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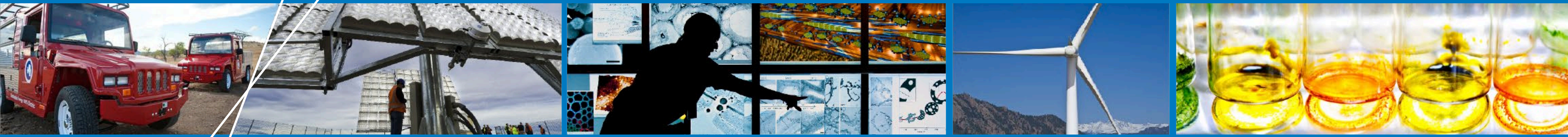
A Fuzzy-Logic Subsumption Controller for Home Energy Management Systems



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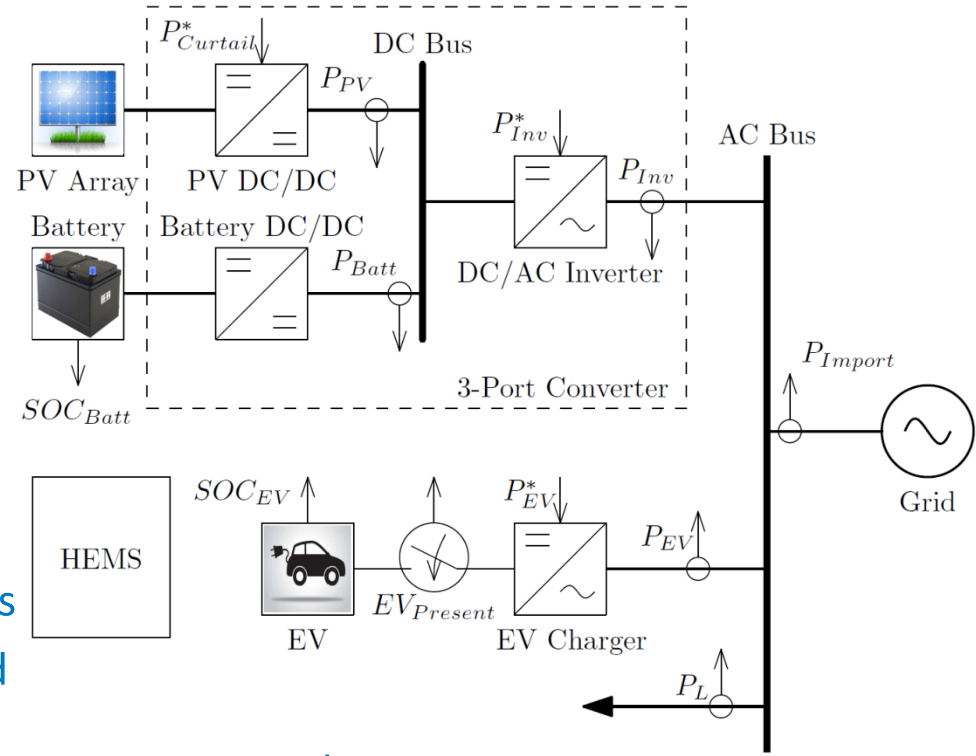
Problem: HEMS Design for an Example Home

