China's Various Types of new Energy Storage Investment and Operating Costs Analysis

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Abstract: Under the background of "double carbon" target, China's power system will be transformed to a new power system with new energy as the main source, and energy storage as a flexible regulating power source will assume an important role in the new power system. However, except for pumped storage, new energy storage technologies are still in the early stage of commercialization and scale development, and the related tariff policy and market mechanism are not perfect, and there are problems such as poor cost diversion and low effective utilization rate. This paper analyzes the composition of energy storage reinvestment and operation costs, sets the basic parameters of various types of energy storage systems, and uses the levelized cost of electricity to predict the economics of energy storage systems in 2025 and 2030, so as to provide economic decision aids for the investment and operation applications of comprehensive energy storage systems.

Keywords: Energy storage; Investment; Operation

1 Introduction

With the goal of "double carbon", the installed capacity of renewable energy will be developed rapidly, and it is expected that by 2030, the total installed capacity of wind power and solar power will reach more than $1.2*10^8$ kW nationwide. By the end of 2021, the installed capacity of wind power and solar power will reach $3.3*10^8$ kW and $3.1*10^8$ kW respectively [1]. Along with the increasing scale and proportion of renewable energy, the stability and adaptability of the power grid will be affected, and the problems of insufficient peaking capacity of the power system, increased scheduling operation and peaking costs are becoming increasingly prominent. Through the introduction of energy storage, grid-side energy storage can be used as an important means of peak and frequency regulation, improving the utilization rate of existing equipment, reducing grid losses, and improving the stability and safety of system operation. The user side uses energy storage to effectively achieve demand-side management, smooth the load, and achieve the purpose of peak shaving and valley filling.

The literature [1-8] focuses on the methods of various types of energy storage cost measurement, which provides an important reference for the setting of energy storage cost parameters. The literature [9-12], starting from the application status of multivariate electrochemical energy

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storage technology, mainly establishes a multivariate energy storage optimization whole life cycle LCOE model, analyzes the economics of grid-side electrochemical energy storage, and provides effective information on the principles and economics of sodium-sulfur battery and all-vanadium liquid flow battery systems. The literature [13-18] fully exploits the value of energy storage in frequency regulation, peak regulation, black start, etc. for specific scenic power generation cases in Zhejiang Province to find the cost relief path of new energy generation side energy storage and open up the profit space of energy storage. The literature [19-26] established a set of whole-life cycle cost-benefit model to compare and analyze the investment benefits of user-side distributed rooftop PV and PV+energy storage, which has certain guiding significance for current PV+energy storage project investment.

Synthesizing the above literature, this paper establishes the levelized analysis model for various types of energy storage.

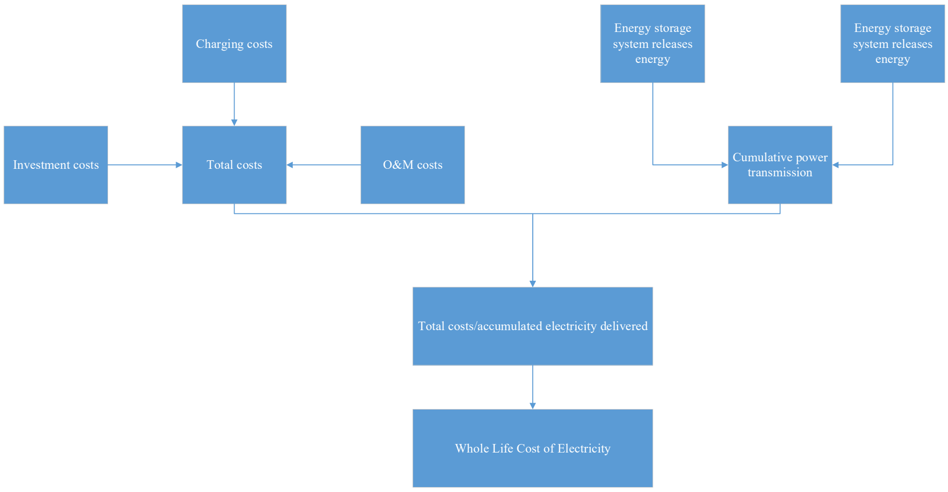

Figure 1. The construction of whole life cost of electricity.

