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PV value-added service pricing model of stand-alone Stackelberg game

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Abstract. With the development of new energy technology, the new-type energy still occupy increasingly larger proportion of the future energy structure, and the development prospect is bright. Under the policy background of further opening the sales side, the concept of PV value-added service is proposed to enhance customer stickiness and gain potential customer of power grid enterprises. In this paper, the pricing model of double photovoltaic value-added service system including three main game participants about the photovoltaic seller, grid company and photovoltaic value-added service consumers as the research subjects, Stackelberg game method is established, put forward the best benefits the pricing method of photovoltaic value-added services. At the same time, the actual situation of the Henan photovoltaic park is studied and analyzed. This paper establishes the Stackelberg double-deck game pricing model of 'spontaneous self-use and residual electricity network' in the region, and determines the optimal pricing in this mode. Finally, two economic evaluation indexes are used to evaluate and summarize the economic benefits of 'spontaneous self-use and residual electricity network' service mode.

1. Introduction

In recent years, China's distributed photovoltaic power generation has developed rapidly, and the development of distributed photovoltaic power generation based on building roof is a hot spot.

As the sales side gradually liberalizes, the internal business of the grid enterprise is divided into regulatory and non-regulated businesses. Carrying out quality value-added services can help grid companies to enhance the competitiveness of non-regulated business segments. Value-added services are essentially a kind of service, not a physical product. They cannot be priced solely by the concept of "cost and revenue". In particular, PV value-added services have the characteristics of a game and need to consider the factors that interact with each participant in the market. Therefore, it is necessary to introduce relevant methods of game theory in the pricing process.

At present, many scholars at home and abroad have studied industrial rooftop photovoltaic systems and game theory pricing methods. However, there is a lack of research that combines photovoltaic applications with grid company value-added services for analysis.

This paper considers the particularity of value-added services and introduces the concept of game to analyze value-added services. Take PV sellers, power grid companies and PV value-added service consumers as the main body of research, Stackelberg game method was used to establish a two-tier



pricing model based on three main body PV value-added service systems, and the pricing of PV value-added services under the optimal income was established.

2. Analysis of annual photovoltaic power generation and value-added services in industrial parks

2.1. Calculation method of roof photovoltaic power generation

This paper calculates the power generation based on the installed capacity of the photovoltaic power generation system and the peak hours of photovoltaic power generation. The annual power generation of photovoltaic power generation system is calculated by the following equation:

$$Q = T_s \cdot P \cdot \eta \cdot (1 - D)^{n-1} \quad (1)$$

Where, T_s is the number of hours of sunshine for the PV system at full load, P is the installed capacity of the rooftop photovoltaic system (in KW), D is the average annual attenuation rate of the solar photovoltaic system, and η is the comprehensive consideration of the impact factors for the photovoltaic system. Comprehensive efficiency afterwards, including: The PV square tilt correction factor, inverter conversion loss factor, line and transformer loss factor are expressed as η_1 , η_2 and η_3 , respectively.

Therefore, the overall efficiency calculation equation for photovoltaic power generation systems is:

$$\eta = (1 - \eta_1) \cdot (1 - \eta_2) \cdot (1 - \eta_3) \quad (2)$$

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2.2. Basic model of PV value-added services

Participants in value-added services include PV equipment vendors, grid companies, PV value-added service consumers, and government agencies. Value-added service participants and models are shown in figure 1.

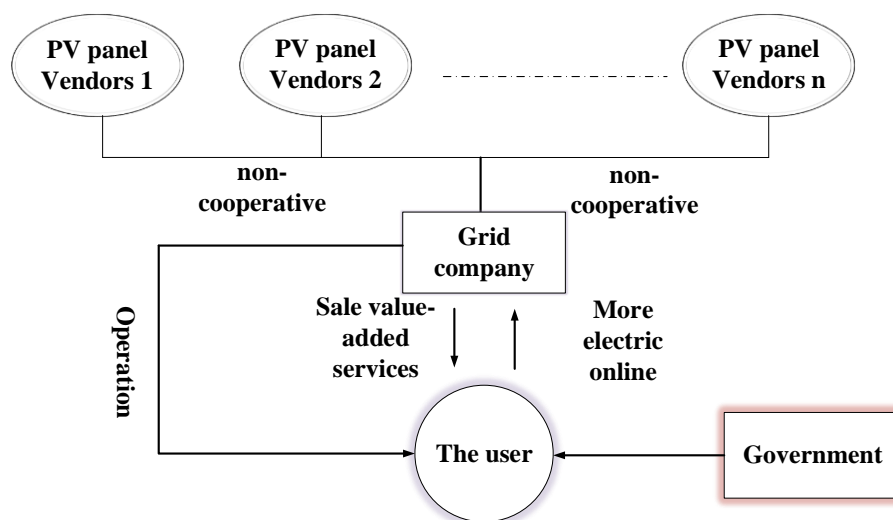


Figure 1. Value-added service participants and models

PV equipment vendors: Providing PV modules to grid companies for a certain amount of revenue.

