Dynamically Administered Critical Peak Pricing for Enhancing Price-Responsive Loads using Consumer Portal

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Contents

Introduction

- Why are price-responsive loads important?
  - Increased volatility of market prices due to electric power industry reforms
  - Demand response(reduction of customer energy usage at times of peak usage) through innovative pricing to increase price-responsiveness of the loads

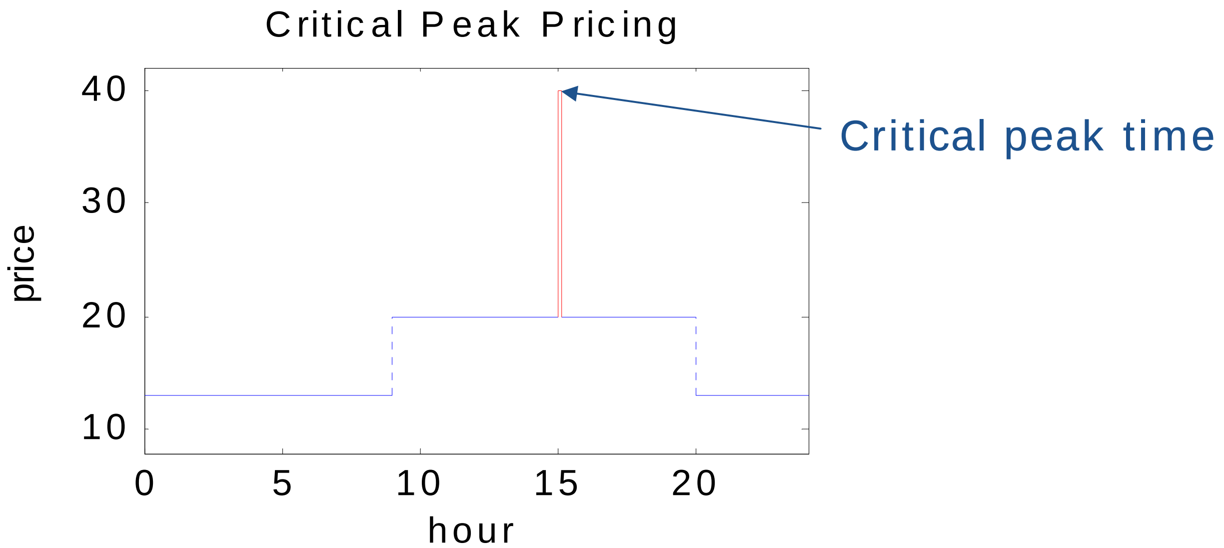
- Critical Peak Pricing for enhancing price-responsive loads
  - Regulatory perspective
  - Economic perspective
  - Technical perspective

Problem Statement

- Economic and technical perspectives of price-responsive loads problem
  - Regulatory perspective: CPP assumed
  - Economic perspective: formulation of the incentive of CPP practitioner
    - CPP practitioner and their incentive defined
  - Technical perspective: maximization of the incentive
    - Optimizing the incentive of CPP practitioner

