Research of Evaluation System for the Investment and Operational Efficiency of Distribution Network

Fangpeng Zheng[1], Yongjun Wang[1], Chunxue Li[2,*] and Ming Zeng[2]
[1]Guizhou Power Grid Corporation, Guiyang, Guizhou, China
[2]School of Economics and Management, North China Electric Power University, Beijing 102206, China
*Corresponding author

***Abstract*—The investment for distribution network construction is an important part of power grid construction. The establishment of analysis model for the investment and operational efficiency of distribution network construction is able to ensure the economic operation and reliability of power system, and has become a key method to the realization of the intensified grid construction. This paper has established the data envelopment analysis model and indicators about demand side response are added. The model is more scientific and accurate. Meanwhile, the practicality of this model has been proved through the example analysis.**

Keywords-distribution network; investment and operational efficiency; data envelopment analysis model

I. INTRODUCTION

Throughout the current research situation in this field, the DEA model is widely used in power grid construction[1,2]. However, there is no research that analyze the investment and operational efficiency of distribution network by the combination of the DEA model[3]. The safe and stable operation of power distribution network that promoted by the implement of the demand side response is not considered as well[4-6]. Based on the lack of research above, this paper will establish a model that combines the DEA model with the entropy method. And a evaluation index system of the investment and operational efficiency of distribution network that is compatible with the demand side response will also be established. After that, the investment and operational efficiency of distribution network will be evaluated using the given model and index system.

II. CONSTRUCTION OF EVALUATION INDEX SYSTEM

The investment of the distribution network is the construction that adapts to the future city grid upgrades and satisfies the regional electricity demand. This paper will establish the evaluation system according to the economic indicators of the investment and operation of the distribution network, and the demand side response of users are also taken into account. The index system is given in TABLE Ⅰ.

- Indicators of the distribution network investment. These indicators reflect the situation of the investment of the distribution network and the cost and benefit of the investment. Including the increased power supply for unit investment, the increased power supply for increased unit substation capacity, the investment payback period, NPV, IRR, etc.. Among them, the investment payback period, NPV and IRR take the annual average value of distribution network investment projects.
- Index of distribution network operation. These indicators reflect the operation of distribution network. Including the capacity-load rate, the line loss rate, the load forecast accuracy, etc..
- Index of demand side response. These indicators reflect the implement of demand response projects dominated by grid enterprises and their impacts on the operation of the distribution network. Including the added value of daily load rate on average, the maximum load reduction, the demand side response costs, the power system expansion investment that can be avoided, etc..

TABLE I. INVESTMENT AND OPERATIONAL EFFICIENCY EVALUATION SYSTEM.

First Class Indicator	Second Class Indicator
Distribution Network Investment	The Increased Power Supply for Unit Investment
	The Increased Power Supply for Increased Unit Substation Capacity
	IRR
	Payback period
	NPV
Distribution Network Operation	The Capacity-load Rate
	The Line Loss Rate
	The Load Forecast Accuracy
Demand Side Response	The Added Value of Daily Load Rate on Average
	The Maximum Load Reduction
	The Demand Side Response Costs
	The Power System Expansion Investment That Can Be Avoided

III. DEA MODELING

DEA (Data Envelopment Analysis) is a non-parametric method that uses mathematical tools to evaluate the effectiveness of the production frontier of economic system. This method is suitable for the performance evaluation of multiple objective decision making units that are multiple-input and multiple-output. Based on relative efficiency, DEA method can evaluate the effectiveness of decision making units of the same type according to multiple indicators input and output. This paper uses DEA to evaluate investment and operational efficiency of distribution networks because of the better adaptability between them.

