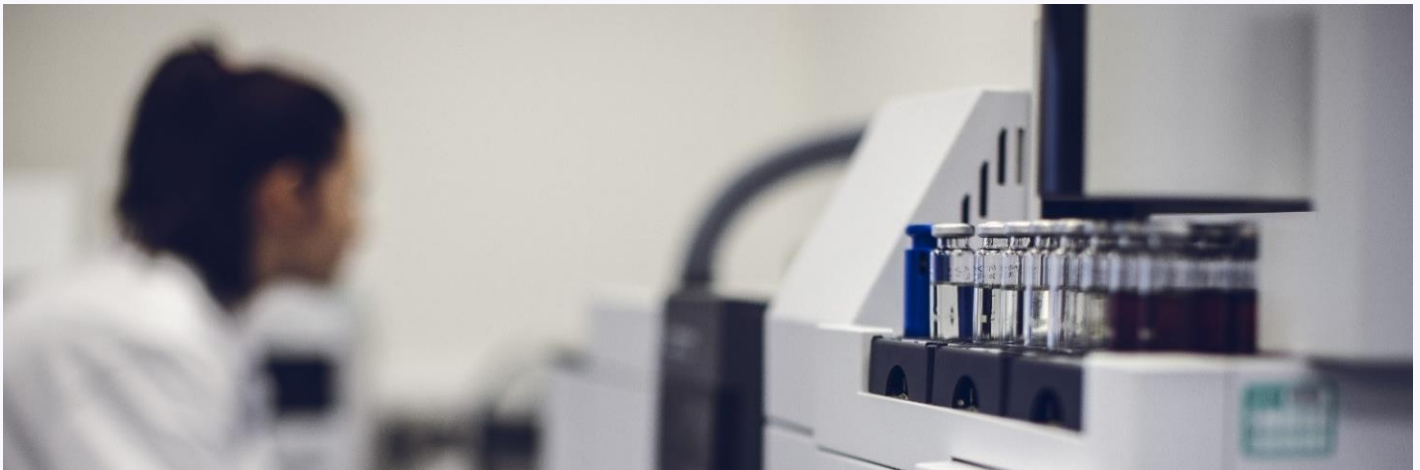


How to gain confidence in your DGA Diagnostics

Improve your accuracy comparing all diagnostic methods using the DGA Matrix



The application of diagnostic methods to analyse DGA results can be challenging, time consuming and difficult to interpret. When should one method be used instead of another? What to do when the diagnostic results are different, sometimes contradictory? **How can you know which diagnostic method is the right one?**

This White Paper describes a new and simple DGA diagnostics comparison method: **the DGA Matrix compares diagnostic results from all the common industry standards providing immediate confidence in the results** and reducing the dependency on expert interpretation.

Executive Summary

The White Paper shows how a DGA Matrix tool can be used obtain an immediate diagnosis based on the Dissolved Gas Analysis (DGA) with increased confidence from comparing all diagnostic methods available in literature; saving time and reducing the dependency on experts for interpretation.

The goal has been accomplished by developing a simple matrix where DGA data are processed and analysed using 11 diagnostic methods.

Each row of the matrix corresponds to one specific method (IEC, Rogers, Dornernburg, Key Gas, Duval Triangles and Pentagons, ETRA, CO₂/CO) while each column correspond to the diagnostic result (No Diagnosis, OK, PD, Stray Gassing, T1, Overheating, Carbonisation, T2, T3, DT, D2, D1).

By observing the results of each method on the same graphic it is very simple to discard outliers, reduce uncertainty and focus on the predominant failure mode. It is also possible to determine specific graphical patterns typical for known defects which will further increase the confidence on the analysis for future cases.

Background

DGA is a very reliable technique for detecting the presence of a fault condition that occur in oil immersed transformer. Several diagnostic methods have been developed since 1960 and published in international standards and guidelines, aimed at identifying the type of faults as a function of temperature (Figure 1).