Background: Critical Peak Pricing

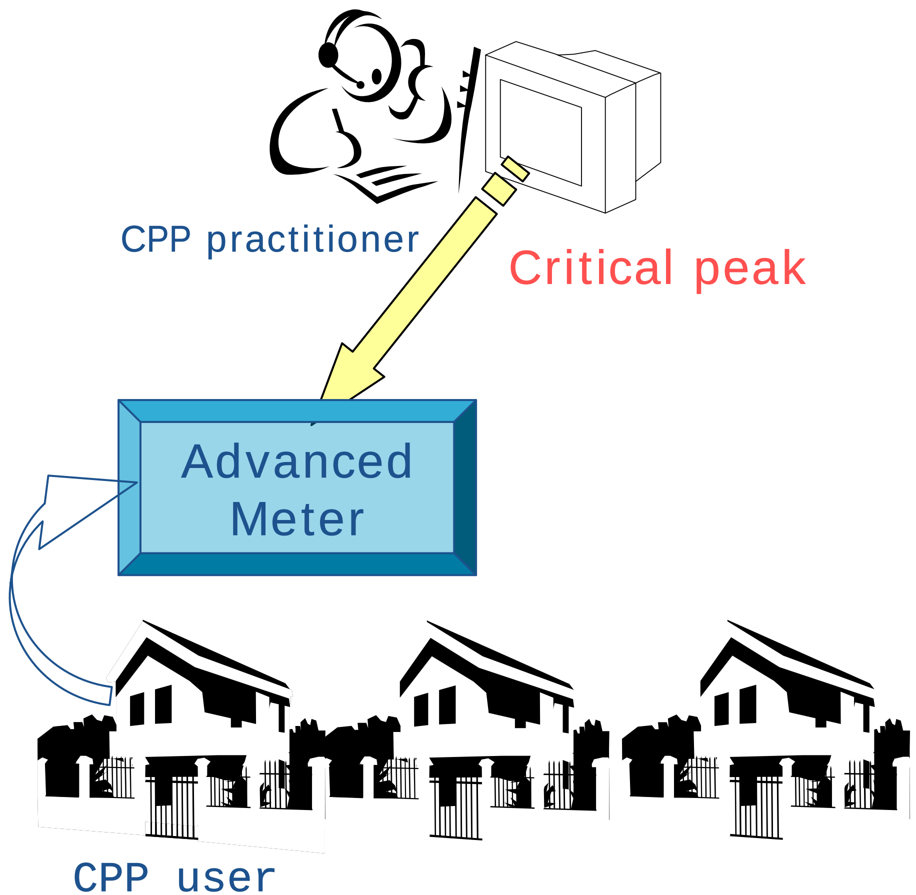
- Critical peak pricing(CPP) [1]
  - One of the various demand response programs, and also the tariffs
  - CPP rates (example)



  - Dynamically-administered CPP (CPP)
    - More responsive to instantaneous accidents
    - Easier for customers to respond
    - Utilizes consumer portal for critical peak events