In data envelopment analysis, assume that there are t DMUs (Decision Making Unit) and each of them have m input variables and n output variables. Among them, x_{ik} stands for the input quantity of the k_{th} DMU towards the i_{th} input variable. y_{jk} stands for the output quantity of the k_{th} DMU towards the j_{th} output variable. o_i stands for the weight of the i_{th} input variable. q_j stands for the weight of the j_{th} output variable. e is the investment efficiency that needs solving. Each DMU has its corresponding efficiency evaluation indict, as the following equation:

$$e_k = \frac{q^T y_k}{o^T x_k} = \frac{\sum_{j=1}^{n} q_j y_{jk}}{\sum_{i=1}^{m} o_i x_{ik}}, k = 1, 2, \cdots, t \tag{1}$$

Constraint conditions is given as:

$$\sigma.\tau. \begin{cases} \frac{q^T y_k}{o^T x_k} \le 1, k = 1, 2, \cdots, t, \\ q \ge 0, o \ge 0, q \ne 0, o \ne 0. \end{cases} \tag{2}$$

Perform Charnes-Cooper transform on it, let $v = \frac{1}{o^T x_0} > 0, \quad \gamma = v \cdot o, \quad \sigma = v \cdot q$. Then original problem can be transformed into equivalent problem of inear programming. Just as the following equation:

$$\max e_{k_0} = \sigma^T y_0 \tag{3}$$

$$\sigma.\tau. \begin{cases} \gamma^T x_k - \sigma^T y_k \ge 0, k = 1, 2, \cdots, t, \\ \gamma^T x_0 = 1, \\ \gamma \ge 0, \quad \sigma \ge 0. \end{cases} \tag{4}$$

Turn the function above into its dual programming and introduce slack variables as follows:

$$\min \varepsilon \tag{5}$$

$$s.t. \begin{cases} \sum_{k=1}^{t} \lambda_k x_k + r^- = \varepsilon x_0 \\ \sum_{k=1}^{t} \lambda_k y_k - r^+ = \varepsilon y_0 \\ r^-, r^+ \ge 0 \\ \lambda_k \ge 0, k = 1, \cdots, t \end{cases} \tag{6}$$

Solve the linear programming model, get ε is the investment and operational efficiency. ε values $0 \le \varepsilon \le 1$, the lower value of ε, the lower efficiency is; the higher value of ε, the higher efficiency is. When ε =1, the efficiency of investment and operation is the highest, therefore, the optimal situation is achieved.

IV. Examples Analysis

A. The Evaluation System After

B. Simplification

As is discussed above, the index system after simplification is shown in TABLE II. Besides, according to the special requirements of DEA model, indicators are divided into input-indicator and output-indicator in this paper.

TABLE II. The indicators investment efficiency evaluation system (after simplification).

Code of Indicators	Name of Indicators	Kinds of Indicators
I_1	The Increased Power Supply for Unit Investment	Output
I_2	The Increased Power Supply for Increased Unit Substation Capacity	Output
I_3	Payback Period	Input
I_4	NPV	Input
I_5	The Capacity-load Rate	Input
I_6	The Line Loss Rate	Output
I_7	The Load Forecast Accuracy	Input
I_8	The Added Value of Daily Load Rate on Average	Output

Data of some cities in north China is given in TABLE III and IV.

TABLE III. DATA FOR THE INDICATORS(1).

Area	Year	I_1/(kW·h/ RMB)	I_2/(MWh/MVA)	I_3	I_4/(million yuan)	I_5
A	2010	3.1	2676.2	13.41	4378.2	2.1
	2011	2.2	2514.9	13.22	3217.1	2.5
	2012	5.1	3292.6	13.78	3690.9	2.3
	2013	7.4	2703.5	13.9	3729.3	2
	2014	8.3	2564.6	14.55	4219.1	2.2
B	2010	1	1002.5	13.25	2563.3	1.9
	2011	1.2	2101.3	14.21	3318.9	1.7
	2012	1.6	902.3	13.22	2231.9	2.3
	2013	-2.5	-101.2	14.64	2918.2	2.1
	2014	0.5	2145.3	15.21	3011.1	2.2
C	2010	0.3	165.8	10.1	2846.3	2.5
	2011	0.5	750.1	10.23	2910.4	2.6
	2012	0.9	1511.4	10.5	3101.1	2.9
	2013	-1.5	1235.6	10.6	3210.2	2.2
	2014	0.7	1451.7	11	2318.5	2.5
D	2010	2.6	1582.7	12.11	3819.2	1.9
	2011	3.1	1286.2	11.67	4012.2	1.8
	2012	3.7	1092	12.14	4110.3	1.6
	2013	3.9	2590.7	12.15	4124.2	2.1
	2014	3.5	3170.8	13.16	4510.3	2.3

TABLE IV. DATA FOR THE INDICATORS(2).