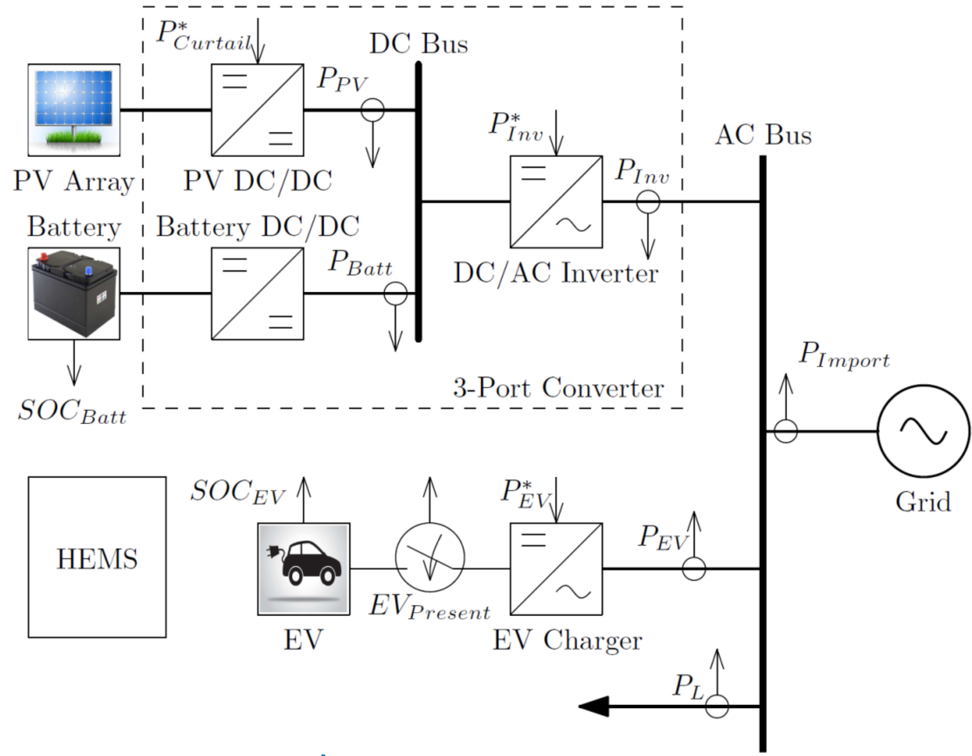
- **Coordinate multiple power devices in an example home**
  - Photovoltaics (PV) array
  - Battery Storage System
  - EV Charger
  - Each has its own simple local controller
- **HEMS Goals:**
  1. Protect the home power system
  2. Satisfy occupant energy demands
  3. Minimize disturbance on the grid
  4. Maximize renewable energy



Example Home Energy System w/ PV, battery, and EV charger

