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Multi-Temporal And Multi-Layered Optimization Of Demand With Risk Management¶

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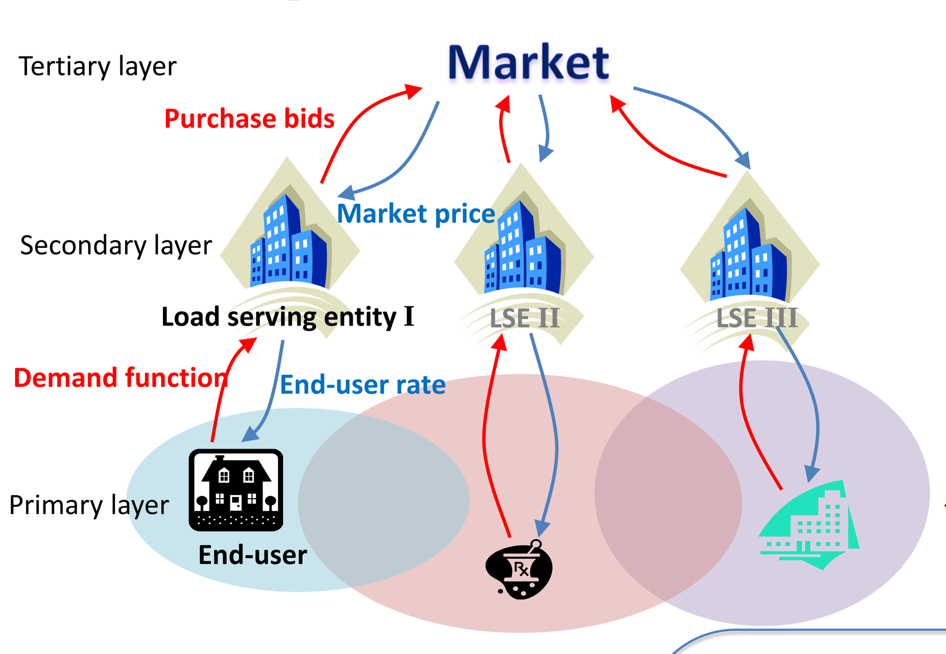
Introduction

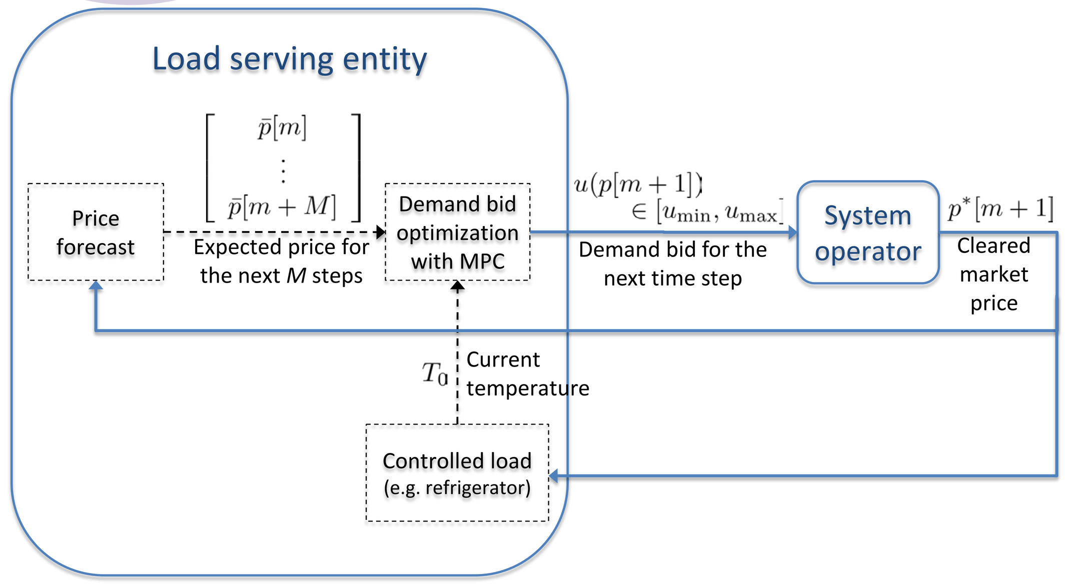
- **Side effects of price-responsive demand** [1]
  - Moral hazard
    : customers artificially affecting the baseline
  - Adverse selection
    : disproportionate participation from customers who anticipate lower consumption
  - Price formation
    : holdback of economically more beneficial consumption due to double payment
- **Root causes of these problems**
  - Compensation based on the *baseline*
  - Information asymmetry between the customers and the operator on the economic preference of consumption
  - Customers' preference does not remain invariant throughout the time
    : changes by the end-user environment, market/system conditions, etc.
- **Solution: demand subscription** [1]
  - Allowing customers to choose different levels of demand with different service conditions
  - Call option that can be interrupted by the real-time market price
- **Adaptive load management (ALM)**: our take on demand subscription
  - Multi-temporal demand subscription from long-term energy procurement and planning to real-time energy adjustment
  - Multi-layered optimization from end-users to load serving entities (LSEs) and the market

