UNIVERSITY OF MICHIGAN-DEARBORN

Stochastic Day-Ahead Resource Scheduling for Economic Operation of Residential Green House

Yi Guo, Jingwei Xiong**,** Xuanchen Liu, and Dr. Wencong Su
Department of Electrical and Computer Engineering
University of Michigan-Dearborn

galvin center for electricity innovation at ILLINOIS INSTITUTE OF TECHNOLOGY

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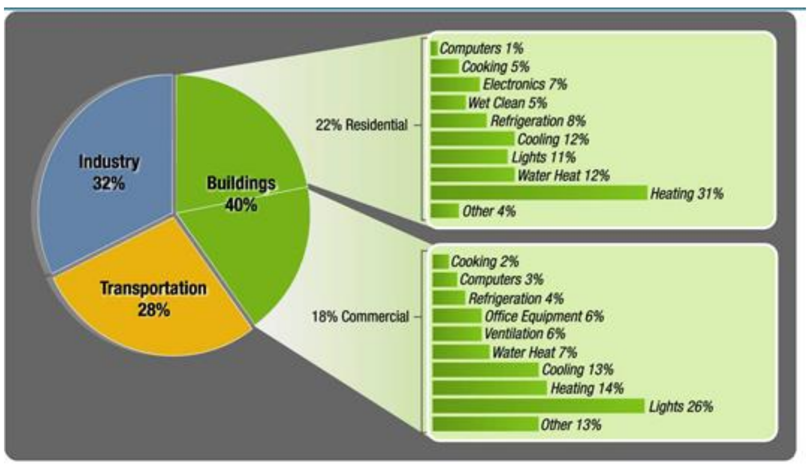
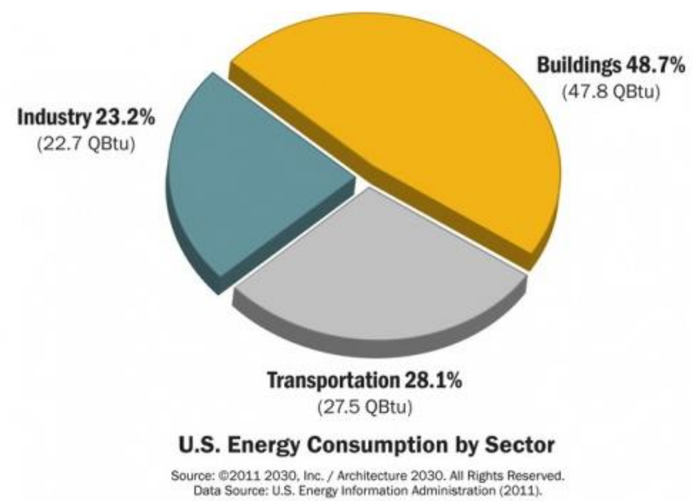
Background:

- Commercial and residential buildings consumed almost 40% of the primary energy and approximately 70% of the electricity in United States
- The energy used by the buildings sector accounts for approximately 47% of the country's carbon emissions and continues to increase.



Data Source: U.S. Energy Information Administration (EIA)