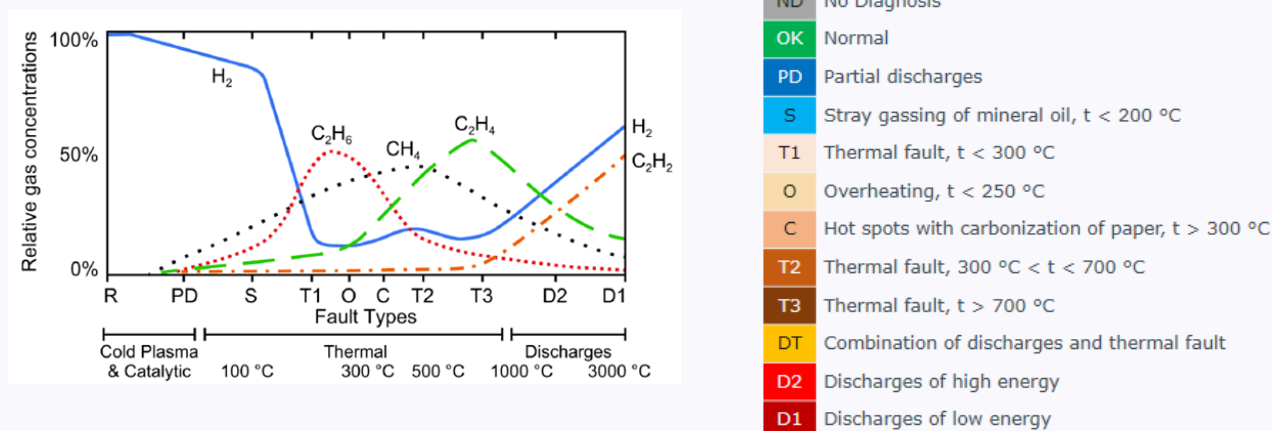


Figure 1: Faults vs temperature (IEEEc57.104 and CIGRETB771) with legend

The methods are described in:

- IEEE C57.104:2019 (Key Gas, Doernenburg, Duval Pentagons, Duval Triangles, CO₂/CO method)
- IEC 60599:2015 (IEC gas ratio, CO₂/CO, Duval Triangles)
- CIGRE TB7 71:2019 (Duval Pentagons, Duval Triangles)
- Electric Technology Research Association (ETRA)

There are however several challenges using these methods:

1. There is **no method that can describe all the failure modes**, so you might need to use more than one, but which ones?
2. Different methods use **different semantics**. For example, Dornenburg calls Thermal decomposition what other methods could indicate as Thermal Faults: T1, T2, T3 or DT; Rogers Ratio uses generic word Arcing what other methods would define D2 or D1
3. **IEC, Rogers and Doernenburg cannot identify faults in 15 to 20% of DGA cases** because DGA values falls outside the defined diagnostic zones (CIGRE TB 771)
4. **Key gas method can fail about 50% cases** (CIGRE TB771), because it frequently diagnoses cases of failure in the paper for aged transformers with CO above 300 ppm; while in reality most are normal condition
5. Diagnostic methods should be used only above some typical gas concentrations, but **what are these limit values?**
6. DuvalT4 and DuvalT5 should be used only in some cases depending on the result of DuvalT1, but many users either use only DuvalT1 (and this could lead to wrong conclusions) or simply **do not remember the conditions under which DuvalT4 or DuvalT5 should be used**
7. Different methods can lead to **different results in case of mixture of failures**.
8. **CO and CO₂ interpretation is too open to individual experience**, and opinion on interpretation has changed also in the standards over the years. Early interpretations focussed just the ratio, now recommended methods for interpretation combine the ratios along with concentrations other gases, but what concentration levels of other gases need to be considered?

At the end, most of users always require an expert eye to understand the condition under which the diagnostic methods must be used and interpreted.

