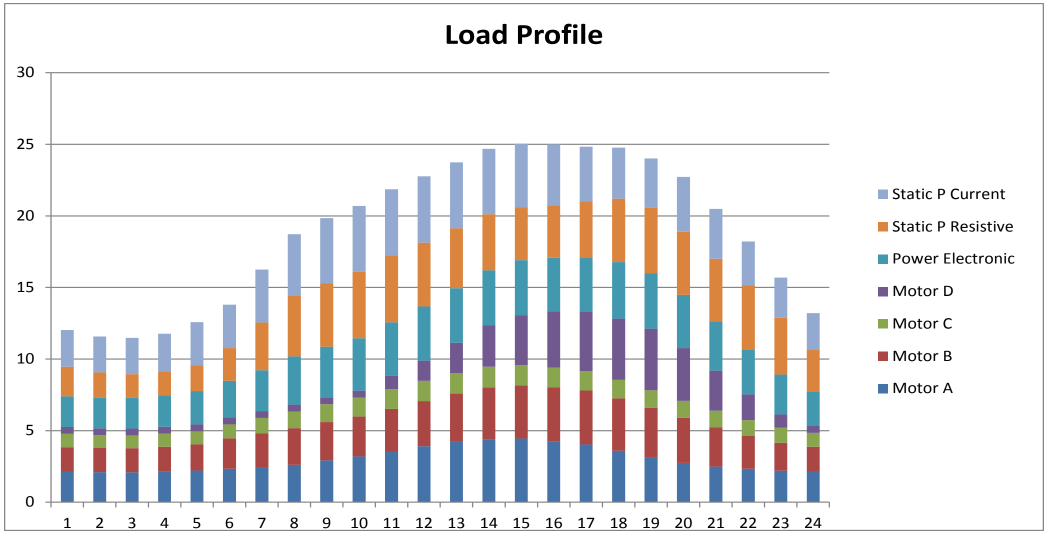
12 climate zones X

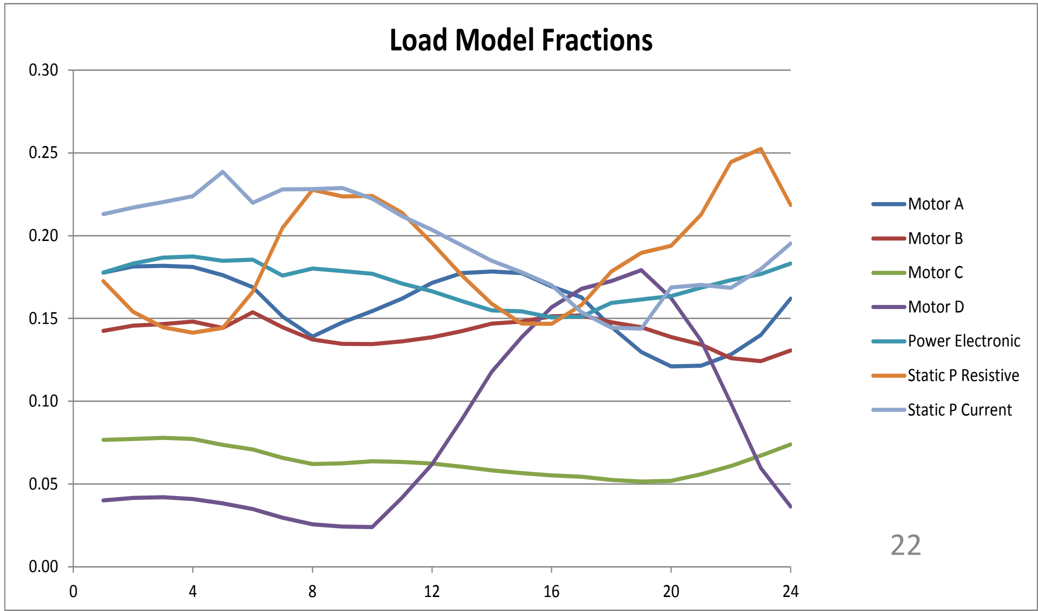
4 feeder types +

10 industrial load types

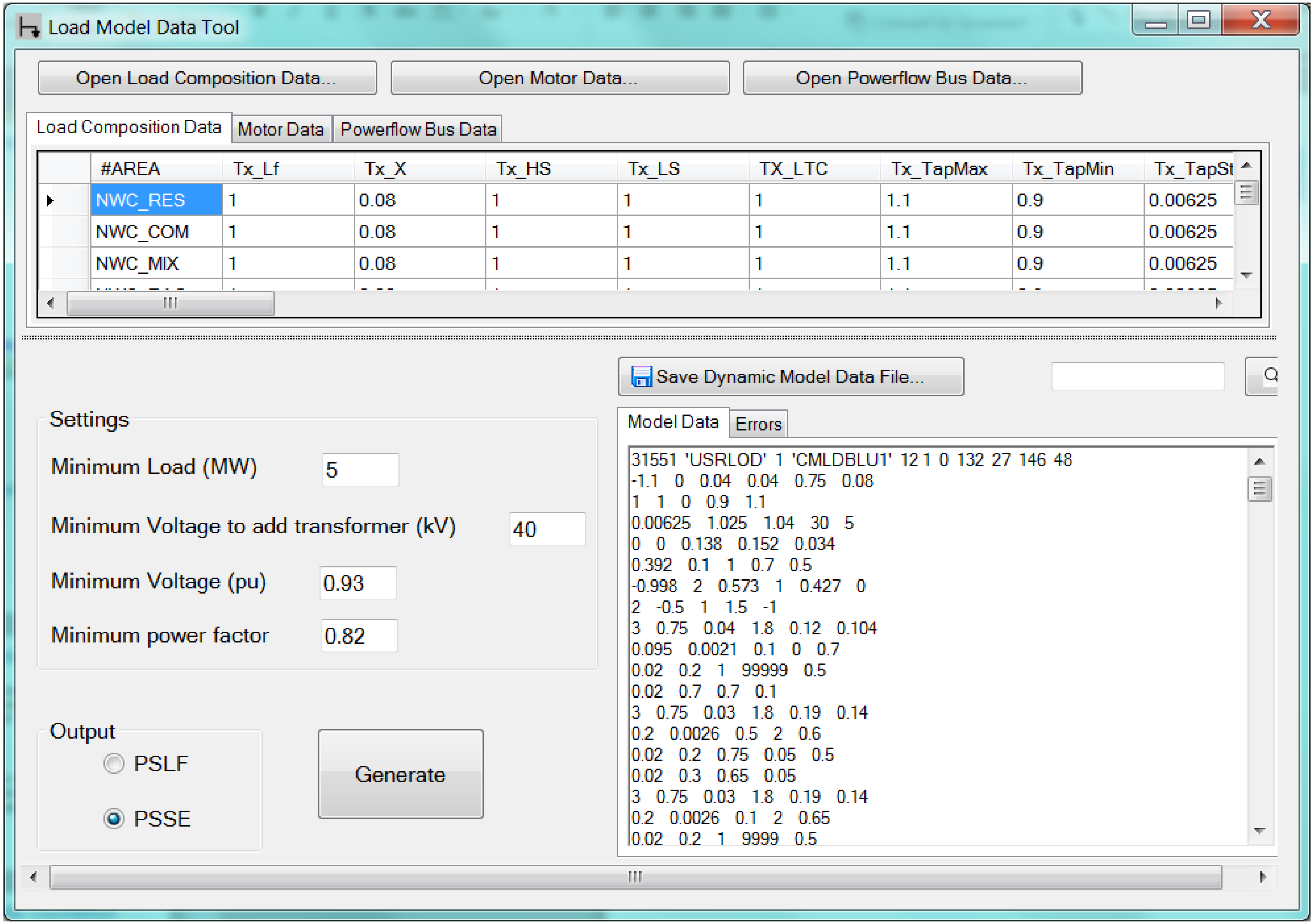
5 seasons

24 hours





Load Model Data Tool



Load Model Data Tool

Load Model Data Tool is used to create composite load model records in GE PSLF and PSS®E

Inputs:

- File with load records, including their "load type identifier"
- Load composition data
- Motor and end-use model data

Output:

