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

Makoto Tanaka
National Graduate Institute for Policy Studies

24th Annual North American Conference of the USAEE/IAEE
July 8-10, 2004
Capital Hilton Hotel, Washington, DC, USA

Table of Contents

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

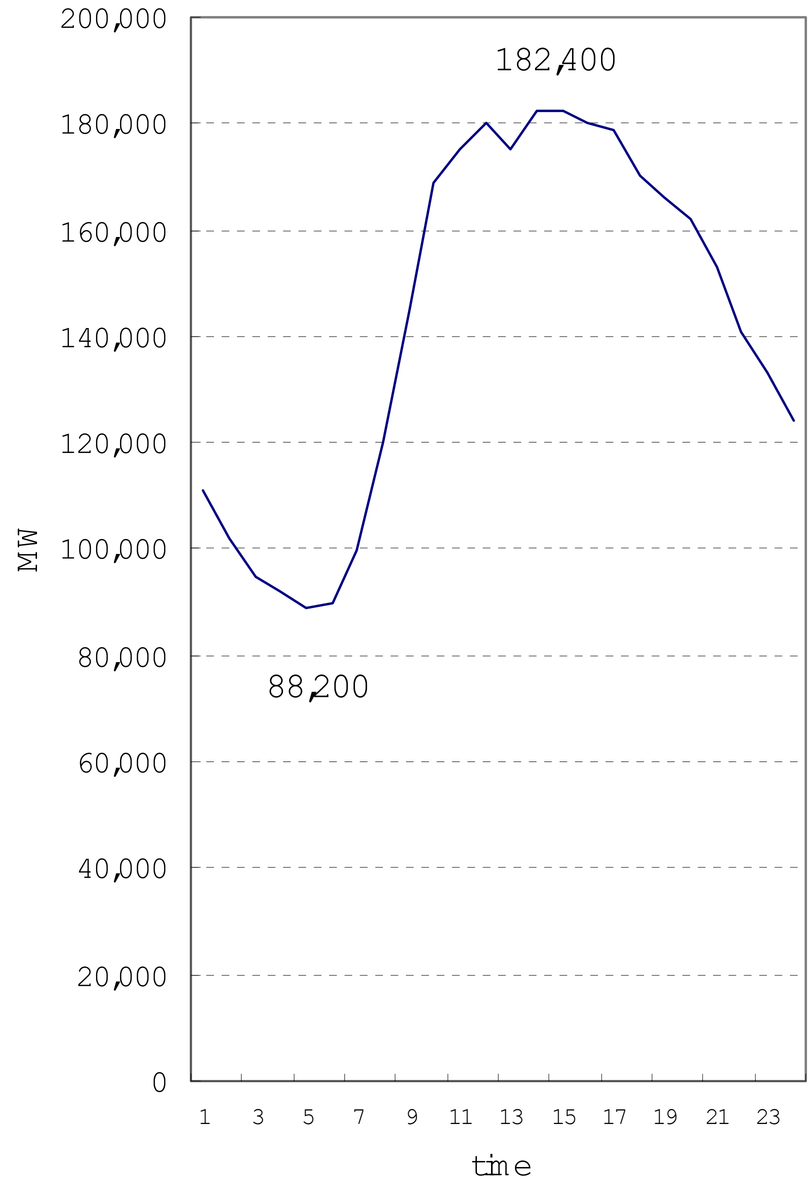


fig. load curve in Japan (2001.7.24)

- 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)

