The Effects of Dynamic Pricing and Photovoltaic Technology on Cost Performance in a Residential House

電力料金を需要に応じて変動させるダイナミック・プライス。これを一般住宅で採用したとき、その損益はどうなるか。また太陽光発電を利用すれば。

Yao Zhang[1], Xingzhi Shi[2], Weijun Gao[3], Soichiro Kuroki[4]

[1]Master Candidate, Graduate School of Environmental Engineering, The University of Kitakyushu, Japan
[2] PhD, Graduate School of Environmental Engineering, The University of Kitakyushu
[3] Professor, Faculty of Environmental Engineering, The University of Kitakyushu
[4] Professor, Faculty of Environmental Engineering, The University of Kitakyushu

Abstract

This paper investigates the effect of dynamic pricing system on residential house use and also analyzes the influence of introducing photovoltaic technology into the dynamic pricing system. Through the calculations, it can be realized that each month of total spending on electricity, dynamic price is higher than using regular prices under the condition that the initial electricity load of residents remains unchanged. The conclusion is that introducing photovoltaic technology into the residential side can eliminate extra fees caused by using dynamic pricing. Compared to consumers using dynamic pricing without equiping with photovoltaic technology, the cost reduction ratio can reached at 35.45%. Additionally, the effect of buy-back price on choosing the capacity of photovoltaic has also been analyzed.

Keywords Dynamic price; Photovoltaic; Economic performance; Electric systemv

1. Introduction

Dynamic pricing is a pricing system that can give consumers powerful incentives to consume less when the system is highly stressed and wholesale prices are very high. As shown in Fig.1, it is a demand response method which requires the participation of both consumers and the power supply enterprises. It is more economical than the time-invariant pricing. Most dynamic electricity pricing currently in use were illustrated as follows. One is to offer residential consumers time-differentiated tariffs that better reflect real-time price variations than traditional flat rates predominant in many markets. Time-differentiated tariffs charge electricity consumers' high prices in peak-load periods and low prices in off-peak periods. Examples of tariffs are the time-of-use (TOU)

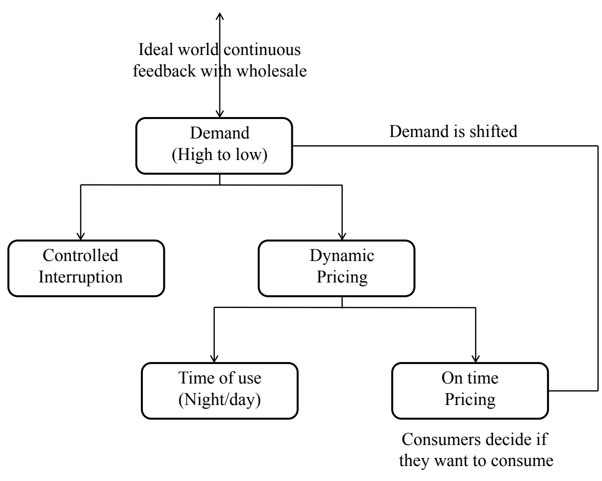

Fig. 1 The way that dynamic pricing shift demand

rate, where prices vary by hours-of-the-day blocks. Another is the more dynamic critical peak pricing (CPP) rate, where higher prices may be imposed if the system is severely constrained as in cold winter periods or warm summer periods. Real-time-price (RTP) is updated every day on an hourly or sub-hourly basis, to closely mirror spot prices in the wholesale market. In these all instances, end-users have incentives to respond to short-term price variations by reducing peak consumption or by shifting peak consumption to off-peak periods.

The target electricity price system in this paper is critical peak pricing. In previous studies, researchers mainly concentrated on the problem of how consumers can effectively respond to the peak electricity price. For this purpose, different methods are used to guide consumers to reduce their electricity consumption in peak period reasonably. The hotspot of their research is to extremely improve the degree of residents' demand-response, ignoring the normal living standards of residents. In contrast, in this paper, we take the perspective of the ordinary residents, assume that the electricity load of residents in peak period remains unchanged for ensuring their original living standard, investigating the effect of dynamic pricing system on the residential house use and also analyzing the influence of introducing the photovoltaic technology into the dynamic pricing system.

2. Case setting

2.1 Data base

2.1.1 Climate data

The strength of solar radiation is the primary consideration in selecting location for PV installation. Local climate and environment factors such as temperature, humidity, precipitation, and wind will constrain the output of PV array. Nevertheless, these are all secondly effects when compared with insolation intensity.