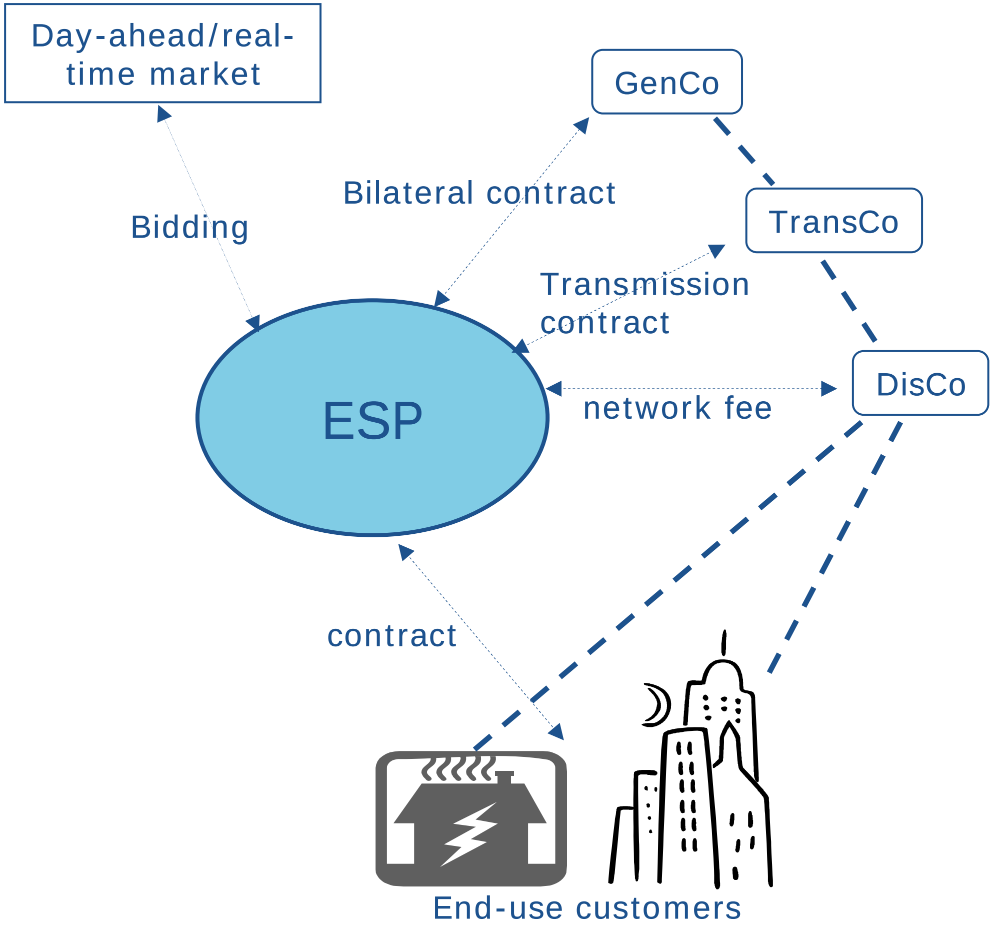
Background: Critical Peak Pricing

- Execution of critical peak time
  → Who is the practitioner?



Background: Critical Peak Pricing

- CPP practitioner: Energy service provider(ESP)
  - Buys electricity from GenCos, TransCos, and DisCos through market or contracts and sells it with related services to end-use customers
  - Goal: maximizing their profit
  - Incentive as CPP practitioner: profit



Formulation

- ESP’s profit equation

  profit = (revenue from the customers) – (purchase cost from the day-ahead/real-time market)

  - Constraints
    - Maximum critical peak times that ESP can issue

      ex) 3 times a month
    - Refraction time: minimum hours that ESP has to wait before issuing another critical peak time

      ex) 24 hours

  - Assumptions
    - Day-ahead and real-time market prices run by hours
    - Non-critical peak time charged by hours, critical peak time by 5 minutes
    - Customer’s rate by hours is defined ahead by contract

Formulation

- ESP's profit equation [by a month(30 days)]

$$\max_{u(t)} \quad \pi$$

Day-ahead price

Real-time market price

$$\pi = \sum_{n=d_j}^{N_{CPP}} R_{d_j} - \sum_{k=1}^{24\times 30} \rho^{DA}[k]\cdot Q_{mkt}[k] - \sum_{t=1}^{12\times 24\times 30} \rho^{RT}(t)\cdot Q_{mkt}(t)$$

where R_{d_j} = Revenue from the customer d_j

Maximum issuable critical peak times

$$0 \le \sum_{t=1}^{12\times 24\times 30} u(t) \le N_{\max} \quad \text{where} \quad u(t) = \begin{cases} 1 & \text{on critical peaks} \\ 0 & \text{otherwise} \end{cases}$$

$$\tau_{i+1} - \tau_i \ge \Delta t_R \quad \text{for} \quad 0 \le i \le N_{\max} - 1$$

Time when i^{th} critical peak time issued

Refraction time

Methodology

- Technical perspective of CPP
  - Maximization of ESP's incentive for CPP
    → Optimization problem of ESP's profit

- Optimization of ESP's profit
  - Deciding when to issue critical peak times that maximize the profit while meeting the constraints with respect to varying market prices
    - Prediction of real-time market price
    - Calculating optimal critical peak times based on the prices predicted

Methodology – Price Prediction

- Calculating optimal critical peak times
  - Price prediction
    - Using price-load relationship based on load prediction

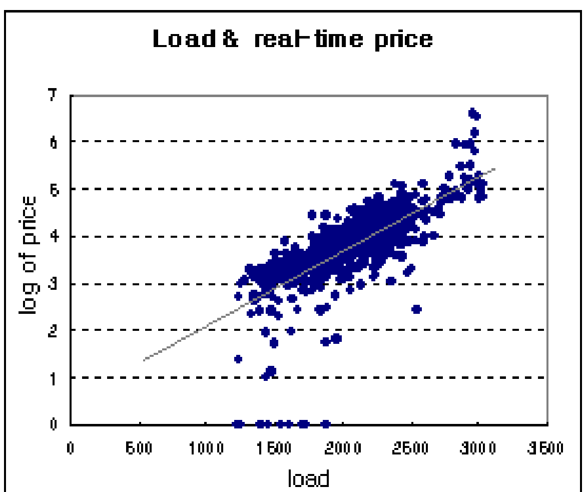
$$\ln \rho_n = aL_n + b$$ [2]

