Predication of Life of Transformer insulation by developing Relationship between Degree of Polymerization and 2- Furfural

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Abstract— *Degradation of cellulosic materials can be identified by measuring dissolved carbon oxide gas content in oil, Degree Polymerization (DP) of paper and 2-Furfurol content in oil. Each method has some advantages and limitations. In case of dissolved carbon oxide gas analysis and furan content determination, sampling is easy but interpretation of result is not very reliable. On the other hand DP measurement of paper is reliable and accurate but it is not practical top draw paper sample from transformer in service. Therefore, attempts are being made to establish a reliable and good correlation among above parameters to get a simple and accurate result. This paper presents relation between DP and furan content. For given oil sample furan content first measured and using above relation DP value can be easily identified. Also this relationship is verified by with results of five no's field failed transformers.*

Index Terms— Insulation, Farun, Degree of polymerization, DGA, paper Insulation, ageing, transformer, electrical

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1.0 INTRODUCTION

Reliable electrical supply has become one of the basic needs for development of society. Gap between demand and supply of electrical power has increase considerably in recent years. Therefore in the present circumstance it is essential to utilize the existing power network to its optimum design capability. Power transformer is vital equipment and the loss of a transformer can have an enormous impact on continuity and reliability of supply and also on cost. Now a day's emphasis is given to condition based maintenance which includes assessment of remaining life. Life assessment enables utilities to take appropriate decision on refurbishment or replacement. The basic philosophy behind life assessment technique lies on the conceptual approach that although there are many apparently random events that may terminate a transformer's life, there is an underlying trend during old age and this can be predicted by giving the appropriate data. The exercise of life assessment of transformer is more relevant in two circumstances. For transformer which shows recurring problem or met with a major failure and Secondly in case of relatively older transformer say having service life more than fifteen years.

Insulation age of a transformer is exclusively decided by life of cellulosic materials. In this study an effort has been made to measure all three ageing indicating parameters (namely carbon oxide gas content, degree of polymerization and furan content) under controlled laboratory ageing condition and then verify these results on few transformers already in service.

2.0 EXPERMENTAL

Two new unused and fresh mineral insulating transformer oil of different chemical base namely paraffinic and naphthenic were chosen for this study. Both oil complies the requirements of relevant national specification IS 335-1993[2]. One new electrical grade paper was taken which conforms the requirement of relevant India specification IS 9335[3]. Paper is dried in vacuum (1 torr) at 100ºC for 2 hours then impregnated with oil under vacuum. Sufficient quantity of oil and paper were taken in the 20:1 proportion by weight. Then oil impregnated paper along with oil kept in a aluminum vessel of ten liter capacity which was equipped with a special silica gel breather to avoid contamination from environmental moisture. Oils of different chemical bases were kept in separate vessels. All vessels were kept in an air circulated electrical oven at 130±2ºC for accelerated ageing. Oil and paper samples from each vessel were taken out periodically

after 28 days thermal ageing. After each cycle of ageing, degree of polymerization of paper, dissolved carbon oxide gas content (as per IS: 9434) using Shimadzu make Gas Chromatograph and furan content were measured by High performance liquid chromatography [HPLC]- make Shimadzu and Agilent. Samples (oil and paper) are also collected from five transformers which met with severe failure and brought to workshop for necessary repairing and refurbishment.

3.0 RESULTS AND DISCUSSION

Accelerator ageing parameters were chosen in such a way that it simulates normal life span of a transformer. Considering six degree rule, thermal ageing at 130ºC for 5 ageing cyclic (i.e. 140 days) is almost equivalent to twenty five years of service in field. The observed results as per table-1, are on expected trend i.e. carbon oxide gas and furan content in oil have increased with ageing whereas degree of polymerization of paper has reduced. However, it is interesting to note that the rate and extent of deterioration in paraffinic based oil is more that naphthenic based oil.

TABLE 1
Research Results for DP and 2-Furfural

Ageing Cycle	Naphthenic		Paraffinic	
	DP	2-Furfural	DP	2-Furfural
28 Days	580	0.7	520	1
56 Days	390	4	380	14
84 Days	230	7	230	7
112 Days	210	9	200	14
140 Days	160	12	150	20

The relation between degree of polymerization of paper and furfural content in oil for paraffinic and naphthenic is shown as per below Figure-1 &2.
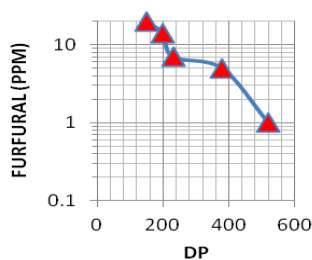

Fig.1. Relationship between DP and 2-Furfural content
Paraffinic

As degree of polymerization of paper decrease, the furfural content in oil increase. This figure 1&2 reveals that DP has linear relation with logarithm of 2-furfural content. From this, the end point norm for life assessment is determined as 10 ppm 2-furfural content in oil equal to 200 DP of paper. Therefore, the remaining life of transformer can be determined by first evaluating oil for furfural content and corresponding DP can be found out by using this figure 1 &2.
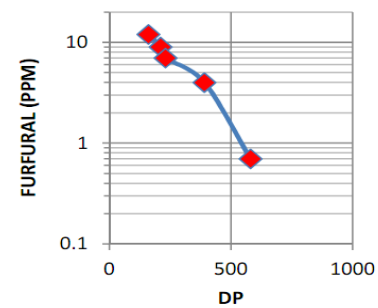

Fig.2. Relationship between DP and 2-Furfural content
Naphthenic

Following table-2 is extracted from Assessing Remnant Life of Transformer based on Furan Content in Transformer Oil and Degree of Polymerization of Solid insulation by Sanjay.G.Patki, S.G.Patil, and Jaspal. S. Wadhwa and Introduction to the Half-Century Transformer by the Transformer Maintenance Institute, S.D. Myers Co., 2002 [4] [5].

