CASE STUDY: Transformer fault detection and repair followed by degassing monitored with online DGA

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Abstract

The paper discusses a case study on a 400 MVA 400/120/21 kV transformer, installed and commissioned in a 400/110 kV transmission substation in Finland in 2003. This ONAN/F transformer is free breathing via silica-gel dehydrating breather (no rubber bag). It has ~100 m3 mineral oil (Nytro 10X).

The transformer had previous gassing history with detected and later repaired faults. The degassing was done to see whether there still exists an active event/fault that produces some gases concealed by gases from previous already repaired faults. The transformer was equipped with Vaisala multi gas DGA monitor prototype that operated through the degassing process as well as the following months afterwards.

Transformer gassing trend and history before degassing

Gassing started in 2005 and was showing rising trend until 2010. Bare metal high temperature thermal fault (T3) was suspected according to the dissolved gas analysis (DGA). However the first electrical measurements in November 2010 did not reveal anything conclusive. Fault was still active and fault gases showing rising trend until 2013. This time the gases started to elevate more rapidly and the repeated DC resistance measurement identified problem to 110 kV 2a phase. Fault was located to 110 kV between bushing and winding outlet main contact. The faulty 110 kV 2a phase contact was repaired in August-September 2013.

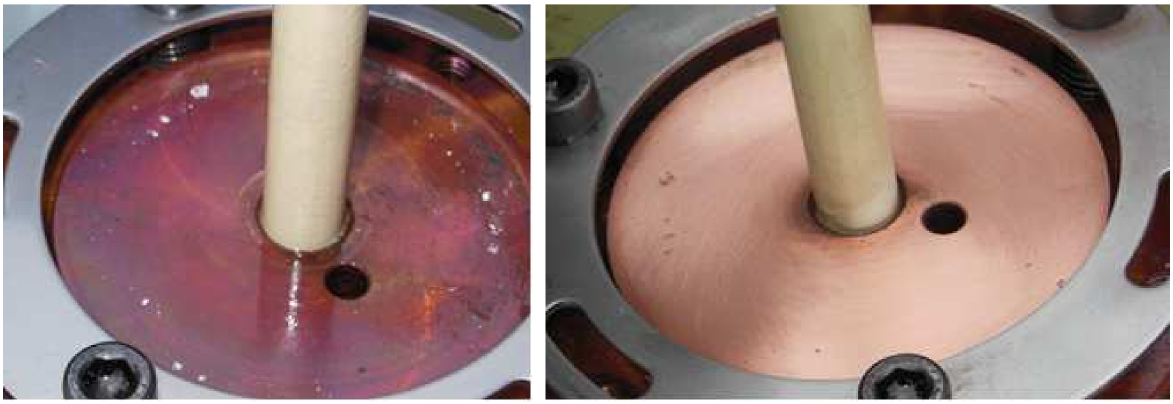

Figure 1 Faulty 110 kV 2a bushing and winding outlet main contact before and after repairing.

Fault gasses had then downward trend until February 2014 and started showing slow rise again until April 2014. After that fault gases started to elevate rapidly and DC resistance measurement localized problem to 110 kV 2c phase. Fault was again at 110 kV side between the bushing and winding outlet main contact and these faults were repaired in June 2014.