The Solution: DGA Matrix

A solution to the common challenges with DGA interpretation and diagnosis, is a new graphical tool, called the **DGA Matrix**. The tool compares the diagnostic results of all common DGA diagnostic methods, immediately translating the results in a standard nomenclature according to IEEE, IEC, ETRA and CIGRE description of fault types. Thanks to the DGA Matrix color coding identifying the fault type is immediate.

How does it work?

Whenever all the gases are under the limit, the DGA Matrix returns OK as diagnosis (Figure 2).

The limits for this diagnosis are from Condition 1 in IEEE C57.104:2008 except for CO2 where 5000 ppm has been used. If gas concentrations exceed the limits, then each method is calculated providing a result between ND (No Diagnosis) and D1 (Low Energy Discharges).

It should be noted in Figure 1 that D1 is indicated after D2. This is reported also in the Matrix for consistency. This diagnostic approach is derived from IEEE and CIGRE, due to the fact that D2 discharge could involve a larger part of oil and result in a lower average temperature due to the exchange of heating. So, if the failure modes are to be sorted by temperature, D1 has to follow D2 (although D2 remains a more energetic and dangerous event than D1).

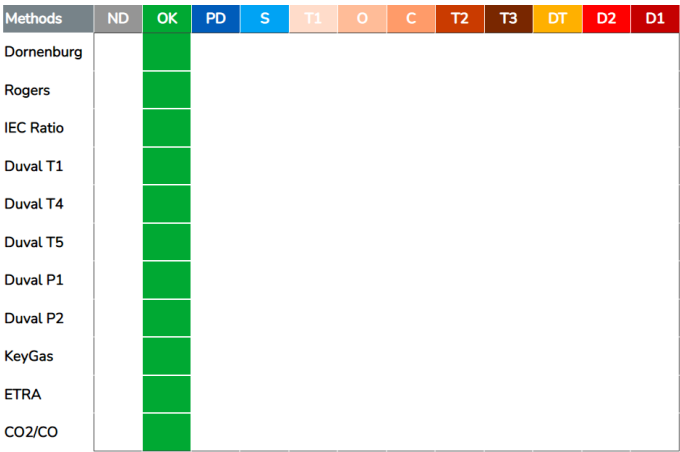


Figure 2: DGA Matrix result for healthy transformer

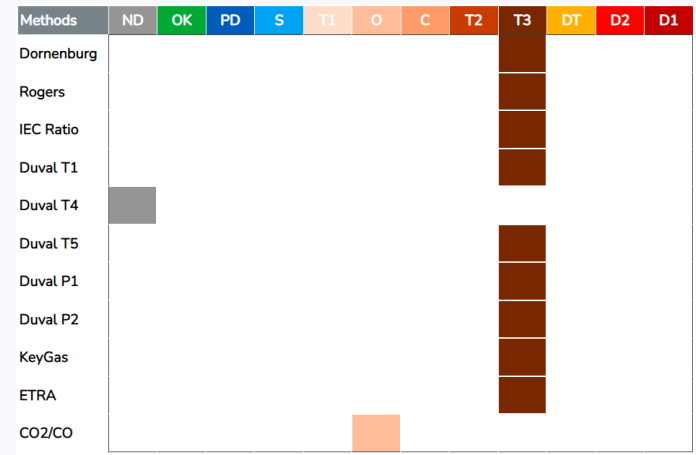


Figure 3: Real Example #1 - Thermal Fault on a 250 MVA autotransformer

Figure 3 shows an example of a serious thermal fault with high gas concentrations (values in Table 1, Example #1). The DGA Matrix shows a very good agreement among all the diagnostic methods, indicating a thermal fault above 700 °C (T3). DuvalT4 is not applicable due to DuvalT1 results, and the ratio between the carbon oxides indicate overheating of the insulation, which is correct in this case.