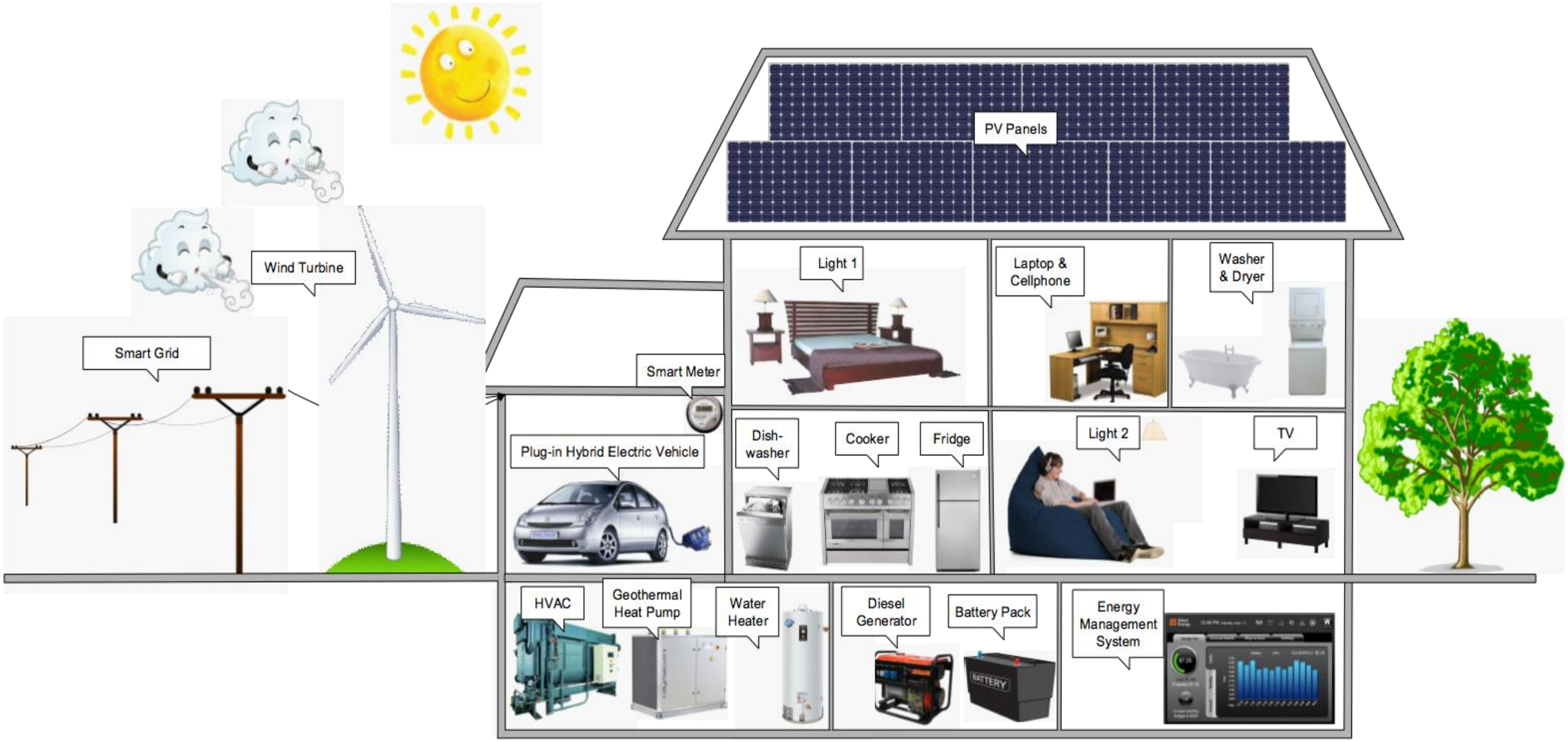


Motivations:

- Increase the utilization of distributed renewable energy resources
- Reduce carbon emissions and non-renewable resource consumption
- Need a promising solution from economic, environmental and political perspectives

Objectives:

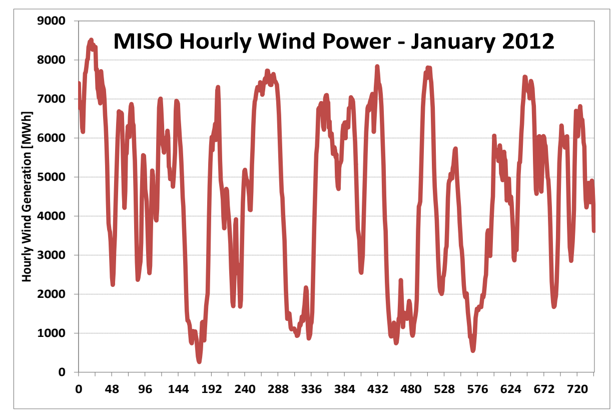
- To utilize as much self-generated renewable electricity as possible to satisfy the power demand of residential green house (RGH)
- To minimize the day-ahead operational cost of RGH while satisfying customer’s preference and various operational constraints



