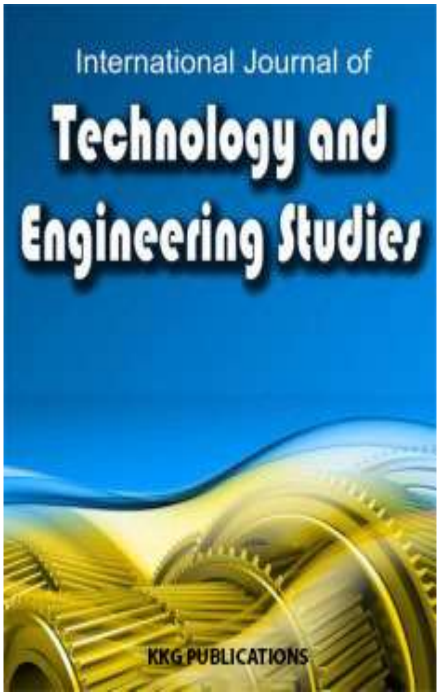

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A COMPUTER PROGRAM FOR FAULT DIAGNOSIS AND ASSESSMENT OF QUALITY INSULATION OIL IN POWER TRANSFORMER BASED DISSOLVED GAS ANALYSIS

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Abstract. This research aims to study the concentrations of gases based on the Dissolved Gas Analysis (DGA) in power transformer oil. The DGA methods(Roger's ratio method, IEC ratio method, and Doernenburg ratio method) are used to develop a computer program for precise diagnosis and simultaneous assessment. This paper used C++ software and matched it with IEC standard 599 to identify the fault types and IEEE standard C57-104.1991 to assess oil quality as per TCG. The appropriate treatments, including single filtering and degassing, double filtering and degassing, and reclamation, are applied without reusing the oil. Suitable treatment is achieved via Roger's ratio method, IEC ratio method, and Sonnenburg ratio method depending on the dissolved gas analysis in the oil. The C ++ program and windows are easy to use and are high enough for fault diagnosis and oil quality evaluation. The programing can assess the oil quality as per IEEE standard and C57-104 -1991 and IEC standard 599 specifications.

INTRODUCTION

The quest of finding a suitable method for accurate fault diagnostics and assessing the oil quality of electrical power transformer for life-long safeguard is ever-demanding. Undoubtedly, the longevity of transformer function and working efficiently have certainly been decided by its insulating quality. Generally, this insulation deteriorates over a time span with the variation of temperature, moisture, oxygen and other environmental factors. The judgment of faults and the assessment of oil quality is one of the most important sources in protecting transformers operational failures. The power transformers are exceptionally expensive and the damage in insulation system often causes high economic loss [1]. In the past, several methodologies are adopted for the diagnosis of faults in the transformer oil to assess the oil quality and different smart standards are developed with the approved specifications including IEEE standard C57-104.1991 [2] and IEC standard 599 [3]. Most of the assessment and diagnosis are based on the computer program. Despite many efforts the efficient and precise determination method of the nature of faults and subsequent rectification mechanism for superior performance is far from being achieved.

It is well known that electrical transformer oils possess a dual function, including insulation and cooling. Their superior insulation and cooling attributes in the coils under a severely elevated change in temperature over extended operational period protects them from faults generation. However, the presence of high electrical pressure, temperature, and harsh environmental conditions produce hydrocarbons (gases) within the oil with strong negative impact on the functioning [4]. Therefore, transformers faults diagnosis and oil quality assessment are obligatory for protective maintenance schedules [5]. Several methods have been developed for fault diagnostics. However, for the assessment of oil quality one has to separate it.

We determine the concentrations of these gases based on the dissolved gas analysis (DGA) in power transformer oil. The DGA methods(Roger's ratio method, IEC ratio method and doernenburg ratio method) are used to develop a computer program for precise diagnosis and simultaneous assessment. In this paper used C++ software and matched with IEC standard 599 to identify the fault types and IEEE standard C57-104.1991 to enough is capable of assessing the quality of oil as per (TCG). The appropriate treatments including single filtering and degassing, double filtering and degassing, as well as reclamation are applied without reusing the oil. The results are analyzed, comparisons are made, and the accurate diagnostics are achieved.

