Assessment of Transformer Oil Quality Using Fuzzy Logic Technique

INTRODUCTION

The life of a transformer is dependant upon life of its insulation. The insulation of a transformer deteriorates over a span of time with temperature, moisture and oxygen. Oil quality assessment is the technique to decide the quality of transformer oil after a specific period of use. The quality of transformer oil decides the efficiency of the transformer while in service. This chapter presents an innovative methodology for assessment of transformer oil quality by using fuzzy logic based decision support system.

The quality of transformer oil can be termed as good if it fulfills the following functional requirements for at least 30 years of service.

- It acts as an electrical insulator.
- It acts as a coolant for transformer winding and core.

Transformer oil free from water particles and sludge acts as a good insulator. Gases are produced in a transformer when it is subjected to electrical, thermal and environmental stresses. These gases get dissolved in oil and provide information about the incipient faults developing in transformer. The oil quality assessment is necessary for deciding preventive maintenance schedules of transformers. So far during the course of study of literature, no work has been found on the assessment of oil quality for deciding future course of action, after a specific period of use. In this dissertation work, an attempt is being made to assess oil quality by using fuzzy logic to arrive at a decision regarding the action to be taken.

RECONDITIONING OF TRANSFORMER OIL

There is a tendency of transformer oil to absorb water vapour from atmosphere due to breathing during service and even during transportation and storage. Water is injurious to transformer insulation system due to the following reasons [1].

- It reduces the electric strength of oil.
- It reduces the resistivity of oil.
- It accelerates deterioration of solid insulation.

Air dissolved in oil induces risk of bubble formation and accelerated oxidation process, leading to chemical deterioration of oil. The biggest contaminator, moisture enters transformer oil from following sources.

- by leakage past gasket
- by absorption within the transformer as a product of degradation of insulation at high temperatures

Transformer oil also gets impregnated with various types of impurities. These may be solid ones like hygroscopic fibers, suspended particles or liquid ones like dissolved water organic and inorganic gases. They bring about a considerable reduction in the dielectric strength of the oil. As an example, oil at 20^{o}C saturated with water (44 PPM) attains only about 25% of the original electric strength with water content of 10 PPM.

Thus, transformer oil is reconditioned to eliminate the following elements.

- free and dissolved water
- solid impurities
- dissolved gases

The possible reconditioning processes are:

- Single Filtering and Degassing
- Double Filtering and Degassing
- Reclamation

The oil quality assessment method developed in this dissertation is based on finding the Total Hydrocarbon Gas (TCG) content in the oil. Depending upon TCG and severity of different gases present, the Oil Degradation Index (ODI) is evaluated and used to assign one of the above possible courses of action, if it is suitable for reconditioning. The single stage and double stage filtering and degassing are done by vacuum plants. This procedure involves course and fine filtration followed by degassing and dehumidification. The transformer oil is spread over a large surface area under vacuum, after which oil is delivered for use. The single stage and double stage filtering decision depends upon degradation level of used oil as manifested by the concentration of dissolved gases. In addition there are two other classifications.

- No Filtering
- Do Not Use

"No Filtering" condition means oil is not degraded and can be reused without any requirement of reconditioning. "Do Not Use" condition means whole transformer oil is to be replaced with new one, as the oil is degraded to an extent that its reconditioning has become impossible.

Oil reclamation is a process to remove heterogeneous atoms and oxidized products from oil. This is a chemical treatment of oil followed by filtering and degassing. The aim is to remove acid and other harmful compounds by precipitation, sludge formation or by use of chain reaction of organic compounds.

FUZZY MEASURE FOR ASSESSMENT OF TRANSFORMER OIL QUALITY

It is easy to visualize that considerable uncertainty is involved in the process of defining transformer oil quality. Hence, it is imperative to use fuzzy logic for this purpose. The fuzzy measure for the assessment of oil quality is based on a combination of knowledge about TCG along with particular key gases evolved due to fault condition. The decision making process is based on the degree of match between current and permissible limits of dissolved gases and the fuzzy rule based system. The method is designed to compute the fuzzy measure named as transformer Oil Degradation Index (ODI), by integration of the information of different hydrocarbon gases formed in transformer oil. This approach uses a knowledge base to derive Oil Degradation Index (ODI). The transformer oil quality data is transformed into a normalized fuzzy number with membership grade function adjusted for characterizing transformer oil quality based on the data available from both normal and faulty transformers.

