The Evaluation Method of Distribution Network Operation Performance Based on Combination Weighting and Improved Grey Correlation

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Abstract. Reasonable evaluation of distribution network operation performance can provide reference for distribution network planning, transformation and operation optimization. This has an important impact on the security and stability of the distribution network. Based on related indexes, a method of distribution network operation level evaluation is proposed based on combination weighting and improved grey correlation. Firstly, the correlation coefficient of each evaluation index of distribution network operation performance is introduced, and the combined weight method is used to modify the comprehensive weight of each index, and then the Comprehensive Evaluation Index of each region is obtained, thus, the weak area of distribution network operation performance is identified and the target area in urgent need of transformation is obtained. Then, the mean difference influence coefficient is introduced to improve the traditional grey correlation method, and the correlation degree between the influencing factors of distribution network operation performance and the Comprehensive Evaluation Index is obtained, so as to get the influence degree of each influencing factor on the distribution network operation performance, determine the renovation plan. Finally, the effectiveness and superiority of the proposed method are verified by an example.

Keywords: Operation Performance · Combination Of Empowerment · Improved Grey Correlation · Comprehensive Evaluation

1 Introduction

With the continuous development of smart grid and energy internet strategy, the form of power and power network are faced with different changes, and the new form puts forward higher requirements for the operation performance of distribution network [1], reasonable evaluation of the operation performance of distribution net-work can provide reference for the planning, transformation and operation optimization of distribution net-work, which has a very important impact on the security and stability of distribution network [2].

There are many indexes that affect the operation performance of distribution network, such as the common comprehensive line loss rate [3], line heavy load ratio [4],

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distribution transformer heavy load ratio [5], etc., and the operation performance of distribution network can't be evaluated simply by a single index [6, 7]. How to use each single index to construct the Comprehensive Evaluation Index is the research emphasis of distribution network operation performance evaluation, and the key to construct the Comprehensive Evaluation Index is to determine the index weight [8].

In present research, there are two common methods of weighting: subjective weighting and objective weighting. Literature [9] uses the subjective analytic hierarchy process (AHP) to establish the multi-operator analytic hierarchy process (MAHP) fuzzy evaluation model and the corresponding weight solution method, but don't classify and analyze the objective data, it ignores the laws and influences of the data itself. Literature [10, 11] studies the objective weighting, and introduces the order Relation Analysis Method and the improved AHP method combined with the improved entropy weight method to calculate the comprehensive weight of each power quality index. The final decision-making will be influenced by the deviation between the subjective or objective weighting and the calculation of the relative degree of the influencing factors. Literature [12, 13] puts forward the optimization model which combines several typical ways of subjective and objective weights, but it fails to allocate the proportion of subjective and objective weights scientifically and reasonably, ignore the inherent law of data, and the actual situation is not consistent with the scene. Therefore, it is necessary to further study the overall and effective weighting method in order to get a more reasonable comprehensive evaluation index.

After the establishment of the Comprehensive Evaluation Indicators, it is necessary to further determine the degree of correlation between the influencing factors and them in order to obtain the degree of influence of the influencing factors on the operation performance of distribution net-work [14]. In the past, the grey correlation method [15] was used to analyze the correlation degree between each influencing factor and a single index, which can also be used to analyze the correlation degree between each influencing factor and a comprehensive evaluation index. However, the traditional grey correlation method only considers the overall similarity between the reference series and the comparative series when calculating the correlation degree, and does not consider the error coefficient between the series, it may lead to the concentration of the correlation degree between each influencing factor and the Comprehensive Evaluation Index of distribution network operation performance, while the correlation degree of individual influencing factors is too close to each other, and it is difficult to choose when the regional operation performance is improved to provide optimal selection.

