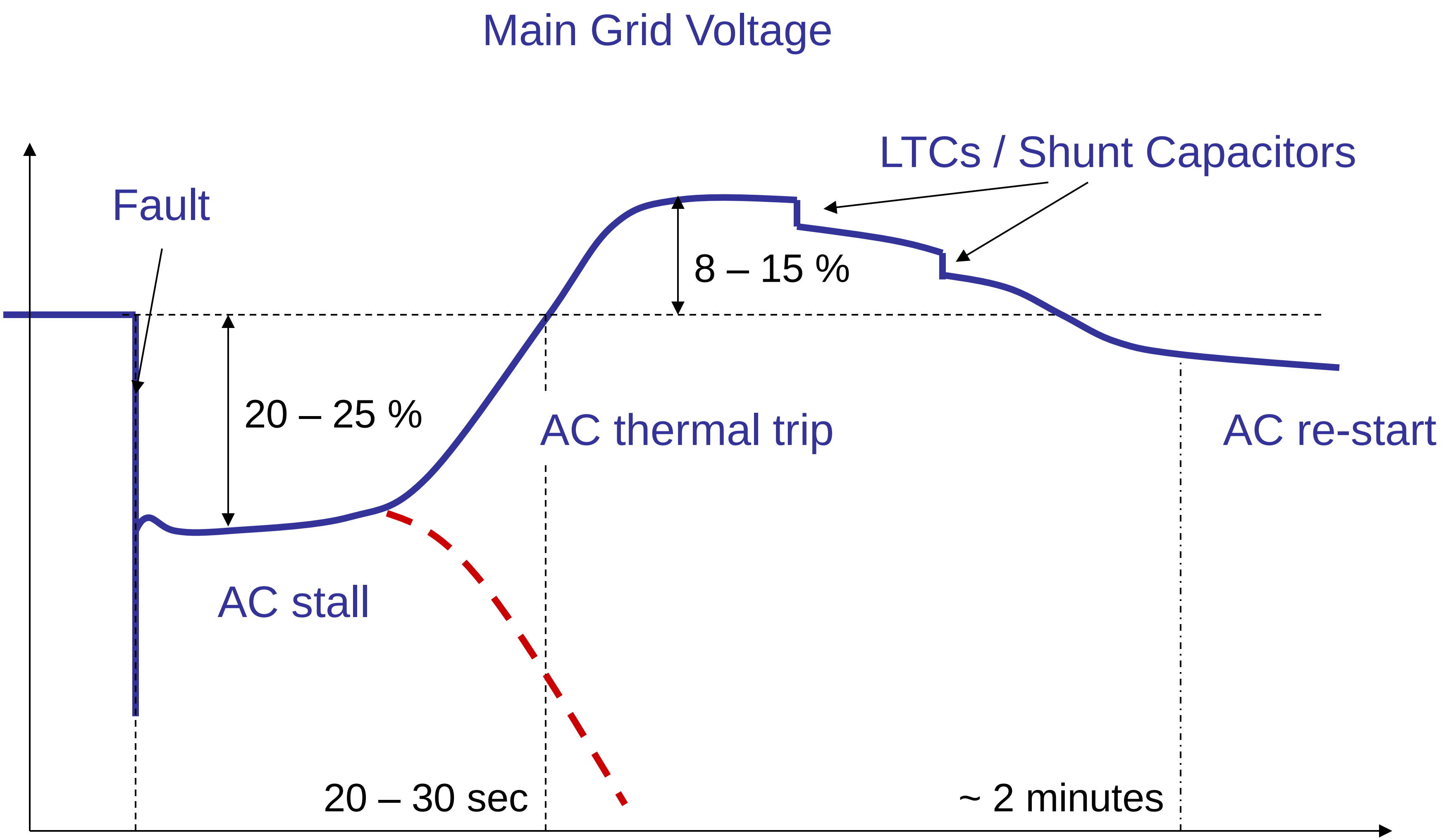
Load Modeling in Grid Simulations and System Performance Issues

Presentation at DOE Workshop

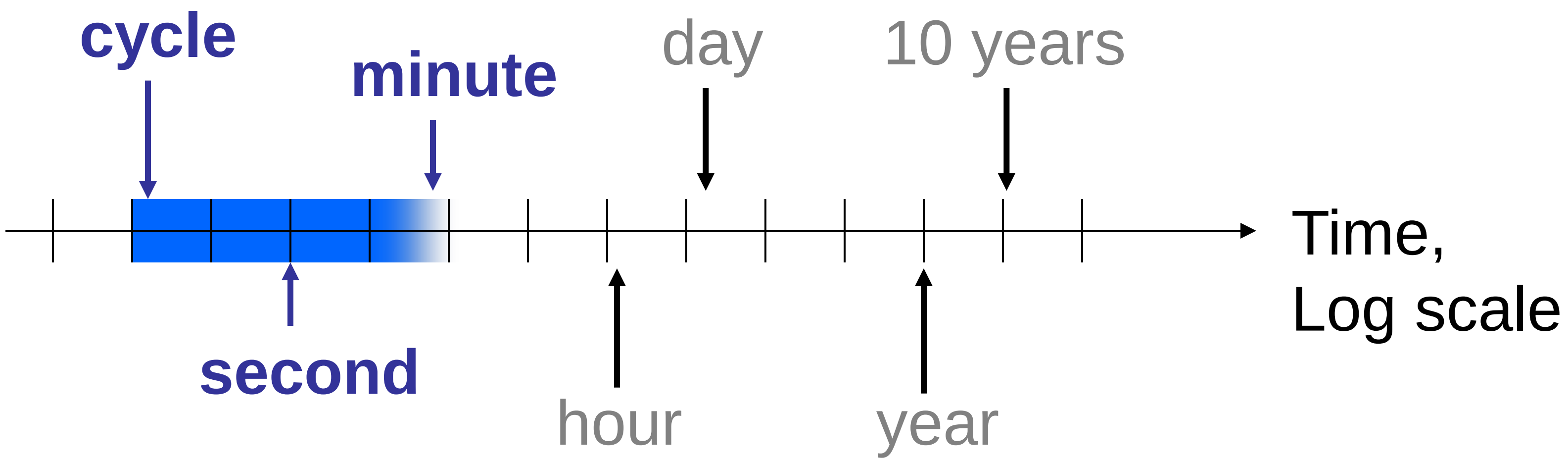
Dmitry Kosterev
Bonneville Power Administration
April 2008

