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Application of Gray Relational Analysis in Power Transformer State Ranking

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ABSTRACT

The grey system theory suitably handles the inferior, incomplete and uncertain information which normally applicable to partially recognized systems. The grey relational analysis is an element of grey system theory and observed to be an appropriate tool intended for power transformer state assessment. GRA determined the state ranking of transformer through complicated interrelationships between multiple factors and variables. The characteristics of dissolved gases in oil may reflect features of insulations which relatively distinguish the condition of transformer. An empirical procedure for state ranking demonstrates the effectiveness and feasibility in a practical sagacity.

Keywords- Key gas method, Grey relational analysis, Target Heart Degree, Power transformer State ranking.

1. INTRODUCTION

Insulation system is the key component of life extension, better availability and higher reliability of any oil immersed transformer [1]. The temperature of the winding and insulation condition limits the transformer loading capabilities [2].Transformer insulations (oil and paper) are essential sources to detect incipient faults, fast developing faults and insulation trending. These parameters generally reflect the health condition of the transformer. Dissolved gas analysis widely used to detect incipient faults within power transformer. The condition diagnose standard such as IEC, IEEE, CIGRE, MSZ National standard’s ratio codes and graphical techniques are widely employed by utilities. The main standards providing guidance for use, analysis, and applications are contained in ANSI/IEEE C57.104 and IEC 60599, commonly known as the "gas guides” [3-4].Several DGA interpretation schemes are based on empirical assumptions and practical knowledge gathered by experts all over the world. Therefore, the evaluation of the condition of power transformer is a complicated decision-making problem that includes several quantitative attributes. It regarded as a type of multi-attribute or multi-criteria decision making (MADM/MCDM) problem. Several common methodologies were proposed for MADM, such as simple additive weighting (SAW), the technique for order preference by similarity to ideal solution (TOPSIS), analytical hierarchy process (AHP), data envelopment analysis (DEA), and Grey relational analysis (GRA) [5]. The grey system theory proposed by Deng has been widely applied to various fields [5-6]. It is useful for managing inferior, incomplete and uncertain information. The GRA was successfully applied to solve a variety of multi-attribute or multi-criteria decision making (MADM/MCDM) problems such as hiring decisions [7], the restoration planning for power distribution systems [8], and the modeling of quality function deployment [9]. The GRA applied here to assess the contribution of DGA parameters of five testing transformers connected in a fleet.

2. PRINCIPLES OF GREY RELATIONAL ANALYSIS

The grey relational analysis relates the degree of similarity or dissimilarity of developing trends between an alternative and the ideal alternative. A stronger association exists if the trend of change between the alternative and the ideal alternative is consistent. If not, the relational grade is smaller [10-11]. The procedure of GRA is to first translate the performance of all alternatives into a comparability sequence. A reference sequence (ideal target sequence) defined according to these sequences. Subsequently, the grey relational coefficients between every compared sequence and the reference sequences are calculated to find the grey relational grade between the reference sequence and every compared sequence. If a comparability sequence translated from an alternative has the highest grey relational grade between the reference sequence and itself, that alternative is the optimal choice [12-17]. The procedures of grey relational analysis can be described as follows:

2.1 Identification of Comparative Series

For a multi-criteria decision making problem, if m alternatives and n attributes exist, the i th alternative can be expressed as $Y_i = (y_{i1}, y_{i2}, ..., y_{ij})$, where y_{ij} is the performance value of attribute j of alternative i . The term Y_i can be translated into the comparability sequence $X_{ij} = (x_{i1}, x_{i2}, ..., x_{ij})$ by using either (1) or (2).

