Equipment Quality Importance Evaluation for Wind/Photovoltaic Energy Storage and Transmission Demonstration Project via Index System and Cluster Analysis

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Abstract. 22 kinds of equipment for wind/photovoltaic energy storage and transmission demonstration project were selected to establish the equipment quality importance index system via their operation and quality supervision data. Then, the evaluation results were combined with the cluster analysis to further classify them from the view of equipment quality importance. The results show that: 22 kinds of equipment can be divided into 3 categories; for specific index in index layer, the equipment quality importance sequence was different with each other due to different function and performance of each equipment; for indexes in target layer and criterion layer, the equipment quality importance sequence was similar, representing the overall role of each equipment in wind/photovoltaic energy storage and transmission project.

1. Introduction

With the gradual depletion of fossil fuels in recent years, the restricting effect of energy resources on the economic growth of society became more and more intensive [1]. The development of efficient, clean and renewable energy has turned into an importance measure to reduce energy consumption and govern the air pollution. Under the background and structure of energy consumption, the exploitation and utilization of renewable energy sources get rapid development in China [2]. The wind/photovoltaic energy storage and transmission project was the first "Golden sun demonstration project", which was jointly launched by the Ministry of finance, the Ministry of science and technology, the National Energy Bureau and the National Power Grid Corp, possessing the largest wind power and photovoltaic power generation, energy storage and smart transmission capability in the world [3].

The rapid development of electric power industry carry out the challenge for the equipment quality: the "double reverse" occurs commonly at the international level; more and more intensive domestic price war; some suppliers gain profits via reducing the quality of products, resulting in increasing product faults in the operation process. In order to promote the products quality, reduce fault rate, ensure the safety of equipment operation, the management of the equipment quality for wind/photovoltaic energy storage and transmission project is the key. Because of abundant equipment type and amount, only with the aid of manual quality information record is not enough to carry on the management work for wind/photovoltaic energy storage and transmission demonstration project. Thus in this paper, 22 kinds of equipment used in the wind/photovoltaic energy storage and transmission project were selected to establish the equipment quality importance index system via their operation data and quality supervision data to achieve classification regulation.

2. Index System Establishment

22 essential equipment for wind/photovoltaic energy storage and transmission project were selected in this paper to evaluate equipment quality importance: wind generator, wind turbine tower, transformer, reactor, switchgear, circuit breaker, isolating switch, box type substation, wind turbine blades, photovoltaic inverter, cable, current transformer, voltage transformer, capacitor, switch

cabinet, polycrystalline silicon PV modules, cables, fittings, insulators, cable branch box, lightning arrester, cable accessories. By using the analytic hierarchy process [4], the evaluation index system of quality problem for wind/photovoltaic energy storage and transmission equipment was established, which contains three layers: target layer (reflecting the overall importance of equipment quality problems)-criterion layer (equipment importance index, equipment quality problem index, equipment management index)-index layer (specific evaluation index of each equipment). The specific index system was shown in Table 1.

The range analysis method was employed to standardize each index value for eliminating the magnitude difference between different indexes [5] (the index values of wind generator were taken as standard values in this paper). When the bigger index value reflects more important equipment quality problem:

$$y_{ij} = (x_{ij} - x_{jmin})/(x_{jmax} - x_{jmin}) \tag{1}$$

When the smaller index value was the better situation:

$$y_{ij} = (x_{jmax} - x_{ij})/(x_{jmax} - x_{jmin}) \tag{2}$$

Then, the mean square difference method was used to calculate each index weight in different layers [6]:

$$E_j = \frac{1}{22}\sum_{i=1}^{22} y_{ij} \tag{3}$$

$$\sigma_j = \sqrt{\frac{1}{22}\sum_{i=1}^{22}(y_{ij} - E_j)^2} \tag{4}$$

$$\omega_j = \frac{\sigma_j}{\sum_{j=1}^{n}\sigma_j} \tag{5}$$

$$\omega_{rj} = \frac{\omega_i}{\sum_{j=1}^{r}\omega_j} \tag{6}$$

$$\omega_r = \frac{\sum_{j=1}^{r}\omega_{rj}}{\sum_{j=1}^{r}\omega_{rj} + \sum_{j=1}^{s}\omega_{sj} + \sum_{j=1}^{t}\omega_{tj}} \tag{7}$$

$$D_j = \frac{S_j}{X_j} \text{ (for equation 1); } D_j = \frac{X_j}{S_j} \text{(for equation 2)} \tag{8}$$

$$B_r = \sum_{j=1}^{r} D_j\,\omega_{rj} \tag{9}$$

$$A = B_r\omega_r + B_s\omega_s + B_t\omega_t \tag{10}$$

Where x_{ij} and y_{ij} were the initial value and standard values of the jth (j=1, 2, …, n) index for the ith (i= 1, 2, ..., 22) equipment; x_{jmin} and x_{jmax} were the maximum and minimum value of the jth index; n was the sum of indexes (r, s, and t were the number of equipment importance index, production quality problem index of equipment, equipment management index); E_j was the mean value of the jth index; σ_j was the standard deviation for the jth index; ω_j was the weight coefficient of the jth index; ω_{rj} was the weight of the jth index in equipment importance index, the equations for equipment quality problem index and equipment management index were similar with equation (6); ω_r was the weight of the equipment importance index, similar with equipment quality problem index and equipment management index; D_j was the value of the jth index; S_i was the current value of the jth index; the X_i was the standard value for the jth index; B_r was the index value of equipment importance index, with the same equation for equipment quality problem index and equipment management index; A was the overall equipment quality importance.

