Applying Grey Theory Prediction Model on the DGA Data of the Transformer Oil and Using It for Fault Diagnosis

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Abstract: - This Non-Destructive Evaluation of Power transformer by monitoring various parameters, to predict its in-service behavior, is very much necessary for operating engineer to avoid catastrophic failures and costly outages. Dissolved Gas Analysis (DGA) is an important tool for transformer fault diagnosis. It is observed that the results of DGA doesn't have a perceivable change over a short period. For less population of data availability grey modeling is used. To apply probability theory, statistics, and fuzzy systems, there is a requirement for a large number of data, then only conclusion or some inference can be drawn. The advantage of using the grey system theory is that, it gives a fair accuracy in predicting the volume of the gases, expected to be generated after some time period, using a small sample of data. In this paper we have done a comparative study on the predicted results obtained by different model of Grey theory mainly whitened model, connotation model and modified grey model. It is found that the error generated from the prediction by all the three model are within the limit of 15% which is acceptable. Additional by linear regression we are establishing a correlation between the key gases. This helps us to detect the abnormality of the situation and diagnose the type of fault. Additional this paper deals with the study on the behavior of the gas dissolved in the oil which has undergone filtration and the one without filtration. Through graphical means it has been clearly shown that filtration at periodic interval will extend the life of the transformer. It has been shown that the rate of gas generation also plays an important role to detect an active fault.

Key-Words: - Transformer, Dissolve gas analysis (DGA), Grey model, Modified grey model, Regression theory, Correlation, Fault diagnosis, filtration

1 Introduction

Power transformers are the heart of the high voltage transmission and distribution system. Failure of the power transformer results not only in the loss of the revenue, but also has a negative impact on the reliability and quality of the delivered power and the distribution system. Major power transformers are filled with a fluid that serves several purposes. The fluid acts as a dielectric media, an insulator, and as a heat transfer agent. The most common type of fluid used in transformers is of a mineral oil origin. Few transformers are also filled with combustion-resistant vegetable oil-based dielectric coolants or synthetic pentaerythritol tetra fatty acid esters. The later type is not very common till date. In this paper the studies are related to only those transformers, which are filled with mineral oil. During the service, there is usually a slow degradation of the mineral oil and the solid insulating materials such as a paper, pressboard etc which are made up of cellulose, leading to the generation of certain gases, that get dissolved in the oil. However, when there is an electrical fault within the transformer, gases are generated at a much more rapid rate. There are typically nine gases, namely oxygen, nitrogen, hydrogen, methane, acetylene, ethane, ethylene, carbon-dioxide and carbon-mono-oxide get generated in course of time [4,5]. The concentration of a particular gas depends on the type of fault, that is occurring. Conversely, one can say that each type of fault generate certain gases, which are popularly known as the key gases [4,5] of that particular fault. All the gasses have their own distribution pattern. Thus by determining the various gases present and their amounts, one can derive the nature of the faults, which have been occurring in the transformer so far. If these faults are detected in advance, before it leads to a catastrophic failure, preventive measures can be taken which would not only reduce the loss of revenue but also increases the life of the transformer. Efforts have been made to assess the health of the transformer during service through a series of diagnostic tests. Major emphasis of these diagnostic tools is to detect the incipient fault [8] prior to their developing into major faults. Dissolved gas analysis (DGA) [3,4,5] is one such powerful diagnostic tools, which helps to detect faults at an early stage by detecting abnormal changes in the composition of gasses dissolved in the transformer oil, before the other protective gadgets like buchholz relay responds. It is mostly the first available indication of a malfunction which leads eventually to the breakdown in the transformer, if not rectified. DGA has gained a world wide acceptance as a diagnostic method for the detection of transformer internal faults. The data obtain from the DGA method effective forecasting of fault may be done. However, the difficulty lies in finding a sizeable number of samples. Probability theory and statistics deal with the data nexus or relation of the systems encompassing large samples embodied in statistic history laws. Regression models or probability relation, are subject to laws, such as the law of large numbers [6]. Fuzzy set and theories are used to elaborate or analyze events that have not yet been possible to express with general mathematical functions, but elaborated via conception that is not clear for the time being. Another approach is grey system theory [1,7], which is applicable were the data available is of small volume. It has been observed that results of the DGA for a particular transformer doesn't produce perceivable change over a small period of time. Since, there exist limited information, events dealt with grey system theory also possess uncertainty. Therefore, to contrast grey system theory to probability, statistics and fuzzy we have to characterize the nature of their uncertainty. The advantage of using the grey system theory is that, it gives a fair accuracy in predicting the volume of the gases, expected to be generated after some time period, using a small sample of data. In this paper, with the help of grey modeling a comprehensive study from the results obtained by different models of Grey theory [1,7] is done. It is shown that the range of error in predicting the volume of the gases generated is small and hence it is a very good tool to predict the future probability of a fault. A study was carried out on the prediction accuracy of different models, by collecting field DGA data and applying MATALB and EXCEL simulation on them. The validity of the observation is established through graphs and tables. Additionally by establishing a correlation between the gases, under abnormal condition, it is shown, how these predicting methods are useful to diagnose a fault [4]. Beside fault prediction this paper highlights the advantages of maintenance of transformer by oil filtration. We know some failures can be limited or prevented by maintenance. Oil filtration is one of the methods to remove the dissolve gases and preserve the oil quality. Oil filtration plays a key role in achieving optimum performance, reliability and longevity of the equipment. Clean oil is vital for transformer to run at optimum efficiency and minimum downtime. There are numerous options for filtering and controlling contamination level like strainers, centrifugal separators, disposal filters, cleanable filters etc