$$X_{ij} = \frac{Yij - \min(Yij, i=1,2\ldots\ldots m)}{\max(Yij, i=1,2\ldots\ldots m) - \min(Yij, i=1,2\ldots\ldots m)} \text{ for} \tag{1}$$

i = 1, 2, ……, m ; j = 1, 2, ……, n

$$X_{ij} = \frac{\max(Yij, i=1,2\ldots\ldots m) - Yij}{\max(Yij, i=1,2\ldots\ldots m) - \min(Yij, i=1,2\ldots\ldots m)} \text{ for} \tag{2}$$

i = 1, 2, ……, m ; j = 1, 2, ……, n

Equation (1) is used for benefit attributes and (2) is used for cost attributes. All DGA parametric values are scaled into [0, 1] by applying the grey relational generating procedure using (1) or (2). For an attribute j of alternative i, if the value xij, which was processed by grey relational generating procedure, is equal to 1, or nearer to 1 than the value for any other alternative, the performance of alternative i is optimal for the attribute j . Therefore, an alternative is the optimal choice if all of its performance values are closest to or equal to 1. However, this type of alternative does not usually exist [9-11]. Hence defined the reference sequence X_0 as (x_{01}, x_{02}, ..., x_{0j}), and subsequently aimed to find the alternative in which the comparability sequence is the closest to the reference sequence.

2.2 Grey relational coefficient

The Grey relational coefficient(GRC) must first be determined before we obtain the Grey relation Grade.GRC is used for determining how close X_{ij} is to X_{0j} .The best grey relational coefficient is a sequence that closer to X_0. If the grade of local grey relation is brought to define Grey relational coefficient, γ (X_{0j}, X_{ij}), it can be expressed as following:

$$\gamma (X_{0j}, X_{ij}) = \frac{\Delta \min + \xi \Delta \max}{\Delta ij + \xi \Delta \max} \text{ for } i = 1, 2, \ldots\ldots, m; j = 1, 2, \ldots\ldots, n \qquad (3)$$

$$\Delta ij = \| X_{0j} - X_{ij} \|$$

$$\Delta \min = \min (\Delta ij, i = 1, 2, \ldots\ldots, m : j = 1, 2, \ldots\ldots, n),$$

$$\Delta \max = \max (\Delta ij, i = 1, 2, \ldots\ldots, m : j = 1, 2, \ldots\ldots, n),$$

ξ is the distinguishing coefficient, $\xi \in [0, 1]$ .The purpose of the distinguishing coefficient is to expand or compress the range of the grey relational coefficient. The distinguishing coefficient ξ set as 0.5 mostly, denoting the up-apart value and down-apart value of different information space have the same weight [9-11]. Δ ij is the absolute deviation value of the reference series and the compared one.

2.3 Grey relational Grade

The grey relational grade, a weight sum of grey relational coefficient, is taken as follows:

$$\Gamma(X_0, X_i) = \sum_{j=1}^{n} Wj * \boldsymbol{\gamma} \, (\mathbf{Xoj, Xij}) \text{ for } i = 1, 2, \ldots\ldots, m; \qquad (4)$$

Where, Γ (Xo, Xi) is the grey relational grade between X_0 and X_i . It represents the level of correlation between the reference sequence and the comparability sequence. wj is the weight of attribute j and usually $\sum_{j=1}^{n} Wj = 1$ and sometime depends on the judgments of the decision makers or the structure of the proposed problem. The grey relational grade indicates the degree of similarity between the comparability sequence and the reference sequence [9-11]. As discussed, for each attribute, the reference sequence represents the optimal performance that can be achieved by any of the comparability sequences. Therefore, if a comparability sequence for an alternative obtains the highest grey relational grade with the reference sequence, the comparability sequence is most similar to the reference sequence, and that alternative would be the optimal choice [12-17].