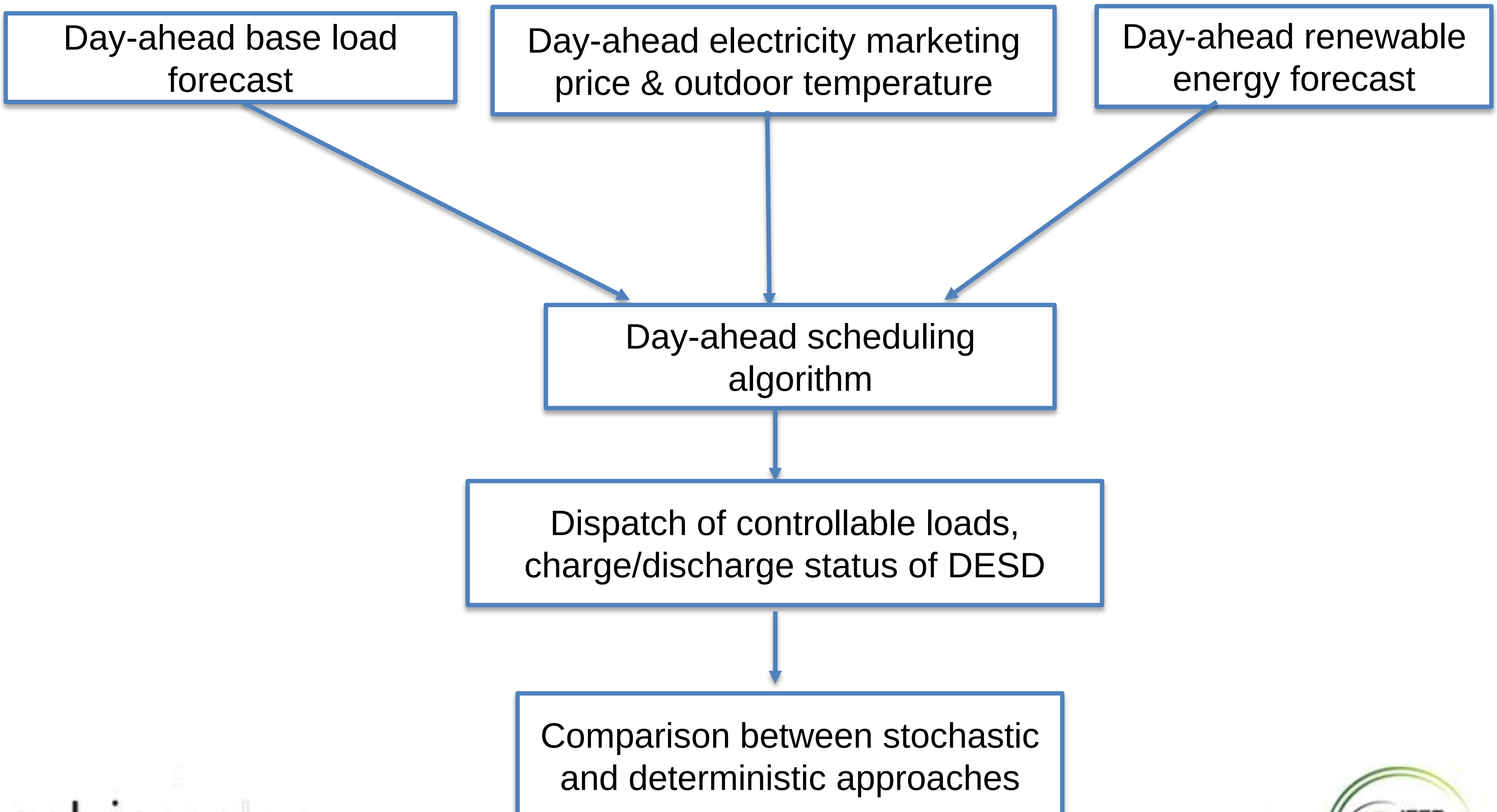
- On-site renewable energy generation (e.g., PV panel, wind turbine)
- Distributed energy storage devices (e.g., electric vehicle, battery pack)
- Controllable load (e.g., smart appliances)

Challenges:

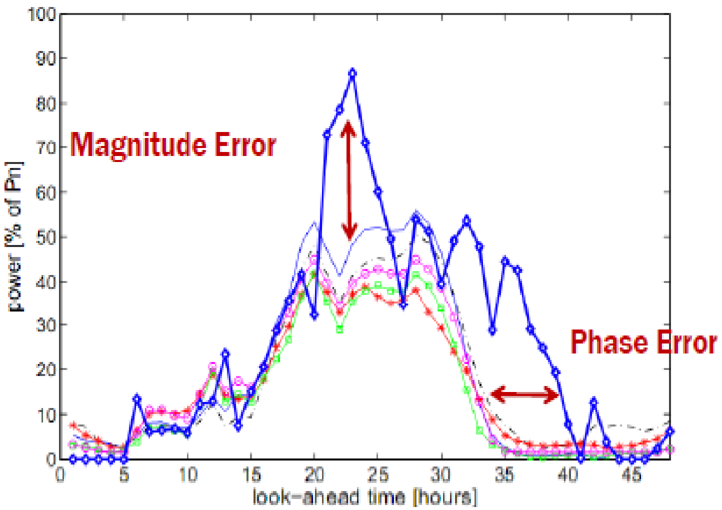
- Uncertainty: The inherent intermittency and variability of distributed renewable energy resources (e.g., wind and solar) complicate the real-world operations.
- Forecasting error of renewable generation is still large
- Need to satisfy a number of physical and cyber constraints, as well as customer's preference
- Self-confined and self-balanced small system
- Utilities are concerned about how the high penetration of RGH will affect the grid stability.
- Need a well-justified business model