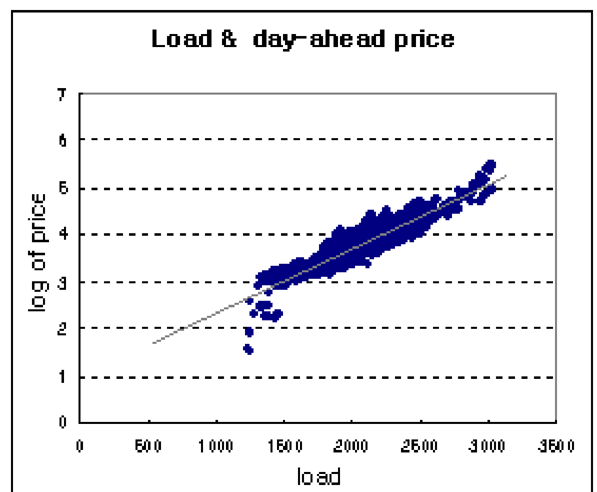
    - Incorporating with the models concerning volatility of price
      - Random walk, mean reversion, jump diffusion

[3]

$a = 0.0104$

$b = 3.1328$





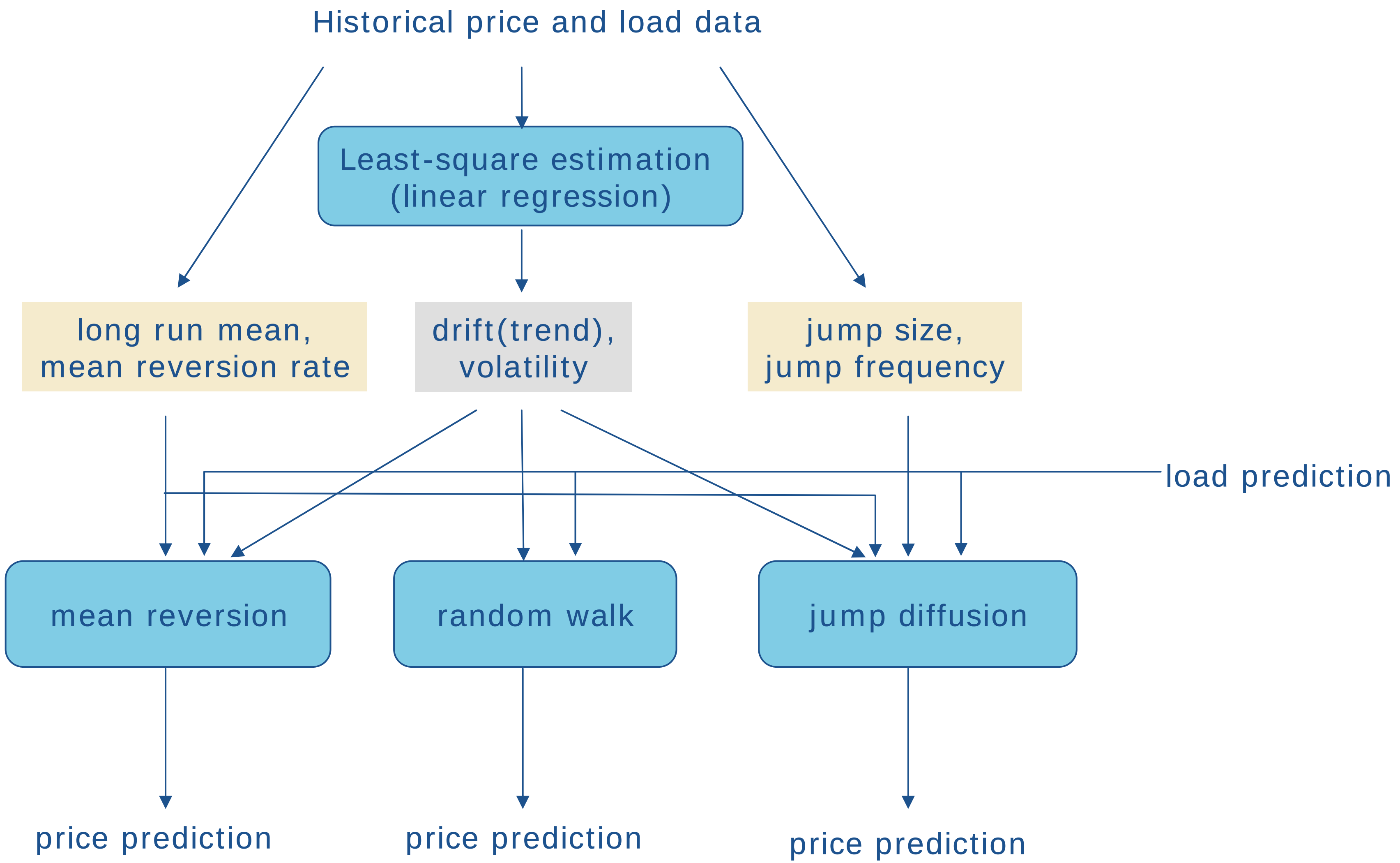
$a = 0.0167$

$b = 2.9149$

Methodology – Price Prediction

- Three price prediction methods including volatility [5],[6],[7]
  - Developed and widely in financial engineering
    - Random walk (Brownian motion) model
      - Prediction based on the drift and volatility of price
    - Mean reversion model
      - Price always reverting to a certain level while showing volatility
    - Jump diffusion model
      - Price sometimes having “spikes”
      - Get the frequency and size of spikes from historical data and apply them to prediction