2 Various types of energy storage levelized cost analysis model

2.1 Analysis of the basic parameters of energy storage investment and operation

The cost of each component of the energy storage system is roughly divided into two parts: capacity-related and power-related, i.e., capacity cost and power cost. There are also some costs that are not related to capacity and power, such as battery management system (EMS), which account for a relatively small amount and are not considered in the measurement process. The system power cost formula is as follows:

$$LCOS=\frac{\left[\left(C_E+\frac{C_P}{d}\right)+\left(C_E+\frac{C_P}{d}\right)\cdot\sum_{t=1}^{T}\frac{O\&\mathrm{M}(t)}{(1+r)^t}+\frac{P_C}{\eta}\sum_{t=1}^{T}\frac{n(t)}{(1+r)^t}\right]}{\eta\cdot\sum_{t=1}^{T}\frac{n(t)}{(1+r)^t}} \tag{1}$$

1) Capacity cost C_E: refers to the equipment and construction costs related to energy storage capacity, such as the cost of equipment and construction costs of batteries and battery containers in battery energy storage; the cost of reservoirs in pumped storage power plants; the cost of gas storage chambers and thermal storage systems in compressed air energy storage, etc.

2) Power cost C_P: refers to power-related energy storage equipment and construction costs, such as equipment such as converters and transformers in battery storage systems; turbines in pumped storage power plants; compressors and expanders in compressed air energy storage, etc.

3) Charging cost: Different provinces have different types of power generation feed-in tariffs, which can be unified without considering the charging cost, and only consider the cost of its storage and release process.

4) Operation and maintenance cost: mainly includes labor, fuel power, parts replacement, etc.

5) Cumulative power output: refers to how many degrees of electricity can be released or cycled in the whole life cycle of the energy storage system. It involves the system life of the energy storage system T (in years), the number of cycles per year $n(t)$, and the cycle efficiency η.

The specific meaning of each element in the formula is shown in Table 1.

Table 1. The specific meaning of each element in the formula.

Input Items	Unit	Definition	Description
d	hour	Discharge time at rated power	Example: A 5MW (power when charging and discharging) energy storage station with a capacity of 10MWh takes two hours to charge or discharge at rated capacity.
P_C	yuan/kWh	The price of buying electricity when charging	It is difficult to compare electricity prices in different regions, so charging costs are not considered here.
η	%	Energy storage station cycle efficiency	It refers to the conversion efficiency of the battery, the ratio of the power discharged from the battery to the power charged in the equal charging and discharging time when the current is kept constant. Cycle efficiency 85% means charging 100 kWh and discharging only 85 kWh due to conversion efficiency and other factors.
T	year	System life	min (cycle life/annual cycle count, calendar life)
$n(t)$	time/year	Number of cycles per year	
r	%	Discount rate	
$O\&M(t)$	%	O&M costs in year t (installed ratio)	
C_E	yuan/kWh	Installed cost with capacity	
C_P	yuan/kW	Power-dependent installed cost	

(1) Energy storage capacity cost

Capacity cost = unit capacity cost * energy storage capacity.

It is assumed that the capacity cost of various energy storage methods is estimated to decrease by 10% in 2025 and 20% in 2030.

Lead carbon battery, because the cost of lead material accounts for a relatively large proportion, its capacity cost decline space is more limited, 2025, 2030 capacity cost is estimated to remain unchanged.

Pumped storage, the capacity cost of pumped storage is estimated to increase by 5% and 10% in 2025 and 2030.

Compressed air energy storage equipment used have been highly mature, the cost decline is limited, to 2025, 2030, the cost is estimated to decline 5%, 10%.

Hydrogen energy storage, 2025, 2030 capacity costs are estimated to remain unchanged.

(2) Energy storage power cost

Power cost = unit power cost * energy storage power = unit power cost * energy storage capacity / length of discharge.

Lead carbon battery: material costs account for a relatively high, limited room for cost reduction, 2025, 2030, the estimated cost of lead carbon battery power will drop 5%, 10%. Other kinds of electrochemical energy storage power cost 2025, 2030 will drop 120%, 20%.

Mechanical energy storage: considering the compressor, expander, gas storage, heat exchange and other equipment used in compressed air energy storage have been highly mature, so its power cost decline is also limited, estimated to 2025, 2030 down to 8,500 yuan/kW, 7,500 yuan/kW.

Hydrogen energy storage: The power cost of hydrogen energy storage is estimated to decrease by 5% and 10% in 2025 and 2030.

(3) Energy storage charging and discharging efficiency

In 2025 and 2030, the charging and discharging efficiency of lithium-ion and sodium-ion batteries will reach 85% and 90%; the charging and discharging efficiency of liquid flow batteries and lead-carbon batteries will reach 80% and 85%; the charging and discharging efficiency of pumped storage and compressed air storage will be slightly improved, but the charging and discharging efficiency is low compared with other technologies.

(4) Energy storage equipment discount rate

The discount rate refers to the ratio of the expected future earnings for a limited period of time discounted to the present value. The higher the discount rate, it means the higher the preference for the present. Assume that the discount rate of energy storage cost is 7%.

(5) Energy storage equipment operation and maintenance rate

The annual operation and maintenance cost is generally about 3% of the initial investment cost.

