Load Modeling and Control

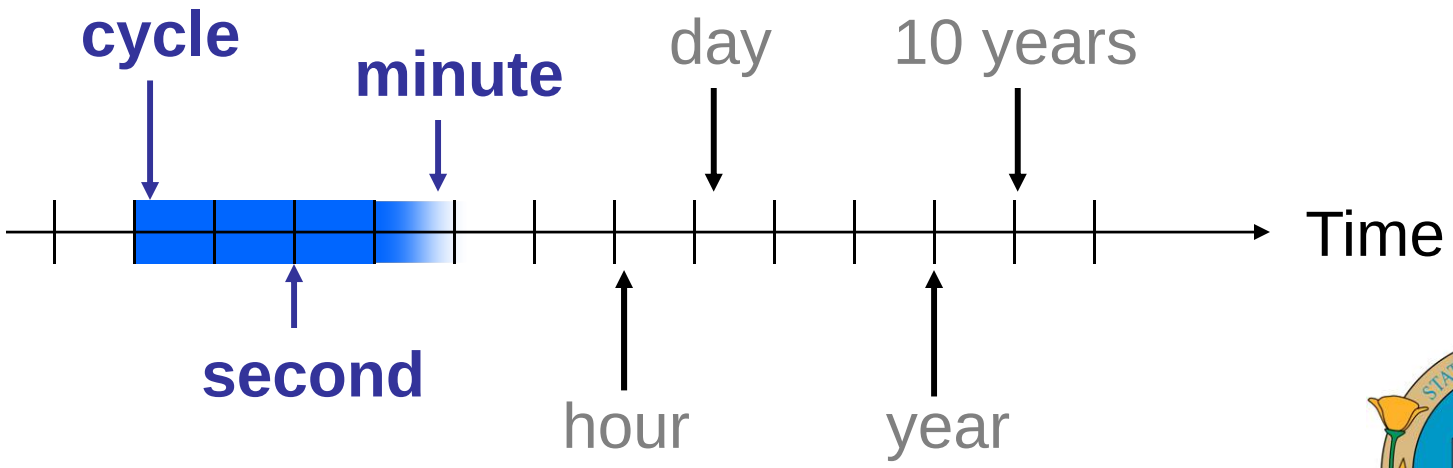
Transmission Research Colloquium
Sacramento, CA

September 11, 2008

Bob Yinger, Southern California Edison
Bernard Lesieutre, LBNL
Dmitry Kosterev, Bonneville Power Administration

Load Modeling and Control
Timescale of Interest

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



Fundamental Changes in Load Characteristics

Electronic Ballast Discharge Lighting

Air-Conditioning and Heat Pumps

Power Electronics (Computers, Data Centers, VFDs)

Plug-in Hybrid Electric Vehicles
Photo-Voltaic Panels

Incandescent Lighting

Resistive Space and Water Heating

Aluminum smelters

Fundamental Changes in Load Characteristics

- Resistive loads are energy inefficient but "grid-friendly"
- New loads are more energy efficient (VFDs, heat pumps, CFLs), but create greater challenge for grid dynamic stability
- Grid impacts of distributed generation (PV) need to be assessed, appropriate standards developed

Fundamental Changes in Load Characteristics

- Loads play much more influential role in power system stability
  - Load-Induced voltage stability
    - Multiple events of delayed voltage recovery in Southern California, Texas and the Southeast
  - Damping of inter-area power oscillations

- Need for models to understand load behavior and to develop a portfolio of solutions

Load Models

System Studies

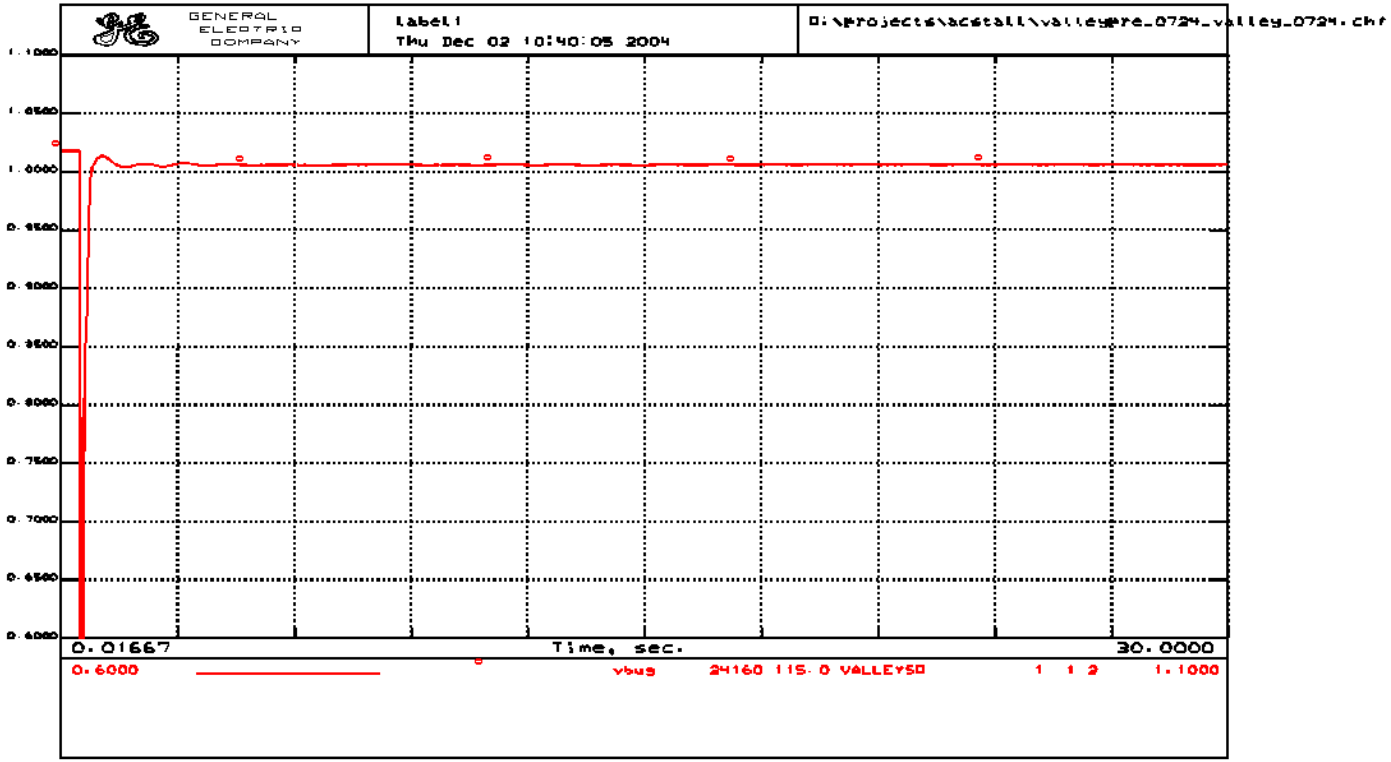
Portfolio of Solutions
(System & End-Use)

