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Optimization-based Management of Energy Systems

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May 11, 2010

for

ENVIRONMENT,ENERGY SECURITY & SUSTAINABILITY SYMPOSIUM & EXHIBITIONE2S2

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **MAY 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**
4. TITLE AND SUBTITLE **Optimization-based Management of Energy Systems**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United Technologies Research Center,411 Silver Lane,East Hartford,CT,06108**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Presented at the NDIA Environment, Energy Security & Sustainability (E2S2) Symposium & Exhibition held 9-12 May 2011 in New Orleans, LA. U.S. Government or Federal Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

Why Distributed Power Systems / Energy Microgrids?

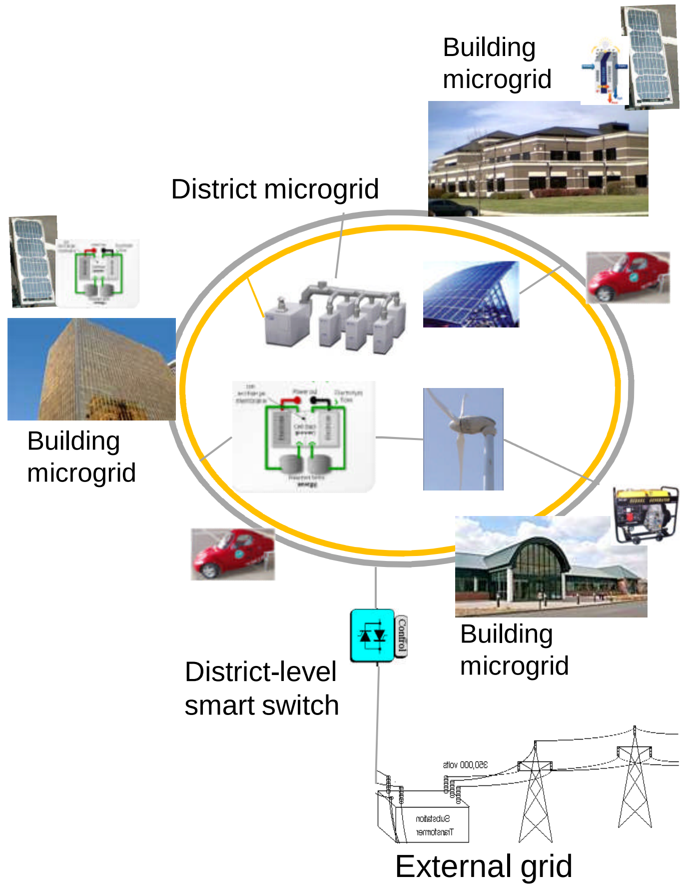
Security of supply, reduced energy, and minimized environmental impact

Security of energy supply

- ***Vulnerable loads*** served under all operating conditions.
- 'Customizable' ***power quality and reliability***
- **Seamless transition** between islanding and off-grid operation

Reduced energy costs and environmental impact

- Improved power systems architectures
  - ***Waste heat utilization***
    - 85-90% fuel utilization vs. 40-50% for central power
  - ***Renewable sources with energy storage***
  - ***Maximize ROI***
- Integrated demand/supply management:
  - ***Reduced energy consumption/cost,***
  - ***Peak shaving***
- **Decrease** in T&D **losses and** required **infrastructure**



- **Energy microgrids are distributed power systems with the capability to work seamless in islanding and grid-connected modes.**
- **They include thermal and electrical systems**

Energy Microgrids and Energy Management System (EMS)

Value and benefits

Objective

- To evaluate the benefits of microgrid and optimization-based supervisory system
- To understand the impact of equipment down-time and the value of perfect weather/loads information

Challenges

- Uncertainty in data and forecasts
- Results depend on microgrid architecture, weather and prices