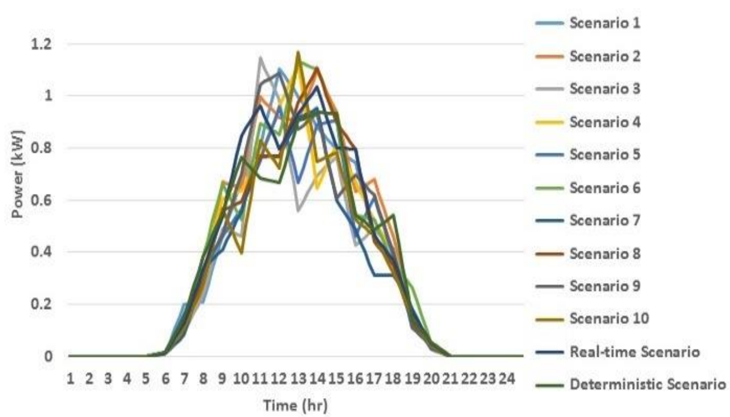
The Day-ahead Resource Scheduling Process



- The deterministic approach is sensitive to the point forecasting errors.



Uncertainty Representation	
Probabilistic	Quantiles
	Interval Forecasts
	Probability Mass Function
	Probability Density Function
Risk Indices	Meteo Risk Index
	Prediction Risk Index
Scenarios of Generation	Scenarios with Temporal Dependency
	Scenarios with Spatial/Temporal Dependency



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- Formulated the scenario-based stochastic energy scheduling
- Explicit representation of the uncertainty in problem formulation
- Minimize the **expectation** of costs

$$f_{total} = f_{grid} + f_{DESD} + f_{solar}$$

Dispatch of controllable loads

Charge/discharge status of DESD

$$f_{grid} = \sum_t \rho_t \times [P_U^t + P_H^t + u_C^t P_C + u_D^t P_D + prob^s \times \sum_s (u_{B,c}^t P_{B,c}^{t,s} - u_{B,d}^t P_{B,d}^{t,s} - P_G^{t,s})]$$

Electricity price at t-th interval

Probability of scenarios

Solar generation at t-th interval in scenario s

$$f_{DESD} = \sum_t \eta \times prob^s \sum_s (u_{B,c}^t P_{B,c}^{t,s} + u_{B,d}^t P_{B,d}^{t,s})$$

Degradation cost of DESD during charge/discharge process

ρ_t : day-ahead electricity marketing price ($/kWh) at t-th time interval.
P_U^t & P_H^t : the power consumption rate (kW) of uncontrollable loads and HVAC system, respectively, at t-th time interval
$P_{B,c}^{t,s}$ & $P_{B,d}^{t,s}$: DESD (e.g. battery banks) charging and discharging process in scenario s, at t-th time interval
$P_G^{t,s}$: the on-site renewable generation (kW) in scenario s, at t-th time interval
P_C & P_D: the rated power (kW) of clothes washer and dryer
$prob^s$: an equal probability of all the scenarios
u_C^t, u_D^t, $u_{B,c}^t$ & $u_{B,d}^t$: the ON/OFF status (e.g. 1/0) of clothes washer, dryer, charge and discharge process of DESD, respectively
η : the degradation cost coefficient ($/kW) for DESD.