System Performance Monitoring

Load Modeling

Motivation for Better Load Modeling

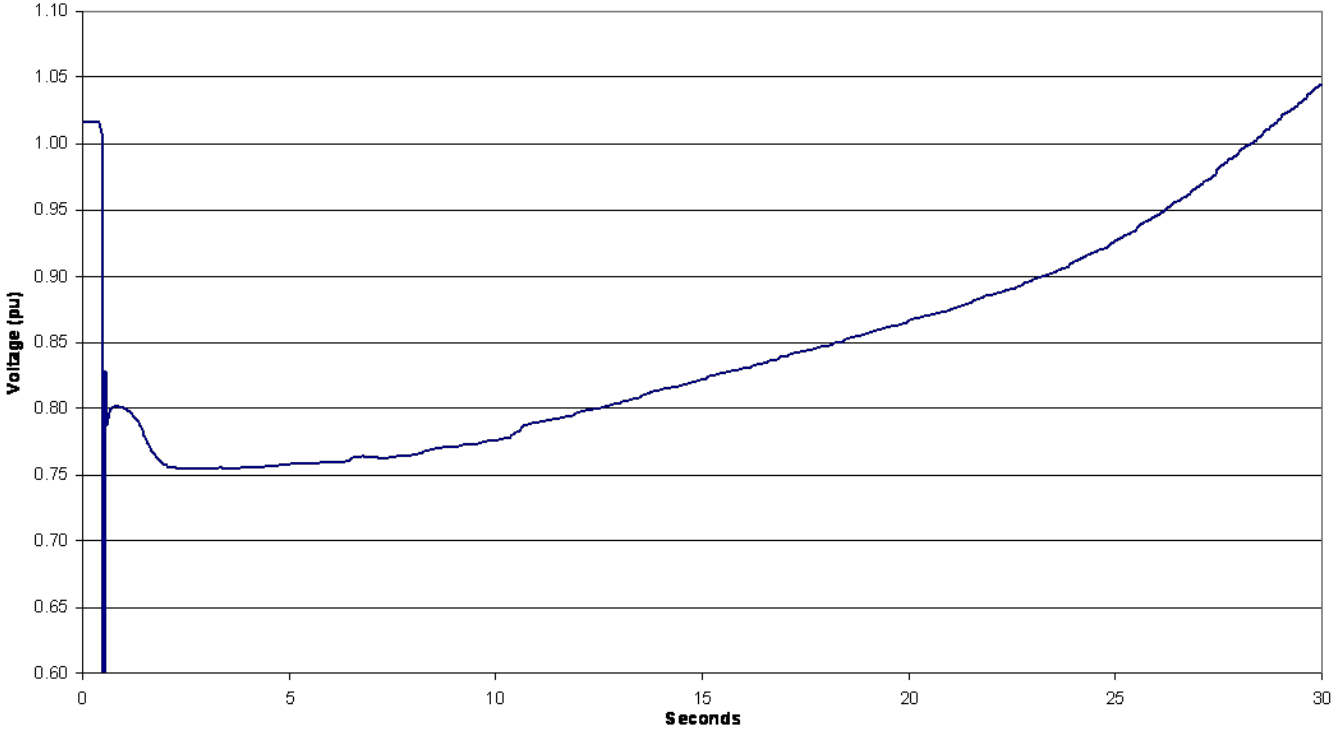
This is what we thought would happen (in 2004) …



Simulations
– instantaneous voltage recovery

Motivation for Better Load Modeling

… and this is what **actually** happened



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

WECC Load Modeling

- WECC is in final stages of development and implementation of a composite load model

- CEC made important contributions to the project:
  - Development of models of single-phase air-conditioning units
  - Load composition analysis
  - Benefit from other CEC-funded projects:
    - 2006 Commercial End-Use Survey
    - LBNL load composition studies

