ECONOMICS RESEARCH FOR PHOTOVOLTAIC POWER GENERATION PROJECT BASED ON DIFFERENT BUSINESS MODEL

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ABSTRACT

This paper presents an in-depth economic analysis on Photovoltaic power generation (PV) project. The research is based on nine business and technical proposals which with different investment operational pattern and different distributed generation (DG) integration technology of PV project. An all-life-cycle benefit/cost (B/C) assessment methods was used to assess the feasibility of the project. Through the accurately simulate of an annual PV output and load curves from typical time, received electric power and energy balance calculations and revenue forecast results. And then different operators' electricity price benefits based on china's complex tariff mechanism was estimated in this paper, while the initial PV panel investment, operation and maintenance, distribution network investment and losses of PV projects were calculated. Finally, through the PI value come to the best business model. Calculation results show that if power grid enterprise as the PV power producer, and use of virtual power plant technology for DG integration means more investment value than other business mode.

INTRODUCTION

Over the past year, China's PV project showing an external cooling but internal heat development trend. With the technological innovation and incentives to advance China's distributed generation Projects, solar photovoltaic power generation system has been basically formed a stable technology and industrial systems, especially in residential construction of solar photovoltaic power generation system, its installed capacity has been developing rapidly. Although these projects have many advantages in clean energy and energy efficiency, an accurate and reasonable economic analysis with whole life-cycle of the project is the most concerned of investors, but that is the one which very difficult to predict.

The first reason that the economy of PV project is hard to estimate is because the complex business operation and management mode. If the power supply enterprises and individual investors as an investment or operation body respectively, their costs and benefits will vary greatly. Second, when establish PV project's economic analysis model, many previous studies all focused on the generation cost[1], but electricity price return need to be considered an important index and major part of the investment return which will affect investors' decisions.

Third, the most difficulty and key point of electricity revenue calculation for PV project is the electric power and energy forecasting. And there is no relevant theory and research about it by now[2]. If the user load forecast and PV output forecast not accurate enough, it will lead to system design and operation mode selection not reasonable[3-4].

BUSINESS MODEL AND DG INTEGRATION TECHNOLOGY FOR PV PROJECTS

A proposal for PV grid-connected system is composed of three parts, one is the investment and operational pattern, the other is the PV integration mode, and the third is the selection of demarcation point.

Investment Operational Pattern

At present, with the participation of National Energy Bureau, DG project business and operation pattern had a total of three possible:

Business mode 1: DG investors responsible for generate and supply power.

Business mode 2: Power grid enterprises responsible for generate and supply power.

Business mode 3: DG investors responsible for generate and power grid enterpris responsible for supply.

DG Integration Technology

DG integration technology mainly includes virtual power plant (VPP) technology and micro-grid (MG) technology:

Grid-connected mode 1: VPP technology.It is equivalent to a power generation area.

Grid-connected mode 2: MG technology. This mode consumes electricity at the place where it is generated.

ECONOMIC ANALYSIS MODEL FOR PV PROJECT

Initial income model for project

This part mainly focuses on I, the first year of income for different mode and technical scheme.

$$I = S + G \tag{1}$$

Where S is the photovoltaic power sale revenue in china's complex tariff mechanism and the income of price difference between purchase and sale electricity, and G is the government subsidies income.

A. Caculation of S :

$$S = 365 \times (E_t \times P_t + E_k \times P_k + E_p \times P_p) \tag{2}$$

Where E_t is the surplus electricity of PV generation during a typical day; P_t is the price that PV electricity sales to grid enterprise; E_k is the electricity of PV generation self-supply during a typical day; P_k is the photovoltaic electricity sales tariff; E_p is the purchase value of electricity of PV investor during a typical days; P_t is the price difference of purchase electricity from power supply company and sale electricity to end users.

B. Caculation of *G* :

$$G = P \times 50\% \quad (3)$$

Where P is the initial investment of PV project.

