



Adaptive Load Management

Jhi-Young (J.Y.) Joo and Marija Ilić

Electric Energy Systems Group
Electrical and Computer Engineering
Carnegie Mellon University

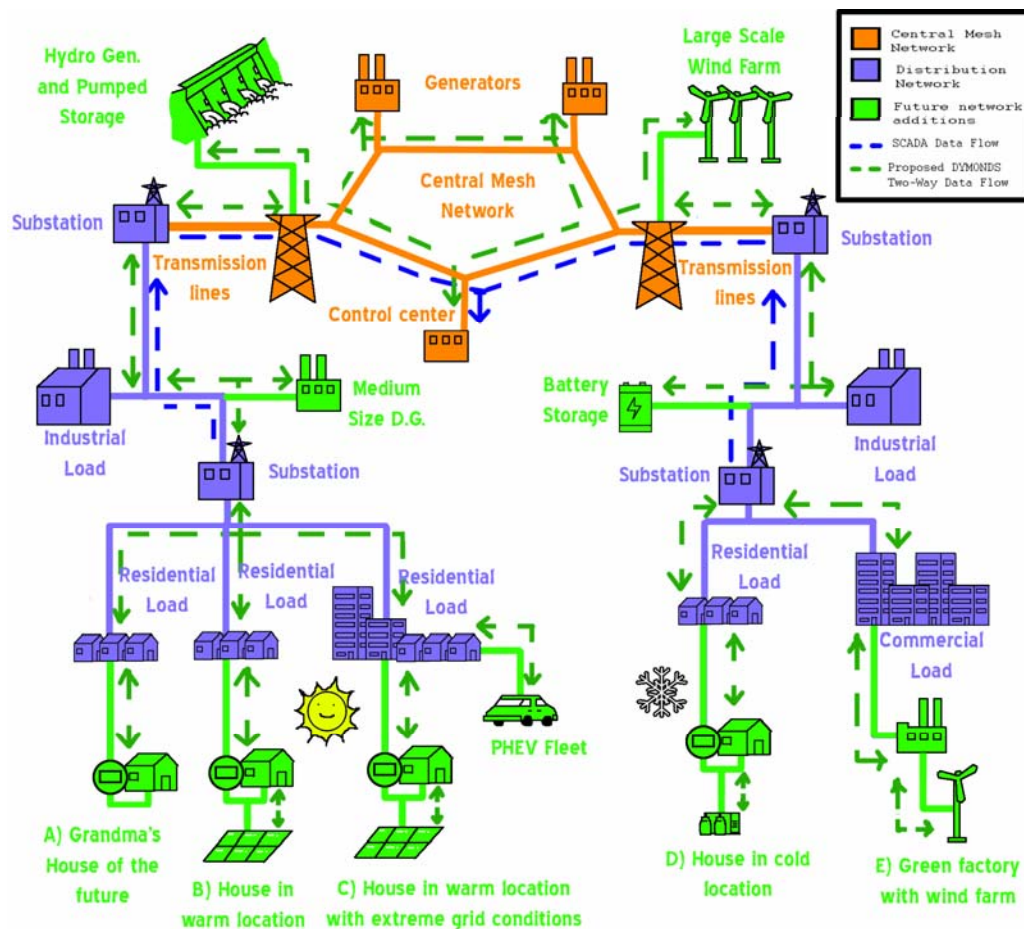
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Outline

❖ Adaptive load management (ALM)

- Future electric energy systems DYMONDS and demand response
- Motivation and main ideas
- Schematics – information flow
- Cost analysis
- Future work and open questions

Future electric energy systems



Artwork by Andrew Hsu, EESG

❖ Distributed optimization / decision-making

- Flexible & dynamic system components
- Higher uncertainty

Why demand response?

❖ Change in supply attributes

- Distributed generation resources
 - ❖ Higher uncertainty, intermittency
 - ❖ Requires quick response of the system (higher ramping rates)