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LITERATURE REVIEW

Recently, several interpretative techniques such as IEC 60599 Standard ratio codes, IEEE Standard C57-104, Roger and Doernenburg ratio codes, Key gas method, CIGRE guidelines, MSZ-09-00.0352 National Standard ratio codes and graphical method of Duval triangle are developed to predict the emergence of faults and to determine their types. All these methods of fault diagnosis are based on a celebrated DGA scheme [6].

In the Key gas method the decomposition of gases in the transformers oil and paper insulation are caused by temperature dependent faults. The occurrence of various faults such as over-heating of oil and cellulose, corona and arcing in oil produce certain gases and their proportions act as faults indicator types [7].

In Doernenburg's ratio method values of CH_4/H_2, C_2H_6/C_2H_2, C_2H_2/CH_4, and C_2H_2/C_2H_4 are used to indicate the emergence of thermal fault (corona and arcing) see table1.

TABLE 1
SUGGESTED DIAGNOSIS FROM GAS RATIOS OF DOERNENBURG METHOD [9]

Suggested Diagnosis	R1=CH4/H2 Extracted From Oil	Gas Space	R2=C2H2/C2H4 Extracted From Oil	Gas Space	R3=C2H2/CH4 Extracted From Oil	Gas Space	R4=C2H6/C2H2 Extracted From Oil	Gas Space
1- Thermal Decomposition	>1.0	>0.1	<0.75	<1.0	<0.3	<0.1	>0.4	>0.2
2- Corona (Low Intensity PD)	<0.1	<0.01	Not Significant		<0.3	<0.1	>0.4	>0.2
3-Arcing (High Intensity PD)	>0.1 <0.1	>0.01 <0.01	>0.75	>1.0	>0.3	>0.1	<0.4	<0.2

Based on thermal degradation principles and DGA this method utilizes ANS/IEEE Standard C57.104-1991. The method being a complex one with insufficient ratio ranges, the implementation may result in no interpretation [6, 8].

TABLE 2
SUGGESTED DIAGNOSIS FROM GAS RATIOS OF IEC METHOD [10]

Case No.	C2H2 / C2H4	CH4 / H2	C2H4 / C2H6	Characteristic fault
0	< o.1	>0.1 < 1	< o.1	No fault
1	< o.1But not significant	< o.1	< 1	Partial discharges of low energy density
2	>1 < 3	< o.1	< 1	Partial discharges of low energy density
3	> 3	>0.1 < 1	> 3	Discharges of low energy
4	>1 < 3	>0.1 < 1	> 3	Discharges of High Energy
5	< o.1	>0.1 < 1	< 3	Thermal fault of low Temperature < 150 C˚
6	< o.1	< 3	< 1	Thermal fault of low Temperature < 150 C˚ - 300 C˚
7	< o.1	> 3	> 1 < 3	Thermal fault of medium temperature range 300 C˚- 700 C˚
8	< o.1	> 3	> 3	Thermal fault of high temperature >700 C˚

The Duval triangle method considers the concentrations (ppm) of methane (CH_4), ethylene (C_2H_4), and acetylene (C_2H_2) and expresses ($CH_4 + C_2H_4 + C_2H_2$) as a total gas percentage. The evaluation relies upon a chart (work point) in the triangular coordinate system which is subdivided into fault zones. The located point in the fault zone signifies the likely fault type that gets generated from gas concentrations combination [9].

IEC Basic Ratio Method is similar to the Roger's Ratio method except the ratio C_2H_6/CH_4 is excluded because of limited temperature range of decomposition see table 2. Other gas ratios such as C_2H_2/CH_4, CH_4/H_2, C_2H_4/C_2H_6 are used to generate the codes for interpretation [10]. Finally, the Roger's ratio method is regarded as the most widely used techniques. Typically, three or four ratios are used for sufficient accuracy. For instance, the initial Roger's ratio method uses four ratios such as CH_4/H_2, C_2H_6/CH_4, C_2H_4/C_2H_6 and C_2H_2/C_2H_4 to diagnose the incipient fault conditions and the normal condition as summarized in table 3 [11]. The types of generated faults in the oil can be determined via the algorithm once the gases the ratios are known.

