• **End-Use Load is Evolving** – Electronically coupled loads, distributed generation, etc.

• **Continually Changing** – End-use load continually changes
  - Day, time, season, geography, weather, economics, etc.

• **Difficult to Model** – Even with load composition known, difficult to relate to load model parameters – *Rules of Association*

• **Minimal Data** – Distribution data hard to collect; often minimal collaboration between transmission and distribution entities

• **Best Practices** – Sharing best practices and experiences is critical

• **Benchmarking** – Historical events can be benchmarked against today’s models

• **Prediction** – Does not make them useful for predicting future events
What’s in Your House?

- Inverters are everywhere
- Variable frequency motor drives
- CFL & LED lighting
- Plug-in electric vehicles
- Motors
• Solar energy penetration is growing rapidly; likely to continue into future
  ▪ Declining cost of materials
  ▪ More economical

• May not be “BES”, but this has an impact on reliability and performance

• This is likely not in your planning model; it needs to be!

• **Collaboration key to develop best practices**
Battery storage systems are also increasingly becoming popular

- Declining cost of materials
- More economical

“If I can cheaply put rooftop panels on my house, store my energy, and use it through the night, why wouldn’t I?”

- Grid will likely still play a critical role
- What are its electrical characteristics?
- How is this being modeled?

**Collaboration key to develop best practices**
• End-use load (response) changing rapidly – need collaboration between utility industry, manufacturing community, and end-use standards; ensure devices are grid friendly
  ▪ Energy Efficient Loads are often not “Grid Friendly”

• Voltage sensitive loads often trip
  ▪ Normally cleared faults – 1-φ motor stalling can occur for normally cleared 3-phase faults, Sensitivity to point on wave voltages, voltage rate of change, voltage magnitude and duration, etc.
  ▪ Slowly-cleared faults – power quality requirements

• Behind the meter generation (distributed resources) becoming increasing popular – solar, micro-turbines, etc.
  ▪ Some of those resources have voltage and frequency ride-through sensitivities
  ▪ How should these be modeled??
Loss of voltage-sensitive loads are NOT classified as Consequential Load Loss (NERC Glossary*)

**Consequential Load Loss**
All Load that is no longer served by the Transmission system as a result of Transmission Facilities being removed from service by a Protection System operation designed to isolate the fault.

**Non-Consequential Load Loss**
Non-Interruptible Load loss that does not include: (1) Consequential Load Loss, (2) the response of voltage sensitive Load, or (3) Load that is disconnected from the System by end-user equipment.

- Models not perfect – need improvements to address complexities
- Transient voltage response study criteria is vague

Voltage Sensitivities Highlighted

• Toronto, Ontario – 2007
  ▪ 230 kV cap bank failure – slow clearing 3-Ø fault
  ▪ 1,700 MW of voltage-sensitive load lost in the Greater Toronto Area

• Salt Lake Valley – 2009
  ▪ low voltage spike initiated ~920 MW non-consequential load lost
  ▪ 138 kV SLG fault of 4 cycles, evolving into a three-phase fault for 6 more cycles; 10 cycles total fault duration
  ▪ Load – several server farms – voltage-sensitive loads transfer to backup power sources

• Washington, DC Area – 2015
  ▪ Protracted 230 kV fault created prolonged low-voltage
  ▪ ~445 MW load lost
    o Some voltage sensitive load transferred to backup supplies
    o Some tripped by end-user connection protection action
TPL-001-4 requires use of “a Load model which represents the expected dynamic behavior of Loads ... considering the behavior of induction motor Loads.”

\[ P+jQ = P_0[p_1 V^2+p_2 V+p_3] \]
\[ Q = Q_0[q_1 V^2+q_2 V+q_3] \]

**FROM...**

**TO...**

- 3-phase Motors – Fans, Pumps, Compressors
- 1-phase Induction Motors
- Power Electronic Load
- Static (Polynomial) Load
- Distribution Equivalent
• TPL-001-4 requires PCs and TPs have a transient voltage response criteria in place
  ▪ Clarification is needed – Is this transient voltage dip criteria or a transient voltage recovery criteria?
• How does transient voltage response criteria directly relate to reliability?
  ▪ Used as a metric for ensuring reliability
  ▪ Future work to focus on developing a criteria that directly relates to continuity of the bulk power system for large voltage excursions.
  ▪ Need improved models (on load and generation side) to accomplish this
• **High Probability, Low Risk** – Faults such as SLG, simple generator trips, etc., should be evaluated against a criteria in which continuity of serving load is priority
  - Load bus transient voltage response criteria
• **Low Probability, High Risk** – Faults such as 3-phase or stuck breaker should have a criteria in which continuity of the bulk power system is priority
  - PRC-024 ride through requirements
• **Resolution of Consequential vs. Non-Consequential Load Loss** – Clarify how to classify voltage-sensitive and frequency-sensitive loads in reliability analysis
• Share best practices for dynamic load modeling and FIDVR events
• Share best practices for non-traditional resource modeling
• Collaborate with software vendors to further develop and improve available dynamic models in software
• Continue engaging manufacturing community to raise awareness of grid needs – promote grid-friendly devices
• Engage in IEEE equipment standards – awareness of aggregate impact of multiple small devices
• Collect as much load data as possible (classification, end use, feeder information, etc.)
• Develop a process for creating load models – zonal or regional load models are NOT sufficient
• Sensitivity, sensitivity, and more sensitivity studies
Questions and Answers