In order to solve these problems, this paper proposes a method of distribution network operation performance evaluation based on combination weighting and improved grey correlation. Firstly, the combined weight analysis method, which combines the objective entropy weight method and the subjective analytic hierarchy process, is adopted to scientifically and reasonably modify the comprehensive weight of each single index by introducing the correlation related coefficient, according to the comprehensive weight, the comprehensive evaluation indexes of each region are calculated, and the weak areas of distribution network operation performance are judged, and the target areas in urgent need of transformation are obtained. Then, the traditional grey correlation method is improved by introducing the mean difference coefficient, and the correlation degree between each influencing factor and the Comprehensive Evaluation Index is calculated, so we can get more accurate influence degree of each influence factor to the distribution network operation performance, and determine the transformation plan. Finally, the effectiveness and superiority of the proposed method are verified by an example. The principle of distribution network operation performance analysis based on combination weighting and improved grey correlation is shown in Fig. 1.

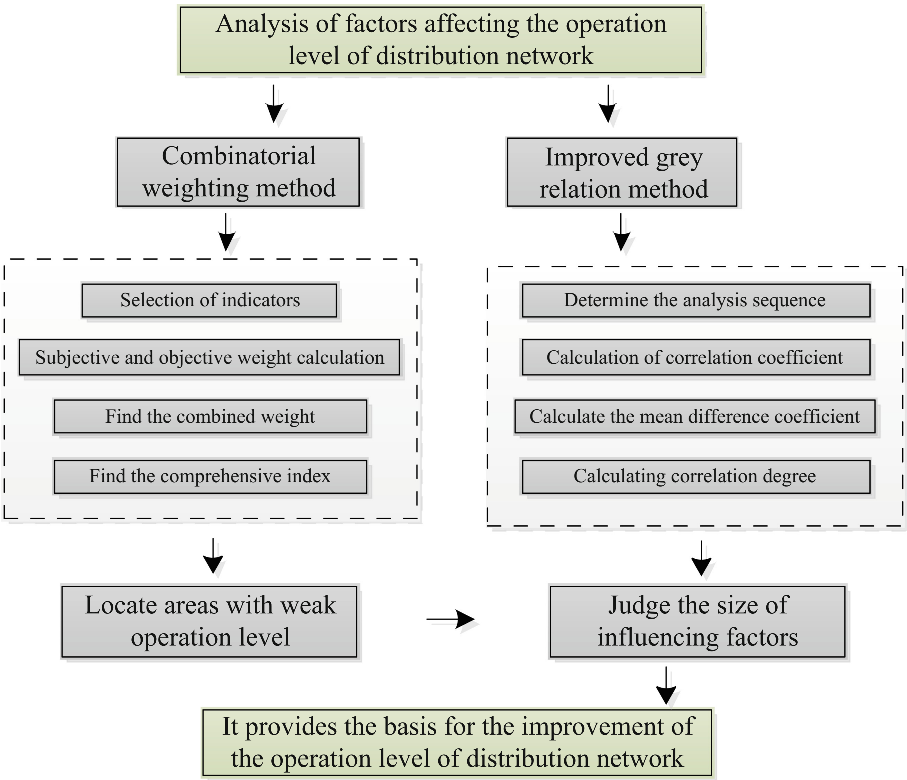

Fig. 1. Schematic diagram of distribution network operation performance analysis

2 Strives for the Comprehensive Evaluation Index

This paper uses the combination of subjective and objective weighting method to give the index reasonable weighting.

2.1 The Determination of Single Evaluation Index Weight

In this paper, three typical indexes, which are Y1) Composite line loss ratio, Y2) line heavy load ratio and Y3) distribution transformer heavy load ratio, are selected as single index to evaluate distribution network operation performance. The following single indicator of the weight of the calculation.

Subjective Weight Calculation

The analytic hierarchy process is used to calculate the weight of each index of distribution network operation performance, which can be carried out in two steps as follows:

Step 1: build the judgment matrix

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & x_{ij} & \vdots \\ x_{n1} & \cdots & x_{nn} \end{bmatrix} \tag{1}$$

According to the experience of experts and decision-makers, the judgment matrix X shown in formula (1) can be obtained by using 1–9 and its reciprocal as the criterion of comparison between the two indexes. Each value represents the relative importance between the two indexes.

Step two: the AHP weights for each indicator are calculated as follows:

$$\mathrm{W_{1j}} = \frac{1}{\mathrm{n}} \sum_{i=1}^{\mathrm{n}} \frac{\mathrm{x_{ij}}}{\sum_{i=1}^{\mathrm{n}} \mathrm{x_{ij}}} \tag{2}$$

In the formula, W_{1j} indicates that the weight of single index j can be calculated by AHP.

