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The Value of Accurate Forecasts and a Probabilistic Method for Robust Scheduling of Residential Distributed Energy Resources

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Presentation Outline

- 'Smart' homes
- DER scheduling in a 'smart' home
  - Optimize acquisition of energy services
  - Quantify the importance of using accurate forecasts
  - Scheduling under forecast uncertainty
- Energy service decision-support tool
- Demonstration using the 'smart' home case study
- Conclusions

'Smart' Homes

- Objectives
  - energy management
  - comfort and security
  - health care and assistance
- Enabling technologies
  - smart appliances
  - sensors
  - networks
  - intelligence and control

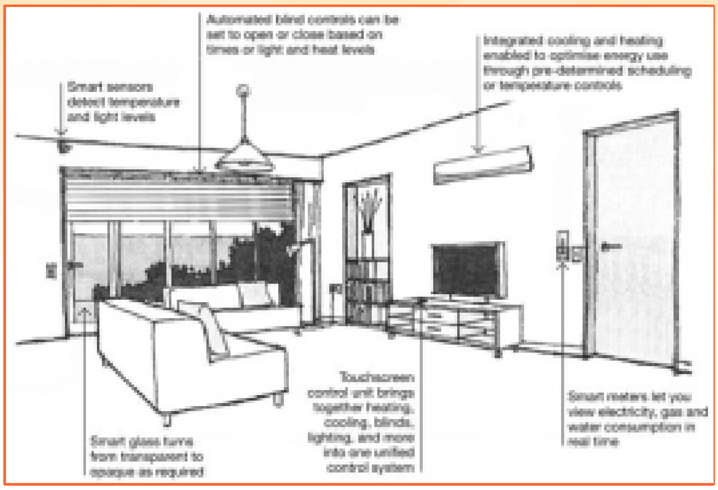


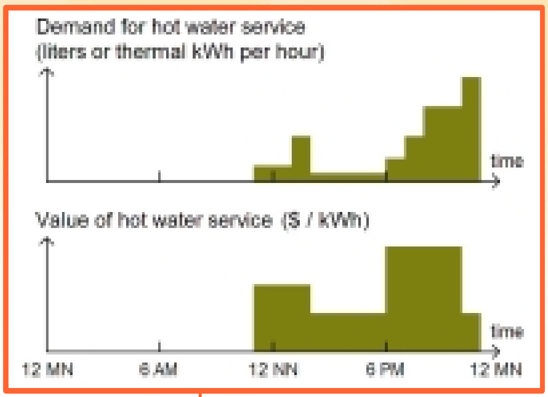
image from www.yourhome.gov.au

DER Scheduling for 'Smart' Homes

- Distributed energy resources
- Scheduling of DER to optimize acquisition of energy services
- Deterministic scheduling
  - Formulate schedule based on forecasted information
  - Demand, occupancy, weather, electricity price, etc.
- Energy service decision-support tool
- Value of making accurate forecasts
  - Determination
  - Demonstration using a case study
- Robust scheduling under uncertainty
  - Approach to formulating robust schedules
  - Demonstration using a case study

Energy Service Decision-Support Tool*

- Energy service model
  - Temporal variation of demand
  - Temporal variation of value
- DER Scheduler
  - Schedule the operation of DER to maximize the net benefit of energy services
  - Net benefit = "benefit derived from availability of service" – "cost of provision"
  - Schedules are solved using co-evolutionary particle swarm optimization

