

Comprehensive assessment of Power Demand Side Management (PDSM) based on PCA-fuzzy synthetic evaluation

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Abstract. Integrated with the characteristics of comprehensive assessment, comprehensive evaluation index system of power demand side management (PDSM) is established. A quantitative evaluation model of PDSM implementation is proposed. In the model, index weight is calculated through principal components analysis (PCA) to grade each parameter based on fuzzy synthetic evaluation. Analysis results of PDSM in Beijing illustrate the feasibility and validity of the presented method.

1. Introduction

PDSM is a kind of power consumption management activity, which optimizes power consumption way, economizes energy and reduces cost. It focuses on load management, integrated resource planning and energy efficiency. The detailed content includes peak shaving, valley filling, load transfer, power saving and variable load [1-3]. The means of PDSM are divided into four parts: technical means, economic means, guide means and administrative means[4].

The previous evaluation index of PDSM implementation mainly aims at energy conservation and pollution reduction or market benefit, which is incomprehensive and unsystematical[5-6]. Traditional PDSM comprehensive assessment system is based on AHP (analytic hierarchy process), but the qualitative measure is influenced by human factors greatly[7-8]. A more objective method must be adopted.

This paper presents a model of PDSM comprehensive assessment combining subjective and objective index. Quantitative index can be obtained from data and research; qualitative index needs evaluating through fuzzy statistical method. All index weight is given by PCA and the distribution vector is ensured. Using multi-level fuzzy comprehensive evaluation, the assessment of PDSM is attained. PDSM evaluation of Beijing is carried out, and the results show that the model is practicable.

2. Comprehensive evaluation index system of PDSM

There are 23 evaluation index, X_1, X_2, \dots, X_{23} of PDSM, which forms the table.1[7-8].

Typical ones are selected for introduction and calculation is below.

A. Quantitative index

X_1 : Avoidable capacity is the saving generation capacity during peak load period.

$$F_N = \Delta N_\gamma \cdot I_j \quad \Delta N_\gamma = e_\gamma \Delta P_f$$

Above, F_N is the cost of avoidable peak load capacity, I_j is the unit investment of generating set, ΔN_γ is the avoidable peak load capacity, ΔP_f is the avoidable power, e_γ is the coefficient of avoidable capacity, which are 1.32-1.63 generally.

X_{17} : SO_2 emissions are the reduced SO_2 emissions of power plants.

$$A_{SO_2} = \lambda_{SO_2} \cdot B \quad \lambda_{SO_2} = \alpha_s \cdot \beta_{SO_2} \cdot \gamma_s$$

Above, A_{SO_2} are the reduced emissions of SO_2 , λ_{SO_2} is the coefficient of reduced emissions, α_s is the sulfur content rate of coal, β_{SO_2} is the conversion factor from S to SO_2 , γ_s is release rate of S .

For Chinese coal-fired power plants, $\alpha_s = 1.0\% - 1.2\%$, $\beta_{SO_2} = 2$, $\gamma_s = 0.85$.

B. Qualitative index

It's hard to obtain the relationship between client satisfaction X_{10} , Sustainable development X_{21} , Economic development X_{22} or Government image X_{23} and PDSM by formula. Adopting 5-point scale, experts mark implementation of PDSM.

Table.1 Comprehensive evaluation index system of PDSM

Generation side	Grid side	Big user	Society
	Input		Environmental benefits
	X_5 Reduced power sale		X_{16} CO_2 emissions
	X_6 Cost of advocacy	Input	X_{17} SO_2 emissions
X_1 Avoidable capacity		X_{12} Equipment	X_{18} NO_x emissions
X_2 Avoidable fuel	Benefits	X_{13} Cost of operation	X_{19} Solid waste emissions
X_3 Unit start and stop	X_7 Grid investment		X_{20} Wastewater emissions
X_4 Pollution compensation	X_8 Maintenance	Benefits	Development benefits
	X_9 Reliability	X_{14} Payback period	X_{21} Sustainable development
	X_{10} Client satisfaction	X_{15} Cost of brownout	X_{22} Economic development
	X_{11} Load rate		X_{23} Government image

