Load Modeling in WECC

DOE-NERC FIDVR Workshop

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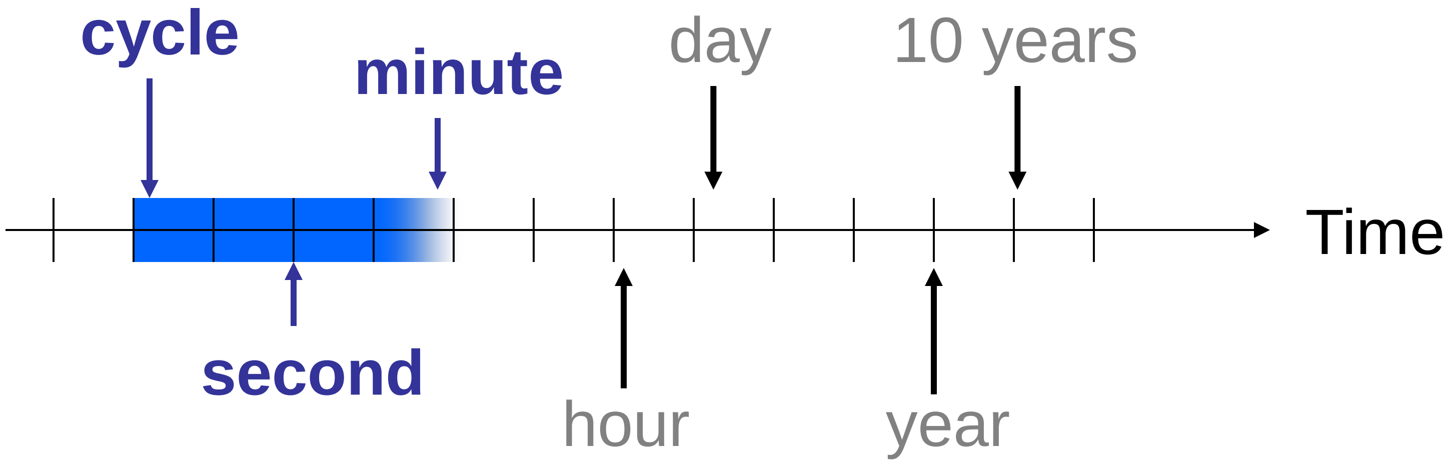
Load Modeling
Timescale of Interest

Our primary interest is the *dynamic behavior* of loads in cycle to minute time frame, not projections of future demand.



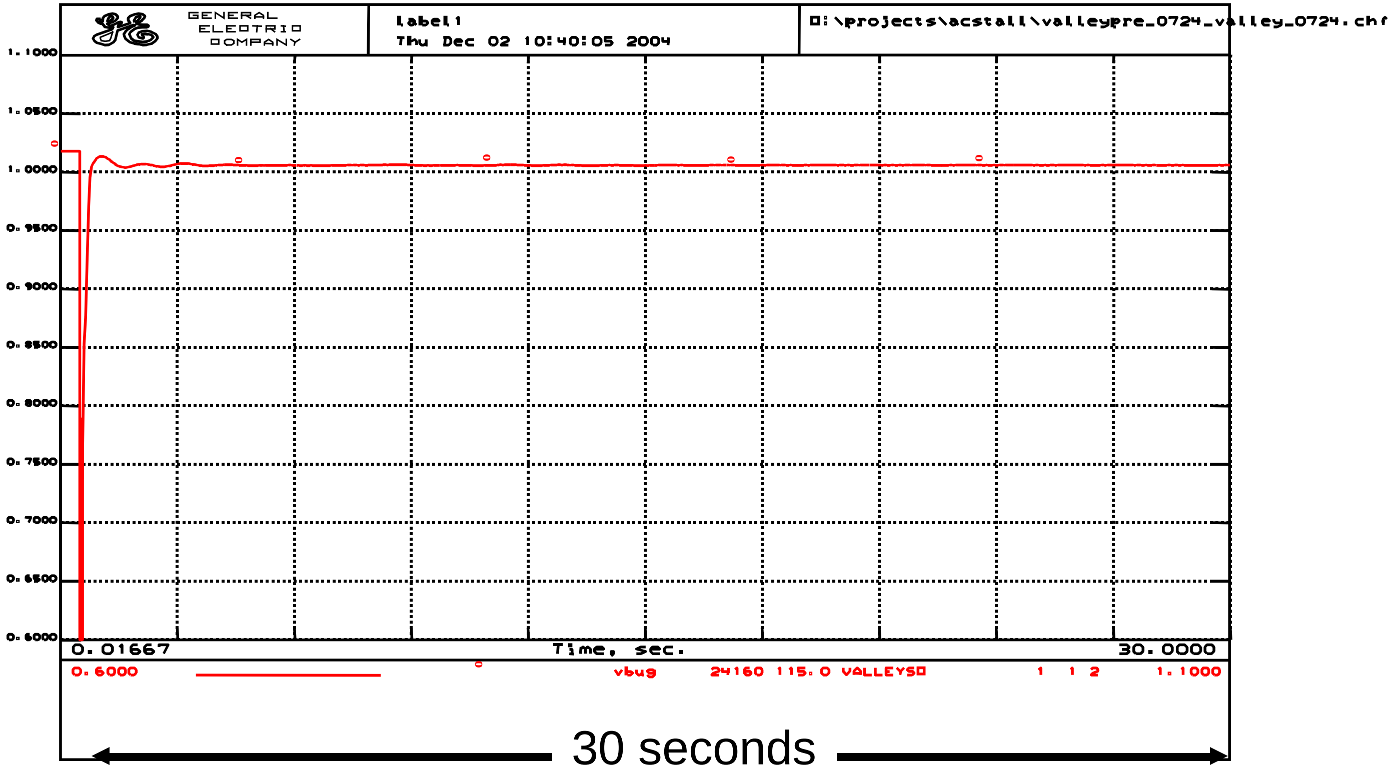
Load Model Development

History Of Load Modeling in WECC

- 1990's – Constant current real, constant impedance reactive models connected to a transmission bus
- 1990's – IEEE Task Force recommends dynamic load modeling, however the recommendation 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 – 2001 – 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
  - Recognized model limitations and the need to continue…

Motivation for Better Load Modeling

This is what we thought would happen using "interim" load model…



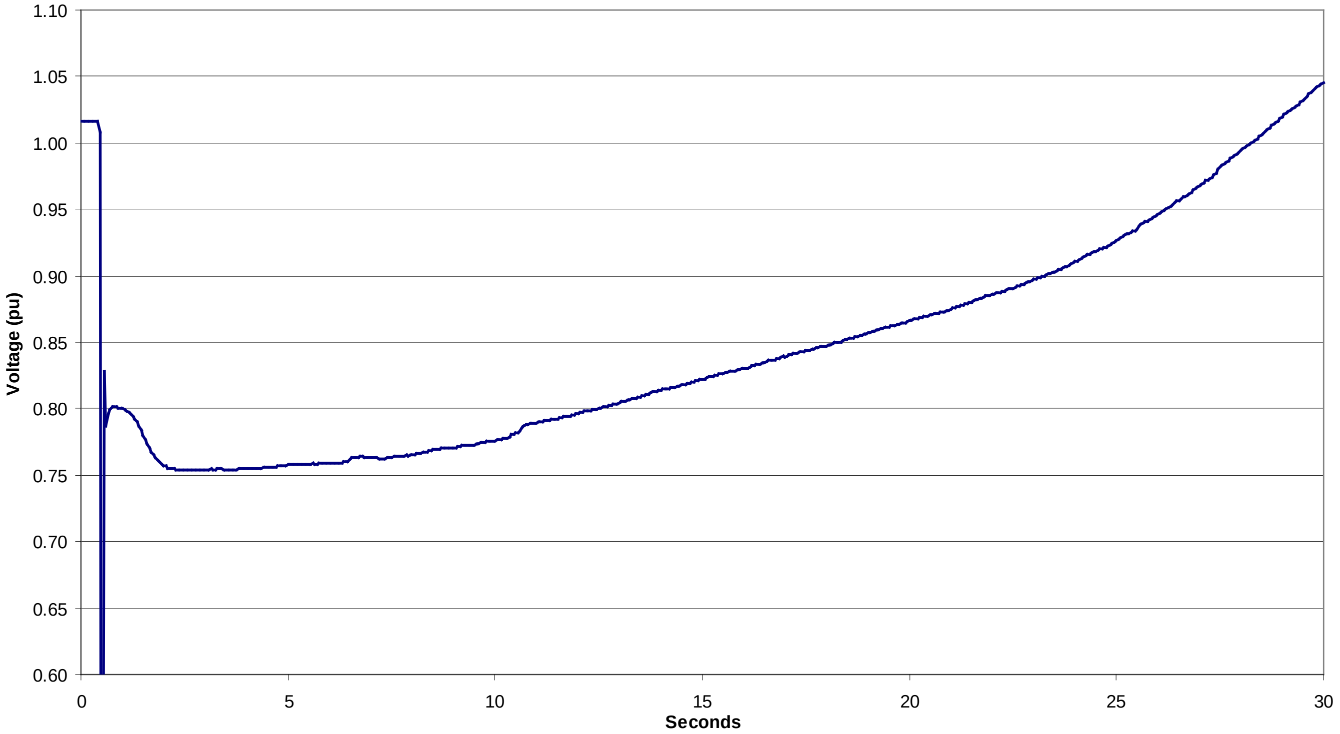
Simulations
– instantaneous voltage recovery

