A Power Generation Side Energy Storage Power Station Evaluation Strategy Model Based on the Combination of AHP and EWM to Assign Weight

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Abstract—With the strong support of national policies towards renewable energy, the rapid proliferation of energy storage stations has been observed. In order to provide guidance for the operational management and state monitoring of these energy storage stations, this paper proposes an evaluation framework for such facilities. Departing from the dimensions of adjustment capacity and operational proficiency, an applicability assessment model for electric energy storage technology is constructed. The model structure is hierarchically organized into goal layer, criterion layer, indicator layer, and alternative layer. Grounded on foundational data from the indicator layer, a combination of Analytic Hierarchy Process (AHP) and Entropy Weight Method (EWM) is employed to compute indicator weights and relationship matrices. Independent evaluations and comprehensive assessments for distinct criteria are undertaken, culminating in the determination of applicability assessment outcomes for different strategies. These outcomes hold substantial implications for the planning, policy formulation, and commercial utilization of electric energy storage, rendering this research a pivotal reference.

Keywords: AHP; Entropy weight method; Evaluation System; Energy storage power station

1. INTRODUCTION

Guided by the new strategy of energy security, China's new energy sector has achieved remarkable development, emerging as a pivotal source of additional power generation. With an increasing number of local policies mandating energy storage for new energy sources, the demand for energy storage facilities has been expanding year by year. The operational status of these energy storage stations holds significant importance in facilitating the rational and orderly scheduling of charging and discharging activities by maintenance departments. Thus, this paper proposes an evaluation framework addressing this issue.

Presently, there have been notable achievements in developing an evaluation framework for energy storage stations within the domestic context. Reference [1] explores the establishment of a comprehensive assessment system for energy storage station benefits, bridging gaps in foreign energy storage benefit systems and domestic research. Reference [2] constructs an

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operational status evaluation system based on five dimensions: power supply reliability, charging efficiency, power quality, operational status, and auxiliary services for distribution grids. However, its judgment matrix relies entirely on subjective experience, potentially deviating evaluation results from actual performance. Despite different perspectives offered by references [3-5] in proposing evaluation indicators for power energy storage, their evaluation models only consider weight coefficients, thereby retaining strong subjectivity in their assessment outcomes. Reference [6] employs multiple evaluation methods, with one method serving as the primary analysis tool and others as supplements.

In this paper, a comprehensive evaluation approach is established, predominantly employing the Analytic Hierarchy Process (AHP) with subjective weight assignment as the core, supported by the Entropy Weight Method (EWM) for objective weight determination. This fusion of subjective and objective evaluation methods balances the disparities between subjective and objective attribute values, accommodating both engineering applicability and objectivity in assessment outcomes.

2. Materials and Methods

2.1. Evaluating indicator

In order to optimize the assessment strategy for energy storage stations, a diagnostic methodology for grid-side energy storage projects has been formulated. This methodology encompasses 38 technical diagnostic indicators. These indicators are mainly divided into two aspects: regulating ability and business level. Regulating ability mainly evaluates the peak shaving and valley filling, power frequency regulation, and power dispatch capabilities of energy storage stations, while business level evaluates the profitability level of energy storage stations, reflecting their investment value. These indicators include those stipulated in the standards outlined in reference [7].

2.2. Weight Allocation Methods

1) Analytic Hierarchy Process (AHP): AHP represents a complex problem as an ordered hierarchical structure, and provides the order (or weight) of alternative solutions through supervisor judgment and scientific calculation. Following the principles of AHP, the hierarchical evaluation framework for the aforementioned set of indicators is constructed, consisting of the goal layer, criterion layer, and alternative layer, as illustrated in Fig 1. Subsequently, pairwise comparison matrices are formulated to reflect the relative importance between indicators. Based on the level of significance, corresponding weights are assigned to each target.