Objective Weight Calculation

The entropy weight method can make full use of objective data to determine objective weight. The specific calculation steps are as follows:

The first step is to standardize the original evaluation index matrix.

Let m be the evaluation index and n be the evaluation object, the original data matrix Y can be obtained as follows:

$$Y = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & y_{ij} & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{3}$$

In the formula, Y_{ij} represents the value of the j single indicator in the i region.

After the normalization of the above original matrix, the resulting matrix Y'.

Step two: define the index entropy.

In the evaluation problem with m evaluation indexes and n evaluation objects, the first step is to determine the normalized value Pij, and then the entropy value e_j of the corresponding indexes can be obtained as shown in formula (4). The entropy calculation can be expressed as:

$$e_j = -k\sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{4}$$

In the formula, k = 1/lnm, and define $Pij = 0$, $P_{ij} lnP_{ij} = 0$.

Step three: calculate the weight of the index.

After calculating the entropy of index j, the weight of index j is calculated as follows:

$$W_{2j} = \frac{1 - e_j}{\sum_{j=1}^{n} 1 - e_j} \tag{5}$$

In the formula, W_{2J} is used to calculate the weight of single index j by entropy weight method.

2.2 The Calculation of the Combination Weight

This paper introduced the correlation coefficient, the final combination weights can be calculated more objectively by using the correlation coefficient between the weight and each index calculated by the single weighting method.

The first step is to determine the coefficient of Pirsson coefficient V_{ij}, and then the correlation coefficient L_j, as shown in formula (6).

$$L_j = \frac{\sum\limits_{i=1}^{m}\sum\limits_{j=1}^{n} \left|V_{ij}\right| - 3}{\sum\limits_{j=1}^{n} \left|V_{ij}\right| - 1} \tag{6}$$

In the formula, X and Y denote the sequence of index i and Index j.

The combination weights are determined as follows:

$$W_j = \frac{\sqrt{W_{1j} \cdot W_{2j} \cdot L_j}}{\sum\limits_{j=1}^{n} \sqrt{W_{1j} \cdot W_{2j} \cdot L_j}} \tag{7}$$

In the formula, W_j is the final combination weight of single index j.

2.3 The Establishment of Comprehensive Evaluation Index

Using the value of the combination weight and the normalized value of the index, it first needs to determine the normalized value of the group i data under the j index y''_{ij}.

The Comprehensive Evaluation Index under the power supply i area can be obtained as shown in formula (8).

$$Z_i = \sum_{j=1}^{n} \sqrt{W_j . y_{ij}''} \tag{8}$$

The comprehensive evaluation index, the greater the representative operation performance, the better, according to the size of the corresponding value of each area, can determine run performance relatively weak areas.

3 The Improved Grey Correlation Method is Used to Calculate the Correlation Degree

The operation performance of distribution network is mainly affected by the following nine factors: A1) high-loss distribution transformer ratio; A2) integrated voltage pass rate; A3) line N-1 pass rate; A4) power supply reliability rate; A5) low-voltage station area proportion; A6) line standardized connection rate; A7) line connection rate; A8) overall household distribution transformer capacity; A9) line frequent trip rate.

In this paper, the error influence coefficient is introduced to improve the traditional grey correlation method, so that the correlation degree between each influence factor and the Comprehensive Evaluation Index is calculated.

3.1 Determine the Analysis Matrix

The analysis matrix B as shown in formula (9) can be obtained by using the Comprehensive Evaluation Index as the reference sequence and the nine influencing factors as the comparison sequence.

$$\boldsymbol{B} = \begin{bmatrix} \boldsymbol{b_0(1)} & \boldsymbol{b_1(1)} & \ldots & \boldsymbol{b_n(1)} \\ \boldsymbol{b_0(2)} & \boldsymbol{b_1(2)} & \ldots & \boldsymbol{b_n(2)} \\ \vdots & \vdots & \boldsymbol{b_i(j)} & \vdots \\ \boldsymbol{b_0(m)} & \boldsymbol{b_1(m)} & \ldots & \boldsymbol{b_n(m)} \end{bmatrix} \tag{9}$$

In the formula, b_0 represents the reference series composed of comprehensive evaluation indexes, and b_1–b_n represents the comparison series composed of influencing factors. $b_i(j)$ and $b_n(m)$ represent the j number of the first influencing factor and n influencing factors in the m-dimensional analysis matrix, respectively.