As the third largest island of Japan, Kyushu has advantageous conditions of climate and geothermal character. The annual cumulated hourly irradiation and hourly maximal irradiation are shown as Fig. 2. According to this profile, it can be seen that maximum irradiation is at 12:00 in the midday.

2.1.2 Electricity load data

In this study, a two-story detached house with floor area of 183m^2 has been selected as a case study. Fig. 2 shows the load changes within one day of residential users in three representative months.

In January, as Fig. 3 shows, the electricity load of residential consumers decreased slowly from 1:00 to 4:00. It began to rise slowly from 5:00 to 7:00, owing to the residents' daily activities in the morning. About 8:00, the load reached at morning peak period, after

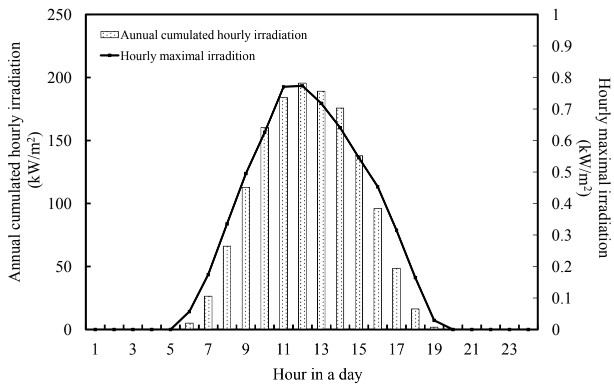

Fig. 2 Annual cumulated hourly irradiation and hourly maximal irradiation

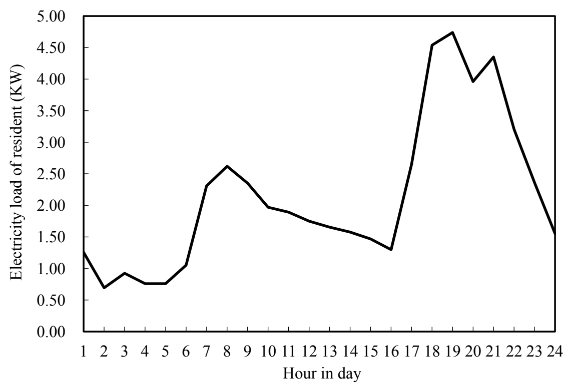

Fig. 3 Electricity load of residential consumers in January

which the load fell slightly. In the period from 16:00 to 19:00, the load curve continued its rise, reaching an evening peak at 19:00 and continued until 21:00. Then it began to fall, reaching a low point at 5:00. In January, the maximum load was 4.74kW, the minimum load was 0.69kW, and the peak-vale difference was 4.05kW.

In August, as Fig. 4 shows, from 8:00 in the morning, some household appliances resulted in the load reaching 1.23kW. After that, due to the high temperature in summer, cooling load began to increase making the load rise to a higher level. From 18:00, most people left work, so household appliances' opening rate increased and the load continued to climb. At 20:00, night lighting gradually commenced, and the electricity load reached a maximum at 21:00.