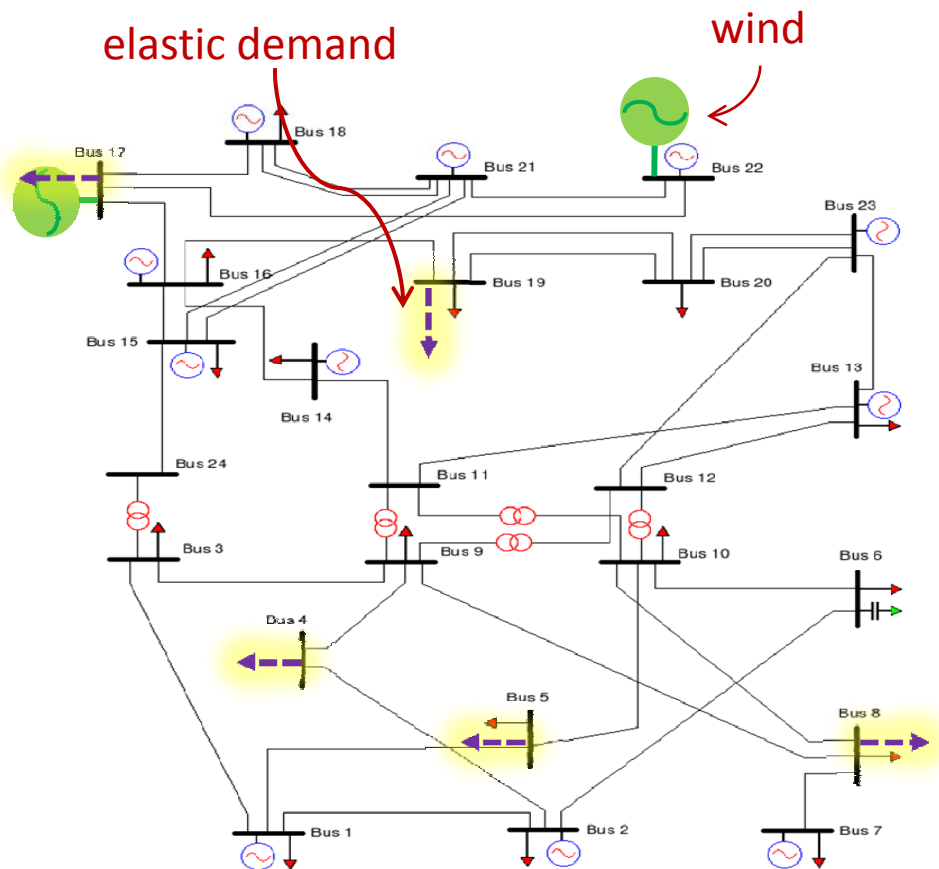
❖ Higher cost of additional capacity

- Need for load shifting

❖ End-users' needs

- Energy efficiency and lower energy cost

Elastic demand with wind generation [2]

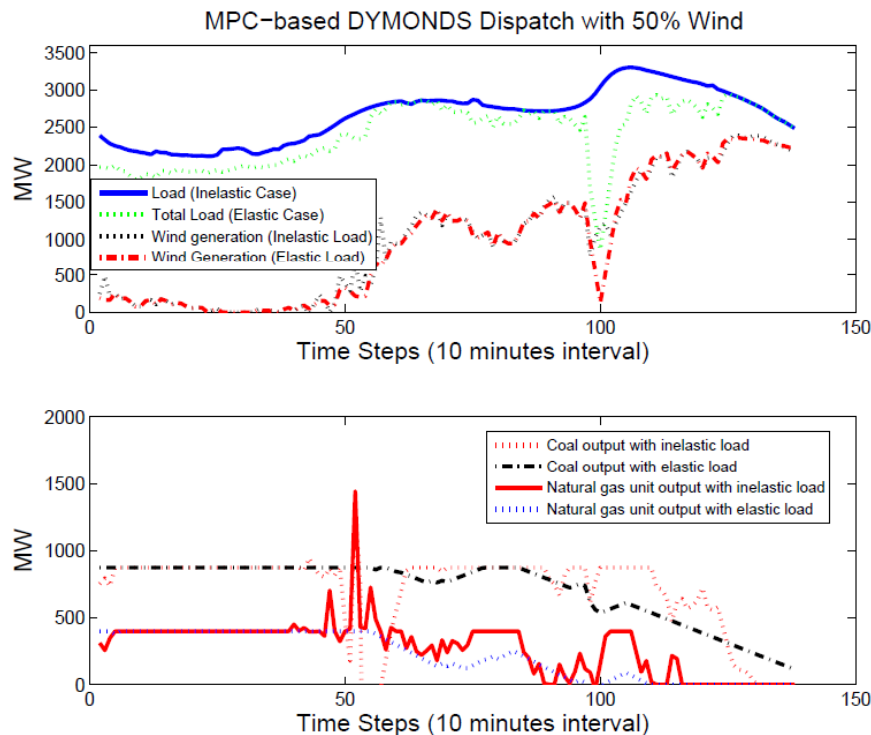


IEEE 24-bus Reliability Test System-1996

❖ System setup

- Demand responsive to hourly real-time pricing of the system
→ demand curves
- Price reflecting the true cost of the supply including cost of ramping rates
→ look-ahead dispatch

Elastic demand with wind generation [2]



❖ If demand can respond rapidly to the system price, it can compensate for the high intermittency of renewable resources.