Delayed Voltage Recovery Event



Load Modeling
Timescale of Interest

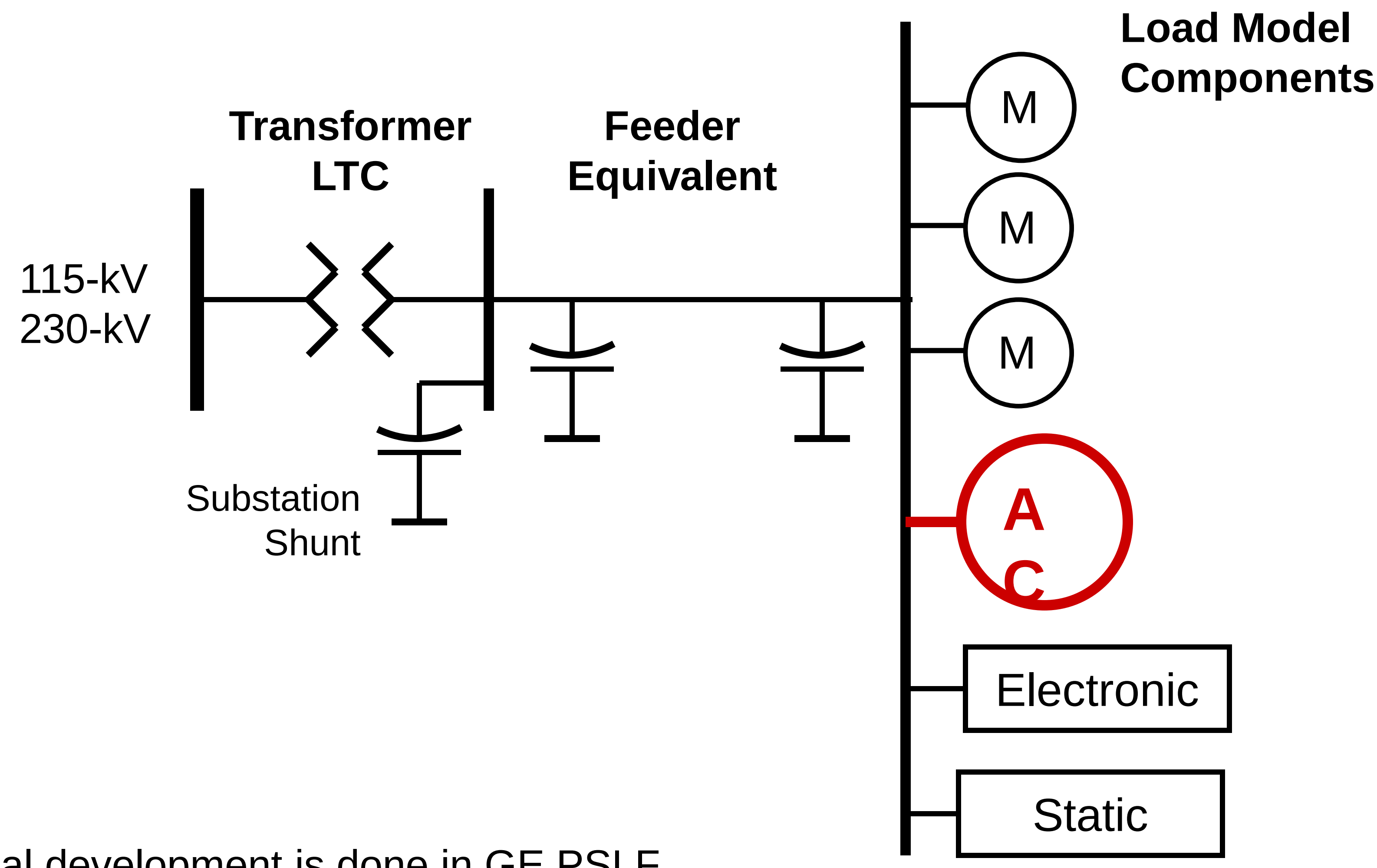
Our primary interest is the fast dynamic response of loads, not projections of future demand.



Load Modeling in WECC

- Load Model Structure:
  - Composite load model in WECC production programs
  - Explicit load representation
- Load Model Data
- System Impact Studies:
  - Sensitivity, Validation, System Performance

WECC Composite Load Model



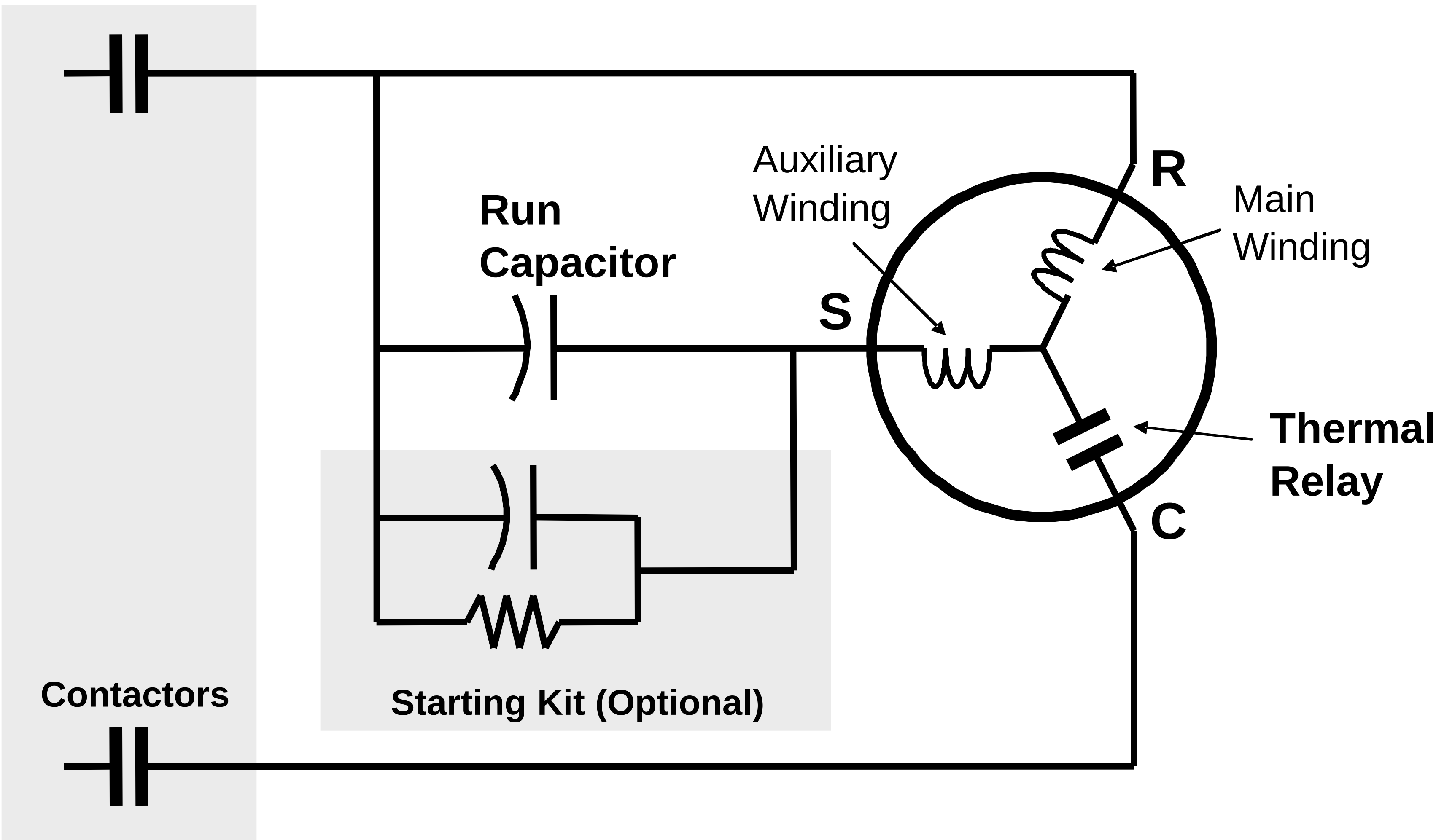
Initial development is done in GE PSLF

Load Model Structure

- WECC developed EPCL routines for explicit load representation in PSLF program in 2004–05:
  - Add Transformer
  - Add Feeder Equivalent
  - Create Load Composition
- WECC developed a user-defined model of single-phase residential air-conditioners
- WECC is working with GE on developing a composite load model in PSLF program
  - Specifications are developed in March 2006
  - Several releases have been tested since April 2007
  - Final version is expected in Q1 of 2009

