Real-Time Pricing for Managing a Steep Change of Electricity Demand

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1. Background

- **A steep change of electricity demand**
  - especially on summer morning

- **Generators must ramp up their units quickly**
  - supply & demand must be balanced instantaneously

![fig. load curve in Japan (2001.7.24)](image-url)
Supply-side measures

- the ramping capability of power supply equipment has been technologically improved

The rate of a demand change is given

Allocative inefficiency
● Demand-side measures

- price signals induce demand responses
- peak-load pricing, real-time pricing (RTP)

A new approach to real-time pricing that explicitly incorporates the ramping cost

The optimal rate of a demand change
2. Model

2.1 Electricity demand

- Time-varying demand

\[ p(t) = P(x(t), t) \]

\( t \): time, \( x(t) \): quantity of power

- The gross benefit of consumption

\[ B(x(t), t) \equiv \int_0^{x(t)} P(q, t) dq \]
2.2 Electricity supply

- The ramping process
  - starting up, shutting down, loading, unloading, etc.

- The ramping cost
  - ramping process causes wear and tear on equipment and shortens the life of components
  - equipment needs special mechanical designs for fast ramping
The ramping cost

- the outage cost incurred by an electric power shortage

Chao, H. P. (1983)
“Peak Load Pricing and Capacity Planning with Demand and Supply Uncertainty”

A steep change of electricity demand raises the possibility of a power shortage

The expected social cost of an outage
- **The ramping cost: a general formula**
  - a function of the rate of a demand change
    \[
    S(x(t)) \equiv \frac{dx(t)}{dt}
    \]
  - assume that the marginal ramping cost is increasing
    \[
    S''(x(t)) > 0
    \]

- **The variable cost**
  \[
  C(x(t))
  \]

fig. example of the ramping cost func.
3. Optimal Pricing

- Maximization of social welfare

\[
\max_{x(t) \geq 0} W^s = \int_0^T \{ B(x(t), t) - C(x(t)) - S(x & t) \} \, dt
\]

Considering the ramping cost explicitly

\[
p^s(t) = C'(x^s(t)) - S''(x & (t)) \Delta x(t)
\]

RTP-S: Real-Time Pricing for Managing a Steep Change of Demand

The optimal rate of a demand change
4. Numerical Example

Flat rate:
The base case

The price path

The demand path
Flat rate vs. RTP

RTP

The price path

The demand path under RTP

The demand path
Flat rate vs. RTP vs. RTP-S

RTP-S
The price path

The demand path under RTP-S

The demand path

Flat rate vs. RTP vs. RTP-S

The price path

The demand path under RTP-S

The demand path
5. Practical Applications

- RTP-S in a competitive electricity market

  A day-ahead market:
  - generators offer supply schedules
  - consumers submit demand schedules
  - the market operator sets the price schedules

Generators incorporate their ramping cost into their offers

RTP-S in a day-ahead market
6. Conclusions

✓ RTP-S: Real-Time Pricing for Managing a Steep Change of Demand
   - Optimal rate of a demand change
   - Ramping cost considered explicitly

✓ Long-run effect

✓ RTP-S in competitive electricity markets

✓ Further theoretical and empirical research on the ramping cost