Test cases architectures

- Determined by minimizing initial cost with renewable usage constraints

	NC	CO	OK	NY	TX
Grid	Yes, unlimited	Yes, unlimited	Yes, unlimited	Yes, unlimited	Yes, unlimited
Solar PV (KW)	35 MW	0	0	0	20 MW
Wind turbines(kW)	65 MW	70 MW	65 MW	55 MW	50 MW
CHP (microturbines+absChiller)	5 MW microturbines	17.5 MW microturbines	35 MW microturbines	27.5 MW microturbines	12.5 MW microturbines
Diesel generators	4 MW	2 MW	8 MW	12 MW	2 MW
Batteries, LiI (kWh capacity)	1 MWh	1 MWh	1 MWh	1 MWh	1 MWh

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Energy Microgrids and Energy Management System (EMS)

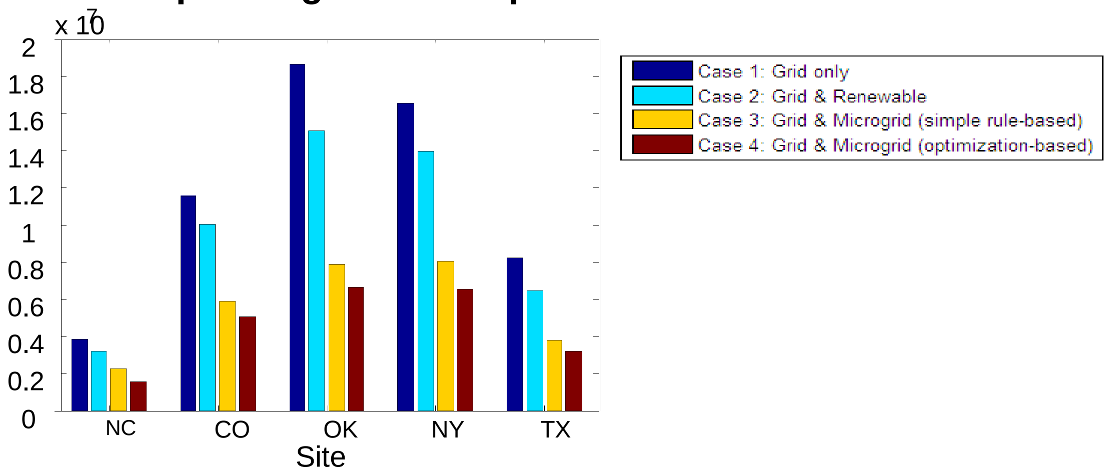
Value and benefits: Optimization-based EMS could provide 5-20% cost savings compared to ruled base approaches

Key Results

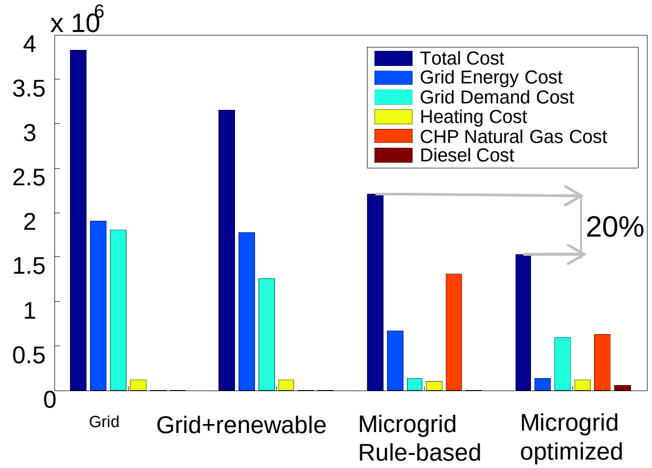
✓ Feasible microgrids architectures are able to provide 50-60% annual operating cost reduction

✓ Optimization-based supervisory microgrid control provides an average annual 5-20% cost reduction compared with simple rule-based control strategy

Annual Operating Cost Comparison



Operating Cost by Category (Site: NC)