- PSS®E DYR and PSLF DYD model data records

Studies

Model Acceptance and Validation Studies

Tens of thousands runs have been done with composite load model up to date

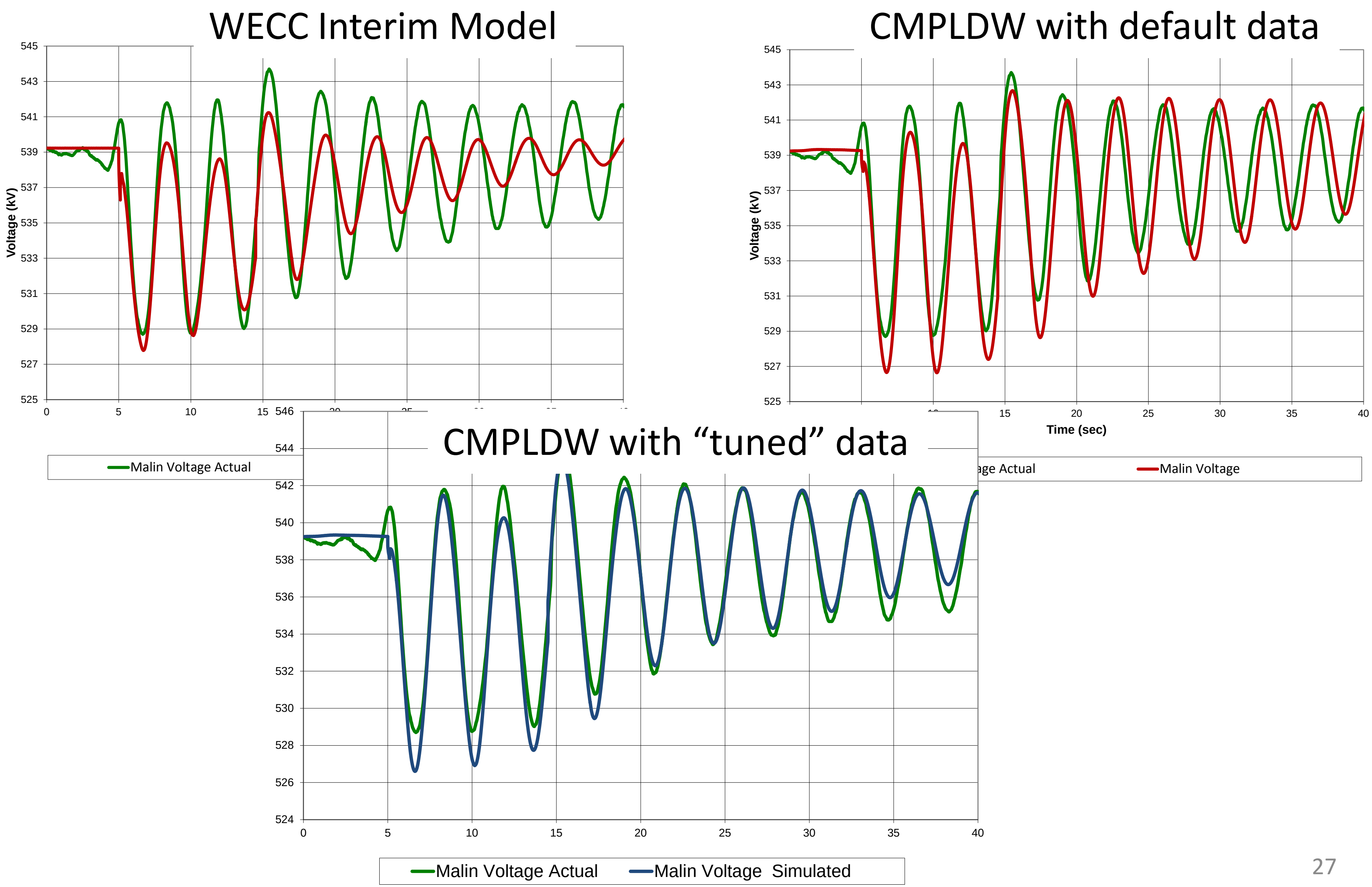
Validate model impact on power system performance:

- Large interconnection-wide disturbances
- Faults that include FIDVR

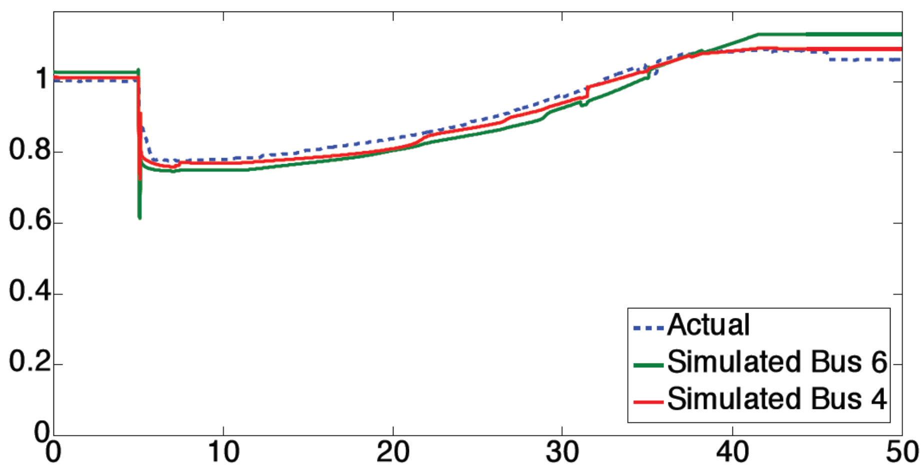
Challenges:

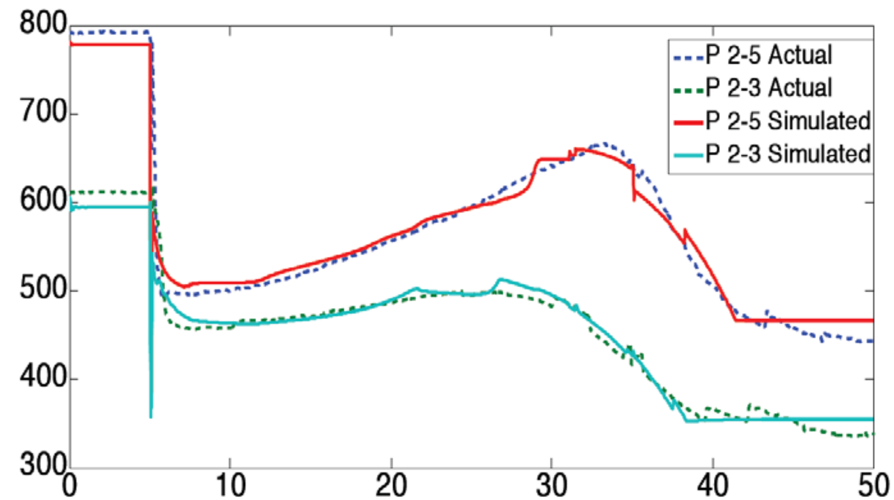
- Load composition varies daily and seasonally
- Lack of disturbance recordings, particularly FIDVR records outside Valley area in Southern California

