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Significance of Operational Data on DGA Interpretation on Tap-Changers

Dissolved Gas Analysis (DGA) has become a well-established diagnostic method for liquid-filled transformers, without laying claim to be an exact science. Due to its nature, the thermal deterioration of organic liquids (e.g. mineral oils and esters) can provide varying gas patterns and gas amounts when exposed to a defined value of thermal stress. With this, defined limit values must be understood as an indication for typical resp. irregular gassing behaviour, but not as a sharp line between faulty and non-faulty equipment. Furthermore, handling errors during sampling, the gas extraction method used, the calibration of the gas chromatograph and reliability of Ostwald coefficients may further increase the uncertainty of ppm values generated for each gas.

Anyhow, typical gas patterns with key gases for failures like sparking/partial discharge, arcing and different grades of overheating were identified and meaningful gas ratios were defined (e.g. Rogers et.al.). Quotient methods have been further refined in Duval triangles and pentagons. Unfortunately, in practice the gas patterns are often not clear enough to allow a definite assignment to a certain failure, either because the failure is not distinct or more than one failure is active. DGA results are further blurred by the uncertainty caused by the above mentioned liquid characteristics and the measuring method.

Up to now, no method was available to factor the intrinsic uncertainty of DGA. With the advent of artificial intelligence (AI) techniques, new methods are being derived which can handle this uncertainty. The result of AI based DGA interpretation is no longer a comparison of ppm or quotient numbers with admissible ranges or limit values, but a stochastic probability for the occurrence of a failure. Suitable algorithms are trained with rated data sets from available DGA databases by supervised learning, where each data set (each DGA) has been rated by a status (state). When applied to an unknown DGA, the probability for each state is calculated.

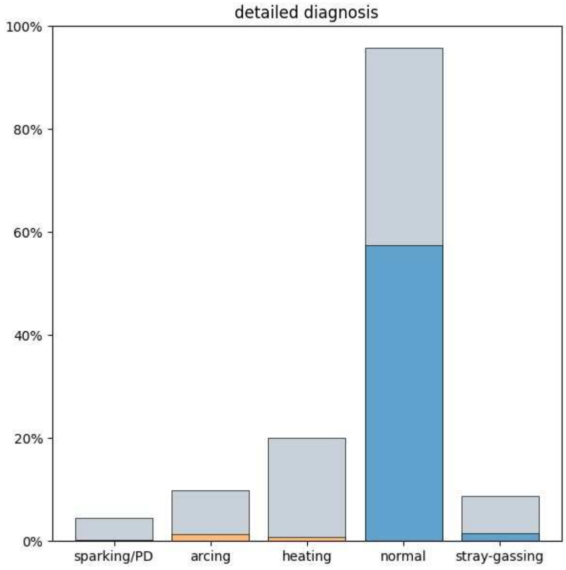
This method does not only work for transformer DGA but is also applicable to vacuum type on-load tap-changers. Here, the oil conditions are similar as for the transformer. Because the switching arcs are encapsulated inside vacuum interrupters, no severe oil deterioration takes place. Only some sparking/low energy arcing from commutation contacts plus low temperature heating from the transition resistors may occur during normal service. With this, the thermal stress on the oil is similar as in the transformer, where the winding produces low temperature heating and, for regulated transformers with on-load tap-changer (OLTC), the contacts of a change-over selector may produce some sparking/low energy arcing. Absolute ppm values in the tap-changer oil compartment are typically 1-digit or in the low 2-digit range, which renders quotient methods as unreliable. AI methods can handle such situations without problems.

The possible states for DGA on vacuum type OLTCs were defined as follows:

- sparking or partial discharge
- arcing
- heating
- normal
- stray-gassing

The latter "stray-gassing" is important to respect the self-gassing activity of some oils when in contact with certain steels, paints or other materials, or if a passivator additive has been added. The amount of gases caused by stray-gassing can completely mask a gas pattern caused by an incipient failure. As it cannot be avoided, it has to be regarded as "normal".

Fig. 1 shows a diagnosis of a typical network application with vacuum type OLTC in normal service. The columns for "normal" and "stray-gassing" are blue, "sparking/PD", "heating" and "arcing" represent failure modes in orange (colors chosen for color-blind persons). It can be seen that the uncertainty (grey) is quite high. This is due to the fact that no operational data were available to be integrated in the interpretation.