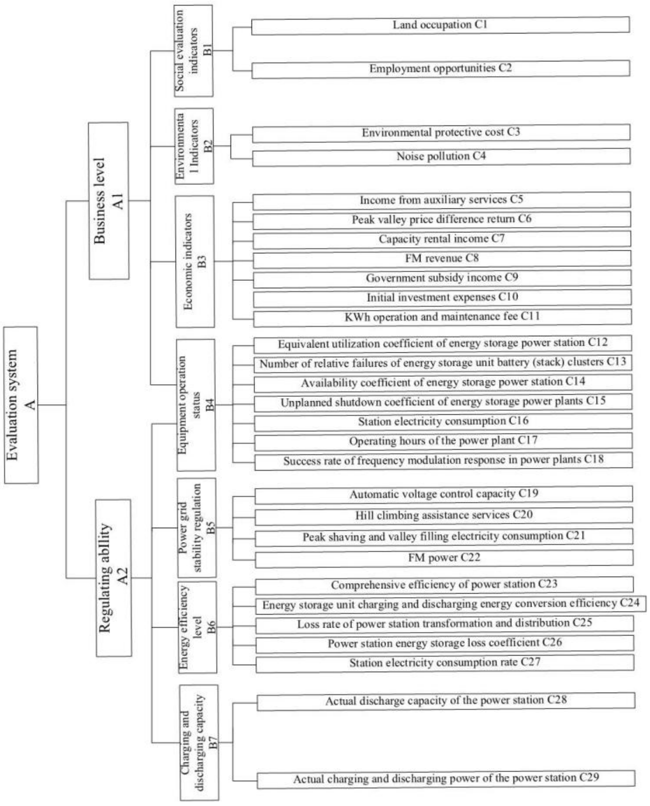

Fig 1: Energy Storage Power Station Evaluation System

Next, construct a judgment matrix and calculate the weight coefficients. Below are some of the main judgment matrices.

	A1	A2
A1	1	3
A2	1/3	1

	B1	B2	B3	B4
B1	1	3	4	2
B2	1/3	1	2	3
B3	1/4	1/2	1	1
B4	1/2	1/3	1	1

	B4	B5	B6	B7
B4	1	2	1/2	1
B5	1/2	1	1/2	1
B6	2	2	1	2
B7	1	1	1/2	1

	C7	C8	C9	C10	C11
C7	1	2	1	2	2
C8	1/2	1	2	3	3
C9	1	1/2	1	4	3
C10	1/2	1/3	1/4	1	1/2
C11	1/2	1/3	1/3	2	1

	C12	C13	C14	C15	C16	C17	C18
C12	1	3	2	1	1	3	2
C13	1/3	1	2	3	1/2	1	1
C14	1/2	1/2	1	1/2	1	1	2
C15	1	1/3	2	1	1/2	1/2	1
C16	1	2	1	2	1	2	1
C17	1/3	1	1	2	1/2	1	1
C18	1/2	1	1/2	1	1	1	1

	C19	C20	C21	C22
C19	1	1	2	1/2
C20	1	1	2	1/2
C21	1/2	1/2	1	1/3
C22	2	2	3	1

	C23	C24	C25	C26	C27
C23	1	1/3	1	1	1
C24	3	1	3	3	3
C25	1	1/3	1	1	2
C26	1	1/3	1	1	1
C27	1	1/3	1/2	1	1

2) Entropy Weight Method (EWM) : The EWM is an objective weighting method, whose basic idea is to determine objective weights based on the variability of indicators. Principle based on: The smaller the degree of variation of the indicator, the less information it reflects, and its corresponding weight should also be lower. The EWM method effectively showcases the distinguishing capability of indicators, enabling the determination of more objective and theoretically-grounded weights. Its reliability is higher, offering a profound basis for weight assignment.

The EWM method effectively showcases the distinguishing capability of indicators, enabling the determination of more objective and theoretically-grounded weights. Its reliability is higher, offering a profound basis for weight assignment.