Methodology – Price Prediction



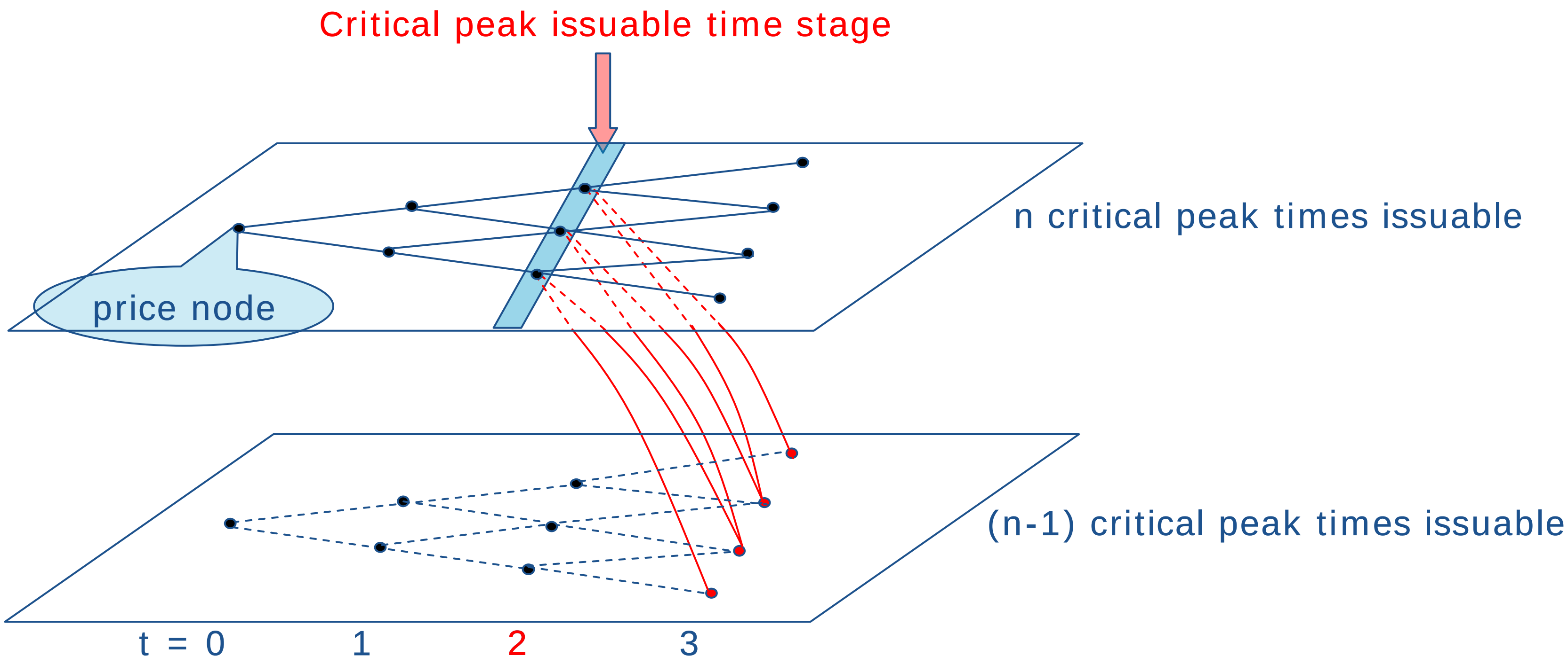
Methodology - Swing Option

- Calculating optimal critical peak times
  - Profit at a time stage depends on market price, issuable critical peak times left, and minimum wait time until the next issuable critical peak time.

  - Analogous to swing option valuation problem
    - Definition of swing option