Table 1 Established evaluation index system of equipment quality importance for wind/photovoltaic energy storage and transmission demonstration project

Target layer	Criterion layer	Index layer
overall equipment quality importance	equipment importance index	core status
		engineering efficiency influence
		engineering progress influence
		production
		components similarity
		quality grade
		unnormal operation influence
		security to power distribution network
	equipment quality problem index	machining process complexity
		quality inspection information
		insulation test
		characteristic test
		electrical test
	equipment management index	on-line monitoring
		real-time running status
		Fault defects and abnormal records
		supplier specialized manufacturing capabilities
		supplier technical scheme solving ability
		maintenance costs
		quality records complete rate
		supplies equipment preservation rate
		quality management system
		quality management system completeness

3. Results and Discussions

The specific calculated index values of target layer and criterion layer were listed in Table 2. Quality importance of 22 kinds of equipment exists significant difference, and the equipment quality importance sequence in each index of criterion layer matches the importance sequence of target layer, presenting the overall equipment quality importance in wind/photovoltaic energy storage and transmission equipment demonstration project reflects in the operation and management lifecycle obviously and any problem is likely to cause significant loss to wind/photovoltaic energy storage and transmission demonstration project. Meanwhile, the evaluation index values of different equipment in index layer exist importance cross phenomenon, that is mean not all indexes meet the overall importance sequence. Through all the conclusions obtained above we can see, the different function and performance of each equipment decides the difference importance sequence in the specific index of index layer, but the comprehensive importance sequence are similar in target layer and criterion layer with significant law. For further analysis, the calculated evaluation index values of different equipment in 3 layers were used to carry out cluster analysis (Fig. 1). From Fig. 1, 22 kinds of equipment can be divided into 3 categories: the first category is named core equipment, containing wind generator, wind turbine tower, transformer, reactor, switchgear, circuit breaker, isolating switch, box type substation, wind turbine blades and inverter; the second category is named replaceable equipment, containing cable, current transformer, voltage transformer, capacitor switch cabinet, polycrystalline silicon photovoltaic module; the third category is named large-scale production equipment, containing fittings, insulators, cable branch box, lightning arrester, cable accessories and cables. Combined with the grouping results and calculated evaluation values we can see: the overall importance index values of essential equipment are all larger than 0.85; 6 replaceable equipment distributed in 0.70~0.85; 6 large-scale production equipment are all smaller than 0.60.

Table 2 Calculated evaluation index values of equipment quality importance for wind/photovoltaic energy storage and transmission demonstration project

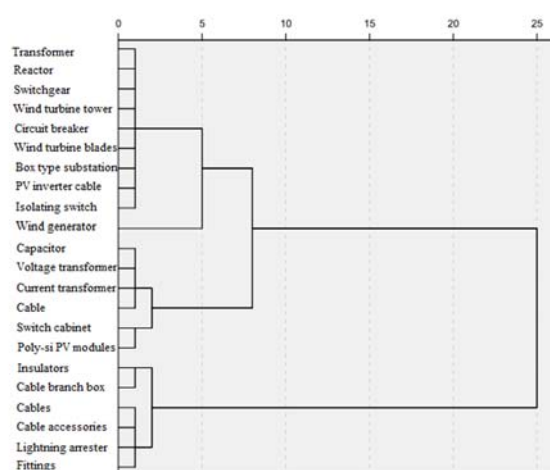| Equipment	Overall equipment quality importance	Equipment importance index	Equipment quality problem index	Equipment management index
wind generator	1.000	1.000	1.000	1.000
wind turbine tower	0.898	0.898	0.874	0.921
transformer	0.883	0.860	0.880	0.909
reactor	0.882	0.857	0.882	0.907
switchgear	0.883	0.841	0.888	0.920
circuit breaker	0.890	0.888	0.871	0.913
isolating switch	0.851	0.815	0.860	0.878
box type substation	0.855	0.808	0.850	0.907
wind turbine blades	0.897	0.875	0.885	0.931
photovoltaic inverter	0.856	0.828	0.847	0.894
cable	0.734	0.685	0.757	0.760
current transformer	0.766	0.660	0.822	0.814
capacitor	0.775	0.689	0.790	0.844
voltage transformer	0.775	0.667	0.803	0.856
switch cabinet	0.701	0.589	0.718	0.787
polycrystalline silicon PV modules	0.729	0.554	0.819	0.814
cables	0.550	0.374	0.637	0.640
fittings	0.527	0.318	0.639	0.622
insulators	0.611	0.414	0.741	0.679
cable branch box	0.602	0.420	0.700	0.687
lightning arrester	0.539	0.375	0.644	0.598
cable accessories	0.565	0.377	0.667	0.651

Fig. 1 Clustering of 22 kinds of equipment based on cluster analysis

4. Conclusion

(1) The evaluation index system of equipment quality importance was established via analytic hierarchy process from three views of equipment importance index, production quality problem index of equipment and equipment management index: different function and performance of each

equipment decide the difference importance sequence in specific index, but the comprehensive importance sequence are similar in target layer and criterion layer.

(2) 22 kinds of can be divided into 3 categories via cluster analysis: 10 core equipment; 6 replaceable equipment; 6 large-scale production equipment. Meanwhile, the demarcation intervals for 3 categories were 0.85~1, 0.7~0.85 and 0~0.6.

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