Annual Cost Savings of Microgrid	NC	CO	OK	NY	TX
Scenario 2 (Grid & Renewable)	17%	13%	19%	16%	21%
Scenario 3 (Grid & Microgrid, Rule-based)	41%	49%	58%	51%	54%
Scenario 4 (Grid & Microgrid, Optimization-based)	60%	56%	64%	61%	61%
CO_2 Reduction					
Scenario 4 (Grid & Microgrid, Optimization-based)	33%	35%	36%	35%	36%

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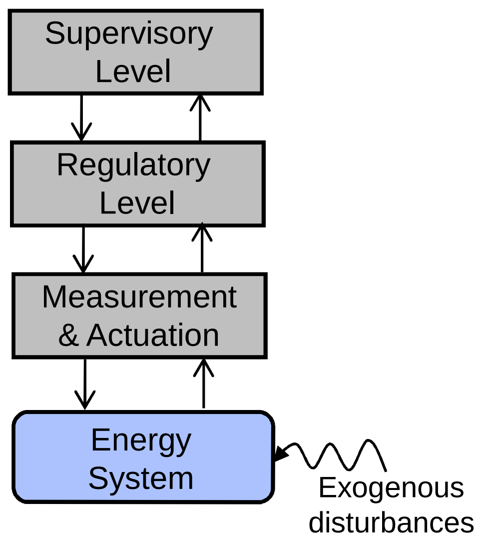
Energy Management System for Energy Systems

Overview

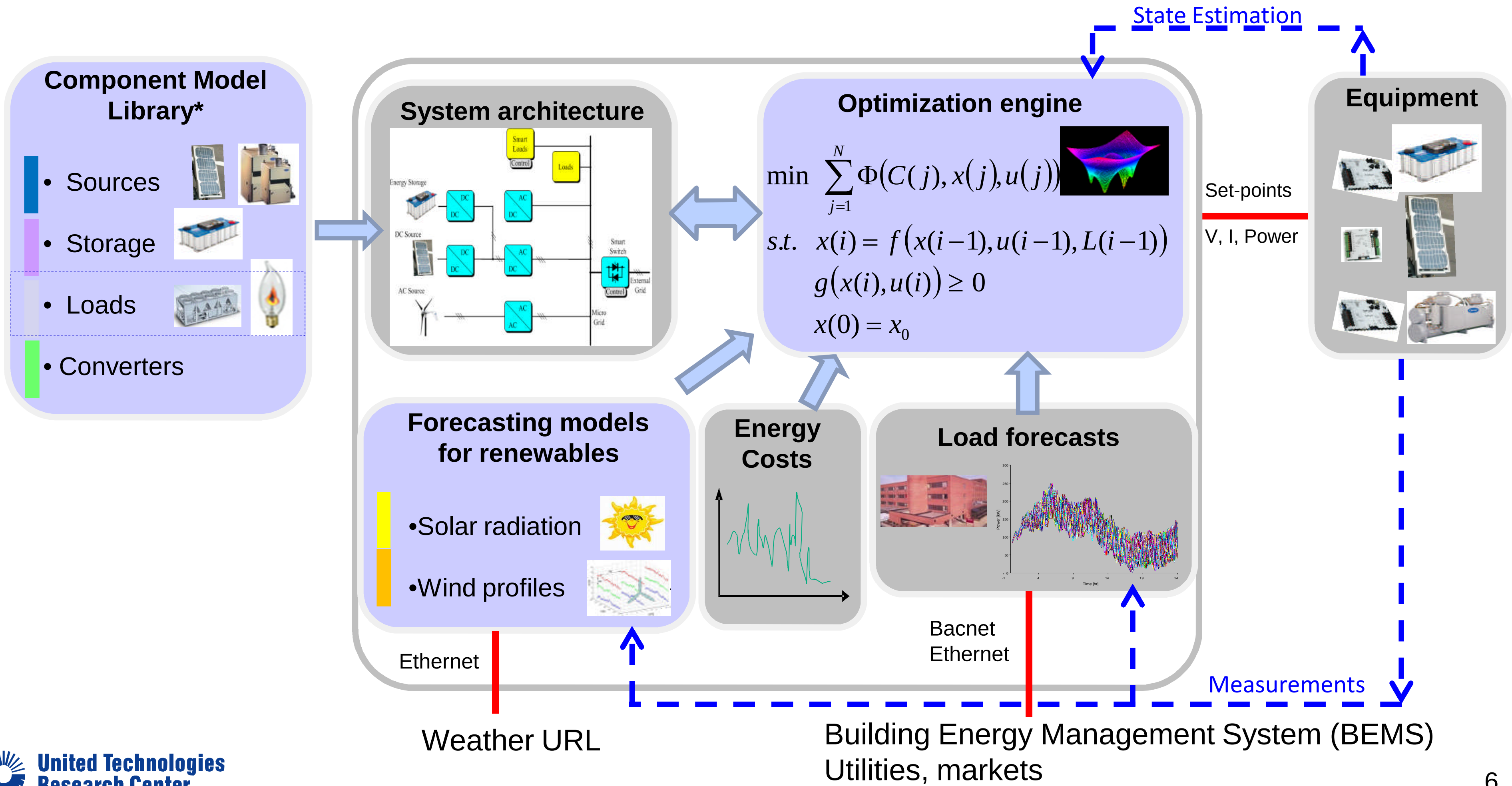
- Energy Management System (EMS) performs effective coordination and dispatching of distributed energy resources
  - Functionally similar to economic dispatch & unit commitment in power systems
  - Selects combination of sources and storage to meet demand
  - Considers constraints on availability of supply and operational limitations
  - Interfaces with customers and utilities
- Conventional dispatching systems are optimization-based and use steady-state models
- Renewable intermittency and memory associated with storage require planning and forecasting
- Systematic decision-making with uncertainties in demand and availability of renewable resources