2025, 2030 energy storage levelized unit cost of electricity calculation

The relevant parameters for the calculation of the levelized cost of electricity for energy storage in 2025 and 2030 are listed in the table 2 below:

Table 2. Parameter Assumptions for Levelized Cost of Electricity.

Indicators	Energy Storage Technology	Installed capacity	Discharge time d	Power Cost C_P	Capacity Cost C_E	Cycle life	Number of cycles per year n	System life T	Charging and discharging efficiency η
unit		MW	h	yuan/kW	yuan/(kW·h)	time	time/year	year	%
2025	Lithium-ion battery	1	4	300	800	6000	350	12	88
	Sodium ion battery	1	4	300	1500	6000	350	12	88
	All-Vanadium Liquid Flow Battery	1	8	1746	863	15000	350	30	82
	Sodium-sulfur batteries	1	4	2000	2000	6000	350	30	85
	Lead Carbon Battery	1	4	300	700	2000	350	8	85
	Pumped storage	1	8	5000	100	-	350	30	75
	Compressed air energy storage	1	8	8000	100	-	350	30	55
	Hydrogen Storage	1	8	15000	50	6000	350	30	40
2030	Lithium-ion battery	1	4	240	640	9393	350	16	90
	Sodium ion battery	1	4	240	1200	9393	350	16	90
	All-Vanadium Liquid Flow Battery	1	8	1397	690	19530	350	40	85
	Sodium-sulfur batteries	1	4	1600	1600	7221	350	20	90
	Lead Carbon Battery	1	4	270	700	3250	350	9	85
	Pumped storage	1	8	5500	110	-	350	33	78
	Compressed air energy storage	1	8	7500	90	-	350	33	58
	Hydrogen Storage	1	8	13500	50	7221	350	20	-

Table 3. Energy storage technology kilowatt-hour costs by type, 2025.

2025 various types of energy storage technology kilowatt-hour cost									
unit	Description	Lithium-ion battery	Sodium ion battery	All-Vanadium Liquid Flow Battery	Lead Carbon Battery	Pumped storage	Compressed air energy storage	Sodium-sulfur batteries	Hydrogen Storage
hour	Discharge time at rated power	4	4	8	4	8	8	4	8
yuan/kWh	The price of buying electricity when charging	0	0	0	0	0	0	0	0
%	AC-AC cycle efficiency for energy storage stations	88	88	82	85	75	55	85	40
year	System life	12	11	30	7	30	30	17	17
time	Number of cycles in year t	350	350	350	350	350	350	350	350
%	Discount rate	7	7	7	7	7	7	7	7
%	O&M costs in year t	3	3	5	3	3	3	3	3
yuan/kWh	Installed cost with capacity	800	1500	863	700	100	100	2000	50
yuan/kW	Power-dependent installed cost	300	300	1746	300	5000	8000	2000	15000
yuan/kWh	Levelized cost of electricity	0.44	0.84	0.49	0.56	0.31	0.63	1.11	1.82

As shown in the table 3 above, in 2025, the cost of electricity for each type of energy storage technology is ranked from lowest to highest: pumped storage < lithium-ion battery < all-vanadium liquid flow battery < lead carbon battery < compressed air < sodium-ion battery < sodium-sulfur battery < hydrogen energy storage. Pumped storage is still the lowest cost of electricity, significantly lower than other energy storage technologies, lithium-ion, all-vanadium liquid flow battery energy storage costs are comparable, is second only to pumped storage lower cost of electricity technology. Compressed air energy storage, sodium ion battery energy storage cost is under 1 yuan / kWh, sodium-sulfur batteries, hydrogen storage does not yet have the cost advantage.

Table 4. Energy storage technology cost per kilowatt-hour in 2030.

2030 various types of energy storage technology kilowatt-hour cost									
unit	Description	Lithium-ion battery	Sodium ion battery	All-Vanadium Liquid Flow Battery	Lead Carbon Battery	Pumped storage	Compressed air energy storage	Sodium-sulfur batteries	Hydrogen Storage
hour	Discharge time at rated power	4	4	8	4	8	8	4	8
yuan/kWh	The price of buying electricity when charging	0	0	0	0	0	0	0	0
%	AC-AC cycle efficiency for energy storage stations	90	90	85	85	78	58	90	40
year	System life	16	16	40	9	33	33	20	20

time	Number of cycles in year t	350	350	350	350	350	350	350	350
%	Discount rate	7	7	7	7	7	7	7	7
%	O&M costs in year t	3	3	5	3	3	3	3	3
yuan/kWh	Installed cost with capacity	640	1200	690	700	110	90	1600	50
yuan/kW	Power-dependent installed cost	240	240	1397	270	5500	7500	1600	13500
yuan/kWh	Levelized cost of electricity	0.30	0.54	0.36	0.47	0.32	0.55	0.78	1.54

