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Analysis of Cost Development Trend of Photovoltaic Power Generation in China Based on Learning Curve

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Abstract: *Based on the Learning Curve model, this paper presents the development trend of PV power generation in China. It uses constant learning rates to analyze the development trend of PV Power generation unit cost in the future ten years in our country. Then it predicts that the cost of PV power generation in 2020 is expected to match the traditional fossil fuels and will be realized the large-scale commercial operation stage.*

Keywords: *PV power; learning curve; generating cost; low-carbon energy*

1. INTRODUCE

With the development of the world economy, the problems of global energy shortage and environmental pollution have become increasingly serious, and as a "zero emissions, no pollution" clean energy, Solar PV power has been widespread concerned in the world. China has abundant solar energy resources, and it is estimated that the average amount of radiation in most areas in China is more than 4 KW/m^2, and the total amount of radiation solar in I region (such as eastern Xinjiang, western Qinghai and other regions) reach 6680 MJ/m^2 to 8400 MJ/m^2 [1].So, there is no resource constraints of China's development of PV power generation. In recent years, the development of China's PV power generation is fast, but there is still bottleneck to be breakthrough to achieve greater development and application, including the Internet policy, technology of power generation and the core issue is the cost of electricity. Despite the current decline in the cost of PV power generation is large, compared with other energy (especially conventional energy sources), it still remain high leave, directly restricts the market competitiveness. Currently, there is lack of quantitative research for the cost of PV power generation, in order to promote the development of PV power generation, and further research the development trend of PV power generation cost in China in the future, this paper put a quantitative predictive analysis in the cost of PV power generation during 2015-2020 based on the Learning Curve model.

2. THE DEVELOPMENT OF PV GENERATION IN CHINA

2.1. PV Installed Capacity

In 2011,the growth of China's PV installed capacity was explosive, new capacity had reached 2007MW, more than total installed capacity of PV in 2010,with the growth of 224.75%.The PV installed capacity during 2010-2015 was totaled and is listed in table 1[2].

Table1. *PV cumulative installed capacity from 2010 to 2015*

Year	Capacity of PV(unit:MW)	Growth rate (%)
2010	893	139.41
2011	2,900	224.75
2012	6,100	110.34
2013	9,300	52.46
2014	12,800	37.63
2015	16,600	29.69

2.2. Trend of PV Power Generation Unit Cost

With technological advances in the production of raw materials、increasing level in processes and gradually expanding the scale of production, the cost of solar PV power generation reduced significantly in the past 10 years. In 2005, unit cost of PV power generation is about ￥4-5/($kw \bullet h$),it felled to ￥1.5/($kw \bullet h$)in a drop of 96. 97% in 2010,And further reduced to about ￥0.8/($kw \bullet h$) in 2015[3].

3. PREDICTION OF PV POWER GENERATION COST IN CHINA

3.1. Research Ideas

This paper studies the change of PV power generation cost in next 5 years via the following steps ①analysis the changes of PV power generation cost at this stage and determine the current learning rate for PV power generation cost based on time-series data of 2010-2015 ②use the cumulative installed capacity and power generation cost in 2015 as the starting point, forecast the trend of PV power generation cost during 2016 -2020 ③ estimate the learning costs and financial subsidies from 2015 to the end of the real commercial operation.

3.2 Learning curve for modeling the cost of PV power generation

The learning curve model could quantify the cost reduction due to the scale effect. PV power generation, wind power and other new energy industry have advantageous scale effect in the early stages of development, so the relationship between the cost and the cumulative PV installed capacity in line with the learning curve model. Thus, the learn curve model indicates a decrease in the unit cost of PV power generation, which can be forcast as:

$$C = C_0 Q^{-b} \quad ①$$

$$L_R = 1 - P_R \quad ②$$

$$P_R = 2^{-b} \quad ③$$

Where C denotes the unit cost of PV power generation, as a function of Q;C_O is the unit cost of power generation when the cumulative installed capacity of PV is 1MW; Q denotes cumulative installed capacity of PV; and b represents the learning coefficient, which can be used to calculate the progress ratio(PR)and learning ratio(LR).When PR=95%, which means the capacity of PV power generation increased by one time, the unit cost of power generation decreased by 5%[4].

3.2. Learning Curve for Modeling the Cost of PV Power Generation at the Present Stage

The learning curve of PV power cost at the present stage in China can calculated from the data of installed capacity and power generation cost during 2010-2015 in China.Fig.1 shows that learning rate changes in different phases. During the period 2010-2011 the learning rate remained at 20%,and during 2011 -2015 the learning rate remained at 15%.This differences show that the learning rate of PV power generation cost vary within the range of 15%-20%,and the learning rate decreases year by year indicates that the decrease of PV power generation cost is not obvious after 2011.