Initial cost model for project

This part mainly focuses on *C*, the first year of cost for different mode and technical scheme.

$$C = I_g + M + L_l + I_e \quad (4)$$

Where *Ig* is the initial investment of PV generation, *M* is the operation and maintenance costs of PV project, ,L_l is the cost of distribution line loss, and *Ie*. Is the equipment investment of distribution network.

A. Caculation of *Ig* :

$$I_g = W \times C_w = \frac{1000}{8760} \times A \times Q_w \times R_f \times (1 - L_s) \times C_w \quad (5)$$

Where *W* is the installed capacity of PV power generation; *Cw* is the unit installed capacity cost of PV power generation; A is the total area of photovoltaic panels; *Qw* is the unit power output of PV power; R_f is the efficiency of PV power supply module; *Ls* is the loss of system.

B. Caculation of *M* :

$$M = I \times R_m \quad (6)$$

Where *Rm* represents the operation and maintenance rate of PV power generation.

C. Caculation of L_l:

$$L_l = L_{l1} + L_{l2} \quad (7)$$

In which:

$$L_{l1} = 365 \times (E_k \times R_{l1} \times P_k) \quad (8)$$

Where L_{l1} represents the line loss of E_k; R_{l1} is the estimated percentage for energy loss of E_k which was made according to its transmission distance.

$$L_{l2} = 365 \times (E_t \times R_{l2} \times P_t) \quad (9)$$

Where L_{l2} represents the line loss of E_t; R_{l2} is the estimated percentage for energy loss of E_t which was made according to its transmission distance.

D. Caculation of I_e :

$$I_e = \sum_{i=0}^{n} Q_i \times I_i \quad (10)$$

Where *Qi* represents the construction scale of distribution line, switch, transformer, measuring meter and other equipment for distribution network; *Ii* is the comprehensive cost of unit equipment.

Income / cost present value model within the overall life cycle for project

On the base of above models, the calculation for overall income and overall cost within the life cycle of PV project is proposed. And the loan interest, equipment depreciation expenses need to be considered.

$$Bp = \sum_{t=0}^{n} Bt(P_B / F_B, i_c, t) = \sum_{t=0}^{n} Bt(1 + i_c)^{-t} \quad (11)$$

$$Cp = \sum_{t=0}^{n} Ct(P_C / F_C, i_c, t) = \sum_{t=0}^{n} Ct(1 + i_c)^{-t} \quad (12)$$

Where *Bp*,*Cp* are income and cost present value within overall life cycle for one of a technical proposal for PV project; F_B, F_C, are the final value, its meaning is to show the initial income or cost convert to the final value of a life period; *t* is the life period; P_B,P_C are the present value, represents the initial income of early stage of construction; *Bt*, *Ct* are the annual income in life period; i_c is the discount rate.

Benefit / cost （B/C） ratio of each proposal for PV project

$$PI = B/C \quad (13)$$

Where *PI* is the ratio of benefit and cost of each proposal, if *PI* greater than 1, indicates that this program is profitable. And we should choose the best proposal with maximum gross income in the items which *PI* value greater than 1.

ELECTRIC POWER AND ENERGY BALANCE AND PREDICTION FOR PV PROJECT

This paper first proposes the use of photovoltaic power output and load forecasting curve for electric power and energy forecasting, and then combined with the electrovalency system to calculate electricity sales income for PV project. The diagram of this theory is shown in Figure 1.

