Load Modeling in WECC

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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

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
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.

Critical speed = 30% of rated

Critical voltage near 60%

Plot prepared by Dr. Bernard Lesieutre, LBNL (now with University of Wisconsin)
(b) Compressor Motors Inertia is Very Low

H = 0.03 – 0.05 seconds

E.g. 3.5-ton compressor motor: Weight: 4.6 kg
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?

Current (Amps)

Pressure (Psi)

Compressor Pressure

Current

Time (sec)

What do the motors do after they stall?

- stall
- thermal trip
- thermal re-close
- thermal trip
What do the motors do after they stall?

- stall
- thermal trip
- successful restart

Current [pu] vs Time [sec]

Compressor Pressure vs Time [sec]
* 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
Load Model Data
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

500 KV System

- Standard Motor Model
- New A/C Motor Model
- PMU Data

Voltage (p.u.)

Time (sec)

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

Sensitivity to load composition

Bus Voltage

Volts Per Hertz

Consequential plant trips

Sensitivity to motor protection
Line protection
Generator and SVC tripping

Time
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