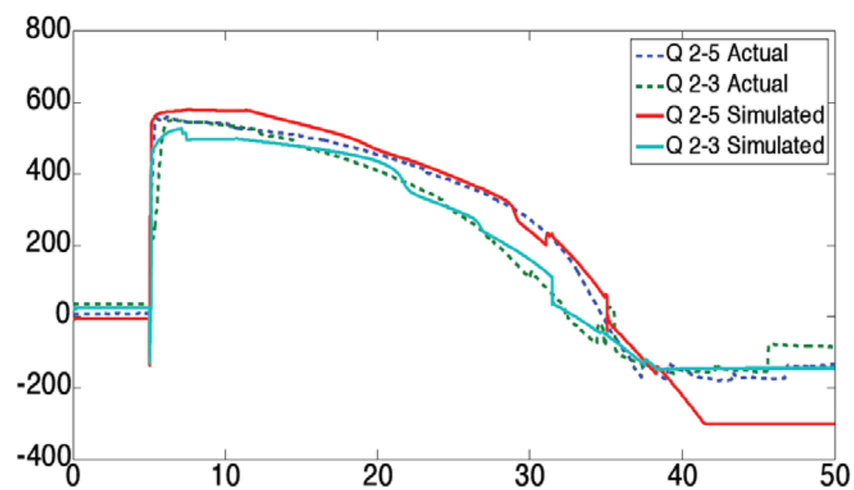
August 4, 2000 Oscillation



Reproducing Delayed Voltage Recovery Events with Composite Load Model



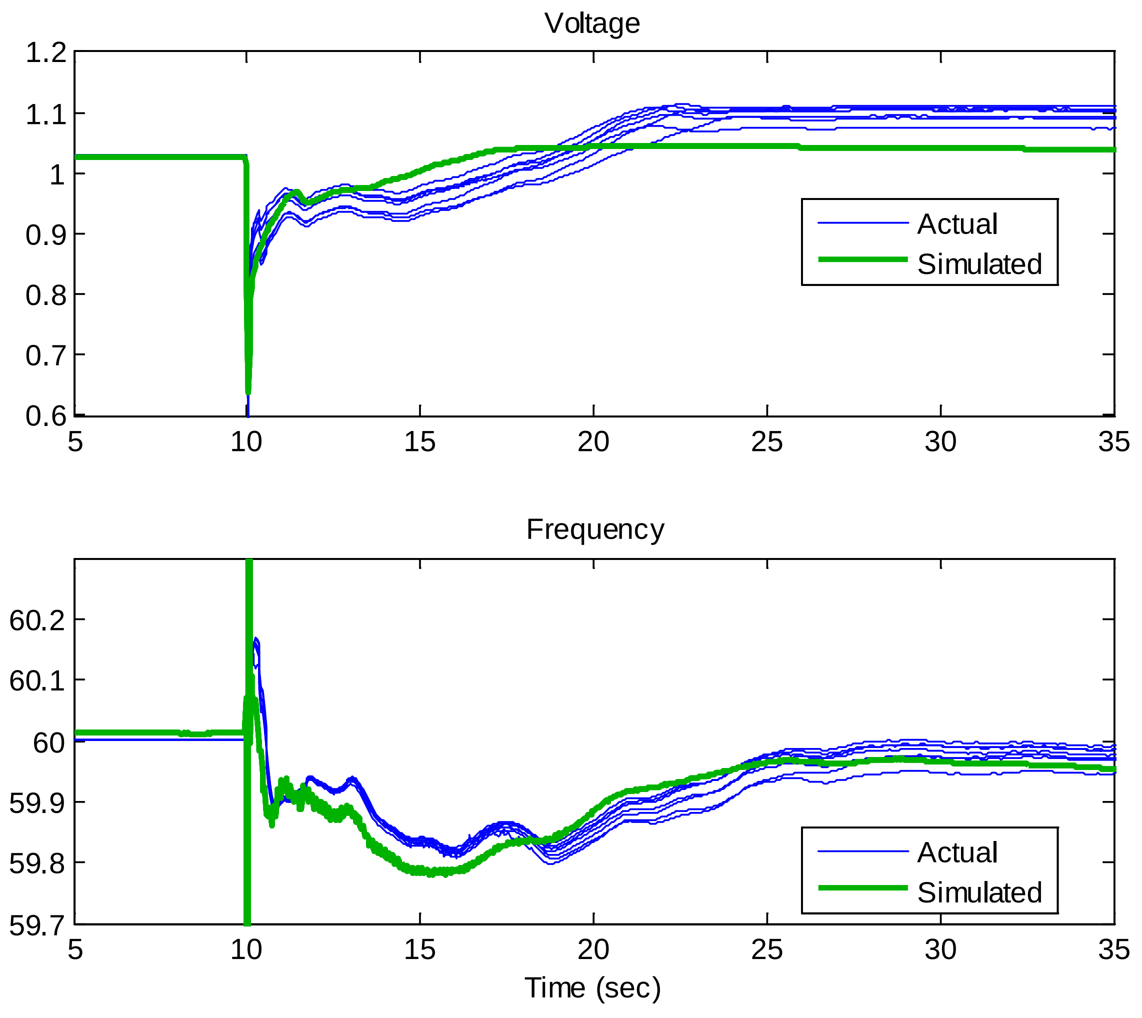




Simulations of delayed voltage recovery event due to air-conditioner stalling
Models can be tuned to reproduce historic events reasonably well

Done by Alex Borden and Bernard Lesieutre at University of Wisonsin

July 28, 2003
Hassayampa Fault Sensitivities



System Impact Studies

- We were able to tune the composite load model to reproduce historic system events

  That said…

- Composite load model was more conservative in simulating the severity of FIDVR events than we expected
- Another concern is high sensitivity of results with respect to stall and motor protection assumptions

  Therefore,

- **WECC adopted phased implementation of composite load model: Phase I – air-conditioner stalling feature is disabled**

Implementation

Phased Implementation in the West

2011 WECC approved phased implementation plan:

- Model indicated AC stalling much greater than what experienced in reality outside Valley area in Southern California
- Lack of validation outside Valley area
- WECC voltage dip criteria
- More gradual transition

Phase I – air-conditioner stalling feature is disabled

WECC membership performed system impact studies
Model data revisions were implemented
WECC approved composite load model in 2013

Starting 2014, all WECC planning and seasonal operating cases include Phase I composite load model

Lesson's Learned from Phase I Implementation

Phase I model impacted system performance:

- Damping of inter-area power oscillations
- Transient voltage dip

The impact is observable during large disturbances and close to the operating limit, the impact is less significant during small events

Several utilities voiced concerns about load tripping

Where we are now …

- Composite load model is implemented in GE PSLF and Siemens PTI PSS®E, similar models exist in Power World, Power Tech TSAT
- Tools are developed for load model data management
- "Default" data sets are prepared
- WECC is taking phased approach for approving the composite load model for TPL compliance studies
  - Phase 1: air-conditioner stalling is disabled by setting Tstall parameter to a large number
  - Phase 2: better understand the reliability implications of delayed voltage recovery due to air-conditioner stalling, develop appropriate reliability metrics

