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Research on Quantitative Analysis of Investment Benefit of Integrated Energy System in Park of Multi-investors

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Abstract. The industrial park has become an important experimental area for power reform. Under the conditions of incremental distribution market liberalization, diversified power sources and loads, the investment interface of park integrated energy system has been divided, investment entities have become diversified, and the analysis of investment benefits has become complex. The paper proposes the park IES operation models on different interfaces, studies the methodology of calculating the full lifecycle investment benefit of different components of park IES. Based on the typical cases, it proposes the future direction of business development of park integrated energy service provider.

1. Introduction

The integrated energy system (IES) means in the process of planning, construction, operation, etc. all stages of energy production, energy supply network, conversion, transformation, storage, consumption, transaction, etc. are coordinated and optimized in an organic manner to form an integrated system of energy production, supply and consumption [1,2]. China is currently in the critical moment of energy transition with prominent issues like high energy cost. The IES plays an important role in the improvement of energy utilization efficiency, realization of scale-up development of renewable energy and sustainable energy supply, and consolidation of flexibility and security of social energy supply, which is the proper meaning of "building a clean, low-carbon, safe and efficient modern energy system".

Countries across the world have developed various strategies regarding the IES construction and development, and kicked off several science and technology projects in this field with the topics covering aspects like fundamental theory, key technology, core equipment, engineering demonstration, etc. At present, the IES-based integrated energy service has become an important direction of transition of many power enterprises, new energy enterprises and grid enterprises [3,4,5,6].

With the progress of market-oriented reform of electric power sector, the industry park turns out to be an important experimental zone of power reform and the construction; and operation of park IES becomes a primary business of integrated energy service providers. Under the scenario of liberalization of incremental distribution grid and the access of more extensive source loads, the investment in park IES is more diversified with multi investors, which also leads to complicated analysis of investment benefit. A few present economic studies of park IES target at individual



components e.g. quantitative estimation of distributed PV [7,8,9] and assessment of distributed natural gas and distribution network by economic indicators. However, the quantitative estimation of investment benefit is not available yet [10]. Furthermore, as the new issue incurred in the power reform process, there has been no available research results for reference that relate to quantitative analysis of investment benefit by interface of IES for multi investors.

The paper firstly analyses the impact of liberalization of incremental distribution grid and power selling side upon the investment and operation of park IES, and proposes the park IES operation models on different interfaces; secondly, it studies the methodology of calculating the full lifecycle investment benefit of different components of park IES, and establishes the quantitative model of full lifecycle investment benefit of park IES for multi investors; thirdly it selects the typical cases to prove the model of calculating the park IES investment benefit for multi investors; in the final conclusions, it proposes the future direction of business development of park integrated energy service provider.

2. Operation model of park IES under the new power reform

Given the diversified source load, the park IES consists of distributed power sources (distributed PV, distributed wind power, distribute natural gas, biomass, etc.), incremental distribution network, energy storage apparatus, load, etc. [11]. The No. 9 document of power reform suggests "liberalization of investment in incremental power distribution business to the qualified market players", "liberalization of construction of distribute power sources at user side, support the localized investment and construction of various distributed power sources like solar power, wind power, biomass power and gas CCHP, etc." The latest Notice on Further Promotion of Incremental Power Distribution Business Reform (draft for comments) ([2018] No. 356) states "encourage the construction of distributed power sources by the proprietors of incremental power distribution projects in the distribution areas in line with local resource conditions and energy consumption demand." Therefore, the social investors may invest one or several distributed power sources (including energy storage) and one or several sections of incremental power distribution networks (investment in both distributed power source and incremental distribution network). Therefore, the park IES operation models on different investment interfaces include the integrated generation, distribution and sale of distributed source, integrated generation and sale of distributed source, integrated distribution and sale of distributed source and single operation of distribution network.

Under different operation models, the investors integrate different resources of different business sectors, thus gaining different benefits. For instance, under the single operation of power distribution network model, the investor possesses the distribution network resource and deals with power distribution business, thus gaining the benefit of "licensed cost plus reasonable profit"; under the integrated model of power generation and sale, the investor possesses the resources of both distributed power generation and user load, and thus gains the benefit of power sale revenue to end users—"wheeling cost". If an investor concurrently deals in several services, it gains multiple benefits. Table 1 shows the benefit components under different operation models of park IES.