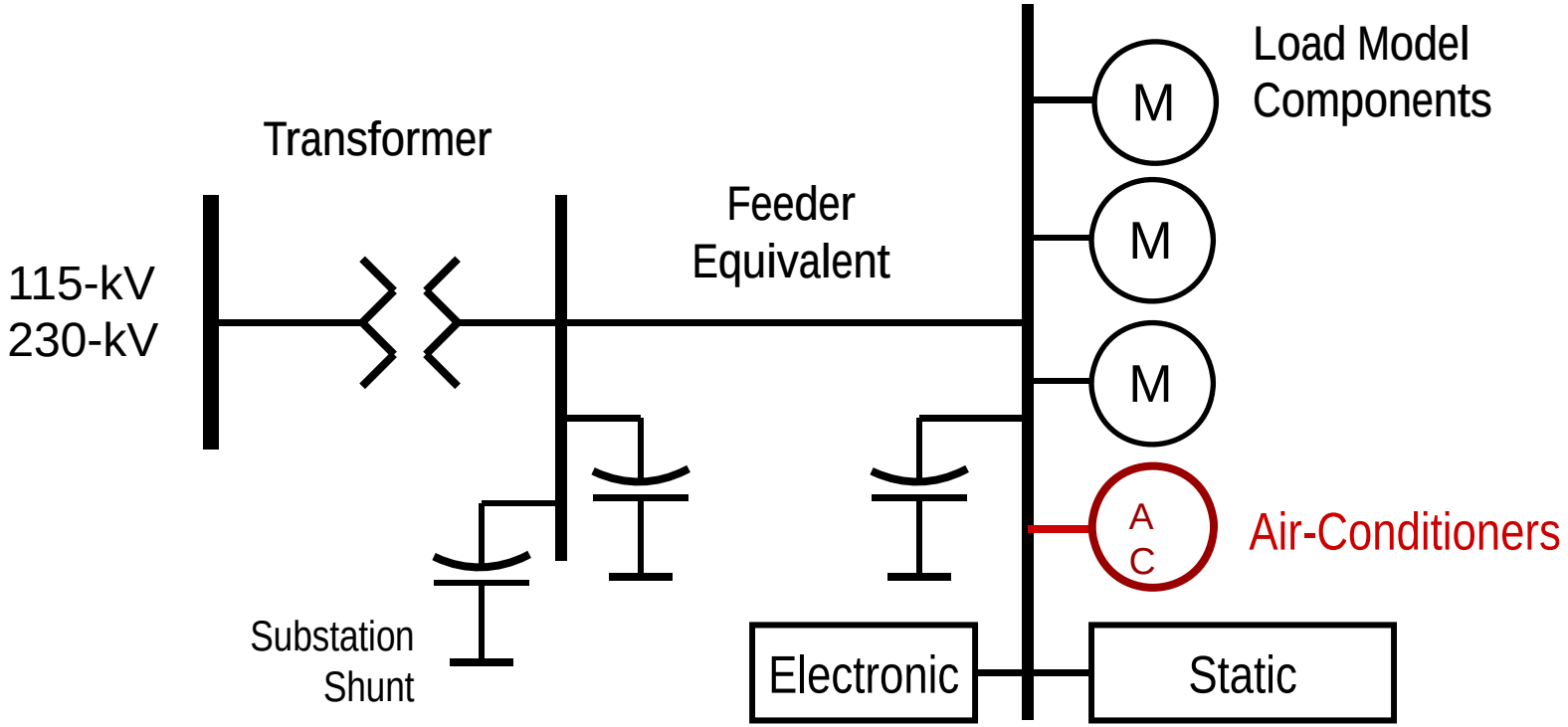
Single-Phase AC Motors

- Residential AC compressor motors are single-phase capacitor-run
- Compressors have high nominal power factor 0.95 to 0.98
- Compressor power increases with temperature
- Compressors stall at high voltages (if voltage dips to 55-60% for 3 cycles or longer at 100F ambient). Stall voltage increases with temperature
- Once compressor motor stalls, it is likely to remain stalled even if the voltage is recovered (Newer scroll units have shown ability to re-start)
- Stalled motor consumes 5 to 7 times of its nominal current
- Thermal relay trips motor in 3 to 20 seconds, has an inverse time over-current characteristic