Motivation for Better Load Modeling

… and this is what **actually** happened

100%

75%



30 seconds

Reality

– 30-second voltage recovery, 12 seconds below 80%

History Of FIDVR Load Modeling

- Late 1980's – Southern California Edison observed events of delayed voltage recovery attributed to stalling of residential air-conditioners
- 1994 – Florida Power published an IEEE paper on the similar experiences of delayed voltage recovery following transmission faults
- 1997 – SCE model validation study of Lugo event:
  - Need to represent a distribution equivalent
  - Need to have special models for air-conditioning load
- 2005–2008 – Similar observations are made by Southern Company in their analysis of FIDVR events in Atlanta area

Looking Forward

- Loads will play much more influential role in power system stability
- Resistive-type loads are phasing out (incandescent lights and resistive heating)
  - Energy inefficient but "grid-friendly"
- Electronic loads, VFDs, AC compressors, heat pumps, CFLs are moving in
  - Energy efficient but have undesirable characteristics from standpoint of grid dynamic stability
  - Increasing penetration of residential air-conditioners

WECC Load Modeling Task Force

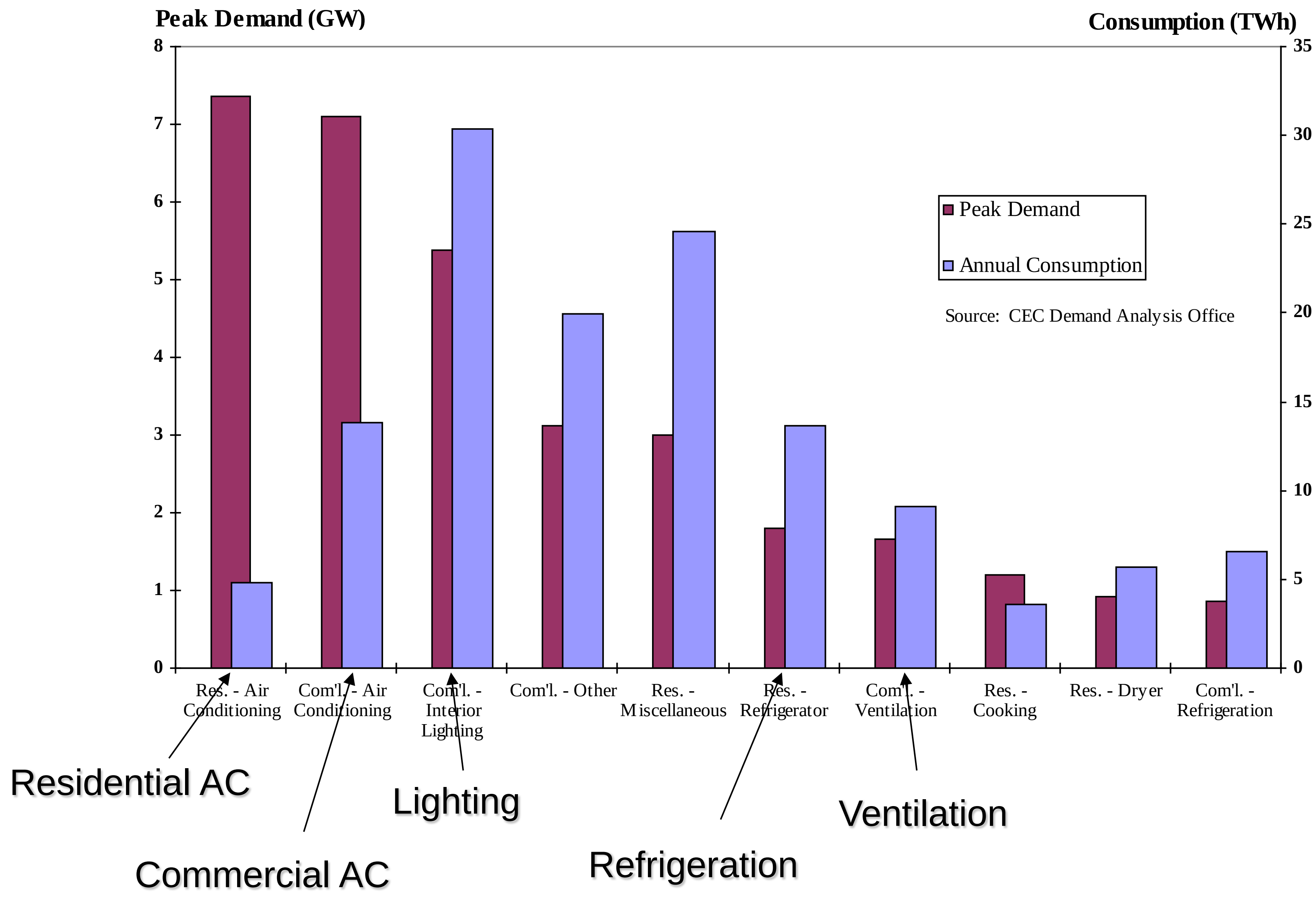
- WECC LMTF was formed in 2002
- Component-based approach
  - Understand load behavior over the wide range of disturbances
- Bottom-up model *development*
- Top-down model *validation*

Questions

- How to capture the variety of electrical end-uses in the model ?
- How to represent electrical distance between the transmission bus and a end-user buses with a distribution equivalent ?
- How to represent seasonal / daily / geographical variations in load composition ?
- How to validate load model performance ?