3.2 Determine the Correlation Coefficient

According to the analysis matrix after normalization, the difference sequence $C_i\ (j)$ is calculated from the absolute difference between the comparison sequence and the reference sequence, as shown in formula (10), and then the difference matrix is composed of the difference sequence.

$$C_i(j) = \left| b_0'(j) - b_i'(j) \right| \tag{10}$$

The maximum and minimum elements of the difference matrix are expressed as C_{max} and C_{min}, respectively. And the correlation coefficient $g_i(j)$ according to the data in the difference matrix is shown in formula (11):

$$g_i(j) = \frac{C_{\min} + 0.5C_{\max}}{C_i(j) + 0.5C_{\max}} \tag{11}$$

3.3 The Mean Difference Influence Coefficient is Introduced

The mean square error value can be determined according to the comparison sequence and the reference sequence, and then the distance mean difference coefficient can be obtained, as shown in formula (12):

$$w_i = \frac{1}{e^{\partial_i}} \tag{12}$$

3.4 Calculate the Correlation Degree of the Influencing Factors

The correlation degree of each influencing factor is calculated by the spatial distance coefficient and the correlation coefficient together, as follows:

$$r_i = \frac{1}{n} w_i \sum_{i=1}^{m} g_i(j) \tag{13}$$

In the formula, r_i is the correlation degree of the i influencing factor.

The correlation degree indicates the influence degree of each influence factor on the Comprehensive Evaluation Index, that is, the influence degree on the operation performance.

4 Conclusion of Actual Case Analysis

Above provides nine influencing factors for correlation analysis and three categories of single evaluation indicators for calculation of comprehensive evaluation indicators.

4.1 The Determination of Single Index Weight

The single indicator data for the performance of operation of the distribution networks in the eight regions are shown in Table 1.

Table 1. Single indicator data sheet

Area	Combined line loss rate	Proportion of line overload	Distribution transformer heavy ratio
Area 1	3.60	11.31	4.08
Area 2	4.18	7.83	3.84
Area 3	3.91	8.71	3.13
Area 4	3.38	10.04	3.81
Area 5	4.50	10.36	3.14
Area 6	5.12	6.03	3.86
Area 7	4.28	9.05	4.06
Area 8	5.33	7.83	3.65

According to the single index shown in the table above, the AHP weights, entropy weights and combination weights of line loss rate, line heavy load ratio and distribution transformer heavy load ratio are shown in Table 2.

Table 2. Each weight value data table

	Combined line loss rate	Proportion of line overload	Distribution transformer heavy ratio
Weight of AHP	0.66	0.16	0.19
Entropy weight method	0.27	0.27	0.46
Combination weight	0.58	0.24	0.19

The value of the Comprehensive Evaluation Index reflects the operation performance of the distribution network in each region. From Table 3 and Fig. 2, if the operation performance of distribution network needs to be adjusted at this stage, priority should be given to the area with the weakest performance of distribution network operation 3.

Table 3. Evaluation of comprehensive index values for region

Area	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7	Area 8
Index	0.81	0.79	0.74	0.77	0.84	0.86	0.83	0.91