Single-Phase A/C Compressor Motor Model

A/C Compressor Motor



1-phase motor has 2 windings

Single-Phase Motors – Steady-State

(a) Compressor motor in a 3-ton air-conditioning unit

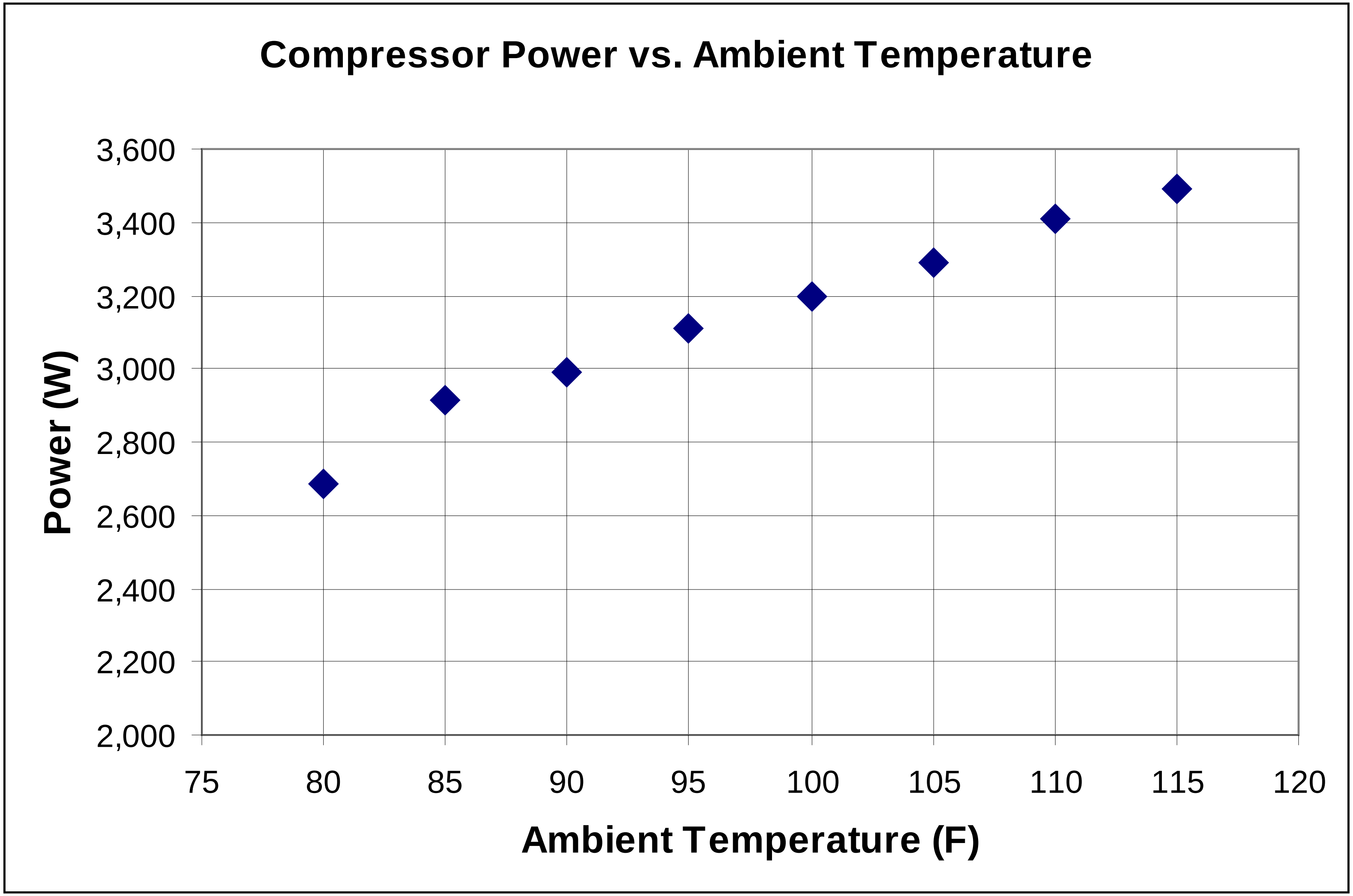
	Total	Main	Auxiliary(*)
Real Power, W	3180	1910	1270
Reactive Power, VAR	730	1645	-915
Power Factor, Per Unit	0.974	0.758	-0.81

(b) Compressor motor in a 3.5-ton air-conditioning unit

	Total	Main	Auxiliary(*)
Real Power, W	3790	2500	1290
Reactive Power, VAR	800	2000	-1200
Power Factor, Per Unit	0.978	0.781	-0.732

Notice high power factor

Single-Phase Motors – Steady-State



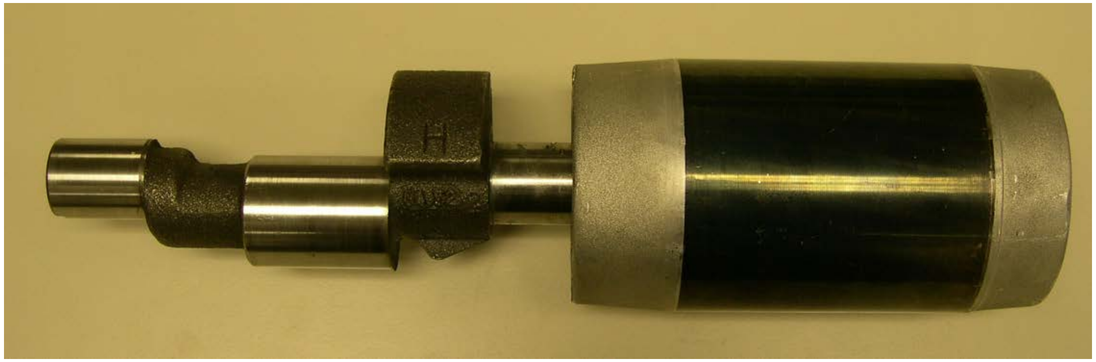
3-ton compressor motor

Compressor Motor Tests – Motor Inertia

H = 0.03 – 0.05 seconds

E.g. 3.5-ton compressor motor:

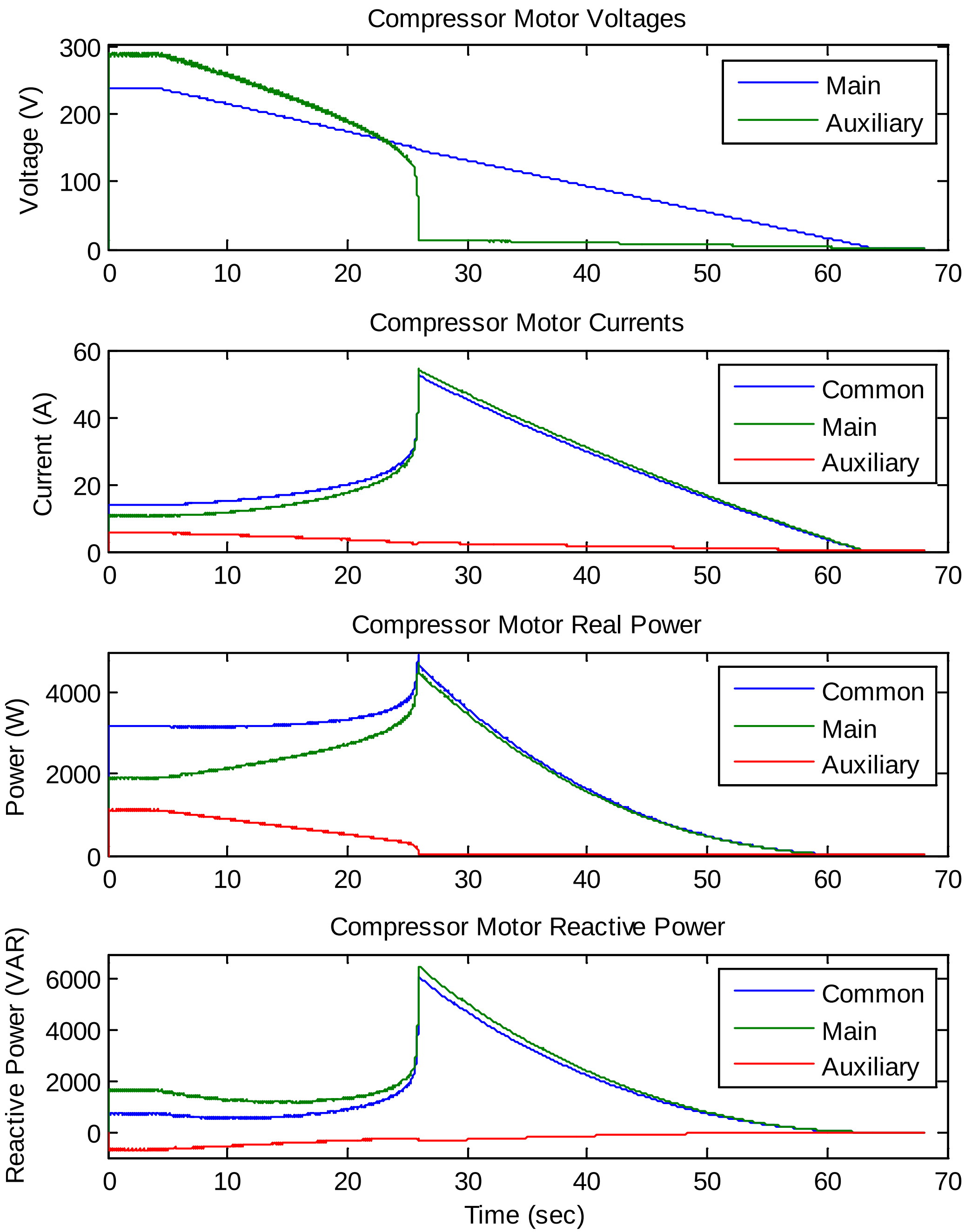
Weight: 4.6 kg



75 mm

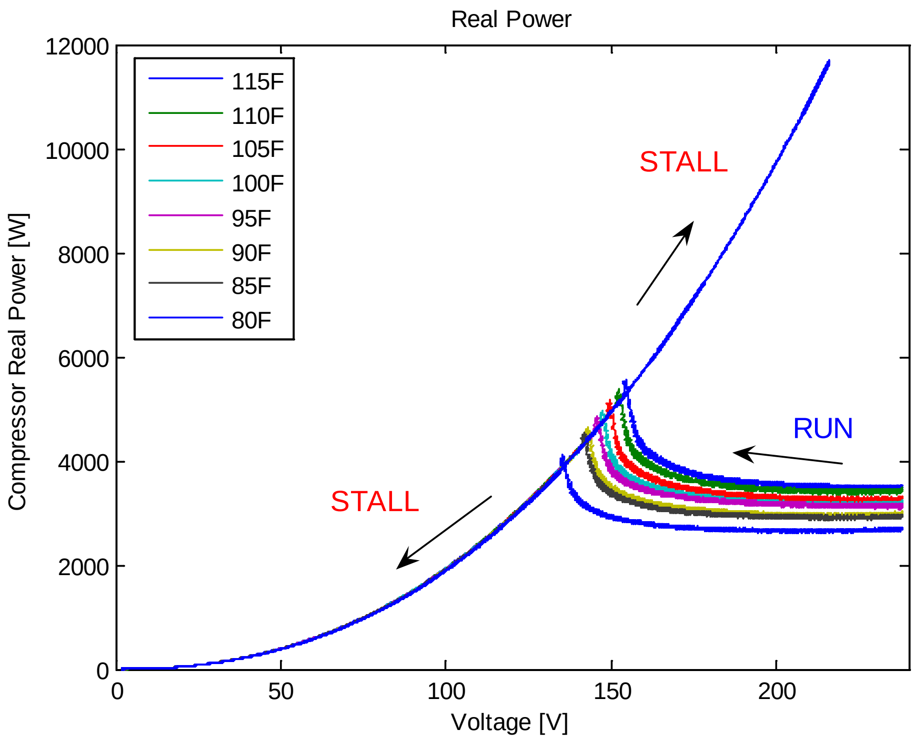
310 mm

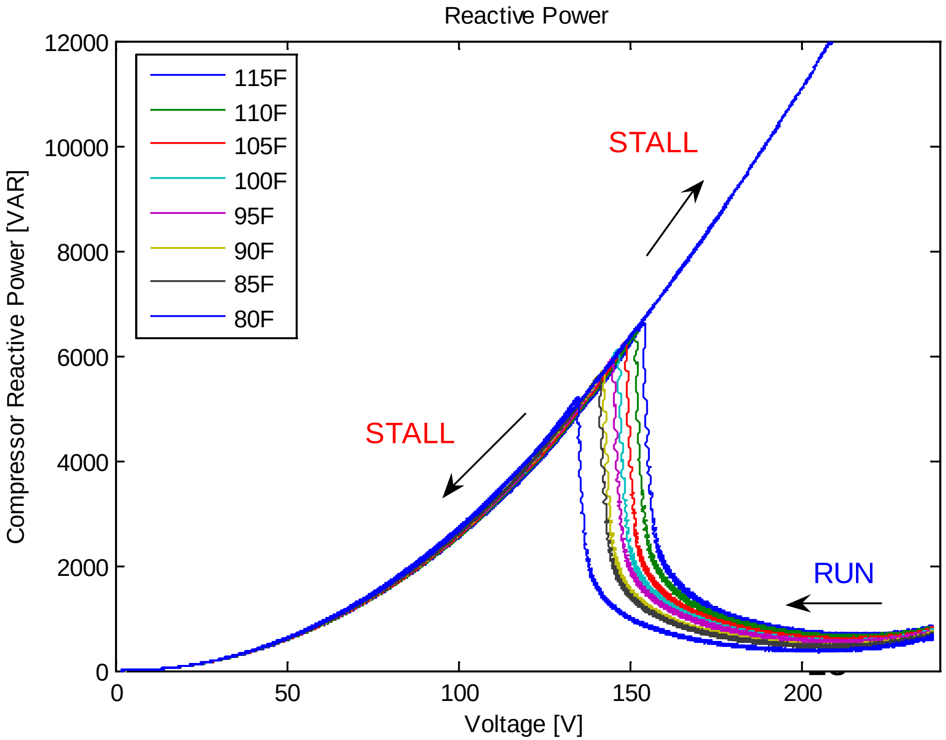
Compressor Motor Tests – Voltage Ramp



Notice motor non-symmetric behavior becomes more pronounced as voltage ramps down

Compressor Motor Tests – Power-Voltage Trajectories





Notice that stall voltage increases with temperature

1ϕ – AC Motor Tests

- Compressor motor is 1-phase capacitor-run motor, has 2 windings
- Nominal power factor is relatively high 0.95 – 0.97
- Compressor load and stall voltage increase with temperature
- Compressor motor inertia is very low (~0.05 sec)
- Compressor motor is non-symmetric, non-symmetry becomes more pronounced as voltage declines
- Once the motor stalls it is likely to remain stalled until coolant pressure is equalized, very few motors can re-start