[1] Hung-po Chao, "Price-Responsive Demand for a Smart Grid World," The Electricity Journal, 2010, Vol.23, No.1

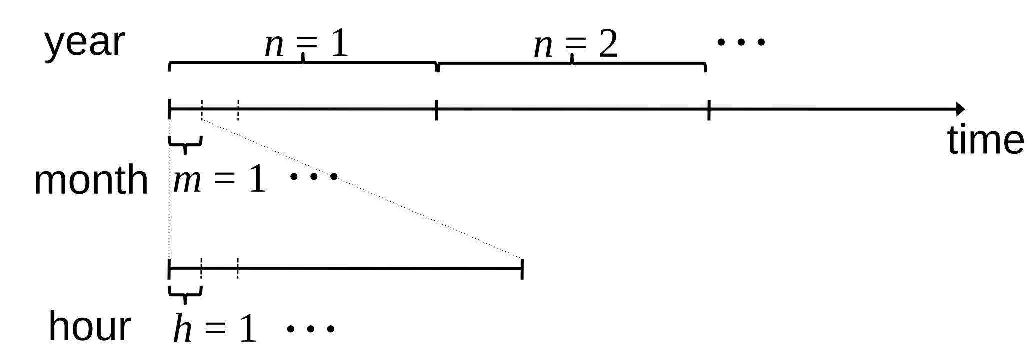
- **Schematic plot of ALM**



- **Information exchange between LSE and system operator**



Multi-temporal and multi-layered optimization



- **Long-term energy procurement**
  - **Assumptions and settings**
    - Long-term contract offer given from a supplier
    - Hourly energy rate ($/MWh) offered, with the minimum and maximum limits of energy amount (MWh)
    - Aggregated end-user groups of hourly demand forecast given as a stochastic process
    - Hourly spot market (day-ahead and real-time market price) forecast given as a stochastic process
      → can be correlated with the demand
  - **LSE's objective**
    : minimizing expected cost less revenue from end-users
    while minimizing the uncertainty to a certain level that the LSE wants
    - Decision variables
      : long-term contract amount, long-term end-user rate (if long-term demand function with respect to the rate known)
    - Method of minimizing risk
      : conditional value-at-risk (CVaR)
    - Long-term demand function
      : end-users' tradeoff between investment cost in energy efficiency measures and savings from energy cost

$$\min_{y,r,\zeta} \underbrace{\sum_{h=1}^{N_h}\{p_n^{\rm lt}y_{\rm a}[h] + \hat{p}_m^{\rm lt}y_m[h] + \hat{p}_{\rm sp}y_{\rm sp}[h]\}}_{\text{Energy purchase cost}} + \underbrace{\beta F_\alpha(y_{\rm a},\zeta)}_{\text{CVaR}} - \underbrace{\sum_{n=1}^{N} r^T[n]\hat{u}_n(r[n], C_{{\rm inv},n})}_{\text{Revenue}}$$

$$\text{subject to } E\{d_h\} = y_{\rm a}[h] + y_{\rm m}[h] + y_{\rm sp}[h] \text{ for } h = 1,\cdots,N_h$$

Sum of purchase should equal to the mean of the demand forecast

$$y_{\rm a,min} \le y_{\rm a}[h] \le y_{\rm a,max} \text{ for } h = 1,\cdots,N_h$$

Contract amount constraints

$$y_{\rm m,min} \le y_{\rm m}[h] \le y_{\rm m,max} \text{ for } h = 1,\cdots,N_h$$

Contract amount constraints

$$E\{\sum_{h=h_{\rm n,start}}^{h_{\rm n,end}} d_h\} = \hat{u}_n(r[n], C_{{\rm inv},n}) \text{ for } n = 1,\cdots,N$$

Long-term demand function

$$\hat{u}_{n,\min} \le \hat{u}_n \le \hat{u}_{m,\max} \text{ for } n = 1,\cdots,N$$