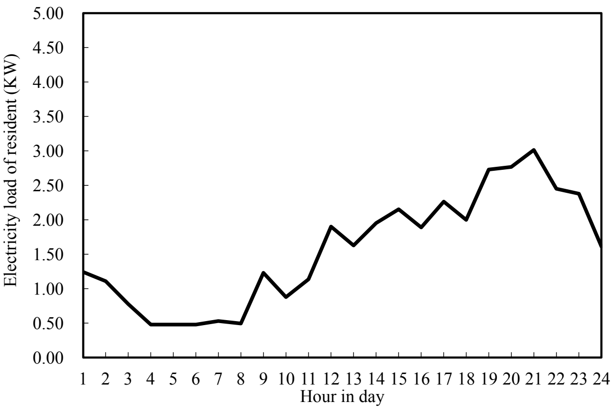

Fig. 4 Electricity load of residential consumers in August

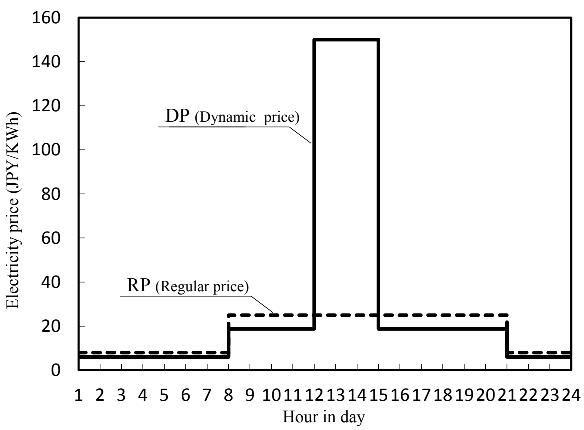

Fig. 5 Electricity price in a day

2.1.3 Electricity price data

Here, we choose time-of-use electricity price as the research target. There are two primary ways of pricing, one is the regular price (RP), and the other is the dynamic price (DP), both of them are shown as Fig 5. For RP, the price is 8JPY/kWh for 1:00 to 7:00 and 22:00 to 24:00, and 25JPY/kWh for 8:00 to 21:00. For DP the price is 6JPY/kWh for 1:00 to 7:00 and 22:00 to 24:00, 18.75JPY/kWh for 8:00 to 12:00 and 16:00 to 21:00, and 150JPY/kWh for 12:00 to 15:00. Compared with the regular price, the dynamic price in the periods 1:00-7:00, 22:00-24:00, 8:00-12:00 and 16:00-21:00 declined in the proportion of 25%. The peak period price from 12:00 to 15:00 of DP is about 6 times higher than the RP.

2.1.4 Photovoltaic data

Photovoltaic is a method of generating electrical power by converting solar radiation into direct current electricity. PV properties are shown as Table 1. In this paper, we chose ND-165AA model of photovoltaic panels produced by Sharp. The output of that panel is 165 W and efficiency is 14.3%. According to electricity load, the whole area of photovoltaic panel is 34.965 m^2 and capacity is 5 kW. The initial cost of that panel is 460000 JPY/kW and lifetime is 20 years.

Table 1 Photovoltaic information

Content	PV
Output(W)	165
Efficiency	14.30%
Whole area(m2)	34.965
Capacity(kW)	5
Initial cost(JPY/kW)	460000
Life time(year)	20

Table 2 Three different cases

	Electricity price mode	Photovoltaic
Case 1	Regular price	not have
Case 2	Dynamic price	not have
Case 3	Dynamic price	have

2.2 Case setting

Three different ways were planned for the cases. The related information was shown in Table 2. We let case 1 only use the regular price as shown in Fig. 3. Case 2 used the dynamic price as shown on Fig. 3. Both case 1 and case 2 are not equipped with photovoltaic. Through the comparison between case 1 and case 2, we can draw a conclusion about whether the residents can benefit from using dynamic price. In case 3 using the dynamic price, meanwhile, photovoltaic was introduced. Through the comparison between case 2 and case 3, we can determine whether introducing photovoltaic into the residential side can eliminate extra fees caused by using dynamic price.

3. Case Analysis

3.1 The effect of dynamic pricing on the cost performance in a residential house

In a general way, there is a difference in the peak load period between residential consumers and all consumers including commercial and industry sectors. Due to time delays, it will have a negative influence on residential consumers when using dynamic pricing at high load period. In order to get a clear conclusion, this paper compared the cost effects caused by using regular pricing and using dynamic price, using an analysis between case 1 and case 2. As shown in Fig. 6, every month of all spending on electricity using dynamic price is higher than that using regular price. In July, August and September, the cost of using dynamic price is about 67% higher than that using regular price.

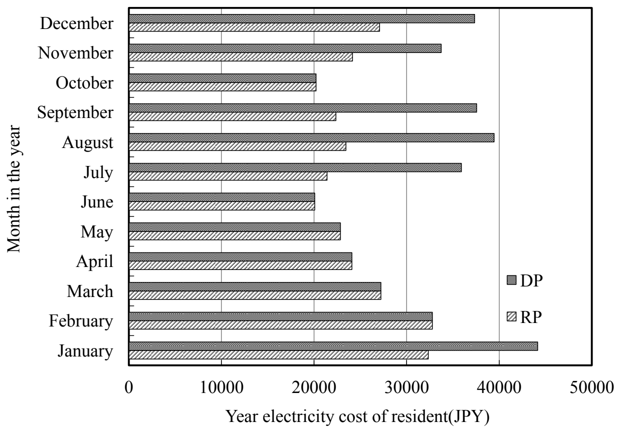

Fig. 6 Total cost comparison between regular price and dynamic price in residential house