Single-Phase Motor Models

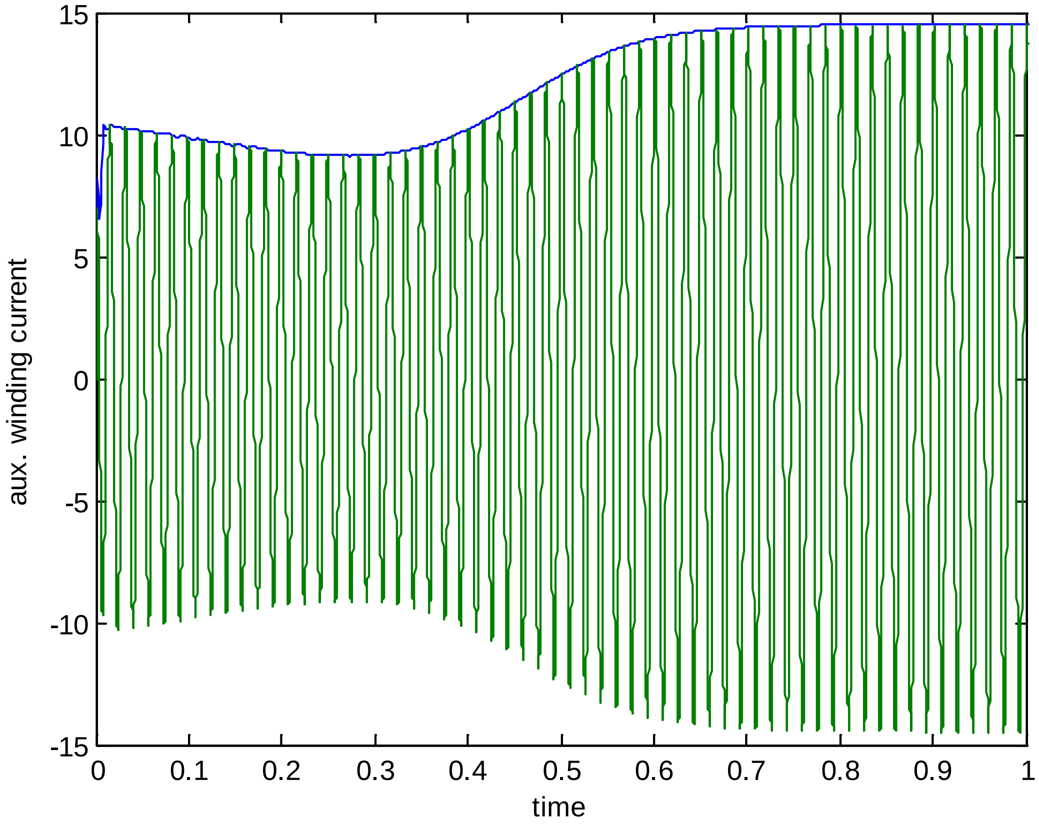
- Three-phase motor models cannot represent behavior of single-phase motors:
  - Stalling phenomenon (3-phase motor model usually stalls at much lower voltages)
  - Real and reactive power when stalled
  - Steady-state sensitivities of real and reactive power with respect to voltage and frequency
- Single-phase motor models exist but require point-of-wave simulations
  - Not acceptable for positive-sequence grid simulators which use ¼ cycle time step

Single-Phase Motor Models

- Phasor Models
- Performance-Type Models
  - Several variations
- Hybrid model
  - Originally developed by SCE, enhanced by EPRI

- Single-Phase Waveform Conversion

Phasor Model*



* This model was developed by Bernard Lesieutre at LBNL, and his research was funded by California Energy Commission's Public Energy Research Program, WA# MR-049, through the California Institute for Energy and Environment, Award Number MTX-060-1.

Phasor Model

- Can be simulated with ¼ cycle time step used in the grid simulators
- Uses differential equations to represent motor dynamics
- Matches well most tests:
  - Voltage steps, ramp, oscillations
  - Frequency steps
  - Correctly identifies faults when compressor motor stalls from the faults when compressor motor re-accelerates

Phasor Model

- Outstanding research issues:
  - Torque model: Simulated inertia had to reduced to about ½ of the measured to reproduce motor stalling. This may be because of torque of a reciprocating compressor is not modeled appropriately when motor stalls. Higher inertia fits well with the oscillation tests. Bernie plans to repeat the tests for a scroll compressor.
- Outstanding implementation issues:
  - John Undrill is working on “motorc” model in GE PSLF. Still, need to reconcile Bernie’s MATLAB model and John’s “motorc” model

Phasor Model

- The model has been useful in developing understanding of single-phase motors. The model will be a valuable addition to grid simulators as a stand-alone model to study specific motor behavior.
- The model, however, may not be the best choice for grid-level studies, as the model precision is lost when representing an aggregate behavior of multiple motors in a feeder.

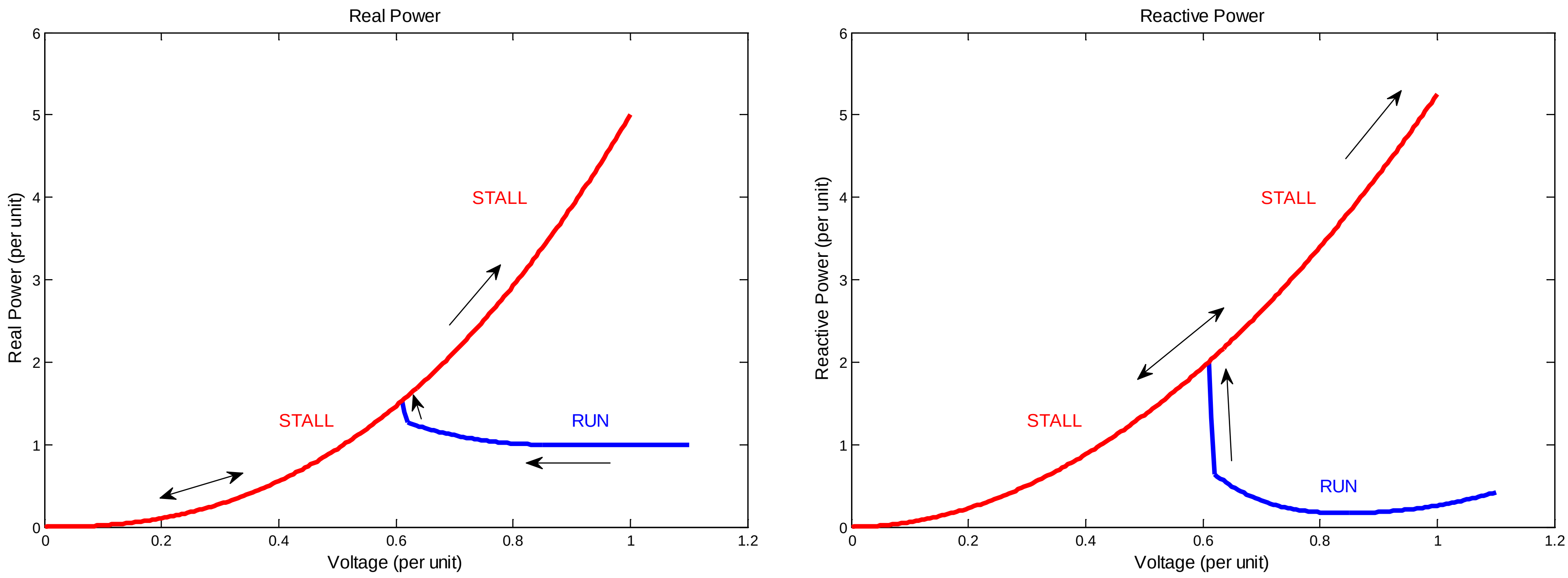
AC Motor Model

- Grid-simulation model
  - Simulation of the impact of air-conditioning loads on the grid dynamic performance
- Equipment model
  - Gain the insight in the dynamic behavior of air-conditioning units
- Coordination and cross-calibration of the models

Performance-Type Models

- The model has two states: running and stalled
- The transition from running to stalled state is done based on the motor voltage
- Running state is represented with static exponential models
- Stalled state is represented with an equivalent impedance $R_{STALL} + j\,X_{STALL}$