2 Grey Modeling

2.1 Introduction

The simplest and most elementary form of Grey model is GM(1,1) [1]. It is proposed as a number sequence forecasting model to extrapolate the original data sequence. The concept of the grey theory was first derived by Deng in China in the year 1986 [1]. It describes GM(1,1) model as approximations via least-square estimations, at the first-order differential equation level. The accuracy lies in the approximations of the derivatives and integrals of a given function. Deng named them as inverse accumulative generating operators (I-AGO) and accumulative generating operators (AGO) [1,2]. The AGO is one of the most important characteristics of the grey theory, and its main purpose is to reduce randomness, and it also reduces the noise, embedded in the input data. If the original data series is represented by $x^{(0)} = \{x^{(0)}(1), x^{(0)}(2), .., x^{(0)}(n)\}$ and the h-AGO transformation [1] is expressed as

$$x^{(h)}(k) = \sum_{j=1}^{k} x^{(h-1)}(j) \tag{1}$$

Where h is the number of the transformations and k is the sample number. Firstly, the Deng's primitive model [1] is considered. Let the volume of a particular gas dissolved in the transformer oil sampled at a periodic interval of time be considered as a vector X= (x(1) x(2)…..(n)). One variable first order grey differential equation can be written as

$$\frac{dz(t)}{dt} + az(t) = b \tag{2}$$

Where Z is the double AGO (2-AGO) transformation of original series X where.

$$y(k) = \sum_{i=1}^{k} x(i) \quad (3)$$

$$z(k) = \sum_{i=1}^{k} y(i) \quad (4)$$

Here a is the state parameter and b corresponds to the sum of the factors affecting physical parameter [1,2].

$$\begin{bmatrix} y(2) \\ y(3) \\ . \\ . \\ y(n) \end{bmatrix} = \begin{bmatrix} -\frac{1}{2}z(2)+z(1) & 1 \\ -\frac{1}{2}z(3)+z(2) & 1 \\ . & \\ . & \\ -\frac{1}{2}z(n)+z(n-1) & 1 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix} \quad (5)$$

$$A = A = [ab]^T = (B^T B)^{-1} B^T Y \quad (6)$$

$$Y' = [y(2) \quad y(3)....y(n)]^T \quad (7)$$

The gas forecasting equation of Z is expressed as follows.

$$z(k+1) = \left(z(1) - \frac{b}{a}\right)e^{-ak} + \frac{b}{a} \quad (8)$$

for k= 0,1,…,n

Equation (8) describes the whitened model of GM(1,1) [1]. Besides this, there is another predictive model called the Connotation model of GM(1,1) [1]. The gas forecasting equation of Z for the connotation model is as follows.

$$Z(k+1)=\left(\frac{1-0.5a}{1+0.5a}\right)^{k-2\frac{b-az(1)}{1+0.5a}} \quad (9)$$

The relation between the original field data and the corresponding predicted value is expressed as absolute percentage error denoted by the function Є%.

$$\text{Where } Є\% = \left|\frac{x(i)-x(\hat{i})}{x(i)}\right|(100) \quad (10)$$

2.1.1 Sub-subsection

To demonstrate the usefulness and effectiveness of the grey modeling, DGA data were collected from the testing lab, where transformer oils are sent at a regular interval. The detail specification of the transformers is shown in Table 1.

Table 1 DGA data obtained from the oil of the transformers having the following specification.