In 2023, the cost of electricity for various types of energy storage technologies is ranked from low to high: lithium-ion batteries < pumped storage < all-vanadium liquid flow batteries < lead-carbon batteries < sodium-ion batteries < compressed air < sodium-sulfur batteries < hydrogen energy storage. If the capacity cost and power cost of lithium-ion batteries can be reduced by 20% in 2020-2030, the levelized cost of electricity for energy storage will be lower than the most economical pumped storage in 2030. As shown in the table 4 above, All-vanadium liquid flow batteries and lithium-ion batteries are expected to achieve significant cost reductions, and by 2030 are the two technologies with the lowest cost of electricity in electrochemical energy storage. Lead carbon batteries, sodium ion batteries, compressed air energy storage unit cost followed. Hydrogen energy storage kilowatt-hour cost is still at a high level.

The comparative evolution of the cost of electricity for each type of energy storage technology from 2025 to 2030 is shown in the table 5:

Table 5. Comparison of the kilowatt-hour cost of various energy storage technologies in 2025 and 2030.

Contrast Analysis								
	Lithium-ion battery	Sodium ion battery	All-Vanadium Liquid Flow Battery	Lead Carbon Battery	Pumped storage	Compressed air energy storage	Sodium-sulfur batteries	Hydrogen Storage
2020	0.443	0.835	0.492	0.562	0.305	0.632	1.113	1.821
2030	0.302	0.543	0.363	0.473	0.317	0.549	0.790	1.544
Drop	-31.83%	-34.95%	-26.15%	-15.70%	3.69%	-13.17%	-29.03%	-15.21%

3 All types of energy storage operating cost sensitivity analysis

3.1 Sodium ion battery energy storage

(1) Sodium ion battery energy storage system measurement parameters assumptions

Energy storage system includes battery system BMS, PCS, EMS, transformers, racks, connecting cables, convergence cabinets, lightning protection and grounding systems, monitoring and alarm systems, etc.

1) Initial investment cost: lithium-ion began industrialization, assuming that the maturity period can be 20%-30% lower than lithium iron batteries, the initial capacity investment control in 500-700 Yuan/kWh, set 100MW/200MWh project initial investment cost of 1.1 Yuan/Wh.

2) Annual operation and maintenance cost: It takes about 3.7% per year, which is 0.041 Yuan/Wh.

3) Life time: can be cycled 2000-8000 times, set the average annual cycle times 300 times, the system life is 10 years.

4) Cycle efficiency: generally 84%-90%, set 88%.

5) Discount rate: Since the financing cost is generally 4%-5%, 6% can be taken as the discount rate.

The assumptions of measured parameters of sodium ion battery energy storage system are shown in Table 6.

Table 6. Assumptions of measured parameters of sodium ion battery energy storage system.

Parameters	Numerical value	Unit
Initial Investment Costs	1.1	yuan/Wh
Operation and Maintenance Costs	0.041	yuan/Wh
System Residual Value Rate	5	%
System Power	100	MW
System Capacity	200	MWh
Discharge Depth	100	%
Cycling efficiency	88	%
Number of cycles per year	300	time
System life	10	year
Annual loss rate	1.5	%
Discount rate	6	%
Tax rate	25	%

(2) Calculation of LOCS for sodium ion battery energy storage system

The measurement coefficient and data of sodium ion battery KWH cost are shown in the table 7.

Table 7. Sodium ion battery kilowatt-hour cost measurement.

Sodium ion battery	0	1	2	3	4	5	6	7	8	9	10
Initial investment (million yuan)	220										
Annual operation and maintenance cost (million yuan)		8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
Annual depreciation (million yuan)		20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
Tax deduction due to depreciation (million yuan)		5.225	5.225	5.225	5.225	5.225	5.225	5.225	5.225	5.225	5.225
Annual Electricity (MWh)		52800	52008	51227.88	50459.462	49702.570	48957.031	48222.676	47499.336	46786.846	46085.043
Discount factor		0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558
Present value of O&M costs (million yuan)	60.353	7.736	7.298	6.885	6.495	6.128	5.781	5.453	5.145	4.854	4.579
Present value of tax relief (million yuan)	38.456	4.929	4.650	4.387	4.139	3.904	3.683	3.475	3.278	3.093	2.918
Present value of electricity discharged (MWh)	366031.432	49811.321	46286.935	43011.916	39968.620	37140.652	34512.775	32070.834	29801.671	27693.062	25733.647
Unit cost of electricity (yuan/kWh)	0.661										

The kilowatt-hour cost of sodium-ion batteries is calculated to be 0.661 Yuan/kWh, which is comparable to that of lithium iron phosphate batteries.