Energy Management System Framework

EMS performs effective *coordination* and *dispatching* of distributed energy resources

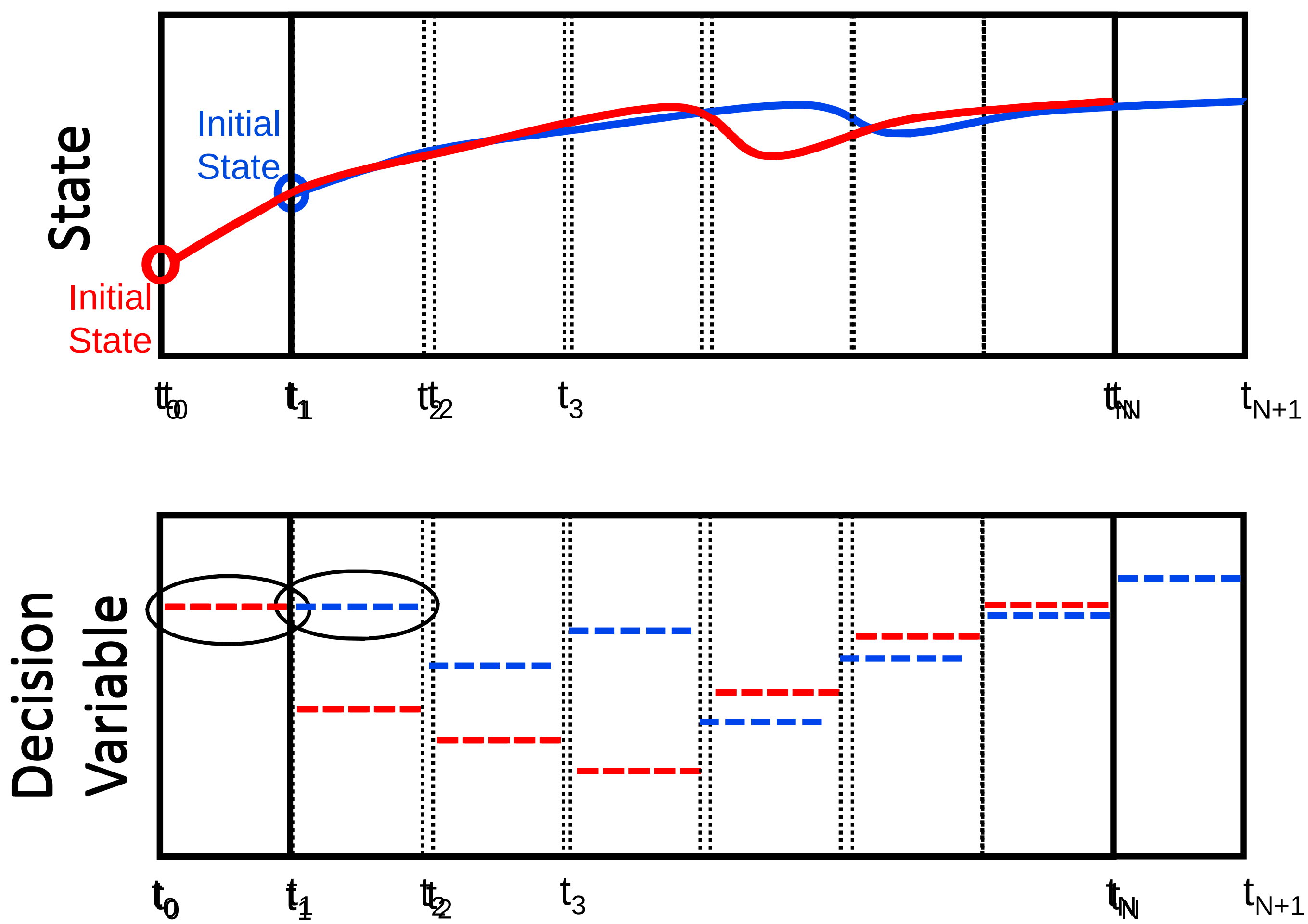
- Renewable intermittency and memory associated with storage → planning & forecasting
- Combines elements of forecasting, model prediction, and state estimation
- Repeated solution of finite-horizon stochastic programming problems



Energy Management System Framework

Real-time Model Predictive Methodology

Repeated decision-making over finite horizons



Energy Management Framework: *Dealing with Uncertainties*

Handling Uncertainties in Predicting Energy Resources and Load Profiles

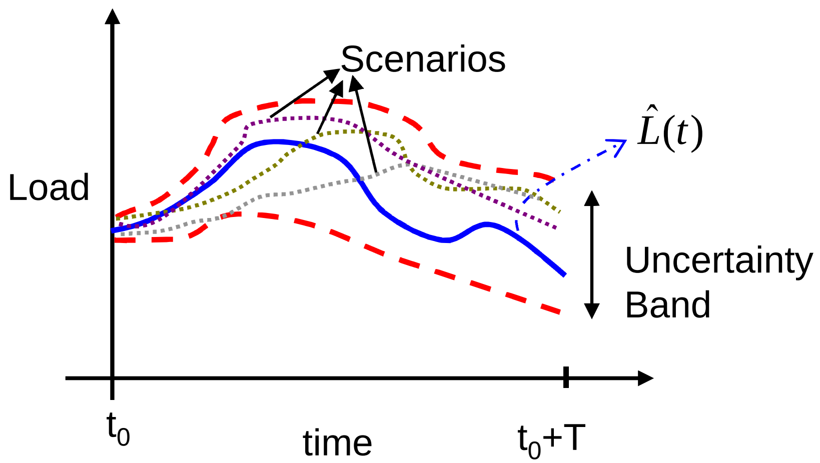
- Operational decisions have to be made in the face renewable resources and load forecast uncertainty.
- We explored different methods to determine set-points for optimal operation