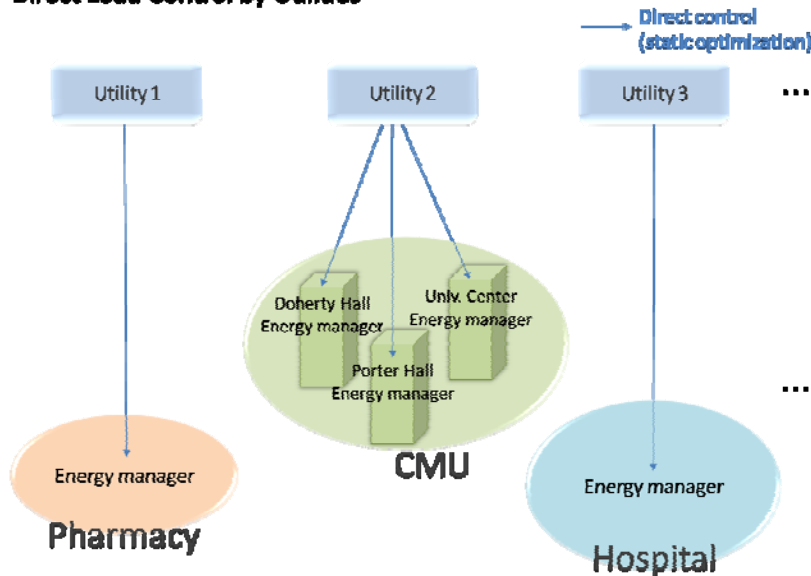
❖ What do we need in terms of system operation?

The main ideas of ALM

- ❖ **System's perspective:** What is **the right information** required to balance the system with demand response?
 - Where do we see the value of DR in the system balancing mechanism?
- ❖ **End-users' perspective:** Reflecting **various end-users' needs** and preferences
 - End-users' **willingness to pay** for energy service
- ❖ **Load aggregators' role**
 - Physical energy mediator between system/market and end-users
 - **Information exchange junction/processor** between market and end-users
 - Value of aggregating different resources and risk management

Previous demand response scheme: Direct load control

Direct Load Control by Utilities



❖ One-way flow of information

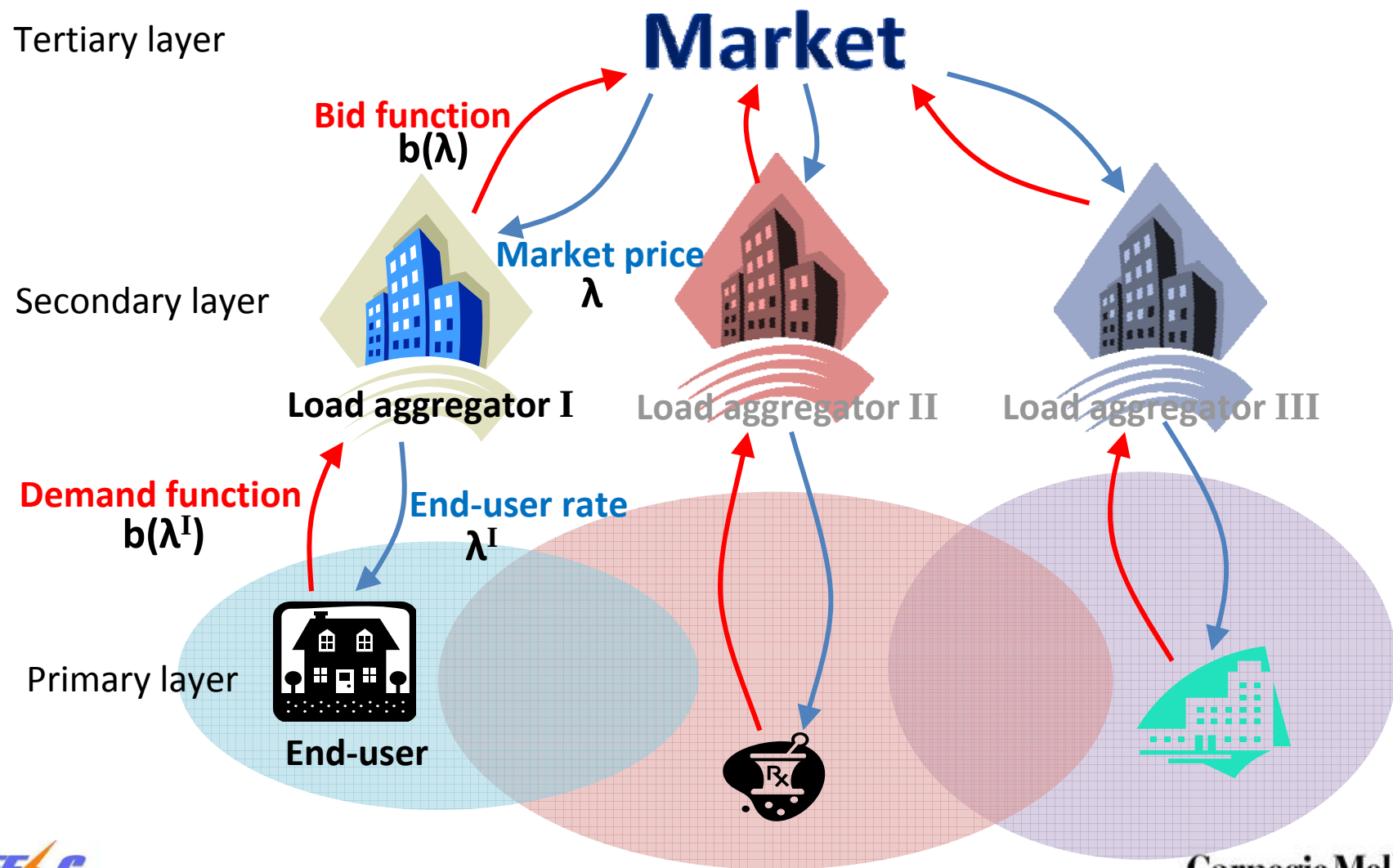
- Load management conducted by utilities
- Top-down control

