Economic Analysis of Distributed Electricity-Hydrogen Coupling System Operation Models

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Abstract: The selection of a reasonable operating mode for the distributed electric hydrogen coupling system is the key to its sustainable development. Firstly, four operational modes of distributed electric hydrogen coupling system were proposed, namely "independent investment+independent operation", "independent investment+entrusted operation", "cooperative investment+cooperative operation", and "cooperative investment+entrusted operation". Three operational entities, namely power grid enterprises, energy storage enterprises, and new energy enterprises, were analyzed through SWOT strategy; Secondly, a cost-benefit model and economic evaluation index system for the distributed electric hydrogen coupling system under different operating modes were constructed; Finally, simulation calculations were conducted on different participating entities under different operating modes. The results indicate that:For State Grid Corporation of China, the "independent investment+independent operation" model is the most cost-effective. For new energy power generation enterprises, the "independent investment+independent operation" model has the best economic efficiency. For energy storage enterprises, the "cooperative investment+cooperative operation" model is the most cost-effective.

Keywords: Distributed electric-hydrogen coupling system, operating model, Economic analysis

1 INTRODUCTION

Promoting cleaner substitution in energy development and electricity substitution in energy consumption is an important way to achieve the goal of "double carbon". The use of wind and photovoltaic power generation can effectively reduce the pollution and damage to the environment caused by thermal power generation, and is an important means to achieve the transformation of energy structure. However, wind and photovoltaic power has the characteristics of intermittency and randomness, and its large-scale access brings challenges to the safe and stable operation of the power grid. Configuration of energy storage equipment can reduce the impact of renewable energy on grid operation. Hydrogen energy has the characteristics of high energy density, large storage capacity, long time and clean and non-polluting [1, 2], the use of renewable energy to produce hydrogen can not only play the advantages of hydrogen energy storage, but also increase the consumption of wind and light, thus reducing the consumption of fossil energy and greenhouse gas emissions, which is of great significance to alleviate the problem of energy scarcity and environmental pollution in China,

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and to promote the achievement of the dual-carbon goals [3].

Existing studies have not researched much on the operation mode of distributed electric-hydrogen coupling system, and mainly researched more on the operation mode of distributed energy system or microgrid. Literature [4] proposed three microgrid operation modes, and the commercial operation mode with the best return was derived from the analysis of the arithmetic examples. Literature [5, 6] studied the project operation strategy of integrated energy systems, proposed three operation models, and compared and analyzed different operation entities. Literature [7] analyzed the costs and benefits of the integrated energy system, and measured the economic benefits of various subjects under four operation models. Literature [8] constructed the net present value model of cost and benefit of grid investment and the evaluation system of grid investment decision. Literature [9] constructed an integrated energy service model based on energy sharing and evaluated its economic feasibility. Literature [10] evaluated and compared the net benefits and cost margins of different user types under different tariff models on the basis of constructing a cost-benefit model based on the structure of distributed photovoltaic energy storage system. A techno-economic model of a grid-connected photovoltaic (PV) energy storage plant with an energy storage system and the grid as a back-up power source is presented in Literature [11]. The model determines the rated power of the PV system and the capacity of the storage system with the objective of minimizing the levelized cost by taking into account the operational as well as the management strategy of the PV storage plant. Literature [12] constructs an economic model considering solar irradiation intensity, PV system cost, and operation and maintenance cost, and uses net present value, internal rate of return, and payback period as economic evaluation indicators.

Distributed electric-hydrogen coupling system stakeholders are numerous, from the horizontal perspective from the user, enterprise to the relevant government departments, and from the vertical perspective from the equipment manufacturer to the grid company, new energy company and then to the energy storage enterprise, all of which can be the main body of the system's investment and operation. For the investor, choosing a reasonable operation mode can get a good investment return, and for the electric-hydrogen coupling system, choosing a reasonable operation mode can attract more enterprises to participate in the investment and construction, expand the scale of development, further increase the consumption of renewable energy, and provide safe and stable power. Therefore, the economic analysis of the operation mode of distributed electric-hydrogen coupling system can provide a certain reference to bring the optimal economic benefits for the investor, the operator and the society.