Table 1. Benefit Components under Different Operation Models of Park IES

Operation model	Business scope	Benefit component
Integration of power generation, distribution and sale	Power generation, power distribution and power sale	Power sale revenue to end users
Integration of power generation and sale	Power generation and power sale	Power sale revenue to end users—"wheeling cost"
Integration of power distribution and sale	Power distribution and power sale	Power sale revenue –power purchase cost
Single operation of power distribution network	Power distribution	"Licensed cost plus reasonable profit", i.e. "wheeling cost"

3. Model of quantitative investment benefit of park IES for multi investors

3.1. Model of IES individual component cost

The cost of IES individual component includes the initial investment cost of construction period, operation and maintenance cost of operation period, financial cost, taxes and fees, fuel cost (for distributed natural gas and biomass only), station service loss, etc.

3.1.1 Initial investment of construction period

$$C_i = C_w * W \quad (1)$$

Where C_i is the total investment of construction period including equipment expense, construction engineering fee, installation engineering fee, etc.; W is the installed capacity (kW); C_w is the unit cost of installed capacity (CNY/kW).

3.1.2 Cost of operation period

$$C_o = C_m + C_f + C_e + C_d + C_s \quad (2)$$

Where C_o stands for the annual total operation cost (CNY), C_m for operation & maintenance cost (CNY), C_d for sum of capital and interest (CNY), C_s for taxes and fees (CNY), C_f for fuel cost (CNY) and C_e for station service power cost (CNY).

(1) Annual operation & maintenance cost

$$C_m = C_g * (P_1 + P_2 + P_3) \quad (3)$$

Where P_1 , P_2 and P_3 are operation & maintenance rate, labor cost rate and other rates respectively.

(2) Annual loan interest

By repayment of average capital plus interest, the annual repayment sum of capital and interest is:

$$C_d = C_i * R_p * \left(R_l * (1 + R_l)^{n_4} \right) / \left((1 + R_l)^{n_4} - 1 \right) \quad (4)$$

Where C_d is the sum of capital and interest, R_p is the proportion of capital, R_l is the annual loan interest, and n_4 is the repayment years.

(3) Annual taxes and fees

$$\begin{cases} C_s = P_1 + P_2 + P_3 \\ P_1 = R_1 - R_2 \\ R_1 = R_s (1 + D_1) / D_1 \\ R_2 = C_f * (1 + D_2) / D_2 \\ P_2 = P_1 * D_3 \\ P_3 = \begin{cases} 0 & (0 < n \leq 3) \\ 0.5 * I * D_4 & (4 < n \leq 6) \\ I * D_4 & (n > 6) \end{cases} \end{cases} \quad (5)$$

Where C_s includes taxes and fees and P_1 , P_2 and P_3 are VAT, surtax and income tax respectively. D_1 , D_2 , D_3 and D_4 are VAT rate, VAT input deduction rate, VAT surtax rate and income tax rate. R_s is sales income, C_f is fuel cost and I is after-tax profit. The policy of Three Exemptions and Three Halves is implemented in the calculation of corporate income tax.

(4) Annual fuel cost

$$C_f = G_e * V_e * P_f \quad (6)$$

Where C_f stands for the fuel cost, G_e for annual power output (kWh), V_e for the quantity of fuel consumption for unit power output (m³/kWh) and P_f for the price of fuel (CNY/m³).

(5) Annual station service power cost

$$C_e = G_e * R_f * P_s \quad (7)$$

Where C_e is the cost of station service power, G_e is the annual power output (kWh), R_f is the proportion of station service power and P_s is the price of sold power (CNY/kWh).

3.2. Benefit model of IES individual component

The benefits of IES individual component include the initial investment subsidy, heating/cooling revenue (natural gas), power revenue, kWh subsidy, etc.

3.2.1 Initial investment subsidy

$$I_b = C_w * W \quad (8)$$

Where I_b is the initial investment subsidy, W is the installed capacity (kW) and C_{ps} is the initial investment subsidy of unit installed capacity (CNY/kW).

3.2.2 Power subsidy

$$I_{se} = G_{se} * P_g \quad (9)$$

Where I_{se} is the revenue of power subsidy, G_{se} is the annual quantity of subsidized power (kWh) and P_g is the subsidized tariff.