❖ Exclusive contracts between supply and demand

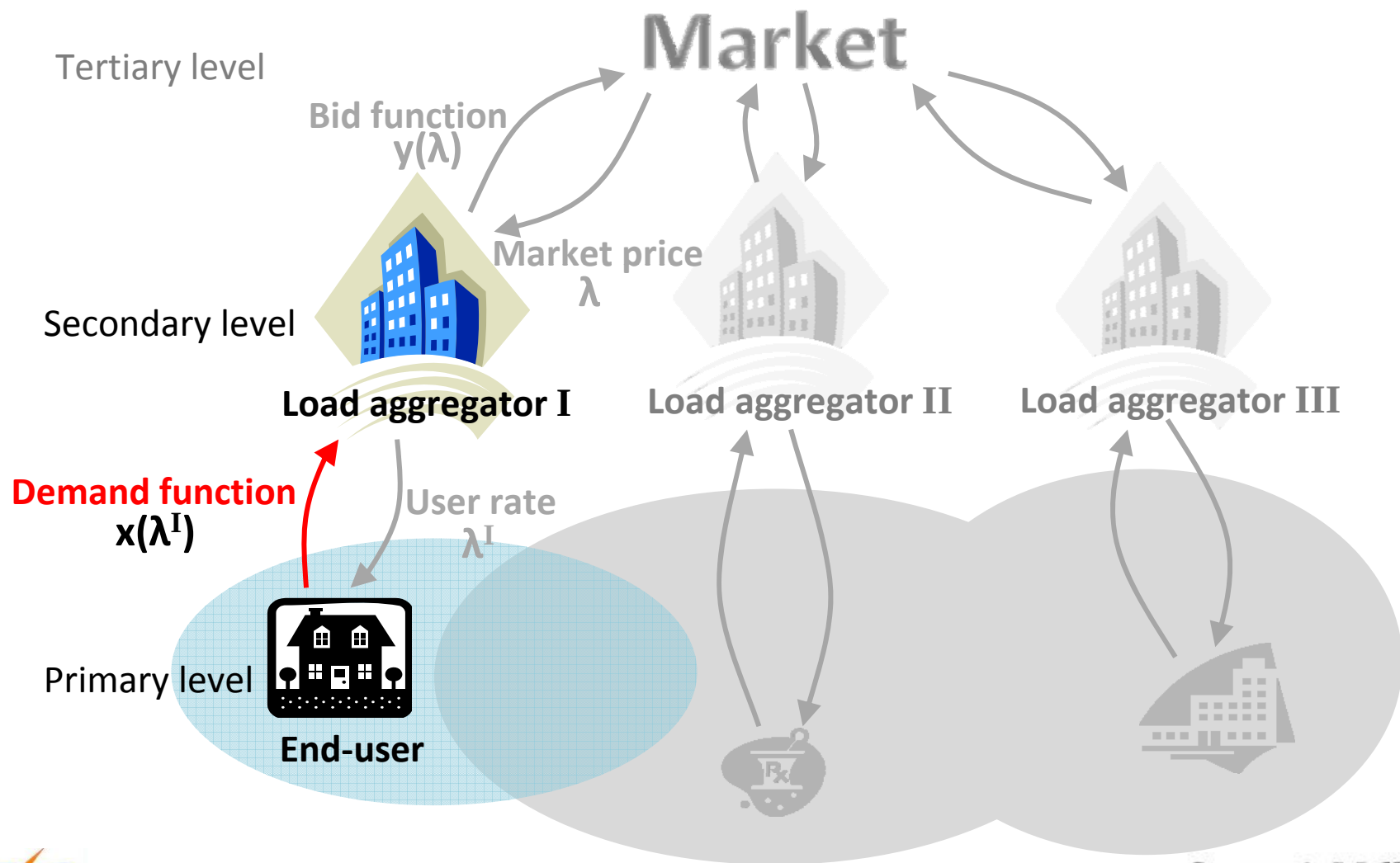
❖ Direct load control

- Regardless of end-users' preferences
- No access to market information for end-users
- End-users' information invisible to system

Information flow of ALM



Multi-layered ALM – end-users to LAs



Multi-layered ALM – end-users to LAs

- ❖ Obtaining **individual demand function** subject to temperature comfort level

$$\min_{\{x_i\}} \sum_{k=k_0}^{k_0+N} \left[\lambda^{LA}[k] \cdot x_i[k] + \left\{ (T_i[k] - T_i^{\max})^2 + (T_i[k] - T_i^{\min})^2 \right\} \right]$$

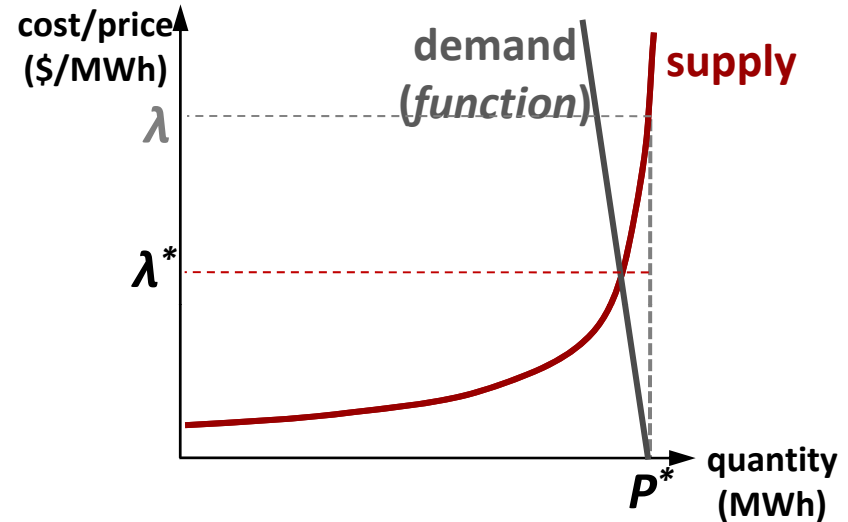