⇩

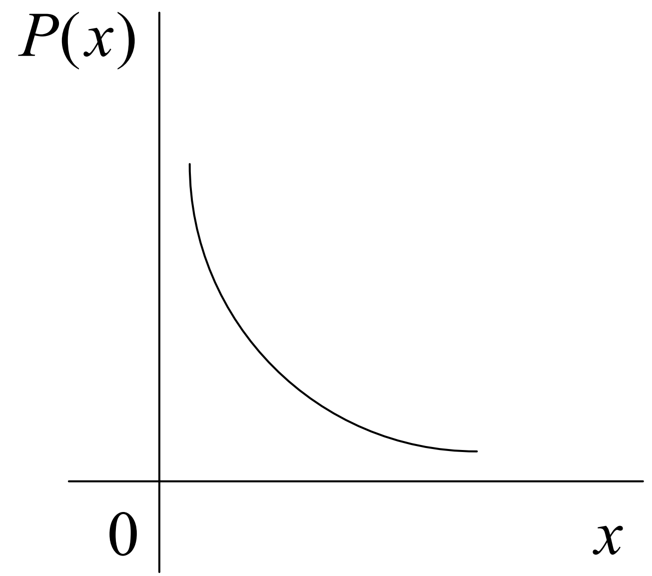
A new approach to real-time pricing that explicitly incorporates **the ramping cost**

⇩

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

    cf. Wang and Shahidehpour (1995)
  - 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** $\dot{x}(t) \equiv \dfrac{dx(t)}{dt}$

$$S(\dot{x}(t))$$

  - assume that the marginal ramping cost $S'(\dot{x}(t))$ is increasing

$$S''(\dot{x}(t)) > 0$$

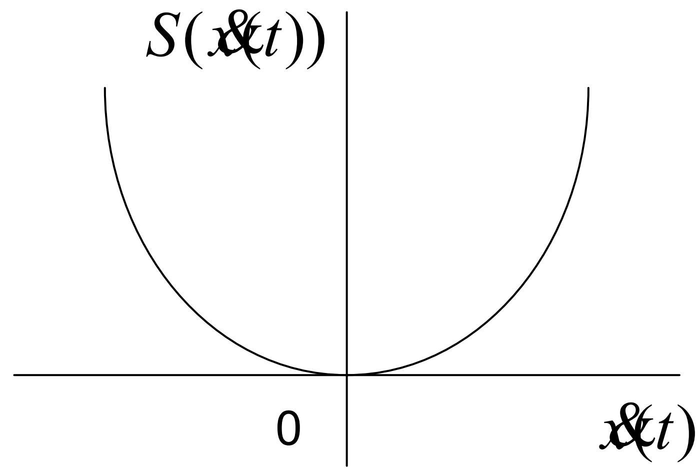


fig. example of the ramping cost func.

- The variable cost

$$C(x(t))$$

3. Optimal Pricing

- Maximization of social welfare

$$\max_{x(t)\geq 0} : W^s \equiv \int_0^T \{B(x(t),t) - C(x(t)) \boxed{- S(\dot{x}(t))} \}dt$$