End-users' consumption limits

$$\text{where } F_\alpha(y_{\rm a},\zeta) = \zeta + \frac{1}{1-\alpha}E\{[p_n^{\rm lt}y_{\rm a}[h] + \hat{p}_m^{\rm lt}y_m[h] + \hat{p}_{\rm sp}y_{\rm sp}[h] - \zeta]^+\}$$

- **Short-term energy balance**
  - **Assumptions and settings**
    - Long-term contract locked in as a call option and decide on spot market transaction
    - Hourly day-ahead and real-time market price forecast given as a stochastic process
    - End-users' utility given as a state dynamic model with energy consumption as an input (e.g. indoor temperature)
  - **LSE's objective**
    : minimizing expected cost less revenue from end-users
    while minimizing the uncertainty to a certain level that the LSE wants
    subject to end-users' physical/economic constraints on demand
    - Decision variables
      : day-ahead and real-time purchase amount

$$\min_{x,y,u,\zeta} \sum_{h=1}^{H}\{\underbrace{\hat{p}_{{\rm sp},h}y_{\rm sp}[h]}_{\text{Purchase cost}} - \underbrace{r[h]^T\hat{u}[h]}_{\text{Revenue}} - \xi \underbrace{f(x[h],\hat{u}[h])}_{\substack{\text{End-users' cost} \\ \text{(monetary and non-monetary)}}}\} + \underbrace{\beta F_\alpha(y_{\rm h},\zeta)}_{\text{CVaR}}$$

$$\text{subject to } E\{d_h\} - y_{\rm a}^\star[h] - y_{\rm m}^\star[h] = y_{\rm sp}[h]$$

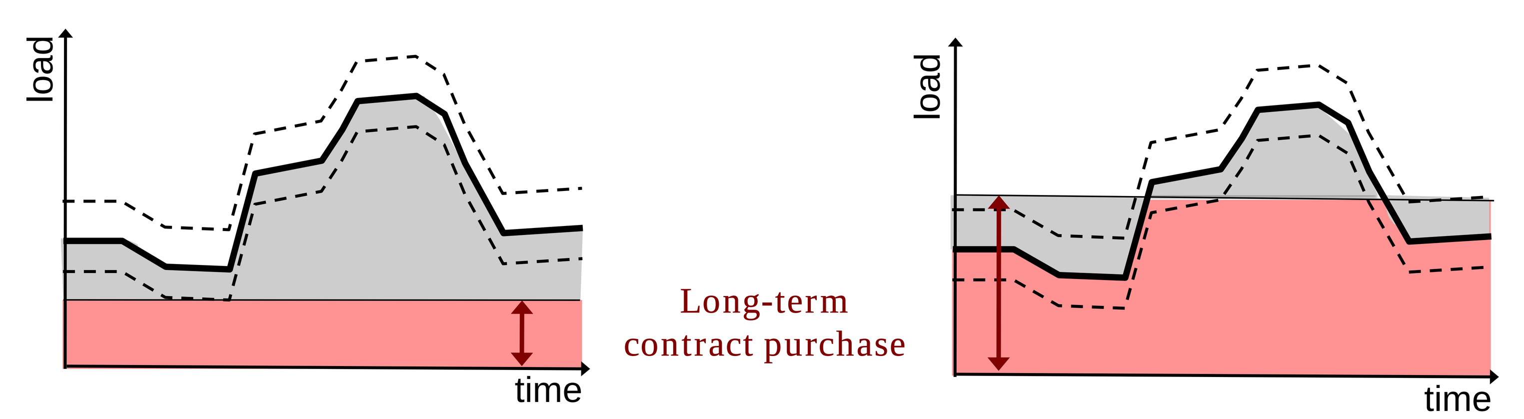
$$x[h+1] = g(x[h],\hat{u}[h],\theta_h)$$

End-users' utility state dynamics

$$x_{\min}[h] \le x[h] \le x_{\max}[h]$$

$$\hat{u}_{\min}[h] \le \hat{u}[h] \le \hat{u}_{\max}[h] \text{for all } h = 1,\cdots,H$$

- **Illustration of risk proneness and LSE's portfolio**



Financially risk-averse or physically risk-prone LSE

Physically risk-averse or financially risk-prone LSE

Concluding remarks

- **Demand subscription throughout the timeline and on multiple layers of demand side**
  - Enabling different risk distribution
    - according to the risk proneness
    - subject to various constraints of customers
    - adjusting to time-varying conditions of the customers
- This framework calls for **frequent and timely information exchange** between the end-users, LSEs, and the system/market operators
  - Support of IT infrastructure required

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¶Based on the paper by the authors accepted for IEEE Power and Energy Society General Meeting, July 2012 "Distributed Multi-Temporal Risk Management Approach To Designing Dynamic Pricing"