where $T_i[k+1] = A_i T_i[k] + B_i x_i[k]$

subject to $T_i^{\min} \leq T_i[k] \leq T_i^{\max}$ for all k

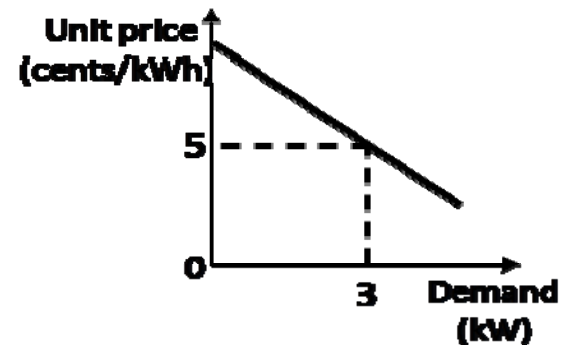
- ❖ Obtain different optimal energy usage $x_i[k]$'s for different temperature setpoint $\lambda[k]$'s to infer demand functions

Demand function

- ❖ Mathematical model of price-responsive loads
 - Integrated into the system optimization
- ❖ Includes information of end-users' utility (benefit)
- ❖ Function of end-users' willingness-to-pay
 - With respect to electricity demand quantity



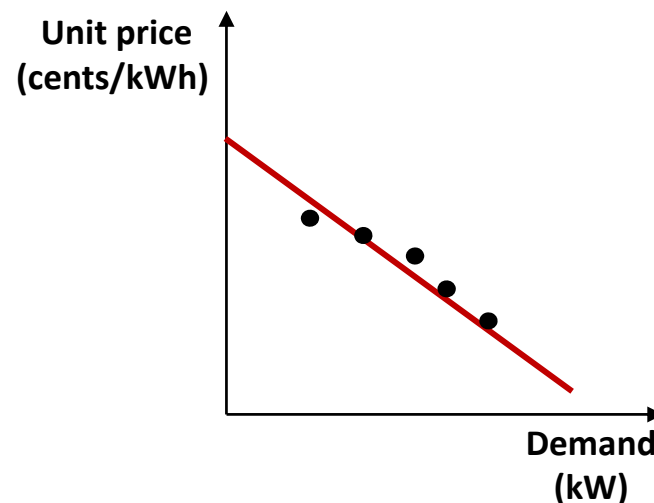
$$d(P_D) = aP_D + b$$



Demand function (cont'd)

