CONDITION ASSESSMENT AND FAULT DIAGNOSIS OF TWO LOAD TAP CHANGERS USING DISSOLVED GAS ANALYSIS

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ABSTRACT

Considering the objectives of "condition based preventative maintenance strategy", condition assessment was performed over two load tap changers of 125 MVA power transformers in 230/63 substations using dissolved gas analysis (DGA).
The selected load tap changers were: (1) an MR M-type load tap changer and (2) an Elin load tap changer. Choosing load tap changers of 230/63 kV power transformers are quite reasonable since the mentioned power transformers are the most frequently being used power transformers in Iran.
The oil samplings were performed according to ASTM D 3613 standard, in two stages and in a three-month interval. Furthermore, samples were analyzed for dissolved gases considering ASTM D 3612 standard.

INTRODUCTION

Load tap changers (LTCs) for power transformers are the only movable part of power transformers and they suffer from various aging mechanisms [1]. LTCs are essential components of the electrical networks and it has been estimated that more than 30% of all transformer failures are due to faulty LTCs [2], [3]. Mechanical malfunction, increased contact resistance, localized thermal stress, material failure, breakdown of the insulating oil (coking), contact wear, improper design or high loads cause common failures in LTCs [2].
Among the classical maintenance strategies; corrective maintenance, period based preventative maintenance and condition based preventative maintenance [4]; the latter is the most accepted strategy for LTCs. This is due to several advantages such as reduction in the required number of maintenance visits, maintenance costs, possible interruptions to supply, number of catastrophic failures and also increment in the reliability of power delivery and distribution [5] which are in accordance with utilities aim to extend the service intervals and monitor equipment condition [2].
There are several methods such as dissolved gas analysis in oil (DGA), dissolved metals in oil analysis, suspended particles in oil analysis, acoustic and vibration fingerprints, motor power fingerprints, position measurement of the driving axis, static and dynamic resistance measurements, temperature difference measurement, infrared thermography, chemical implants which are used as condition monitoring and diagnostic methods to detect the incipient signs of deterioration in LTCs.
Among the mentioned techniques, dissolved gas analysis is accepted as a sensitive, informative and reliable technique [6] and is widely used in incipient faults detection in transformers [7-9]. In the last few years the method has been recommended by IEEE Power & Energy society for fault detection in LTCs [10].
This technique is based on the determination of types and amounts of dissolved gases in oil, as well as interpretation of the obtained results. Since LTCs contain switching contacts immersed in the insulating oil, as byproducts of normal operation, combustible gases (especially hydrogen, methane, ethane, ethylene and acetylene) are usually formed [10, 11]. Despite the variability of gas accumulation even under normal conditions in non-faulty equipment, it is possible to discern certain patterns which can be used to distinguish between normal and faulty behavior of the equipment in many cases [10]. Unusual gas concentrations and also gas concentrations ratios have been found to be useful indicators of the faults presence [10, 12].

PERFORMANCE PROCEDURE

The Pilot LTCs

Two load tap changers of 125 MVA power transformers in 230/63 substations were selected as pilot LTCs due to the fact that 230/63 kV transformers are considered as the most frequently being used power transformers in Iran.
The selected load tap changers were: (1) an MR M-type and (2) an Elin load tap changers; which are called as LTC1 and LTC2, respectively. The characteristic information of the LTCs such as LTC's type and operating time has been presented in Table 1.

Table 1. The characteristics of the pilot LTCs

Characteristic	LTC1	LTC2
Manufacturer	MR, Germany	Elin, Austria
LTC's type	MIIIY500	MLG3.720
Operating time	19 years	26 years
Last Overhaul date	August 2007	2003

The pilot LTCs had sampling valves in the bottom of the

equipment which facilitated sampling procedure. Furthermore it was possible to have overhaul over the equipment in the near future which enables the authors to have eye inspection over the selected LTCs to compare their predictions with the results from inspection.
It should be noted that according to manufacturer advice, overhaul operation for LTC1 should be performed every 7 years or the number of operation of 80,000, depending on which is reached first. For LTC2 the overhaul operation criteria are every 5-7 years or the number of operation of 70,000, depending on which is reached first.

Oil Sampling

Oil samplings were performed in accordance with ASTM D 3613 standard. The samples were tagged, packed and forwarded to the laboratory considering the mentioned standard [13].
There is some information for each sampling stage presented in Table 2.

Table 2. The Information for Each Sampling Stage

Pilot LTC	LTC1		LTC2	
Sampling stage	1st	2nd	1st	2nd
Sampling date	Feb. 2012	May 2012	March 2012	June 2012
No. of operation	2568	3162	203030	203528
Tap position	16	14	20	22
Oil Temp.	27ºC	37ºC	28ºC	29ºC
Environ. Temp.	21ºC	30ºC	18ºC	21ºC

Samples' Analyzing Procedure

The oil samples were analyzed using ASTM D 3612 standard for determining dissolved gas type and amount in a reliable laboratory [14].