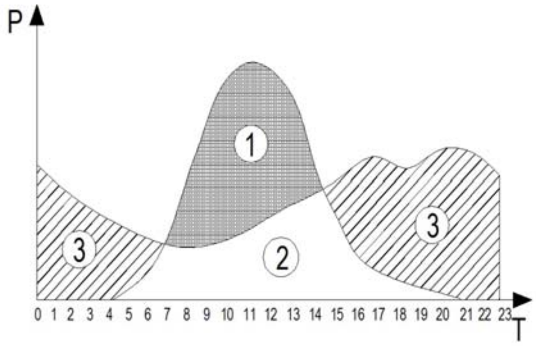

Fig.1 Typical variation of Photovoltaic power output and load forecasting curve

The different shadow area (①,②,③)is the sale of electricity power from different subjects, then multiplies different electricity sale price will achieve different income for PV project. If the partial area ② equals the area ②+③, that the electricity and energy can balance.

$$E_t = \int_{t_1}^{t_2} [f_1(t) - f_2(t)] \cdot dt \quad (14)$$

$$E_k = \left[\int_0^{t_1} f_1(t)\cdot dt + \int_{t_1}^{t_2} f_2(t)\cdot dt + \int_{t_2}^{t} f_1(t)\cdot dt\right] \quad (15)$$

$$E_p = \left\{\int_0^{t_1} [f_2(t) - f_1(t)]\cdot dt + \int_{t_2}^{t} [f_2(t) - f_1(t)]\cdot dt\right\} \quad (16)$$

Et, Ek, Ep and *S* in equation (2) can be calculated using above equation (15)-(16).

CASE STUDY

Business and technical proposal design

This paper presents 9 proposals and finish the actual economic evaluation base on a key and large residential construction of PV project of China which installation capacity is nearly 13MW.The 9 proposals are in table 1:

Table 1 Business and technical proposal design

Proposal	Investment main body	PV Power producer investors	Power supply enterprise	Demarc
1	DG	DG	DG	1
2	Grid	Grid	Grid	1
3	DG	DG	Grid	1
4	DG	DG	DG	2
5	Grid	Grid	Grid	2
6	DG	DG	Grid	2
7	DG	DG	DG	3
8	Grid	Grid	Grid	3
9	DG	DG	Grid	3

Notes:
1.DG represent DG investors;Grid represent Power grid enterprise.
2.Demarcation Point1: 10kV line of 35kV substation;
3.Demarcation Point2: high voltage line of box-type transformer substation ;
4.Demarcation Point3: 0.4kV line of distribution box of each building.

Photovoltaic power output and load forecasting results throughout the year

Figures 2-5 show the typical variation of PV power output and load forecasting curve in in four different seasons of a year.

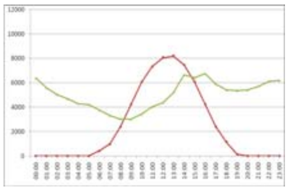

Figure 2. Spring

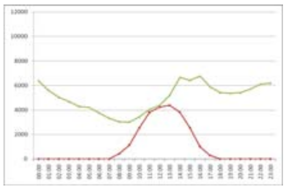

Figure 3. Summer

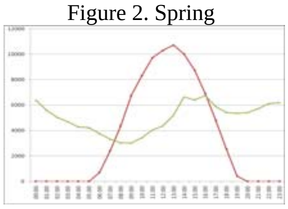

Figure4. Autumn

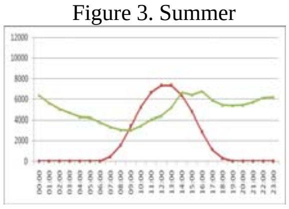

Figure 5. Winter

B/C predict within the overall life cycle for project

A .China's tariff mechanism:

Table 2 China's tariff mechanism

Price type	User type	Price （RMB/kWh）
PV electricity sales price	——	0.25
PV power producer purchasing price for electricity	——	0.55
Ordinary sale price of electricity of users	Resident	0.59
	Commercial	0.845
	Non resident	0.692

B. Initial income and cost for project:

Table 3 and 4 give the first year income and cost for project.