❖ How to obtain from individual temperature control

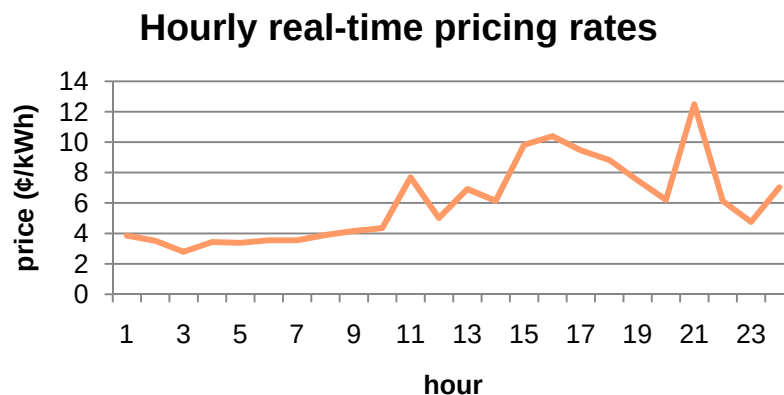
- Calculate optimal energy usage by hours with a given electricity price
- Perturb the given price by a certain percentage (e.g. $\pm 20\%$) and re-calculate optimal energy usage with new prices
- Curve-fit price-demand quantity pairs to identify the parameters of a demand function



Cost analysis of ALM

❖ Problem setup

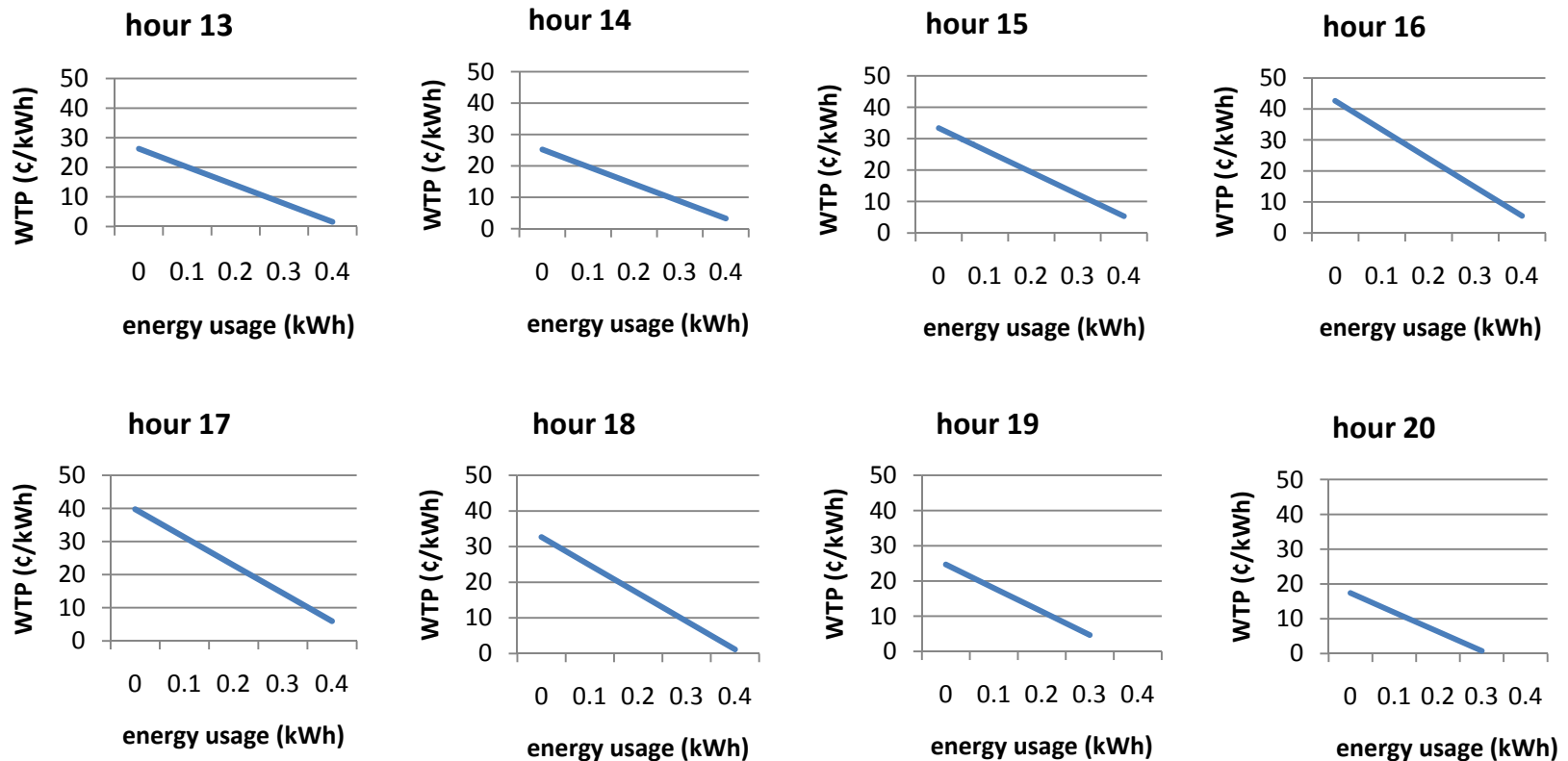
- 10 end-users with different temperature preferences
- Optimizing energy usage over 24 hours
 - ❖ Hourly-varying electricity price given (real-time pricing)
 - ❖ Outdoor weather temperature given