BPA Performance Model



Characteristics and stall voltage are adjusted depending on the motor load factor

Performance Model

- Easy to implement
- Model provides good representation of the motor real and reactive power for slow variations of voltage and frequency
- Model does not capture well voltage and frequency dynamics above 0.7 Hz.
- Model is “happier” to stall than the actual motor
- Model captures well motor current, real and reactive power during the stall condition

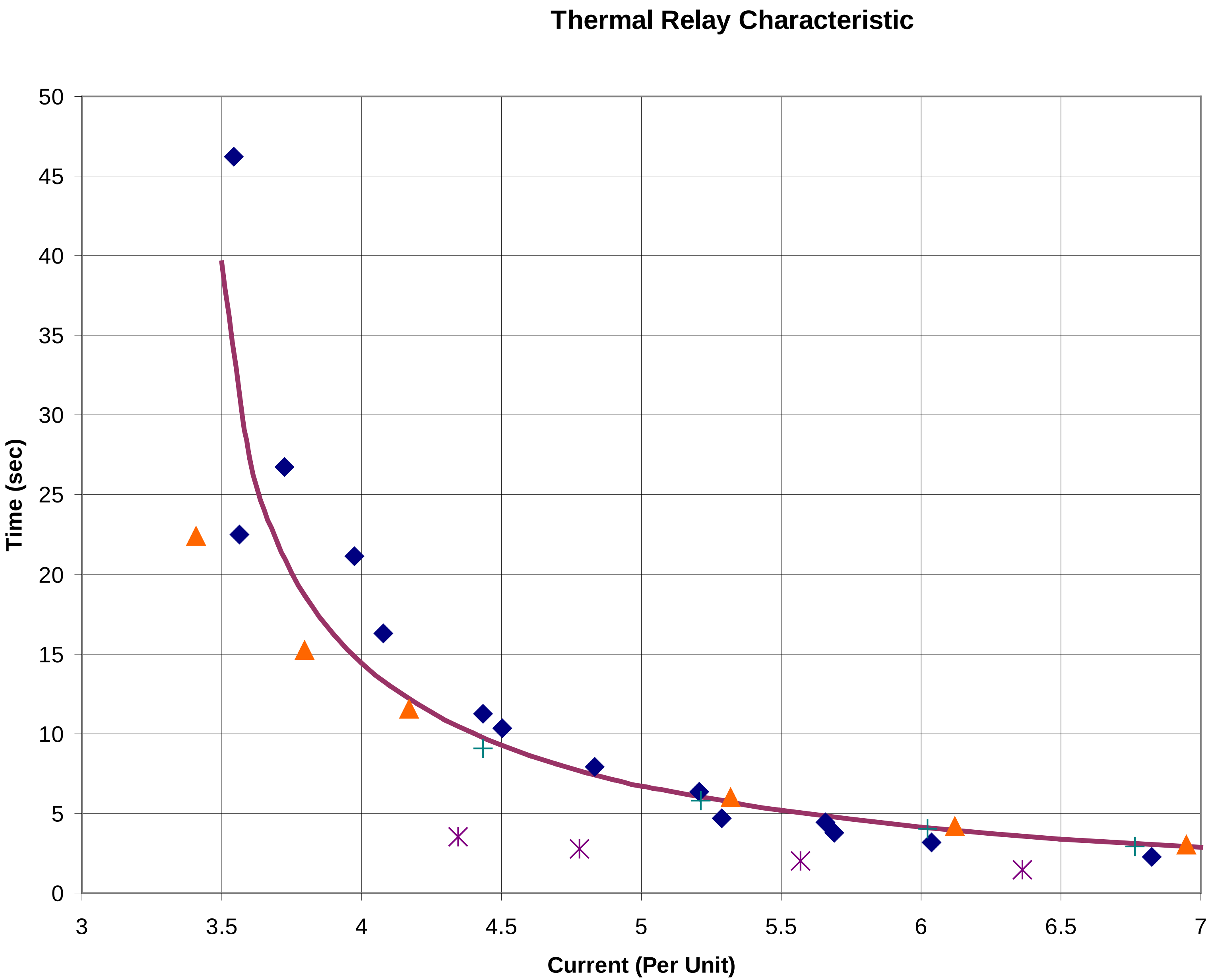
1ϕ - AC Unit Model

Model Includes:

- Compressor Motor Model
- Thermal Relay Model
- Under-Voltage Relay (proposed by SCE) Model
- Condensing Unit Controls / Contactors

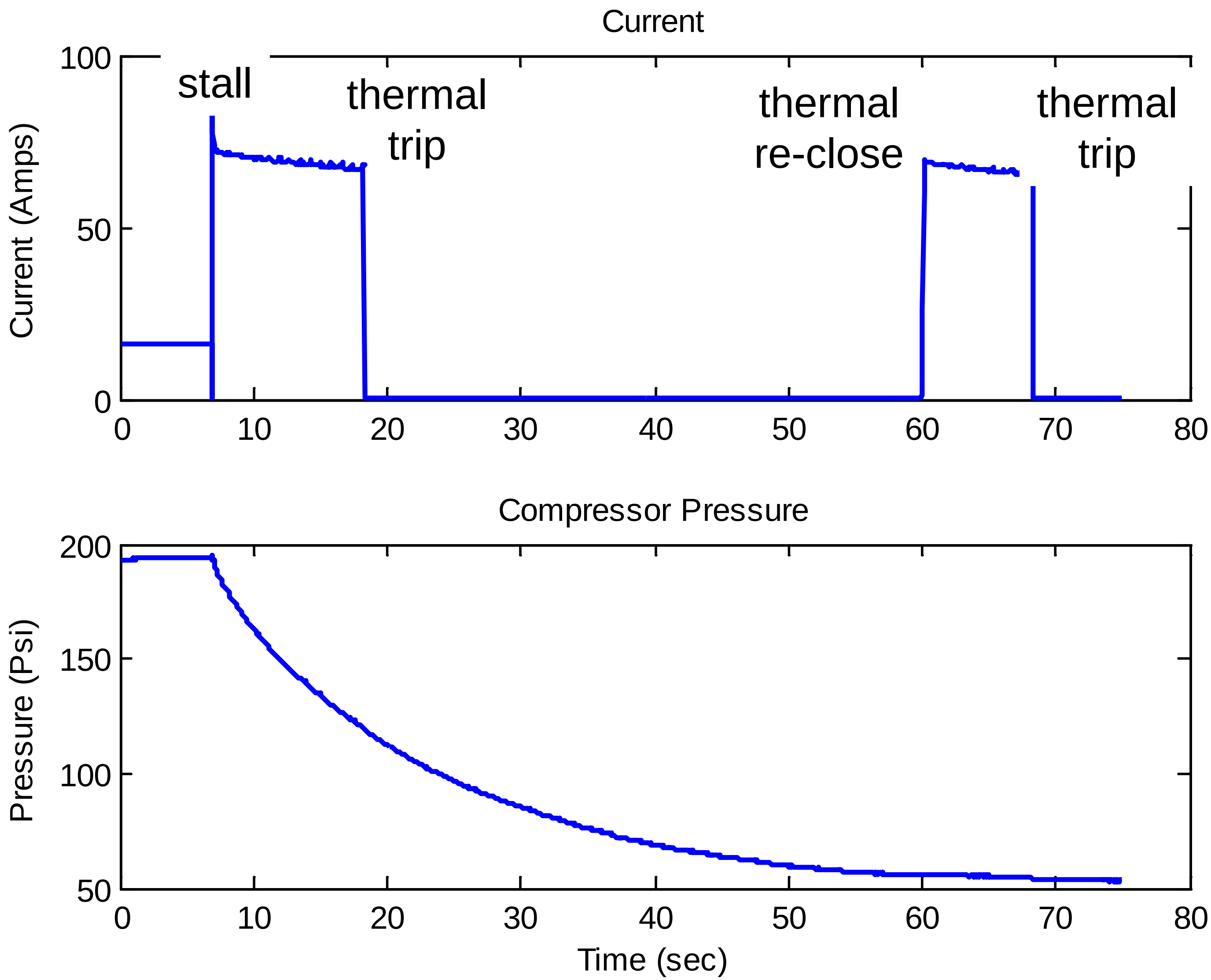
Model Does NOT Include:

