Modern Applied Science
www.ccsenet.org/journal.html
Vol. 2, No. 2
March 2008

# Peak Load Shifting Distribution by Fuzzy Method Based on Weight Compromise Coefficient

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**Abstract**

The distribution of power supply limiting in multi-zone is discussed by means of combining analytical hierarchy process and fuzzy sets theory. From the greatest factors in power limiting distribution, guide line system and hierarchy structure are established. Also, the relative membership degree functions are determined. A novel multi-objective group decision model is suggested by introducing a compromise coefficient between subjective weight and objective weight, which can give attention to both. The model is applied to peak load shifting distribution and the result manifests this model is reasonable and applicable.

**Keywords:** Analytical hierarchy process, Fuzzy sets theory, Multi-objective, Group decision model

## 1. Introduction

Because of the fast development, Power supply crisis happened in east and centre of China frequently since 2003. In order to solve this problem, many investment and work for generate electricity capacity extending have been launched by State Grid Corporation of China around the whole country, including Three Gorges Dam. However, these cannot afford the large electricity consumption. Although some economic and political measures have been used to peak load shifting control, power limiting is still necessary for power grid security while the pinnacle coming. According to power limiting standards and safety requirements of each area, also the integrated analysis of society, economy, and environment, etc, how to distribute the finite peak power capacity over every area reasonable and get the safest grid and least loss is important. The solving of this problem is meaningful.

Peak load shifting distribution is an important task and it needs knowledge and experiment of many persons. At the same time, it is a little fuzzy. So the method of combining fuzzy sets theory with hierarchy analysis is used to discuss the multi-objective group decision of multi-zone peak load shifting, according to the systemic analysis of society, economy, resource and environment. Therefore, power limiting distribution belongs to nonlinear multi-objective group decision category.

## 2. Construct Peak Load Shifting Distribution Decision System

### *2.1Power limiting distribution guide line system and hierarchy structure building*

The reasonable time distribution of peak load shifting in multi-zone is for the sake of power capacity standard and least loss based on the grid security. In this aspect, there are many factors, which are related to range and time of power limiting, also the conditions of social economy, such as population, industry configuration, parameter of national economy and so on. Some of them can be showed in economic quantity. Such as population in power limiting area, number of electricity enterprises in power limiting area and gross product in power limiting area, etc. Furthermore, it is hard to estimate some potential indirect benefit like effect on economy, adjustment of economy structure, damage for environment. The necessity of peak load shifting control is usually appraised by economic benefit. And these always affect the distribution of power limiting time. So it has some deficiency. Thus, the guide line system and hierarchy structure (Fig 1.) should be established according to the parameters picking up from the factors affecting power supply limiting like society, economy and so on. This will be good to the reasonable distribution of power limiting time and least loss. And the law of clear conception, abundant information, easy calculation and show justice is necessary.

### *2.2 Building and determining relative membership degree functions of each parameter*

Decision-making parameters always have four types in multi-objective decision problem. “a” is “excellent with large”, “b” is “excellent with small”, “c” is “fixed value” and “d” is “inter-zone”.

The type of “fixed value” parameter is a kind of parameter that the excellent value is a constant. Inter-zone means that the parameter value in some fixed region is excellent. The purpose of decision parameter classification is for compare among same parameters.

According to the difference between decision parameter types, parameter set F can be classified.

$$F=\bigcup_{i=1}^{4}F_i,\quad F_i \cap F_j=\Phi\ (i, j=1, 2, 3, 4, i\neq j).$$

In this equation, $F_i$ ( $i$ = 1 ,2 ,3 ,4) is the kind of a, b, c and d respectively, and $\Phi$ is null.

Because of the difference between multi-objective dimensions, it needs to standardize the decision matrix M. And then, the eigenvalue of each decision parameter in relative state can be got. The expression of standardization is as follows.

$$a_{\max}=\max\{a_{ij}:1\le i\le n, 1\le j\le r\} \tag{1}$$

$$a_{\min}=\min\{a_{ij}:1\le i\le n, 1\le j\le r\} \tag{2}$$

( $r_{ij}$ is relative membership degree of parameter $j$ in zone $i$, *max* and *min* is the symbol for taking maximum and minimum respectively, $\alpha_{ij}$ is the objective value of parameter $j$($r$ in all) in zone $i$($n$ in all) and have character of fuzzy by effect of value and statistical error.)