Type	Voltage. Ratio (KV)	Type of cooling	MVA
Distribution	15.75/20	OFAF	250
Distribution	15.75/6.9	ONAF	16
Distribution	400/133	ONAF	31.5
Distribution	132/11	ONAF	20

Table 2: Concentration of CO gas in ppm, for transformer 1, taken at a regular interval of 4 months, along with its calculated value from whitened and connotation model. The related errors corresponding to those models are computed.

k	$x^{(0)}$ sample	$x^{(0)}(k)$ Whit	$x^{(0)}(k)$ Conn	є % Whit	є % Conn
1	85	85	85		
2	97	97.98	101.0	1.01	4.17
3	152	165.9	173.3	9.18	14.04
4	316	281.1	297.3	11.04	5.89
5	491	476.1	510.1	3.02	3.89

Each data set at a time consists of mainly 5 to 6 gases. From a transformer these data sets were collected over a period of time, at measured intervals. Hence, 4 to 5 sets of data were collected from a each transformer. In the database, the concentration of all the gases are expressed by parts per million (ppm). For example, 100 ppm is equal to 0.01 ml (gas) / 100 ml (oil). DGA data related to carbon mono-oxide (CO) and Ethane (C_2H_6), collected from two different transformers are shown in Table 2 and Table 3. With the help of equation (8) and (9), the predicted value of the gas generated by whitened and connotation model is calculated. Related errors corresponding to those models are computed using equation (10).

A graphical representation of comparative study of Whitened and Connotation model for two different gases namely CO and C_2H_6 for different transformers is shown Fig 1 and Fig 2. From the two figures it can be predicted that the results obtained from the two models have only marginal difference. To check the accuracy of prediction the error generated by the two models is calculated from equation (10) and it is represented in the Fig 3. In both the models the error is within 15%, which is acceptable

Table 3: Concentration of C_2H_6 gas in ppm for transformer 2, taken at a regular interval of 4 months, along with its calculated value from whitened and connotation model. The related errors corresponding to those models are computed.

k	$x^{(0)}$ sample	$x^{(0)}(k)$ Whit	$x^{(0)}(k)$ Conn	ε % Whit	ε % Conn
1	6	6	6		
2	8	7.52	7.64	5.90	4.39
3	12	11.16	11.40	6.97	4.98
4	16	16.55	16.99	3.46	6.23
5	26	24.54	25.33	5.58	2.54

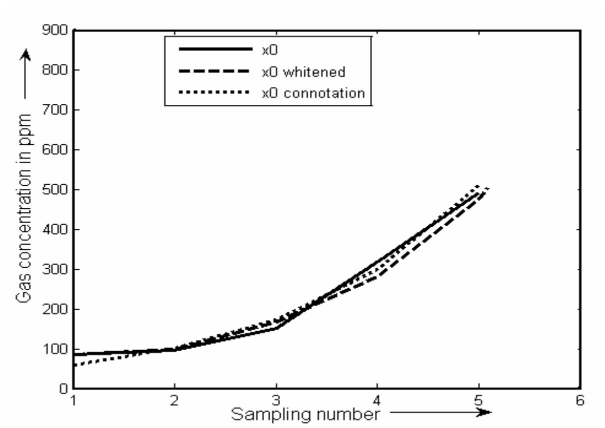

Fig 1 Comparison of predicted value of gas CO in ppm obtained from whitened & connotation Model with the original field data.

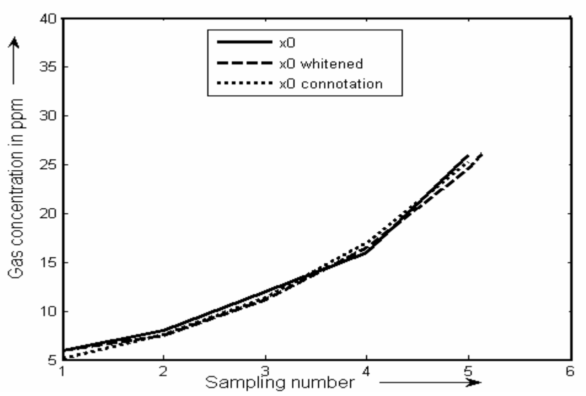

Fig 2 Comparison of predicted value of C_2H_6 gas in ppm obtained from whitened & connotation model with the original field data.

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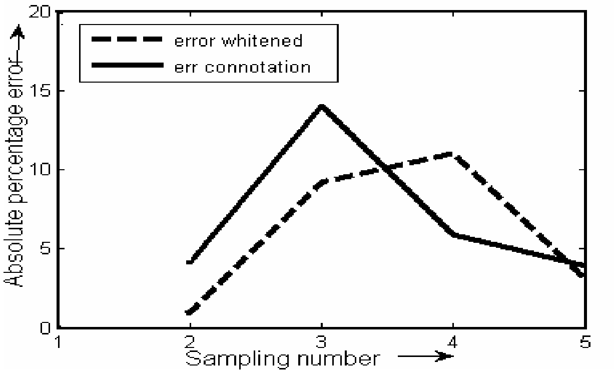


Fig 3 Comparision of error in prediction by whitened & connotation model for CO gas.