Example 1,
only DGA values

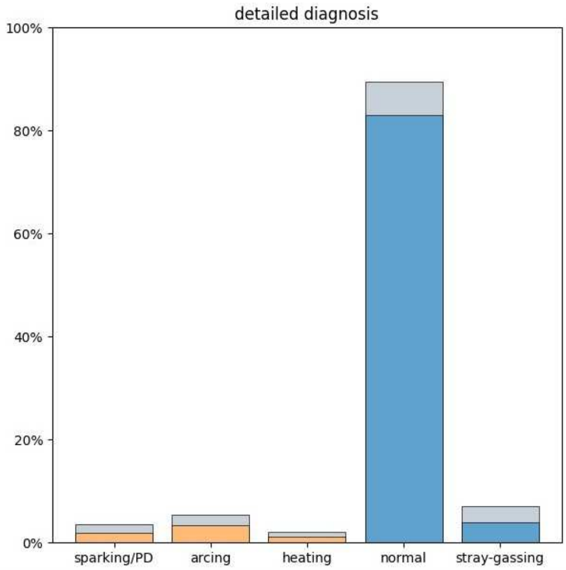
H_2	50 ppm
CH_4	10 ppm
C_2H_6	10 ppm
C_2H_4	8 ppm
C_2H_2	3 ppm
CO	75 ppm
CO_2	600 ppm

Fig. 1: DGA diagnosis of vacuum-type OLTC in normal service; high uncertainty

The AI diagnosis can significantly be improved if equipment-specific parameters and application data like

- number of operations (since last oil change)
- years in service (since last oil change)
- sealing (free-breathing or closed type conservator)
- etc.

are taken into account. Fig. 2 shows the result of the same DGA, supplemented with operational data.



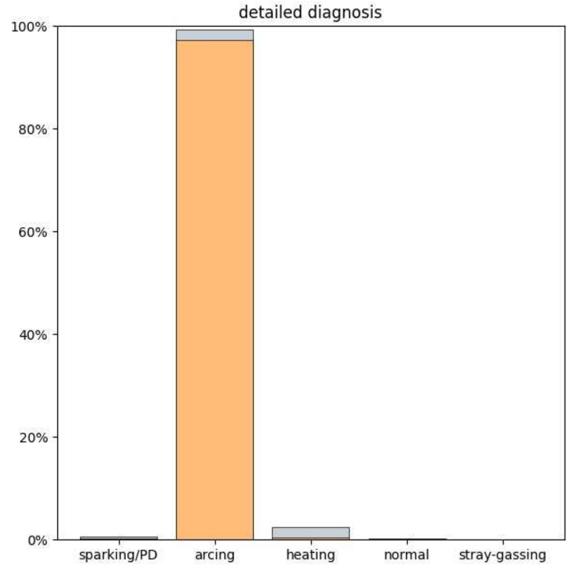
Example 1,
same DGA values, plus operational data

H_2	50 ppm
CH_4	10 ppm
C_2H_6	10 ppm
C_2H_4	8 ppm
C_2H_2	3 ppm
CO	75 ppm
CO_2	600 ppm

- 20000 operations
- 7 years in service
- ...

Fig. 2: DGA diagnosis of vacuum-type OLTC in normal service; low uncertainty

DGAs of vacuum-type OLTCs with high ppm values usually represent failure cases. In these cases, the AI algorithm will output a diagnosis with low uncertainty, even if no or less operational data are available; see Fig. 3.



Example 2, only DGA values

H2	76 ppm
CH4	14 ppm
C2H6	9 ppm
C2H4	51 ppm
C2H2	233 ppm
CO	119 ppm
CO2	1389 ppm

Fig. 3: DGA diagnosis of vacuum-type OLTC after arcing failure; low uncertainty

Like a human expert, the algorithm evaluates absolute gas values, relation between gases and operational data to calculate probabilities and uncertainties. Because the output of the AI algorithm always contains the probability of all possible failure modes, it is also possible to detect multiple failures, such as they are caused by a loose connection on a live current path. In several cases, a combination of heating and sparking/arcing can be observed, due to obvious reasons.

Conclusion

The OLTC examples have shown that AI based methods provide additional value compared to conventional DGA interpretation methods. Suitable AI algorithms can incorporate the intrinsic uncertainty of DGA, which is represented by a probability of all possible states, in combination with their uncertainty. For vacuum type OLTCs, a precise diagnosis is often only possible by evaluating additional operational data.
These findings also apply to DGA on transformers or other oil-filled equipment, and methods can be transferred easily.