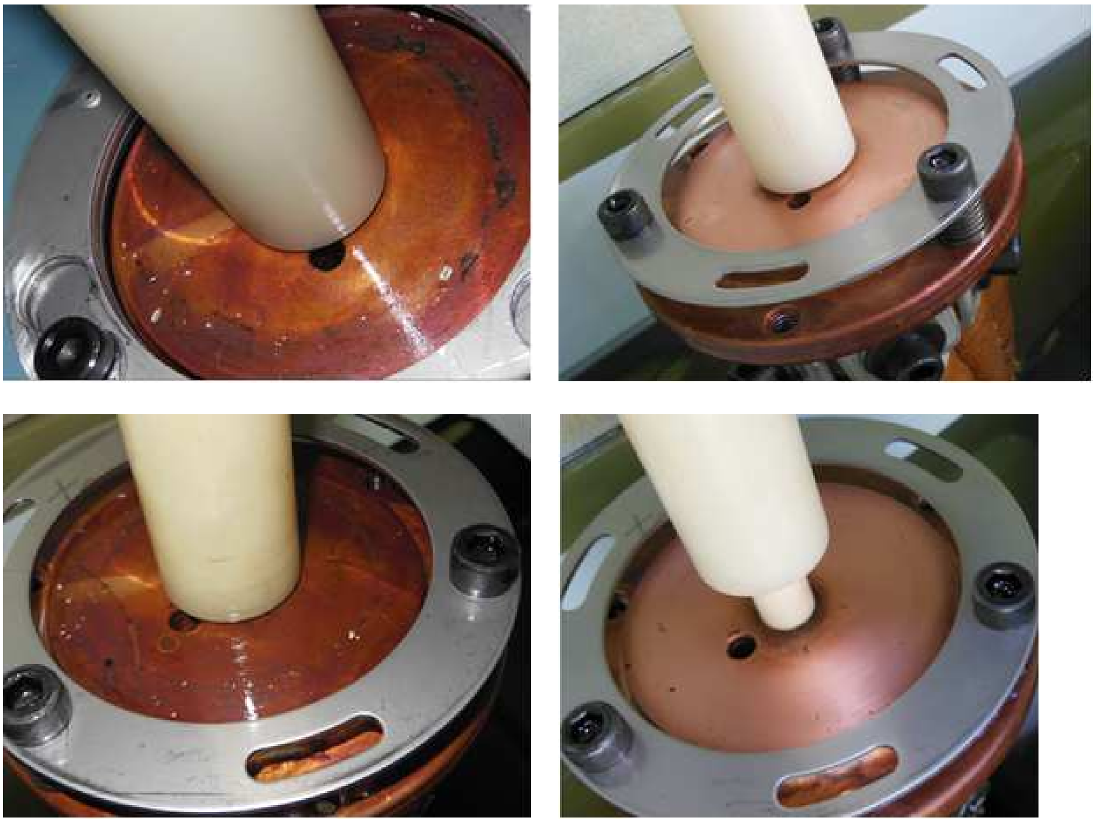

Figure 2 Faulty 110 kV 2b and 2c bushing and winding outlet main contacts before and after repairing.

After the last repair of the transformer, fault gas levels were relatively high. In order to see whether there still was an active fault, degassing of the transformer was scheduled in November 2015. The actual degassing process was run by a service provider.

Table 1 Gas concentrations (ppm in oil) before and after repairing. NA=not available

	Monitor	**H2**	**CO**	**CO2**	**CH4**	**C2H6**	**C2H4**	**C2H2**
6/2005	Laboratory X	3	106	1089	8	4	8	1
10/2010	Laboratory X	44	109	2496	180	133	557	3
	Brand Y	60	99	2341	181	130	529	0
	Brand X, 24 h avg.	70	120	NA	NA	NA	620	8
6/2013	Brand Y	80	78	2529	165	170	732	1
	Brand X, 24 h avg.	100	80	NA	NA	NA	680	2
7/2013	Brand X, 24 h avg.	120	80	NA	NA	NA	690	2
5/2014	Brand Y	108	73	2219	333	284	1192	3
	Brand X, 24 avg.	220	60	NA	NA	NA	780	2
9/2014	Laboratory Y	33	105	1830	175	140	685	3
	Brand X, 24 h avg.	60	80	NA	NA	NA	760	2

Online DGA monitor

Two weeks before the degassing took place, the transformer was equipped with a new online DGA monitor, which takes the oil for analysis from the bottom sampling valve and returns it to the top valve. In this monitor, gases are extracted from oil under vacuum and analysed in optical infrared (IR) measurement module. Hydrogen and moisture were measured in oil phase prior to the vacuum extraction.