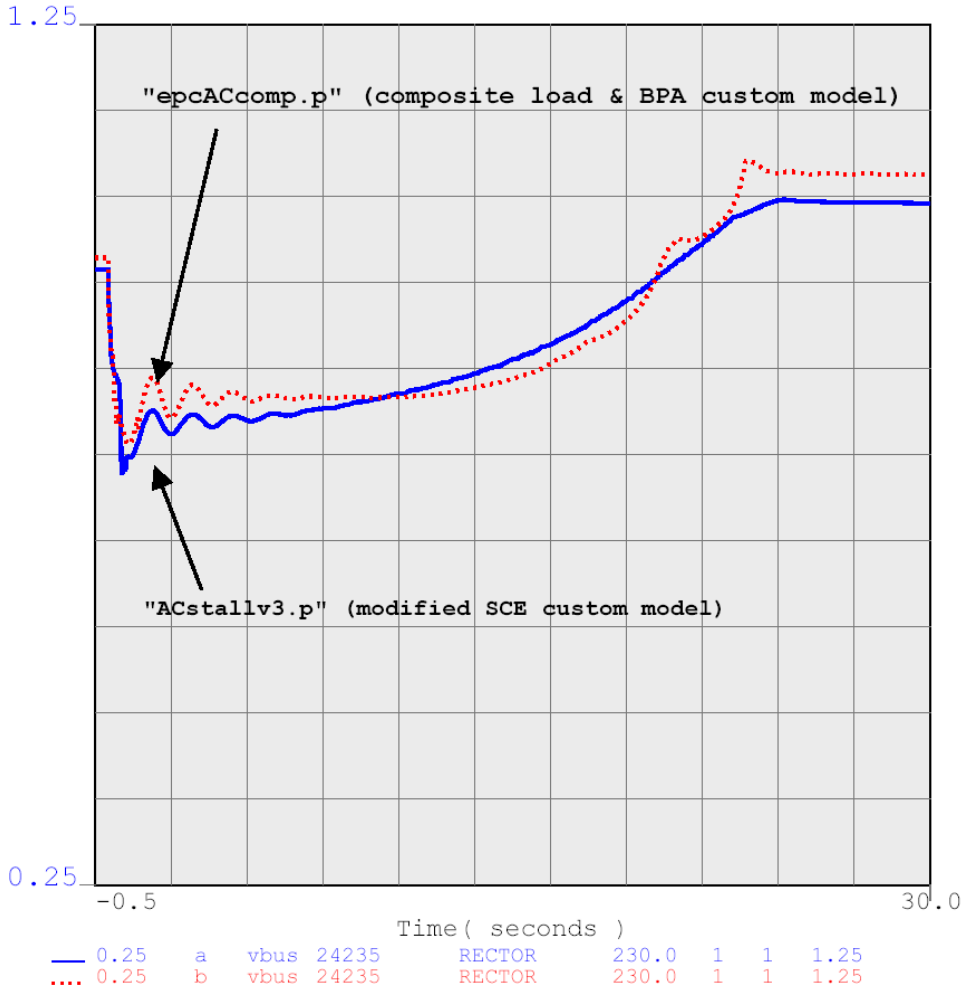
1-phase Compressor Motor Models

- A White Paper with modeling requirements is developed first
- Several Modeling Approaches are considered, prototyped and tested:
  - Phasor Models
  - Performance-Type Models
    - Polynomial-type models
  - Hybrid model
    - Initially developed by SCE, enhanced by EPRI

New Load Model



Load Model Validation

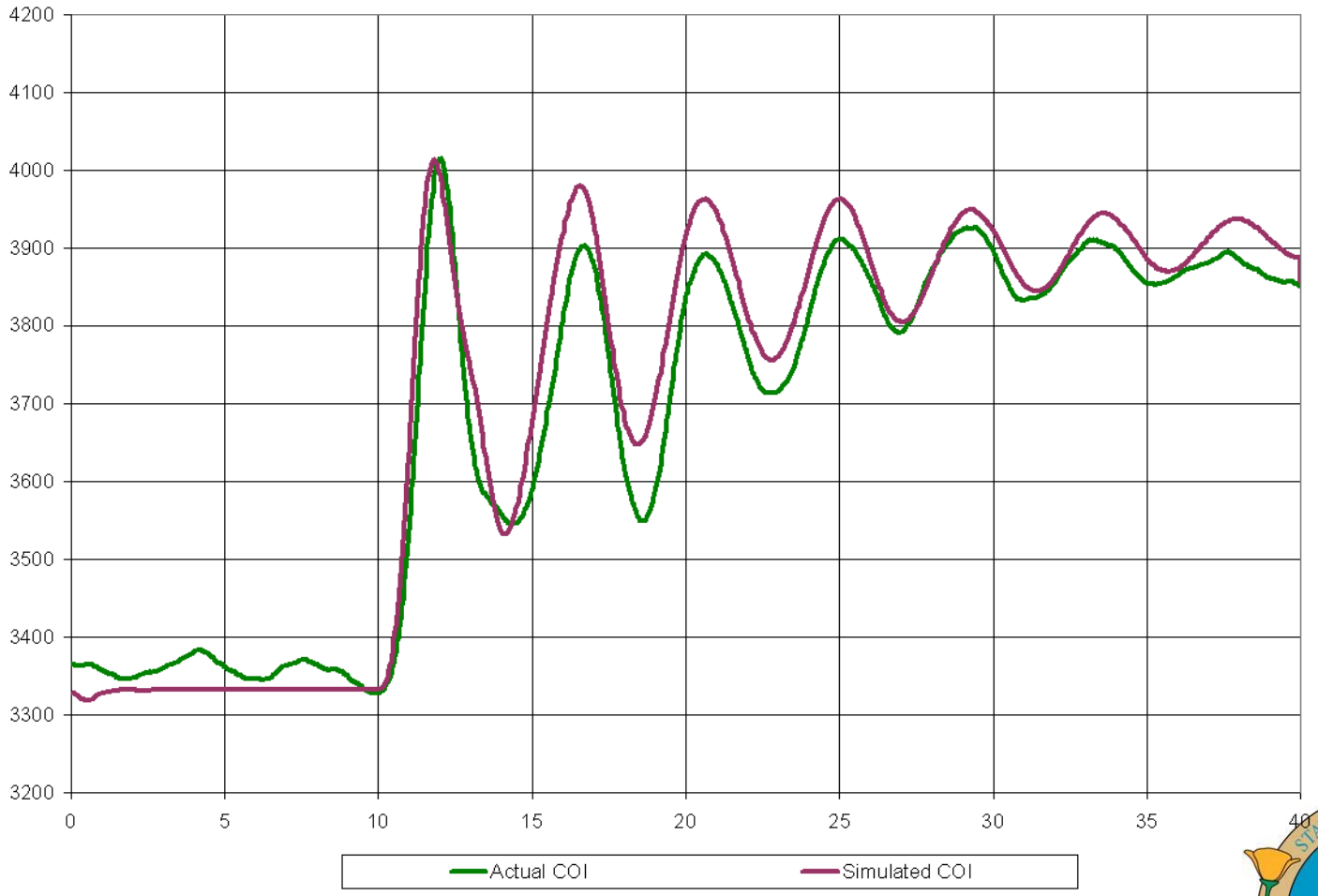


Capable of reproducing the phenomenon of delayed voltage recovery

Explicit representation

1phase A/C models

Load Model Validation



Inter-area Power oscillations

WECC Load Modeling

- WECC needs better information in the following areas:
  - Load composition data
  - Motor protection data