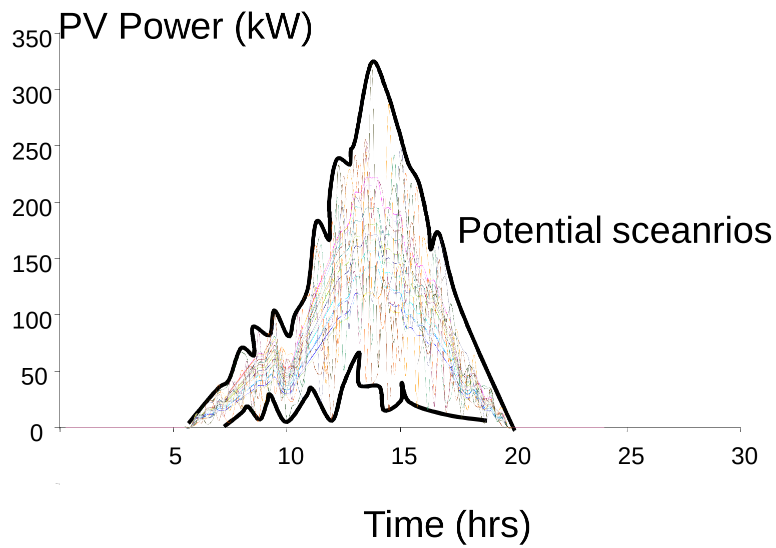
  Method 1, Perfect information: Use perfect/exact forecast

  Method 2, expected-value solution: Use the average of different forecasted scenarios

  Method 3, stochastic solution: Factors uncertainties for decision-making using a stochastic programming formulation. It assumes that:

  - It is impossible to find a solution that is ideal under all circumstances
  - Decisions are balanced, or hedged against the various scenarios





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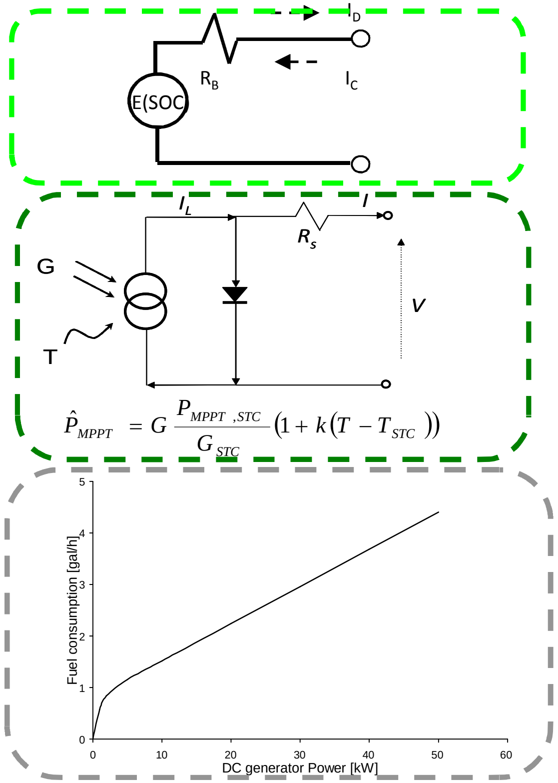
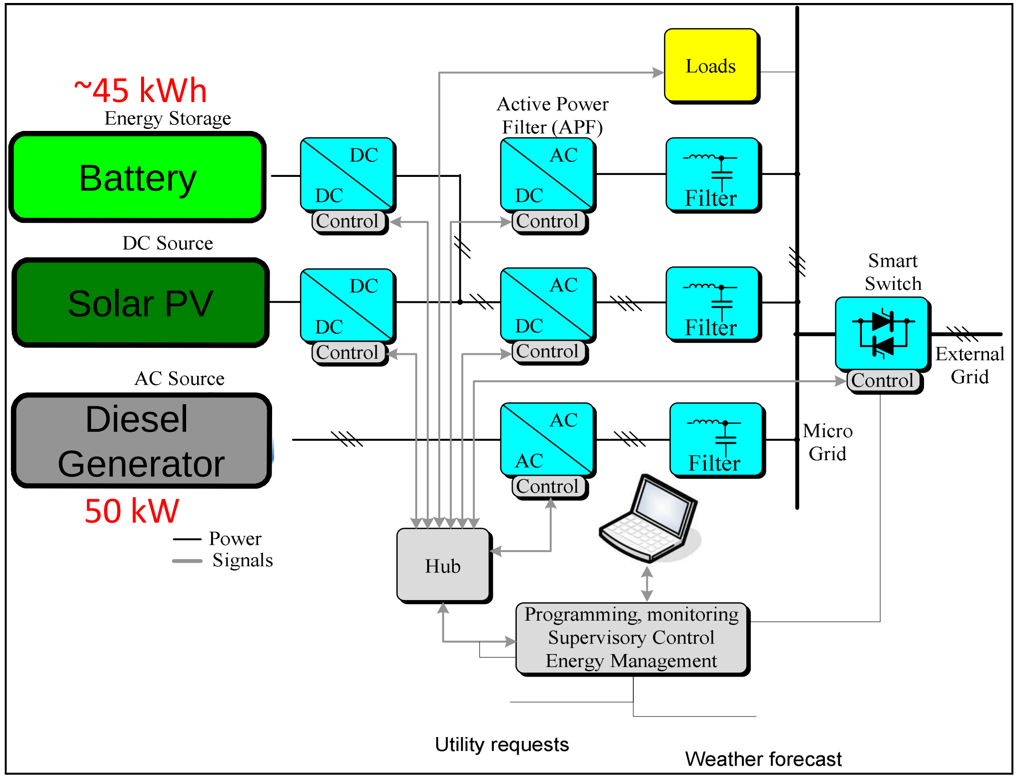
Energy Management Framework: *Dealing with Uncertainties*