Since the new online DGA monitor was still under development it was not connected to the utility's centralized monitoring system, but was remotely operated by Vaisala R&D via a 3G modem. The average measurement cycle was set to 90 minutes and the monitoring data was read and recorded without any filtering or averaging. Actual degassing process started on Nov 17th and finished Nov 20th. The DGA monitor operated normally during the degassing process as well as the following months to see how the gases from oil in paper appeared to whole oil volume.

Figure 3 400 MVA transformer with Vaisala online DGA-monitor prototype (red circle).

Degassing

The degassing process treated the 100 m3 oil volume roughly 3 times at 80 °C during 3 days while the transformer was off-load. The process decreased gas amounts in oil to one tenth, which was confirmed both with the individual gas measurements as well as from the pressure of total dissolved gases (Figure 7). Ambient temperature varied between 0 to 10 °C during the degassing process.

Results and discussion

CO_2 amount in oil started to increase sharply after degassing process finished, main source probably being ambient air. Also ethylene increased clearly. However, it stabilized for two months following again with slight increase. The reference methods confirmed the increases. As of now it is not clear whether the increase in CO_2 and C_2H_4 amounts is due to that gas was "stored" in paper and released to form equilibrium between paper-oil and whole oil volume, or if there is a hot spot in oil only.

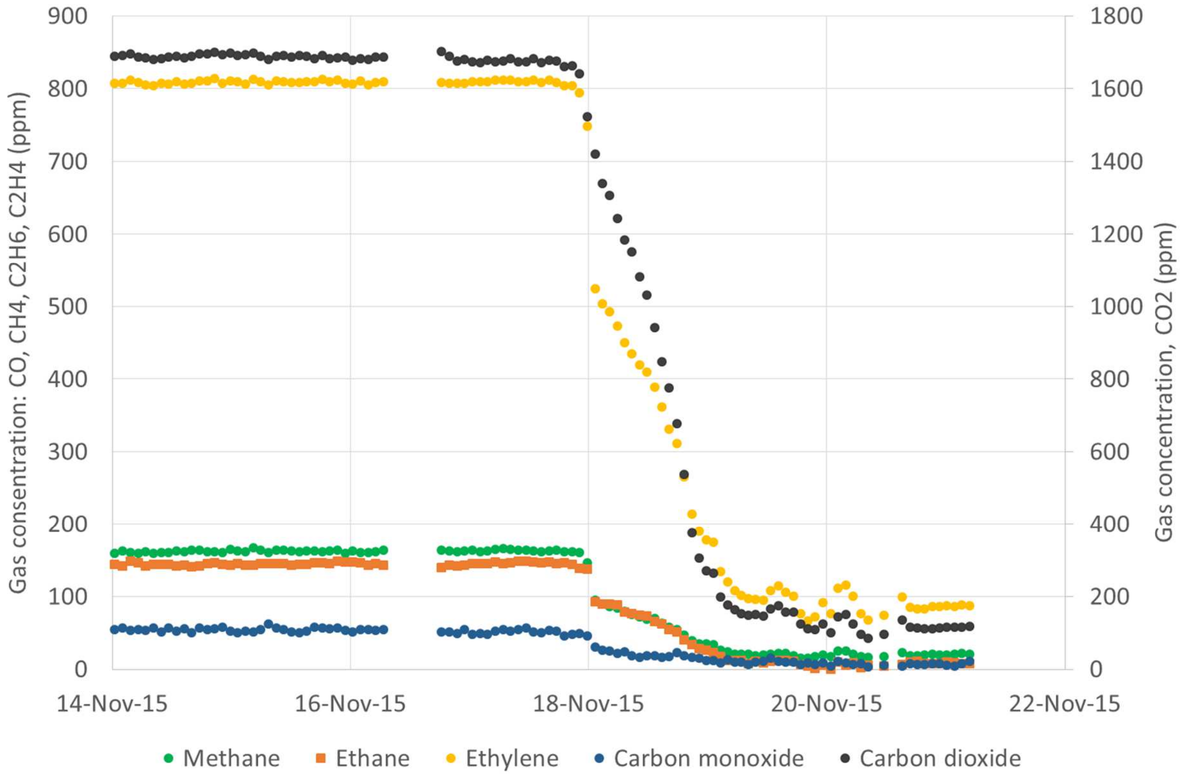

Figure 4 DGA monitoring data before, during and shortly after the degassing. Acetylene not available and hydrogen was 0 ppm already before the degassing thus removed from graph. Individual measurement points presented without averaging.