      - A type of option traded in energy markets
      - Having multiple exercise rights with a constraint on the amount traded

Methodology – Swing Option

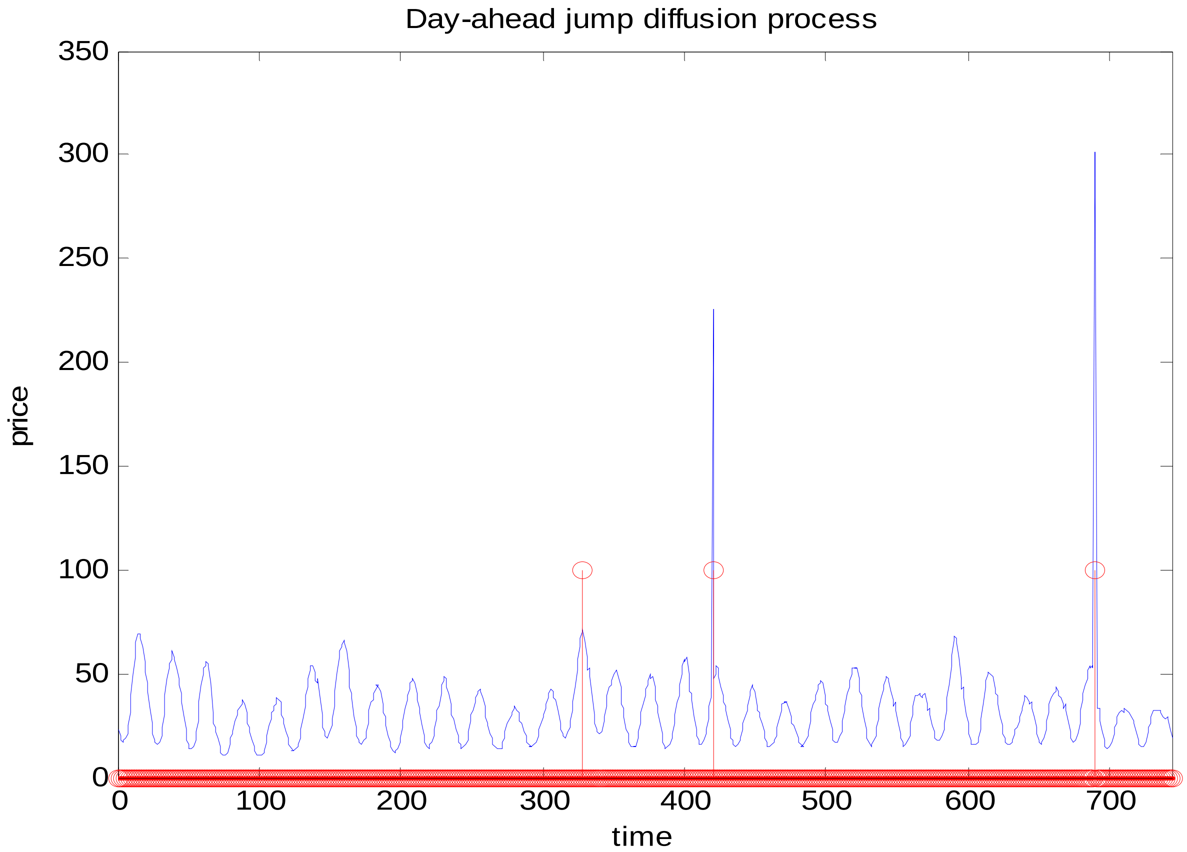
- Critical peak problem using swing option evaluation method
  - Calculate profit on each node, and trace the optimal path through backward dynamic programming



