ECONOMIC ANALYSIS OF SOLAR PHOTOVOLTAIC BASED ON LIFE CYCLE COSTING

YIN LIN-LIN*
Technical& Economic Consulting Centre of Electric Power Construction, China Electricity Council, China

ABSTRACT

Solar PV (Photovoltaic) power, which is sustainable – economically, environmentally and socially, is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions, even if currently it needs relatively more investment especially for initial construction cost. A model for PV generation cost is established based on life cycle costing and a reasonable payback of investment. Then factors influencing the economy of PV power generating are discussed, such as the local solar resource, efficiency of PV system, technical lifetime of PV plant, price of PV modules and so on, most of which are improvable by technological innovation. On the basis above, on-grid price trends of PV power and thermal power are predicted, which comes to the conclusion that PV power generation will achieve competitiveness with the power grid retail prices in the next decade.

Keywords: *Economic Analysis, Life Cycle Costing, Solar PV Generating.*

1. INTRODUCTION

There is a pressing need to accelerate the development of advanced clean energy technologies in order to address the global challenges of energy security, climate change and sustainable development. Solar electrical energy generation has been of catholic concern by countries all over the world, which is more sustainable- economically, environmentally and socially. Solar photovoltaic (PV), which generates electricity through the direct conversion of sunlight, is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions.

Global PV capacity has been increasing at an average annual growth rate of more than 40% since 2000(Figure 1) and it has significant potential for long-term growth over the next decades. It is envisioned (IEA, 2010) that by 2050, PV will provide 11% of global electricity production (4 500 TWh per year), corresponding to 3 000 gigawatt of cumulative installed PV capacity.

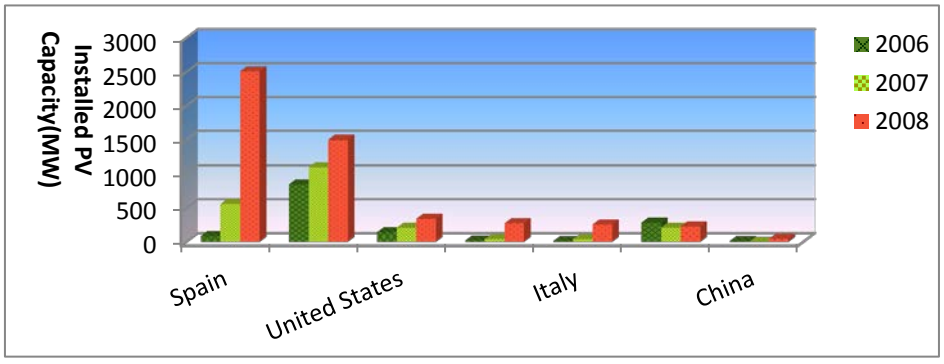

Figure 1: New Installed PV Capacity in Leading Countries

Source：Global market outlook for Photovoltaic until 2013, EPIA, 2009.03

Since the 2000's, with the implement of series of incentive policies and economic support schemes, the PV industry in China has developed significantly (Table 1). According to the 12th FIVE-year Plan of power industry development issued by China Electricity Council that until 2015, the total capacity of solar power will reach 200 Megawatt, and the number of it will come to 2000 Megawatt until 2020. But this new energy power generation is not able to compete with the traditional power generation in price, which has been the bottleneck restricting the development of the PV industry. Therefore, an in-depth study to the cost of PV power generation is of great importance, which will provide the government with a basis for the new development policies and financial support to new energy industry.

Table 1: Annual PV Capacity in China

Year	1990	1995	2000	2002	2004	2006	2007	2008	2009
New Installed Capacity（MW）	0.5	1.55	3	18.5	10	10	20	40	160
Cumulative Capacity（MW）	1.78	6.63	19	42	62	80	100	140	300

Source: China Electricity Council, 2010.

2. MODEL AND METHODOLOGY

2.1. THE MODEL

Levelized Energy Costs (LEC) is one of the common indicators in current study of economic analysis. While considering the particularity of Solar PV generating, as well as the purpose of analysing the economic efficiency of it, which aims to stimulating the enthusiasm of investors, and consequently promoting the development of solar PV power industry in China, model for PV generation cost should be established following these two principles below.