Problem: HEMS Design for an Example Home

- **Practical Problem Characteristics:**
  - Satisfy both hard (physical) constraints and soft (objective) constraints
  - Pursue multiple (often competing) goals
  - Respond to fast, unpredictable changes [1]
  - Inexpensive and require minimal infrastructure to implement



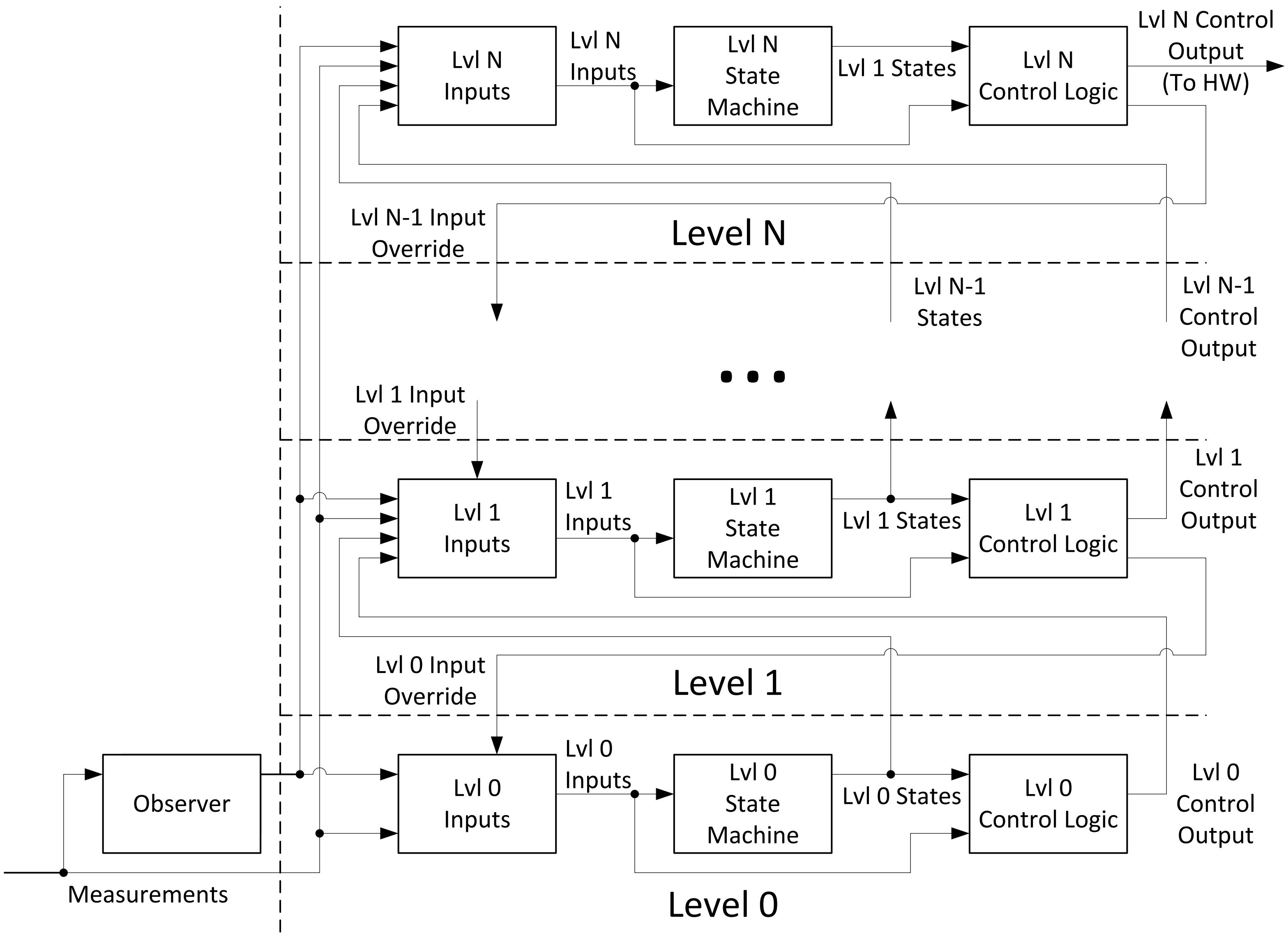
Example Home Energy System w/ PV, battery, and EV charger