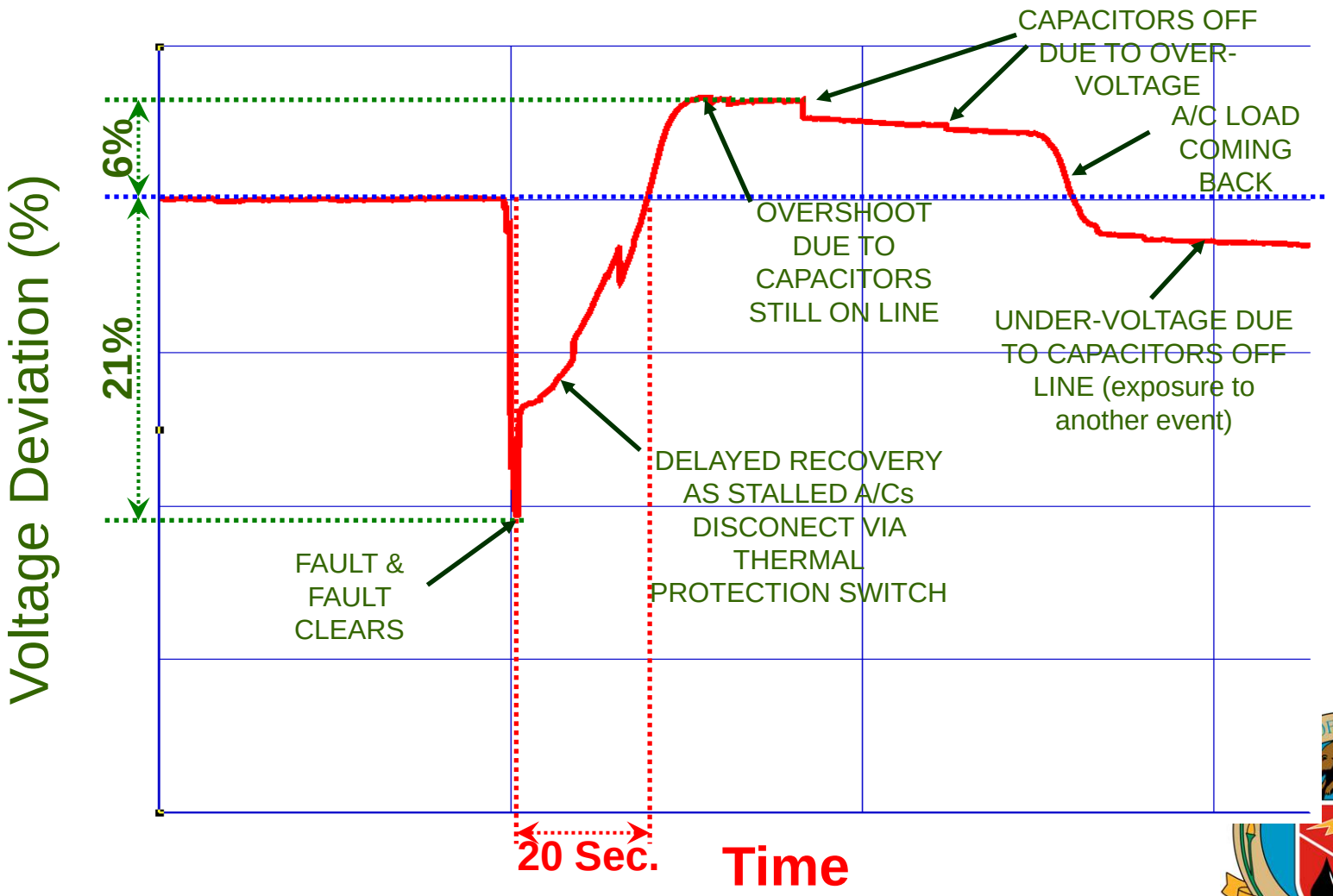
- WECC is shifting from model development to model validation and system impact studies

System Studies

- Inter-regional stability:
  - Voltage stability of major WECC paths (COI, EOR, P15 and P26)
  - Damping of inter-area oscillations
- Fault-Induced Voltage Recovery in 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

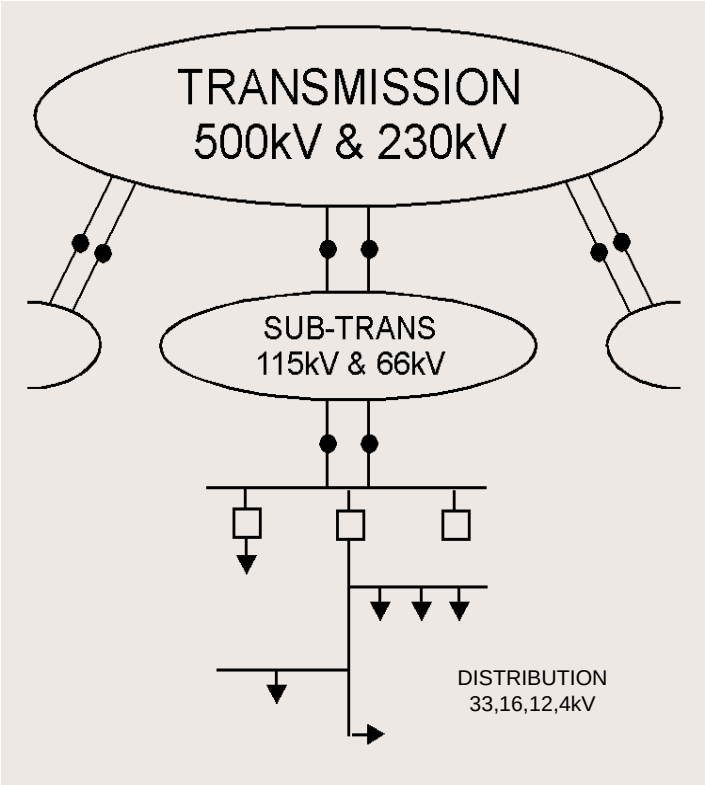
Solutions to Fault-Induced Delayed Voltage Recovery

What is FIDVR ?