For type a,

$$r_{ij}=\frac{a_{ij}-a_{\min}}{a_{\max}-a_{\min}}\ (1\le i\le n, 1\le j\le r, f_k\in F_1) \tag{3}$$

For type b,

$$r_{ij}=\frac{a_{\max}-a_{ij}}{a_{\max}-a_{\min}}\ (1\le i\le n, 1\le j\le r, f_k\in F_2) \tag{4}$$

For type c,

$$r_{ij}=\begin{cases}1.0, & a_{ij}=a^0\\ 1.0-\dfrac{|a_{ij}-a^0|}{\max\{a_{ij}-a^0\}}, & a_{ij}\neq a^0\end{cases}\quad (1\le i\le n, 1\le j\le r, f_k\in F_3) \tag{5}$$

$a^0$ is the optimal constant of parameter $f_k$.

For type d,

$$r_{ij}=\begin{cases}1.0-\dfrac{|b_1-a_{ij}|}{\max\{b_1-a_{ij}, a_{ij}-b_2\}}, & a_{ij}<b_1\\ 1.0, & b_1\le a_{ij}\le b_2\\ 1.0-\dfrac{|a_{ij}-b_2|}{\max\{b_1-a_{ij}, a_{ij}-b_2\}}, & a_{ij}>b_2\end{cases}\quad (1\le i\le n, 1\le j\le r, f_k\in F_4) \tag{6}$$

$[b_1, b_2]$ is the optimal region value of parameter $f_k$.

The decision eigenvalue matrix can be taken from the equations above.

From Fig. 1, the experts get that the Power limiting region whose population are more, electro-enterprise are more, the total value of produce are more, economic loss of Power limiting are more, proportion of using electricity peak are more, the average temperature is more, the proportion of ice air condition are less, the distributed proportion of Power Limiting distribution for Peak Load Shifting are more.

Thus, these factors are all “b”, except the scale of reconcilable peak enterprises and ice air condition are “a”.

## 3. Parameter Relative Weight Value Calculation

As a multi-objective decision method for combination of quality and quantity, hierarchy analysis has been applied extensively. But there are few examples about how to solve the group decision problem with hierarchy analysis method. In this paper, weighted geometry average group vector sort method based on different expert knowledge structure, has been used to deal with the hobby of some experts in multi-zone peak load shifting controlling time distribution and the problem of group hobby from knowledge structure.

### *3.1 The choice of expert group*

The time of peak load shifting is mainly affected by the factors in Figure 1. Thus, the composition of expert group is always peak load shifting control expert and electric power programming expert, etc. Also including electric utility manage expert, grid economy expert and grid security expert, who are accomplished in operation, theory and scientific research respectively. Obviously, the reasonable decision weight of each expert for each factor in Figure 1 is different.

*3.2 The weight vector calculation of judging matrix for each expert*

In case of the number of expert is s and the number of reasonable peak load shifting control distribution factor or parameter is n,

$$P=\{P_1,P_2,\ldots P_n\} \tag{7}$$

The important degree should be judged by every expert though all effecting factors. If $V$ is the important degree judged matrix for factors building by expert *i*,

$$V=\begin{pmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{s1} & \cdots & v_{sn} \end{pmatrix} \tag{8}$$

$V$ follows AHP method. And the weight vector of factors judged by expert $i$ can be taken according to the judged matrix.

Normalized the judged matrix $V$, $V'$ can be taken.

$$V'=\begin{pmatrix} v'_{11} & \cdots & v'_{1n} \\ \vdots & \ddots & \vdots \\ v'_{s1} & \cdots & v_{sn} \end{pmatrix} \tag{9}$$

$$v'_{ij}=\frac{v_{ij}}{\sum_{k=1}^{n} v_{ik}}, i=1,2,\ldots\ldots, s \tag{10}$$

*3.3 The synthesis of expert weight vector*

In the decision group, there are two methods for weight vectors synthesis of every decision-maker generally: one is synthesis of judged matrix; the other is synthesis of weight vector. Weight vector synthesize mainly use arithmetic weighted average synthesis. In this model, the relative important degree of each element has been considered and imported into the formula in the form of weight value. And this makes the appraising process reasonable. However, the weight determined in this way completely ignores the subjective information of decision-maker like knowledge, experience and hobby. Thus, it cannot afford needing of objective situations. So, a novel method for completing the parameter weight decision of multi-objective decision problem has been brought forward in this paper as follows.