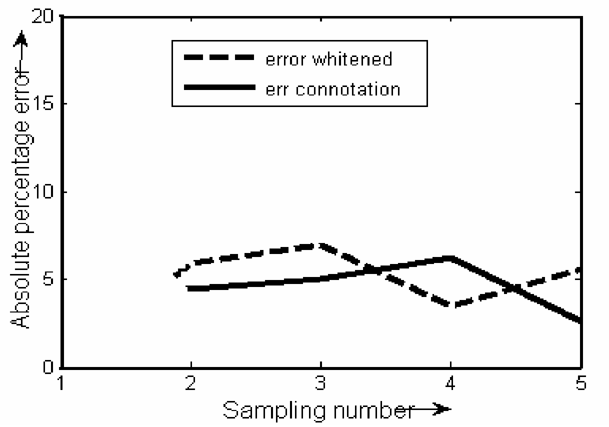


Fig 4 Comparision of error in prediction by whitened & connation gey model for C_2H_6 gas.

Till now we have delt with two gases dissolve in transformer oil, namely co and C_2H_6. Besides them there are other gases present in the transformer oil. The computed error resulted from their predicted value by whitened and connotation model are shown in Table 4 and 5 for two different transformers. The error range is within 8%, which is acceptable.

Table 4: Error generated from the prediction by both the models for the other gases dissolved in the transformer oil for transformer 1

Gases	H_2	CH_4	C_2H_4	C_2H_6	CO_2
ε % White	2.04	0.06	0.81	0.17	1.43
ε % Conno	2.80	2.90	2.35	4.08	2.99

Table 5: Error generated from the prediction by both the models for the other gases dissolved in the transformer oil for transformer 2.

Gases	H_2	CH_4	C_2H_4	CO	CO_2
ε % White	7.39	2.09	0.81	1.65	0.30
ε % Conno	7.24	2.09	2.49	2.02	0.66

Modified Grey Modeling

Finally, the prediction results x of oil dissolved gas at t=k+1 can be obtained by the double inverse accumulated generating operation (2-IAGO) of equation (8) [7].

$$x(k+1) = z(k+1) - 2z(k) + z(k-1) \quad (11)$$

for k=0,1,..,n

2.2.1. Examples and Simulations

A comparision is drawn between the whitened (8) and modified grey model (11). For that we are using the same set of field data of Ethane (C_2H_6) and Carbon mono-oxide (CO) gas. The results are tabulated and the corresponding whitened model error (10) along with the absolute percentage error (10) is calculated. From the values obtianed through whitened (8) and modified Grey model (11) , it is clearly visible that over a period of time these gases that are generated in the trnsformer oil have a exponential rise as shown in Fig 5 and Fig 6. Their related errors to prediction are shown in Fig 7 and Fig 8. From the graphs we can conclude that the cumulative error in modified grey model is minimum. For the other gases present in the transformer oil, the results of absolute percentage errors are calculated as shown in equation (10). Hence it is observed that in grey system theory though there are small number of samples still, modelling and analysis can be done. There is no need of a priori information or the distribution function pattern. From the above examples and simulated results it can be seen that the accuracies of predicting the volume of the gases generated are well within a permissible limit. From the values obtianed through whitened (8) and modified Grey model (11) , it is clearly visible that over a period of time these gases that are generated in the trnsformer oil have a exponential rise as shown in Fig 5 and Fig 6. Their related errors to prediction are shown in Fig 7 and Fig 8.

Table 6 Concentration of CO gas in ppm for transformer 1 taken at a regular interval of 4 months, along with its calculated value from whitened and modified grey model. The related errors corresponding to these models are computed.

K	$x^{(0)}$	$x^{(0)}(k)$ Whit	$x^{(0)}(k)$ Mod	ϵ Whit	ϵ %
1	85	85	85		
2	97	97.98	269.91	1.01	35.65
3	152	165.96	152.51	9.18	0.06
4	316	281.11	261.19	11.04	3.46
5	491	476.14	361.66	3.02	5.26

Table 7 Concentration of C_2H_6 gas in ppm for transformer 2 taken at a regular interval of 4 months, along with its calculated value from whitened and modified grey model. The related errors corresponding to those models are computed.