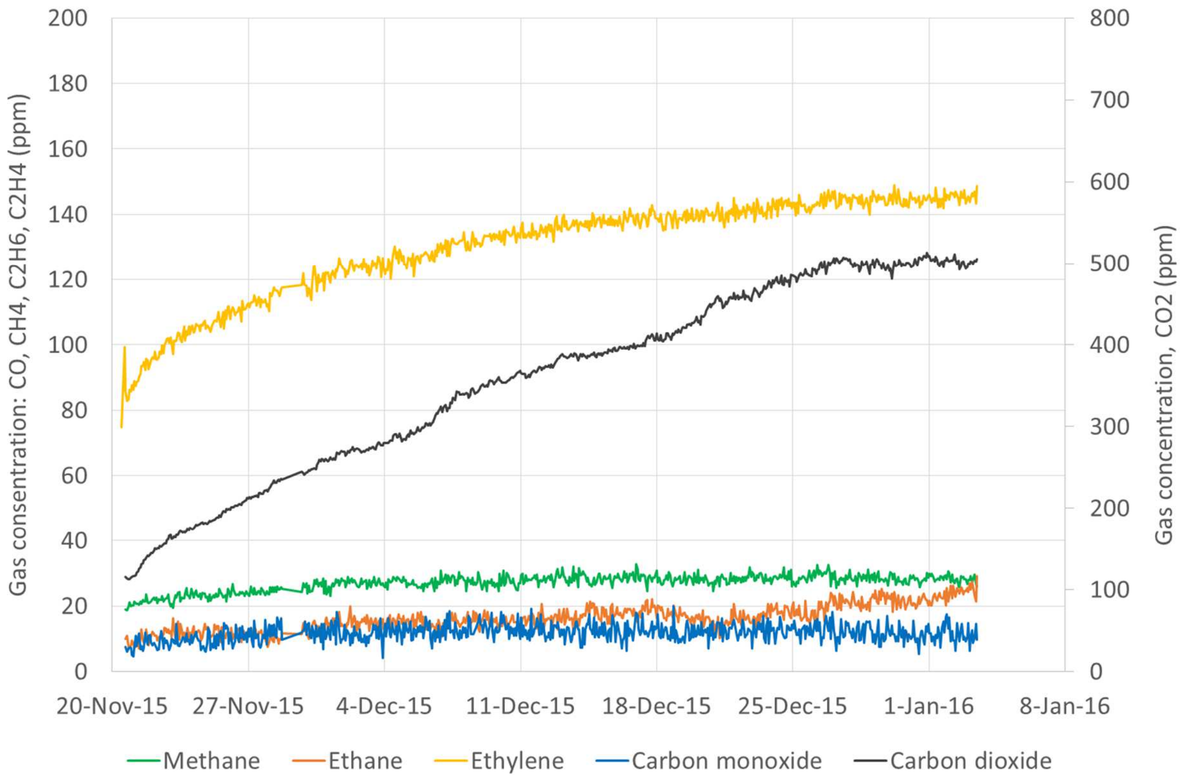

Figure 5 DGA monitoring data after the degassing. Acetylene not available and hydrogen was 0 ppm thus removed from graph.