Suppose, some experts is appraising the peak load shifting control distribution parameters. The number of experts is *s*, and the distribution is n. the determinate weight vector can be taken with the method above.

$$v^{(l)}=(v_{l1},v_{l2},v_{l3},\ldots v_{ln})^T \tag{11}$$

$$\sum_{k=1}^{n} v_{lk}=1(0\le v_{lk}\le 1)\ (k=1,2,\ldots n;\quad l=1,2,\ldots s) \tag{12}$$

In case of weight of *each* decision-maker $D_l$ is $\lambda_l$,

$$\sum_{k=1}^{s}\lambda_l=1(0\le\lambda_l\le 1)\ (l=1,2,\ldots s) \tag{13}$$

And then, $\omega=(\omega_1,\omega_2,\ldots\omega_n)^T$ is the unknown weight vector. Normalized $\omega_k$, we can get

$$\omega_k=\frac{\sum_{i=1}^{s}\lambda_l v_{lk}}{\sum_{k=1}^{n}\sum_{l=1}^{s}\lambda_l v_{lk}} \tag{14}$$

The weight of decision-maker is usually determined by the appraisement between them. That's the subjective weight $\delta_l$( $l$ = 1 , 2 , ..., $s$). But in fact, the weight of decision-maker is not always coincident with the subjective weight. So it is necessary to fix $\delta_l$ according to the problem and result of decision practically.

$y_{lu}$ can be defined as the distance of $\omega^{(l)}$ and $\omega^{(u)}$ ( $l$ , $u$ = 1 ,2 , ..., $s$).

$$y_{lu} = y(\omega^{(l)}, \omega^{(u)}) = \sqrt{\sum_{k=1}^{n} (\omega_{lk} - \omega_{uk})^2} \tag{15}$$

So it is easy to see that $0 \le y(\omega^{(l)}, \omega^{(u)}) \le 1$ . Smaller the $y(\omega^{(l)}, \omega^{(u)})$ is, closer the distance is.

Supposing $e_l = \sum_{k=1}^{s} y_{lk}$ $(k = 1, 2, ..., s)$,

$e_l$ manifests the close degree between $\omega^{(l)}$ of decision-maker $D_l$ and others. And if $e_l$ is smaller, $\omega^{(l)}$ will be closer with the other weight vectors. Thus, we can use (16) as the objective weight of decision-maker $D_l$.

$$\beta_l = \frac{1/e_l}{\sum_{l=1}^{s} (1/e_l)} \quad l = 1, 2, \dots, s \tag{16}$$

It is easy to see that $\beta_l$ indicates the different degree of target weight decision between decision-maker $D_l$ and the others. Thus the final weight of decision-maker $l$ can be determined by

$$\lambda_l = \mu\delta_l + (1-\mu)\beta_l, \quad l = 1, 2, ..., s \quad 0 \le \mu \le 1 \tag{17}$$

It indicates the different degree for the subjective weight and objective weight.

**4. Optimized Distribution Decision Calculation of Multi-objective Power Limiting Time Distribution**

For the hierarchy model structure in Figure 1, the fuzzy synthesized decision model of multi-objective power limiting time distribution in multi-zone is established as follows.

$$Z = R \circ W = \begin{pmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{pmatrix} \circ \begin{pmatrix} \omega_1 \\ \vdots \\ \omega_n \end{pmatrix} \tag{18}$$

In the equation above, $R$ is the relative membership degree matrix, $r_{ij}$ means the relative membership degree of the parameter $j$ in zone $i$ of $m$, $W$ is the parameter weight vector determined by group decision theory, $\omega_j$ is the weight of parameter $j$ of $n$ under group decision, $Z$ is the scale vector of zone power limiting time distribution. “o” is the fuzzy arithmetic operators. The scale of power limiting distribution of each region can be taken according to equation (18).

**5. Research of Examples**

According to the data from the charge department of Liaoning province, a peak load shifting distribution in six regions is planned to operate in summer of 2005. The social economy of six regions is shown in Table 1. The loss is in Table 2.