Firstly, the initial investment of Solar PV power plant is much higher than that of fossil power plant, conversely the Operation and Maintenance costs of the former is quite lower than that of the latter one(Figure 2). The general theory of power plant costing only focus on the initial investment, which draws the conclusion, that Solar PV power plant is of poor economic efficiency. But it is neither comprehensive nor objective to assess whether a Solar PV power plant is economical, without taking the Operation and Maintenance costs into consideration. Life Cycle Costing(LCC) theory, which makes much of project's life cycle costing, provides a new perspective and theoretical tools for the economic analysis to a Solar PV power plant. Therefore, the PV generation cost model here is established based on LCC.

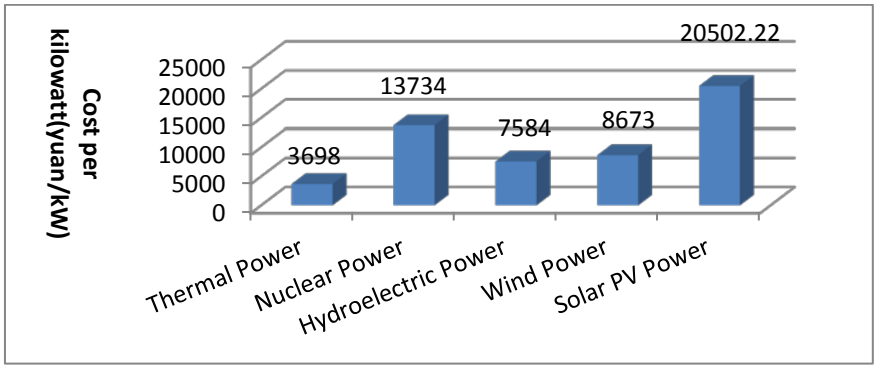

Figure 2: Cost per Kilowatt of Various Forms of Electricity Generation

Source: China Electricity Council,2010.

Secondly, with the view of stimulating investors' enthusiasm, the cost of Solar PV generation plant should take into account a reasonable investment return to the investors, which means the enterprise cost expenses, taxes, surplus accumulation fund, incomes to repay loans and internal rate of return of capital(e.g.8%).

By making reference to the prevenient research(Dersch, *et al.*,2004; Tsoutsos, *et al*.,2003), cost of PV Power is mainly depended by these five factors, i.e.:

- C_{Dep} - depreciation cost;
- $C_{O\&M}$ - annual cost of operations and maintenance (O&M);
- $C_{Inter}^{'}$ - annual loan interest;
- $C_{Incom}^{'}$ - annual return of capital;
- $G^{'}$ - annual capacity of generation.

And the cost model for PV Power is established based on the principles above, which is as follows:

$$C_{PV} = \frac{C_{Dep} + C_{O\&M} + C_{Inter}^{'} + C_{Incom}^{'}}{G^{'}} \quad \text{(Eq: 01)}$$

C_{Dep} is the annual cost of the initial investment(I_{int}) that turn to the fixed assets with the complement of the power plant construction. Depreciation is commonly by the composite life method.

$$C_{Dep} = \frac{I_{int} - V_{scr}}{N} \quad \text{(Eq: 02)}$$

Where, V_{scr} = scrap value of the PV power plant; and N= life time of the PV power plant.

$C_{O\&M}$ represents the average value of the operations and maintenance (O&M) costs among the whole lifetime of the Solar PV plant. There are 7 items, i.e. repairing expense, wages and welfare, labour insurance and welfare, housing fund, materials fee, Insurance and others, most of which mainly increase in direct proportion to Capacity of the PV power plant, and in addition repairing expense also depends to main equipment’s Technical Lifetime.

$C_{Inter}^{'}$ and $C_{Incom}^{'}$ all arise from the initial investment to the PV power plant, part of which loan from the bank corresponds to the former one, and the latter one to the capital part from the owner likewise.

$G^{'}$ is the average capacity of generation. The PV power generation with a certain installed PV capacity is mainly depends upon the local solar resource, the specific PV technologies (e.g., crystalline silicon, thin films, or emerging and novel devices), and the efficiency of PV system. Large on-grid Solar PV plant with crystalline silicon is studied in this paper considering the current condition in China.

