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The fuzzy decision of transformer economic operation

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Abstract: - This paper presents a new intelligent method of fuzzy optimization, about the online decision-making of transformer economic operation. The method can automatically divide the daily load curve into several important time periods and regulate the transformer operation status within these periods to reduce the loss of energy in transformer to a minimum to achieve the goal of saving energy and increasing economic benefit. It makes the on-line intelligent control come true and it makes up the defection of previous on-line control methods of transformer economic operation. The result of simulation shows that the method is effective.

Key-Words: - Power Transformer, Economic Operation, Fuzzy Decision, Changing Weight

1 Introduction

The Economic Operation of power transformer is an important measure of saving energy in power network operation. Nowadays much literature probe into the question deeply and widely, and the works on the aspect has been published[1]. The general method of transformer economic operation is: to calculate the critical load values SC_i (i=1 2… n) among all the operation modes; to find out the best operation mode when the actual load value S is bigger or smaller than the critical load values SC_i, to get the lowest energy loss of transformer; If the actual load value S become bigger than $SC_i + \Delta S$ or smaller than $SC_i - \Delta S$, the operation mode of transformers should be changed. Capacity margin ΔS is used to avoid the frequent changing the status of switch. Because the most values of load change in a wide range, and frequently, the effect of capacity margin ΔS on avoiding frequent operation of switch is little.

The work in [2] presents a method to divide the daily load curve into two typical time periods and regulate the transformer operation status within the two periods to reduce the loss of energy in transformer to a minimum. But the method only takes two modes of the combination of transformers in one day, while the changes of loads are various. Thus the advantage of the transformer economic operation can not be fully taken, if the operation status of transformers has been changed only once a day. Further more, the advantage of the load curve of short term load forecasting can not be fully taken also, for the method only makes use of two time points, the starting point and end point of the peak load period. [3] puts forward a method of using historical or the forecast load data, to analyze the energy loss of main transformers in all time periods of a day and under all kinds of operation modes respectively, accordingly to arrange the economic operation modes of main transformer every day. In this kind of situation, if the load of substation waves frequently, the energy loss curves generated by all kinds of operation modes will bring out too many points of intersection. Thus, the number of combination among all kinds of operation modes of all time periods will be extremely large, and it will take a great deal of computer system resources to carry out the comparative analysis of them. If there are many substations in power distribution network, the situation of system resources consumption will be more serious.

In this paper we make use of forecast load data to calculate the energy loss of all kinds of transformer operation modes, and get the energy loss curves. The points of intersection among all this curves could be found out. After some simplifications, the left points of intersection will be the time points of changing transformer operation mode correspondingly. Every day can be divided into a number of time periods with these time points. For every time period, the area of relative energy loss and the influence of the economic operation mode in neighbor time periods are considered as two indexes to estimate which operation mode should be adopted. The idea that the value of weight changes along with the changing length of various time periods has been introduced into this paper. Because, embarking from the human dispatcher's visual angle, the influence of neighbor time periods has been taken into account, the judgment result reflect a long time scope load change situation. In other words, it is a transformer optimal operation in which the switch operating time gap has been considered.

2 Division of Daily Energy Loss Curve

The analytical expression of comprehensive energy loss of single transformer with two-winding is

$$\Delta P = (P_o + kQ_o) + (P_k + kQ_k)(S / S_e)^2 \qquad (1)$$

where: S_e = transformer rated capacity (kVA); S = transformer actual load (kVA); P_o = idling active loss (kW); P_k = short-circuits active loss (kW); Q_o = idling reactive loss (kVA); ($Q_o = I_o\% S_e / 100$ and $I_o\%$ =idling electric current percentage); Q_k = short-circuits reactive loss (kVA); ($Q_k = U_k\% S_e / 100$ and $U_k\%$ = short-circuit voltage percentage); k = reactive power economy equivalent.