(3) Sensitivity analysis of sodium ion battery energy storage system LOCS

The parameter assumptions for sensitivity analysis of sodium ion batteries. are shown in the following table 8.

Table 8. Parameter assumptions for sensitivity analysis of sodium ion batteries.

Initial investment cost (yuan/Wh)					
		1.2	1.1	1	0.9
Number of annual cycles (time)	200	1.08	0.99	0.90	0.81
	300	0.72	0.66	0.60	0.54
	400	0.54	0.50	0.45	0.40
	500	0.43	0.40	0.36	0.33
	600	0.36	0.33	0.30	0.27

Assuming an initial investment cost of 0.9-1.2 Yuan/Wh, a lifetime of 10 years, and a cycle life range of 2000-6000 cycles, a sensitivity analysis is done for sodium ion batteries. If the cost is below 1.1 Yuan/Wh and the cycle life is above 3000 cycles.

It can be calculated that the cost of kWh will be between 0.270-0.662 Yuan/kWh, which is better than LiFePO4.

3.2 All-vanadium liquid flow battery energy storage

(1) Assumptions of energy storage parameters of all-vanadium liquid flow battery system

The electrolyte of the liquid flow battery and the reactor can be arranged separately to achieve the mutual conversion of electrical energy and chemical energy through the reversible chemical reaction when the positive and negative electrolytes flow through the reactor; the power generation and energy storage capacity can be amplified by adjusting the capacity of the reactor or the electrolyte. Liquid flow battery systems include sodium polysulfide/bromine system, all-vanadium system, zinc/bromine system, and iron/chromium system. Liquid flow battery conversion efficiency is low, 60%-65%; long cycle life, all-vanadium liquid flow battery charge/discharge cycle life can reach more than 10,000 times; construction cost: 3500-4000 yuan/kwh; short construction cycle.

1) Initial investment cost: capacity cost 2 Yuan/Wh, power cost 5-6 Yuan/W; assume 100MW/400MWh project investment cost is 13 Yuan/W.

2) Annual operation and maintenance cost: 0.5% of investment cost per year, which is 0.065 Yuan/W.

3) System life: 12,000 cycles, 600 cycles per year, 20 years of system life

4) Cycle efficiency: 70%-85%, tentatively set at 75%.

5) Discount rate: considering the current financing cost of central energy enterprises at 4%-5%, 6% is chosen as the discount rate

The assumptions of measured parameters for all-vanadium liquid flow battery energy storage system are shown in the following table 9.

Table 9. Assumptions of measured parameters for all-vanadium liquid flow battery energy storage system.

Parameter	Numerical value	Unit
Initial Investment Cost	13	yuan/W
Energy Unit Cost	5	yuan/Wh
Power Unit Cost	2	yuan/W
Operation and Maintenance Costs	0.065	yuan/Wh
System Residual Value Ratio	5	%
System Power	100	MW
System Capacity	400	MWh
Discharge Depth	100	%
Cycling efficiency	75	%
Number of cycles per year	600	time
System life	20	year
Discount rate	6	%
Tax rate	25	%

(2) Calculation of LOCS for all-vanadium liquid flow battery energy storage system

The All-Vanadium Liquid Flow Battery Power Costing are shown in the following table 10.

Table 10. All-Vanadium Liquid Flow Battery Power Costing.

All-Vanadium Liquid Flow Battery	0	1	2	3	4	-	16	17	18	19	20
Initial investment (million yuan)	1300					-					
Annual O&M cost (million yuan)		26	26	26	26	-	26	26	26	26	26
Annual depreciation (million yuan)		61.75	61.75	61.75	61.75	-	61.75	61.75	61.75	61.75	61.75
Tax relief due to depreciation (million yuan)		15.438	15.438	15.438	15.438	-	15.438	15.438	15.438	15.438	15.438
Annual Electricity (MWh)		180000	180000	180000	180000	-	180000	180000	180000	180000	180000
Discount factor		0.943	0.890	0.840	0.792	-	0.394	0.371	0.350	0.331	0.312
Present value of O&M costs (million yuan)	135.792	24.528	23.140	21.830	20.594	-	10.235	9.655	9.109	8.593	8.107
Present value of tax relief (million yuan)	80.627	14.564	13.739	12.962	12.228	-	6.077	5.733	5.408	5.102	4.813
Present value of electricity discharged (MWh)	940100.012	169811.321	160199.359	151131.471	142576.859	-	70856.331	66845.595	63061.882	59492.342	56124.851
Unit cost of electricity (yuan/kWh)	0.688										

The calculated kWh cost of all-vanadium liquid flow batteries is 0.688 Yuan/kWh, which is currently the highest cost approach for energy storage systems.

(3) Sensitivity analysis of LOCS for all-vanadium liquid flow battery energy storage system

The parameter Assumptions for Sensitivity Analysis of All-Vanadium Liquid Flow Batteries are shown in the following table 11.