[1] D. Lachut, N. Banerjee, and S. Rollins, "Predictability of energy use in homes," in *Green Computing Conference (IGCC), 2014 International*, 2014

Approach: Fuzzy-Logic Behavioral Control

- **Optimization-based HEMS controllers have high performance in theory but difficult to implement**
  - Require significant computation and communication => expensive
  - Slow loop timestep => poorly matched to fast time constants
  - Require predictions of future => poorly matched to unpredictable conditions
- **Alternative: Behavioral control with fuzzy-logic blending**
  - Implement multiple controllers ("behaviors"), each with its own goal/approach
  - Combine behaviors in a context-specific way with fuzzy logic
  - Intelligent response emerges from blending of behaviors
- **Hypothesized Advantages:**
  - Simple Implementation => inexpensive
  - Fast loop response => better matched to quick changes
  - No predictions required => better matched to unpredictability
  - Pursue multiple goals and make context-dependent tradeoffs

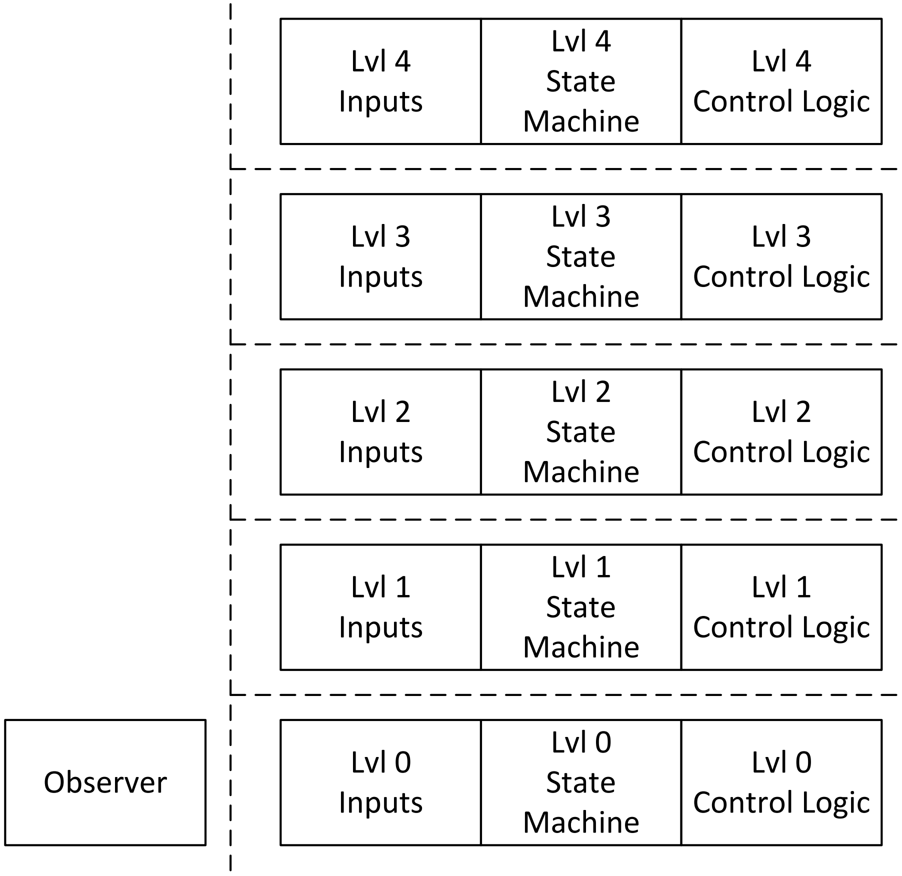
Subsumption-Like Architecture for HEMS



[2] R. A. Brooks, "A robust layered control system for a mobile robot," *IEEE Journal of Robotics and Automation, 1986*

Example HEMS Implementation

- **Level 0**
  - PV MPP
  - SOC Protection
  - EV Default Charging
- **Level 1**
  - PV Smoothing (like [3])
  - EV Defer/Must Charge State Machine
- **Level 2**
  - EV Early Charge
- **Level 3**
  - Import Power Flattening (extension of [4])
- **Level 4**
  - PV Curtailment