Grid company: Provide consumers with complete PV value-added supporting services including installation, operation and maintenance, so as to charge consumers accordingly. At the same time, the grid company purchases surplus electricity from consumers, and the total revenue is the sale of value-

added services minus the cost of purchasing electricity from the surplus electricity.

Consumers: After purchasing services, not only can you save on electricity purchase costs, but you can also sell surplus electricity to the grid to generate revenue.

Government: As a blender of value-added services, it provides policy support and financial assistance for the entire package to gain environmental benefits and increase tax revenue.

The purpose of the entire value-added service design is to maximize economic benefits and reduce operating costs, in line with the idea of game theory. The ultimate goal of the game is to minimize the cost of running the system for any uncertainty in the system. Therefore, the problem of maximizing economic benefits can also be transformed into the optimal pricing problem among the participants. Therefore, the Stackelberg game is used to solve the problem.

3. Benefit maximization problem and Stackelberg double-layer game model

This paper considers the game system consisting of photovoltaic sellers, power grids and PV consumers. It uses game theory to transform value-added service design problems into pricing problems based on PV value-added services, so as to study the economic benefits of the system.

3.1. Market participants analysis

- Photovoltaic panel suppliers: Provide various types of photovoltaic panels for grid companies.
- Photovoltaic value-added service consumers (i.e. various types of users in the park): purchases of PV value-added services provided by the grid.
- Photovoltaic value-added service providers (i.e. grid companies): provide a variety of services to consumers.

3.2. Parameter setting

Let p be the sales price of photovoltaic panels. The market expectation of sales volume function is determined by potential market demand and stochastic fluctuation factors, expressed by function $y(p)$. It is known from the literature [1] that the market expected sales volume function can generally be divided into two forms: a linear expectation function and a fixed elastic coefficient expectation function. Since the PV value-added service is a new type of product, the linear expectation function is adopted, and q is the sales volume. a is the potential market scale of the photovoltaic panel value-added service, which can be equivalent to the local photovoltaic power generation. b is the price elasticity factor for the sales price of PV panel value-added services, that is, the rate of change of sales volume with the sales price, then:

$$y(\rho) = q = a - b\rho \quad (3)$$

3.3. Grid company sells photovoltaic value-added service layer model

In the time period $[t, t+1]$, the grid company wants to maximize its own interests, need to adjust the price of PV value-added services, consider the price sensitivity of consumers, combined with the desire to buy, between sales volume and sales price. Look for balance. The revenue of the photovoltaic value-added service obtained in the time period t can be expressed as:

$$\prod_r = (\rho_r - \omega + c_\theta) \cdot q_r \quad (4)$$

$$q_r = a - b \cdot p_r \quad (5)$$

$$c_\theta = \rho_r \cdot \lambda - c_g \quad (6)$$

Among them, q_r and p_r are respectively PV panel sales price and sales volume of r PV panel sellers, ω is the wholesale price of photovoltaic panels, c is the annual income of PV maintenance services, PV maintenance for PV value-added service consumers each year. The proportion of expenditure to the price of value-added services, c_g is the cost of providing photovoltaic maintenance services to the

grid company itself.

In this case, the optimal benefit of the grid can be expressed as:

$$\max \Pi_r = [\rho_r \cdot (1 + \lambda) - \omega - c_g] \cdot (a - b \cdot \rho_r) \quad (7)$$

Solve according to the literature [2].

$$\frac{d\Pi_r}{d\rho_r} = 0 \quad (8)$$

Among them, w is considered as a fixed value, so that the optimal solution of the value-added service price provided by the grid can be obtained.

3.4. Establishment of a consumer layer model for photovoltaic value-added services

The mode of using self-supplemented residual power to access the Internet is equivalent to distributed energy. According to the regulations, distributed photovoltaic power generation projects that have been put into operation nationwide since January 1, 2018 and adopt the “spontaneous use and surplus online” mode. The standard is 0.37 yuan per kWh.