Table 11. Parameter Assumptions for Sensitivity Analysis of All-Vanadium Liquid Flow Batteries.

Initial investment cost (yuan/Wh)					
		14	13	12	11
Number of annual cycles (time)	300	1.112	1.033	0.953	0.874
	500	0.890	0.830	0.76	0.70
	600	0.741	0.690	0.64	0.580
	700	0.635	0.590	0.545	0.499
	800	0.556	0.516	0.477	0.437

3.3 Lead carbon battery energy storage

(1) Lead-carbon battery energy storage system measurement parameters assumptions

1) Initial investment cost: The construction cost is 1300-1800 Yuan/kWh, assuming that the initial investment cost of 100MW/200MWh project is 1 Yuan/Wh.

2) Annual operation and maintenance cost: 4% of the investment cost per year, which is 0.04 Yuan/Wh.

3) System life: the cycle life of lead carbon battery is 3000-4200 times, the average annual cycle times is 600 times, and the life of energy storage system is 6 years.

4) Cycle efficiency: 70%-85%, tentatively set at 75%.

5) Discount rate: considering the current financing cost of central energy enterprises at 4%-5%, 6% is chosen as the discount rate

6) Depth of discharge: set at 70%.

The assumptions of measured parameters of lead-carbon battery energy storage system are shown in the following table 12.

Table 12. Assumptions of measured parameters of lead-carbon battery energy storage system.

Parameter	Numerical value	Unit
Initial Investment Costs	1	yuan/Wh
Operation and Maintenance Costs	0.04	yuan/Wh
System Residual Value Rate	5	%
System Power	100	MW
System Capacity	200	MWh
Discharge Depth	70	%
Cycling efficiency	75	%
Number of cycles per year	600	time
System life	5	year
Discount rate	6	%
Tax rate	25	%

(2) Lead-carbon battery energy storage system LOCS calculation

The Lead-carbon battery kilowatt-hour cost measurement are shown in the following table 13.

Table 13. Lead-carbon battery kilowatt-hour cost measurement.

Lead Carbon Battery	0	1	2	3	4	5	6
Initial investment (million yuan)	200						
Annual O&M cost (million yuan)		8	8	8	8	8	8
Annual depreciation (million yuan)		31.667	31.667	31.667	31.667	31.667	31.667
Tax relief due to depreciation (million yuan)		7.917	7.917	7.917	7.917	7.917	7.917
Annual Electricity (MWh)		63000	63000	63000	63000	63000	63000
Discount factor		0.943	0.890	0.840	0.792	0.747	0.705
Present value of O&M costs (million yuan)	39.339	7.547	7.120	6.717	6.337	5.978	5.640

Present value of tax relief (million yuan)	38.929	7.469	7.046	6.647	6.271	5.916	5.581
Present value of electricity discharged (MWh)	30979 1.433	59433. 962	56069. 776	52896. 015	49901. 901	47077. 265	44412. 514
Unit cost of electricity (yuan/kWh)	0.647						

The cost per kWh of lead-carbon batteries is calculated to be 0.647 Yuan/kWh.

(3) Lead-carbon battery energy storage system LOCS sensitivity analysis

The parameter assumptions for sensitivity analysis of lead-carbon batteries are shown in the following table 14.

Table 14. Parameter assumptions for sensitivity analysis of lead-carbon batteries.

Initial investment cost (yuan/Wh)					
		1.1	1	0.9	0.8
Number of annual cycles (time)	300	1.398	1.294	1.19	1.086
	400	1.048	0.97	0.892	0.814
	500	0.839	0.776	0.714	0.652
	600	0.699	0.647	0.595	0.543
	700	0.599	0.555	0.51	0.465

Assuming an initial investment cost of 0.8-1.1Yuan/Wh, a lifetime of 6 years, and an annual cycle count of 300-700 times in the range, a sensitivity analysis is done for lead-carbon batteries. It can be calculated that the kWh cost will be between 0.465-1.398 Yuan/KWh.

3.4 Lithium iron phosphate battery energy storage

(1) lithium iron phosphate energy storage system measurement parameters assumptions

Lithium-ion battery materials suitable for energy storage are mainly lithium iron phosphate, ternary (lithium nickel cobalt manganate), lithium titanate, etc. Technology has the ability to be applied on a large scale, suitable for peaking, frequency regulation, new energy consumption, emergency accident backup, black start.

1) Initial investment cost: including energy cost, PCS, BMS, EMS system cost, construction cost and other costs. Construction costs are generally 1500-2000 yuan/KWh, lithium-ion battery energy storage system initial investment costs due to project differences have some differences, comprehensive recent lithium-ion battery energy storage project winning bid price of 1.5 yuan/Wh.