3.2.3 Power revenue

$$I_s = G_e * (1 - R_f) * P_e \quad (10)$$

Where I_s is the sales revenue of power, G_e is the annual power output (kWh), R_f is the proportion of station service power and P_e is the price of electricity (CNY/kWh, the tariff of user's sales catalog for self-used pattern, the desulfurized benchmark tariff for grid-connected pattern, and contractual tariff for market-oriented trading pattern).

3.2.4 Heating/cooling revenue

$$I_{hc} = G_h * P_h + G_c * P_c \quad (11)$$

Where I_{hc} is the heating/cooling revenue, P_h and P_c are the heating price and cooling price respectively (CNY/kWh) and G_h and G_c are quantity of heating sales and quantity of cooling sales (CNY/kWh), which is converted to power in thermal calculation.

3.3. Model of investment benefit calculation of individual component of IES

The investment benefit calculation of full lifecycle of individual component of IES includes the net present value, internal rate of return and cost per kWh (for distributed power source).

3.3.1 Net present value. The net present value is a dynamic evaluation indicator of profitability of technical scheme throughout its lifetime (including the construction period and operation period).

$$NPV_i = \sum_{t=0}^n CF_{it} \frac{1}{(1 + i_0)^t} = \sum_{t=0}^n (CI_{it} - CO_{it}) \frac{1}{(1 + i_0)^t} \quad (12)$$

Where NPV_i is the NPV of the i^{th} component of IES, CF_{it} is the net cash flow of the i^{th} component in the t^{th} year, CI_{it} is the cash inflow of the i^{th} component in the t^{th} year, CO_{it} is the cash outflow of the i^{th} component in the t^{th} year, n is the lifecycle (sum of construction period and operation period) i_0 is the standard discount rate.

$$CI_{it} = \begin{cases} 0 & (t < n_1 + 1) \\ C_s + C_{hc} + C_{se} & (n_1 < t < n_1 + n_2 + 1) \end{cases} \quad (13)$$

Where C_{se} , C_s and C_{hc} are power subsidy, power sales revenue and heating/cooling sales revenue respectively and n_1 and n_2 are the length of construction period and operation period respectively.

$$CO_{it} = \begin{cases} C_{ig} / n_1 & (t < n_1 + 1) \\ C_{io} & (n_1 < t < n_1 + n_2 + 1) \end{cases} \quad (14)$$

Where C_{ig} is the initial investment subsidy of the i^{th} component of IES while C_{io} is the total cost of operation period of the i^{th} component.

3.3.2 Internal rate of return (IRR)

$$\sum_{t=0}^n CF_{it} \frac{1}{(1 + IRR_i)^t} = 0 \quad (15)$$

Where IRR_i is the IRR of the i^{th} component while CF_{it} is the net cash flow of the i^{th} component in the t^{th} year.

3.3.3 Cost per kWh

$$LCOE_i = \left(\sum_{t=1}^{n2} \frac{C_{it}}{(1 + IRR_i)^t} \right) / \left(\sum_{t=1}^{n2} \frac{Q_{it}}{(1 + IRR_i)^t} \right) \quad (16)$$

Where $LCOE_i$ is the cost per kWh of the i^{th} component, IRR_i is the IRR of the i^{th} component, C_{it} is the sum of cost of the i^{th} component in the t^{th} year including depreciation, operation & maintenance cost, fuel cost, taxes and fees, interest and station service power cost, and Q_{it} is the power output (including heating) of the i^{th} component in the t^{th} year.

3.4. Model of investment benefit calculation of IES for multi investors

Any component of IES is invested by a certain investor while the investor may concurrently put investment in several components (including power source and network). Therefore, the estimation of investment benefit for investors is the sum of investment benefits of several components. The IES investment benefit for multi investors is described by NPV and IRR. Given the investor A as an example, the total NPV of the i^{th} component invested by the investor A is:

$$NPV_A = \sum_{t=0}^n \left(\sum_{i=1}^m CF_{it} \right) \frac{1}{(1 + i_0)^t} = \sum_{t=0}^n \left(\sum_{i=1}^m (CI_{it} - CO_{it}) \right) \frac{1}{(1 + i_0)^t} \quad (17)$$

Where CF_{it} is the net cash flow of the i^{th} component in the t^{th} year invested by the investor A, CI_{it} is the cash inflow of the i^{th} component in the t^{th} year, CO_{it} is the cash outflow of the i^{th} component in the t^{th} year, n is the lifecycle (sum of construction period and operation period) i_0 is the standard discount rate.