TABLE 3
SUGGESTED DIAGNOSIS FROM GAS RATIOS OF ROGER'S METHOD. [11]

CH4/H2	C2H6/CH4	C2H4/C2H6	C2H2/C2H4	Suggested Diagnosis
<0.1 >1.0	>1.0	>1.0	>0.5	Normal
>=0.1	>1.0	>1.0	>0.5	Partial Discharge corona
>=0.1	>1.0	>1.0	>=0.5 or >=3.0 >3.0	Partial Discharge corona with Tracking
<0.1 >1.0	>1.0	>=3.0	>=3.0	Continuous discharge
>1.0 <1.0	<1.0	>= 1.0 or >= 3.0 < 3.0	>= 0.5 or >= 3.0 < 3.0	Arc-with power follow through
>1.0 <1.0	<1.0	<1.0	>= 0.5 < 3.0	Arc-no power follow through
>= 1.0 or >= 3.0 < 3.0	<1.0	<1.0	< 0.5	Slight Overheating to 150 C°
>= 1.0 or >= 3.0 < 3.0	>= 1.0	<1.0	< 0.5	Overheating 150 – 200 C°
>1.0 <1.0	>= 1.0	<1.0	< 0.5	Overheating 200 – 300 C°
>1.0 <1.0	>1.0	>= 1.0 < 3.0	< 0.5	General conductors overheating
>= 1.0 < 3.0	<1.0	>= 1.0 < 3.0	< 0.5	Circulating currents in windings
>= 1.0 < 3.0	<1.0	>= 3.0	< 0.5	Circulating currents core and tank; overloaded joints

METHOD AND MATERIALS

The program is designed on the basis of dissolved gas analysis (DGA) methods in the oil. Roger's ratio method, IEC ratio method and doernenburg ratio method are used to diagnose the faults and TCG method is employed in the process of assessing the insulating oil quality as per the specification of IEC standard 599 and IEEE C57.104.1991, respectively. The flow chart of the algorithm is displayed in Figure 1.

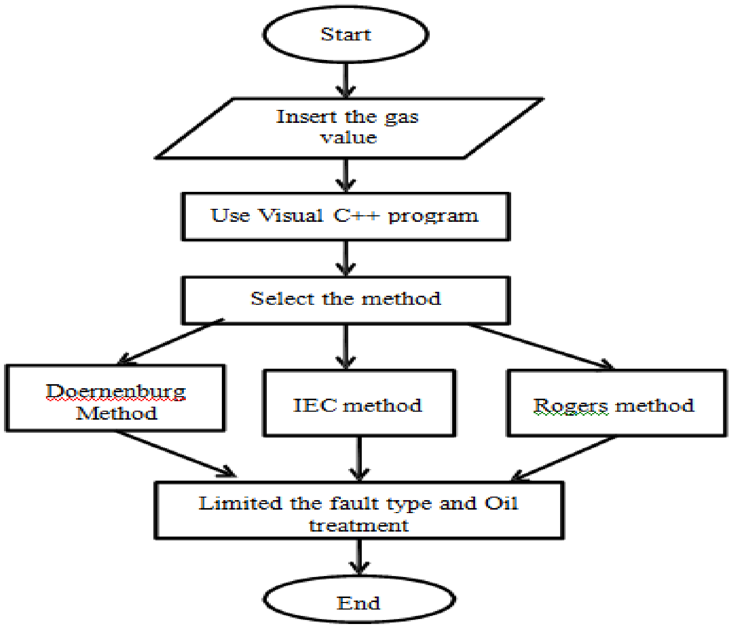

Fig. 1. Flowchart of the program

Visual C++ programming language is used and the data for dissolved gases in the oil are inserted through the menu driven windows where a message showing the type of faults and the form of state oil appeared as shown in Figure 2.