2) Annual operation and maintenance costs: operation and maintenance costs include fuel and power costs during the operation of the power station, as well as parts replacement, system maintenance, labor costs necessary to maintain the operation of the power station. The O&M cost accounts for 5% of the initial investment cost.

3) System residual value rate: the residual value of the energy storage system at the end of life minus the net value of the disposal costs, depending on the type of battery accounts for 3%-40% of the initial investment cost. Among them, lithium iron phosphate batteries compared to other types of battery recovery value is lower, assuming that the system residual value rate of 5%.

4) System life: lithium-ion battery cycle life of 5000 times, the average annual cycle times 500 times, the system life of 10 years.

5) Discount rate: Considering the current financing cost of central energy enterprises at 4%-5%, 6% is selected as the discount rate.

6) Other assumptions: Assume 90% depth of discharge, 88% energy storage cycle efficiency, and 75% end-of-life capacity

The LiFePO4 energy storage system measurement parameters assumptions are shown in the following table 15.

Table 15 LiFePO4 energy storage system measurement parameters assumptions.

Parameter	Numerical value	Unit
Initial Investment Costs	1.5	yuan/Wh
Operation and Maintenance Costs	5	%
System Residual Value Rate	5	%
System Capacity	100	MWh
Discharge Depth	90	%
Cycling efficiency	88	%
Number of cycles per year	500	time
System life	10	year
Annual loss rate	2.5	%
Discount rate	6	%
Tax rate	25	%

(2) Calculation of LOCS for LiFePO4 energy storage system

The Lithium iron phosphate battery kilowatt-hour cost measurement are shown in the following table 16.

Table 16. Lithium iron phosphate battery kilowatt-hour cost measurement.

Lithium iron phosphate batteries	0	1	2	3	4	5	6	7	8	9	10
Initial investment (million yuan)	150										
Annual O&M cost (million yuan)		7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Annual depreciation (million yuan)		14.25	14.25	14.25	14.25	14.25	14.25	14.25	14.25	14.25	14.25
Tax relief due to depreciation (million yuan)		3.563	3.563	3.563	3.563	3.563	3.563	3.563	3.563	3.563	3.563
Annual Electricity (MWh)		39600	38610	37644.75	36703.631	35786.040	34891.389	34019.105	33168.627	32339.411	31530.926
Discount factor		0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558
Present value of O&M costs (million yuan)	55.201	7.075	6.675	6.297	5.941	5.604	5.287	4.988	4.706	4.439	4.188
Present value of tax relief (million yuan)	26.220	3.361	3.171	2.991	2.822	2.662	2.511	2.369	2.235	2.109	1.989
Present value of electricity discharged (MWh)	263923.096	37358.491	34362.763	31607.258	29072.714	26741.411	24597.053	22624.648	20810.407	19141.648	17606.704
Unit cost of electricity (yuan/kWh)	0.678										

The kilowatt-hour cost of LiFePO4 is calculated to be 0.678 Yuan/kWh.

(3) Lithium iron phosphate energy storage system LOCS sensitivity analysis

The parameter assumptions for sensitivity analysis of lithium iron phosphate batteries are shown in the following table 17.

Table 17. Parameter assumptions for sensitivity analysis of lithium iron phosphate batteries.

Initial investment cost (yuan/Wh)					
		1.6	1.5	1.4	1.3
Number of annual cycles (time)	300	1.206	1.130	1.054	0.978
	400	0.905	0.848	0.791	0.733
	500	0.724	0.678	0.632	0.587
	600	0.603	0.565	0.527	0.489
	700	0.517	0.484	0.452	0.419

Assuming an initial investment cost of 1.3-1.6 Yuan/Wh, a life of 10 years, and an annual cycle count of 300-700 times in the range, a sensitivity analysis is done on lithium iron phosphate batteries. It can be calculated that the cost of kilowatt-hour will be between 0.419-1.206 yuan/KWh.

Reduce the initial investment cost, improve the battery cycle life, enhance the battery conversion efficiency is the main way to reduce the cost of energy storage kilowatt-hour, the current lithium-ion battery energy efficiency conversion rate is the highest of all energy storage technology. According to Ningde Times 2025 development target, the cycle life of energy storage system will reach 10,000 times, and the energy efficiency will reach 98%, and the cost of electricity for LiFePO4 will be close to that of pumped storage power plant.

3.5 Compressed air energy storage

(1) Compressed air energy storage system measurement parameters assumptions

1) Initial investment cost: The initial investment cost of compressed air energy storage is 6-7.5 Yuan/W, and the cost of 100MW level is expected to reach below 6000 Yuan/kW, assuming that the unit investment cost of 100MW/400MWh project is 6 Yuan/W.