3. GREY RELATIONAL ANALYSIS IN POWER TRANSFORMER STATE RANKING

The fleet of five power transformer commissioned in 1979 rating of 220/22 KV, 25KVA is selected for investigation. DGA data of key gases and parameters such as oil temperature, tan delta, resistivity and water content are utilizes in the study. On the basis of GRA principle the computational procedures for transformer state ranking evaluation described as follows:

3.1 Grey Relational formation

The reference and comparability sequences created as shown in the Table-I. The grey relational generating process in which equation (1) used for benefit attributes i.e. intended to resistivity. The other nine parameters normalizes by applying equation (2) as cost attributes which includes key gases, oil temperature, water contents and dielectric dissipation factor. For example in case of water content, the maximal value is 20 and the minimal value is 9. By applying equation (2), the results of grey relational generating of T-1 is equal to $X_{01}(1) = 0.6363$; $X_{01}(4) = (20-11) / (20-9) = 0.8181$ and $X_{01}(10) = 0$. All results of grey relational generation to normalize the sequences are shown in Table-II

Table I: The reference and comparability sequences

Performance Attributes	Comp. string	DGA Samples of Testing Transformer				
		T-1	T-2	T-3	T-4	T-5
Oil temp.	32	40	38	32	44	54
DDF	0.006	0.011	0.013	0.012	0.012	0.006
Resistivity	3.77	2.05	2.04	2.12	2.38	3.77
Water contents	9	11	10	9	12	20
CO	18	118	18	20	104	50
CH4	24	153	28	24	169	128
CO2	806	3795	819	806	3828	1412
C_2H4	1	22	5	5	26	1
C_2H6	13	46	14	13	56	23
H2	270	2936	550	270	2152	2349

*Dielectric Dissipation factor

Table II: The normalized sequences

Performance Attributes	Comp. Sequence (X0)	DGA Samples of Testing Transformer				
		T-1	T-2	T-3	T-4	T-5
Oil temp.	1	X01(1) = 0.636	X02(1) = 0.727	X03(1) = 1	X04(1) = 0.454	X05(1) = 0
DDF*	1	X01(2) = 0.285	X02(2) = 0	X03(2)= 0.142	X04(2) = 0.142	X05(2) = 1
Resistivity	1	X01(3) = 0.005	X02(3) = 0	X03(3)= 0.046	X04(3) = 0.196	X05(3) = 1
Water contents	1	X01(4) = 0.818	X02(4) = 0.909	X03(4)= 1	X04(4) = 0.727	X05(4) = 0
CO	1	X01(5) = 0	X02(5) = 1	X03(5)= 0.98	X04(5) = 0.14	X05(5) = 0.68
CH4	1	X01(6) = 0.110	X02(6) = 0.972	X03(6)= 1	X04(6) = 0	X05(6) = 0.282
CO2	1	X01(7) = 0.010	X02(7) = 0.9956	X03(7)= 1	X04(7) = 0	X05(7) = 0.799
C_2H4	1	X01(8) = 0.16	X02(8) = 0.84	X03(8)= 0.84	X04(8) = 0	X05(8) = 1
C_2H6	1	X01(9) = 0.232	X02(9) = 0.976	X03(9)= 1	X04(9) = 0	X05(9) = 0.767
H2	1	X01(10) = 0	X02(10) = 0.894	X03(10)= 1	X04(10) = 0.294	X05(10) = 0.2

3.2 Determine the Grey Relational Deviation

The reference sequence Xo and the deviation sequences Δ ij can be defined as:

Δij = || X0j - Xij || The deviation sequences values of T-1 for samples at point K=1, 2 ….10 is illustrated as follows:

Δ01(1) = || 1 - 0.6363 || = 0.3637; Δ01 (4) = 0.1818 and Δ01 (10) = 1

All the deviation values of normalized sequences after processing can be seen in Table III. The minimum and maximum deviation values from Δ ij matrix are taken as follows: Δ min = 0 and Δ max= 1.