In the time period $[t, t+1]$, when using this mode of operation, the amount of electricity on the Internet = the amount of electricity generated by the photovoltaic panel - the actual electricity consumption of the consumer, and Q is the total power generation of the photovoltaic power generation system, and Q_0 is the consumer. According to the policy, the subsidy per kWh of the photovoltaic power generation system is h . The price of the consumer in the region to sell back to the grid is h_1 , and the local city power benchmark price is j . When $Q - Q_0 \geq 0$, such operation The net benefit that consumers can obtain in a model of value-added services is:

$$\Pi_l = Q \cdot h + Q_0 \cdot j + (Q - Q_0) \cdot h_1 - \rho_r \cdot (q_l + \lambda) \quad (9)$$

If $Q - Q_0 < 0$, then:

$$\Pi_l = Q_0 \cdot j - \rho_r \cdot (q_l + \lambda) \quad (10)$$

Analysis of numerical examples of game model

3.5. Study description

Based on the oretrical analysis of the above game theory model, two value-added service models are set up and compared to show their differences on economic benefits. Here, Henan is selected as the location for the analysis of the case study. Because Henan is in the third level of solar radiation grading, that is, the area where the amount of radiation is medium, it has a certain universality.

Photovoltaic board sales seller layer game model calculation:

First, this paper analyze the price of each layer of the game theory, and calculate the annual power generation in Henan by equation 1. According to statistics, the annual radiation amount in Henan is about 5850 MJ/m², and the annual sunshine hours are between 1050 and 1400. The annual sunshine hours are 1200. Considering that most consumers use fixed brackets, the relationship between the annual light hours listed in the table below and the number of hours of full-load photovoltaic panels shows that the full-scale power generation time in Henan, China is $T_s=900$ hours. For the general park users, for the 3,570-square-meter plant, it is enough to install a 250 kW photovoltaic power generation system, so set $P=250$. It can be known from the parameters of the photovoltaic panel that the maximum power of each photovoltaic panel is 300W, and the average output power is set to 100W here. Therefore, the factory can be equipped with 2,500 photovoltaic panels.

Table 1. Effectiveness of each influencing factor

	Coefficient name	Corresponding loss rate
η_1	<i>Line loss</i>	4%
η_2	<i>Inverter loss</i>	5%
η_3	<i>Mismatch loss</i>	4%

The photovoltaic power generation system has a cycle of about 20 years, and the photovoltaic power generation system has a decay rate of 0.55%. The efficiency of each impact factor is shown in table 1. Therefore, the overall efficiency of the system is 87.6%, so that the annual power generation of the photovoltaic power generation system can be obtained. for:

$$Q = 900 \cdot 250 \cdot 87.6\% \cdot (1 - 0.55\%)^{n-1} \quad (11)$$

At present, the average market price of photovoltaic modules is 0.3 US dollars per watt. According to the actual market situation, the purchase cost of each photovoltaic module is 570 yuan, so there is $w=570$, and $a=2500$ and $b=0.8$ are set at the same time. In this example we can see that there are footnotes after each author name and only 5 addresses; the 6th footnote might say, for example, 'Author to whom any correspondence should be addressed.' In addition, acknowledgment of grants or funding, temporary addresses etc might also be indicated by footnotes.

3.6. Grid layer game model calculation

From the grid-level game model, the PV board's value-added service revenues obtained by the grid are:

$$\prod_r = [\rho_r \cdot (1 + \lambda) - \omega - c_g] \cdot (a - b \cdot \rho_r) \quad (12)$$

Among them, the annual PV maintenance expenditure of PV value-added consumers accounts for the proportion of the value-added service price, which is generally 1%~3%, and 3% here. The cost of the PV company's own PV maintenance services is 1% to 3% of the wholesale price of PV panels, and 3% is also used here. Therefore: $c_g = w \times 3\%$. From $a=2500$, $b=0.8$, the optimal solution for grid efficiency in this case is:

$$\max \prod_r = \max(-0.824\rho_r^2 + 3348.68\rho_r - 2417750) \quad (13)$$

From the available $d\prod_r/d\rho_r = 0$, the optimal solution for voltage-value-added services is: $\rho_r = 2031.97$. Therefore, the value-added service of the grid company that has obtained the most profit is priced at 2031.97 yuan.

3.7. Consumer layer game model calculation

It is known from the reference [3]-[4] that the main operating mode of photovoltaic value-added services is the self-sufficient residual power access mode, which is equivalent to the application of distributed energy. When the amount of power generated by the system is greater than the amount of electricity used by the user, the system can transmit power to the grid [5]. The photovoltaic power generation time is from 7:00 am to 5:00 pm, which coincides with the office and production time of the park. The utilization rate of photovoltaic power generation is high, 90% of the photovoltaic power generation capacity can be used efficiently, and 10% of the photovoltaic power generation capacity is sent online.

According to the regulations, the subsidy per unit of electricity for this type of distributed energy photovoltaic power generation model is 0.42 yuan, and the subsidy time is 20 years after the completion of the project. As the third-class resource area photovoltaic project in Henan Province, the on-grid price is 1 yuan per kilowatt-hour, and the electricity cost in Henan province is 0.61 yuan.