Table 1: Weight allocation

Subsystem	Evaluation factors	Evaluating indicator	Weight
A1	B1	C1	2.99%
		C2	2.99%
	B2	C3	0.60%
		C4	0.53%
		C5	0.60%
		C6	0.70%
		C7	1.80%
	B3	C8	2.24%
		C9	4.17%
		C10	1.21%
		C11	2.24%
	B4	C12	9.09%
		C13	4.76%
		C14	4.68%
		C15	7.14%
A2		C16	4.53%
		C17	4.40%
		C18	5.69%
	B5	C19	4.90%
		C20	4.90%
		C21	2.68%
		C22	2.56%
		C23	0.82%
		C24	1.20%
		C25	2.54%
	B6	C26	4.61%
		C27	4.61%
	B7	C28	7.21%
		C29	3.61%

AHP has a greater advantage over EWM in determining weights based on decision-maker intentions, but its objectivity is relatively poor and subjectivity is relatively strong; The use of EWM has objective advantages, but it cannot reflect the degree to which decision-makers attach importance to different indicators, and it will have a certain weight and the opposite degree to the actual indicators.

In response to the advantages and disadvantages of subjective and objective weighting methods, we also strive to control the subjective randomness within a certain range, achieving a positive balance in subjective and objective weighting. Objectively. The weighting of indicators is fair, achieving the internal unity of subjectivity and objectivity, and the evaluation results are true, scientific, and trustworthy. Therefore, when assigning weights to indicators, consideration should be given to the inherent statistical patterns and authoritative values between indicator data. A reasonable decision-making indicator weighting method was proposed, which combines AHP and EWM to compensate for the shortcomings of single weighting. After obtaining results separately using AHP and EWM, a combination of the two methods is employed. The ultimate outcome of weight allocation is presented in Table 1.

2.3. Scoring Criteria

A comprehensive assessment approach is employed to establish the scoring criteria for the evaluation system. The procedure involves the following steps:

Identification of Evaluation Items: Determine which indicators will be evaluated using this method Formulation of Evaluation Levels and Criteria: Firstly, establish uniform evaluation levels or score ranges for each evaluation indicator. Subsequently, develop criteria for each level of each evaluation indicator to guide the scoring process. These criteria generally integrate both qualitative and quantitative aspects, with a primary or secondary focus on either, depending on the specific context.

Creation of Scoring Sheet: This sheet encompasses all evaluation indicators, their level differentiations, and corresponding scores.

Table 2: Calculation rules for indicator scores

Evaluating indicator	Full score	Scoring Criteria	Score
C1	100	C1<100%	100
		C1<90%	90
		C1<80%	80
C2	100	C2<100%	100
		C2<90%	90
		C2<80%	80
C3	100	C3>5%	100
		C3>10%	90
		C3>15%	80
C4	100	C4<10%	100
		C4<20%	95
		C4<30%	90
C5	100	C5<5%	100
		C5<10%	90
		C5<15%	80
C6	100	C6<90%	100
		C6<80%	90
		C6<70%	80
C7	100	C7<90%	100
		C7<80%	90
		C7<70%	80
C8	100	C8<100%	100
		C8<90%	90
		C8<80%	80
C9	100	C9<90%	100
		C9<80%	90
		C9<70%	80
C10	100	C10>30%	100
		C10>25%	90
		C10>20%	80
C11	100	C11>30%	100
		C11>25%	90

		C11>20%	80
C12	100	C12<100%	100
		C12<90%	90
		C12<80%	80
C13	100	C13>8760h	100
		C13>7880h	90
		C13>7000h	80
C14	100	C14<5%	100
		C14<10%	90
		C14<15%	80
C15	100	C15<5%	100
		C15<10%	90
		C15<15%	80
C16	100	C16<100%	100
		C16<90%	90
		C16<80%	80
C17	100	C17<5%	100
		C17<10%	90
		C17<15%	80
C18	100	C18<95%	100
		C18<90%	90
		C18<85%	80
C19	100	C19<0.2 yuan/kWh	100
		C19<0.3 yuan/kWh	90
		C19<0.4 yuan/kWh	80
C20	100	C20=0%	100
		C20<5%	90
		C20<10%	80
C21	100	The scoring rules for each revenue indicator are formulated based on specific circumstances.	
C22	100		
C23	100		
C24	100		
C25	100		
C26	100	C26<40	100
		C26<50	90
		C26<60	80
C27	100	C27<5%	100
		C27<10%	90
		C27<15%	80
C28	100	This scoring rule is related to the scale of energy storage power plants.	
C29	100		