2 Typical Operation Models of Distributed Electricity-Hydrogen Coupling Systems

Distributed electric-hydrogen coupling system is favored by many stakeholders for its unique high efficiency, low carbon and reliability. Through the analysis, the main participants of the distributed electric-hydrogen coupling system are power grid enterprises, distributed new energy generation enterprises and energy storage companies, and the SWOT analyses of the three main parties are shown in Fig 1 to 3.

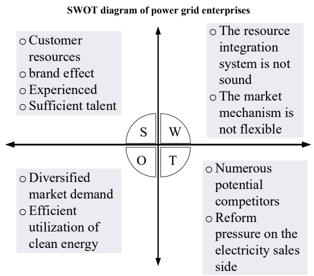

Fig 1. SWOT diagram of power grid enterprises participating in distributed electric hydrogen coupling system

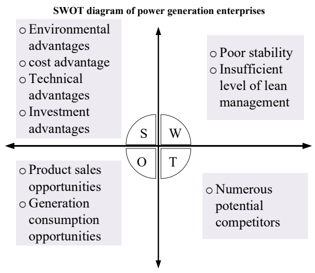

Fig 2. SWOT diagram of power generation enterprises participating in distributed electricity-hydrogen coupling system

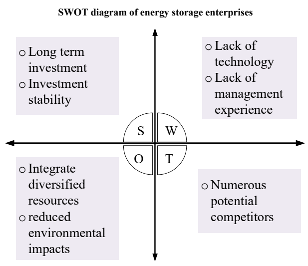

Fig 3. SWOT diagram of energy storage enterprises participating in distributed electric hydrogen coupling system

There are four typical investment and operation modes in distributed electric-hydrogen coupling systems:

(1) "Independent investment + independent operation"

Grid enterprises, energy storage enterprises, distributed new energy generation enterprises and other participants are independently responsible for the investment and operation of the distributed electricity-hydrogen coupling system, bear all the investment and operation costs, and exclusively enjoy the benefits of the system. Distributed electric-hydrogen coupling system economic benefit analysis model.

(2) "Independent investment + entrusted operation"

Grid enterprises, energy storage enterprises, distributed new energy generation enterprises and other participants are independently responsible for the investment in the distributed electricity-hydrogen coupling system and bear all the investment costs; the system operation is entrusted to a third-party operating unit, and the proportion of the system operating income.

(3) "Cooperative investment + cooperative operation"

Grid companies, energy storage companies, distributed new energy generation companies and other subjects are jointly responsible for the investment and operation of the distributed electricity-hydrogen coupling system, and share the benefits of the system.

(4) "Cooperative investment + entrusted operation"

Multiple subjects cooperate and are jointly responsible for the investment of the distributed electric-hydrogen coupling system; the system operation is entrusted to a third-party operating unit, and the system operating income is obtained proportionally.

3 COST-BENEFIT ANALYSIS OF DISTRIBUTED ELECTRIC-HYDROGEN COUPLING SYSTEMS

3.1 Cost-benefit modelling of different operating modes

(1) Cost-benefit analysis model for independent investment + independent operation

The cost under the independent investment + independent operation model is shown in equation (1). The benefits under the independent investment + independent operation model are shown in equation (2):

$$\begin{cases} C_1^{total} = C_{Inv}^{total} + C_{yy\_1}^{total} \\ C_{Inv}^{total} = \sum_{i=1}^{n} C_{Inv}^{i} \\ C_{yy\_1}^{total} = \sum_{t=1}^{T}\sum_{i=1}^{n} C_{yy}^{it} \end{cases} \tag{1}$$

$$R_1^{total} = \sum_{t=1}^{T}\sum_{i=1}^{n} R^{it} \tag{2}$$

Where , C_1^{total} , C_{Inv}^{total} , $C_{yy\_1}^{total}$ are the total cost, investment and construction cost, and operation cost under the independent investment + independent operation mode, respectively; C_{Inv}^{i} is the investment and construction cost of the ith unit; and C_{yy}^{it} is the operation cost of the ith unit in the tth year; R_1^{total} is the total return under the stand-alone investment + stand-alone operation model; R^{it} is the return of the ith equipment in year t.