Table 1: Gas concentrations (ppm)		
Gas	Example #1	Example #2
H2	1090	1603
CH4	4017	75
C2H6	1408	4
C2H4	6292	3
C2H2	10	0
CO	563	67
CO2	1360	445

The second real-life case study, shown in Figure 4, involves a Partial Discharge (PD) phenomenon (ppm values in Table 1, Example #2) between a shunt and the tank wall. The DGA Matrix shows good agreement for all those methods capable to identify PD, thus significantly increasing the confidence on the analysis.

Example #2 confirms that using just one diagnostic method, like DuvalT1, would not provide an accurate diagnosis, since it would indicate this fault as a thermal fault instead of PD. If we then look at the DGA Matrix, all the additional methods like the DuvalT4, Pentagons, ETRA and Rogers are used to complete the diagnosis and confirm that it is a failure mode due to PD. In this way the diagnosis becomes more certain and reliable.

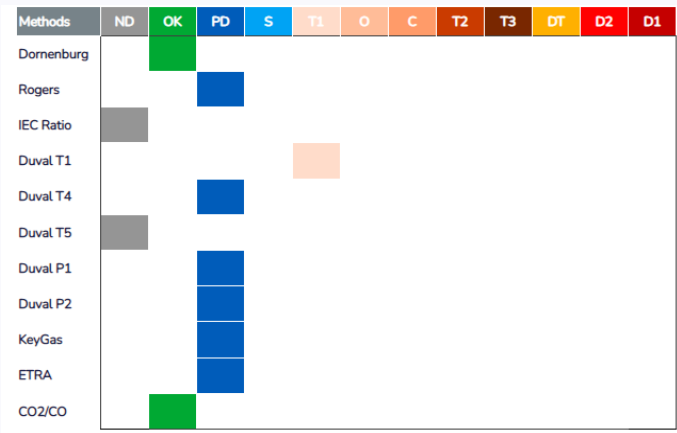


Figure 4: Real Example #2 - Partial Discharges between shunt and tank

DGA Matrix for typical failure modes

The following section shows real examples taken from the literature and Camlin database, analysed using the DGA Matrix.

Known Fault Type: **PD** in three phases, in oil (Camlin Energy library)

Gas	ppm
H ₂	1495
CH ₄	81
C ₂ H ₆	14
C ₂ H ₄	6
C ₂ H ₂	0
CO	48
CO ₂	959

Methods	ND	OK	PD	S	T1	O	C	T2	T3	DT	D2	D1
Dornenburg												
Rogers												
IEC Ratio												
Duval T1												
Duval T4												
Duval T5												
Duval P1												
Duval P2												
KeyGas												
ETRA												
CO ₂ /CO												

Comments: Most methods identify correctly PD

Known Fault Type: **Stray Gassing** (ref: EDP Labelec database)

Gas	ppm
H ₂	133
CH ₄	177
C ₂ H ₆	224
C ₂ H ₄	8.7
C ₂ H ₂	0
CO	363
CO ₂	480

Methods	ND	OK	PD	S	T1	O	C	T2	T3	DT	D2	D1
Dornenburg												
Rogers												
IEC Ratio												
Duval T1												
Duval T4												
Duval T5												
Duval P1												
Duval P2												
KeyGas												
ETRA												
CO ₂ /CO												

Comments: Stray gassing can be diagnosed only by Duval methods. It is often accompanied with either Thermal T1 or PD result from the other methods. However, in this case DuvalT1 alone would not be not correct.