- Indoor and Outdoor fans are modeled separately

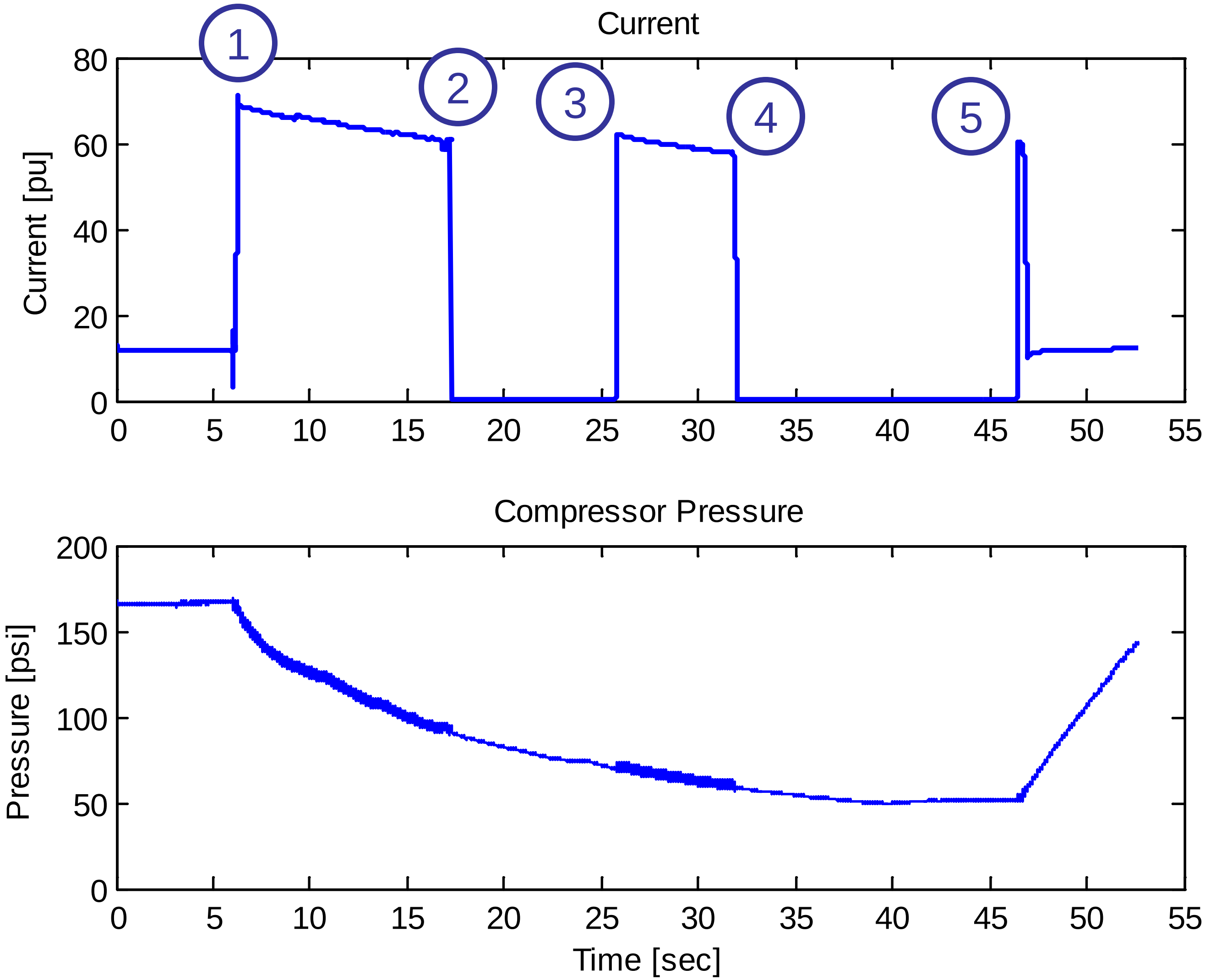


Thermal Relay Characteristic
Time (sec)
50
45
40
35
30
25
20
15
10
5
0
3
3.5
4
4.5
5
5.5
6
6.5
7
Current (Per Unit)

Thermal Protection



Thermal Protection

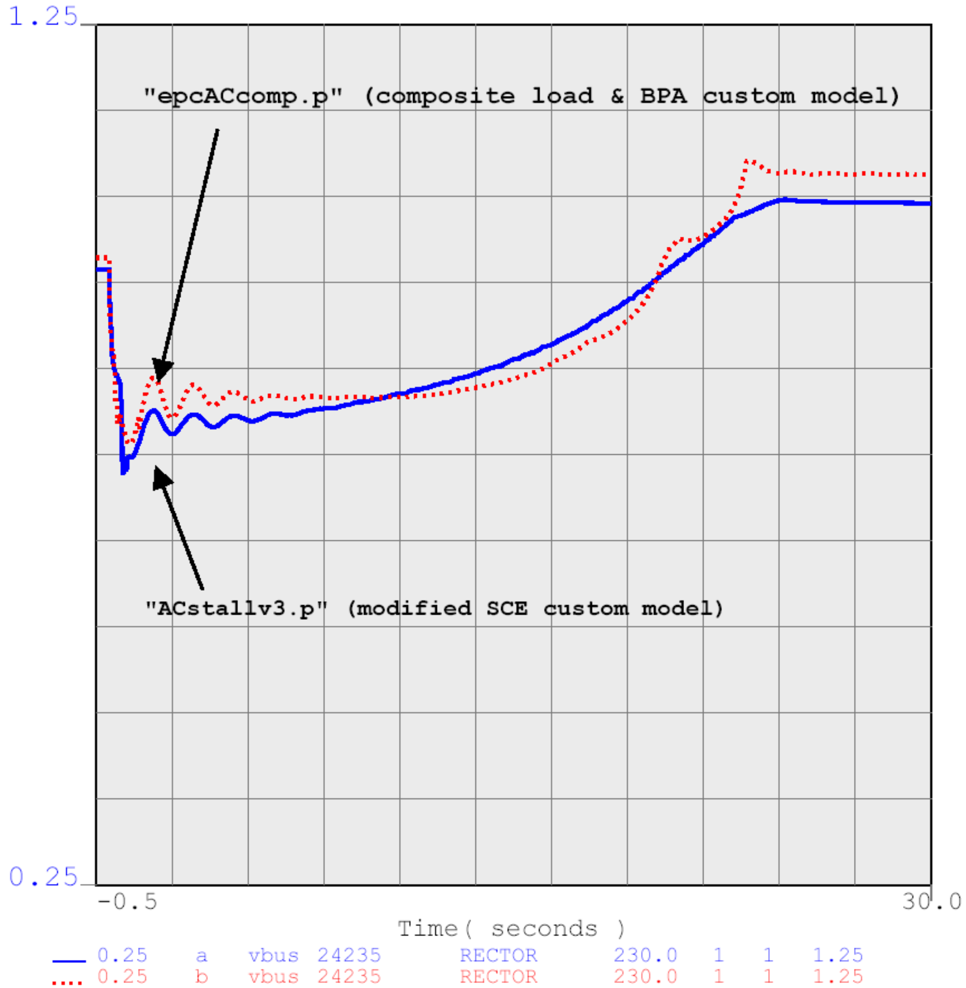


WECC Status

- AC-Motor Model Development:
  - Include "performance" – type AC compressor model in a WECC composite load model
  - Continue development of the "motorc" model as a stand-alone model in power system simulators
  - WECC is preparing a detailed report on 1-ϕ compressor testing and modeling
- Composite load model is expected to be done in Q1 2009:
  - Prototype is currently available in GE PSLF 16.1
  - Outstanding development – 1-phase motors, connect to UVLS and UFLS data records
  - Model acceptance tests and system performance studies
  - Load composition data