(2) Independent investment + entrusted operation cost-benefit analysis model

The total cost under the independent investment + entrusted operation mode is the investment and construction cost, as shown in equation (3). The total return under the independent investment + commissioning model is specified in equation (4):

$$\begin{cases} C_2^{total} = C_{Inv}^{total} \\ C_{Inv}^{total} = \sum_{i=1}^{n} C_{Inv}^{i} \end{cases} \tag{3}$$

$$R_2^{total} = \sum_{t=1}^{T} \left(\sum_{i=1}^{n} R^{it} - \sum_{i=1}^{n} C_{yy}^{i} \right) \cdot k \tag{4}$$

Where C_2^{total} is the total cost under the independent investment + commissioning model; C_{yy}^{i} is the operating cost of the ith component and k is the profit sharing ratio.

(3) Cost-benefit analysis model of "Co-investment + Co-operation".

The cost under the agreed investment ratio model is shown in equation (5); The return under the agreed investment ratio model is shown in equation (6):

$$\begin{cases} C_{3j}^{total} = \left(C_{Inv}^{total} + C_{yy\_3}^{total} \right) \cdot k_j \\ C_{Inv}^{total} = \sum_{i=1}^{n} C_{Inv}^{i} \\ C_{yy3}^{total} = \sum_{t=1}^{T} \sum_{i=1}^{n} C_{yy}^{it} \end{cases} \tag{5}$$

$$R_{4j}^{total} = \sum_{t=1}^{T} \sum_{i=1}^{n} R^{ijt} \cdot k_j \tag{6}$$

where C_{3j}^{total} is the investment cost of the jth subject under the agreed investment ratio model; k_j is the investment ratio of the jth subject under the agreed investment ratio model; R_{4j}^{total} is the return of the jth subject in the agreed investment ratio model.

(4) Co-investment + entrusted operation benefit analysis model

Under the agreed investment ratio model, the cost of co-investment + commissioning is shown in equation (7); Under the agreed investment ratio model, the return on co-investment + entrusted operation is shown in equation (8):

$$\begin{cases} C_{4j}^{total} = C_{Inv}^{total} \cdot k_j \\ C_{Inv}^{total} = \sum_{i=1}^{n} C_{Inv}^{i} \end{cases} \tag{7}$$

$$\begin{cases} R_4^{total} = R^{total} \cdot k_j \\ R^{total} = \sum_{t=1}^{T} \left(\sum_{i=1}^{n} R^{it} - \sum_{i=1}^{n} C_{yy}^{i} \right) \cdot k \end{cases} \tag{8}$$

3.2 Indicator system for evaluating different modes of operation

Through quantitative analysis of the costs and benefits under various modes, the feasibility of the programme can then be judged on the basis of the relevant indicators of economic benefits, and the following three assessment indicators are mainly used for the analysis of project benefits.

(1) Net Present Value

Net present value (NPV) project investment evaluation in one of the key indicators, can reflect the project business status, and in the calculation of the full consideration of the time value of money, the net present value of the project life cycle of the annual cash flow based on a predetermined benchmark discount rate discounted to the calculation of the base period of the present value of the sum of the whole cycle of cash inflows (CI) and cash outflows (CO) of the difference between the calculation formula is as follows:

$$NPV = \sum_{t=0}^{n} (CI - CO)_t (1+i)^t \tag{9}$$

If the net present value is greater than zero, it indicates that the project returns are good, the project cash inflow is greater than the outflow, and the project can be invested in this project; otherwise, it indicates that the project returns are poor, the project cash inflow is less than or equal to the outflow, and the expected level of returns cannot be achieved.

(2) Internal Rate of Return

The internal rate of return (IRR) is the discount rate at which the net present value is zero over the life of the project investment, i.e., the discount rate at which the present value of future cash inflows is exactly equal to the present value of future cash outflows, and is calculated as follows:

$$\sum_{t=0}^{n} (CI - CO)_t (1+IRR)^t = 0 \tag{10}$$

The larger the IRR value, the better the profitability of the investment programme. If the internal rate of return is greater than or equal to the base rate of return, the project is feasible from an economic point of view; otherwise, the project is not feasible from an economic point of view and the investment should be rejected.

(3) Dynamic payback period

The dynamic payback period is the time required to recover the present value of the initial capital invested in the project after taking into account the time value of money, i.e., the number of years in which the cumulative net present value of the project turns from a negative to a positive figure, and is calculated using the following formula [11]:

$$\sum_{t=0}^{P_t} (CI - CO)_t (1+i)^t = 0 \tag{11}$$

Compare the dynamic payback period with the life of the project, if the payback period is less than the life of the project, it indicates that the initial investment cost can be recovered within the life of the project, and this investment programme can be considered; otherwise, it indicates that the initial investment cost cannot be recovered within the life of the project, and the programme is infeasible; the dynamic payback period is expected to allow the project to recover its investment as early as possible, and the shorter the payback period, the more favorable it will be.