Considering **the ramping cost** explicitly

$$p^s(t) = C'(x^s(t)) \boxed{- S''(\dot{x}^s(t))\, \ddot{x}^s(t)}$$

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

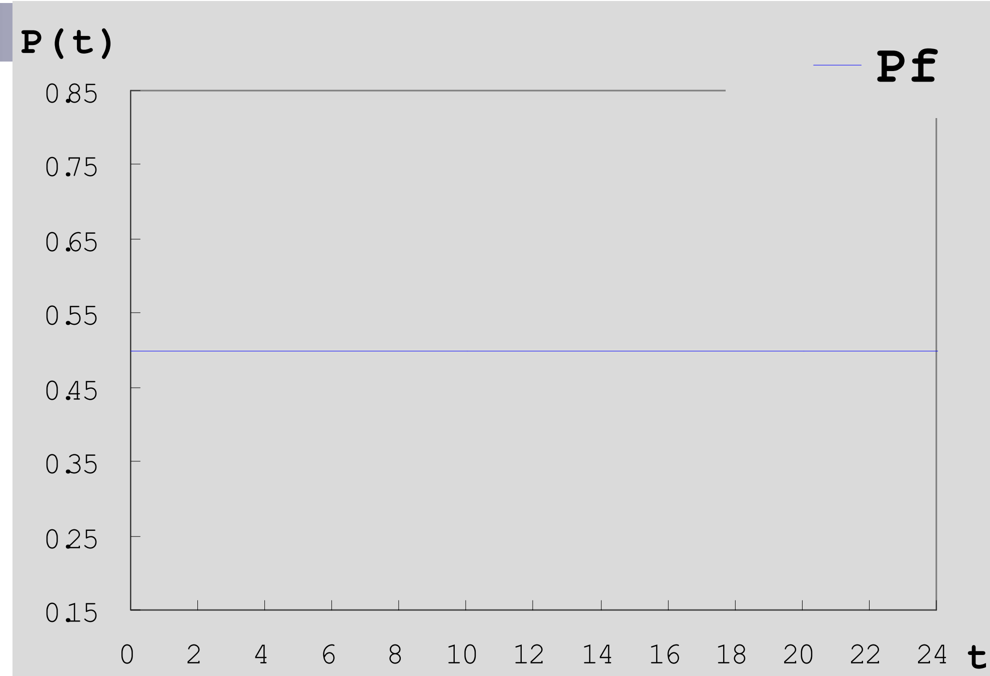
The optimal rate of a demand change

4. Numerical Example

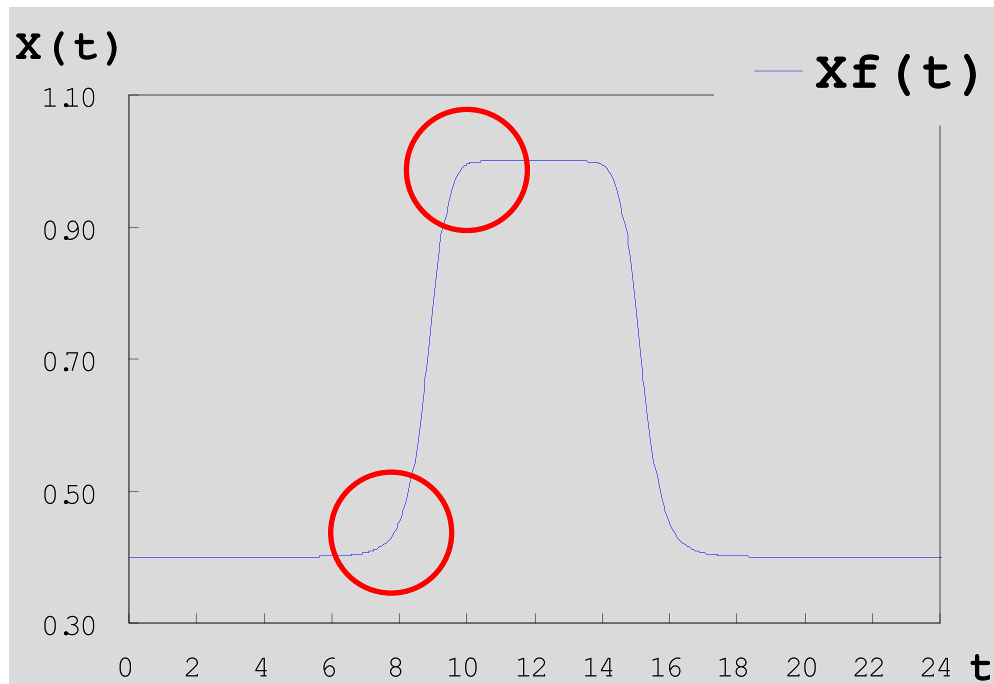
Flat rate :

