Infrastructure Requirements for Highly Responsive Load Control

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Vision

• Distribution Automation and Control (DAC) systems have potentially major effects on costs, social impacts, and even on the nature of the power system itself, especially as dispersed storage, generation, and customer interaction become more prevalent.

• Faster supply-demand balancing is obtained by employing "governor-type" action on certain types of loads using a Frequency Adaptive Power Energy Rescheduler (FAPER) to assist or even replace conventional turbine-governed systems and spinning reserve.

• Conventional metering is replaced by a Marketing Interface to Customer (MIC) which, in addition to measuring power usage, multiplies that usage by posted price and records total cost.

  – Nearly 30 years ago!!!!
Motivation

• Demand pattern is from CAISO.
• Vehicles are made to charge when drivers arrive home.
• 10 million vehicles equates to about 60% penetration in CA.
• Taken from Lemoine et al, *Environmental Research Letters*, 2008.
Overview

- **Purpose:** Explore ways in which loads might be controlled to minimize operating cost, and improve power system efficiency and reliability.
- **Look to the history of load control to establish an informed perspective for future developments.**
- **The degree to which grid services can be provided by demand control is limited by:**
  - Expectations for end-use function.
  - Limitations in the communications and control infrastructure.
Key advantages of controlling loads

- Variability in total contribution of a large number of small loads is less than that of a small number of large loads.
- Load response is almost instantaneous, not limited by ramp rates.
- Loads are highly distributed, allowing spatially precise response.
- Potential for load response to replace inefficient peaking generation.
- Spatial and temporal flexibility of loads is well suited to supporting intermittent renewable generation.
- Loads are already embedded in the power system, and advanced metering infrastructure (AMI) is being rolled out.
Conventional power system operation

- Economic dispatch and unit commitment.
- Automatic generation control (regulation).
- Frequency response:
  - Inertial response.
  - Governor action.
- Contingency (spinning) reserves.
- Voltage collapse prevention.
Prior work on load control

- Load shifting.
  - Typically open-loop.
  - May induce post-control “pick-up”.
  - Many loads are well suited to load shifting, but not all.
Prior work (continued)

- **Energy imbalance**
  - Pacific Northwest National Lab trial introduced frequency droop characteristic into home appliances.
    - Operators did not like frequency-responsive loads because demand was no longer predictable.

- **Contingency reserves**
  - Under-frequency and under-voltage load shedding schemes are common.
    - Such schemes are not selective, and tend to be disruptive.
  - Advanced metering infrastructure (AMI) offers the opportunity for selective load control.
Load control “constraints”

• Dual (competing) objectives:
  – Local control objective, e.g., maintain temperature close to setpoint.
  – System service, e.g., balance renewable generation output.

• Load control strategies must be consistent with the legacy system operating philosophy.

• Centralized control of large numbers of loads is impractical.
Hierarchical load control

- Aggregator builds a model of load controllability.
  - Must take into account load availability and willingness to participate.
  - Load model should allow prediction over a finite horizon.
Communications

Advanced Metering Infrastructure

- Bandwidth
- Latency
- Data ownership

Illustrations courtesy of Itron Inc.
Load control by setpoint variation

- Steady-state temperature distribution for 10,000 cooling loads.
- Temperature behaviour modelled according to:
  \[ \theta_{n+1} = a\theta_n + (1 - a)(\theta_{amb} - m_nK) + w_n \]
- Regions:
  - ‘a’ contains only loads in the off state.
  - ‘b’ contains loads in both the on and off state.
  - ‘c’ contains only loads in the on state.

**Control strategy:**
- Increase load by lowering setpoint.
- Decrease load by raising setpoint.
Example: tracking wind generation

- Controlling 60,000 AC loads to follow wind variations.

From Callaway: Tapping the energy storage potential in electric loads.
Conclusions

• Challenge for load control is to balance end-use performance with delivery of system-level service.

• Control is highly dependent upon the cyber infrastructure.
  – Communication, computation and control.
  – Current “smart grid” technology may be inadequate for highly responsive load control.