Mitigating Renewables Intermittency through Nondisruptive Distributed Load Control

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Research Objectives

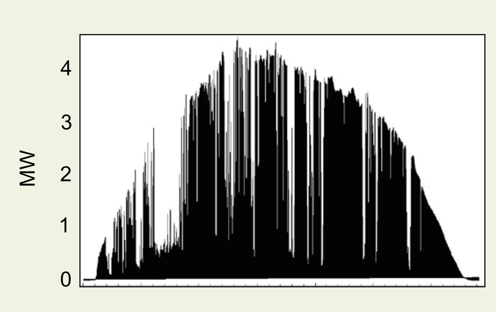
• Understand the potential for demand side flexibility to support variable and uncertain production from renewable sources.

• Develop modeling and control strategies that preserve end-use function while delivering systemic benefits.

• Develop strategies to work within the current and future constraints of grid information technology infrastructure.

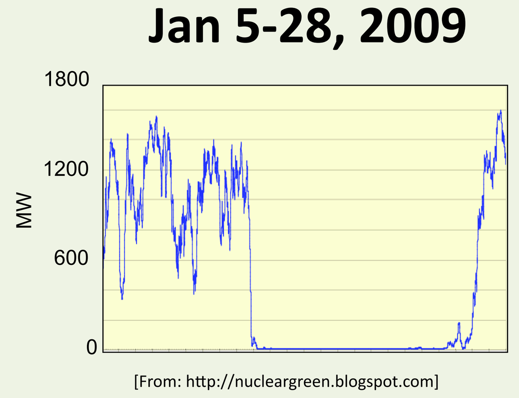
Importance for the Future Grid

Solar PV Generation (10 sec increments) One day



[From: http://www.megawattsf.com/gridstorage/]

Wind Generation (5 min increments) Jan 5-28, 2009



[From: http://nucleargreen.blogspot.com]

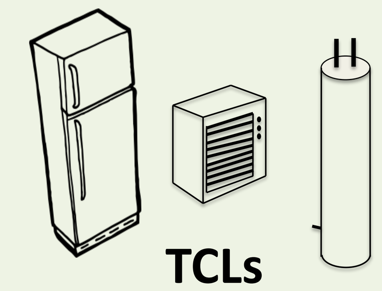
- Wind and solar power are intermittent renewable resources.
- Using more intermittent resources requires more power systems services such as load following and regulation.
- These services could be provided by:
  - Fast-acting power plants
  - Energy storage devices
  - Loads, especially 'thermostatically controlled loads,' or TCLs
- TCLs are well-suited to providing these services because they can act like energy storage devices, modulating their load around their baseline consumption.

Research Deliverables

• Large-scale modeling and state estimation strategies for demand response.

• Evaluation of the technical and economic impacts of demand response for renewables integration.

Research Approach



1. Develop a modeling framework for heterogeneous TCL populations.
2. Quantify how well TCLs could provide regulation and load following.
3. Explore implications of limited sensing and communications.
4. Quantify resource potential, costs of enabling infrastructure, and potential profits.

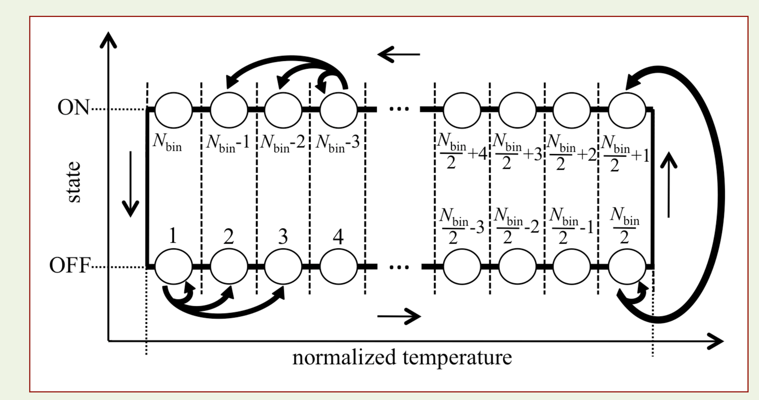
Accomplishments to Date

TCL Population Model

$$x(k+1) = Ax(k) + Bu(k)$$
$$y(k) = Cx(k)$$

x, the state: the fraction of TCLs in each bin
A, the transpose of Markov Transition Matrix
Bu, the input: ON/OFF control
C, the observer vector/matrix
y, the system output: aggregate power and, possibly, the state