K	$x^{(0)}$	$x^{(0)}(k)$ Whit	$x^{(0)}(k)$ Mod	ϵ Whit	ϵ %
1	6	6	6		
2	8	7.52	21.09	5.90	32.73
3	12	11.16	11.71	6.97	0.48
4	16	16.55	13.85	3.46	2.68
5	26	24.54	21.31	5.58	3.60

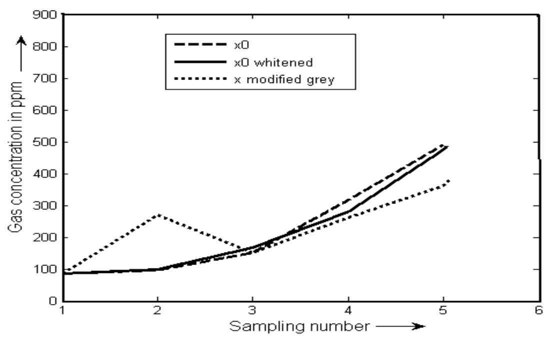


Fig 5 Comparison of predicted value of co gas in ppm obtained from whitened and modified grey model with the original field data.

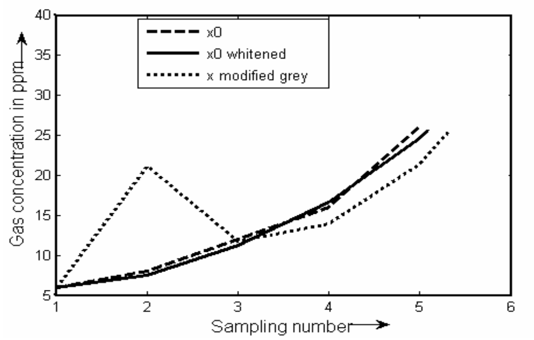


Fig 6 Comparison of predicted value of C_2H_6 gas in ppm obtained from whitened & modified grey model with the original field data.

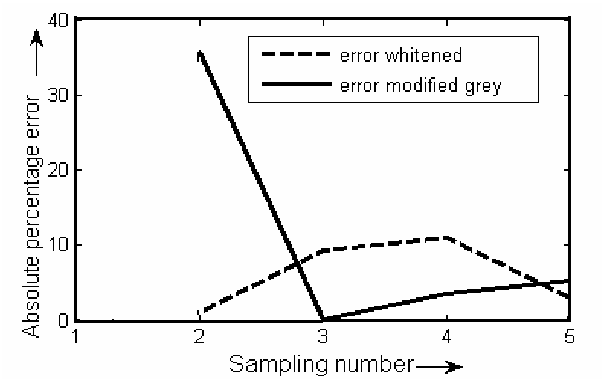


Fig 7 Comparision of error in prediction by whitened and modified Gey model for CO gas of transformer 1.

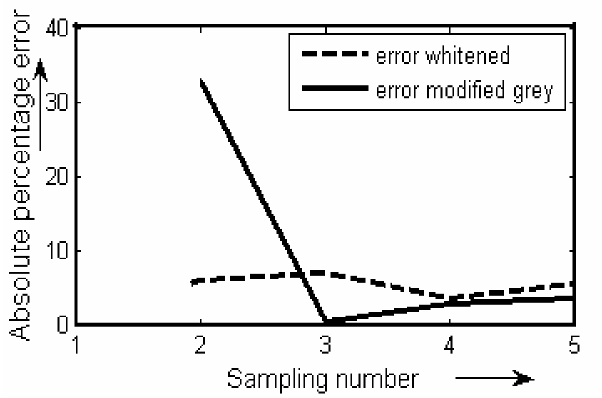


Fig 8 Comparision of error in prediction by whitened & modified Gey model for C_2H_6 gas of transformer 2.

From the graphs we can conclude that the cumulative error in modified grey model is minimum. For the other gases present in the transformer oil, the results of absolute percentage errors are listed in Table 8 and Table 9.

Table 8: Generated Percentage Error in prediction for other gases in Transformer 1

Gas	CH_4	C_2H_4	C_2H_6	CO_2	H_2
ε %	3.3	2. 54	5.26	2.26	1.09

Table 9: Generated Percentage Error in prediction for other gases in Transformer 2

Gas	CH_4	C_2H_4	CO	CO_2	H_2
ε %	1.49	2.03	1.01	0.70	2.11

Hence it is observed that in grey system theory though there are small number of samples still, modelling and analysis can be done. There is no need of a priori information or the distribution function pattern. From the above examples and simulated results it can be seen that the accuracies of predicting the volume of the gases generated are well within a permissible limit.