2) Annual operation and maintenance cost: Compressed air energy storage repair and maintenance cost is relatively high, requiring about 2% per year, assuming that the operation and maintenance cost is 0.1 Yuan/W.

3) System life: the main facilities can be used for 30-50 years, set the annual cycle times 500 times, the system life of 40 years

4) Cycle efficiency: high-capacity compressed air energy storage power plant efficiency has reached 70%, advanced energy storage projects can reach 75%. Set the cycle efficiency of 73%.

5) Discount rate: Considering the current financing cost of central energy enterprises at 4%-5%, 6% is chosen as the discount rate.

The Assumptions of measured parameters of compressed air energy storage storage system are shown in the following table 18.

Table 18. Assumptions of measured parameters of compressed air energy storage storage system.

Parameter	Numerical value	Unit
Initial Investment Costs	6	yuan/W
Operation and Maintenance Costs	0.1	yuan/W
System Residual Value Rate	5	%
System Power	100	MW
System Capacity	400	MWh

Cycle Efficiency	73	%
Number of cycles per year	500	time
System life	40	year
Discount rate	6	%
Tax rate	25	%

(2) Compressed air energy storage system LOCS calculation

The compressed air energy storage kilowatt-hour costing are shown in the following table 19.

Table 19. Compressed air energy storage kilowatt-hour costing.

Compressed air energy storage	0	1	2	3	4	-	36	37	38	39	40
Initial investment (million yuan)	600					-					
Annual O&M cost (million yuan)		10	10	10	10	-	10	10	10	10	10
Annual depreciation (million yuan)		14.25	14.25	14.25	14.25	-	14.25	14.25	14.25	14.25	14.25
Tax relief due to depreciation (million yuan)		3.563	3.563	3.563	3.563	-	3.563	3.563	3.563	3.563	3.563
Annual Electricity (MWh)		146000	146000	146000	146000	-	146000	146000	146000	146000	146000
Discount factor		0.943	0.890	0.840	0.792	-	0.123	0.116	0.109	0.103	0.097
Present value of O&M costs (million yuan)	40.132	9.434	8.900	8.396	7.921	-	1.227	1.158	1.092	1.031	0.972
Present value of tax relief (million yuan)	14.297	3.361	3.171	2.991	2.822	-	0.437	0.413	0.389	0.367	0.346
Present value of electricity discharged (MWh)	585920.794	137735.849	129939.480	122584.415	115645.675	-	17920.153	16905.804	15948.872	15046.106	14194.439
Unit cost of electricity (yuan/kWh)	0.520										

The unit cost of compressed air energy storage is calculated to be 0.520 Yuan/kWh.

(3) Compressed air energy storage system LOCS sensitivity analysis

The parameter assumptions for compressed air energy storage sensitivity analysis are shown in the following table 20.

Table 20. Parameter assumptions for compressed air energy storage sensitivity analysis.

		Initial investment cost (yuan/Wh)			
		6.5	6	5.5	5
Number of annual cycles (time)	300	0.563	0.529	0.494	0.460
	400	0.422	0.397	0.371	0.345
	500	0.338	0.317	0.296	0.276
	600	0.282	0.264	0.247	0.230
	700	0.241	0.227	0.212	0.197

Assuming an initial investment cost of 5-6.5 Yuan/Wh, a life of 40 years, and an annual cycle count of 300-700 times in the range, a sensitivity analysis is done on lithium iron phosphate batteries. It can be calculated that the cost of kWh will be between 0.197-0.563 yuan/kWh. The change of initial investment and utilization hours has a great impact on the cost of electricity, and with the progress of technology, the initial investment still has room for decline; utilization hours mainly depends on the utilization rate of the power plant in actual operation, the higher the number of charge and discharge per day, the lower the cost.

If the future compressed air unit investment is reduced to the same level as the pumped storage power plant investment, the electrical energy conversion efficiency increased to 65%; battery type energy storage unit investment reduced by 50%, lithium-ion battery cycle life of 5000 times, pumped storage power plant and compressed air cost of electricity is basically equivalent, mainly because the compressed air construction period is shorter resulting in lower annual costs, battery type energy storage cost of electricity is the highest.

4 Conclusion

Overall, due to the short overall construction cycle, the levelized cost of compressed air energy storage is the lowest, and may be comparable to the cost of pumped storage power plants in the future. In comparison, the levelized electricity cost of battery type energy storage is higher, and the investment cost, construction cost, battery cycle time, and electrical energy conversion efficiency are all aspects of great cost investment, and different battery energy storage has different technical points to overcome. Therefore, when analyzing whether a technology is practically feasible, we should not only look at the cost of electricity, but also look at the comprehensive assessment of different technology types in terms of cycle times, use cycles, load power and technical difficulty under sensitivity analysis to select the optimal energy storage strategy.

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