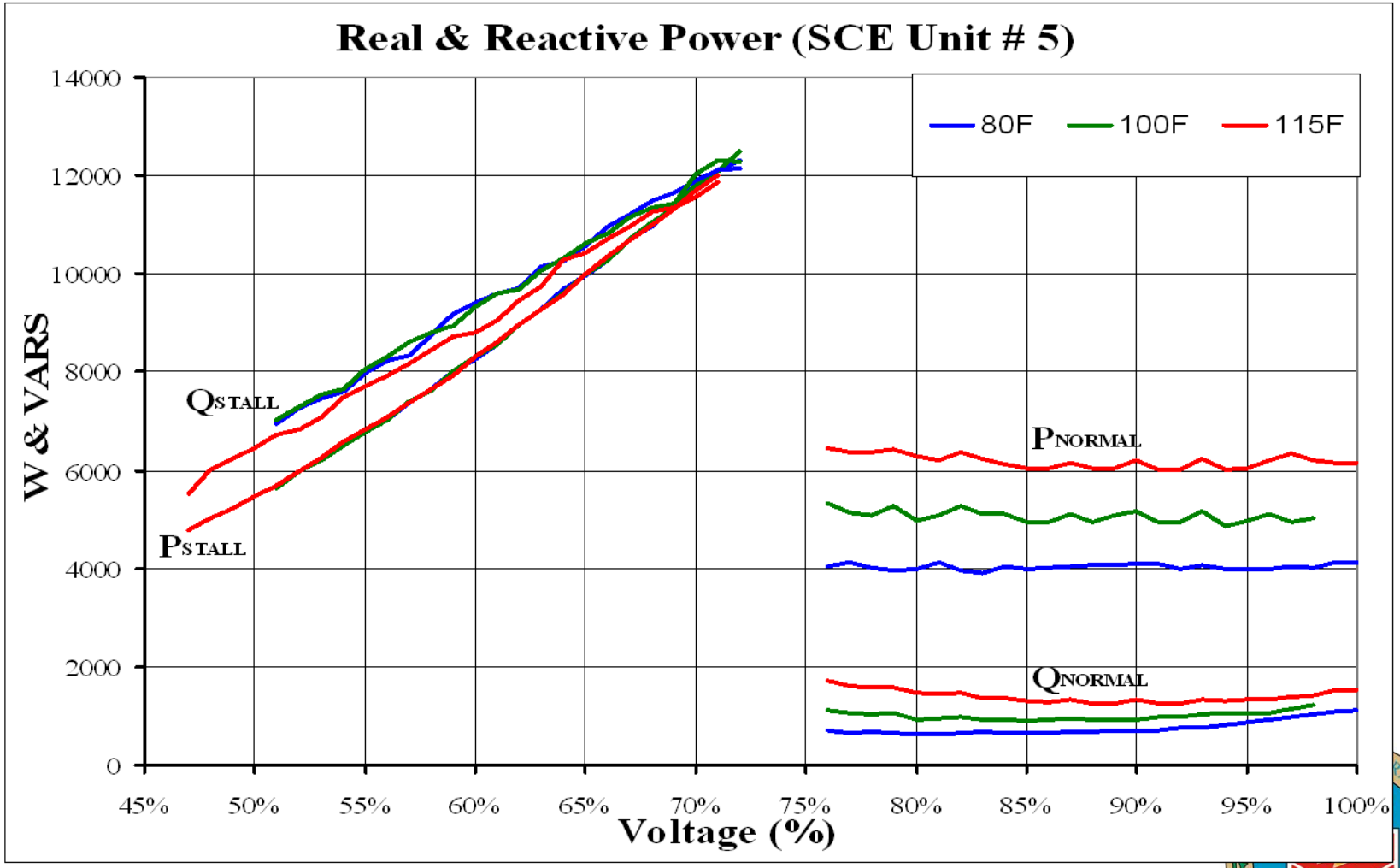


Why Are We Concerned?