Load Model Studies

Load Model Studies

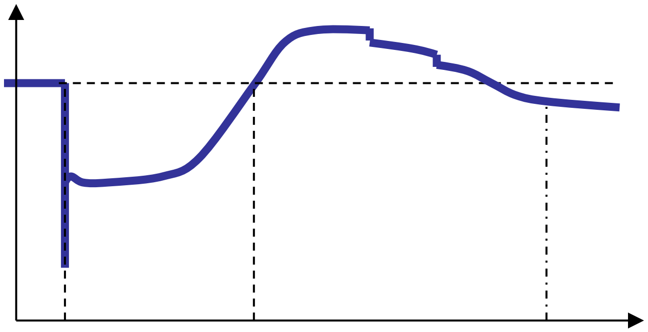


Explicit load representation

“Performance” model for 1phase A/C units

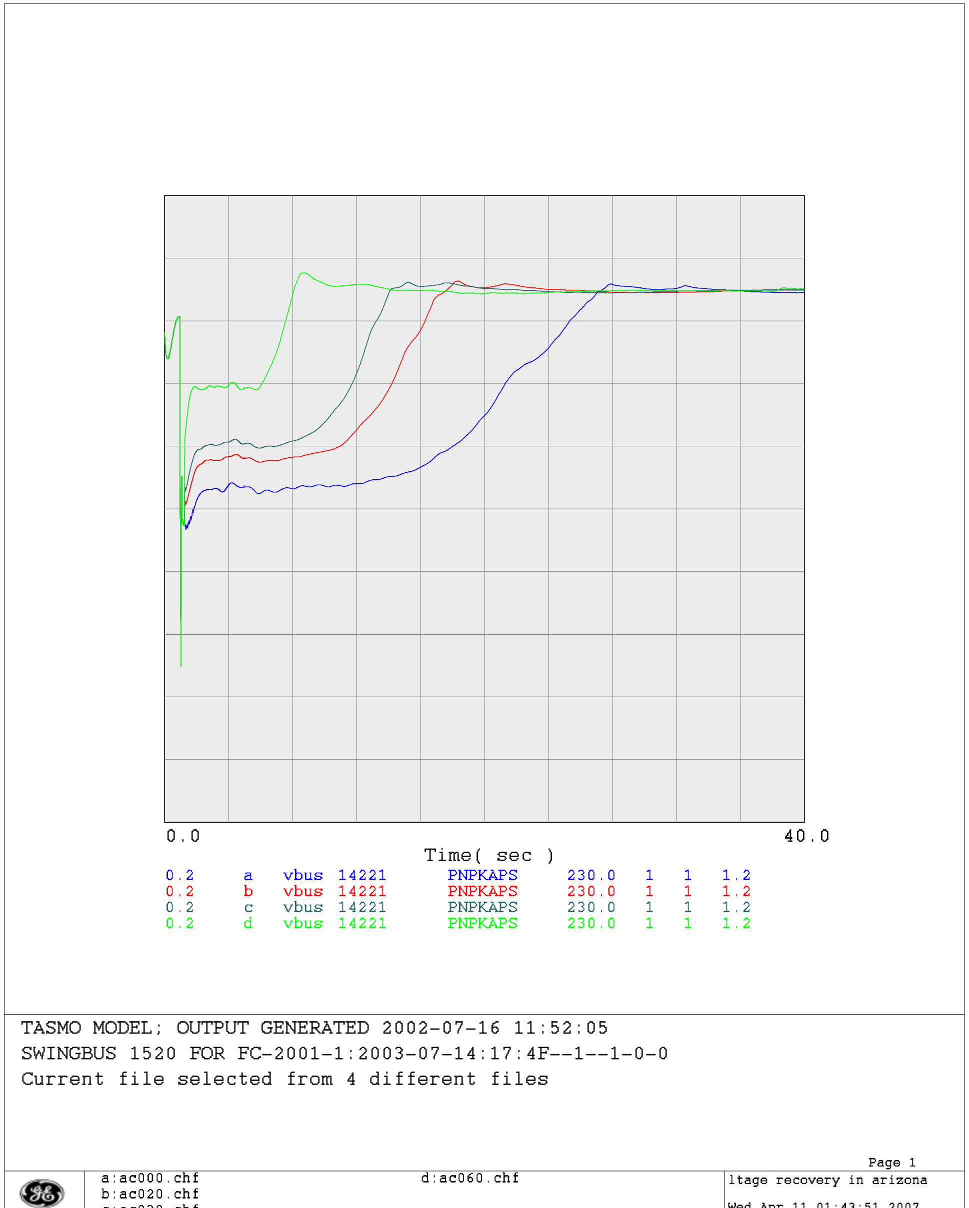
Simulations done by Robert Tucker, SCE

System Studies



- AC Units Stall:
  - A grid fault turns into a "wide-area" fault
  - Represents a risk to voltage stability
    - Risk of generator reducing reactive power by OEL
    - Risk of operation of Zone 3 protection
  - Need to disconnect stalled AC units from the grid
  - Need to contain the affected area
- AC Units are disconnected:
  - "Your risks can change rapidly"
  - Risk of major over-voltages, equipment damage and protective tripping
  - Dynamic reactive resources help

Studies of Solutions



3-hase fault
Hassayampa – Palo Verde
Normal clearing

Explicit load representation

“Performance” A/C model

Residential AC is 30% of load

Baseline simulation
20% of a/c tripped by UV relay
30% of a/c tripped by UV relay
60% of a/c tripped by UV relay

Our Viewpoint

- Large metro areas:
  - Increasing amount of air-conditioning load
  - Limited dynamic voltage support – generators are remote and VARS do not travel well
  - Prone to dynamic voltage stability problems
- BPA view of the risks:
  - Risk of voltage collapse developing in a metro area
  - Risk of voltage collapse cascading outside metro area
  - Risk of extreme over-voltages
- Solutions:
  - Equipment-level solutions
  - System solutions – dynamic VARs are needed
  - Special Protection Schemes to prevent outage spread

Acknowledgement

- WECC composite load model is a collaborative development of many researchers, including
  - Bill Price and John Undrill, retired from General Electric
  - Anatoly Meklin, Pacific Gas and Electric
  - Bernie Lesieutre, LBNL, University of Wisconsin
  - Richard Bravo, Garry Chinn, Robert Tucker – Southern California Edison
  - Steve Yang and Frank Puyleart – Bonneville Power Administration
  - Irina Green – California ISO
  - Donald Davies, WECC Staff
  - Orlando Ciniglio – Idaho Power Company
  - Donald Sutphin, VIASYN
  - Peter Mackin, Navigant Consulting
- AC Modeling Research:
  - California Energy Commission's Public Energy Research Program, WA# MR-049, through the California Institute for Energy and Environment, Award Number MTX-060-1
  - BPA Technology Innovation Office