System used to exploit Methods of Dealing with Uncertainties





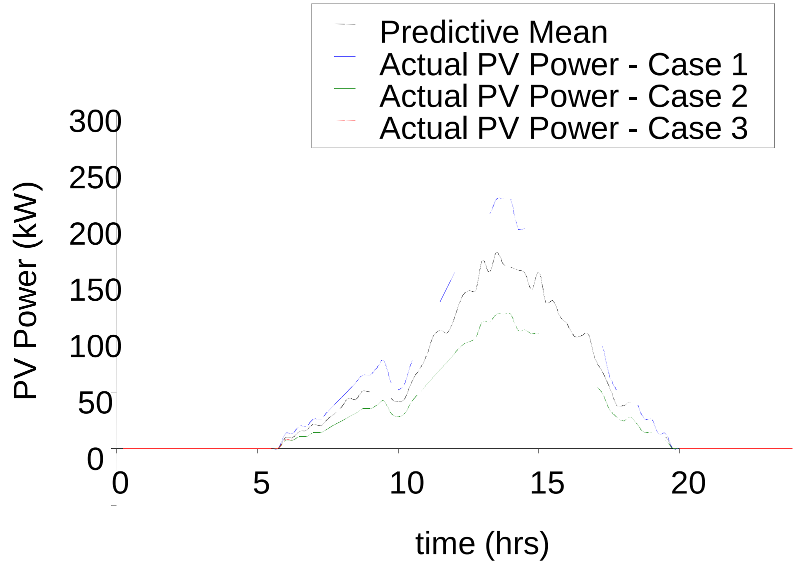
- Grid-connected system
- Realistic cost data; objective to minimize monthly operating cost
- Load forecast is exact (can be easily relaxed)
- 24 hr horizon with 15 minute time-step