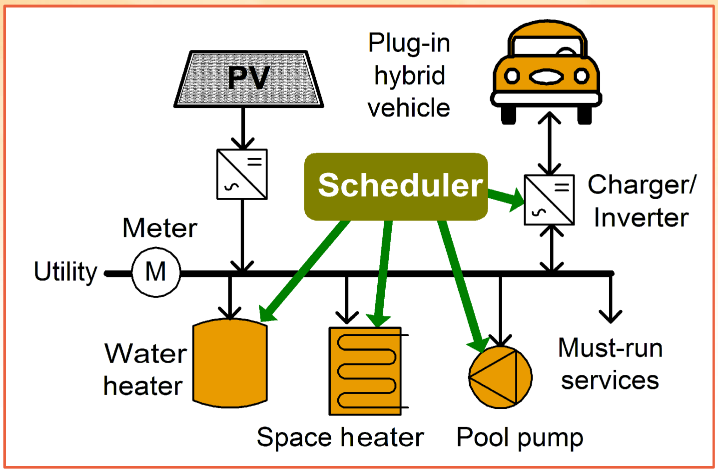


$$\sum_{t=1}^{T}\left(\left(\sum_{i=1}^{S}\lambda_{ES,i}(t)U_{ES,i}(t,\mathbf{x})\right)-Cost\right)$$

* M. A. Pedrasa, E. D. Spooner and I. F. MacGill, "Improved energy service provision through the intelligent control of distributed energy resources," 2009 IEEE Bucharest PowerTech Conference, Bucharest, Romania, Jun 2009.

Case Study: Description

- Services to provide
  - Space heating
  - Hot water
  - PHEV charging
  - Pool pumping
  - Others
- DER
  - Space heater
  - Water heater
  - Pool pump
  - PHEV
  - PV system
- Electricity tariff



Time-of-Use (ToU) Interval	Rate ($/kWh)
Peak: 2 – 8 PM	0.3564
Shoulder: 7 AM – 2 PM, 8 – 10 PM	0.1408
Off-peak: 10 PM – 7 AM	0.0814
Critical peak price (CPP): 5 – 8 PM	2.000

Value of Accurate Forecasts

- Scheduling under uncertainty
- Implement schedules optimized for other scenarios to the scenario that turned out
  - Compare against the correct schedule
  - Incur additional costs
- Value of accurate forecast = avoided costs if the forecast is accurate

DESCRIPTION OF SCENARIO SxDxBxCx

Condition	Value of *x*: 1	Value of *x*: 0
S: Solar insolation	Sunny	Cloudy
D: Demand for must-run and hot water service	Normal	Low
B: PHEV available as storage DER (8 AM to 5 PM)	Yes	No
C: Critical Peak Pricing	Yes	No

Value of Accurate Forecasts

Implemented schedules

Scenario corresponding to the implemented schedule

Actual Scenario	1 S1D1 B1C0	2 S0D1 B1C0	3 S1D0 B1C0	4 S0D0 B1C0	5 S1D1 B0C0	6 S0D1 B0C0	7 S1D0 B0C0	8 S0D0 B0C0	9 S1D1 B1C1	10 S0D1 B1C1	11 S1D0 B1C1	12 S0D0 B1C1	13 S1D1 B0C1	14 S0D1 B0C1	15 S1D0 B0C1	16 S0D0 B0C1
1 S1D1B1C0	**\$3.91**	0%^{S}	90%^{D}	95%	15%^{B}	15%	105%	105%	15%^{C}	15%	95%	95%	30%	30%	120%	120%
2 S0D1B1C0	0%^{S}	**\$6.01**	60%	60%^{D}	10%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20%	20%	80%	80%
3 S1D0B1C0	0%^{D}	5%	**\$1.44**	0%^{S}	40%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80%	80%	80%	75%
4 S0D0B1C0	0%	0%^{D}	0%^{S}	**\$3.54**	15%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30%	30%	30%	30%
5 S1D1B0C0	0%^{B}	0%	75%	75%	**\$4.79**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10%^{C}	10%	85%	85%
6 S0D1B0C0	0%	0%^{B}	50%	55%	0%^{S}	**\$6.88**	50%	50%^{D}	10%	10%	55%	50%	10%	10%^{C}	60%	60%
7 S1D0B0C0	0%	0%	0%^{B}	0%	0%^{D}	0%	**\$2.31**	0%^{S}	25%	25%	0%	0%	25%	25%	25%^{C}	25%
8 S0D0B0C0	0%	0%	0%	0%^{B}	[illegible]	[illegible]	0%^{S}	**\$4.41**	15%	15%	0%	0%	15%	15%	15%	15%^{C}
9 S1D1B1C1	100%^{C}	95%	150%	155	[illegible]	[illegible]	155%	155%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10 S0D1B1C1	75%	75%^{C}	115%	120	[illegible]	[illegible]	120%	120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11 S1D0B1C1	260%	255%	270%^{C}	285%	315%	300%	290%	290%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12 S0D0B1C1	110%	105%	110%	120%^{C}	130%	125%	120%	120%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13 S1D1B0C1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	30%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14 S0D1B0C1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15 S1D0B0C1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16 S0D0B0C1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10%^{C}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