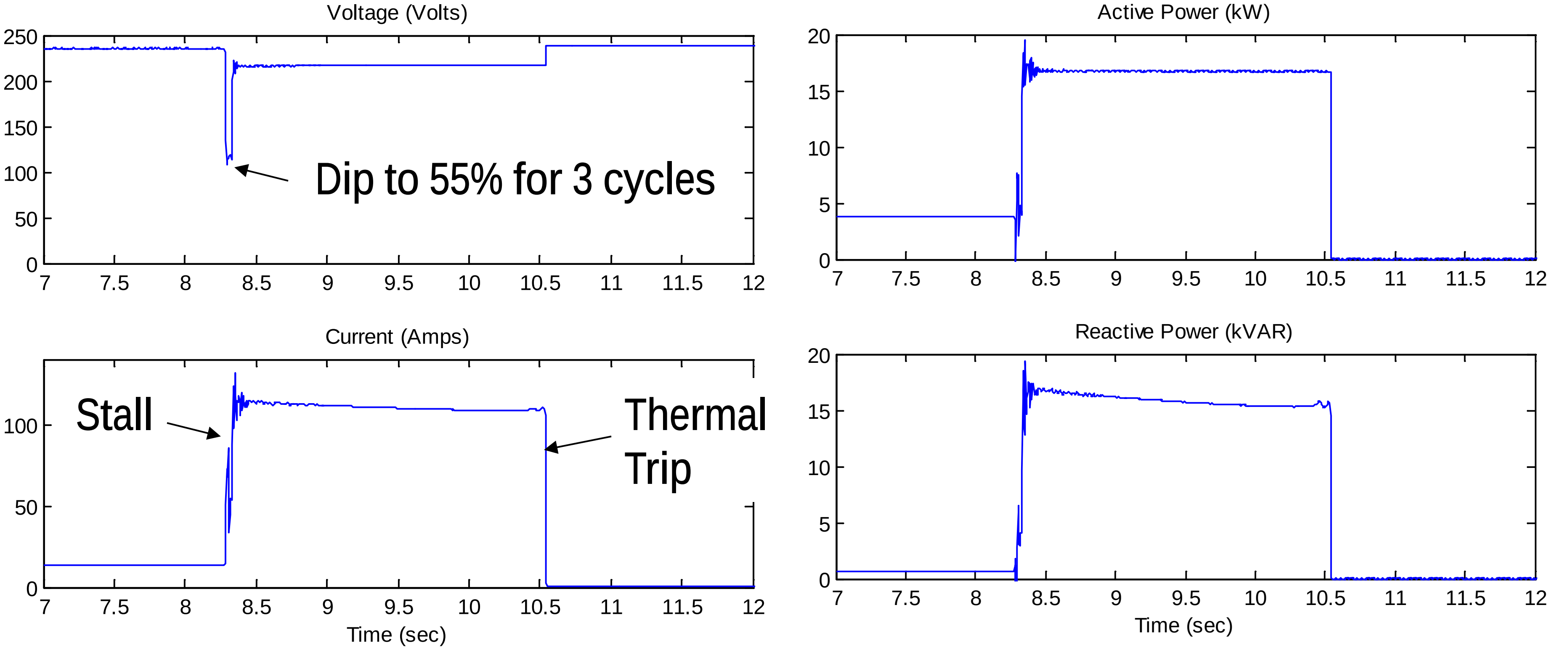
Modeling Electrical End-Use

LBNL Electricity Use In California Study



Residential Single-Phase Air-Conditioners

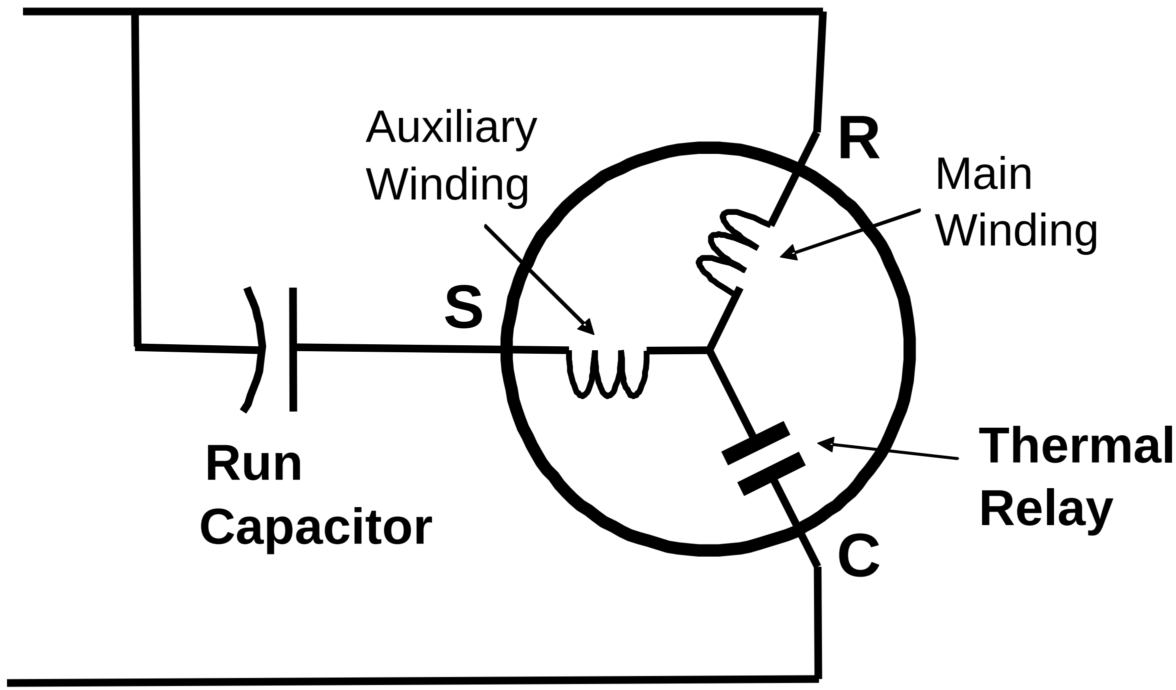
A/C Compressor Motors are Prone to Stall



To find out WHY,

SCE, BPA and EPRI tested more than 30 AC units

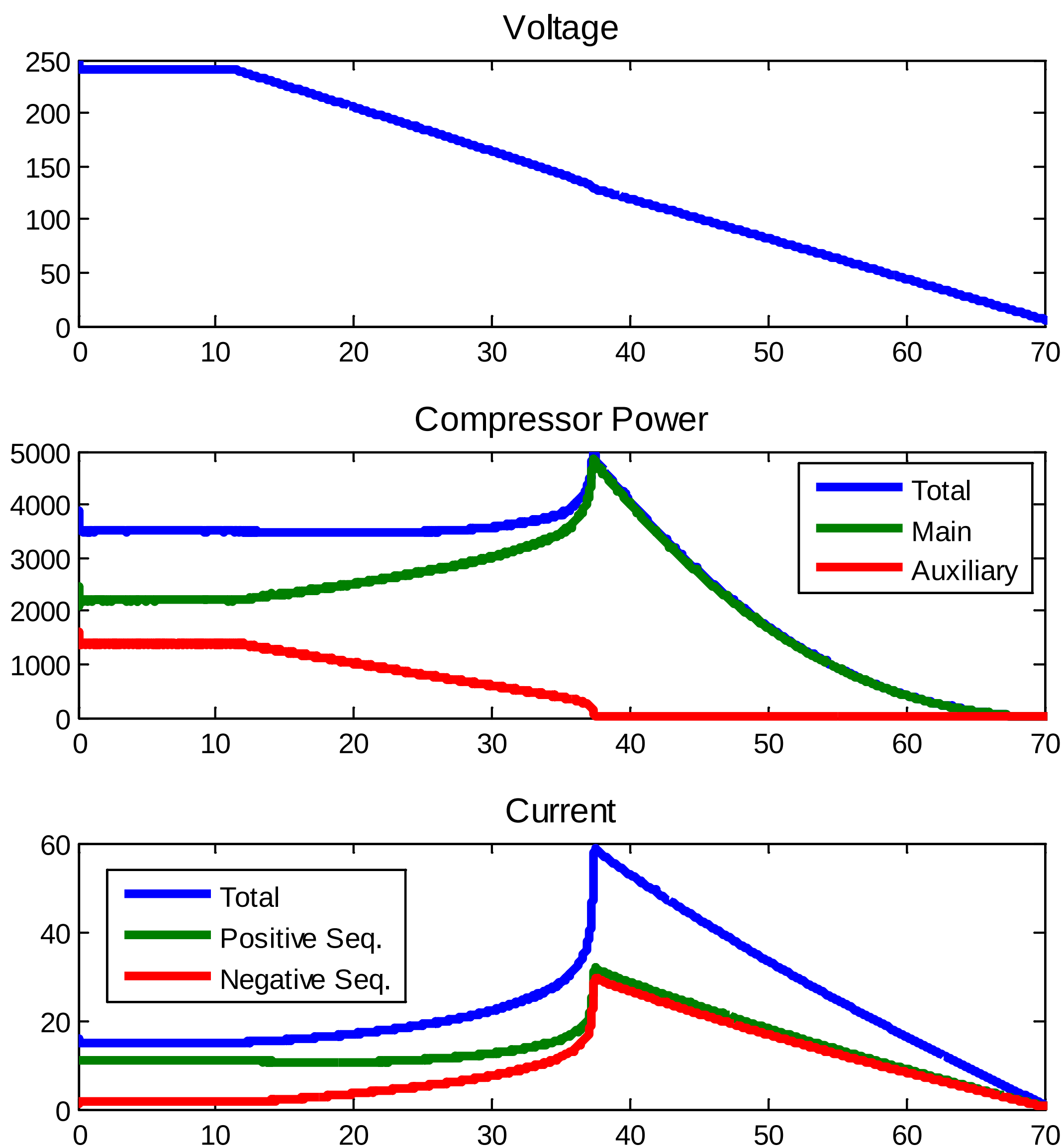
(a) A/C Compressor Motors are non-symmetric



1 phase supply, 2 windings

capacitor-run motor

(a) A/C Compressor Motors are non-symmetric

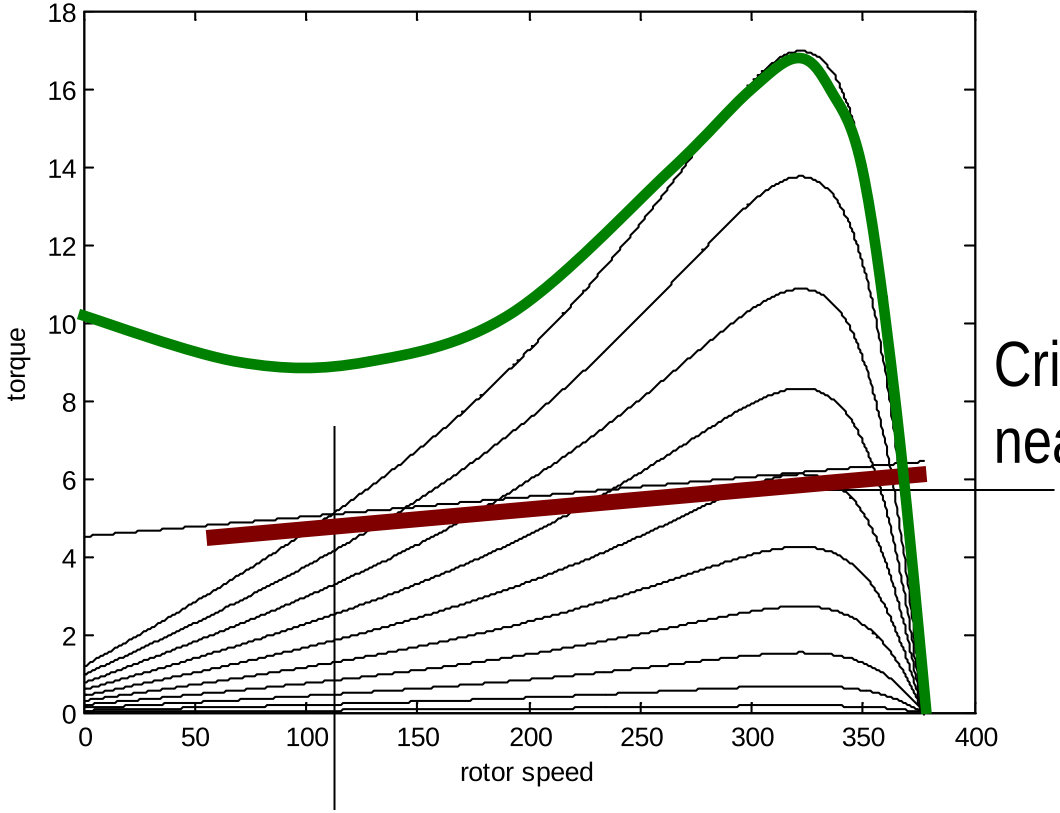


Non-symmetry becomes more pronounced as the supply voltage is declining

The forward-rotating torque component is counter-acted by backward-rotating component at lower voltages