2.2. METHODOLOGY

The main objective of this paper is to study the economical efficiency of Solar PV generating, and to identify the key factors which influence the cost of Solar PV power. Hence Sensitivity Analysis Method, which is a commonly used method of uncertainty in economic evaluation of investment projects, is adopted in this discussion. By quantitative analysis, we get a sensitivity coefficient which

indicates the influence degree of one or set of factors' changes to the economic indicators with such a method. We will choose numbers of crucial factors to the cost of Solar PV generating for Sensitivity Analysis, e.g. price of the PV modules, annual sun hours, and so on. And in this Sensitivity Analysis, we find the incidence relationship between changes of Solar PV generating cost and a crucial factor by changing the value of this crucial factor in sequence, provided that other factors given a fixed value.

3. RESULTS AND DISCUSSIONS

3.1. BOUNDARY CONDITIONS

Based on a number of large on-grid Solar PV plants which had newly constructed in west China, a typical Solar PV plant is made up with the common parameters, and accordingly the boundary conditions are identified as shown in Table 1:

Table 1: Boundary Conditions

Parameters	Boundary conditions	Explanations
Installed Capacity	10MW	A commonly capacity at present
Technical Lifetime	25 years	Based on current technical level
Comprehensive efficiency of PV generation system	80%	Considering system aging in lifecycle(ZHANG Zhen,2008)
annual average sun hours	2835 hours	Provided that the plant is located in western China where is rich in solar energy resources
PV module price	11yuan/kW	Considering the average level of constructed plants and the current price level
Proportion of loans in Initial investment	80%	According to a general level of construction projects in China
Interest rate	5.94%	
Rate of capital return	8%	benchmark yield in China

3.2. COST ESTIMATES AND ANALYSIS

Based on the boundary conditions above, according to the Power Engineering Construction Budget and Calculate Standard, the total fixed investment of the plant is 190.71Million Yuan, which comes to 195.24Million Yuan with the interest for the construction period. And correspondingly the unit investment is 19508 Yuan per kilowatt. Taking O&M cost, financial cost etc. into consideration comprehensively, cost of the Solar PV power generation of a large on-grid plant in western China is 1.079 Yuan per kilowatt-hour. Price fluctuates with several factors, which are analysed as follows.

- **PV modules Price**

A huge sum of money is needed during the construction period of a Solar PV plant. As can be seen in Figure 3, analysis of numbers of PV power plants' investment shows that equipment expense take up a

large proportion (more than 70%) (Figure 3), which is mainly depends on the price of PV modules. Therefore, a Sensitivity Analysis to the factor of PV modules price is carried out.

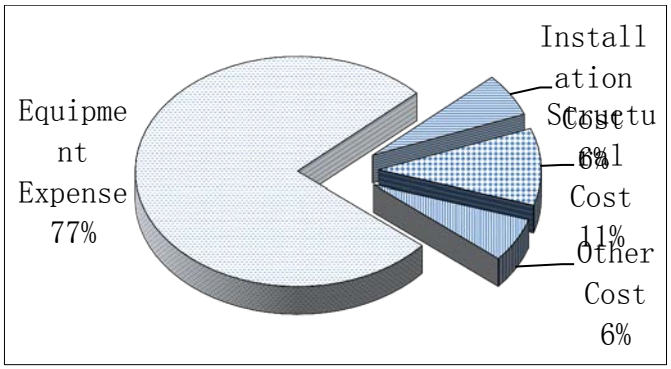

Figure 3: Structure of Initial Investment of on-grid Solar PV Plant

While price of PV modules varies, we can get two series of price of PV power and the initial investment of Solar PV power based on the premise that all the other parameters are fixed. PV generation cost varies with the price of PV modules consequently with the sensitivity coefficient at 0.52, meaning that price of PV power generation will rise/fall by 0.52% if the price of PV modules rise/fall by 1%(Figure 4). Therefore, it makes significant contributions to reduce the price of PV power, which fluctuate according to technology changes, the price of main raw material and supply and demand condition on PV market. In other words, it is quite possible to reduce price of PV power by improving these aspects above.