The analytical expression of comprehensive energy loss of parallel transformers with two-winding is

$$\Delta P_\Sigma = (P_{Ao} + kQ_{Ao}) + (P_{Bo} + kQ_{Bo}) + (P_{Ak} + kQ_{Ak})(S_A / S_{Ae})^2 + (P_{Bk} + kQ_{Bk})(S_B / S_{Be})^2 \qquad (2)$$

where: S_A = the value of load distributed to

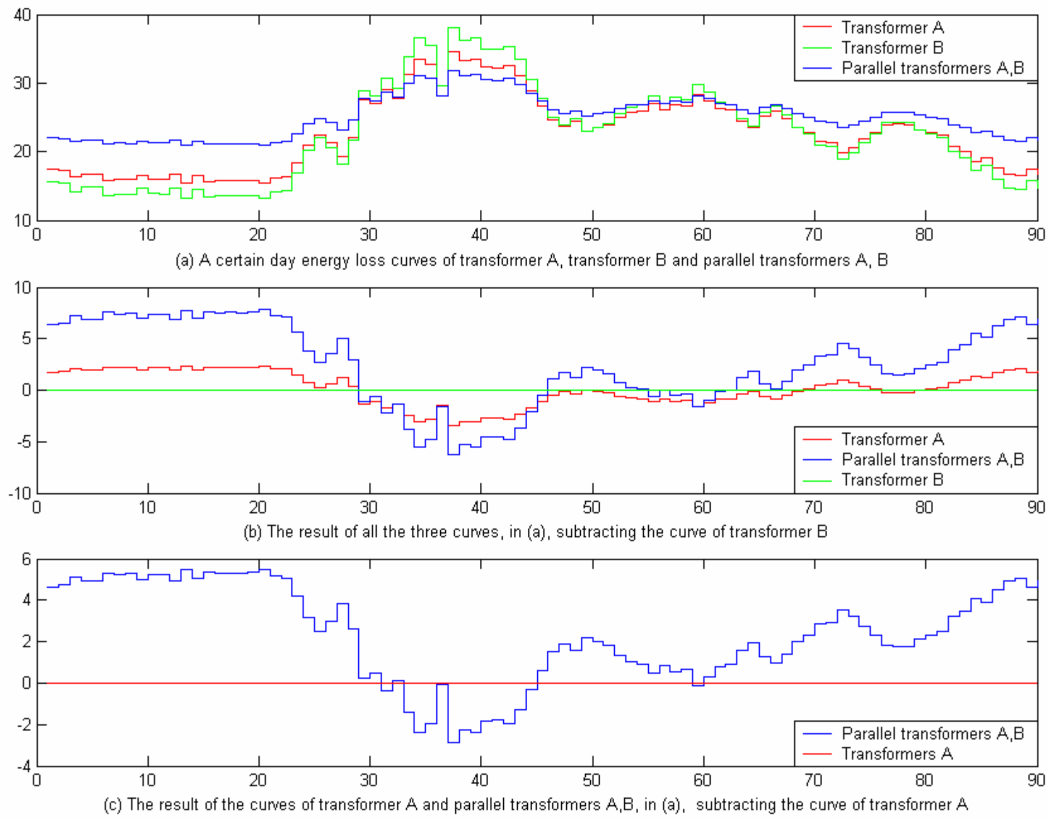

Fig.1 The daily energy loss curves and their conversion for 3 operation modes

transformer A ($S_A = SU'_{Bk} / (U_{Ak} + U'_{Bk})$); S_B = the value of load distributed to transformer B ($S_B = SU_{Ak} / (U_{Ak} + U'_{Bk})$); U'_{Bk} =The value of transformer B short-circuit voltage percentage converted to the capacity S_{Ae} ($U'_{Bk} = S_{Ae} U_{Bk} / S_{Be}$);