The base case

The price path



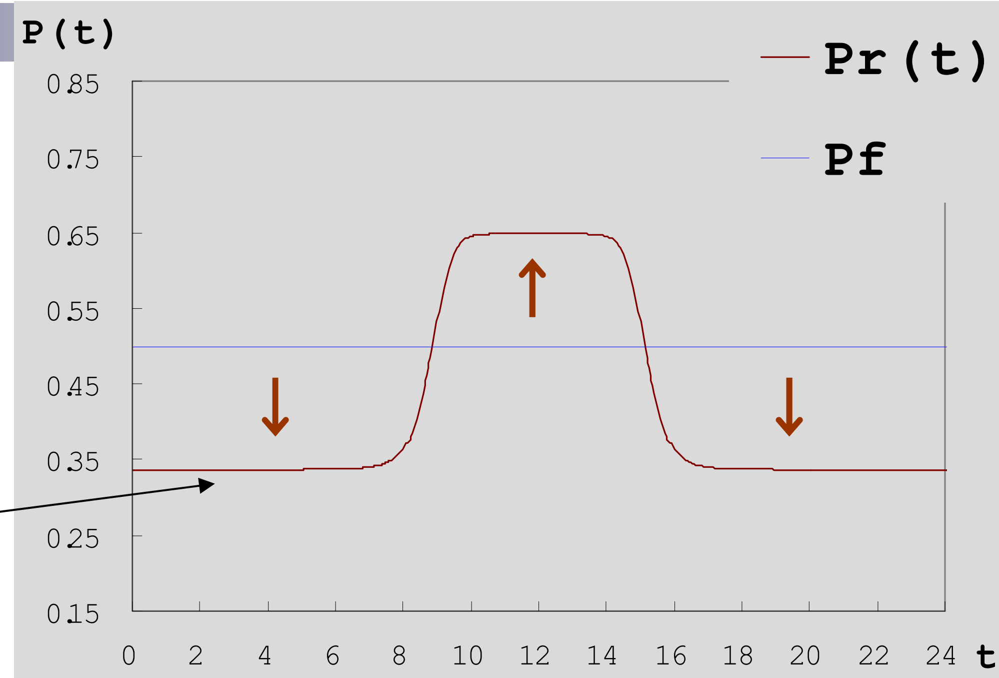
The demand path



Flat rate vs. RTP

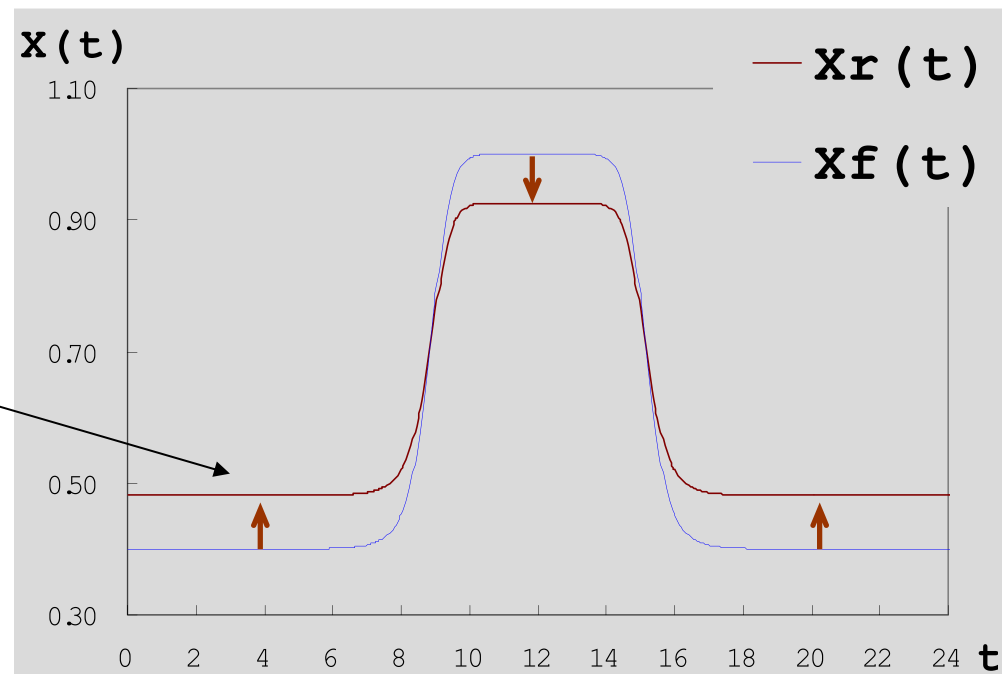
RTP

The price path

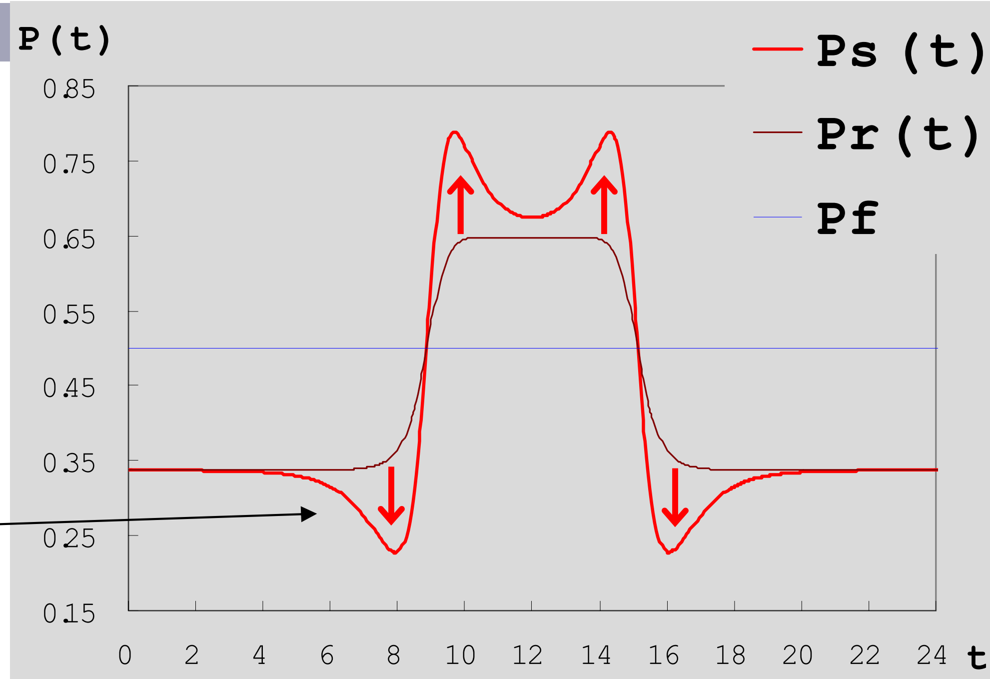