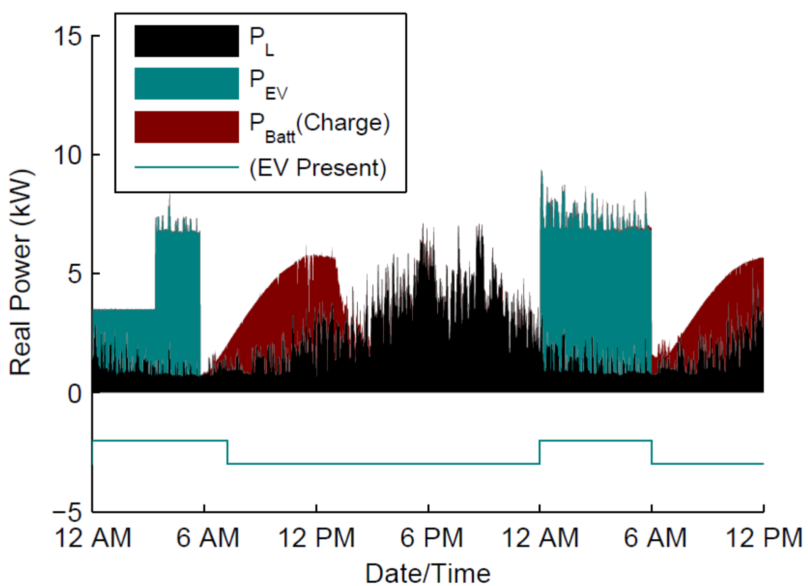


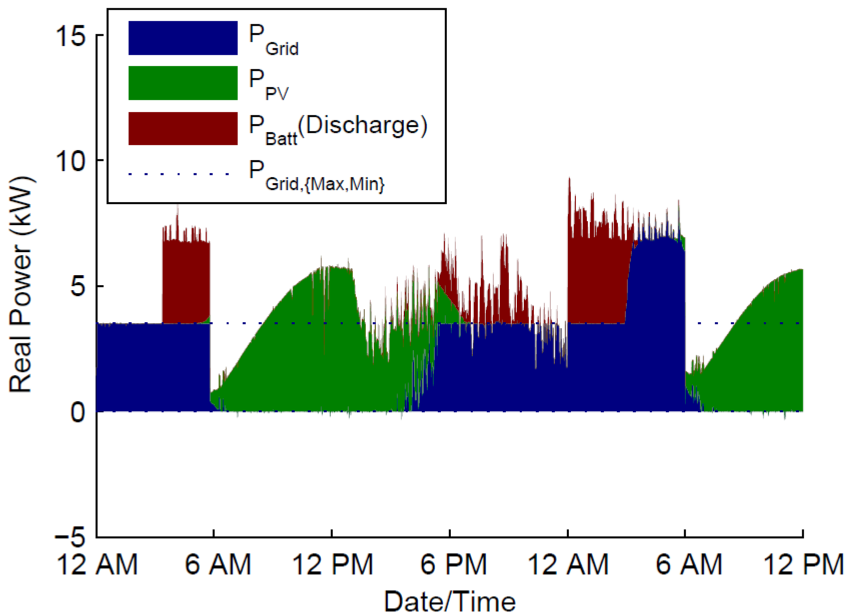
[3] A. Ellis, D. Schoenwald, et al, "PV output smoothing with energy storage," in *Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE*, 2012

[4] I. Koutsopoulos, V. Hatzi, and L. Tassiulas, "Optimal energy storage control policies for the smart power grid," in *Smart Grid Communications (SmartGridComm), 2011 IEEE International Conference on*, 2011

Example HEMS Simulation

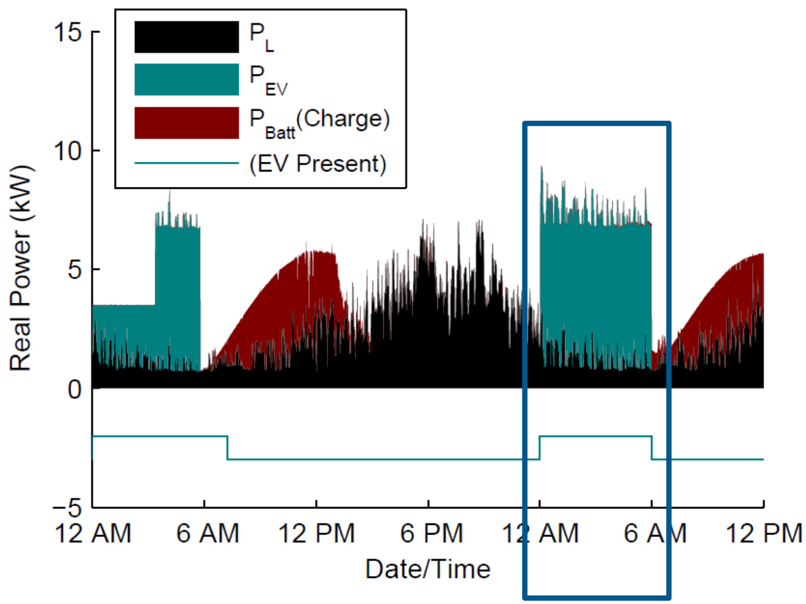
- **Simulation of example home energy system**
  - 24-hour period based on measured data from Anatolia, CA in August 2012
  - HEMS is operating w/ 1 second timestep
- **HEMS performance:**
  - Maintain all physical variables within their limits (mostly Level 0)
  - Charges EV to meet a charge deadline of 100% EV SOC @ 6 AM (Levels 1/2)
  - Discharges battery at high demand times to limit import power (Level 3)
  - Charge battery from PV when excess power is available (Level 3)