INTERPRETATION OF DGA RESULTS

Interpretation of DGA data for both LTCs was performed as following:
First step: Comparison of each sampling stage data to the LTC monthly watch criteria (presented by Youngblood et al. [15]) was carried out. If none of the concentrations exceeds the threshold values, the LTC performance is concluded to be normal operation.
Second step: In case of exceeding one of the gas concentration from its threshold value, the possibility of fault presence was investigated by gas concentration ratio method presented in reference [16]. If the ratios were in the "Needs attention" range, the equipment is in normal operating condition. However, sampling in three-month intervals is recommended.
Third stage: In the case of laying data in the "Possible damage" or "Detected damage" range, fault exists in the equipment. In this condition using the Duval triangle 2, the fault type would be identified [17].
In addition of mentioned interpretation, a comparison between DGA results interpretation from two sampling stages was performed.

RESULTS AND DISCUSSION

Figures 1 and 2 demonstrate dissolved gases in oil concentrations (including key, other and total dissolved combustible gases concentration (TDCG)) for each sampling stage for both pilot LTCs, respectively.

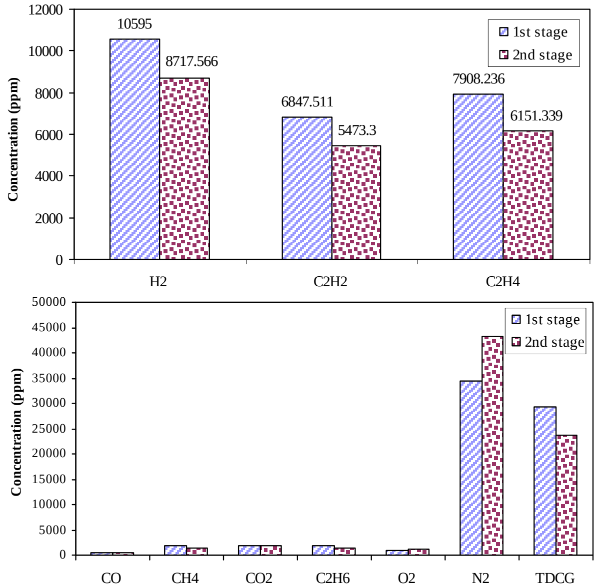

Figure 1. Dissolved gases concentrations for LTC1

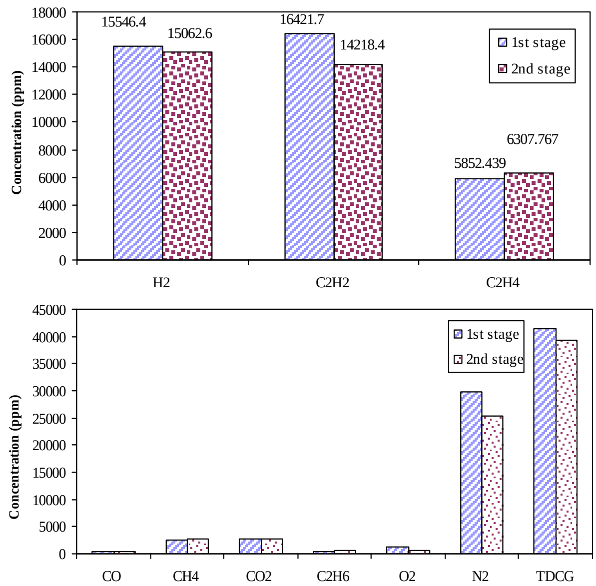

Figure 2. Dissolved gases concentrations for LTC2

Using the LTC monthly watch criteria (1st step), it was revealed that the concentrations of hydrogen, ethylene and acetylene (key gases) for both sampling stages in both pilot LTCs are beyond the criteria. Therefore, the gas ratio method (2nd step) using following ratios should be applied.

$$FR = \frac{C_2H_2 + H_2}{CH_4 + C_2H_6 + C_2H_4 + C_2H_2 + CO + H_2} \quad (1)$$

$$R_1 = \frac{CH_4 + C_2H_6 + C_2H_4}{CH_4 + C_2H_6 + C_2H_4 + C_2H_2} \quad (2)$$

$$R_2 = \frac{CH_4 + C_2H_6 + C_2H_4}{C_2H_2} \quad (3)$$

$$R_3 = \frac{C_2H_4}{C_2H_2} \quad (4)$$

Calculated ratios for both sampling data of LTC1 showed that, except R_1 ratio which was laid in "Possible damage" range, all other ratios corresponded to "Needs attention" range. However, all ratios for LTC2 were laid in "Needs attention" range.

To identify fault type in LTC1 and also to ensure the fault absence in LTC2, the Duval triangle 2 was applied (3rd step), as shown in Figures 3 and 4, respectively.