3 Application of prediction by establishing the co-relation theory

The main faults occuring in the transformer oil are Corona, overheating of oil, Arching and overheating of cellulose. Typical fault gas distribution shows that when a fault occurs two or three gases play important roles as reflected in fig 9. Here we consider only one type of fault, arching for analysis. By applying the whitened model on five values (24, 27, 38, 107, 207) of CH_4 the new predicted values are shown in the Table 11. Applying the linear

Table 10: Percentage of gas concentration in an arching fault

Arching in oil	Percent of Vol
H_2	39
CO_2	2
CO	4
CH_4	10
C_2H_4	6
C_2H_2	35

In most of the faults hydrogen gas generation is high. So, by seeing its volume no clear fault diagnosis can be made. For example, in Arching fault, besides hydrogen CH_4 and C_2H_2 are the key gases[11]. Field data were collected and only two gases were selected for analysis. We selected Methane and Acetylene (CH_4 and C_2H_2) as they exhibited a rising tendency. From the field data of the two gases a correlation between them could be established by the linear regression

$$y = 1.0638\,x + 61.34 \qquad (12)$$

Table 11. Volume of the gas predicted in ppm by whitened and modified grey model. By corelation equation C_2H_2 value in ppm is calculated.

Sr.	CH_4	C_2H_2	Whitened CH_4	Modified Grey CH_4	By co-relation C_2H_2
1	22	79			84.74
2	24	81	24	24	86.87
3	27	97	21.2	65.606	90.06
4	38	78	43.1	23.041	101.76
5	107	224	87.3	63.361	175.166
6	207	261	177.1	95.902	281.54
7	370	1371	433.98	158.79	

equation (12) to the value predicted by whitened model, for CH_4 gas($x = 433.98$ at $k=7$) we can forecast the value of y at that sampling instance. y represents the ppm of C_2H_2 should be generated under normal condition, which is calculated to be 523.007 ppm. Where as the field data collected shows a value of 1371 ppm for C_2H_2 , which is approximately two and half times the predicted value. Hence abnormality is observed and the generation of the gas shows a steep rise which can lead to arching fault [3]. This diagnosis is supported by the modified grey model. Taking the same values of CH_4, prediction is done with the help of modified grey model [1] and the values are shown in the Table 11. Substituting the value of x= 158.79 in the equation (12) we can forecast the value of C_2H_2 generated as 230.26 ppm. Where as the actual value of gas generated is 1371 ppm, which is nearly six times more than the predicted value. Hence we can clearly see that abnormality has occurred and as the two gases mentioned above are responsible for the arching fault besides hydrogen, we can conclude that the arching fault has occurred and remedial action has to be taken.

3 Filtration

Failures in a transformer can occur due to different reasons. Some failures can be limited or prevented by maintenance others cannot. Some failures depend on degradation processes. The source of fault may lie in design, manufacturing, material used, transportation, storage, incorrect erection at site, incorrect maintenance, abnormal overload, over fluxing, lightning, external short circuit and loss of cooling. All failures cannot be avoided by preventive maintenance. Among the above mentioned causes, failures due to design, manufacture and lightning can not be avoided by maintenance. . Fig 10 shows the distribution of failure rate vs time [12].

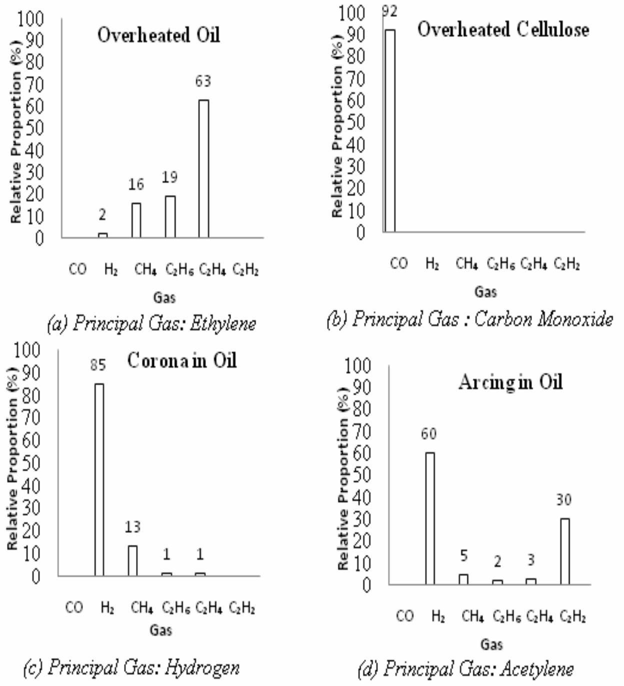


Fig 9. Corresponding to a particular fault volume of key gases preseent in the oil.