(a) Single-phase motors produce much less electrical torque than a comparable 3-phase motor at lower voltages and slower speeds

Torque/speed and load torque curves



Critical speed = 30% of rated

Critical voltage near 60%

Plot prepared by Dr. Bernard Lesieutre, LBNL (now with University of Wisconsin)

Electrical torque for 1-phase motor at various voltages

Electrical torque for 3-phase motor at nominal voltage

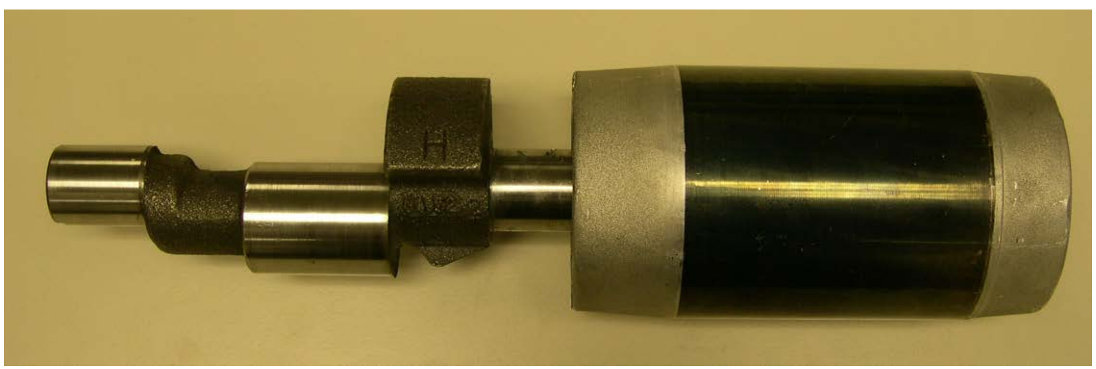
Mechanical load torque

(b) Compressor Motors Inertia is Very Low

H = 0.03 – 0.05 seconds

E.g. 3.5-ton compressor motor:

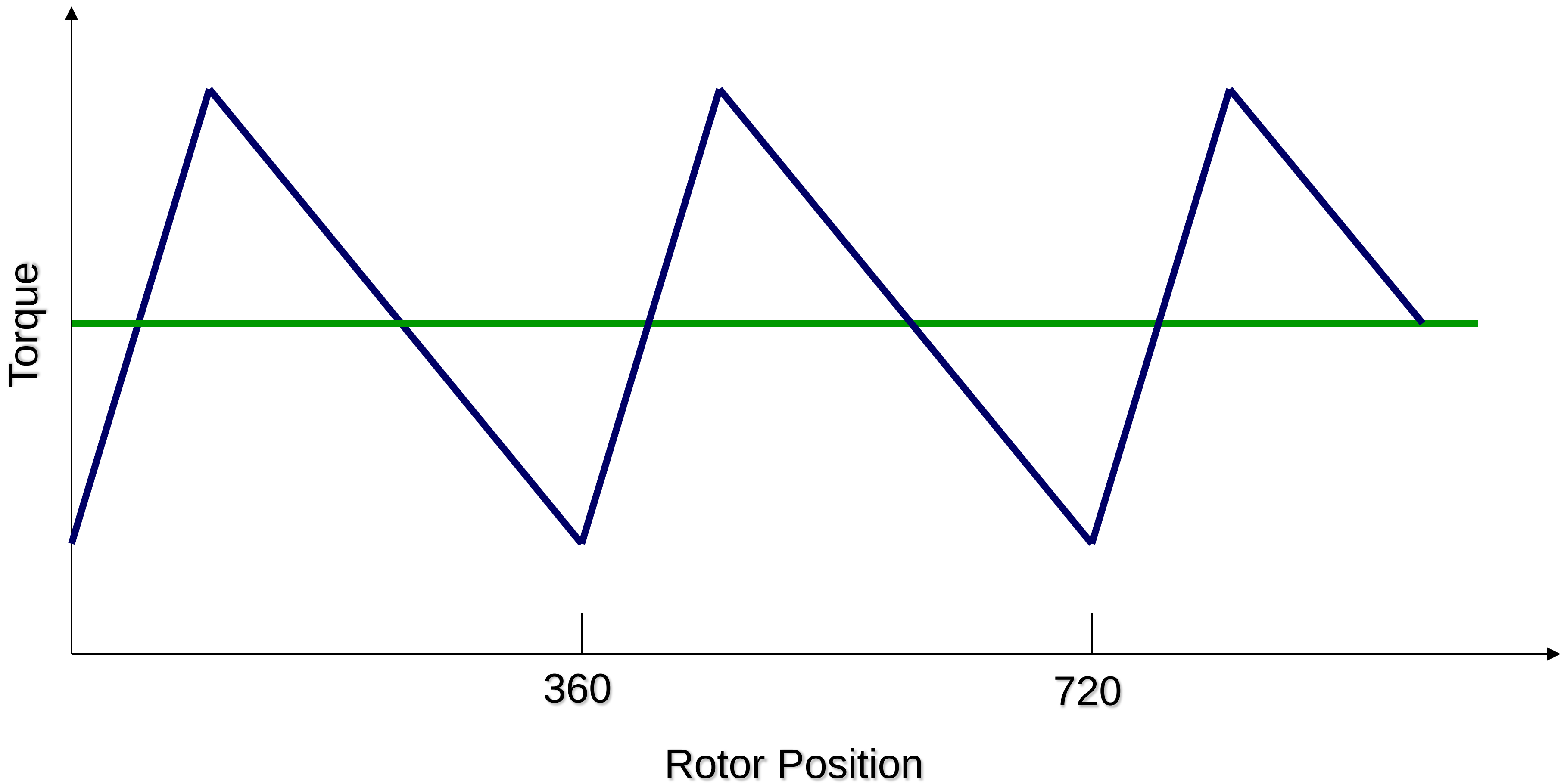
Weight: 4.6 kg



75 mm

310 mm

(c) Compressor Load Torque

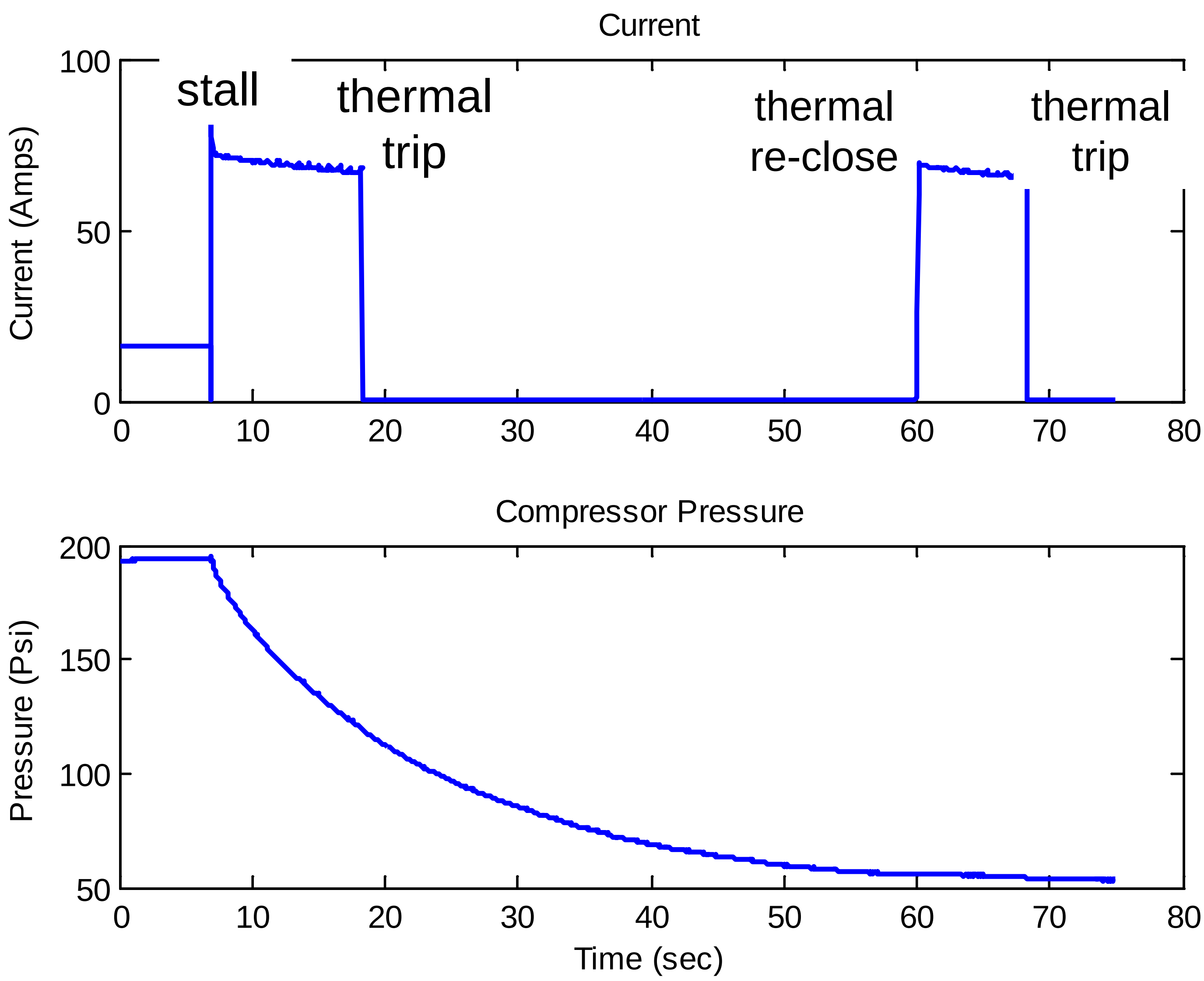


It is very possible that the motor stalls at the next compression cycle

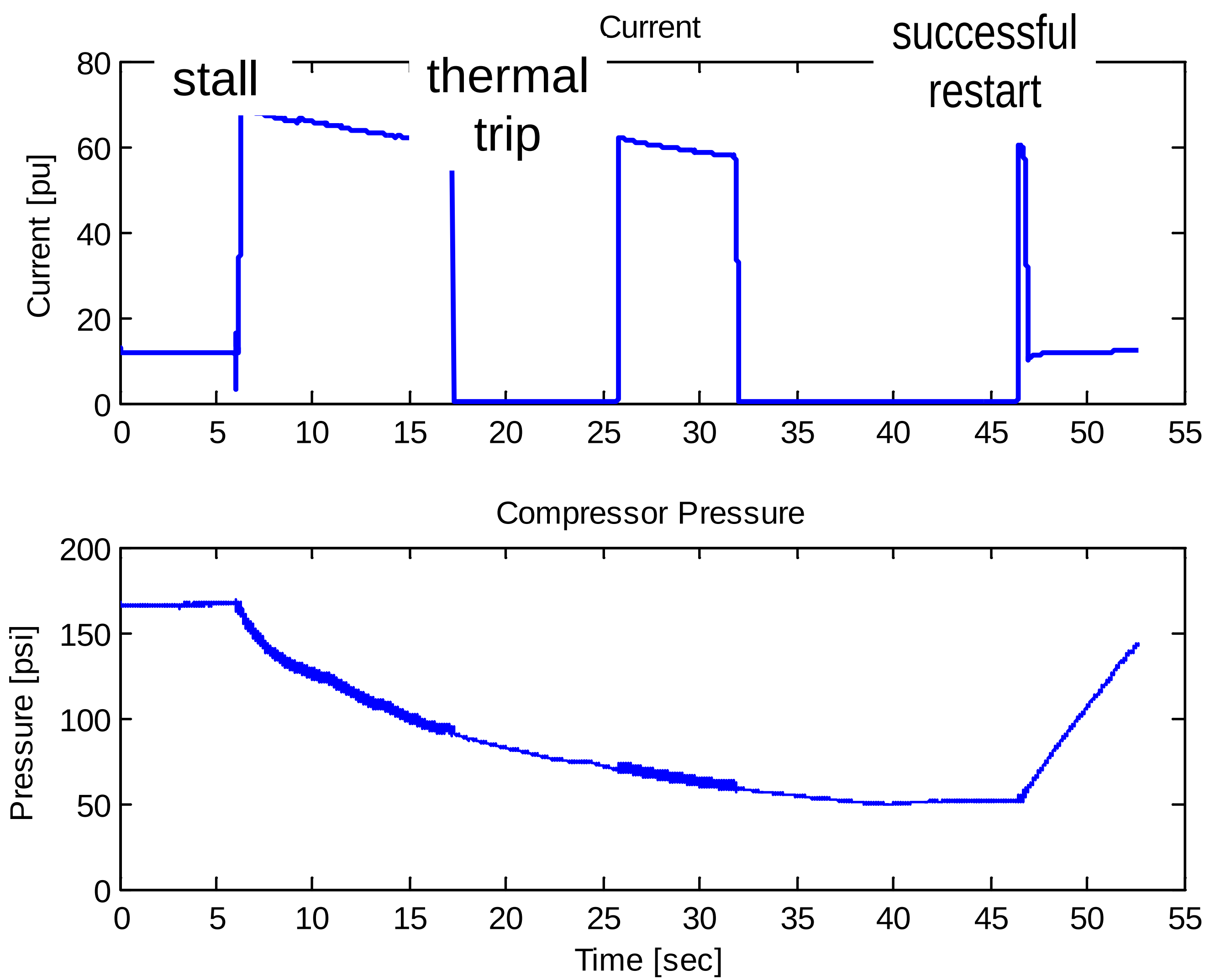
Types of Compressors

- There are two types of compressors – reciprocating and scroll
  - Reciprocating compressors represent majority of the installed capacity
  - Scroll units will be majority of new units moving forward
- Scroll compressors have more favorable characteristics:
  - Less prone to stall (lower voltage, longer sag)
  - Can re-accelerate when the voltage recovers above 90%
  - Pressure seems to equalize faster
  - However, can restart and run backwards for hours

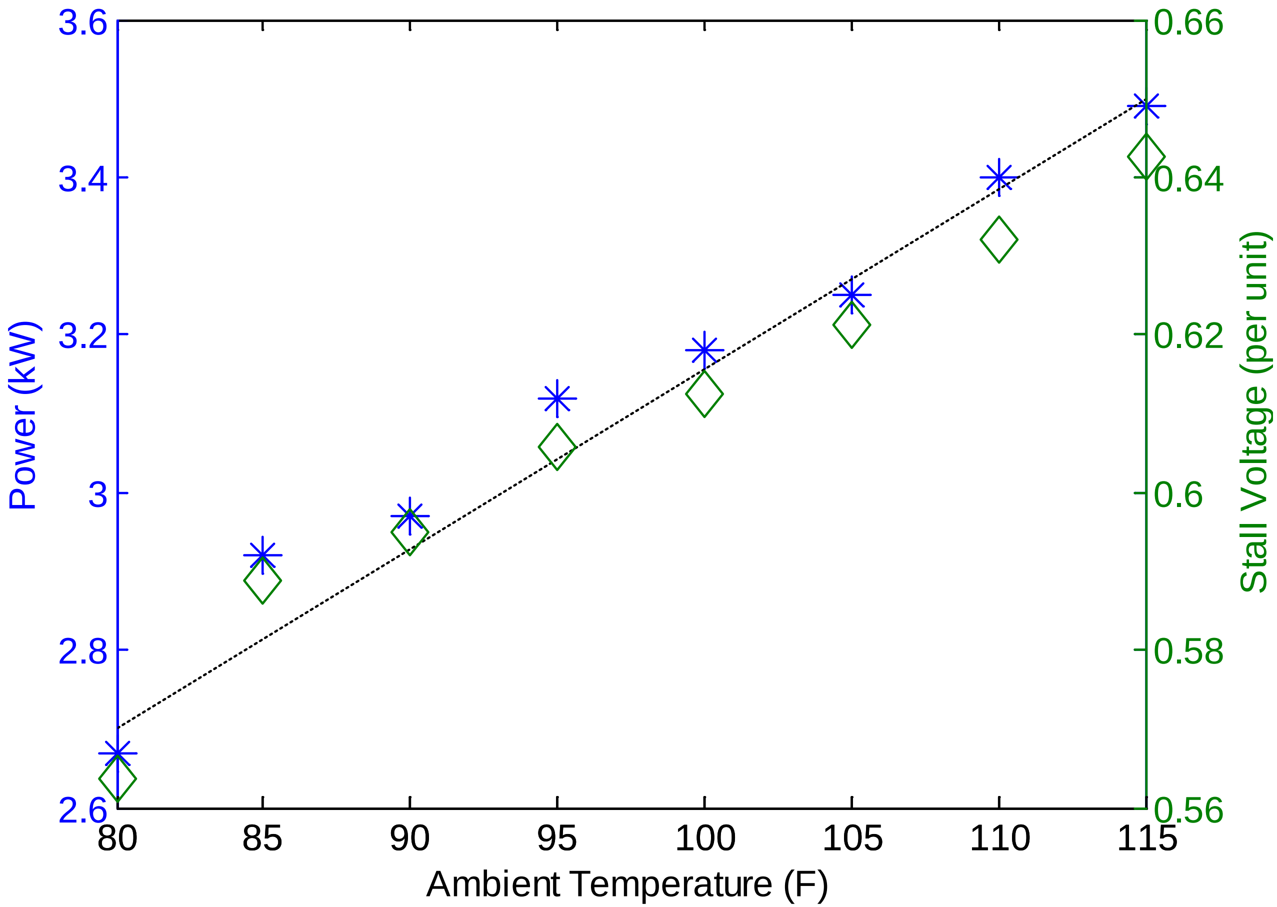
What do the motors do after they stall ?



