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Analysis Of Investment Benefits Of Distributed Photovoltaic Power Generation Projects Built In Different Periods In China

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Abstract
Investigate the cost of distributed photovoltaic power generation in different periods, use the payback period and internal rate of return (IRR) as economic evaluation indexes, and propose a new power generation estimation method for 20 years based on 3-year power generation data of actual cases to analyze the annual net revenue, revenue source ratio, payback period and IRR of distributed photovoltaic power generation systems in six periods. The results show that factors such as the amount of initial investment, government subsidy, provincial subsidy and the proportion of self-consumption limit the return on investment of photovoltaic systems built in different periods. With the rapid implementation of the subsidy reduction policy, the progress in photovoltaic power generation technology and the rapid decline in scale costs, the photovoltaic industry has slowly bottomed out since 2019, and the payback period of distributed photovoltaic power plants is about 7 years during this period. The internal rate of return can reach more than 13%, and decentralized photovoltaic power generation projects have received more attention.

Keywords*:Distributed photovoltaic power generation, Power generation, Construction Cost, Economic efficiency*

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I. Introduction

In recent years, energy shortages and environmental pollution have attracted much attention, and photovoltaic power generation has developed rapidly as a clean and renewable energy generation method. According to statistics, 48.2 million kilowatts of new photovoltaic power will be installed in China in 2020, including 32.68 million kilowatts of centralized photovoltaic power plants and 15.52 million kilowatts of distributed photovoltaic power (National Energy Administration, 2021). Decentralized photovoltaic power generation has developed rapidly since 2016, from the time when most projects chose to be fully connected to the grid to the time when "self-generation, surplus power online" becomes the absolute preference. This change is mainly influenced by policy and concept change (Li et al.,2020; Wang et al.,2020). However, due to the different construction costs and different subsidy policies in different periods, the investment returns of decentralized photovoltaic power generation projects are also very different. At present, when analyzing the advantages of PV power generation projects at home and abroad, the operation mode and economic benefits of PV power generation projects are mostly analyzed based on a certain time, a certain region (Mitsanon et al.,2020), a certain capacity or a certain environment. Wen Zekun et al. analyzed the economic benefits of a 5KW photovoltaic power generation project in Xinyu, Jiangxi Province (Wen et al.,2018), and Lu Zheng et al. analyzed the costs and benefits of customer-side photovoltaic power generation projects (Lu et al.,2021). We studied the investment benefits of decentralized photovoltaic power generation in commercial buildings (Ran Bin et al.,2021). Consider the problem of appropriate utilization of new energy considering operating costs (Dong Yu et al.,2021). This paper analyzes the investment efficiency of distributed photovoltaic power generation projects built since 2018 in the mode of "self-generation and grid-connection of surplus power" The paper attempts to provide a reference basis for investment in distributed photovoltaic power generation projects to gradually transition to the era of grid parity.

II. Research subjects and research methods

Data source

In recent years, energy shortages and environmental pollution have attracted much attention, and photovoltaic power generation has developed rapidly as a clean and renewable energy generation method. According to statistics, 48.2 million kilowatts of new photovoltaic power will be installed in China in 2020, including 32.68 million kilowatts of centralized photovoltaic power plants and 15.52 million kilowatts of distributed photovoltaic power (National Energy Administration, 2021). Decentralized photovoltaic power generation has developed rapidly since 2016, from the time when most projects opted for full grid connection to the time when "self-generation, surplus power online" becomes the absolute preference. This change is mainly influenced by policy and concept change (Li et al.,2020; Wang et al.,2020). However, due to the different construction costs and different subsidy policies in different periods, the investment returns of decentralized photovoltaic power generation projects are also very different. At present, when analyzing the advantages of PV power generation projects at home and abroad, the operation mode and economic benefits of PV power generation projects are mostly analyzed based on a certain time, a certain region (Mitsanon et al., 2020), a certain capacity or a certain environment. Wen Zekun et al. analyzed the economic benefits of a 5KW photovoltaic power generation project in Xinyu, Jiangxi Province (Wen et al.,2018), and Lu Zheng et al. analyzed the costs and benefits of customer-side photovoltaic power generation projects (Lu et al.,2021). We studied the investment benefits of decentralized photovoltaic power generation in commercial buildings (Ran Bin et al.,2021). Consider the problem of appropriate utilization of the new energy considering the operating cost (Dong Yu et al.,2021). This paper analyzes the investment efficiency of distributed photovoltaic power generation projects built since 2018 in the mode of "self-generation and grid-connection of excess power". The paper attempts to provide a reference basis for investment in decentralized photovoltaic power generation projects to gradually transition to the grid parity era.