According to Michel Duval one can expect to see roughly 7-10% of concentrations prior to degassing to recover back in oil during the following days/weeks after degassing process. This is due to gases in oil that was impregnated in paper, but did not go through the treatment. The amount may vary somewhat depending on the ratio of solid insulation to oil mass. In this case the ratio was known. However, from measured ethylene level we can conclude that it increased from roughly 70 ppm to 145 ppm within 6 weeks post degassing and then stabilizing (Figure 5). This 75 ppm increase is roughly 9% of the ethylene level prior degassing process.

Other gases except carbon dioxide remained stable over the winter 2015-2016. In March ethylene level started to increase again having even a level step in May 2015. This gassing tendency of ethylene may relate to transformer internal actions as it appears the same time as top oil temperature level increases as well (Figure 6).

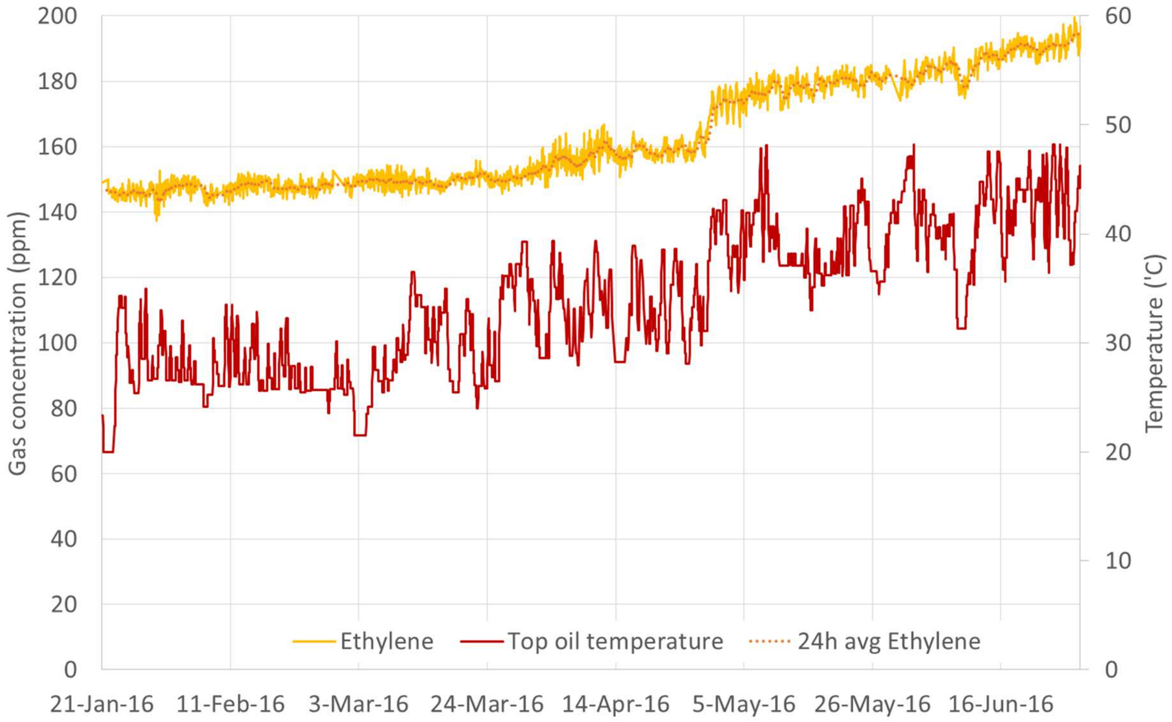

Figure 6 Ethylene concentration and top oil temperature.

Table 2 lists the gas concentrations prior to degassing, right after it and 11 months later. In this case, there were 4 different analysis methods used of which one traditional laboratory analysis, one offline method, one commercial online monitor and the Vaisala online DGA prototype. Although there were clear differences in the results the magnitude of gas levels were consistent. All methods also confirmed that there was significant increase in some gas levels during the following year after degassing. One device failed, thus results were not available right after the degassing until it was repaired. Also there were some differences which gas parameters were available.