The IRR of investor A is:

$$\sum_{t=0}^n \sum_{i=1}^m CF_{it} \frac{1}{(1 + i_A^*)^t} = 0 \quad (18)$$

Where i_A^* is the total IRR of the i^{th} component in the t^{th} year invested by the investor A and CF_{it} is the net cash flow of the i^{th} component in the t^{th} year.

4. Case example

4.1. Project overview

The micro-grid project (mainly the wind and solar power) of a park depends on the 2.5MW wind turbine and 500kWp solar power unit where the annual output of wind turbine is about 1.496 million kWh, and the solar power output is about 474,000kWh. Each year it returns about 320,000-400,000kWh to the grid, the annual consumption of park load is around 6.7 million kWh and the output of solar and wind power accounts for 30% of total load demand. The design purpose of this project is to reasonably utilize the local wind and solar energy resources, and in line with local load conditions uplift the proportion of local clean energy resource to more than 70% in the upcoming several years by micro-turbines, solar and wind power units.

4.2. Cost efficiency analysis

Pursuant to the Provisional Rules for Construction of Grid-Connected Micro-grids (F.G.N.Y. [2017] No. 1339), "encourage the investment from all kinds of enterprises and professional energy service companies, construction and operation of micro-grid projects. The distributed power sources, power

distribution facilities and consumers of the micro-grid may be of different investors." Therefore, the micro-grid can be divided into different investment interfaces and funded by different investors. The benefit rate of investor under different operation models are as follows:

Operation model 1: under the integrated model of power generation, distribution and sales, the micro-grid of park is wholly invested by A, including wind power, solar power, natural gas and park distribution network. Table 2 shows the investment benefit calculations of investor A, with the unit investment benefit of distribution network manifested by the tariffs of wind, solar and gas power without deduction of transmission and distribution cost.

Table 2. Investors' income under generation-distribution-sales integration

Component	Unit cost of installed capacity	Annual using hour	Equivalent electricity price (CNY/kWh)	IRR
wind	8500	1642	0.77	9.84%
PV	6500	1000	1.02	11.04%
Gas turbine	20000	6480	0.77	5.09%
Distribution network	2000	-	-	-
IES	-	-	-	8%

Operation models 2 & 4: They respectively refer to the integrated model of power generation and sales, and the model of single operation of distribution network; under which, the micro-grid of park is co-invested by A and B. Investor A invests in the wind power, solar power and natural gas power, deals in power generation and sales business, and sells power in a market-oriented manner; investor B invests in the park distribution network and deals in power distribution network business. The investment benefits are shown in Table 3:

Table 3. Investors' income under generation- sales integration and distribution network independent operation

Investor	Component	Price (CNY/kWh)	IRR of single equipment	IRR of all equipment
A (power generation and sales business)	wind	0.74	9.21%	9%
	PV	1.00	10.64%	
	Gas turbine	0.65	-0.58%	
B (power distribution network business)	Distribution network	0.13	-1.37%	-1.37%

Operation 3: under the integrated model, the micro-grid of park is co-invested by A and B. Investor A invests in the wind power, solar power and natural gas power and deals in power generation, which is all connected with the grid; investor B invests in the park distribution network and deals in power distribution and sales business. The investment benefits are shown in Table 3:

Table 4. Investors' income under distribution-sales integration

Investor	Component	Price (CNY/kWh)	IRR of single equipment	IRR of all equipment
A (power generation business)	wind	0.57	4.69%	9%
	PV	0.97	10.03%	
	Gas turbine	0.65	-0.58%	
B (power distribution and sales business)	Distribution network	0.77	10.07%	10.07%

Reflected by the comparison of aforesaid models, the model of integrated power generation, distribution and sales gain the highest benefit, which is followed by the integrated power distribution and sales, and then the single operation of distribution network. The integration of power generation, distribution and consumption can improve the asset utilization rate and thus is more cost efficient.

5. Conclusion

The paper proposes four operation models of park IES in accordance with the categorization of investment interfaces under the new power reform, and hence establishes the model of quantitative investment benefit of park IES for multi-investors together with cases. The different operation models represent different investment categories that significantly influence the results of investment benefit. In general, the integration of multiple resources helps improve the cost efficiency.

In addition, the park IES still is limited in energy and network benefits, which in future requires the exploration of more diversified value-added businesses, provision of multi-energy and services, focusing on integrated energy service and improvement of its profitability through more channels.

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