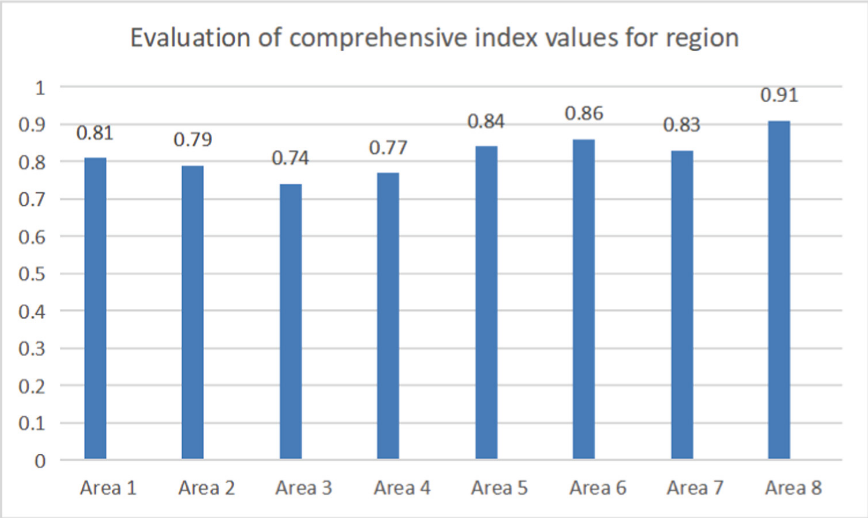

Fig. 2. Evaluation of comprehensive index values for region

4.2 The Calculation of Correlation Degree

The data of nine kinds of influencing factors on the operation performance of distribution network in different regions are shown in Table 4.

Table 4. Influencing factors data table

Area	A1	A2	A3	A4	A5
Area 1	3.23	94.54	36.65	85.64	31.72
Area 2	4.96	95.08	36.55	88.57	33.92
Area 3	4.93	95.48	37.50	94.91	32.60
Area 4	4.93	95.98	37.60	95.11	34.32
Area 5	2.86	70.02	34.55	80.41	24.08
Area 6	3.89	70.73	34.64	81.85	26.27
Area 7	4.01	72.49	35.44	88.80	28.51

(*continued*)

Table 4. (*continued*)

Area	A1	A2	A3	A4	A5
Area 8	4.09	76.52	34.83	94.93	32.08
Area	A6	A 7	A 8	A9	
Area 1	0	77.54	2.34	7.13	
Area 2	26.03	78.33	28.06	6.15	
Area 3	52.03	80.92	38.22	7.52	
Area 4	65.62	85.31	52.28	5.18	
Area 5	0.23	51.10	2.41	9.82	
Area 6	7.71	56.90	22.25	8.70	
Area 7	22.28	61.14	35.19	6.39	
Area 8	54.10	64.02	38.18	7.75	

Here set up five other groups of method correlation degree calculation results. The first group uses the traditional grey correlation method but still considers the correlation coefficient when calculating the correlation degree, and the second group uses the improved grey correlation method without considering the correlation coefficient. After that, the three groups used a single index instead of a comprehensive evaluation index to calculate the degree of association. The third group calculates the correlation degree with the comprehensive line loss rate as the comprehensive Index, the fourth group calculates the correlation degree with the line heavy load ratio as the comprehensive index, and the fifth group calculates the correlation degree with the line heavy load ratio as the distribution transformer heavy load ratio. Each group of correlation order are shown in Table 5.

Table 5. Ranking table of correlation degree results

	Group 1	Group 2	Group 3	Group 4	Group 5	This article
A1	6	7	7	7	7	6
A2	5	5	6	3	5	5
A3	2	1	3	2	2	2
A4	3	4	2	4	1	3
A5	4	8	4	5	4	4
A6	9	9	9	9	9	9
A7	7	2	1	6	6	7
A8	8	3	8	8	8	8
A9	1	6	5	1	3	1

By comparing the correlation degrees in the table above, the order of the influencing factors is as follows: A9 > A3 > A4 > A5 > A2 > A1 > A7 > A8 > A6. The third group was ranked as A7 > A4 > A3 > A5 > A9 > A2 > A1 > A8 > A6, and the fourth group was A9 > A3 > A2 > A4 > A5 > A7 > A1 > A8 > A6. The fifth group is ranked A4 > A3 > A9 > A5 > A2 > A7 > A1 > A8 > A6.

From the above, the low voltage station area ratio and the average load rate relative to other factors are the lowest correlation ranking. However, when only a single index is considered, the third group with the highest degree of correlation is the comprehensive voltage qualification rate, the fourth group with the highest degree of correlation is the frequent trip rate of the line, and the fifth group with the highest degree of correlation is the power supply reliability rate, in order to find out the influential factors in the current stage, we neglect the influence of other indicators when we judge the magnitude of the influence factors, it is easy to be out of line with the actual situation, and it is difficult to provide a more comprehensive reference method for the improvement of the operation performance of the distribution network. In this paper, the method combines three cases of considering only one index, and comprehensively considers the ranking of the degree of association under the condition of three cases of single index, which effectively avoids the error caused by individual index, it provides a more comprehensive and objective method for improving the operation performance of distribution network.