Table III: The Deviation Sequences

Performance Attributes	Comp. Sequence (X0)	DGA Samples of Testing Transformer				
		T-1	T-2	T-3	T-4	T-5
Oil temp.	1	Δ01(1)= 0.363	Δ02(1)= 0.272	Δ03(1)= 0	Δ04(1)= 0.545	Δ05(1)= 1
DDF	1	Δ01(2)= 0.714	Δ02(2)= 1	Δ03(2)= 0.857	Δ04(2)= 0.857	Δ05(2)= 0
Resistivity	1	Δ01(3)= 0.995	Δ02(3)= 1	Δ03(3)= 0.954	Δ04(3)= 0.804	Δ05(3)= 0
Water contents	1	Δ01(4)= 0.181	Δ02(4)= 0.090	Δ03(4)= 0	Δ04(4)= 0.272	Δ05(4)= 1
CO	1	Δ01(5)= 1	Δ02(5)= 0	Δ03(5)= 0 .02	Δ04(5)= 0.86	Δ05(5)= 0.32
CH4	1	Δ01(6)= 0.889	Δ02(6)= 0.027	Δ03(6)= 0	Δ04(6)= 1	Δ05(6)= 0.717
CO2	1	Δ01(7)= 0.989	Δ02(7)= 0.004	Δ03(7)= 0	Δ04(7)= 1	Δ05(7)= 0.200
C_2H4	1	Δ01(8)= 0.84	Δ02(8)= 0.16	Δ03(8)= 0 .16	Δ04(8)= 1	Δ05(8)= 0
C_2H6	1	Δ01(9)= 0.767	Δ02(9)= 0.023	Δ03(9)= 0	Δ04(9)= 1	Δ05(9)= 0.232
H2	1	Δ01(10)= 1	Δ02(10)= 0.10	Δ03(10)= 0	Δ04(10)= 0.7059	Δ05(10)= 0.779

3.3 Grey Relational Coefficient calculation

All performance attributes assumed to be equally important hence with equal weighting, the distinguishing coefficient ξ set as 0.5. By applying Eq. (3) signifies the up-apart value and down-apart value of different information space. The grey relation coefficient of some samples of T-1 illustrated below and rest of the coefficients are shown in Table IV.

$\gamma\ (X_0\ (1), X_1(1)) = (0 + 0.5 * 1) / (0.3637 + 0.5 *1) = 0.5789$

$\gamma\ (X_0\ (4), X_1(4)) = (0 + 0.5 * 1) / (0.1818 + 0.5 *1) = 0.7333$

$\gamma(X_0(10), X_1(10)) = (0 + 0.5 * 1) / (1 + 0.5 *1) = 0.3333$

Table IV: Results of grey relational coefficient, Grade and Ranking of Testing Transformers

Performance Attributes	Comp. Sequence (X0)	DGA Samples of Testing Transformer				
		T-1	T-2	T-3	T-4	T-5
Oil temp.	1	0.578	0.647	1	0.478	0.333
DDF	1	0.411	0.333	0.368	0.368	1
Resistivity	1	0.334	0.333	0.343	0.383	1
Water contents	1	0.733	0.846	1	0.647	0.333
CO	1	0.333	1	0.961	0.367	0.609

CH4	1	0.359	0.947	1	0.333	0.410
CO2	1	0.335	0.991	1	0.333	0.713
C_2H4	1	0.373	0.7575	0.7575	0.3333	1
C_2H6	1	0.344	0.955	1	0.333	0.682
H2	1	0.333	0.826	1	0.414	0.390
Summation	--	4.188	7.638	8.431	3.992	6.474
Grade	--	0.418	0.763	0.843	0.399	0.647
Ranking	--	4	2	1	5	3

3.4 Grey Relational Grades

The 10 parameters in the study are used as performance attributes to decide the grey relational grades of testing transformers, therefore weighting of ten attributes decided to be (1/10). The summation of all attributes in the last row of Table IV shows the ranking of transformers. Finally the approaching degree ranking of transformer decided as - T3 > T2 > T5 > T1 > T4.

4. Conclusion

The key gas method of IEC ought to be superior and shows certain degree of success in identifying the state of transformers. The characteristics of additional parameters may also reflect different aspects of insulations that relatively discriminate the state assessment of transformers to some extent. The grey relational approach has proven to be effective in evaluating the transformers condition without the standard fault model. GRA is significantly proved to measure the correlation between five transformers based on a multi-attribute environment. The results obtained in this work can be useful for maintenance activities and the procedure adopted here also constructive in comprehensive analysis by applying more attributes.

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