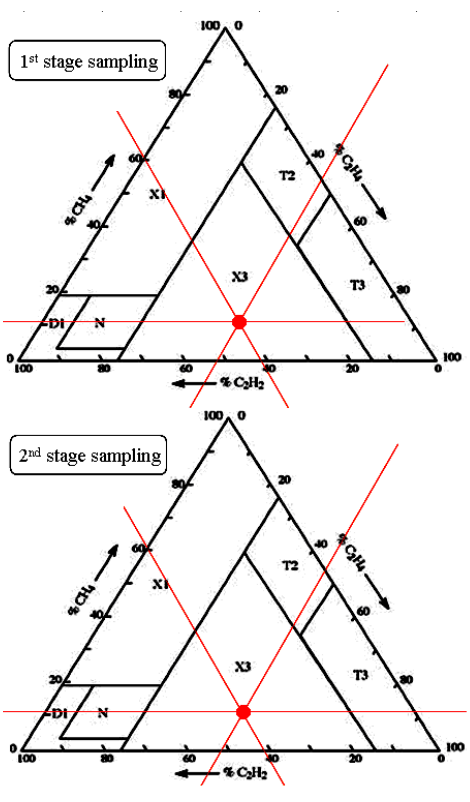

Figure 3. Condition assessment of LTC1 using the Duval triangle 2 for the 1st and 2nd stage samplings

The Triangle coordinates corresponding to DGA results can be calculated using following equations:

$$\%CH_4 = \frac{CH_4}{CH_4 + C_2H_4 + C_2H_2} \times 100 \quad (5)$$

$$\%C_2H_4 = \frac{C_2H_4}{CH_4 + C_2H_4 + C_2H_2} \times 100 \quad (6)$$

$$\%C_2H_2 = \frac{C_2H_2}{CH_4 + C_2H_4 + C_2H_2} \times 100 \quad (7)$$

For LTC1 (Figure 3) the crossing point for both sampling stages were located in X3 section which corresponded to in progress thermal fault with light coking or increased resistance of the contacts or severe arcing. Therefore, it is recommended to test or inspect the LTC for signs of faults. However, this is in spite of the fact that the number of tap changes is very low (much lower than 80,000) and the number of years since last overhaul is less than 7 years (the recommended overhaul criteria by manufacturer).

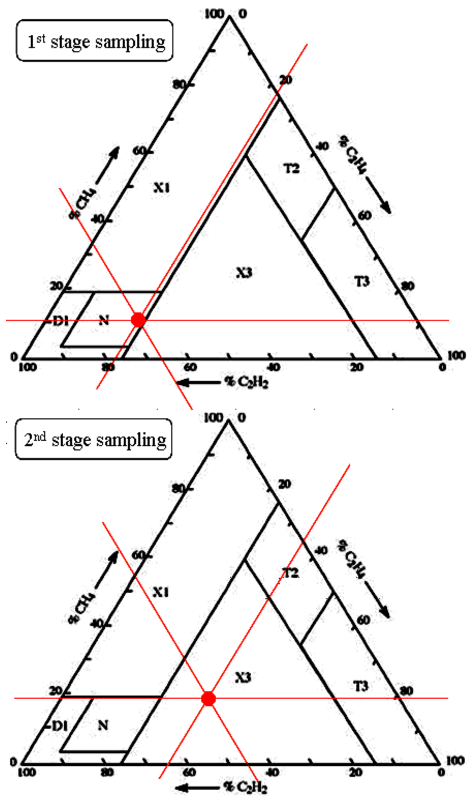

Figure 4. Condition assessment of LTC2 using the Duval triangle 2 for the 1st and 2nd stage samplings

DGA data interpretation for LTC2 (Figure 4) shows that for the 1st sampling stage, the crossing point is located in N section which indicates the normal operation and fault absence. While for the 2nd sampling stage, the crossing point is placed in X3 section which related to in progress thermal fault with light coking or increased resistance of the contacts or severe arcing. In this case equipment inspection is recommended.

Despite the recommended overhaul criteria by manufacturer that the overhaul operation should have performed at least 2-5 years ago, LTC2 is in good condition in the 1st sampling stage. However, there are signs of fault presence in the 2nd sampling stage. Therefore performing overhaul for LTC2 is suggested, but it is not an obligation.

CONCLUSIONS

Condition assessment was performed over two load tap changers of 125 MVA power transformers in 230/63 substations using dissolved gas analysis (DGA). Interpretation of DGA data was carried out using Threshold value method, Gas concentration ratio method as well as the Duval triangle 2 method. The obtained results from data interpretation were used in making decision for overhaul operation over the selected equipment.

DGA data interpretation reveals that there were in progress thermal fault with light coking or increased resistance of the contacts or severe arcing in the LTCs. Performing overhaul for LTC1 is strongly recommended, while it is not an obligation for LTC2 overhaul (regarding its determined good condition in the 1st sampling stage). However, this is despite the suggested overhaul criteria by the manufacturers that recommend no overhaul for LTC1 and necessary overhaul for LTC2.

In case of impossibility for performing overhaul operation over the LTCs in the near future, it is advised to perform dissolved gas analysis in three-month intervals. This would help to be aware of the equipment condition which would avert catastrophic failures.

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