\$14.02	0%^{S}	25%^{D}	25%
0%^{S}	**\$16.11**	20%	20%^{D}
0%^{D}	0%	**\$5.30**	0%^{S}
0%	0%^{D}	0%^{S}	**\$7.39**

Sunny, normal demand, no PHEV, no CPP

worst

Sunny, low demand, with PHEV, with CPP

Actual day

Tariff: ToU energy + ToU feed-in + Occassional CPP

Value of Accurate Forecasts

- Tariff 1: ToU energy + ToU net feed-in
  - No value in making accurate solar insolation forecast
  - Significant value in making accurate (a) demand, (b) PHEV availability, and (c) CPP forecasts
- Tariff 2: ToU energy + no payment to any export
  - Significant value in making accurate (a) solar insolation, (b) demand, and (c) PHEV availability forecasts
  - Value in making accurate CPP forecasts is less significant

Robust Scheduling Under Uncertainty

- Determine schedule *x* that maximizes the *expected* net benefit over all plausible future outcomes

$$\sum_{n=1}^{N} \pi_n \cdot F(x, Sc_n)$$

forecasted probability of scenario Sc_n

resulting net benefit when schedule x is used during scenario Sc_n

Robust Scheduling Under Uncertainty

- CPP forecast uncertainty (Tariff: ToU energy + ToU net feed-in)
  - CPP not likely to happen (10% prob.)
  - CPP likely to happen (90%)
  - CPP can go either way (50%)

Actual scenario[1]:	Implemented schedule, assuming CPP probability = π_C				
	0%	100%	10%	50%	90%
No CPP	**3.91**	4.49	3.93	3.94	4.51
With CPP	13.99	**7.06**	7.67	7.64	7.06
Expected cost	3.91	7.06	4.30	5.79	6.81

[1] The end-users are certain that it is sunny, demand is normal, and the PHEV is available as storage.

Robust Scheduling Under Uncertainty

- Solar insolation and demand forecast uncertainty (Tariff: ToU energy + no payment for any export)
  - Most likely to be sunny (80%)
  - Probably demand is normal (60%)

Actual scenario	Assumed proba-bility	Schedule for scenario S1D1 B1C0	S1D0 B1C0	S0D1 B1C0	S0D0 B1C0	Robust schedule x_R
S1D1B1C0	48%	**4.32**	8.22	4.80	8.53	4.37
S1D0B1C0	32%	2.75	**2.11**	3.20	2.49	2.18
S0D1B1C0	12%	6.41	10.23	**6.02**	9.75	6.46
S0D0B1C0	8%	4.77	4.15	4.31	**3.63**	4.24

Conclusions

- We were able to demonstrate
  - how to determine the value of making accurate forecasts using the ES-DST
    - results enable end-users to identify which forecasted information are crucial to making optimal schedules
  - how to formulate robust schedules using the ES-DST under forecast uncertainty
- These capabilities of the ES-DST were demonstrated using a 4-DER 'smart' home
  - complex DER models and different tariff structures
  - involves complex optimization problem
- Recent research developments

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Many of our publications are available at www.ceem.unsw.edu.au
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and

Questions?

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