Numerical Example

- Critical peak decision $N_{\max} = 3, \quad \Delta t_R = 24$
  - A sample price path from jump diffusion model

$$\ln \rho_n = \ln \rho_{n-1} + a(L_n - L_{n-1}) + \alpha(l - \ln \rho_{n-1}) + \eta\left(\ln \rho_{n-1}(\kappa + \delta)\right) + \sigma\sqrt{\Delta t}$$



[3]

$a = 0.00137$

$\sigma = 0.0668$

$l = 39.620$

$\alpha = 0.0461$

$f_{jp} = 0.00538$

$m_{jp} = 4.723$

Numerical Example

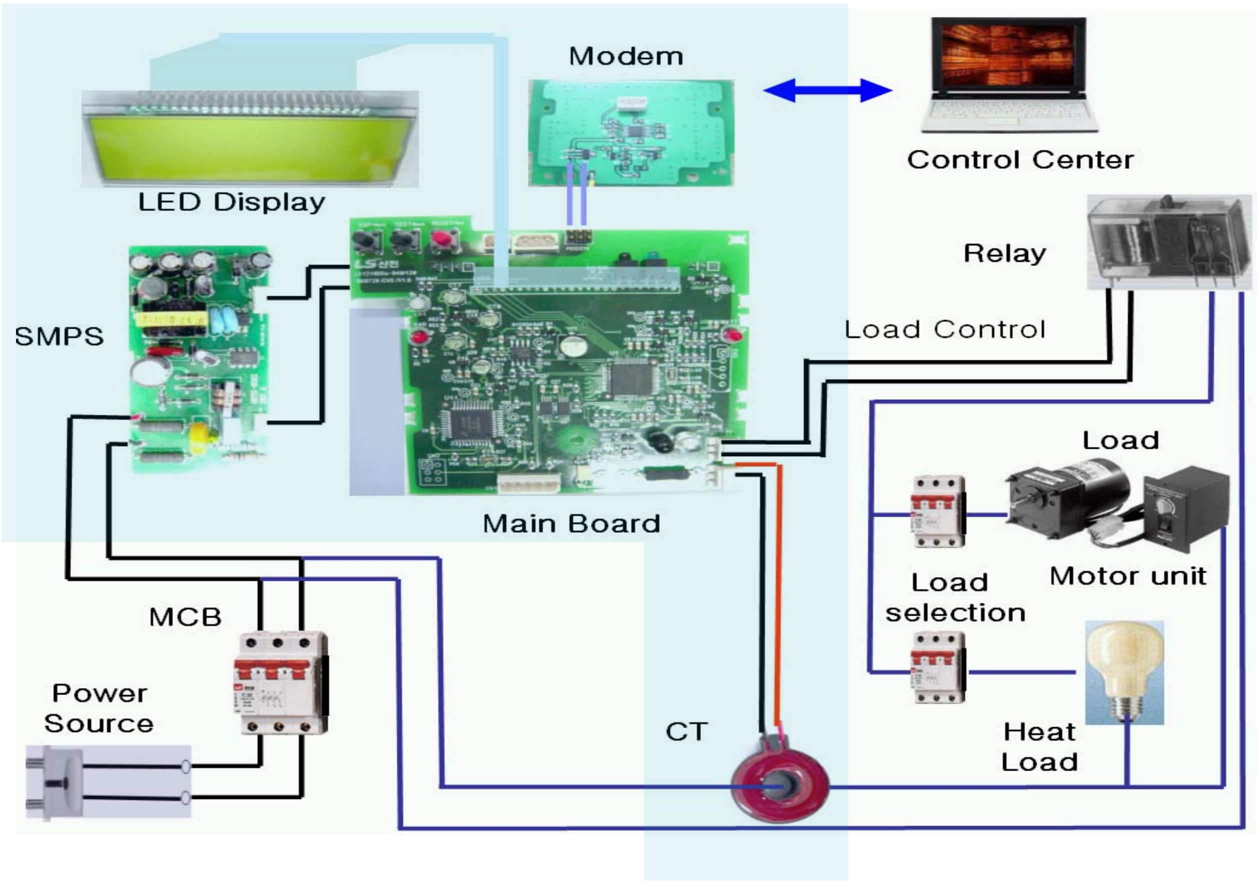
- Interpretation of the simulation results
  - Optimal critical peak times on the highest prices regardless of the price prediction models
    - (Decisions where ESP's profit maximizes)