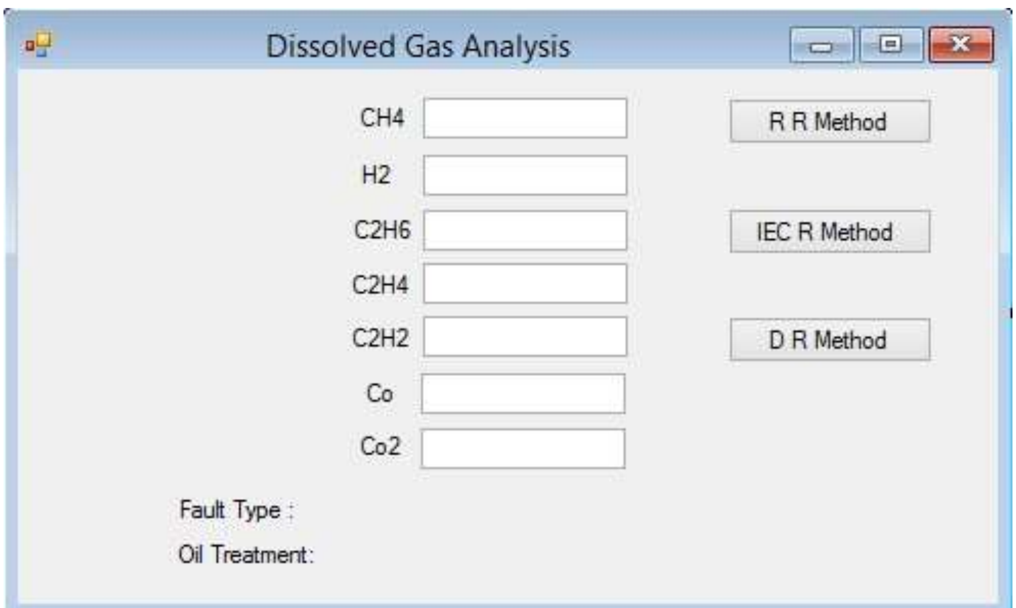

Fig. 2. Window of interface program

Forty samples are taken from the oil insulation for power transformers and sent to a laboratory for analysis to determine the oil dissolved gas ratios for gases including hydrogen, methane, ethane, ethylene, acetylene, Carbon monoxide and Carbon dioxide . These gases are considered as input data for the program as summarized in table 4.

TABLE 4
THE VALUE OF GASES TAKEN FROM FORTY SAMPLES.

No.of samples	Gas value						
	CH4	H2	C2H6	C2H4	C2H2	CO	CO2
1	4	2	5	3	0.001	152	6608
2	5	13	3	4	3	116	2525
3	11	0.001	4	3	0.001	96	4188
4	0.01	0.01	1	1	0.001	57	2580
5	2	11	2	2	0.001	124	2664
6	3	11	2	3	0.001	92	1657
7	7	5	6	0.01	0.001	78	1177
8	0.01	0.01	0.001	0.01	0.001	23	1043
9	7	14	1	61	0.001	1050	5836
10	4	13	1	44	0.001	730	2334
11	0.001	7	0.0001	28	0.001	355	2374
12	0.01	6	0.001	8	0.001	193	2031
13	49	25	69	10	0.01	343	1309
14	65	40	87	12	0.01	408	1456
15	0.1	1	0.1	13	0.01	151	1909
16	27	10	49	4	0.01	146	683
17	109	789	11	156	873	515	5347
18	90	647	10	129	638	428	2439
19	44	144	12	118	583	192	3945
20	38	379	7	46	198	150	2287
21	0.01	8	0.001	13	0.001	214	1943
22	2	0.01	0.0001	12	0.001	144	1310
23	3	2	1	14	0.001	163	1132
24	4	0.1	1	8	0.001	64	1158
25	0.002	0.001	0.01	6	0.001	125	1309
26	0.001	12	0.01	26	0.002	234	2696
27	4	0.002	1	25	0.002	267	2238
28	4		1	25	0.001	221	2122
29	31	10	89	7	0.001	165	1065
30	0.001	0.01	0.01	2	0.001	68	685
31	9	190	25	3	0.01	393	3029
32	8	199	20	3	0.01	256	1886
33	8	149	17	3	0.01	215	1861
34	0.01	22	8	1	0.001	155	1098
35	0.01	3	0.001	1	0.001	39	828
36	2	7	1	1	0.001	31	739
37	8	40	2	1	0.001	41	855
38	0.01	0.1	0.001	1	0.001	68	745
39	2	10	5	2	0.0001	154	4297
40	2	12	3	1	0.0001	129	2333

After entering the data into the program through the window interface, the fault diagnosis is performed and the transformer oil treatment is carried out. The algorithm achieves good results in terms of fault diagnosis and oil status assessment as provided in table 5.