3. Comprehensive evaluation model of PDSM

A. Determination of index weight

PCA is used to determinate the weight of PDSM index[9]. Calculating the linear combination of the p index, new comprehensive index can be attained. The first principal component F_1 is of the maximum variance, and then is F_2 . In this way, p principal components can be constructed. Cumulative contribution rate reaches 85%, which indicates principal components contain main information of previous index. PCA mathematical model is as follows:

$$F_1 = a_{11}x_1 + a_{21}x_2 + \cdots + a_{p1}x_p$$

$$F_2 = a_{12}x_1 + a_{22}x_2 + \cdots + a_{p2}x_p$$

$$\vdots$$

$$F_p = a_{1m}x_1 + a_{2m}x_2 + \cdots + a_{pm}x_p$$

Where $a_{1i}, a_{2i}, \cdots, a_{pi}$ ($i = 1, \cdots, m$) is the eigenvectors corresponding to eigenvalues, x_1, x_2, \cdots, x_p is the variables of standardized data-processing.

By weighted average method, the coefficient of index in each principal components can be changed into that of comprehensive score model. The index weight is the coefficient of comprehensive score model.

B. Multi-level fuzzy comprehensive evaluation

As for the index of large number, multi-level fuzzy comprehensive evaluation is adopted. The explanation to second-level fuzzy comprehensive evaluation is given as follows[7-8]:

The factor set \mathbf{U} of m dimension is divided into several subsets $\mathbf{U}_i = \{\mathbf{U}_{i1}, \mathbf{U}_{i2}, \cdots, \mathbf{U}_{in}\}$, ($i = 1, 2, \cdots, k$). The comments and corresponding membership of evaluation set $\mathbf{V} = \{v_1, v_2, \cdots, v_n\}$ is below:

$$P = \begin{cases} 0.85 \leq \mu \leq 1.0(\text{excellent}), 0.70 \leq \mu \leq 0.85(\text{good}), 0.60 \leq \mu \leq 0.70(\text{ordinary}) \\ 0.40 \leq \mu \leq 0.60(\text{poor}), 0 \leq \mu \leq 0.40(\text{bad}) \end{cases}$$

The comprehensive evaluation of \mathbf{U}_i : $\mathbf{B}_i = \mathbf{A}_i \circ \mathbf{R}_i = (b_{i1}, b_{i2}, \dots, b_{im})$

Where, $\mathbf{A}_i = \{a_{i1}, a_{i2}, \dots, a_{in}\}$ is the weight vector set calculated by PCA, \mathbf{R}_i is the single factor evaluation matrix of \mathbf{U}_i .

$$\text{The single factor evaluation matrix of } \mathbf{U} = \{u_1, u_2, \dots, u_k\}: \mathbf{R} = \begin{bmatrix} \mathbf{B}_1 \\ \mathbf{B}_2 \\ \vdots \\ \mathbf{B}_k \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1m} \\ b_{21} & b_{22} & \dots & b_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ b_{k1} & b_{k2} & \dots & b_{km} \end{bmatrix}$$

4. Example test of PDSM comprehensive evaluation system

According to the research index data of Beijing in 2000-2015, PDSM implementation is analysed and evaluated.

The extraction of principal components is shown in table.2.

Table.2 The extraction information of principal components

Component	Contribution rate(%)	Cumulative contribution rate(%)
1	24.914	24.914
2	17.913	42.827
11	21.554	64.381
21	22.682	87.063

The cumulative contribution rate of index X_1 , X_2 , X_{11} and X_{21} is 87.063%, which shows principal components contain Most information of PDSM index.

The calculated results of 4 principal components is below:

$$F_1 = 0.867x_1 + 0.638x_2 + 0.549x_3 - 0.297x_4 \dots + 0.543x_{20} + 0.414x_{21} + 0.318x_{22} + 0.413x_{23}$$

$$F_2 = 0.281x_1 + 0.314x_2 - 0.372x_3 + 0.546x_4 \dots + 0.462x_{20} + 0.371x_{21} - 0.122x_{22} + 0.154x_{23}$$

$$F_3 = 0.422x_1 + 0.217x_2 + 0.661x_3 + 0.542x_4 \dots - 0.232x_{20} + 0.274x_{21} + 0.105x_{22} - 0.021x_{23}$$

$$F_4 = 0.181x_1 + 0.632x_2 + 0.142x_3 + 0.892x_4 \dots + 0.724x_{20} + 0.831x_{21} + 0.278x_{22} + 0.108x_{23}$$

The

comprehensive score model is as follows:

$$Y = 0.463x_1 + 0.448x_2 + 0.253x_3 + 0.375x_4 \dots + 0.367x_{20} + 0.454x_{21} + 0.142x_{22} + 0.175x_{23}$$

The

coefficient of comprehensive score mode is index weight of PDSM. To present simply, the percentage of index weight is shown in table.3.