C. B/C ratio of each proposal for PV project:

Table 5 and figure 6 show the final B/C ratio of annual cost present value within overall life cycle of each proposal for PV project

Table 5 B/C ratio of annual cost present value

Proposal	Benefits	Cost	B/C
1	5672.24	5297.61	1.07
2	5695.91	2729.55	2.09
3	1603.22	2446.63	0.66
4	13405.67	11127.57	1.20
5	13453.01	5991.45	2.25
6	3206.43	5296.68	0.61
7	7659.77	30219.07	0.25
8	7683.44	17053.75	0.45
9	1603.22	2648.34	0.61

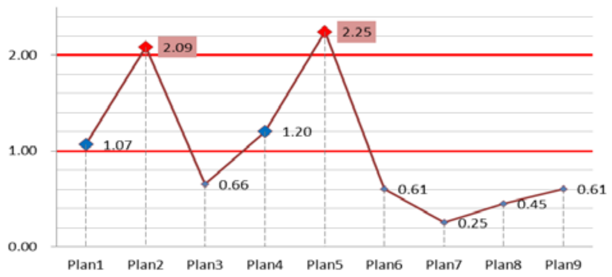

Figure6. B/C value of annual cost present value

The calculation result indicates that:

i. Proposal 5 and 2 is the optimal program, the power grid enterprise as the PV power producer, and the property right demarcation point in 2 or 1, the *PI* value in 1.5-2.5.

ii. Proposal 4 and 1 is the balance program, the independent PV power produce power and power grid enterprises supply power, the *PI* value in 1-1.5.

iii. All else is the loss solution, the proposal 7 is the smallest one, the independent PV power producers generate and supply power to end users and the property right demarcation point in 3, the *PI* value in 0.2.

CONCLUSION

This paper presents an all-life-cycle B/C assessment method in economic analysis for PV project based on different business and technical mode. The theory of electric power and energy revenue forecast through simulating of an annual PV output and load curves from typical time is firstly proposed. And different operators' electricity price benefits based on china's complex tariff mechanism is also firstly studied in this paper.

Calculation results show that the method in the economic evaluation of PV projects is valid and accurate. If power grid enterprise as the PV power producer, and use of virtual power plant technology for DG integration means more investment value than other business mode. This study provide technical support for the rational use of uncontrollable and controllable distributed generation, and make a contribution for the investors' business model and integration technology selection of distributed generation projects .

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Table 3 First year income for project Unit：Million yuan

Proposal	*Ek*Pk*365*			*Et*Pt*365*	*Et*Pk*365*	*G*	Total
	Resident	Commercial	Non resident				
1	4221.23	209.86	206.47	24.60	—	10085.50	14747.65
2	4221.23	209.86	206.47	—	48.27	10085.50	14771.32
3	—	—	—	593.13	—	10085.50	10678.63
4	10314.35	479.67	542.26	49.20		20171.00	31556.49
5	10314.35	479.67	542.26	0.00	96.54	20171.00	31603.83
6	—	—	—	1186.25	—	20171.00	21357.25
7	6030.33	299.80	294.96	24.60	—	10085.50	16735.18
8	6030.33	299.80	294.96	—	48.27	10085.50	16758.85
9	—	—	—	593.13	—	10085.50	10678.63

Table 4 First year cost for project Unit：Million yuan

Proposal	PV generation investment cost				Distribution network investment	Purchasing electricity cost	Annual rent for roof	Loan interest	Total
	PV panel investment	Operation and maintenance cost	Line losses	Power losses					
1	20171	605	102	0.51	2549.8	2568	61	356	26413
2	20171	605	102	0.51	2549.8	—	61	356	23845
3	20171	605	—	—	—	—	61	356	21192
4	40342	1614	333	1.26	5097.0	5136	121	711	53356
5	40342	1614	333	1.26	5097.0	—	121	711	48220
6	40342	1614	—	—	—	—	121	711	42788
7	20171	807	318	1.80	199332	13165	61	356	2342118
8	20171	807	318	1.80	199332	—	61	356	221046
9	20171	807	—	—	—	—	61	356	21394