State Bin Transition Model



Scenarios for Sensing & Communications

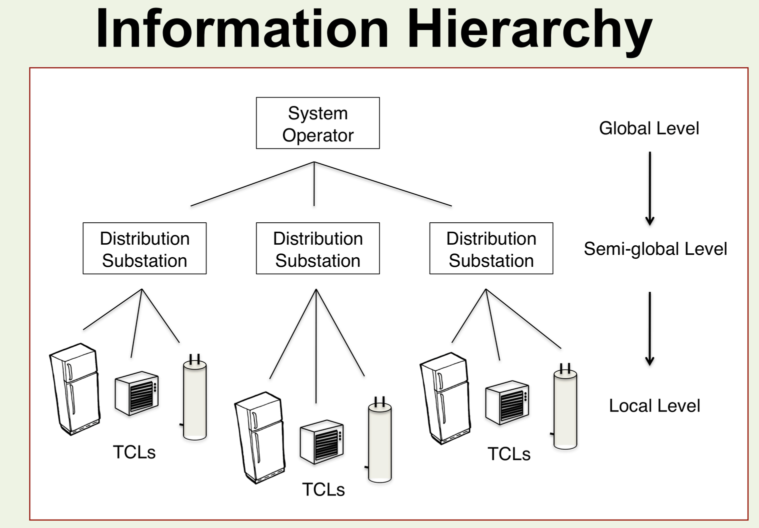
Scenario 1 (Ref. Case):
Full local information (temperature and power consumption) transmitted in real time.

Scenario 2:
Local information available offline. Aggregate power estimated with ON/OFF state information from all or some TCLs in real time.

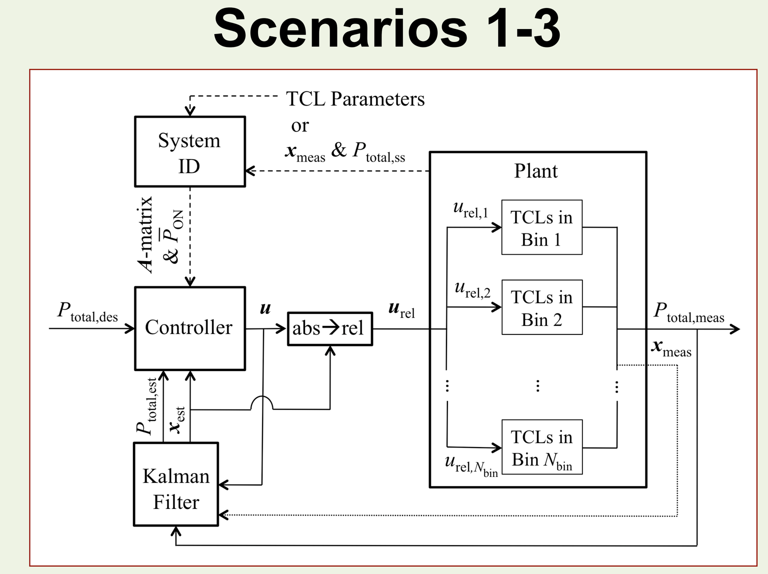
Scenario 3:
Local information available offline. Aggregate power estimated at distribution substation in real time.

Scenario 4:
No information available offline. Aggregate power estimated at distribution substation in real time.