Table 1 List of subsidy policies and construction costs

Different time periods	Grid connection time	National subsidy (Yuan/KWh)	Provincial subsidy (Yuan/KWh)	Construction cost (yuan/W)
Time period one	January 1-May 31, 2018	0.37	0.1	4.6
Time period two	June 1 - July 31, 2018	0	0.1+0.1	4.3
Time period three	August 1 - December 31, 2018	0	0.1	3.7
Time period four	December 31, 2019	0.0404	0.0632	3.5
Time period five	December 31, 2020	0.03	0	3.2
Time period six	2021 - today	0	0	3.4

Annual net income of power station

The service life of general battery panels is generally designed to be 25 years, taking into account the government subsidies and Zhejiang Province subsidies for 20 years and the risk of battery power loss and failure after 20 years. This paper is designed for 20 years without taking inflation into account. The operation and maintenance costs are calculated at 0.05 yuan per watt per year according to the power plant capacity (general industry tariffs). The annual net income of the power plant is the sum of the subsidy policy and the construction cost.

$$\mathrm{L} = (\mathrm{Q1} \times \mathrm{I1}) + (\mathrm{Q2} \times \mathrm{I2}) + \big(\mathrm{Q} \times (\mathrm{I3} + \mathrm{I4})\big) - \mathrm{r} \times \mathrm{P} \tag{1}$$

Where L is the annual net income of the power plant, Q is the annual electricity generation, Q1 is the annual self-generated electricity, Q2 is the annual surplus electricity in the grid, Q=Q1+Q2, I1 is the electricity tariff of the enterprise, I2 is the FGD tariff, I3 is the government subsidy tariff, I4 is the provincial subsidy tariff, P is the capacity of the power plant, r is the operation and maintenance coefficient, which takes the value of 0.05 yuan/watt.

Power generation taking values

The project has been generating electricity for 3 years, from July 2018 to June 2021, and the data on actual electricity generation, feed-in and self-consumption during these 3 years are shown in Table 2. The modules used in this project are all Class A modules. Although there is a problem of module efficiency decay, the decay rate is not high, and the module company promises that the module efficiency in 20 years will be at most 80% of the original module efficiency. Assume the system efficiency at the end of the 20th year as 80%, so the system efficiency decreases by s=0.0115 every year, as follows:

$$(1 - s)^{20} = 0.8 \tag{2}$$

In the actual operation of the project, equipment deterioration is not the main factor affecting power generation. However, equipment failure, ash accumulation in the modules and planned or unplanned power outages of the company have a greater impact on power generation. Therefore, estimating power generation for 20 years only by the rate of equipment wear and tear is a significant error. The three-year data can reflect the

basics of the company's electricity consumption. In this paper, the power generation for 20 years is estimated in the following way. The steps are as follows.
1) Take the average of three years' actual power generation as the data for the second year of the power plant's power generation.
2) Calculate the first year's power generation according to equation 2, and then calculate the 20-year power generation situation again.
3) Use the three-year average of electricity to electricity for self-consumption as the ratio of electricity for self-consumption and excess electricity in the grid for the business of this power plant. We can sell 2% of the power plant's electricity online to the grid company and use the remaining 98% of the electricity for the company's own consumption.

Table 2 Actual power generation of Tianzheng PV power project

Year	PV power generation (KWh)	Grid-connected power (KWh)	Self-use power (KWh)
The first year	731,744.00	30,100.00	701,644.00
The second year	730,695.00	9,290.00	721,405.00
Third year	688,050.00	7,170.00	680,880.00
Average value	716,829.67	15,520.00	701,309.67

Static payback period and internal rate of return
The static amortization period is calculated using the formula:

$$Z = L \times \frac{1-(1-s)^n}{s} \tag{3}$$

Calculation of internal rate of return.

$$Z = \frac{L}{IRR} \times \left(1 - \frac{1}{(1+IRR)^{20}}\right) \tag{4}$$

Where Z is the initial investment amount, L is the annual net return, n is the static amortization period and IRR is the internal rate of return.

III. Results and Discussion

Power generation

From section 2.3 we can see the electricity generation of this power plant for 20 years. The electricity generation of this power plant for 20 years at parity is 651,153.27 KWh, the electricity feed-in at parity is 14098.05 KWh, the electricity for own consumption is 637,055.22 KWh and the total electricity generation is 13,023,065.45 KWh. The relevant data for each year is listed in Table 3.