Energy Management Framework: *Dealing with Uncertainties*

Test Cases used to exploit Methods of Dealing with Uncertainties

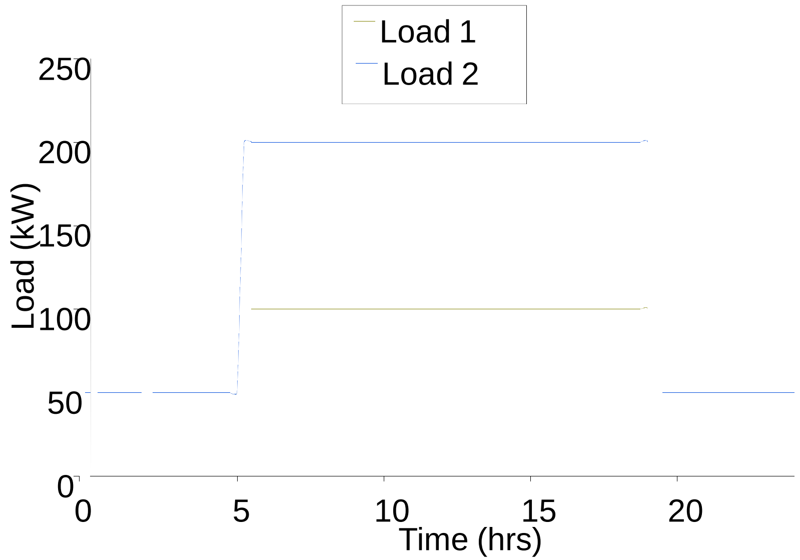
Solar Radiation Forecast:

- Three cases (and predictive mean) considered
- Error in solar radiation forecast translates to error in PV power



Loads Forecast

- Two cases to capture effect of sizing and component interaction
  - Load 1: Load comparable to onsite generation capability
    - Stronger interaction between microgrid components
    - “Good” sizing of micro-grid towards grid independence
  - Load 2: Load larger than onsite generation
    - Weak interaction between microgrid components
    - Grid dependence



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Energy Microgrid Framework Test Cases : Results

Exploring Methods of Dealing with Uncertainties

- Maximum cost of perfect information = Expected value of perfect information
  - Average cost difference between Method 3 and Method 1

Load 1 (Loads comparable with onsite power generation capacity)

	Method 1 Perfect Information	Method 2 Use Predictive mean	% Deviation Method 1 & Method 2	Method 3 Stochastic Programming	% Deviation Method 1 & Method 3
Case 1	**$6,404**	**$6,534**	**2.0**	**$6,694**	**4.5**
Case 2	**$8,331**	**$9,246**	**11.0**	**$8,344**	**0.2**
Case 3	**$7,429**	**$7,908**	**6.4**	**$7,560**	**1.8**
			Avg: 6.46%		Avg: 2.16%

Load 2 (Loads larger with onsite power generation capacity)

	Method 1 Perfect Information	Method 2 Use Predictive mean	% Deviation Method 1 & Method 2	Method 3 Stochastic Programming	% Deviation Method 1 & Method 3
Case 1	**$14,020**	**$14,152**	**0.9**	**$14,157**	**1.0**
Case 2	**$17,996**	**$18,121**	**0.7**	**$18,082**	**0.5**
Case 3	**$16,161**	**$16,683**	**3.2**	**$16,489**	**2.0**
			Avg: 1.6%		Avg: 1.6%

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Energy Management Framework: Conclusions

Future Work and Implementation

Conclusions:

- Stochastic programming helps with decision making under uncertainty
- Stochastic programming tools can drastically reduce the value of perfect information
- Sizing, architecture and magnitude of loads dictate the required accuracy of forecasts

Future work:

- Include equipment reliability in the models / problem formulation
- Extension to include thermal power
- Extension to include load management (combined supply / demand)

The Energy Management Framework introduced in this presentation will be implemented in two energy microgrids demonstrations being prepared for DoD-ESTCP and DoE funded programs