Therefore, in the time period $[t, t+1]$, the "spontaneous use, surplus power online" mode is adopted,

the annual electricity savings of the photovoltaic value-added service consumers is the annual power generation of $\zeta \times 90\% \times (0.61 + 0.42)$ (ζ is the number of photovoltaic panels). The gain from the surplus electricity grid is the annual power generation is $\zeta \times 10\% \times (1 + 0.42)$.

Therefore, the initial investment cost for consumers to purchase PV value-added services is:

$$C_i = \rho_r \cdot q_r = \rho_r \cdot (a - b \cdot \rho_r) = 1776803.34 \quad (14)$$

The annual net income of PV consumers considering PV project maintenance costs under this mode of operation is:

$$\prod_i = 210699.9 \cdot 0.9945^{n-1} - 38351.45 \quad (15)$$

3.8. The economic value analysis of the PV

The economic benefit evaluation index is the meaning of investing in this value-added service model [6].

There are many evaluation indicators for the economic benefits of different products. Most of the literature considers the economic indicators based on the net cash flow as the investment recovery period, and this economic indicator has its own limitations, it only depends on the project life. The full cost and benefit of the period were considered, and the net present value (NPV) and internal rate of return (IRR) were used as dynamic indicators for the evaluation of investment projects, overcoming the shortcomings of the payback period, taking into account the time value of funds. Considering all the costs and benefits of the project life cycle, it has been an important indicator in domestic and foreign investment decisions for decades.

This paper mainly considers the operation mode of “spontaneous use and surplus electricity access”, evaluates the economics of users purchasing PV value-added services, and evaluates the service by calculating the main economic indicators.

The net present value (NPV) refers to the sum of the net benefits created by the investment project in each of its life cycles discounted at the cost of funds, and the internal rate of return (IRR) is the discount rate when the net present value of the project is equal to zero, which is:

$$NPV = \sum_{i=1}^N \frac{B_i - C_i}{(1+r)^i} \quad (16)$$

Where: B is the benefit of value-added services, C is the cost of value-added services, and N is the life of the project.

If:

$$\sum_{i=1}^N \frac{B_i - C_i}{(1+r)^i} = 0 \quad (17)$$

The r is the internal rate of return. Both net present value and internal rate of return are indicators that reflect the profitability of the project. The former reflects absolute profitability, while the latter reflects relative profitability [7].

For the purposes of this paper, the life of a PV value-added service is determined by the length of the life of the PV panel, which is 20 years. From the data in the net cash flow statement, the net present value (NPV) of the PV value-added service in the case of $N=20$ can be obtained. When $NPV=0$, the internal rate of return (IRR) of the PV value-added service can be determined to be 7%. The project is feasible when the internal rate of return of the evaluation project is greater than the benchmark rate of return. Generally, the bank interest rate is used as the benchmark rate of return for the project. From the latest data, the average interest rate of the major banks in 2008 is 2.28%. Therefore, the internal rate of return of the value-added service project is significantly higher than the mark rate of return. Therefore, the value-added service project is feasible. The recycling period of PV value-added services is shown in Figure 2.

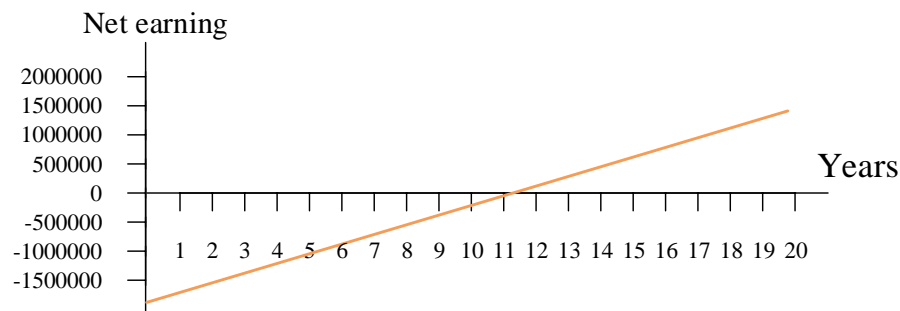


Figure 2. Value-added PV value-added service payback period

As can be seen from Figure 2, consumers can recover the cost in about 10 years after purchasing the PV value-added service.

Conclusion

Based on Stackelberg game theory, this paper models the pricing of PV value-added services. By solving the problem of maximizing economic benefits in the two-layer game model, the optimal pricing of each level is obtained and a complete pricing strategy is given. The economics of the model are verified by the case analysis and calculation of Henan, and the cost can be recovered, and the income can be obtained in a short time. The model of this paper does not depend on the specific PV output data and can be modeled and analyzed according to the actual situation in any region. It has strong universality and has certain promotion needs for grid companies.

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