Table 3 Estimated 20-year power generation capacity of Tianzheng PV power

Year	PV power generation (KWh)	Grid-connected power (KWh)	Self-use power (KWh)
1	725,169.11	15,700.56	709,468.56
2	716,829.67	15,520.00	701,309.67
3	708,586.13	15,341.52	693,244.61
4	700,437.39	15,165.09	685,272.29
5	692,382.36	14,990.69	677,391.66
6	684,419.96	14,818.30	669,601.66
7	676,549.13	14,647.89	661,901.24
8	668,768.81	14,479.44	654,289.37
9	661,077.97	14,312.93	646,765.05
10	653,475.58	14,148.33	639,327.25
11	645,960.61	13,985.62	631,974.98
12	638,532.06	13,824.79	624,707.27
13	631,188.94	13,665.80	617,523.14
14	623,930.27	13,508.65	610,421.62
15	616,755.07	13,353.30	603,401.77
16	609,662.39	13,199.73	596,462.65
17	602,651.27	13,047.94	589,603.33
18	595,720.78	12,897.88	582,822.89
19	588,869.99	12,749.56	576,120.43
20	582,097.99	12,602.94	569,495.05
Average value	651,153.27	14,098.05	637,055.22

Year	PV power generation (KWh)	Grid-connected power (KWh)	Self-use power (KWh)
Total volume	13,023,065.45	281,960.95	12,741,104.49

Annual net income

This paper assumes that the same location, fixed capacity and choice of materials are used in calculating each period's net income. The early or late construction period has no effect on the 20-year average power generation of the power plant and the total power generation figure. Based on the power generation data of Tianzheng power plant, the annual net output of each period can be derived from Equation 1, Table 1 and Table 3, as shown in Table 4.

Table 4 Fixed power station revenue by time period

By Periods	Investment amount (yuan)	State subsidy (yuan)	Provincial subsidy (yuan)	On-grid electricity charge (yuan)	Electricity cost for enterprises (yuan)	Total income (yuan)	Operation and maintenance expenses (yuan)	Annual net income (yuan)
Time period one	3,643,200	240,926.7	65,115.33	5,854.92	382,233.13	694,130.09	39,600.00	654,530.09
Time period two	3,405,600	-	67,115.33	5,854.92	382,233.13	455,203.38	39,600.00	415,603.38
Time period three	2,930,400	-	65,115.33	5,854.92	382,233.13	453,203.38	39,600.00	413,603.38
Time period four	2,772,000	26,306.59	41,152.89	5,854.92	382,233.13	455,547.53	39,600.00	415,947.53
Time period five	2,534,400	19,534.60	-	5,854.92	382,233.13	407,622.65	39,600.00	368,022.65
Time period six	2,692,800	-	-	5,854.92	382,233.13	388,088.05	39,600.00	348,488.05

In Table 4, the investment amount is equal to the power plant capacity multiplied by the construction cost for each period; the annual electricity generation, online electricity and self-utilized electricity are taken as the average value for 20 years; the online electricity cost is equal to the online electricity multiplied by the FGD electricity price and the enterprise electricity cost is equal to the self-utilized electricity multiplied by the enterprise electricity price; the operation and maintenance cost is equal to the power plant capacity multiplied by the operation and maintenance coefficient. For the second period, the provincial subsidy policy stipulates that the project will receive the original provincial subsidy of 0.1 yuan/KWh, but also the subsidy of 0.1 yuan/KWh for the electricity generated in 2018. The total power generation of the power plant in 2018 is 400,000 kWh, the amount of provincial subsidy is 40,000 yuan, which is evenly distributed over 20 years, so the annual amount of provincial subsidy is 65115.33 + 2000 = 67115.33 yuan.