Fuzzy Membership Functions

The input variables to the present classification have different ranges in various hydrocarbon gases viz. CH_4, H_2, C_2H_6, C_2H_4, and C_2H_2 developed during incipient fault detection on the basis of DGA and TCG (Total Gas Content). Trapezoidal membership functions (trapmf) are used for all input variables. The term set of membership functions for all input variables except TCG are:

- Low
- Moderate
- High
- Severe

The input variable TCG uses another term set 'V. High' in addition to above term sets. The input membership functions along with different term sets are shown in Figure 4.1. This figure is generalized for different inputs. The ranges of membership functions for input variables are shown in Table 4.1.

There is only one output variable to assign transformer oil quality. This is called Oil Degradation Index (ODI). ODI value is computed for each input variable defined above. This ODI value and severity of fault as defined by rule base, decide the process to be adopted for reconditioning. The input membership functions are designed to give a constant output over substantial range. The membership of each input variable varies over a definite range, uniformly on both sides (trapezoidal). The full membership (value 1) covers 80% area of total range. This is the reason why output gives a constant ODI in maximum cases thus, making this measure insensitive to small changes in gas concentrations. This is an extremely useful property to take care of normal changes due to operations and ageing. Another significant feature is that this ODI is further correlated to the specific reconditioning procedure of transformer oil. The output membership functions are shown in Figure 4.2 and corresponding range and type of membership functions are shown in Table 4.2.

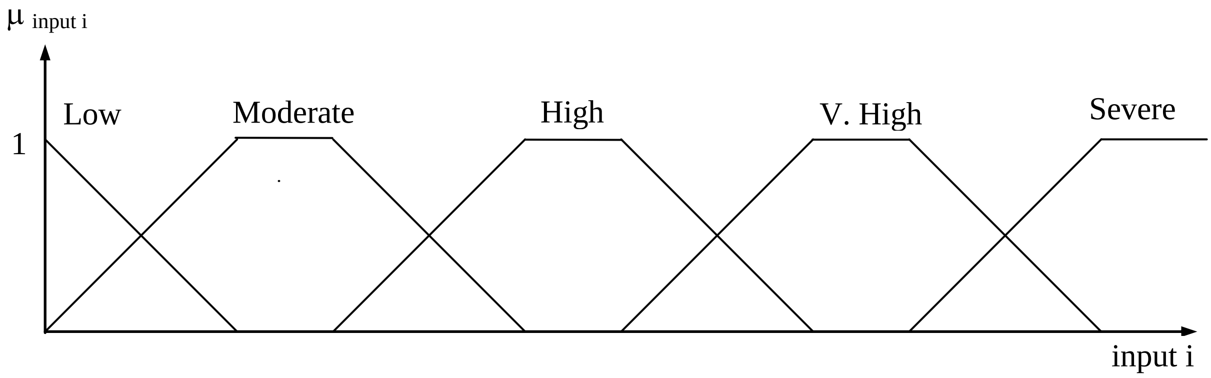

Fig. : Input membership function used in oil reconditioning

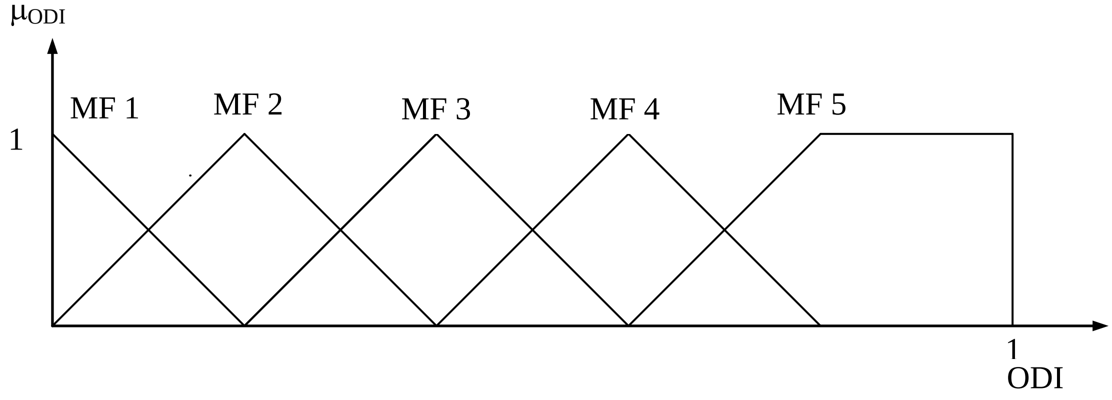

Fig. : Output membership function used in oil reconditioning

Note:

MF 1	=	No Filtering
MF 2	=	Single Filtering & Degassing
MF 3	=	Double Filtering & Degassing
MF 4	=	Reclamation
MF 5	=	Do Not Use

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Fuzzy Rules

The fuzzy rules are developed to match a specific output condition of oil depending upon various input values. 38 rules are developed in all.

Table 4.3 shows the input data for oil quality analysis. The corresponding outputs are shown in Table 4.4. The output oil quality or Oil Degradation Index (ODI) is shown for individual group of inputs.

Table 4.3: Input Data for Oil Quality Assessment

INPUT DATA						
S. No.	**CH_4**	**H_2**	**C_2H_6**	**C_2H_4**	**C_2H_2**	**TCG**
1.	4	3	4	3	0	14
2.	2	1	1	0	0	4
3.	2	2	0	0	0	4
4.	3	2	3	1	0	9
5.	2	2	4	3	0	11
6.	4	2	4	3	0	13
7.	3	2	3	0	0	8
8.	20	9	5	10	0	44
9.	4	7	3	1	0	15
10.	10	14	8	5	0	37
11.	15	13	4	3	0	35
12.	10	13	2	1	0	26
13.	7	17	13	3	0	40
14.	9	12	3	7	0	31
15.	1	0	0	0	0	1
16.	125	95	16	281	0	517
17.	212	68	54	470	0	804
18.	107	32	17	265	0	421
19.	31	42	16	115	0	204
20.	144	60	67	449	9	729
21.	95	1076	4	71	231	1477
22.	20	240	5	28	96	389
23.	32	338	1	32	50	453
24.	117	531	27	132	848	1655

25.	71	79	3	72	115	340
26.	38	41	3	45	58	185
27.	104	110	30	86	131	461
28.	248	125	10	147	179	709
29.	262	222	27	168	410	1089
30.	91	98	18	72	154	433
31.	43	48	3	75	81	250
32.	1107	201	110	2016	6350	9784
33.	47	442	117	67	69	742
34.	1417	114	296	2096	0	3923
35.	4	2	3	4	0	13
36.	99	747	13	97	1036	1992
37.	122	41	31	143	188	525
38.	339	59	42	392	1	833
39.	4	7	3	2	0	16
40.	34	21	5	47	62	169
41.	21	199	0	40	144	404
42.	5365	2973	427	5532	2124	16421
43.	61	65	16	143	3	288
44.	87	16	75	395	30	603
45.	186	813	15	249	1001	2264
46.	38	212	15	47	78	390
47.	16615	2754	3657	31476	613	55155
48.	1393	800	304	2817	3000	8314
49.	770	199	217	1508	72	2766
50.	8784	4906	1404	9924	9671	34689
51.	13	24	5	43	319	404
52.	584	266	328	862	1	2041
53.	10	160	3	1	1	175
54.	619	80	326	2480	0	3505
55.	3997	231	1726	5584	0	11538
56.	24	127	0	32	81	264
57.	4066	9474	353	6552	12997	33442
58.	1053	507	297	1440	17	3314
59.	695	416	74	867	0	2050
60.	207	441	43	224	261	1176
61.	38	212	47	15	78	390
62.	1393	800	304	2817	3000	7314
63.	770	199	217	1508	72	2766
64.	8784	4906	1404	9924	9671	34689
65.	1742	425	7299	37043	158	62349
66.	95	1076	4	71	231	1477

67.	754	244	172	1281	27	2478
68.	167	117	48	481	7	820
69.	1324	858	208	2793	7672	12855
70.	369	137	144	1242	16	1908
71.	27	274	5	33	97	436
72.	370	1249	56	606	1371	3652
73.	20	240	5	28	96	389
74.	79	33	30	215	5	362
75.	22	307	2	33	109	473
76.	144	60	67	449	9	729
77.	9739	2004	2750	5113	0	19606
78.	107	127	11	157	224	623