Take a certain substation as the example. There are two transformers with double windings in the substation. The technical parameters of the transformers are shown as follows: $S_{Ae} = 6300kVA$, $S_{Be} = 5000kVA$, $U_{Ak} = 7.44$, $U_{Bk} = 7.39$, $I_{A0}\% = 0.45$, $I_{B0}\% = 0.38$, $P_{Ao} = 8.22$kW , $P_{Bo} = 5.495$kW , $P_{Ak} = 39.507$kW , $P_{Bk} = 33.881$kW , $k = 0.1$. Daily energy loss curve of transformer A, transformer B and parallel transformers(A and B) can be drawn as fig.1, by the daily forecast load curve and the calculating result of formula (1), (2). In fig.1, x-axis express time and y-axis express energy loss. As we can see in fig.1, the load value of transformers is changing and the technical characteristics of these transformers are different, which cause the comprehensive energy loss of transformers changing non-linearly. Therefore, many points of intersection are created on these energy loss curves. These points of intersection may be correspondingly the time points to changing operation mode of transformers.

For the convenience of analysis, the energy loss curves in fig.1(a) have been converted to some other forms. The daily energy loss curve of transformer B (green curve) is considered as base curve, and all the curves (include the green curve) subtract the base curve to get the curves in fig.1(b). In the same way, if the daily energy loss curve of transformer A (red curve) is considered as base curve, and the daily energy loss curves of transformer A (red curve) and parallel transformers A,B (blue curve) subtract the red curve, the curves in fig.1(c) could be gotten. There are several areas enclosed by blue curve and green curve in fig.1(b). The changing points of positive area to negative area or the points of negative area to positive area may be correspondingly the time points to changing operation mode of transformers. These points divide a day into several time periods. If the absolute value of a certain area is less than a given Threshold value, it will be regarded as zero, and the corresponding time period will be merged into the left time period. If the absolute value of a certain area has been regarded as zero, and the two side areas of it have the same symbol, these three time periods will be merged into one time period. Thus, the time division of a day can be simplified, and a group of time points which divide one day into several time periods can be obtained. The treatment of the area enclosed by red curve and green curve in fig.1(b) or the area enclosed by red curve and blue curve in fig.1(c) is the same as above.

Thus, 3 groups of time points are obtained. These time points are all likely to become the operation mode changing point. By dividing a day into more time periods with the 3 groups of time points, then the fuzzy decision of every time periods can be executed, and the optimal operation mode which take into account both the economic factor, determined by the relative loss area of a time period, and the length of switch operating time interval factor, determined by the comparatively economic operation mode of neighbor time periods.

3 Fuzzy Decision in Every Time Periods

Two transformers with double winding have three kind of operating modes in one time period: operation of single transformer A; operation of single transformer B; operation of parallel transformers A,B. Two factors have been considered: economic factor, that is to say that the value of energy loss in a time period should be as smaller as possible; the influence factor of neighbor time periods, in fact, the switch operating times decreasing will be taken into account.

The data of above section are still used here. According to the above method, the day of fig.1 can be divided into 10 time periods. The energy loss value in these 10 time periods are shown in table 1.

The universe of discourse is

$$U = \{Operation\ of\ \text{single } A, Operation\ of\ \text{single B}, Operation\ of\ \text{parallel AB}\}$$

$$V = \{\text{Time period i, Time period ii, ……, Time period x}\}$$

Table 1 The energy loss value of 3 operating modes in 10 time periods *

Starting and end point / mode	Time period i	Time period ii	Time period iii	Time period iv	Time period v
	1~28	29~32	33~44	45~45	46~54
Single transformer A	480.7104	111.4409	384.0229	26.7014	219.8837
Single transformer B	429.8957	117.0906	415.9733	27.7640	223.2813
Parallel transformers A,B	613.4449	111.8323	363.6164	27.3024	234.1636
Starting and end point / mode	Time period vi	Time period vii	Time period viii	Time period ix	Time period x
	55~61	62~68	69~75	76~79	80~90
Single transformer A	188.3610	173.5057	150.7577	95.1303	208.4965
Single transformer B	196.2376	176.8984	147.2843	95.8569	194.4635
Parallel transformers A,B	191.9381	183.5333	170.6629	102.6041	252.1116

*The interval of forecast is regarded as a time unit.