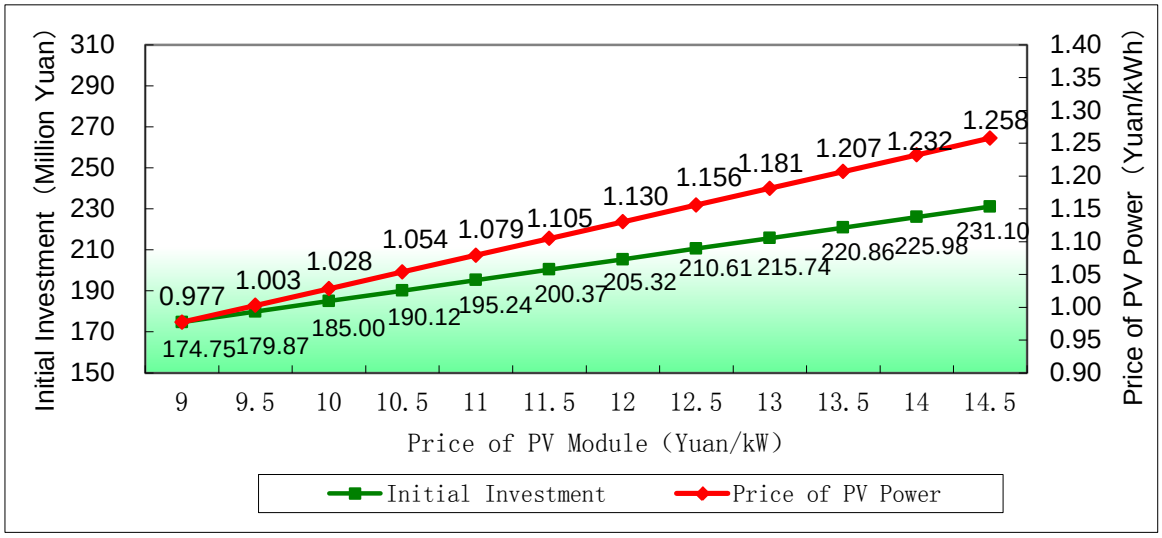

Figure 4: On-grid PV Power Price and PV Module Price

- **Annual Sun Hours**

The amount of solar source is the primary factor in determining the total power generation of on-grid Solar PV plant, which then influences the price of PV power. Likewise, we get a series of price of PV power while price of PV modules varies on the premise that all the other parameters are fixed. The incidence relation between Annual Sun Hours and PV Power Price is shown in Figure 5 below.

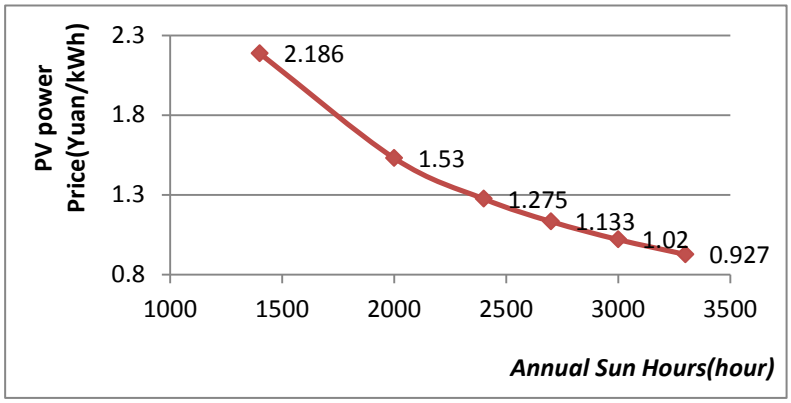

Figure 5: On-grid PV Power Price and Annual Sun Hours

China is one of the countries rich in solar energy resources, but distribution of solar energy resource in China is uneven, which eventually lead to regional diversity of PV power price.

3.3. FUTURE ECONOMICAL COMPETENCY OF SOLAR PV GENERATION

As is widely recognized, that there will be a persistent reduction to the cost of Solar PV generation with technology improvement which means a longer technical lifetime of PV plant, a higher efficiency of PV system and a lower price of PV modules etc..