Table.3 PDSM index weight

X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
0.082	0.079	0.045	0.066	0.041	0.043	0.030	0.043	0.021	0.014	0.066	0.050
X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	
0.037	0.034	0.022	0.015	0.069	0.057	0.032	0.065	0.080	0.025	0.031	

The results of fuzzy comprehensive evaluation is in the following table.4.

Table.4 The results of PDSM comprehensive evaluation

Generation side						Grid side					
0.653						0.670					
						Input			Benifits		
						0.662			0.671		
X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	
0.687	0.731	0.537	0.609	0.928	0.377	0.873	0.587	0.438	0.452	0.954	
Big user						Society					
0.764						0.713					
Input		Benifits		Environmental benifits				Development benifits			
0.773		0.745		0.553				0.862			
X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}
0.638	0.891	0.813	0.656	0.649	0.517	0.539	0.542	0.461	0.837	0.846	0.874

Evaluating the first layer of PDSM evaluation index system, final membership degree in Beijing is 0.703, whose comment is good. In order to obtain clearer evaluation, the result illustrated with a quadrant chart is shown in chart.1[9].

The index weight represents the importance, and the membership represents the evaluation results. On the basis of the average weight and average membership, the chart can be divided into four quadrant.

The index in first quadrant is of high importance and high membership (High attention). Index X_1, X_2, X_{11} and X_{21} is in this quadrant, which deserves to be supported; The index in second quadrant is of high importance but low membership (Priority improvement). Index $X_3, X_4, X_{12}, X_{17}, X_{18}$ and X_{20} is in this quadrant. It is necessary to take the improvement measurements; The index in third quadrant is of low importance and low membership (Unimportant area). Index $X_6, X_8, X_9, X_{10}, X_{15}, X_{16}$ and X_{19} is in this area. These index only needs paying attention to the change of importance; The index in fourth quadrant is of low importance and high membership (Maintain advantage). Index $X_5, X_7, X_{13}, X_{14}, X_{22}$ and X_{23} is in this quadrant, the resources of these index should be transferred to other more important index, such as the index in second quadrant. Obviously, the strengths and weaknesses of PDSM in Beijing is found out to refocus the work.

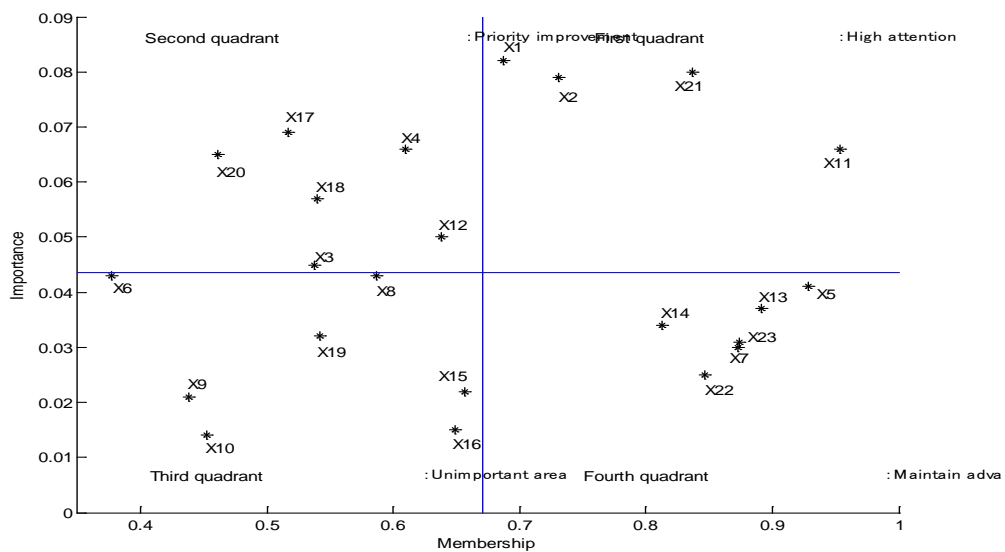


Chart.1 The evaluation of PDSM index

5. Summary

This paper establishes the comprehensive evaluation index system of PDSM. Combining PCA with multi-level fuzzy evaluation, comprehensive evaluation model of PDSM is built. All index weight and membership is obtained. The classification of index makes the assessment easier. The results of PDSM evaluation has important reference value for current implementation and future management work.

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