System constraints:

- Local constraints of controllable loads

$$\sum_{t=1}^{t_C^l} u_C^t \geq 1, \qquad \sum_{t=1}^{t_D^l} u_D^t \geq 1,$$

$$-u_C^t + u_C^{t+1} - \frac{1}{t_C^o - 1}\sum_{i=t+2}^{t+t_C^o} u_C^i \leq 0$$

$$-u_D^t + u_D^{t+1} - \frac{1}{t_D^o - 1}\sum_{i=t+2}^{t+t_D^o} u_D^i \leq 0$$

$$\sum_{t=1}^{M} u_C^t \geq t_C^o * u_D^{M+1}, 1 \leq M \leq N-1$$

- DESD limits
  - $(\text{SoC}_{min} - \text{SoC}_{init}) \times P_B^{total} \leq \sum_1^N P_{B,c}^t - \sum_1^N P_{B,d}^t \leq (\text{SoC}_{max} - \text{SoC}_{init}) \times P_B^{total}$
  - $u_{B,c}^t c \leq P_{B,c}^t \leq u_{B.c}^t P_B^{max}$
  - $u_{B,d}^t P_B^{min} \leq P_{B,d}^t \leq u_{B,d}^t P_B^{max}$
  - $u_{B,c}^k + u_{B,d}^k \leq 1$
  - $P_{B,c}^t + P_C + P_D - P_G^t + P_U^t + P_H^t \geq P_{B,d}^t$

Optimization Framework:

CPLEX:

- Solve MILP optimization problems
- Minimize the operating cost

Matlab:

- Formulate/update the optimization problem and constraints
- Route the optimal control variables

System Inputs:

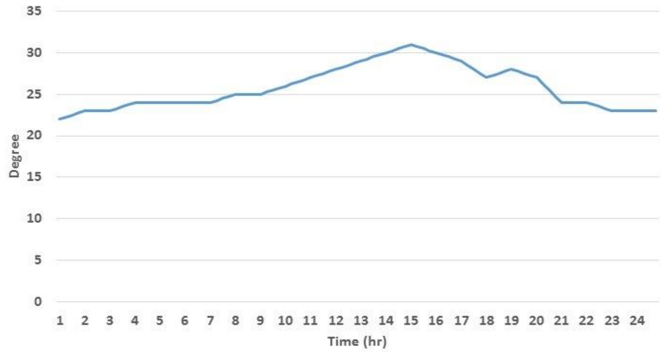


Figure 1. The outdoor temperature

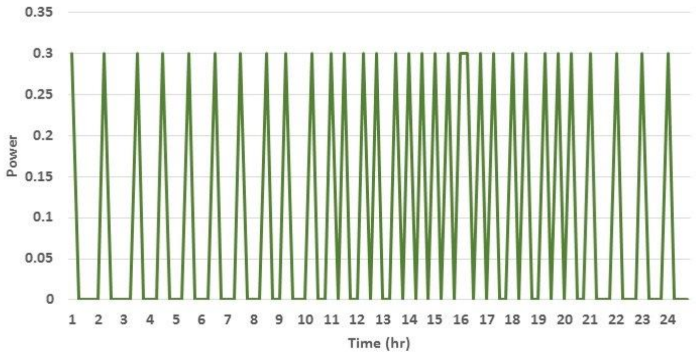


Figure 2. The corresponding HVAC operation

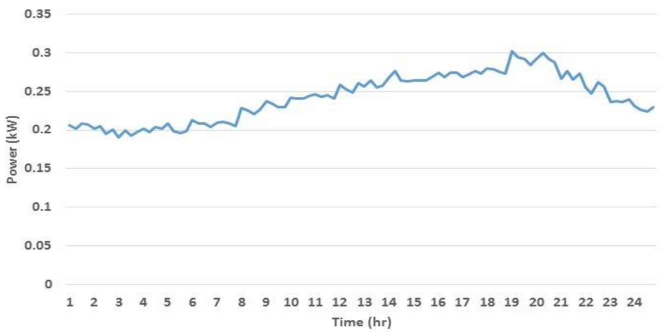


Figure 3. uncontrollable load profile

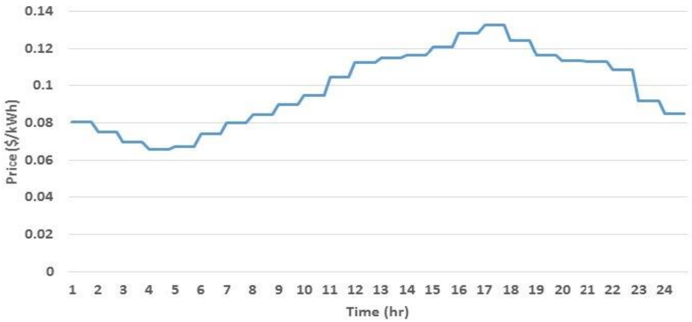
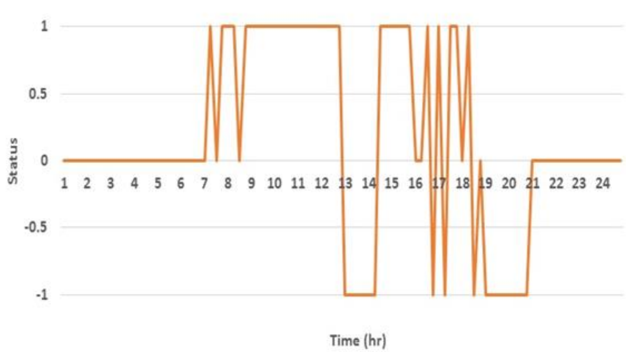