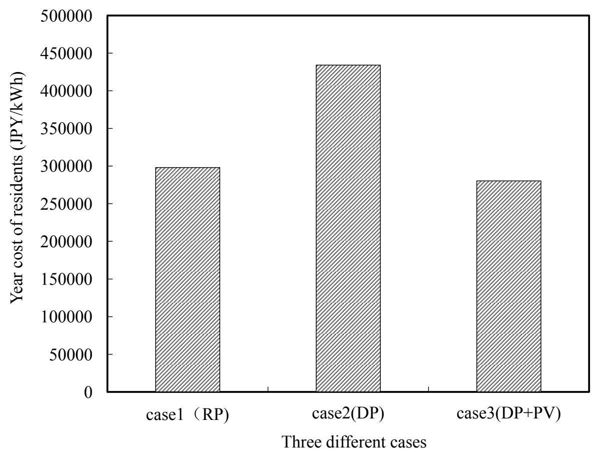

Fig. 7 Total year electricity cost of three cases

3.2 Total cost of residential side influenced by the import of photovoltaic

Dynamic pricing is a demand-response method that can give consumers incentives to consume less when the system is highly stressed. It is an essential way of optimizing power grid. However, residents who use dynamic pricing will suffer economic losses if they want to maintain their original lifestyle unchanged. So it is important for us to make a balance between residential consumers' benefit and the whole grid's improvement.

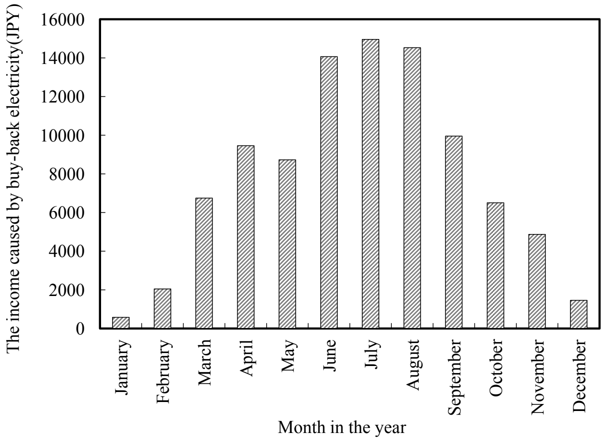

Fig. 8 The profit of buy-back electricity powered by PV

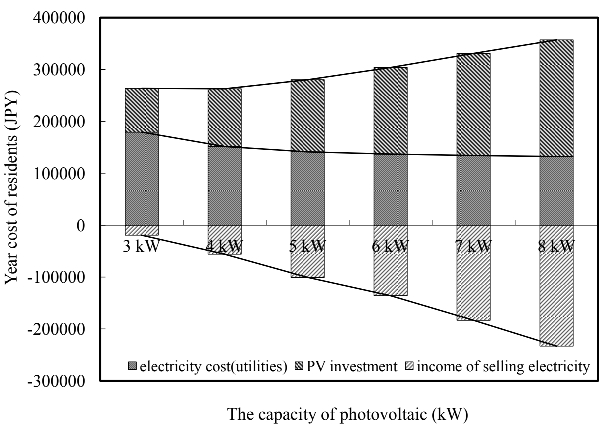

Fig. 9 Component of annual cost of residents

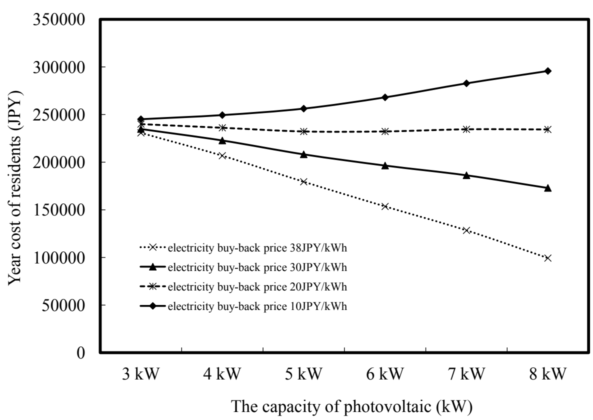

Fig. 10 Effect of buy-back price on choosing capacity of PV

3.2.1 The effect of photovoltaic on the cost performance from residential side

Here, we assume that photovoltaic was introduced into the residential side. The generating capacity of photovoltaic is mainly decided by isolation; it can satisfy the electricity consumption of residential side partly. Meanwhile, when the isolation is high, we can also sell the extra electricity to the power company, using this way to get certain profit.