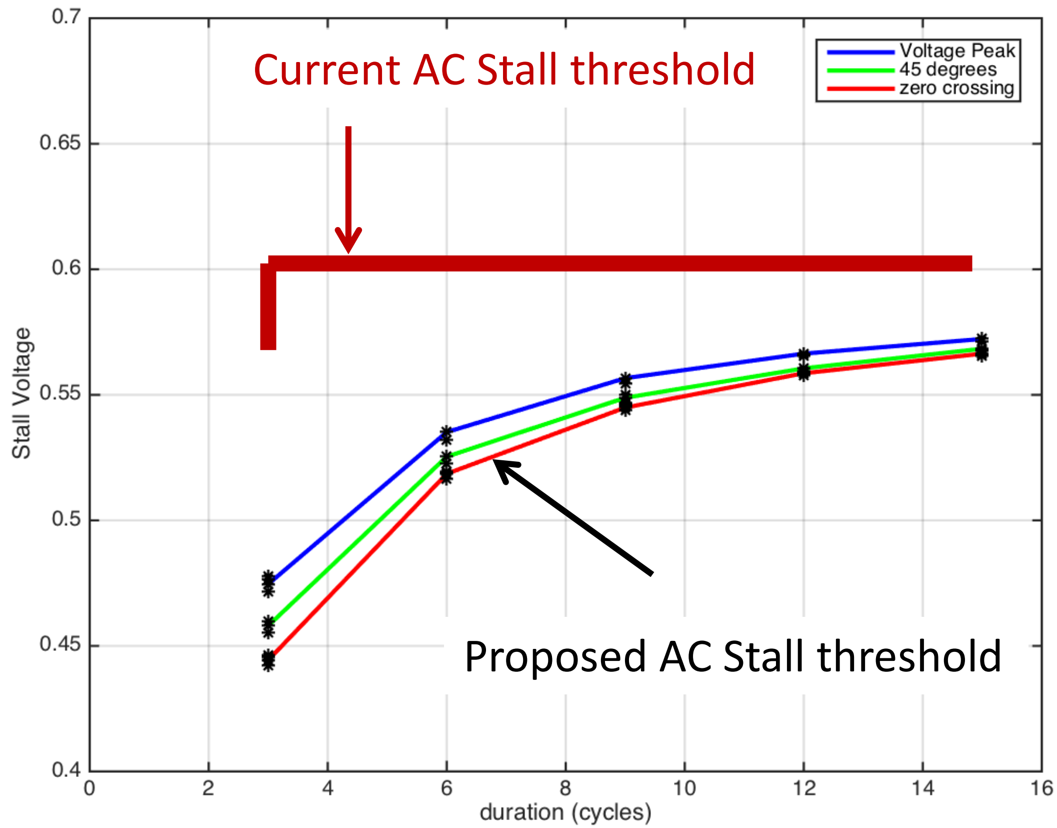
… Where we are now

- All planning and seasonal operational cases prepared by WECC now have composite load model
- Tens of thousands runs have been done with the composite load model up to date
- WECC studies help to improve model data sets

Next Steps

AC Model Revisions

New work by John Undrill, Bernie Lesieutre and BPA suggests that air-conditioners may not stall as easy as previously expected



Planned Revisions to **Model Structure**

Flexible model structure

Electrical end-use characteristics are changing rapidly, as more loads become electronically connected

Modular structure (similarly to generating units)

Air-conditioner models

Revise "performance" model to reflect recent test findings

Add MOTORC dynamic model

Distributed generation

Revision of motor protection

From discrete to more granular

Model Data

Composite load model is a very powerful.

Deepen our understanding of end-uses.

Building surveys

- Installed equipment
- Load shapes
- Protection and control

End-use monitoring

Load shape analysis

Disturbance Monitoring

We need more recording of both FIDVR events as well as large faults not causing FIDVR

- Synchronized recordings at transmission and distribution levels

System impact studies for Phase II and sensitivity studies with respect to model parameters

- Continue after model improvements are completed

Load Modeling – Setting Expectations

We can now achieve the great accuracy with generator models:

- We model physical equipment that is well defined and under our control

We will never be able to achieve a comparable level of accuracy with load models

- Yes, we can tune load models to accurately reproduce and explain past events
- But, Load models is only capable of predicting the future load response only in principle, and not in detail

Thank You