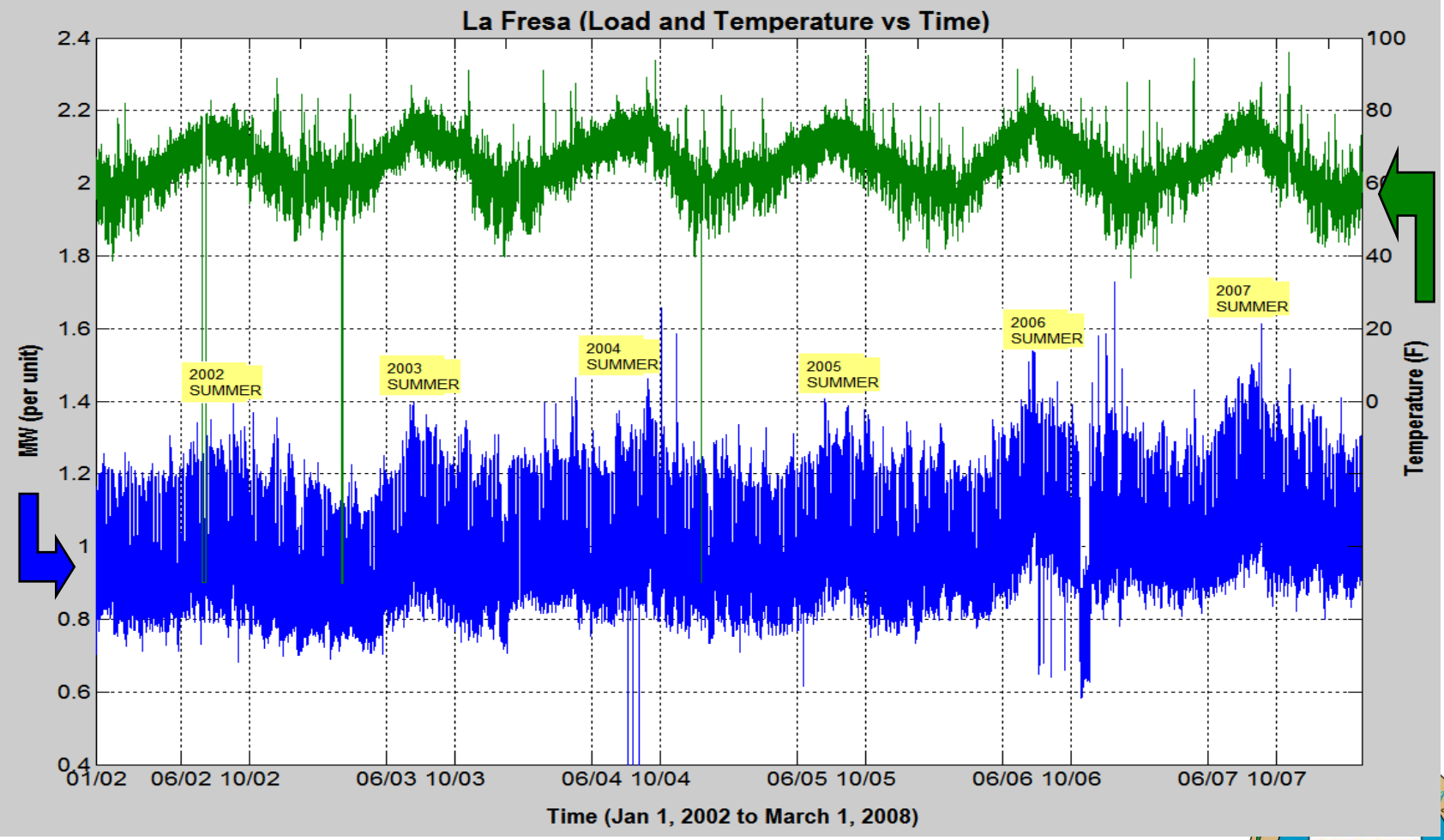
- Undervoltage event could lead to total system voltage collapse
- Presents voltage sag to all customers in the area (PQ issue)
- Getting worse as more homes with air conditioners are built in warm inland areas