The second group is A3 > A7 > A8 > A4 > A2 > A9 > A1 > A5 > A6. The order of line contact rate and line frequent trip rate is too low, which is not in accordance with the actual situation, and the result is easy to produce error, and can't provide effective reference for the operation performance of distribution network.

The first group is ranked A9 > A3 > A4 > A5 > A2 > A1 > A7 > A8 > A6. In this case, the data of A1 and A2, A3 and A4 have little difference and poor reference, so it is difficult to decide the actual correlation degree.

The 20-year index forecast value, 20-year field data and the percentage of improvement are shown in Table 6 and Fig. 3.

Table 6. Improvement in indicators

Attribute for the indicator	Indicators	This article methods	2020 data	Increase in percentage (%)
Positive indicators	All households allocated variable capacity	4.93	4.08	20.83
	Standardized line connection rate	95.48	93.84	1.75
	Line N-1 passrate	37.50	34.13	9.87
	Reliability of power supply	94.91	93.81	1.1
	Line connection rate	32.6	30.14	8.16
	Average load rate	52.03	49.86	4.35
	Integrated voltage pass rate	80.92	78.06	3.66
Negative indicators	Low voltage station area ratio	38.22	40.65	5.98
	Frequency trip rate of line	7.52	8.97	16.16

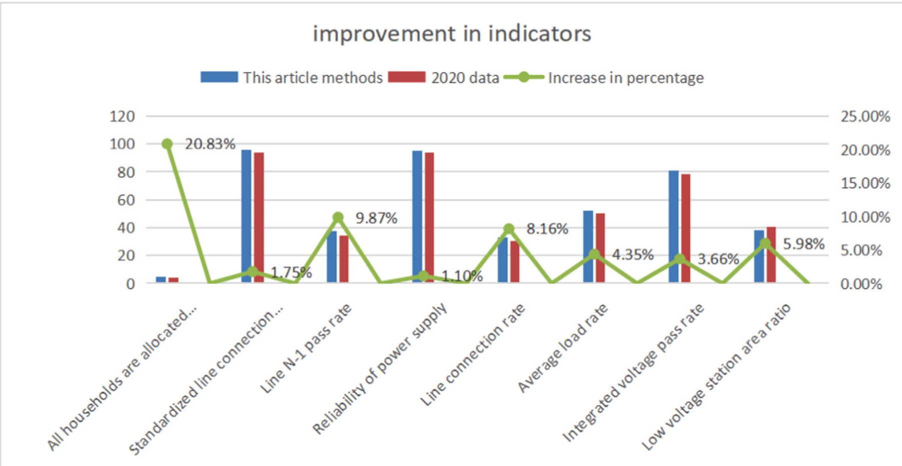

Fig. 3. Improvement in indicators

As shown in Table 6, both the positive and negative indicators, based on the method proposed in this paper to improve the distribution network has a better effect, in which, the main indexes with higher promotion range are the capacity of distributed transformer in the whole world, the passing rate of line N-1 and the frequent trip rate of line. The capacity improvement rate of the whole distribution network is 20.83%, the pass rate of line N-1 is 9.87%, and the frequent trip rate of line is 16.16%, which proves the effectiveness of the proposed method.

To sum up, compared with the existing methods, this method not only effectively avoids the error caused by only considering a single evaluation index, but also improves the calculation method of correlation degree, which greatly improves the accuracy of distribution network operation performance, at the same time can provide support for the reasonable transformation of distribution network.

5 Conclusion

In this paper, a method based on combination weighting and improved grey correlation is proposed to evaluate the operation performance of distribution network:

(1) Compared with the traditional single evaluation index method, the Integrated Evaluation Index method based on combination weighting can identify the weak areas of distribution network more accurately.
(2) Compared with the traditional grey correlation method, the improved grey correlation method is more accurate in calculating the correlation degree and more effective in evaluating the operation performance.

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