The demand path under RTP

The demand path

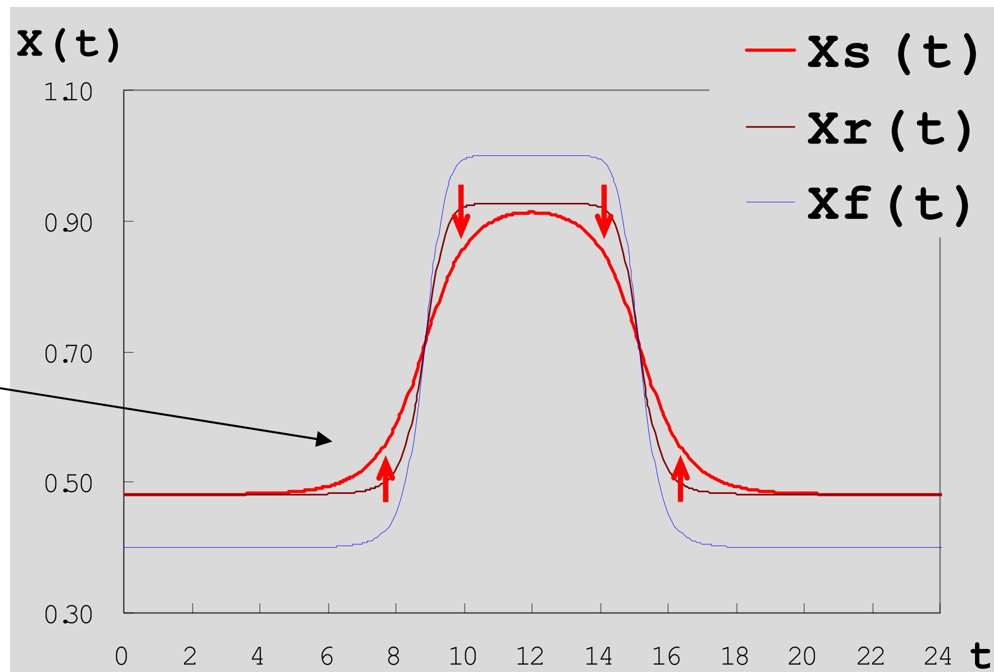


Flat rate vs. RTP vs. RTP-S



RTP-S

The price path



The demand path under RTP-S

The demand path

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