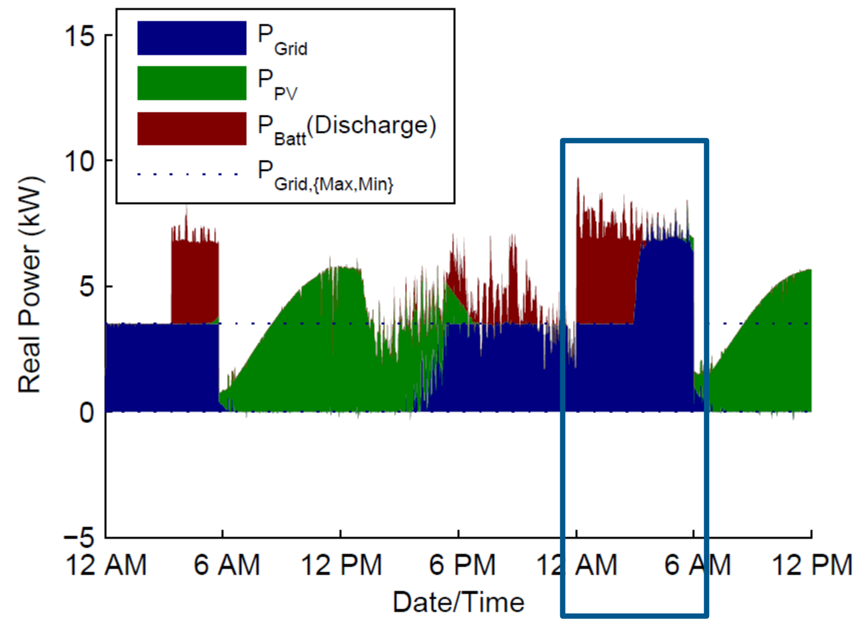




Example HEMS Simulation

- **Curveball: EV arrives home at midnight w/ 5% SOC**
  - Not possible to meet all goals at once
  - HEMS makes choice to partially sacrifice power limiting goal in order to maintain SOC limits and come as close as possible to meeting EV charge deadline
  - This gentle objective tradeoff is in keeping with the original ordering of the goals





Conclusions

- **Behavioral HEMS controller is an effective way of context-dependent blending HEMS functions**
- **Advantages:**
  - Behaviors can be selected from existing grid support functions such as smart EV charging, PV smoothing, etc.
  - Can make context-dependent tradeoffs between competing goals
  - Can enforce both hard (physical) and soft (objective) constraints
  - High loop rate allows it to quickly respond to changes
  - Simple and inexpensive to implement
- **Disadvantages:**
  - No guarantee of optimality
- **Future work:**
  - Detailed comparison with optimization-based HEMS controllers
  - Hybrid Behavioral and Optimizing HEMS controllers?

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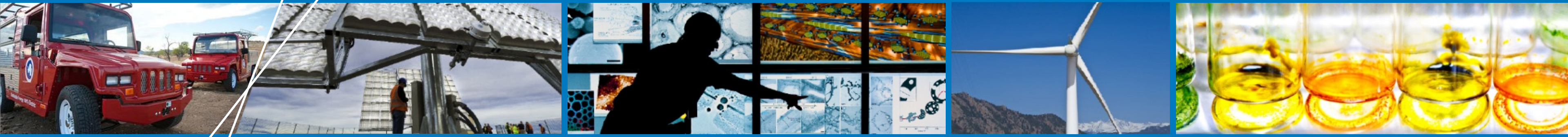

Questions?

Relevant Literature

• Background on Behavioral Control:

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R. A. Brooks, "A robust layered control system for a mobile robot," *Robotics and Automation, IEEE Journal of,* 1986.

R. A. Brooks, "Elephants don't play chess," *Robotics and Autonomous Systems,* 1990.

• Behavioral-like approaches to power device control:

P. T. May-Ostendorp, G. P. Henze, B. Rajagopalan, and C. D. Corbin, "Extraction of supervisory building control rules from model predictive control of windows in a mixed mode building," *Journal of Building Performance Simulation,* 2013.

I. Koutsopoulos, V. Hatzi, and L. Tassiulas, "Optimal energy storage control policies for the smart power grid," in *Smart Grid Communications (SmartGridComm), 2011 IEEE International Conference on*, 2011

S. Barker, A. Mishra, D. Irwin et al, "SmartCap: Flattening peak electricity demand in smart homes," in *Pervasive Computing and Communications (PerCom), 2012 IEEE International Conference on*, 2012

• Example power control types usable as behaviors:

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A. Ellis, D. Schoenwald, J. Hawkins, S. Willard, and B. Arellano, "PV output smoothing with energy storage," in *Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE*, 2012.

S. Abdelrazek and S. Kamalasadan, "Integrated control of battery energy storage management system considering PV capacity firming and energy time shift applications," in *Industry Applications Society Annual Meeting, 2014 IEEE*, 2014.