However maintenance can increase the transformer's ability to withstand overloads and external short circuits up to some limit. overloads and external short circuits up to some limit. As the gases are generated continuously over the period of time, accumulated quantity sometimes reaches a dangerous level. Hence there is a need for a periodic oil filtering by which the dissolved gases are removed and the oil quality is refined. Existing oil filtration units for periodical oil filtrating could be classified into stationary and mobile ones. The other classification is on-line (filtration process is done while machinery is working) and off-line (filtration process is done while machinery is turned–off) regimes. In general most of the transformers in the distribution system are over loaded Main disadvantage of the off-line filtration units is the necessity of costly downtime if the machinery is of non-stop working type. Therefore, mobile filtration units working in on-line regime are the most preferable for industrial applications where the user is able to mobilize oil filtration unit to particular transformer. As per the guidelines of CIGRE the average ppm value of Pre-failure gas concentration in the power transformer is shown in table 12. Pre-failure concentration values were found by CIGRE [13] to be surprisingly similar on different networks, suggesting that failure occurs when a critical amount of insulation is destroyed. CIGRE pre-failure values can therefore be used as a reasonable estimate of the levels of gas formation observed just before failure. From this tabulation we can see when a gas concentration is above the higher limit or fast approaching the limit then filtration is suggested. This is the threshold limit and is used to calculate the probability of failure of the transformer.

Table12: Average Pre-failure gas concentration values observed at CIGRE.

CO	CH_4	C_2H_4	C_2H_6	H_2	C_2H_2	CO_2
2100	400	800	900	725	450	N/R

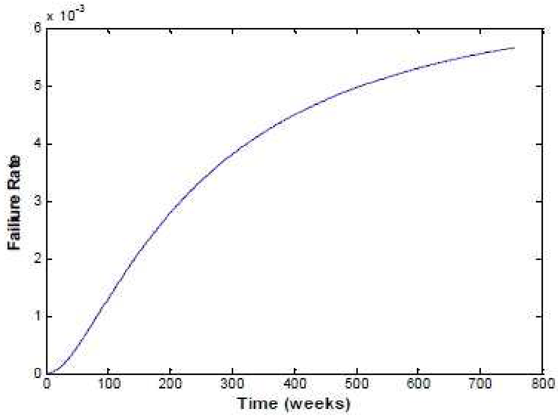
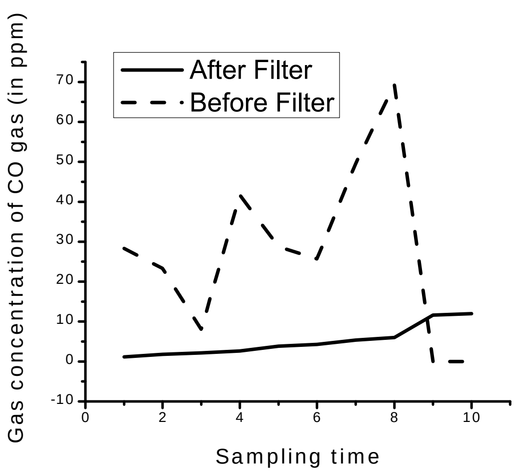


Fig 10 Failure rate due to transformer oil deteriotion.

It has been observed that after filtration of oil there is a remarkable change in the level of dissolved gases. Mainly the carbon particles from the oil are removed, keeping the water content to a minimum. By filtering there is a saving in transformer oil in the long run. If the oil is not filtered and the trend of rise in the gases was allowed to continue then a fault would have occurred. The severity of the fault cannot be

Fig 11 Distribution of CO gas before and after filtration.



predicted but the transformer would be damaged to some extend and a revenue loss would have incurred. In fig 11 and fig 12 shows the distribution pattern of the carbon mono-oxide and methane gas (CO and CH4) in the oil when it is unfiltered and when filtration has been done. These DGA data in table 13 and table 14 are of a distribution transformer, which were collected from the testing laboratory. After the service has been provided the oil quality remains unaltered to some extend. Hence the life of it gets extended. By observing the rising trend of key gases [4] one can predict a type of fault[14]. For this method we don't need to calculate the ratio of the gases but only the concentration of an individual gas[15].

Table 13 CO gas concentration before and after Filtration.

Sampling time	**After filtration**	**Before filtration**
1	1.15	28.32
2	1.77	23.29
3	2.18	8.02
4	2.65	41.67
5	3.85	28.74
6	4.3	25.71
7	5.32	49.58
8	6.04	69.29
9	11.62	100
10	11.98	108

Table 14 CH4 gas concentration before and after Filtration.