Area	Year	I_6/%	I_7/%	I_8/%	I_9/kW	I_{10}/(million yuan)
A	2010	4.2	96.2	4.3	57.4	16.2
	2011	4.6	95.1	3.1	59.3	14.1
	2012	4.9	96.3	3.2	62.4	16.2
	2013	5.1	97.2	3.9	67.3	25.2
	2014	4.8	98.3	3.7	88.3	36.7
B	2010	5.1	93.2	4.1	23.4	10.2
	2011	4.9	94.1	4.4	25.7	8.3
	2012	4.8	93.3	3.2	21.5	8.9
	2013	4.5	95.1	3.6	22.4	9.2
	2014	4.7	96.2	3.3	25.3	8.4
C	2010	5.4	97.9	2.9	31.7	10.2
	2011	5.7	93.2	2.7	28.1	11.1
	2012	5.3	94.1	3.3	29	12.3
	2013	5.1	95.2	3.6	41	13.2
	2014	5	94.4	3.8	45.6	14.6
D	2010	4.5	98.1	4.1	62.34	21.4
	2011	4.3	98.2	4.4	71.2	23.6
	2012	4.6	97.6	4.5	77.9	22.7
	2013	4.8	97.2	4.2	82.1	34.2
	2014	4.9	97.9	3.9	83.2	33.1

C. *DEA Result*

Input data from TABLE III and IV into the model established above, the weight of each indicator is obtained through the entropy weight method, as is shown in TABLE V. Use the saddle point algorithm for optimization, the distribution network investment and operational efficiency of the four cities from 2010-2014 is obtained, as is shown in TABLE V. And Specific investment efficiency trends can be seen in Fig.1.

The results of data envelopment analysis of ABCD, four cities are shown in TABLE V.

TABLE V. THE RESULT OF DATA ENVELOPMENT ANALYSIS.

City	Year	Investment Efficiency
A	2010	0.377
	2011	0.708
	2012	0.858
	2013	0.826
	2014	1.000
B	2010	0.294
	2011	0.467
	2012	0.416
	2013	0.280
	2014	0.449
C	2010	0.413
	2011	0.397
	2012	0.443
	2013	0.425
	2014	0.484
D	2010	0.734
	2011	0.833
	2012	0.885
	2013	0.896
	2014	0.961

Judging from the results, gaps of investment and operational efficiency between these four cities are large. Compared with other three cities, City D has been at a relatively high level; City A had its efficiency greatly improve in 2011. And in 2014, optimum was achieved. Therefore, the investment and operational efficiency of City A in 2014 can be regarded as the benchmarking for calibration management. Because of the large rate of rural network, the efficiency of City C and D are low.

V. CONCLUSIONS

With the development of economic and society, demand for electricity has steadily increased. The construction of power grid, especially the planning and investment of the distribution network, is significant to the development of power industry in the future. In this paper, an evaluation model for the investment and operational efficiency of distribution network based on DEA is established. The entropy weight method is used to give weight indicators scientifically, and measure input and output data for the investment and operation of distribution network. Also, the demand side response is brought into the system to evaluate investment and operational efficiency of distribution networks. It's proved by the analysis of examples that the result of the evaluation system is precise, objective and practical. The model can be used to evaluate investment and operational efficiency of distribution networks of power grid enterprises and promote them to develop DSM work.

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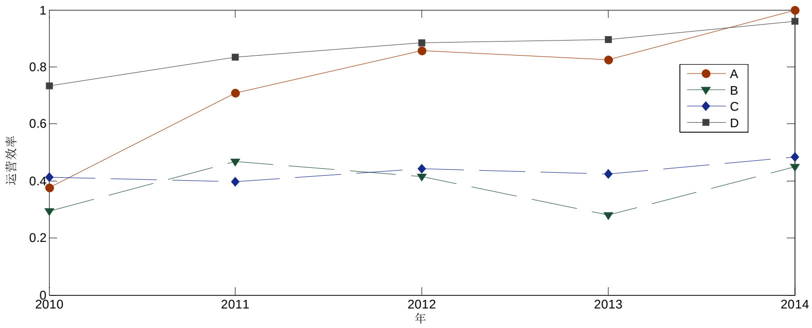

FIGURE I. TREND OF OPERATIONAL EFFICIENCY.