*Table 2 Gas concentrations (ppm in oil) before and right after degassing as well as one year after. Hydrogen <5 ppm with all methods. NA=not available. * Calibration error. Estimate 1-2 ppm*

	Monitor	**CO**	**CO2**	**CH4**	**C2H6**	**C2H4**	**C2H2**
Prior to degassing	Laboratory Y	80	1610	70	145	695	2.7
	Vaisala proto	56	1686	165	142	807	NA
	Brand X	61	NA	NA	NA	720	1.7
	Brand Y	69	2162	127	252	1011	2.5
Right after degassing	Laboratory Y	2.7	35	2.2	13	43	0
	Vaisala proto	4	86	15	2	68	0
	Brand X	Fail	NA	NA	NA	Fail	Fail
	Brand Y	2	401	17	40	97	0
11 months after degassing	Laboratory Y	50	980	7	29	140	1.5
	Vaisala proto	58	1240	21	45	177	6*
	Brand X	96	NA	NA	NA	223	1
	Brand Y (6/2016)	30	1175	30	51	181	1.5

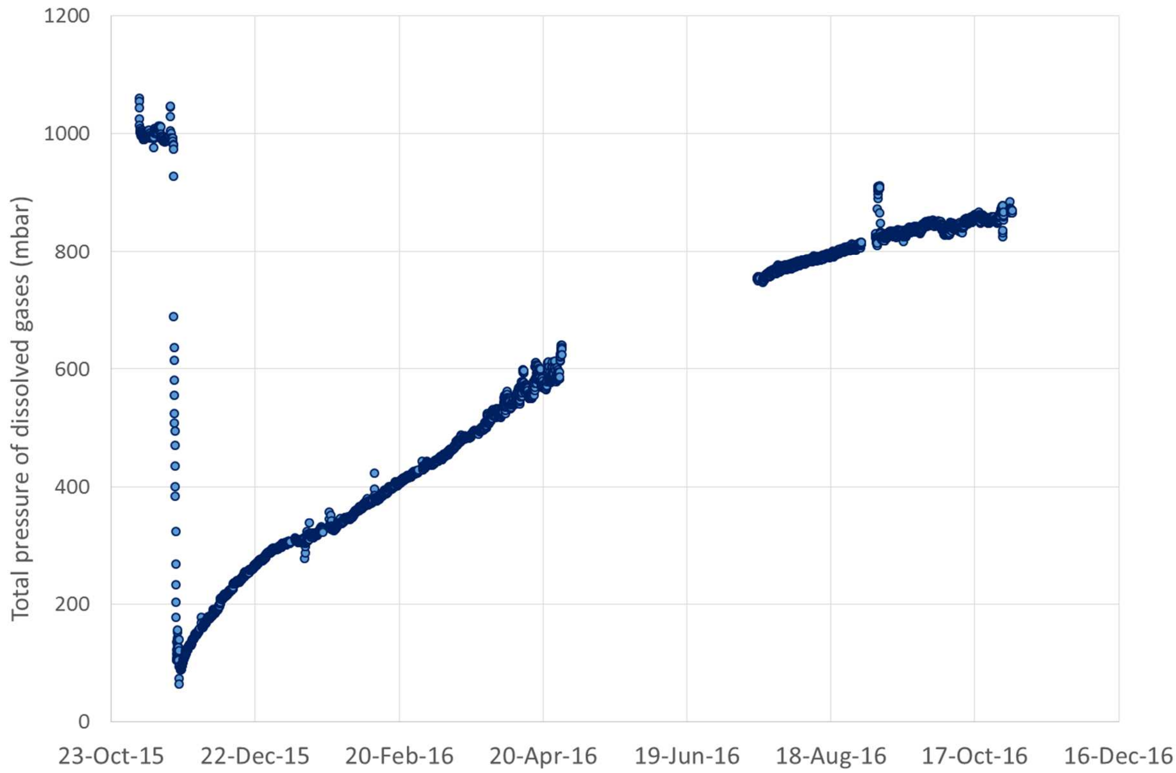

Figure 7 Total pressure of all dissolved gases before, during and after degassing process.