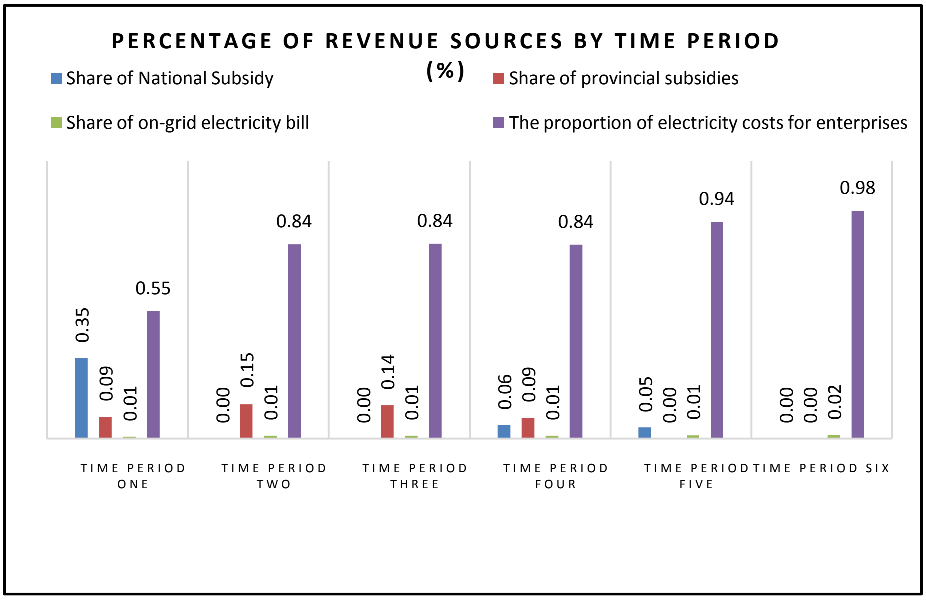

Figure 1 Percentage share of revenue sources of power plants in different time periods

Table 4 shows that the annual net revenue of the power plant varies greatly depending on the policy that the power plant has enjoyed at different times. The highest annual net revenue of more than 650,000 with state and provincial subsidies and less than 350,000 without state and provincial subsidies in period 6. Table 4 also shows that the proportion of state subsidies, provincial subsidies, feed-in tariff and self-consumption tariff varies greatly in different periods. As shown in Figure 1, for power plants connected to the grid before May 31, 2018, the government subsidy accounts for 35% of the total revenue and the provincial subsidy accounts for 9%. In the sixth period, the revenue source is mainly based on the revenue from enterprise self-use tariffs, excluding the state subsidy and provincial subsidy, and the proportion of revenue from enterprise self-use tariffs is 98%. From the first period to the sixth period, in just two and a half years, we can see that decentralized photovoltaic power generation is progressing very rapidly on the road to subsidies. The era of parity has dawned.

Payback period and internal rate of return

From Equation 3, Equation 4 and Table 4, we can determine the payback period and the internal rate of return of power plant projects for each period, as shown in Table 5.

Table 5 Amortization period and internal rate of return of power plant projects by period

By Periods	Investment amount (yuan)	Annual net income (yuan)	Static payback period (years)	Internal Rate of Return (IRR) (%)
Time period one	3643200	654530.09	5.72	17.22
Time period two	3405600	415603.38	8.56	10.57
Time period three	2930400	413603.38	7.35	12.86
Time period four	2772000	415947.53	6.89	13.9
Time period five	2534400	368022.65	7.13	13.34
Time period six	2692800	348488.05	8.05	11.47

As can be seen from Table 5, the first period with the state and provincial subsidies has a static payback period of only 5.72 years and an internal rate of return of 17.22%, which indicates better economic efficiency. In the second period, the initial investment costs of the power plant have yet to decrease due to the sudden elimination of government subsidies. The static payback period is 8.56 years and the internal rate of return is only 10.57%. This phase of the PV industry has entered its darkest hour (Lv et al.,2019). Many small companies have disappeared during this phase and many listed PV companies have seen their share prices fall significantly. Thanks to technological progress and the rapid decline in scaling costs, the PV industry slowly emerged from the trough in 2019, when the payback period was around 7 years. The internal rate of return was able to reach more than 13%, which brought a ray of hope to investors in the PV industry, and more and more people began to pay attention to the PV industry again. In 2021, there was a wave of price increases for silicon wafers, components and other parts of PV raw materials, which increased the initial investment for decentralized PV power generation projects. These foreign subsidies have been removed, which lowers the internal rate of return and extends the payback period. The static payback period is 8.05 years and the internal rate of return is 11.47%.

IV. Conclusion

This paper takes the investment efficiency of decentralized photovoltaic power generation projects in "self-generation, residual power online" mode since 2018 as the research object, briefly outlines the subsidies related to decentralized photovoltaic power generation projects in "self-generation, residual power online" mode since 2018, and proposes a new method for estimating power generation for 20 years based on the actual power generation situation for 3 years. On this basis, the annual net income, the proportion of revenue sources, the payback period and the internal rate of return of decentralized PV power plants in different periods were calculated. The results show that the power plants connected to the grid before May 31, 2018 depend on the revenue from state and provincial subsidies. With the rapid implementation of the subsidy reduction policy and the beginning of the grid parity era, the revenue sources of power plants mainly rely on the revenue from the electricity consumption tariffs of enterprises. From the payback period and internal rate of return situation, since 2019, the PV industry slowly out of the trough period, this time distributed PV power station's investment payback period basically in about 7 years, the internal rate of return can also reach more than 13%, the project research, for distributed PV power generation projects gradually transition to the era of grid parity to provide a period of investment reference value.

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