    = (Decisions when price-responsiveness of loads is mostly needed)

    = (Decisions where end-use customers are most likely to refuse to buy electricity)

Consumer Portal

- Core enabler for providing value-added services to end-use customers through two-way communication between consumers and suppliers



Consumer Portal

- Work done so far
  - Turn off electricity
    - Either when accumulated load consumption reaches a certain point
    - Or when peak demand reaches a certain point

Conclusion & Future work

- Conclusion
  - Incentive of dynamically-administered critical peak pricing(DACPP) is energy service provider(ESP)'s maximized profit
  - ESP's profit maximization problem

    → swing option valuation methodology
  - Critical peak decisions where ESP's incentive maximized coincide with those where loads' price-responsiveness is mostly needed.

- Future work
  - More S/W work from ESP's perspective
    - Categorizing and predicting customers' loads to make smart purchases from the market
  - Implement S/W work onto H/W

Thank you!

References

- [1] Michael Jaske, “Dynamic Pricing, Advanced Metering and Demand Response in Electricity Markets”, 2002
- [2] Eric Allen & Marija Ilić, *Price-Based Commitment Decisions In The Electricity Market*, Springer, 1999
- [3] simulation input price and load data from PJM website http://www.pjm.com
- [4] Patrick Jaillet, Ehud I. Ronn, Stathis Tompaidis, ‘Valuation of Commodity-Based Swing Options’, *Management Science*, Dec. 2003
- [5] Carlos Blanco, Sue Choi & David Soronow, “Energy Price Processes”, *Commodities Now*, Mar. 2001
- [6] Carlos Blanco & David Soronow, “Mean Reverting Processes”, *Commodities Now*, Jun. 2001
- [7] Carlos Blanco & David Soronow, “Jump Diffusion Processes”, *Commodities Now*, Sep. 2001

Appendix I: Notations For Critical Peak Decision Equation

k	time at day-ahead market (unit:1 hour)
t	time at real-time market (unit: 5 min.)
d_j	index for CPP customers
Q_{mkt}	quantity that ESP buys from market
Q_{d_j}	quantity consumed by customer d_j
R_{d_j}	revenue from customer d_j
$u(t)$	1: in case where ESP called a critical peak at time t 0: otherwise
τ_i	when i^{th} critical peak time was called
ρ^{DA}	day-ahead market price
ρ^{RT}	real-time market price

Appendix I: Notations For Critical Peak Decision Equation

N^{CPP}	number of CPP customers
ρ^{CP}	rate for critical peak time
$\rho^{non\text{-}CP}$	rate for non-critical peak time
N_{max}	maximum number of allowed critical peak calls
Δt_R	refraction time (minimum time required between two consecutive critical peak calls)

Appendix II: Methodology – Swing Option Details

- Swing option
  - Example
    - Customer A makes a contract with Provider B to buy 100MWh of electricity every day for the month of March.
    - On the 24th, A finds out that she needs 110MWh of electricity.
      - A can buy 10MWh from another provider.
        → probably more expensive than from B
      - A exercises a swing option for 10MWh from B
  - Constraints
    - Maximum exercises (ex. 5 times)
    - Refraction time: minimum wait time between exercises (ex. 2 days)
    - Minimum and maximum levels of energy tradable on an exercise (ex. 90MWh~120MWh)
  - Analogous to the critical peak decision problem excluding the last constraint
    - Finding an optimal path through backward dynamic programming