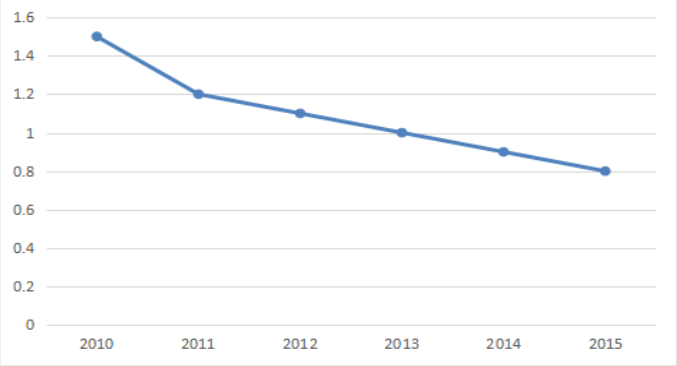

Fig1. *Learning cost curve of PV power generation form 2010 to 2015*

3.3. Learning Curve for Modeling the Cost of PV Power Generation in the Future

3.3.1. Computing result

Supposing the cost of PV power generation develops in a constant learning rate and the constant learning rates are 15% and 20%.In 2015,the cost of PV power generation was about ￥0.8/($kw \bullet h$) and the total installed capacity was 16,600MW,use it as a starting point, according to equations ①-③, we can obtain the cost learning curve of PV power generation during 2015-2020 as is shown in Fig.2. Fig.2 explains the greater learning rate is, the greater decline in the unit cost of PV power generation.

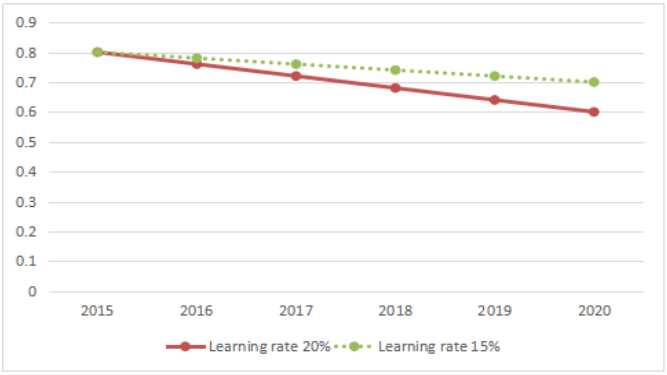

Fig2. *Cost learning curve of PV power generation under different learning rate from 2010 to 2020*

3.3.2. Result analysis

If the learning rate can be maintained at 15%-20% in the next 5 years, the cost of PV power generation in China is expected to drop to ￥0.6/($kw \bullet h$) in 2020.Taking the difference in the estimation of the learning rate using different data into account, the learning rate of PV power generation maintained at 15%-20% is entirely possible in the future. So the PV price will be closer to traditional fossil fuels and have the strength to compete with the traditional fossil energy.

3.4. Estimation of Learning Cost

Learning cost is the cost borne by society when the price shown in the learning curve down to commercial price. In Fig.3 that is the area of the learning curve and the commercial price curve which can be calculated as: $L_c = \int_{N(2015)}^{N(k)_0} \{P[N(k) - P[N(\mathrm{k})_0]]\} dN(k)_0$ ④

where $N(\mathrm{k})$ denotes cumulative installed capacity of PV; $N(\mathrm{k})_0$ represents total installed capacity of PV power generation to achieve commercial operation; $N_{(2015)}$ is the cumulative installed capacity at the end of 2015; $P(N(k)_0)$ is the cost of PV power generation to achieve commercial operation[5].

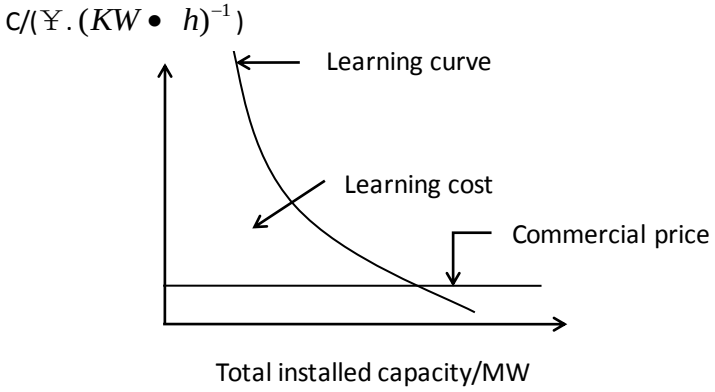

Fig3. *Schematic diagram of learning cost*

Table 2 calculates the learning cost (assuming that average annual utilization of PV is 1500h)[6]for achieving commercial operation and illustrates that PV power generation can be basically achieved commercial operation during 2016-2020 and the learning cost is about ￥25.45-￥28.06 million. If government takes the learning cost as a support funds to promote the PV power generation to achieve commercial, it should bear about 27 million of financial subsidies and make PV with a real market competitiveness.

Table2. *Learning cost of PV power generation achieved commercial operation*

$L_R = 20\%$	$L_R = 15\%$
￥25.45 million	￥28.06 million

4. DISCUSSION

Based on the Learning Curve model, it uses constant learning rates to analyze the development trend of PV Power generation unit cost in the future ten years in our country and estimates the learning cost for achieving commercial operation, thus provides a theoretical support for PV's commercial operation in China.

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