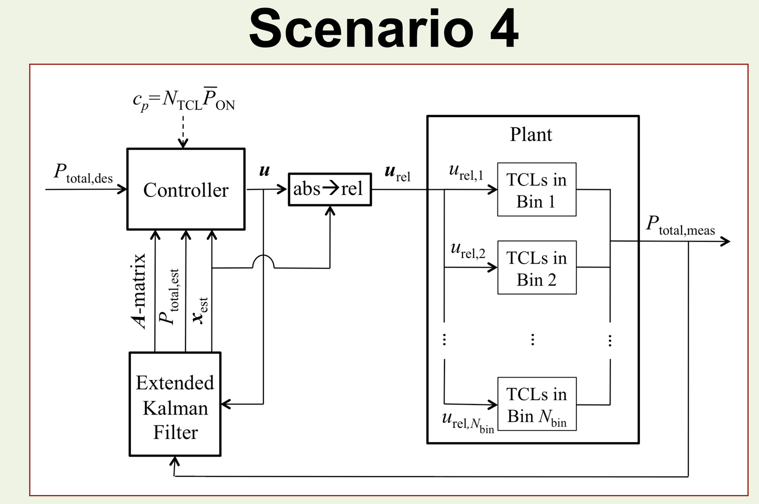
Information Hierarchy



Scenarios 1-3



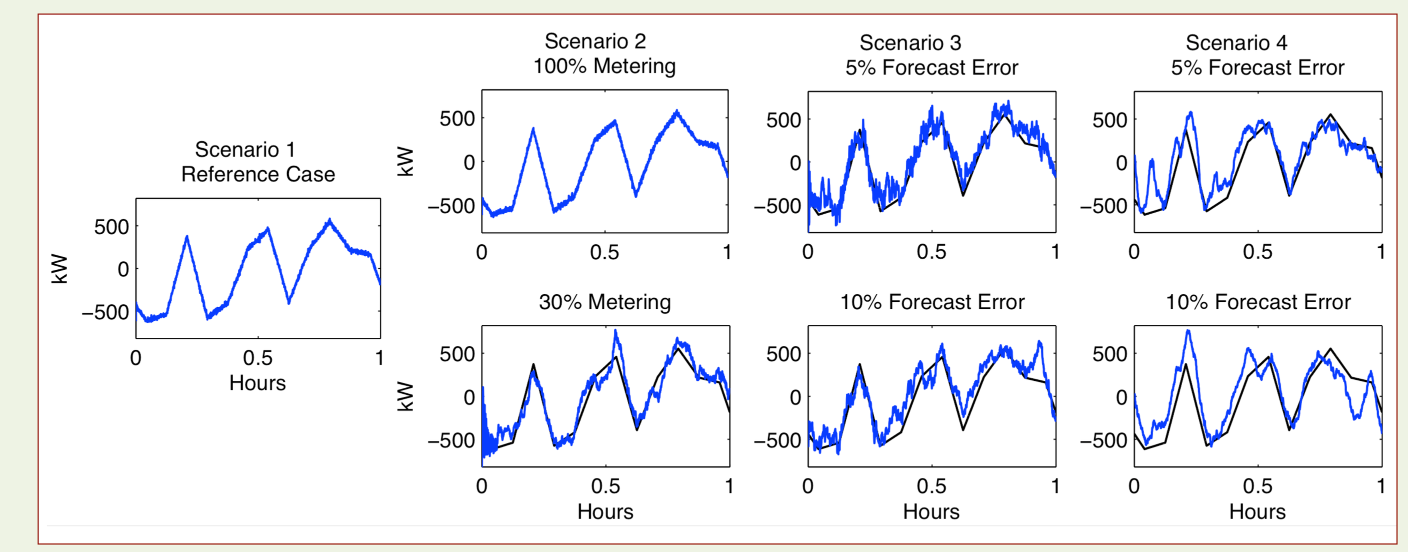
Scenario 4



Further Accomplishments to Date

Tracking Results

1,000 Heterogeneous TCLs Tracking a Load Following Signal



* In Scenarios 3 and 4, aggregate power is estimated with distribution substation load forecasts assuming the standard deviation of the forecast error is 5% or 10%.

Resource Potential

Estimates of the Capacity of 1,000 Heterogeneous TCLs

	Energy (kWh)	Power increase (kW)*	Power decrease (kW)*
Air conditioners	2,500	6,300	1,600
Refrigerators	440	560	24
Heat pump heaters	1,700	6,000	1,900
Electric resistance water heaters	1,200	3,300	23

* Power increase and decrease from steady state power consumption.

Potential Uses of this Research

• This research is a foundation for future research into:
  - other techniques to estimate local load states from aggregate system behavior;
  - more realistic system set-ups including communication delays and constraints; and
  - other methods of load control including setpoint control, duty cycle control, and load switch control.

• This research lays some of the groundwork for a pilot project.