If there are three decision-maker who participate in the decision of peak load shifting controlling distribution, the result can be got using the model above. (The calculation process is omit)

(1) Parameter absolute weight vector of decision-maker one is $V_1'$

$V_1'$ = {0.0428, 0.0231, 0.0877, 0.0104, 0.297, 0.083, 0.241, 0.1363, 0.0485, 0.0302}

(2)Parameter absolute weight vector of decision-maker two is $V_2'$

$V_2'$ = {0.0368, 0.0368, 0.1049, 0.0085, 0.098, 0.148, 0.286, 0.1573, 0.0779, 0.0458}

(3)Parameter absolute weight vector of decision-maker three is $V_3'$

$V_3'$ = {0.1801, 0.0483, 0.1849, 0.0217, 0.079, 0.1273, 0.2134, 0.0583, 0.0544, 0.03263}

(4)According to equation (15),

$y_{12} = 0.2189$, $y_{13} = 0.2923$, $y_{23} = 0.2094$

$e_1 = y_{12} + y_{13} = 0.5112 \quad e_2 = y_{12} + y_{23} = 0.4283$

$e_3 = y_{13} + y_{23} = 0.5017$

(5)According to equation (16),

$\beta_1 = 0.311$, $\beta_2 = 0.372$, $\beta_3 = 0.317$

(6)According to equation (17), suppose $\delta_1 = \delta_2 = \delta_3 = 1/3$ and $\mu = 0.5$,

$\lambda_1 = \mu\delta_1 + (1-\mu)\beta_1 = 0.167 + 0.156 = 0.323$

$\lambda_2 = \mu\delta_2 + (1-\mu)\beta_2 = 0.166 + 0.186 = 0.352$

$\lambda_3 = \mu\delta_3 + (1-\mu)\beta_3 = 0.167 + 0.158 = 0.325$

$W = \lambda_1\omega_1 + \lambda_2\omega_2 + \lambda_3\omega_3$ and normalize it.

$= \{0.0853, 0.0361, 0.1253, 0.0134, 0.1561, 0.1203, 0.2479, 0.1183, 0.0608, 0.0365\}$

(7)According to equation (18), the calculation scale of peak load shifting controlling distribution in each region is as follows:

$Z_1$=7.38% , $Z_2$=23.86% , $Z_3$=1.19% , $Z_4$=26.19% , $Z_5$=19.3% , $Z_6$=22.08%

See Figure 2 and Figure 3.

## 6. Conclusion

According to the diagram (Table 1, Table 2) of peak load shifting period distribution above, it can be seen:

The change of final power supply limiting distribution scale is basically coincident with the decision parameter type defined above, going with the change of social economic parameter and power limiting direct loss. Consequently, it is feasible and will afford the need of power limiting distribution.

Anyway, power limiting distribution is a complicated multi-objective group decision problem. The period distribution decision is related to technology, economy and power limiting standard, also electricity grid security and society stabilization. So the research about distribution will be more complex. In this paper, the power limiting distribution parameter system and hierarchy structure are establish, according to the main factors affecting power supply limiting time distribution. A large system multi-objective group decision model and method based on the combination of hierarchy analysis and fuzzy synthesized appraisement. And from a practical example, the result manifests good. But the research about the social appraisement, national economy appraisement, environment effect appraisement and power limiting uncertainty of peak load shifting controlling distribution should be enhanced from now on.

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Table 1. The Parameter of Social Economy

| regions | Population(10000) | Electricity consumption number | Electricity capacity(Mkw) | Reconcilable peak scale (%) | Product gross(1000rmb) |
|---|---|---|---|---|---|
| 1 | 56.42 | 308 | 47.28 | 17.83 | 476.52 |
| 2 | 23.18 | 106 | 21.53 | 52.12 | 180.63 |
| 3 | 89.13 | 416 | 62.52 | 41.63 | 725.20 |
| 4 | 10.67 | 89 | 18.62 | 71.63 | 97.65 |
| 5 | 36.21 | 218 | 32.15 | 31.25 | 207.26 |
| 6 | 43.56 | 229 | 29.56 | 52.06 | 168.88 |

Table 2. The Economic Loss of Power Limiting

| region | Power limiting capacity(Mkw) | Economic loss of power limiting(1000rmb) | Electricity consumption peak scale(%) | Average temperature | Ice air condition scale(%) |
|---|---|---|---|---|---|
| 1 | 41.07 | 28.71 | 67.12 | 32.5 | 25.6 |
| 2 | 16.52 | 8.28 | 40.06 | 31.2 | 30.1 |
| 3 | 55.73 | 34.62 | 62.56 | 32.7 | 25.7 |
| 4 | 17.64 | 9.43 | 36.11 | 29.8 | 35.2 |
| 5 | 27.35 | 10.52 | 50.12 | 30.6 | 22.6 |
| 6 | 23.06 | 9.31 | 54.58 | 33.3 | 21.7 |