TABLE 5
THE RESULTS ON DIAGNOSING FAULTS AND QUALITY INSULATING OIL ASSESSMENTS.

No.	Fault Type			Oil Treatment
	Rogers Method	IEC Method	Doernenburg Method	
1	Overheating-150-200 ˚c	Fault in cellulose insulating paper	No fault	Good oil no filtering
2	Unidentifiable	No fault	Unidentifiable	Good oil no filtering
3	Unidentifiable	No fault	No fault	Good oil no filtering
4	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
5	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
6	General conductor overheating	Fault in cellulose insulating paper	No fault	Good oil no filtering
7	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
8	Core and tank circulating currents	Fault in cellulose insulating paper	No fault	Good oil no filtering
9	Unidentifiable	No fault	Unidentifiable	Good oil no filtering
10	Unidentifiable	Unidentifiable	Unidentifiable	Good oil no filtering
11	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
12	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
13	Overheating-150-200 ˚c	Thermal fault of low temperature between 150 –	No fault	Single filtering and degassing
14	Overheating-150-200 c	Thermal fault of low temperature between 150 – 300 ˚c	No fault	Single filtering and degassing
15	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
16	Overheating-150-200 ˚c	Thermal fault of low temperature between 150 – 300	No fault	Good oil no filtering
17	Continuous sparking to flooting potential	Unidentifiable	Arcing (high intensity pd)	Double filtering and degassing
18	Continuous sparking to flooting potential	Unidentifiable	Arcing (high intensity pd)	Double filtering and degassing
19	Continuous sparking to flooting potential	Fault in cellulose insulating paper	Arcing (high intensity pd)	Double filtering and degassing
20	Continuous sparking to flooting potential	Fault in cellulose insulating paper	Arcing (high intensity pd)	Double filtering and degassing
21	Unidentifiable	Unidentifiable	No fault	Good oil no filtering

No.	Fault Type			Oil Treatment
	Rogers Method	IEC Method	Doernenburg Method	
22	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
23	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
24	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
25	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
26	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
27	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
28	Normal deterioration	Unidentifiable	No fault	Good oil no filtering
29	Overheating-150-200 ˚c	Thermal fault of low temperature between 150 – 300˚c	No fault	Single filtering and degassing
30	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
31	Overheating-200-300˚c	Partial discharges of low energy density	No fault	Single filtering and degassing
32	Overheating-200-300˚c	Partial discharges of low energy density	No fault	Single filtering and degassing
33	Overheating-200-300˚c	Partial discharges of low energy density	No fault	Single filtering and degassing
34	Unidentifiable	Partial discharges of low energy density	No fault	Good oil no filtering
35	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
36	Unidentifiable	Fault in cellulose insulating paper	No fault	Good oil no filtering
37	Unidentifiable	No fault	No fault	Good oil no filtering
38	Unidentifiable	Unidentifiable	No fault	Good oil no filtering
39	Overheating-200-300˚c	Fault in cellulose insulating paper	No fault	Good oil no filtering
40	Overheating-200-300˚c	Fault in cellulose insulating paper	No fault	Good oil no filtering

RESULTS

After inserting the data ratios of gas-derived samples as furnished in the table 4, the program is tested in each case. The results as summarized in table 5, are appeared to be good and in agreement with the specifications of approved matching standard approved to diagnose faults and assess quality of insulating oil.