What do the motors do after they stall ?



Compressor Motor Steady-State Loading

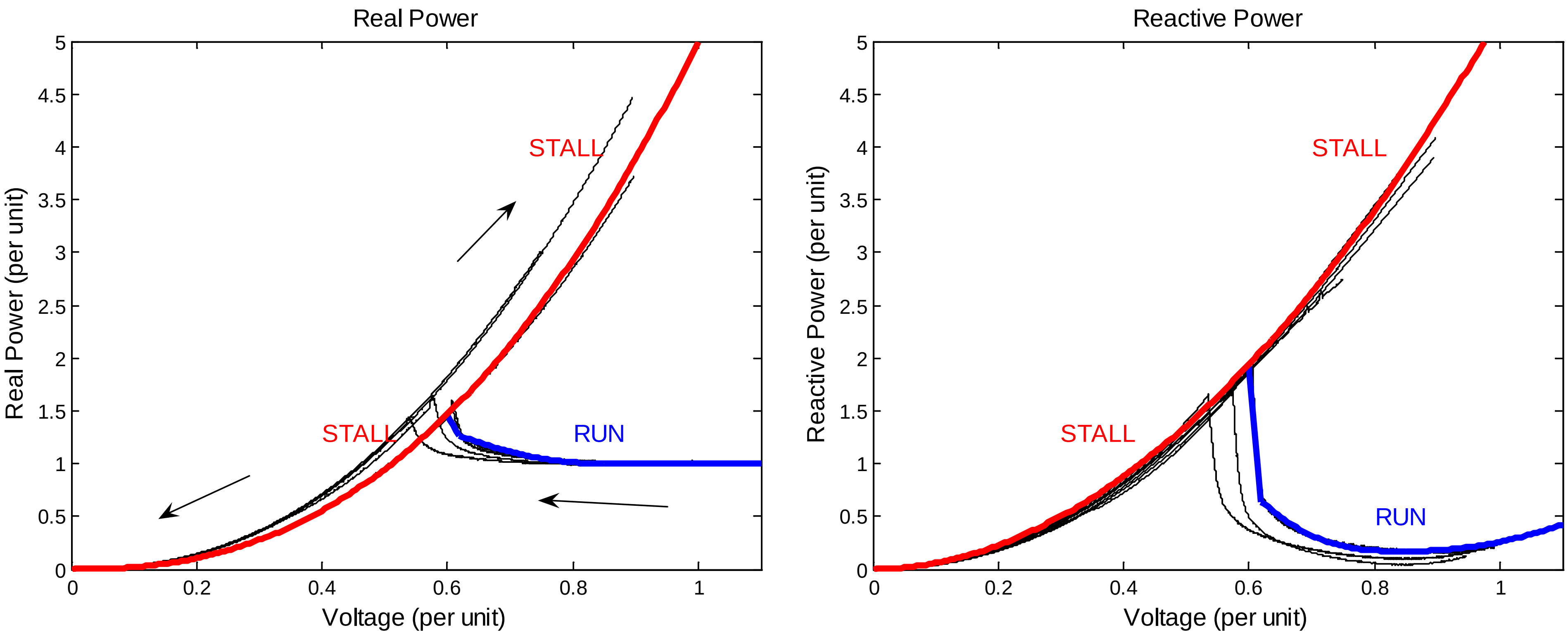


* Compressor motors have high power factor ~0.97

How to Model Single-Phase AC Motors ?

- We were unable to fit the observed behavior into a three-phase motor model structure
- Several Modeling Approaches are considered, prototyped and tested:
  - Phasor Model (MOTORC) – Differential equations, used as a benchmark
  - Performance Model – empiric model based on the test results
  - Hybrid model – three-phase model for running motor, short-circuit impedance when stalled (original SCE approach)

Performance Model
Static Empirical Model



RUN STATE - Polynomial

STALL STATE - Impedance

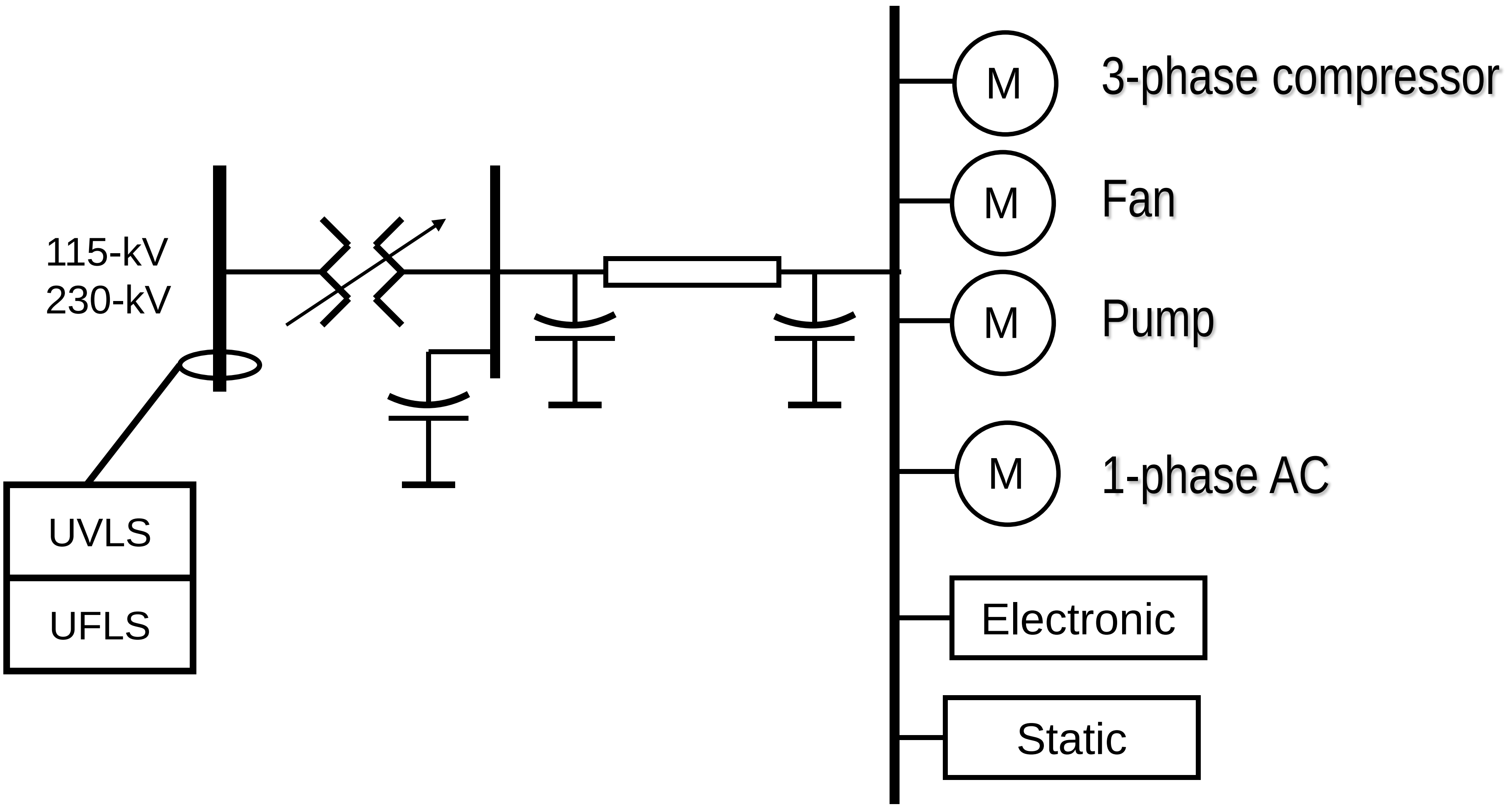
Switch from RUN to STALL when voltage drops below Stall Voltage

Single-Phase Motor Model

- 1-phase model includes:
  - Performance model to represent a single-phase motor model
  - Thermal relay model
  - Under-voltage relay model
  - Contractor model
- Model is validated against actual tests
- Model is tested for numeric stability
- Implemented in PSS®E (ACMTBL) and PSLF (LD1PAC)