Scoring Based on Indicators and Levels: Evaluators gather relevant information regarding the indicators and assign scores to the entities being evaluated. This process involves determining the level achieved for a specific indicator, followed by refining the assessment within that level's score range. This often necessitates horizontal comparison among various entities being evaluated. An illustrative scoring table is provided in Table 2.

3. RESULTS & DISCUSSION

Taking the example of three energy storage power stations, A, B, and C, in a certain region, a comprehensive performance assessment of energy storage power stations for grid peak shaving and frequency regulation is conducted. The assessment involves evaluating and ranking their peak shaving and frequency regulation capabilities [8].

Due to variations in the constructed evaluation systems, a selection of evaluation indicators consistent with our assessment framework is chosen for evaluation. The scores of each evaluation are shown in Table 3.

Table 3: Score Table for the storage power stations.

Evaluating indicator	Score for Station A	Score for Station B	Score for Station C
C1	94	94	94
C3	81	90	74
C6	32	90	20
C8	70	80	90
C9	93	95	94
C10	96	94	93
C12	66	74	65
C13	97	98	97
C14	82	80	91
C16	100	100	100
C24	93	94	90
C25	95	96	96
C26	98	99	97
C27	100	100	100
C28	85	88	86
C29	90	90	90

The formula for calculating scores is as follows:

$$S_N = \sum_i w_i \cdot S_{ci}$$

In the formula: S_N is the final score for the energy storage power station; w_i is the weight of the evaluation index Ci in the evaluation system; S_{ci} is the score obtained by the evaluation indicator Ci in the evaluation system.

The final scores are as follows: Station A has a score of 83.57; Station B has a score of 89.92, and Station C has a score of 83.07. Among them, B power station is significantly superior to A and C power stations in terms of peak shaving range. Although it has certain disadvantages in reliability, it has advantages in comprehensive evaluation. This also reflects the emphasis of the evaluation system on scheduling capability. Based on the evaluation results of the energy storage power stations, it is evident that Station B has the highest score, indicating the best peak shaving and frequency regulation performance. Station A follows in performance, while Station C exhibits the lowest performance.

4. CONCLUSIONS

This study establishes a comprehensive evaluation model based on a mixed subjective and objective weighted optimization method. The following conclusions were drawn:

(1) We conducted research on the operation evaluation of electrochemical energy storage power plants, starting from the frequency regulation capacity and economic benefits, combined with the actual operation of the power grid and the technical parameters of electrochemical energy storage power plants, and proposed specific operational indicators. This model effectively balances the differences between subjective and objective attribute values using AHP and EWM weighting, ensuring the comprehensive engineering applicability and objectivity of the evaluation results.

(2) Based on the actual situation of the power grid and electrochemical energy storage power stations, the scoring requirements for electrochemical energy storage power stations in various specialties of power grid scheduling have been proposed, providing a basis for the power grid regulatory agencies to carry out process control and acceptance of electrochemical energy storage power stations, and establishing a standardized whole process evaluation system.

(3) The feasibility of the diagnostic model was confirmed through the integration of illustrative case studies. This achievement can form an indicator system for the construction and operation of electrochemical energy storage power stations that can be promoted to the application of new energy stations nationwide, further improving the safety of the construction and operation of electrochemical energy storage power stations, helping to objectively and reasonably evaluate energy storage stations, and having important reference significance for optimizing power grid scheduling operation and diagnosing the performance of energy storage facilities.

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