End-user index	Temperature setpoints (°F)	
1	68	75
2	70	77
3	72	75
4	74	79
5	75	80
6	64	75
7	63	77
8	72	79
9	72	77
10	73	81

Cost analysis of ALM (cont'd)

❖ Demand functions of end-user #1

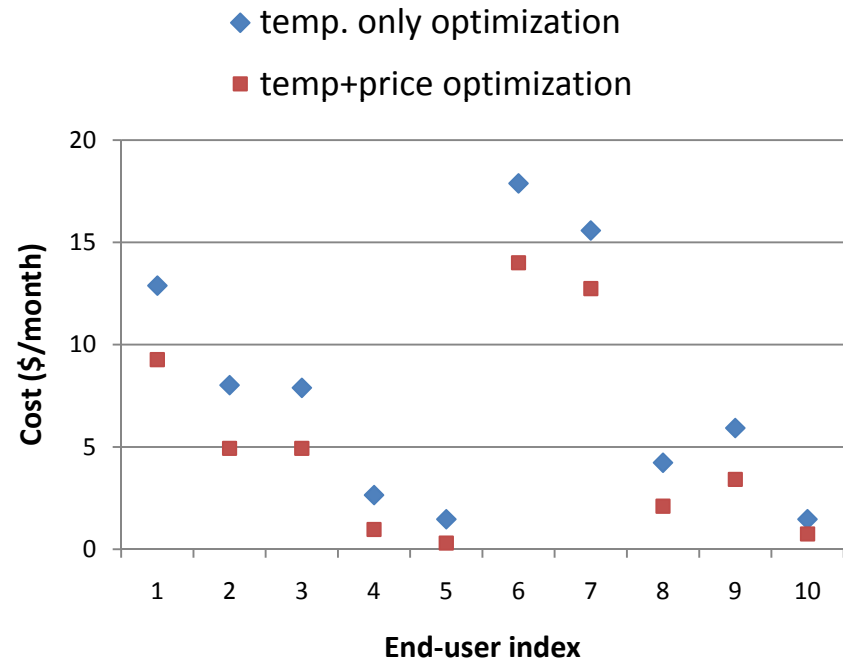


Cost analysis of ALM (cont'd)

❖ Cost savings from “price-conscious” optimization

- Current practice
: end-users little concerned about hourly prices
 - ❖ Introduction of real-time pricing may end up in **energy cost rise** for some end-users
- Intelligent optimization with ALM
: optimization w.r.t. time-varying price saves costs
- 32% of cost savings (as a whole) in this case

End-users' energy costs (hourly RTP)