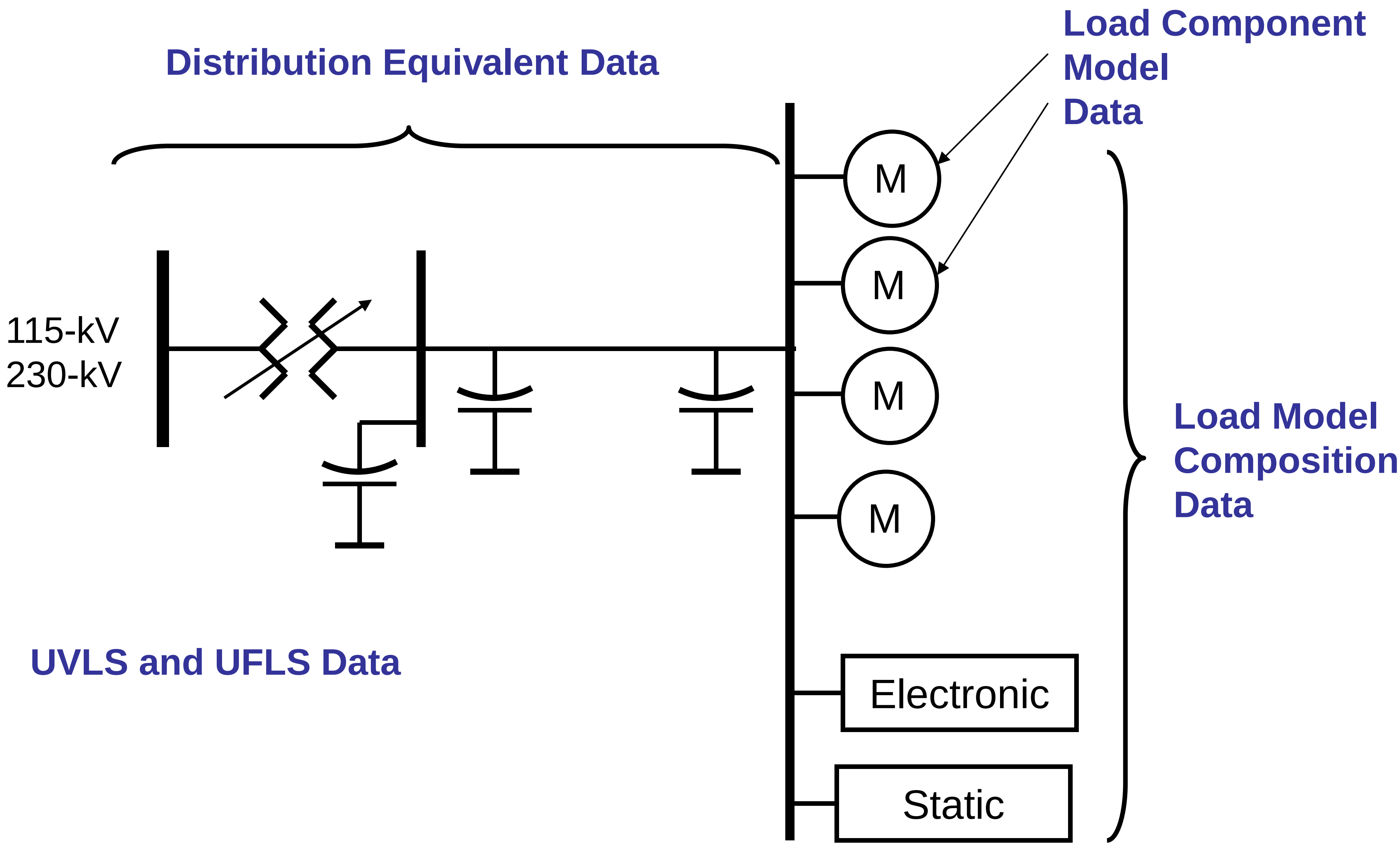
Composite Load Model Structure

Composite Load Model Structure



Load Model Data

WECC Composite Load Model



Load Model Data

- Load model data records include:
  - Distribution equivalent model data
    - PG&E developed methodology, proven to work, feel very confident
  - Model data for load model components (e.g. motor inertia, driven load, electrical data, etc)
    - Getting test data, develop better understanding of end-use characteristics
    - Motor protection and control remains least known
  - Fractions of total load assigned to each load model component
  - UFLS and UVLS data

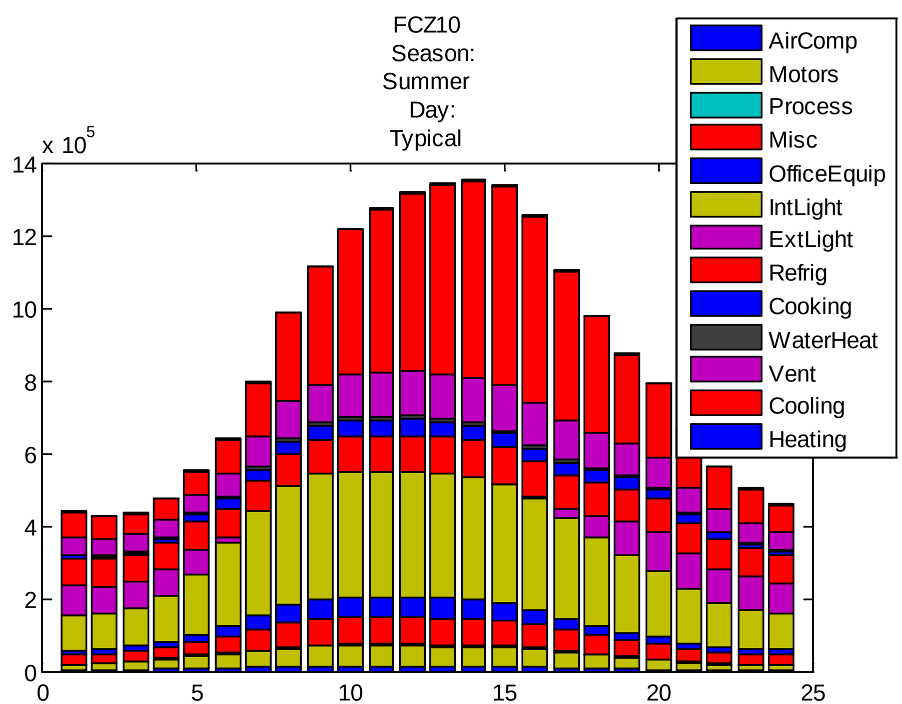
Load Composition

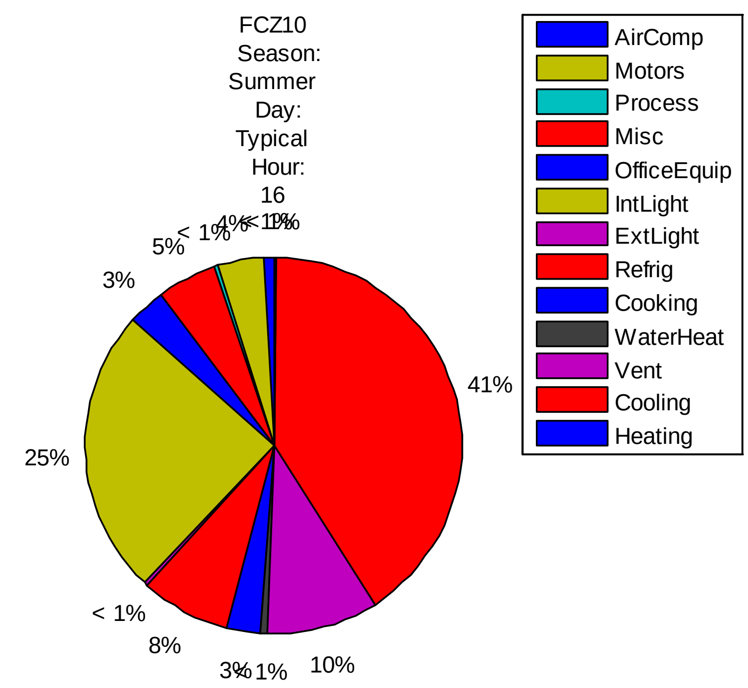
- The most challenging part of model data
- Sources of data:
  - LBNL Reports on Electricity Use in California
  - California Energy Commission: 2006 Commercial End-Use Survey
  - SCADA load profiles
  - BPA end-use monitoring data
- PNNL-BPA Load Composition Model

California Commercial End-Use Survey

- 15 climate zones in California
- Four seasons
- Typical, Hot, Cold, Weekend
- 24-hour data