Table 4.4: OUTPUT: OIL Degradation Index and Suggested Reconditioning Method

S. No.	Oil Degradation Index (ODI)	Reconditioning Method
1.	0.0784	No Filtering
2.	0.0784	No Filtering
3.	0.0784	No Filtering
4.	0.0784	No Filtering
5.	0.0784	No Filtering
6.	0.0784	No Filtering
7.	0.0784	No Filtering
8.	0.0784	No Filtering
9.	0.0784	No Filtering
10.	0.0784	No Filtering
11.	0.0784	No Filtering
12.	0.0784	No Filtering
13.	0.0784	No Filtering
14.	0.0784	No Filtering
15.	0.0784	No Filtering
16.	0.2500	Single Filtering and Degassing
17.	0.2500	Single Filtering and Degassing
18.	0.2500	Single Filtering and Degassing
19.	0.2500	Single Filtering and Degassing
20.	0.2500	Single Filtering and Degassing
21.	0.4500	Double Filtering and Degassing
22.	0.2500	Single Filtering and Degassing
23.	0.2500	Single Filtering and Degassing
24.	0.4500	Double Filtering and Degassing

25.	0.2500	Single Filtering and Degassing
26.	0.2500	Single Filtering and Degassing
27.	0.3500	Double Filtering and Degassing
28.	0.2500	Single Filtering and Degassing
29.	0.3500	Double Filtering and Degassing
30.	0.2500	Single Filtering and Degassing
31.	0.2500	Single Filtering and Degassing
32.	0.8610	Do Not Use
33.	0.4500	Double Filtering and Degassing
34.	0.6500	Reclamation
35.	0.0784	No Filtering
36.	0.4500	Double Filtering and Degassing
37.	0.4500	Double Filtering and Degassing
38.	0.2500	Single Filtering and Degassing
39.	0.0784	No Filtering
40.	0.2500	Single Filtering and Degassing
41.	0.2500	Single Filtering and Degassing
42.	0.7770	Do Not Use
43.	0.2500	Single Filtering and Degassing
44.	0.4500	Double Filtering and Degassing
45.	0.6500	Reclamation
46.	0.2500	Single Filtering and Degassing
47.	0.7770	Do Not Use
48.	0.7770	Do Not Use
49.	0.6500	Reclamation
50.	0.7770	Do Not Use
51.	0.4500	Double Filtering and Degassing
52.	0.4500	Double Filtering and Degassing
53.	0.2500	Single Filtering and Degassing
54.	0.6500	Reclamation
55.	0.7770	Do Not Use
56.	0.2500	Single Filtering and Degassing
57.	0.7770	Do Not Use
58.	0.6500	Reclamation
59.	0.4500	Double Filtering and Degassing
60.	0.3500	Double Filtering and Degassing
61.	0.2500	Single Filtering and Degassing
62.	0.7770	Do Not Use
63.	0.4500	Double Filtering and Degassing
64.	0.7770	Do Not Use
65.	0.8710	Do Not Use
66.	0.4500	Double Filtering and Degassing
67.	0.4500	Double Filtering and Degassing
68.	0.2500	Single Filtering and Degassing
69.	0.7770	Do Not Use
70.	0.4500	Double Filtering and Degassing
71.	0.2500	Single Filtering and Degassing
72.	0.6500	Reclamation

73.	0.2500	Single Filtering and Degassing
74.	0.2500	Single Filtering and Degassing
75.	0.2500	Single Filtering and Degassing
76.	0.2500	Single Filtering and Degassing
77.	0.7770	Do Not Use
78.	0.2500	Single Filtering and Degassing

4.2 CONCLUSION

The method applied in this work is original and innovative in nature. During periodical incipient fault diagnosis of transformers, Oil Degradation Index (ODI) gives additional information for representing quality of oil. This helps in better monitoring of transformer condition. The output results of oil quality assessment can be used for making appropriate decisions regarding the procedure to be adopted for the reconditioning of transformer oil. This will improve life of transformer oil and life of transformer as a whole. Hence, preventive maintenance schedules can be programmed optimally with minimum breakdown.

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