4 EMPIRICAL ANALYSIS

4.1 basic parameter

A distributed electric-hydrogen coupling system is used as an example for calculation and analysis, and the main participants of the electric-hydrogen coupling system include grid enterprises, distributed photovoltaic, distributed wind power, hydrogen storage system and other components. The capacity of PV power generation, wind power generation, hydrogen fuel cell, electrolysis tank and hydrogen storage system is set to be 4MW, 2.5MW, 2MW, 4.5MW and 8000kg respectively, and the total initial investment price of the active distribution network, transmission and distribution price (110kV), transmission and distribution price (10kV), and over-network fee are RMB 89.57million, 0.1138/kWh, 0.1538/kWh, 0.04/kWh, and 0.04/kWh respectively. Benchmark discount rate set at 8 per cent, base reserve rate set at 10 per cent, commissioned operation accrual rate set at 70 per cent, income tax rate set at 25 per cent, surtax rate set at 10 per cent, residual value of fixed assets set at 3 per cent, depreciation life and full life cycle set at 20 years. The parameter settings for each unit are shown in table 1:

Table 1. Operation and maintenance fee rates for each system component operated by each entity

System Components	Operating entity				
	Power Grid Enterprise	Distributed photovoltaic enterprises	Distributed wind power enterprises	Energy storage company	Third-party operating unit
active distribution network	5%	6%	6%	8%	6%
Distributed photovoltaic	1.5%	1.2%	1.2%	2%	1.5%
Distributed wind power	1.2%	1.3%	1.3%	1.5%	1.25%
Electrolyzer	10%	10%	10%	8%	9%
Hydrogen storage system	4%	4%	4%	2%	4%

4.2 Calculation results

(1) "Independent investment + independent operation"

Under the independent investment and independent operation mode, different entities have their own advantages and disadvantages in different aspects, and the operation and maintenance fee rates are different. The economic benefits of each participant in this model are shown in the table 2:

Table 2. Benefit indicators of each subject under the model of "independent investment + independent operation"

index	Grid main body	Main body of new energy power generation	Energy storage business entity	unit
total initial investment	5 9700	59700	59700	ten thousand yuan

Operation and maintenance cost	12722.29	12900.74	13505.79	ten thousand yuan
Total revenue	425718.49	425718.49	425718.49	ten thousand yuan
Average annual profit	4 703.04	4524.59	3919.54	ten thousand yuan
The total profit	9 4060.77	90491.71	78390.70	ten thousand yuan
Financial Net Present Value (After Taxes)	12374.17	11175.00	7093.37	ten thousand yuan
Internal rate of return (after tax)	10.87%	10.61%	9.68%	
Financial Net Present Value (before tax)	23107.48	21508.58	16066.41	ten thousand yuan
Internal rate of return (before tax)	13.23%	12.89%	11.71%	
static payback period	9.04	9.18	9.72	Year
Dynamic payback period	14.44	14.86	16.61	Year

From Table 2 that the accumulative net present values of power grid enterprises, new energy power generation entities, and energy storage entities under this model are 123.7417 million yuan, 111.75 million yuan, and 70.9337 million yuan respectively, and the dynamic investment periods are 14.44 years, 14.86 years and 16.61 years, the internal rate of return was higher than the benchmark rate of return of 8 %, and the benefits were good.