Sampling time	**After filtration**	**Before filtration**
1	0.68	0.89
2	0.80	1.73
3	0.83	2.02
4	1.03	2.54
5	1.06	2.66
6	1.44	2.12
7	1.50	1.24
8	1.57	2.03
9	2.01	2.44

5 Effect of filtration on combustible gas generation rate.

Gases are continuously generated and the rate of generation is also varying. Sometimes over a long period of time there is insignificant rate of generation of gas or in a very sort time period generation rate is fast. This signifies the severity of the fault. Rates of

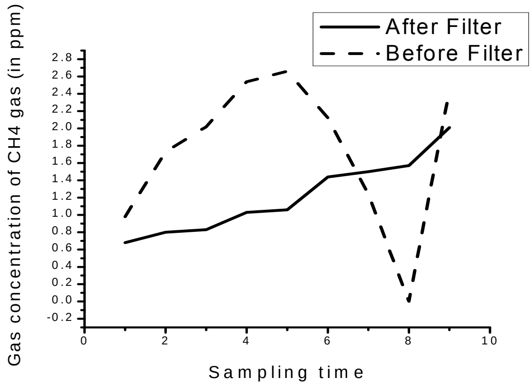


Fig 12 Distribution of CH4 gas before and after filtration.

Table 15.DGA data showing the rate of gas generated and removed by filtration.

H_2	C_2H_6	CO_2	CH_4	CO	C_2H_4	sum	days
2002	18	2100	106	350	7	2476	
2704	49	2682	355	508	13	3616	60
0.1	0.2	5	0.1	0.6	0.2	1	60
							180
1187	10	419	78	63	3	1338	45
1462	11	530	85	64	3	1622	45
0.01	0.01	82	1	2	0.01	3.02	45
							180
601	7	533	47	47	4	702	140
697	14	538	50	48	2	809	140
1	0.1	177	2	4	0.2	7.1	140
							180
1083	68	883	112	176	10	1439	120
1347	52	1179	306	431	12	2136	120
7	0.01	183	1	11	0.7	19.0	120

gas increase are generally considered as more important than the gas concentrations, because they indicate that the faults are active. However, if high concentration of gas persist, even if the fault becomes inactive, may cause permanent damage to the insulation. If the evolution rate is greater than (0.1)ft^3 of combustible gas per day than it indicates the transformer has an active internal fault [5]. To calculate the rate of gas generation, we take the sum of gas concentration (in ppm). The total combustible gases (TDCG) is the sum of all the gases mentioned in table 15, excluding CO_2. The first and the second samples are the two consecutive DGA reading taken for the same transformer after a time span . By using equation (13), the rate of gas generation was calculated. It was observed that when there was a rising trend in the gas generation rate, filtration was done. After filtration the rate reduced remarkably.

$$R = \frac{(s_T - s_O) \times V \times 10^{-6}}{7.5 \times T} \quad (13)$$

where, R= Rate (ft^3 / day)
S_O - First Sample (ppm)
S_T - Second Sample (ppm)
V=Transformer oil in Gallons
T= number of days

DGA data were collected from different distribution transformers of 33kv and 5.1MVA rating over a period of time. These transformers generally have 17,000 liters of oil. In table 15, we have four sets of data. For the first set the three consecutive DGA data were collected at time intervals of 60 days. The third row of data is taken after filtration. Similarly we have four sets of DGA data. Sampling intervals between consecutive data collected for different sets are shown in table 16. We observe that concentration of hydrogen (2700 ppm) in the first set had crossed the average pre- failure limit as mentioned in table 12. Increase in the value of hydrogen is little more than three times. Hence filtration was suggested.

Table16.DGA data set with corresponding time interval.

1st set of DGA data	60 days
2nd set of DGA data	45 days
3rd set of DGA data	140 days
4th set of DGA data	120 days

Table 17.Gas generation rate with sampling time.

SET	Rate	days
I	0.0113	60
I	-(0.036)	60
II	0.0038	45
II	-(0.0251)	45
III	0.0004	140
III	-(0.0034)	140
IV	0.0034	120
IV	-(0.0105)	120

From table 17 we come know that, even when, none of the readings have the gas generation rate greater than (0.1) (ft^3 / day), quite a good amount of gas is accumulated in the oil. This indicates that it is not necessary for an active fault to occur, for the deterioration of the oil [9].

4 Conclusion

By studying different models of Grey forecasting method, it is seem that it is a novel method, when the data volume is small. The error generated in predicting the volume of the gas in the future is well within the limit.. Additional a corelation between the gases is drawn to predict the volume of one gas, from the available data of another gas. This prediction can be a very useful tool for fault diagnosis. By filtration we can offer a service at a regular interval which would improve the health of the transformer oil. Over a long period of time it can be shown that even if the filtration is done there is an accumulation of gases takes place in the oil. Use of these non traditional diagnostic and monitoring techniques is expected to increase the life of the transformers. Repeated applications of these techniques will refine the fault prediction system to a very reliabilable statistical tool. These analitical techniques will enable the field personnels to use the test results very effectively towards the maintenance of transformers. Service engineers will be able to do the job fruitfully without depending on the human experts.

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