3.1 Fuzzy relational matrix of factor I

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The Specification of the energy loss data in table 1 can be executed by following Zadeh formula (3).

$$r_{ij} = \frac{x_{ij} - \bigwedge_{l=1}^{n}\{x_{il}\}}{\bigvee_{l=1}^{n}\{x_{il}\} - \bigwedge_{l=1}^{n}\{x_{il}\}} \qquad (3)$$

Thus, the membership matrix of all the time periods based on the 3 operation modes can be obtained as follows:

$$\underset{\sim 1}{R} = \begin{bmatrix} 0.7232 & 1.0000 & 0 \\ 1.0000 & 0 & 0.9307 \\ 0.6102 & 0 & 1.0000 \\ 1.0000 & 0 & 0.4344 \\ 1.0000 & 0.7621 & 0 \\ 1.0000 & 0 & 0.5459 \\ 1.0000 & 0.6617 & 0 \\ 0.8514 & 1.0000 & 0 \\ 1.0000 & 0.9028 & 0 \\ 0.7566 & 1.0000 & 0 \end{bmatrix}$$

3.2 The calculation of weight

The idea that the value of weight changes has been introduced into this paper, that is to say, the distribution of weight changes along with the changing length of different time periods. A time period longer, the weight on factor I of this period will be bigger. While a time period shorter, the weight will be smaller. Because if a time period is very long, especially when it is longer than 4 hours (15 time units), the operation mode of this time period will be only determined by economic factor I, and not effected by the comparatively economic operation modes of neighbor time periods, and if a time period is very short, especially when it is only 1 or 2 time units, the operation mode of this time period will be almost always determined by its neighbor time period.

In this paper, the weight of two factors in time period i is

$$\underset{\sim \bullet i}{A} = \begin{pmatrix} a_{1i} \\ a_{2i} \end{pmatrix} \qquad (4)$$

The value of a_{1i} and a_{2i} can be calculated as follows:

$$a_{1i} = \begin{cases} 0.6 * l(i)/7 + 0.1 & l(i) \le 7; \\ 0.084 * (l(i) - 7)/5 + 0.7 & 7 < l(i) \le 12; \\ 0.784 + (0.216 * l(i) - 12)/(l\max - 12) & l(i) > 12. \end{cases} \qquad (5)$$

$$a_{2i} = 1 - a_{1i} \qquad (6)$$

where: $l(i)$ = the length of time period i; $l\max$ = the longest time period of all. The constants in formula (5) have been debugged.

Thus, the weight vector for the membership matrix $\underset{\sim 1}{R}$ based on factor I can be calculated by formula (5), and the result can be obtained as follows:

$$\underset{\sim 1}{A} = (a_{1,1}, a_{1,2}, \cdots, a_{1,10}) = [1.00 \;\; 0.44 \;\; 0.78 \;\; 0.18 \;\; 0.73 \;\; 0.70 \;\; 0.70 \;\; 0.70 \;\; 0.44 \;\; 0.77]$$

3.3 Fuzzy relational matrix of factor II

If the membership matrix of energy loss about all time periods is obtained, the influence from the comparatively economic operation modes in neighbor time periods can be calculated then. For example, If a time period is short, and the neighbor time period , one side of it, is comparatively longer, but the operation modes of two time periods are different from the economic operation angle, in order to decrease switch operating times, the operation mode of this time period may still coincide with it's neighbor. The longer the neighbor time periods, the much energy loss they decrease, that is to say, the bigger the value after Specification of the neighbor area enclosed by curve, the bigger the influence of it's neighbor time periods.

According to this kind of thought, If the elements of the membership matrix $\underset{\sim 1}{R}$ multiplied by corresponding elements of weight vector $\underset{\sim 1\bullet}{A}$, the matrix $\underset{\sim 1}{B}$ can be gotten as follows:

$$\underset{\sim 1}{B} = \underset{\sim 1}{A} \circ \underset{\sim 1}{R} = \begin{bmatrix} 0.7232 & 1.0000 & 0 \\ 0.4429 & 0 & 0.4122 \\ 0.4784 & 0 & 0.7840 \\ 0.1857 & 0 & 0.0807 \\ 0.7336 & 0.5591 & 0 \\ 0.7000 & 0 & 0.3821 \\ 0.7000 & 0.4632 & 0 \\ 0.5960 & 0.7000 & 0 \\ 0.4429 & 0.3998 & 0 \\ 0.5804 & 0.7672 & 0 \end{bmatrix}$$