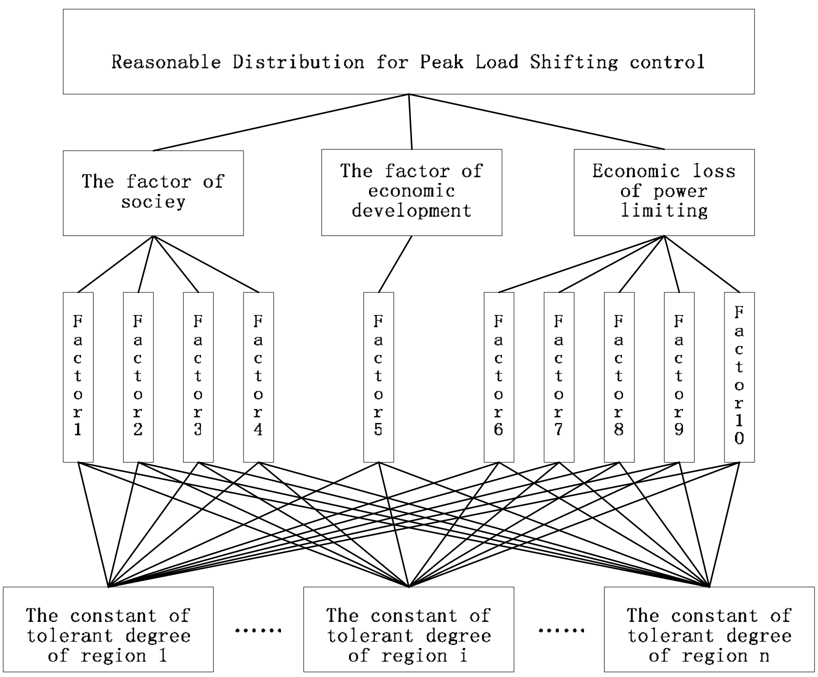


Figure 1. Decision system of Peak Load Shifting Power Limiting Distribution

Note: factor1-The population of region, factor2- The quantity of electro-enterprise, factor3-The capacity of using power, factor4-The proportion of electro-enterprise that can be power-off, factor5-The total value of produce, factor6-The capacity of power limiting, factor7-The economic loss of power liming, factor8-The proportion of peak for using power, factor9-The average temperature, factor10-The proportion of ice air condition

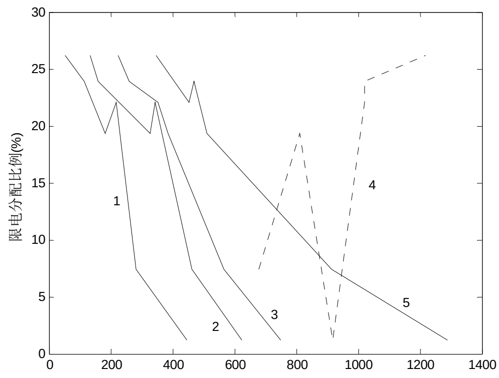


Figure 2. corresponding curve schematic diagram of social economic indicator and Power Limiting Distribution in every region

Population-1

The quantity of electro-enterprise-2

The capacity of using electricity-3

The proportion of moving-peak enterprise-4

The total value of produce-5

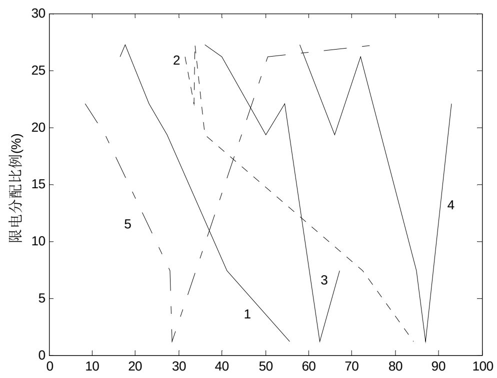


Figure 3. Corresponding curve schematic diagram of the economic loss indicator of Power limiting and Power limiting Distribution proportion

Limited capacity-1

The economic loss of Power limiting-2

Proportion of using electricity peak-3

Average temperature-4

The proportion of ice air condition-5