As shown in Fig. 7, we can see that the total electricity cost of case 3 (equipped with photovoltaic) is lower than the cost of cases 1 and 2. Compared with case 2, the cost decrease ratio reached 35.45% which proved that the introduction of photovoltaic is conducive to reducing residents' extra fee caused by using dynamic price. Introducing photovoltaic can solve the contradiction between the improvement of whole grid and the residential consumers' benefit. Fig. 8 shows the income situation produced by photovoltaic.

Fig. 9 shows the component of annual electricity cost of residential consumers. As anticipated, the cost of system initial investment has a linear increase in capacity. The cost for electricity purchase is decreased as the PV capacity increased. However, the amount of decrease is very slightly. This is because the electricity purchased is mainly for night use, and at that time the generation of PV is almost close to zero.

It is also can seen from Fig. 9 that the income of selling electricity is increased as the PV capacity increases and the growth of initial investment is not as fast as that of income of selling extra electricity generated by PV. Therefore, at the current electricity buy-back price 38JPY/kWh, the total annual electricity cost of residents decreased with the increasing of PV's capacity.

3.2.2 The effect of buy-back pricing on choosing the capacity of photovoltaic appropriately

In addition, the capacity of photovoltaic is not the bigger the better with the change in buy-back price. In Fig. 10, it can be seen that when the buy-back price is 38JPY/kWh, the capacity of PV is the bigger the better. If the buy-back price continued reduction to 20 JPY/kWh, with the increase of PV's capacity, the year electricity cost of residents decreases first, and then starts to increase. When the buy-back price reaches 10 JPY/kWh, the year electricity cost of residents starts to increase with PV's capacity.

4. Conclusion

This paper explores the effects of dynamic pricing and photovoltaic technology on the cost performance in a residential house. It was found that it has no economic benefit for residents to use dynamic pricing if they maintain their original lifestyle. To compensate for this tough situation, photovoltaic technology was supposed to be introduced into residential side. Through calculations, we reached the conclusion that it is feasible to introduce photovoltaic technology into the residential side to reduce extra fees caused by using DP. Specific conclusions can be drawn as follows:

(1) Total spending on electricity each month making use of dynamic pricing is higher than that using regular pricing. In July, August and September, the cost of using dynamic price is about 67% higher than that using regular price.

(3) Introducing photovoltaic technology can solve the contradiction between the improvement of the whole grid and the residential consumers' benefit. Compared to consumers using dynamic pricing who are not equipped with photovoltaic technology, the cost reduction ratio can reach 35.45%.

(4) Buy-back price can strongly influenced the choice of photovoltaic capacity. The capacity of photovoltaic is not the bigger the better in the change of buy-back price. When the buy-back price is 38 JPY/kWh, the annual electricity cost of residents decreased with the increasing of PV capacity. When the buy-back price is 20 JPY/kWh, with the increase of PV capacity, the annual electricity cost of residents decreased at first, and then start to increase. When the buy-back price is 10 JPY/kWh, the annual electricity cost of residents increased with PV capacity.

References

1) Mitchell, Bridger and Jan Acton. 1980. "The Effects of Time-of-Use Rates in the Los Angeles Electricity Study." RAND, N-1533-DWP/HF.
2) Paul L. Joskow. 2012. Dynamic pricing of electricity.
3) Kingmin Wang, Yuju Cheng. 2012. "Analysis of the TOU Rate Scheme and the Demand Reduction Incentive Scheme in Taiwan." Journal of low carbon economy.
4) Karen Herter, Patrick McAuliffe, Arthur Rosenfeld. "An exploratory analysis of California residential customer response to critical peak pricing of electricity." Volume 32, January 2007, 25-34.
5) Bhubaneswari Parida , S. lniyan, Ranko Goic "A review of solar photovoltaic tenologies." Volume 15, Issue 3, April 2011, 1625-1636.
6) Hongbo Ren, Weijun Gao, Yingjun Ruan. "Economic optimization and sensitivity analysis of photovoltaic system in residential buildings." Volume 34, Issue 3, March 2009, 883-889.
7) Shisheng Huang, Jingjie Xiao, Joseph F. Pekny, Gintaras V. Reklaitis. "Optimal Residential Solar Photovoltaic Capacity in Grid connected Applications." Volume 30, 2012, 357-361
8) Federal Energy Regulatory Committee. 2009. A national assessment of demand response potential, staff report, Washington, DC.

Acknowledgment

This research was partly supported and funded by MEXT, Japan (Kiban C, No. 2456072)