Surprisingly the total gas pressure in oil has not reached equilibrium with ambient air pressure even almost one year after degassing (Figure 7). Although it is free breathing transformer the gas diffusion through long tube between the tank and the conservator is very slow process under low temperatures. Also light loading has kept the oil level very stable in the conservator so that there has not obviously occurred real breathing.

As of now it is not clear what the reasons for increasing gas levels are, even under rather low load and temperature. When looking at Duval triangle, the measured online data would suggest T3 high temperature fault. The same time there has been some increase in CO and significant increase in CO2 which may also indicate paper being involved.

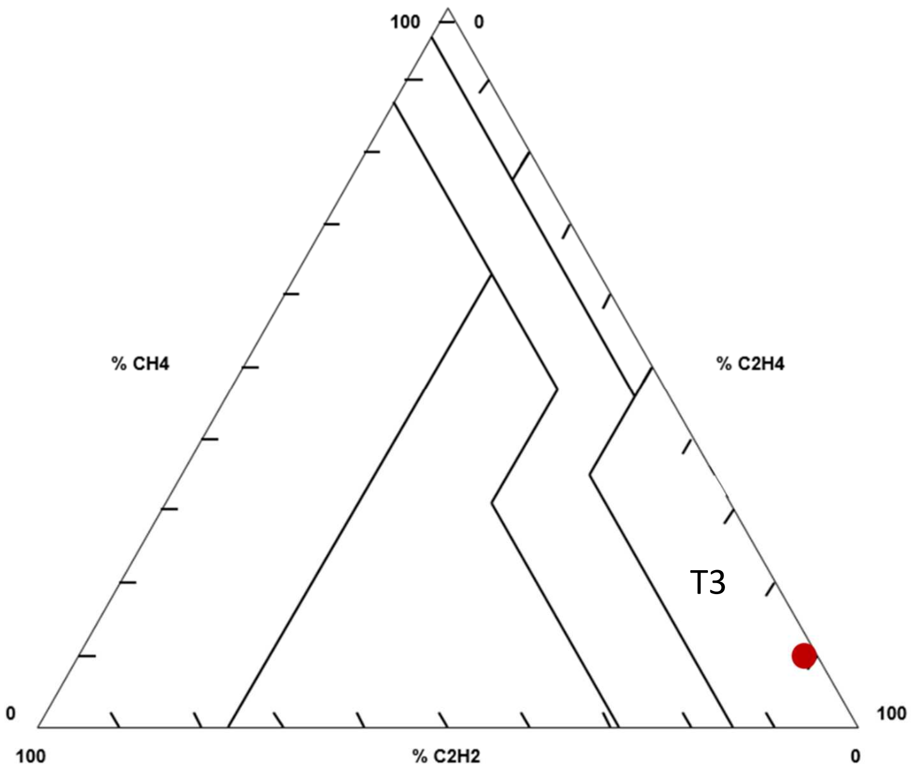

Figure 8 Duval triangle with online data point 11 months after the degassing.

Conclusions

The online DGA monitoring during the degassing process proved that the monitor was able to follow reduction of gas levels in oil real time. Even when the total amount of all dissolved gases decreased to one tenth from the initial level it could easily extract the gases from oil under vacuum. The monitoring data clearly shows that the degassing was not complete, couple of days more could have improved situation so that part of the gases in impregnated oil could have been removed.

The uncomplete degassing process left rather significant amount of gases into the transformer insulation which then later distributed again through the whole oil volume. This gas level "recovery" makes it challenging to interpret data measured after the degassing process. Is significant amount of measured gases still left from earlier faults or is there something new ongoing in this transformer? Should one be concerned or not? Yes, because there were some problems during manufacturing and the installation work (erection) on site. That is why multi gas monitoring device is essential to monitor this unit continuously and with enough accuracy and good repeatability allowing consistent gas trending.