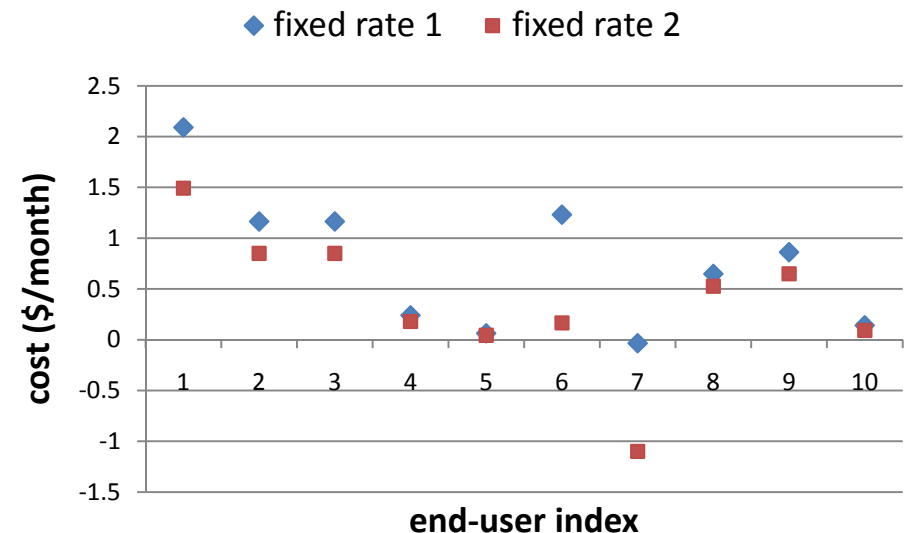


Cost analysis of ALM (cont'd)

❖ Does real-time pricing save costs for all end-users?

- Not necessarily
- Different end-users' load profiles have different values.
- Need to aggregate different end-users' loads in order to distribute cost or benefit properly and maximize profit

Energy cost comparison with RTP



Fixed rate 1: 7.24 ¢/kWh

Fixed rate 2: 7.84 ¢/kWh

Open questions

❖ Who benefits from the cost savings? It depends on

- Load aggregator's portfolio in various energy markets
 - ❖ Long-term contracts, day-ahead/real-time markets, ancillary service markets, etc.
- Load aggregator's aggregation of available resources
 - ❖ Elastic demand, distributed energy resources (e.g. small-scale renewables, electric vehicles)
- Load aggregator's contracts with end-users
 - ❖ Real-time pricing, time-of-use pricing, flat rates, interruptible loads, etc.

❖ What is the smartest way to get end-users' demand preferences?

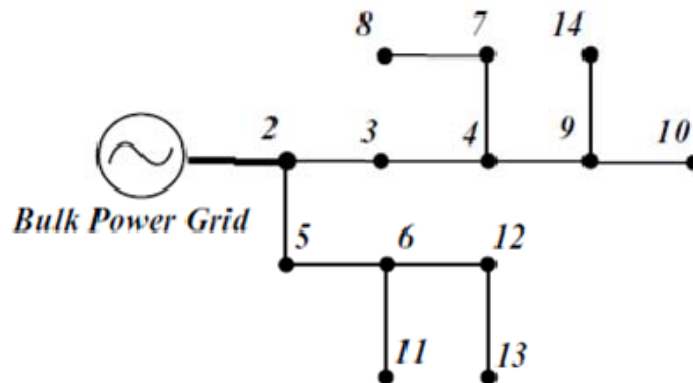
- Temperature settings control
- Price response analysis → hands-on experiment on end-users
- Typical load profile analysis
- Behavior analysis on energy usage
- *and so on...*

References

- 1) J.Y. Joo and M. Ilić, ***A Multi-Layered Adaptive Load Management (ALM) System***, IEEE PES Transmission and Distribution Conference, April 2010, *accepted*
- 2) L. Xie and M. Ilić, ***Model Predictive Economic/Environmental Dispatch of Power Systems with Intermittent Resources***, IEEE PES General Meeting, July 2009
- 3) M. Ilić, L. Xie, and J.Y. Joo, ***Efficient Coordination of Wind Power and Price-Responsive Demand Part I: Theoretical Foundations, Part II: Case Studies***, IEEE Transactions on Power Systems, *under review*, Mar 2010

Cost analysis of ALM (cont'd)

❖ ALM applied to a distribution network



Source: Judith Cardell, *Control Strategies and Dynamic Pricing for Small Scale Distributed Generation in a Deregulated Market*, PhD Thesis, MIT, 1998

❖ Economic dispatch with demand functions

$$\min_{P_i} \sum_{i=1}^n \{C_i(P_i) - B_i(P_i)\}$$

$$\text{subject to } |F_{i,j}| \leq F_{i,j \max}$$

$$0 \leq P_i \leq P_{i, \max} \text{ for } \forall i, j$$

Cost analysis of ALM (cont'd)

❖ ED with and without demand functions

- Without demand functions
 - ❖ Inelastic demand
 - : demand does NOT change w.r.t. price
- With demand functions
 - ❖ Elastic demand
 - : demand changes w.r.t. price
 - demand likely to be lower when price higher
- Cost savings estimate in hour 15 (when demand was highly elastic)
 - : for 13,000 end-users, \$65.12 savings with ALM