Known Fault Type: **Overheated insulation**, iron sheets of lower frame (CIGRE TB771, Table 3.5)

Gas	ppm
H ₂	29
CH ₄	204
C ₂ H ₆	264
C ₂ H ₄	17
C ₂ H ₂	0
CO	24
CO ₂	2000

Methods	ND	OK	PD	S	T1	O	C	T2	T3	DT	D2	D1
Dornenburg												
Rogers												
IEC Ratio												
Duval T1												
Duval T4												
Duval T5												
Duval P1												
Duval P2												
KeyGas												
ETRA												
CO ₂ /CO												

Comments: Most methods indicate T1 or O, indicating a thermal fault at low temperature in oil. The results of DuvalT4 and DuvalP2 confirm that the thermal fault is due to overheated insulation

Known Fault Type: **Carbonisation** of the leads (CIGRE TB771 Table 3.15)

Gas	ppm
H ₂	754
CH ₄	2647
C ₂ H ₆	1127
C ₂ H ₄	2590
C ₂ H ₂	6
CO	150
CO ₂	538

Methods	ND	OK	PD	S	T1	O	C	T2	T3	DT	D2	D1
Dornenburg												
Rogers												
IEC Ratio												
Duval T1												
Duval T4												
Duval T5												
Duval P1												
Duval P2												
KeyGas												
ETRA												
CO ₂ /CO												

Comments: Most methods indicate T2 defect and 2 of them identify C. This must be read as indicated in the Matrix as a Thermal defect >300°C with some carbonisation. Note that CO₂/CO is not indicating C since it is a local carbonisation, not involving large amount of paper.

Known Fault Type: **T3 Thermal Fault** in oil due to Burnt selector (CIGRE TB771 Table 3.9)

Gas	ppm
H2	555
CH4	1054
C2H6	489
C2H4	3540
C2H2	29
CO	327
CO2	4632

Methods	ND	OK	PD	S	T1	O	C	T2	T3	DT	D2	D1
Dornenburg												
Rogers												
IEC Ratio												
Duval T1												
Duval T4												
Duval T5												
Duval P1												
Duval P2												
KeyGas												
ETRA												
CO2/CO												

Comments: Matrix clearly identifies T3 Fault.

Known Fault Type: **D2 Discharges** due to internal transformer arcing (ref IEEE C57.104:2019)

Gas	ppm
H2	154
CH4	60
C2H6	12
C2H4	124
C2H2	163
CO	82
CO2	126

Methods	ND	OK	PD	S	T1	O	C	T2	T3	DT	D2	D1
Dornenburg												
Rogers												
IEC Ratio												
Duval T1												
Duval T4												
Duval T5												
Duval P1												
Duval P2												
KeyGas												
ETRA												
CO2/CO												

Comments: Matrix identifies D2 defect. From paper point of view all ok. Dornenburg is unreliable in this situation

Known Fault Type: **D1 Discharges** due to broken connector on fuse holder (ref IEEE C57.104:2019)

Gas	ppm
H2	188
CH4	89
C2H6	15
C2H4	129
C2H2	631
CO	72
CO2	5769

Methods	ND	OK	PD	S	T1	O	C	T2	T3	DT	D2	D1
Dornenburg												
Rogers												
IEC Ratio												
Duval T1												
Duval T4												
Duval T5												
Duval P1												
Duval P2												
KeyGas												
ETRA												
CO2/CO												

Comments: Matrix clearly identifies Discharges events, mainly D1 type. Dornenburg and Rogers are unreliable.

Conclusions

Both expert and non-expert users can easily and quickly recognise DGA main- and sub-faults with high confidence thanks to the DGA Matrix.

The DGA Matrix:

- Automatically **incorporates internal rules** to enable those methods that depend on the results of other methods (e.g. Duval Triangles and Pentagons)
- **Incorporates rules for minimum gas concentration levels** below which the transformer is considered to OK and the diagnosis is disabled
- **Translates diagnostic results of all industry methods** into the standardised semantic of the fault types: ND, PD, S, T1, O, C, T2, T3, D2, D1
- **Integrates decades of experience** with DGA interpretation, especially for methods that are not 100% defined with strict rules and still leave rooms for interpretation, such as the CO2/CO method.

Try the DGA Matrix at:

<https://camlingroup.com/en-us/dissolved-gas-analysis-dga-matrix>

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