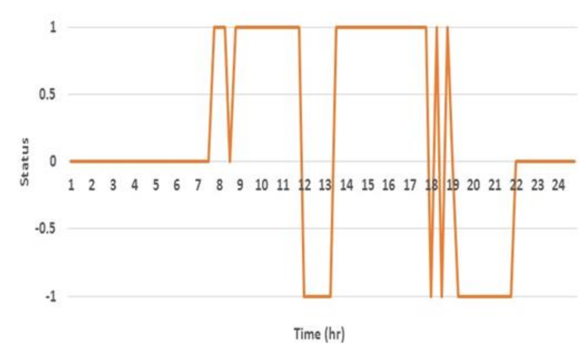
Figure 4. The day-ahead electricity data from utility company

Result Analysis

- Compared the charge/discharge/standby mode of DESD and the optimal dispatch of controllable loads using both stochastic and deterministic modeling

Load	Cloth Washer	Dryer
Stochastic	***3:00 am – 4:00 am***	***11:15 am – 12:45 pm***
Deterministic	***3:00 am – 4:00 am***	***9:15 am – 10:45 pm***

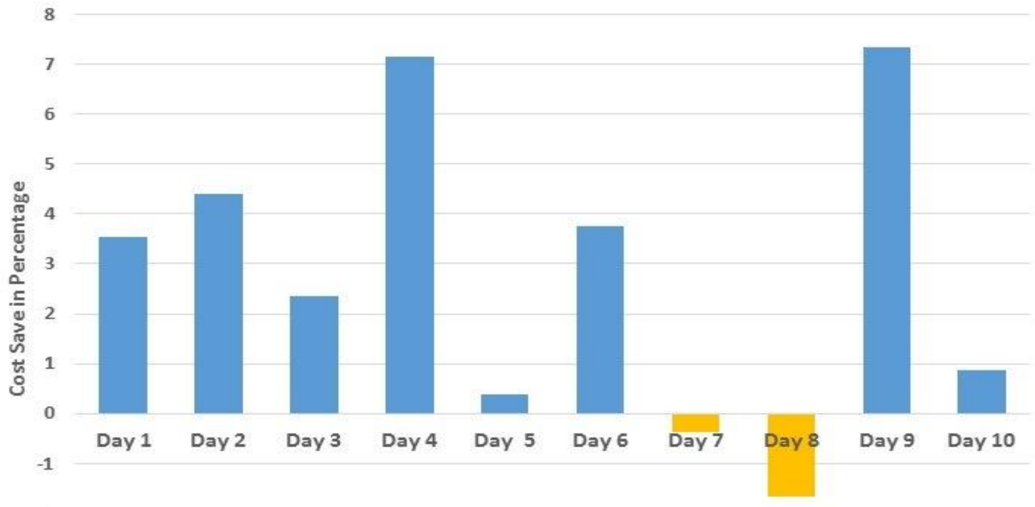




DESD charge/standby/discharge (1/0/-1) Status in Deterministic and Stochastic Case

Result Analysis

- Evaluated the performance of day-ahead energy scheduling by running a economic dispatch simulation that takes into account the actual value of solar power instead of forecasted values
- Demonstrated the notable cost savings of the proposed stochastic approach over deterministic approach over 10 different days



The cost savings of stochastic modeling over deterministic modeling

Future Work

- The existing framework can be extended to real-time operation design with the consideration of real-time weather input, customer preference and comfort level
- This design can be scaled up to a community prospective, since renewable generation facilities will be more easily accessible in the future, every single home can self-generate electricity and participate into the electricity market
- Adopt distributed control approaches (e.g. Distributed Model Predictive Control) to perform real-time power dispatch
- ……

Thank You