(2) Independent investment + entrusted operation

Under this model, grid companies, distributed photovoltaic companies and energy storage companies can independently invest in distributed electricity-hydrogen coupling systems, and hand over the system to third-party operators after the system is completed; for distributed electricity-hydrogen coupling systems during the investment stage, investment The total amount is fixed, and the operating part is charged by a third party at 30 % of the profit. Therefore, in this mode, the cost-effectiveness of each subject is basically the same; the operation and maintenance management level of each component of the integrated energy system by the operating unit is at an average level. However, it has better operation and management experience for the overall intelligent information service system of the system; the economic benefits of each participant in this model are shown in the table 3:

Table 3. Benefit indicators of each subject under the model of "independent investment + entrusted operation"

index	value	unit
total initial investment	59700	ten thousand yuan
Total revenue	120823.45	ten thousand yuan
Average annual profit	43611.45	ten thousand yuan
The total profit	78390.70	ten thousand yuan
Financial Net Present Value (After Taxes)	-5207.43	ten thousand yuan

Internal rate of return (after tax)	6.70%	
Financial Net Present Value (before tax)	-216.06	ten thousand yuan
Internal rate of return (before tax)	7.95%	
static payback period	11.82	Year
Dynamic payback period	cannot be recycled	Year

From Table 3, it can be seen that the total initial investment of each subject under the "independent investment + entrusted operation" model is 597 million yuan, the total income during the operation period is 1208.2345 million yuan, the total profit is 436.1145 million yuan, and the cumulative net present value is negative. The entire investment cannot be recovered during the operation period; the internal rate of return of 6.70 % is lower than the benchmark rate of return of 8%, and the three participating entities cannot make profits in this mode. This is mainly because under the "independent investment + entrusted operation" model, although the total investment is consistent with the "independent investment + independent operation model", the "independent investment + entrusted operation" model needs to accrue 30 % of operating expenses, resulting in an increase in operating costs. leading to a lower internal rate of return.

(3) Cooperative investment + cooperative operation

In this mode, power grid companies, distributed photovoltaic companies and energy storage companies jointly invest in and operate distributed electricity-hydrogen coupling systems, and based on the principle that each entity of the system components participates in investment in areas with strong business capabilities, and operates jointly on the principle of who invests and who operates Power grid companies invest in and operate active distribution networks and hydrogen fuel cells, new energy power generation companies invest in distributed photovoltaics and distributed wind power, and energy storage companies invest in electrolyzers and hydrogen storage systems. Under this model, the cost-benefit analysis of each enterprise is shown in the Table 4:

Table 4. Benefit indicators of each subject under the cooperative investment + cooperative operation mode

index	Power Grid Enterprise	New energy power generation enterprises	Energy storage company	unit
total initial investment	40000	18900	3200	ten thousand yuan
Operation and maintenance cost	11194.65	264.30	1338.87	ten thousand yuan
Total revenue	326513.76	58304.97	37923.62	ten thousand yuan
Average annual profit	2544.37	1428.75	350.38	ten thousand yuan
The total profit	50887.35	28574.97	7007.65	ten thousand yuan
Financial Net Present Value	4174.34	3486.93	1326.28	ten thousand

(After Taxes)				yuan
Internal rate of return (after tax)	9.48%	10.56%	13.56%	
Financial Net Present Value (before tax)	9993.65	6741.41	2122.60	ten thousand yuan
Internal rate of return (before tax)	11.45%	12.83%	16.64%	
static payback period	9.85	9.22	7.81	Year
Dynamic payback period	17.05	14.94	11.23	Year

From Table 4 that the cumulative net present value of power grid enterprises, photovoltaic entities, and energy storage enterprises under the "cooperative investment + cooperative operation" model is 41.7434 million yuan, 34.8693 million yuan, and 13.2628 million yuan respectively. The dynamic investment payback period They are 17.05 years, 14.94 years, and 11.23 years respectively, and the internal rate of return is higher than the benchmark rate of return of 8%, showing good benefits.

(4) Cooperative investment + entrusted operation

Under the "cooperative investment + entrusted operation" model, grid companies invest in active distribution networks and hydrogen fuel cells, distributed photovoltaic companies invest in distributed photovoltaics and distributed wind power, and energy storage companies invest in electrolyzers, hydrogen storage systems and oxygen tanks. Jointly invest in the distributed electric-hydrogen coupling system with the investment system components as a cooperation mechanism. After the system is completed, it will be handed over to a third-party operating unit to undertake, and the entrusted operation fee will be billed at 30% of the profit. The cost-benefit of each subject's participation is shown in the table 5:

Table 5. The main benefit indicators of each enterprise under the cooperative investment + entrusted operation mode

index	Power Grid Enterprise	New energy power generation enterprises	Energy storage company	unit
total initial investment	40000	18900	800	ten thousand yuan
Total revenue	72225.57	36342.74	10266.42	ten thousand yuan
Average annual profit	1024.61	594.94	461.59	ten thousand yuan
The total profit	20492.24	11898.74	9231.76	ten thousand yuan
Financial Net Present Value (After Taxes)	-6446.06	-2316.07	2876.74	ten thousand yuan
Internal rate of return (after tax)	5.55%	6.16%	49.73%	
Financial Net Present Value (before tax)	-4087.43	-958.38	3925.80	ten thousand yuan
Internal rate of return (before tax)	6.47%	7.25%	64.16%	
static payback period	12.86	12.30	3.01	Year
Dynamic payback period	cannot be recycled	cannot be recycled	3.29	Year

From the table, we can see that the power grid enterprise in the "cooperative investment + entrusted operation" mode cumulative net present value of 64,466,600 yuan, the internal rate of return of 5.55 per cent is less than the benchmark rate of return of 8 per cent, in the operating period can not recover the investment cost, should be refused to invest. Photovoltaic enterprises in this mode cumulative net present value of 9,583,800 yuan, the internal rate of return of 6.16 per cent is less than the benchmark rate of return of 8 per cent, in the operating period can not recover investment costs, should refuse to invest. The energy storage enterprise has a cumulative NPV of $287,674,000 under this model, with a higher IRR of 49.73 per cent, and can recover the cost in 3.29 years, so it can invest.

For the State Grid Corporation, the NPV under the "independent investment + independent operation" model is significantly larger than that under the "cooperative investment + cooperative operation" model; and the IRR is higher, indicating that the enterprise has a better return under this model, and the payback period is shorter in the independent model than in the cooperative model. At the same time, the payback period in the independent mode is shorter than that in the co-operation mode, which means that the enterprise can recover the cost in a relatively short period of time and the investment risk is lower. Therefore, from the perspective of economic benefits, grid enterprises should choose the mode of "independent investment + independent operation" to participate in the distributed electric-hydrogen coupling system project. This is mainly because the grid enterprise itself has strong customer resources and investment capacity, through the "independent investment + independent operation" mode can expand business channels, crack part of the power sales side reform pressure, to meet the diversified needs of the market.

For new energy power generation companies, the net present value of "independent investment + independent operation" mode is significantly larger than that of "cooperative investment + cooperative operation" mode, and the benchmark rate of return and payback period of the two modes are relatively close. From the perspective of economic efficiency, new energy power generation companies should choose the "independent investment + independent operation" mode to participate in the distributed electricity-hydrogen coupling system project.

For energy storage enterprises, according to NPV ranking: "independent investment + independent operation" > "cooperative investment + cooperative operation" > "cooperative investment + entrusted operation"; according to IRR ranking: "cooperative investment + cooperative operation" > "cooperative investment + entrusted operation" > "independent investment + independent operation": "cooperative investment + cooperative operation" > "cooperative investment + entrusted operation". According to internal rate of return: "cooperative investment + cooperative operation" > "cooperative investment + entrusted operation" > "independent investment + independent operation": "cooperative investment + cooperative operation" > "independent investment + independent operation": "cooperative investment + cooperative operation" > "cooperative investment + entrusted operation" > "independent investment + independent operation". The initial investment amount of "cooperative investment + cooperative operation" and "cooperative investment + entrusted operation" is the same, so it is necessary to carry out incremental analysis of the two options through the principle of mutually exclusive options. According to the calculation results, the energy storage enterprise in the "independent investment + independent operation" mode than the "cooperative investment + cooperative operation" mode more investment of 565 million yuan, the net present value is greater than zero, indicating that the incremental investment can not only meet the standard but also get a certain return, and the internal rate of return is 8.08%. The internal rate of return is 8.08 per cent, and the incremental investment can be carried out under the benchmark rate of return of 8 per cent. Therefore, the programme with a larger investment amount, namely, the "independent investment + independent operation" mode, should be selected, and the cooperative investment and operation mode is better.

5 CONCLUSION

(1) There are differences in the optimal investment models for different investment entities. For State Grid Corporation of China, the "independent investment+independent operation" and "cooperative investment+cooperative operation" models are more economical.

(2) For new energy power generation enterprises, the "independent investment+independent operation" and "cooperative investment+cooperative operation" models are more economical.

(3) For energy storage enterprises, the "cooperative investment+cooperative operation" model is the most cost-effective.

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