DISCUSSION

The achieved results from our algorithm suggest that one of the significant and necessary maintenance steps must be to identify the status of transformer oil in service to ensure long term functioning. In fact, there are many other methods to diagnose faults and to assess the insulating oil quality via the dissolved gas analysis (DGA). However, we select the Roger's ratio method, IEC ratio method and Doernenburg ratio method, because it precisely provides more details about the types of faults occur in the transformers insulating oil. The insulating oil evaluation is performed through the knowledge of oil deterioration coefficient, which is calculated from the TCG method. Our simple computer program using visual C++ software is capable of detecting the type of faults and can assess the oil status once the values of dissolved gases are entered. In the present developed algorithm the interfacing is very easy and straightforward. A series of conducted tests using this program reveal superior results. The maintenance teams in the sub- stations can promptly act to rectify sudden breakdown of power transformers due to the emergence of faults. In Figure 3 represents a comparison of the methods used in the dissolved gas analysis of the form of percentages to show the extent of compliance with the actual results in the diagnosis of faults and assess the quality of insulating oil. Rogers method was the matching percentage is 50%, the IEC method was the matching percentage is 75% , and the Doernenburg method the matching percentage is 60%. As in the assessment of the quality insulating oil, where the matching percentage is 98%. We note that the methods used in the diagnosis of faults sometimes share a certain diagnosis of fault and sometimes specializes in one way of the three ways to diagnose fault it. In general the final results that compared with the actual results that have been taken in the maintenance of substations and the matched percentages were good and as in Figure 4.

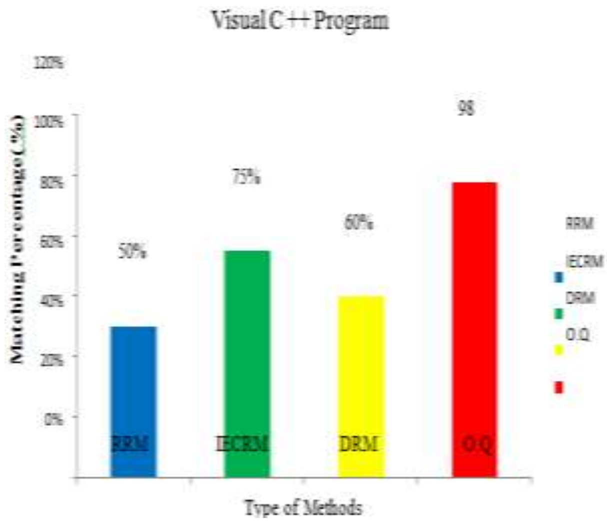

Fig. 3. Comparisons of DGA methods in Visual C++ program

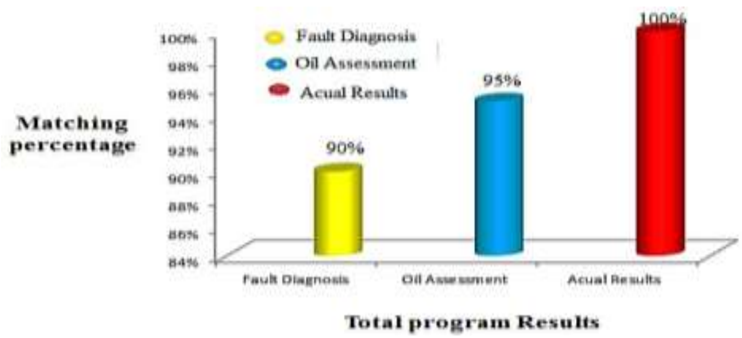

Fig. 4. The Results Comparison with Actual Results

CONCUSION AND RECOMMENDATIONS

This study introduced a simple and yet accurate computer program to identify the fault type and assess the oil quality in the power transformers. The dissolved gas analysis in oil being the reliable method is used for faults diagnosis and insulation oil quality assessment. Roger's ratio method, IEC ratio method and Doernenburg ratio method using DGA in the oil is used where the software employed visual C++ program. The program is highly reliable to diagnose the fault and assessing the quality of insulation oil. The obtained results are quite satisfactory as per IEEE standard and C57-104 and IEC standard 60599 specifications. Furthermore, based on the software results the maintenance team can rectify the occurrence of sudden faults that results power disruption and economic loss. The nature of faults is accurately and efficiently detected and the oil replacement is cited as output in the interfacing.

Declaration of Conflicting Interests

No conflicts of interest are present.

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