TABLE 2
Remaining Life of Transformers

DP Value	Estimated Percentage of remaining life	Suggested interpretation
800	100	Normal Ageing Rate
700	90	
600	79	
500	66	Accelerated Ageing Rate
400	50	
380	46	
360	42	
340	38	Excessive Ageing Danger Zone
320	33	
300	29	
280	24	High Risk of Failure
260	19	
240	13	End of expected life of paper
220	7	
200	0	

Insulation

Five case studies are undertaken here.

4.0 CASE STUDIES

To verify the above norms samples (Paper and Oil) from five field failed power transformer were collected and evaluated for different ageing indicating parameters like, 2-furfural content and dissolved oxides of carbon in oil [1] and degree of polymerization.

4.0.1 CASE STUDY-1

In the case study-1 as per below table 3, a failure in Y phase on high voltage winding was observed upon opening a twenty-year old power transformer. Paper and Oil samples were collected an evaluated.

TABLE 3
Results for Case Study-1

Voltage Class (kV)	132/66
Rating (MVA)	50
Degree of Polymerization (DP)	322
2-Furfural content (ppm)	9.2
Dissolved oxide of carbon (ppm)	2258

It was found that degree of polymerization and furfural content are close to the respective end points (i.e. 200 for DP and 10 ppm for2-furfural). Therefore it is not advisable to use the transformer further by repairing only damaged portion in Y phase.

4.0.2 CASE STUDY-2

Transformer taken up for the second case study as per table 4 was about twenty years old. DGA analysis after failure has indicated thermal fault of medium temperature range

TABLE 4
Results for Case Study-2

Voltage Class (kV)	132/66
Rating (MVA)	20
Degree of Polymerization (DP)	237
2-Furfural content (ppm)	9.0
Dissolved oxide of carbon (ppm)	4573

Transformer was opened at manufactures works and observed faults in winding. Paper and oil samples collected were analyzed for DP and furfural content respectively. Results indicate degradation of paper insulation up to end of life. It is not advisable for repair.

4.0.3 CASE STUDY-3

TABLE 5
Results for Case Study-3

Voltage Class (kV)	66/11
Rating (MVA)	20
Degree of Polymerization (DP)	208
2-Furfural content (ppm)	12
Dissolved oxide of carbon (ppm)	5490

In the third case as per table 5, thermal faults of high temperature range were observed from DGA of oil sample collected after failure of about twenty three year old transformer. Paper and oil samples were collected after opening the transformer at manufacture's works and evaluated for DP and furfural content. Results indicate that the deterioration of paper insulation is very high and it is not advisable for refurbishment of transformer. In other words, results indicate end of insulation life.

4.0.4 CASE STUDY-4

In the fourth case as per table 6, the Transformer was about twenty years old. Oil sample collected for DGA test after failure has indicated Electrical discharges of high energy.

TABLE 6
Results for Case Study-4

Voltage Class (kV)	66/11
Rating (MVA)	10
Degree of Polymerization (DP)	298
2-Furfural content (ppm)	7.5
Dissolved oxide of carbon (ppm)	5822

It was shifted to manufacturer's works where paper and oil samples were collected after opening the transformer and evaluated for DP and furfural content respectively. Results indicate that the values are far below the end points and hence it is advisable to go for refurbishment of transformer.

4.0.2 CASE STUDY-5

In the fifth case as per table 7, the transformer was in operation for about seventeen years. The Buchholz relay had operated during normal operation

TABLE 7
Results for Case Study-5

Voltage Class (kV)	132/11
Rating (MVA)	20
Degree of Polymerization (DP)	245
2-Furfural content (ppm)	6.6
Dissolved oxide of carbon (ppm)	1541

DGA of oil after the failure indicate thermal fault. So transformer was shifted to manufacture's works. Transformer was opened and the winding was found to be melted. Result of DP and furfural content indicate that paper insulation has not deteriorated significantly. Therefore, it is advisable to replace the damaged portions only.

CONCLUSIONS

From this study, following conclusions are drawn.

Degree of deterioration of cellulosic paper is affected by chemical base of transformer oil.

1) A Relationship between life indicating parameters like Degree of polymerization and 2-furfural content is established. The end point criteria for DP of paper and corresponding furfural content in oil 200 and 10 ppm respectively.

2) There is need for development of data bank and more case studies are required to be conducted for verification of the norms developed.

3) It is advisable to monitor the health of paper insulation by monitoring concentration of furfural in oil periodically.

ACKNOWLEDGEMENT

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BIOGRAPHY

Dipak Mehta Graduate in electrical engineering from LD College of engineering Ahmedabad, India in 2003. He has working experience of 8 year in HT switch gear maintenance, operation and testing. He has also worked as lecturer in AITS Rajkot. He is currently doing his M.Tech Research from SVNIT, Surat. He has published three papers' in estimated journals like CPRI and IEEE on transformer insulation analysis.

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