A/C Stall Behavior



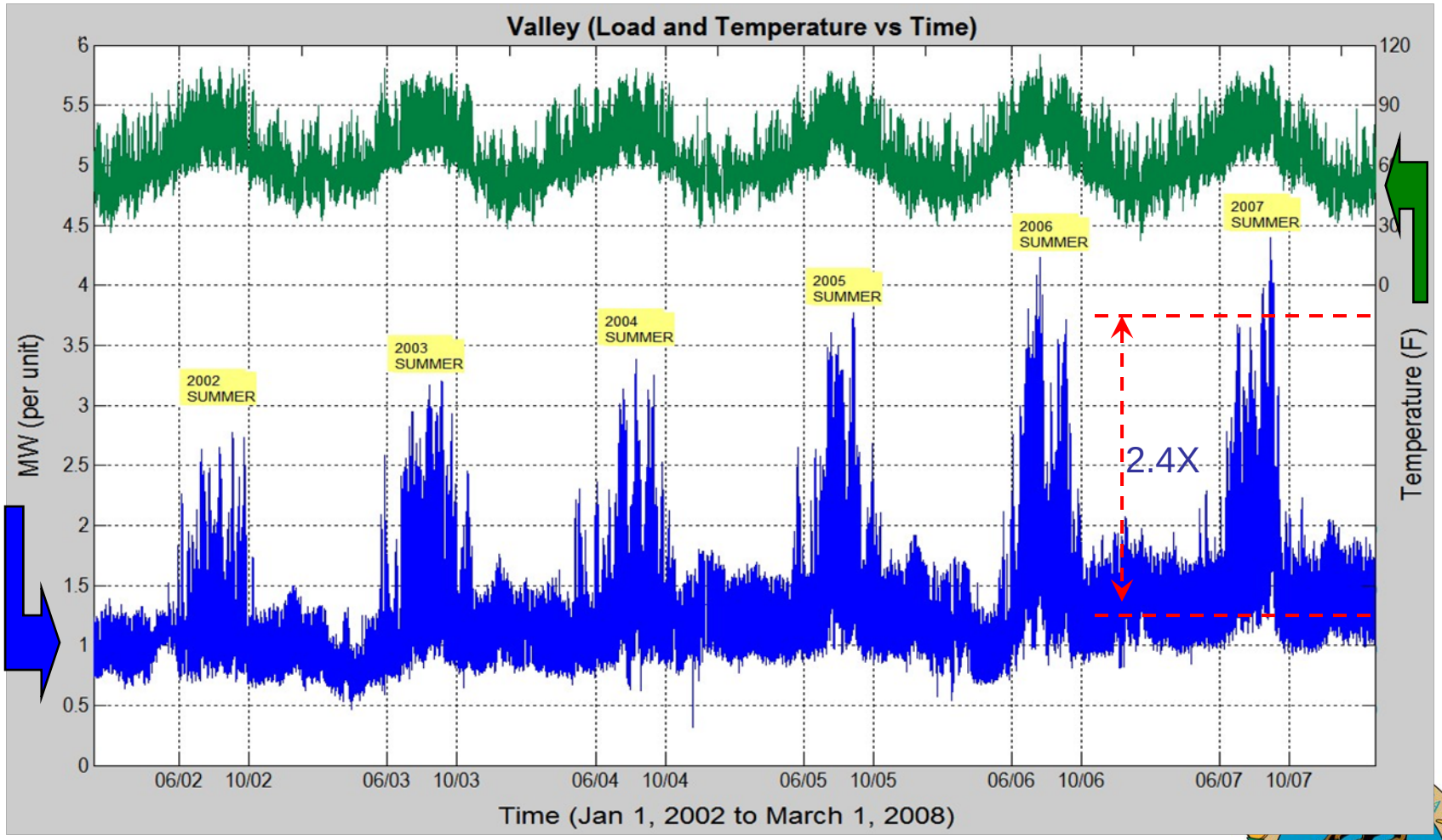
Coastal Load



Peak Load ~ 600 MW

25% of Peak Load is A/C

Inland Load



Peak Load ~ 1,500 MW

60% of Peak Load is A/C

What's Being Done

- Completed A/C tests to obtain better A/C performance data
  - SCE, BPA, and APS/EPRI
- WECC developing new A/C load models to more accurately model A/C stalling effects
- System modeling underway to determine vulnerability
- Evaluating mitigation measures
  - Electric System level
  - A/C Unit level
- Engaging NERC, A/C Industry, Utilities, DOE, and regulatory bodies to develop comprehensive national solutions

Assessment of Electric System Level Measures

- Cannot prevent faults from occurring nor A/C units from stalling
- System level solutions (e.g. SVC, Statcom) :
  - Reduce the size of the area affected
  - Reduce the duration of stall events
- Could be very costly
  - Would need a number of devices throughout the SCE system
  - A large SVC costs $20M to $50M each
- Southern Company and Center Point Energy are deploying SVCs for FIDVR mitigation in Atlanta and Houston metro areas respectively

Assessment of A/C Unit Level Measures

- Fix problem at its source
- Disconnect A/C compressor motors when they stall
  - Reliable detection of a/c stall is required
- New air conditioner standard is needed; e.g.:

  "Any air conditioner shall include features which prevent the compressor from remaining connected to the electrical supply system in a stalled condition for more than {one-tenth?} of a second."
- An A/C standard would keep the future situation from getting worse
- Large number of existing A/C units means retrofit might be necessary

Portfolio of Solutions

- The final product is likely to be a portfolio of solutions including transmission and unit-level solutions. Portfolio is likely to evolve in time.
- Portfolio to address the following risks:
  - Risk of voltage collapse developing in a metro area
  - Risk of voltage collapse cascading outside metro area
  - Risk of extreme over-voltages following AC tripping
- Is FIDVR an indication of a more serious systemic problem ?
- Need a comprehensive review and vetting of the solutions by the industry
  - Electric Power Industry
    - NERC Transmission Issues Subcommittee is issuing a White Paper
    - WECC Planning and Coordinating Committee
    - BPA has a panel of top industry experts
  - Professional Organizations - IEEE
  - Equipment Manufacturer's – NEMA, ASHRE

Project Continuation

Roadmap of Solutions

- System Level Solutions
  - Addition or relocation of reactive resources closer to load – generators, SVCs, Statcoms, DVARs
  - Under-Voltage Load Shedding
  - Limiting affected load by sectionalizing
  - Special Protection Schemes to contain disturbance spread

- Unit-Level Solutions
  - Relays that disconnect a compressor motor when it stalls
  - Devices that make a compressor motor ride through typical faults

- Distributed Generation
  - e.g. PV converters with Voltage Controls

Smart Grid

- The fundamental change in load composition is likely to have negative impact on the transmission reliability if nothing is done
- At the same time, power electronics (VFDs, Distributed PV Generation, PHEV) offer grid control capabilities that did not exist before
- It is time to make the load a part of solution, not a problem

BPA Technology Innovation Office

- Responsible for all BPA R&D, guided by roadmaps, growing budget and FTE commitment
- BPA Technology Innovation is currently funding research in the area of load-induced voltage stability
- BPA hired a panel of industry experts to advise on voltage stability issues, including load-induced voltage stability
- Since Power Electronic loads have shown to have negative impact on voltage stability and damping of inter-area power oscillations, BPA initiated a project to study feasibility of making electronic loads grid-friendly
- BPA continues support of WECC load modeling activities

Industry

- April 2008 - DOE Workshop on Role of Residential Air-Conditioners in Delayed Voltage Recovery
- July 2008 - IEEE General Meeting - Panel Session on Load Modeling – 3 papers
- December 2008 - NERC is planning to release a White Paper on Fault-Induced Delayed Voltage Recovery
- April 2009 - WECC Modeling Workshop is planned, hosted by PG&E

Proposed to CEC

Phase II research to include:

1. Continue studying solutions to Fault-Induced Delayed Voltage Recovery
2. Load model sensitivities
3. Feasibility of single-phase load simulations
4. Load Composition Analysis

Project Contacts

- Bernard Lesieutre (lead), Lawrence Berkeley National Laboratory
  - BCLesieutre@lbl.gov
  - 608-890-1883
- Bob Yinger, Southern California Edison
  - Robert.Yinger@sce.com
  - 626-302-8952
- Richard Bravo, Southern California Edison
  - Richard.Bravo@sce.com
  - 626-302-8146
- Dmitry Kosterev (adviser to CIEE), Bonneville Power Administration
  - dnkosterev@bpa.gov
  - 360-418-8342