Data is available on CEC web-site





Load Composition Data

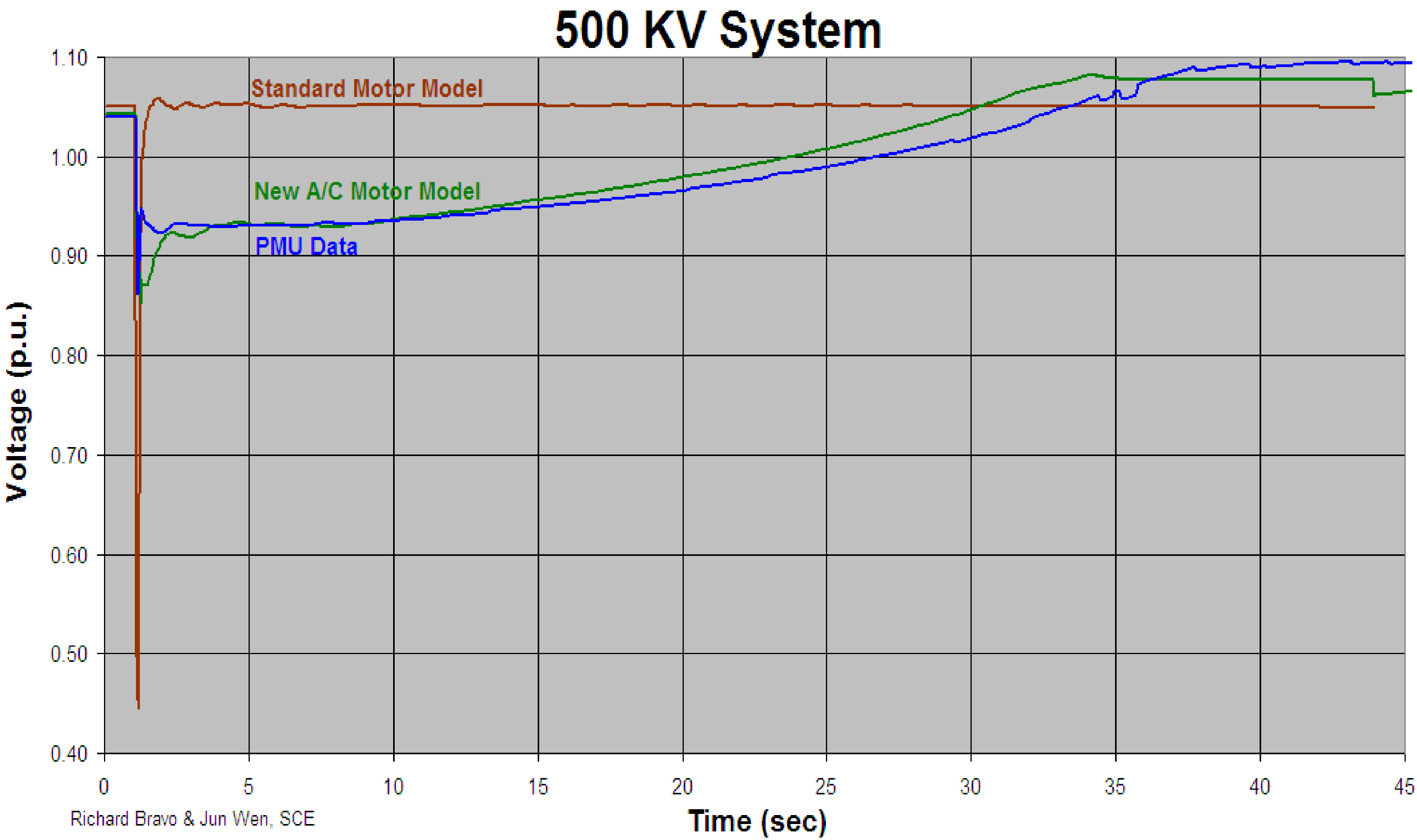
- PNNL-BPA Load Composition Model
- WECC LMTF provided regional defaults
  - winter, summer, and shoulder seasons
  - 6:00, 9:00, 15:00, 18:00 hours
  - Multiple climate zones in WECC
  - Composition for residential, commercial and mixed load types
- Utilities are encouraged to provide bus-specific load composition information

Load Model Studies

Load Model Studies

- Event validation studies, initial focus is on on-peak summer conditions:
  - Local FIDVR events in Southern California
  - Interconnection-wide disturbances
- System impact studies (in progress)
  - Large generation outages in WECC
  - 3-phase faults on major inter-tie
  - 3-phase faults in large load centers

Event Validation Studies

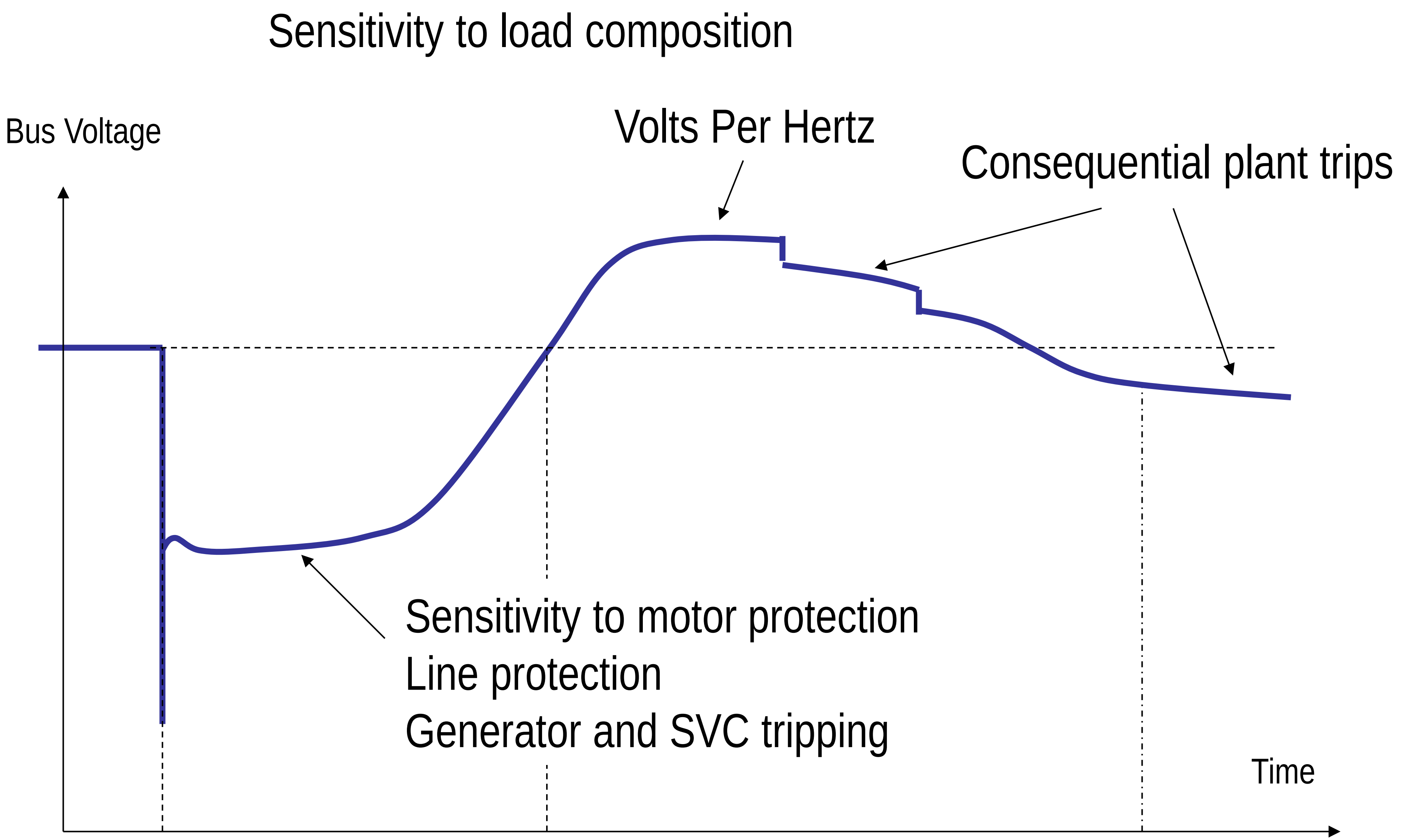


Richard Bravo & Jun Wen, SCE

Load Model Studies – Initial Observations

- What is important for FIDVR studies:
  - Load Composition Data
    - Bus-specific information is recommended
  - Motor control and protection
- Sensitivity studies are required
  - With respect to “reasonable” variations of “key parameters”
  - Scenario planning
    - Generators and SVC may trip because of depressed voltages
    - Plants due to internal protection and control issues
    - Generator protection operation (OEP during low voltages, Volts/Hertz during high voltages)
    - Line protection operation

FIDVR Scenario Planning



Load Model Implementation in WECC

- Load Model Approval:
  - Composite Load Model structure (WE ARE HERE)
  - Load model data
  - Validation and system impact studies

- Process for Load Model Building
  - Tools for managing load model data

- WECC Voltage Dip Criteria

Closing Remarks

- Composite load model is capable of reproducing in principle the phenomenon of delayed voltage recovery that is known to occur
- Composite load model is adequate to evaluate FIDVR exposure risks when used appropriately
- Composite load model is not intended to provide “accurate” representation of details of a particular feeder response
- Composite load model is a tool to help make an engineering judgment when appropriate scenario planning is used

Thank You