Every row of elements in $\underset{\sim 1}{B}$ plus the largest elements in neighbor row within 15 time units, and no changing happened to the position of line, the matrix $\underset{\sim 2}{B}'$ can be obtained. If the elements of the matrix $\underset{\sim 2}{B}'$ multiplied by corresponding elements of weight vector $\underset{\sim 2\bullet}{A}$, the matrix $\underset{\sim 2}{B}$ can be gotten.

$$\underset{\sim}{B}_2' = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0.9111 & 0.7143 \\ 0.9826 & 0 & 0.3325 \\ 1.7343 & 0 & 1.0597 \\ 0.7794 & 0 & 0.6098 \\ 1.3317 & 0.4822 & 0 \\ 1.5417 & 0.8665 & 0 \\ 1.4473 & 1.0090 & 0 \\ 0.5818 & 1.3368 & 0 \\ 0.3346 & 0.8456 & 0 \end{bmatrix}$$

$$\underset{\sim}{B}_2 = \underset{\sim}{A}_2 \circ \underset{\sim}{B}_2' = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0.5076 & 0.3980 \\ 0.2122 & 0 & 0.0718 \\ 1.4122 & 0 & 0.8629 \\ 0.2076 & 0 & 0.1624 \\ 0.3995 & 0.1447 & 0 \\ 0.4625 & 0.2600 & 0 \\ 0.4342 & 0.3027 & 0 \\ 0.3241 & 0.7448 & 0 \\ 0.0779 & 0.1969 & 0 \end{bmatrix}$$

$\underset{\sim}{B}_1$ plus $\underset{\sim}{B}_2$, and after Specification, matrix $\underset{\sim}{B}$ can be obtained as follows:

$$\underset{\sim}{B} = \begin{bmatrix} 0.4197 & 0.5803 & 0 \\ 0.2515 & 0.2883 & 0.4601 \\ 0.4466 & 0 & 0.5534 \\ 0.6287 & 0 & 0.3713 \\ 0.5661 & 0.3362 & 0.0977 \\ 0.6761 & 0.0890 & 0.2350 \\ 0.6165 & 0.3835 & 0 \\ 0.5068 & 0.4932 & 0 \\ 0.4012 & 0.5988 & 0 \\ 0.4058 & 0.5942 & 0 \end{bmatrix}$$

For every row of $\underset{\sim}{B}$, the serial number of the line in which the largest number can be gotten is correspondingly the kind of operation mode should be adopted. From matrix $\underset{\sim}{B}$ and table 1, following result can be obtained: in the 1st~28th time unit, the second operation mode, single transformer B operation mode, should be adopted; in the 29th~44th time unit, the third operation mode, parallel transformers A,B operation mode, should be adopted; in the 45th~75th time unit, the first operation mode, single transformer A operation mode, should be adopted; in the 76th~90th time unit, the second operation mode, single transformer B operation mode, should be adopted.

Thus we can see the result coincides with human dispatcher's thought. Further more, we have calculated many other examples with different load data and different transformer parameters. The results of those examples show that the method is effective.

4 Conclusion

This paper has proposed a new intelligent method of transformer economic operation. Different from other transformer control decision method, this method can automatically take total situation into account, and all the information is utilized adequately. It makes decision just like a human dispatcher, and the result of the decision is satisfying.

References:

[1] HU Jingsheng, *Economic operation of power transformer*. Beijing:China Electric Power Press,1998.

[2] XU Jianzheng, Wang Jian, An artificial neural network based control system for transformer economic operation. *Power System Technology*, Vol.25,No.9,2001,pp.44-47

[3] Zhang Xilin, Zhang Fan, Optimal Operation of Main Transformers with Two-winding[J]. *Electric Power*, Vol.34. No.2,2001,pp.29-31