The national average on-grid rate of thermal power is 0.34Yuan/kWh in 2009, which will rise to 0.65Yuan/kWh by 2020 at a growth-rate of 6%. Meanwhile, the investment to a Solar PV plant will fall rapidly by 10% or more for years to come, which means price of on-grid PV power will down to 0.39 Yuan/kWh. Even the investment falls by 6%, it will down to 0.63Yuan/kWh. In view of the above, price of thermal power and PV power will tend to the same in 2017, i.e. around 0.53 Yuan/kWh. Likely wise, if the reduction rate of PV plant investment turns to 6%, the two will go to 0.63 Yuan/kWh in 2020 (Figure 6). Therefore, it is achievable that PV becomes competitive with the power grid retail prices ("grid parity") in many regions.

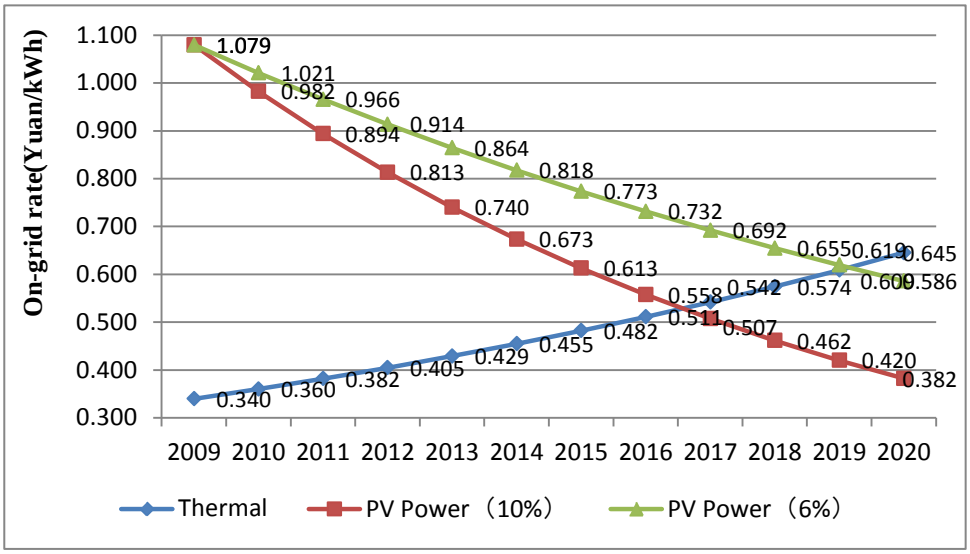

Figure 6 On-grid Price Trends of PV Power and Thermal Power

4. CONCLUSIONS

Solar energy is the most abundant energy resource on earth. But it is of poor competency in economic currently in the starting stage of Solar PV electricity generation. The initial investment of Solar PV power plant is much higher than that of fossil power plant, conversely the Operation and Maintenance costs is quite lower. Taking the life cycle cost and a reasonable payback of investment into consideration, price of on-grid PV power vary with several factors, such as the local solar resource, efficiency of PV system, technical lifetime of PV plant, price of PV modules and so on, most of which are improvable by technological innovation.

There is no doubt that Solar PV electricity generation is expanding very rapidly due to dramatic cost reductions. PV is a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions. Achieving this will require more concerted policy support, and a long-term focus on R&D to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term technology innovations.

5. ACKNOWLEDGEMENT

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6. REFERENCES

IEA(International Energy Agency), 2010. *Technology Roadmap-Solar Photovoltaic energy*.

Jürgen Dersch, Michael Geyer, Ulf Herrmann, 2004. Trough integration into power plants—a study on the performance and economy of integrated solar combined cycle systems. *Energy*, 29, 947-959.

Theocharis Tsoutsos, Vasilis Gekas, Katerina Marketaki, 2003. Technical and economical evaluation of solar thermal power generation. *Renewable Energy*, 28, 873-886.

Li Xin, Li An-ding, Li Bin, Zheng Fei, 2005. Economic analysis of dish/stirling solar power system, *Proceedings of the CSEE*, 25(6), 108-111.

Wang Run-bo, 2009. Financial Analysis of large on-grid solar PV plant, *Sun Energy*, 6,26-28.

ZHANG Zhen, SHEN Hui, CAI Rui-xian, 2008. Progress trend and cost analysis of on-grid photovoltaic system, *Power source technology*, 132(10), 713-716.