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Core and frame insulation of power transformers

Part II: Online fault detection methods, DGA



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ABSTRACT

Defects in the core and frame insulation of oil-filled power transformers are typically identified through dissolved gas analysis (DGA). However, while DGA effectively detects the type of stress present, it does not pinpoint the specific component causing the issue. Although DGA and oil analysis remain the primary diagnostic approaches, additional techniques are necessary to determine whether the problem originates from components such as the core, frame, clamp, or other metal structures. Complementary methods include ground current measurements, infrared thermography, acoustic partial discharge detection, and de-energized resistance testing. This article provides a concise summary of DGA methodologies, compares real-world cases, and highlights relevant data from the literature. It emphasizes that DGA findings are most reliable when corroborated with independent physical or electrical evidence.

KEYWORDS:

DGA, oil tests, core ground, frame insulation, multipoint grounding, grounding current, ethylene, acetylene, thermal fault, hot metal, IEC 60599, IEEE C57.104, SOU-N EE 46.501:2006

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1. Introduction

Core and frame grounding defects are important because they may develop over time without protective operation. A second ground, poor ground contact, a floating core, a metallic particle, frame-to-tank contact, or a shorted clamp path can cause local heating, sparking, or "fire in steel" [1]. DGA is normally the first warning because oil decomposes around the active stress. The practical problem is that poor leads, bushing connections, OLTC contamination, leakage-flux heating, or other hot metallic parts can also produce the same gases. Therefore, the diagnosis must separate two questions: (1) is there active thermal or electrical stress? And (2) is the source probably core/frame related?

2. DGA diagnostic methods

DGA methods should be used as complementary diagnostic guides, not as independent proof of component location. IEC 60599 classifies gases and fault types [2]; IEEE C57.104 provides practical interpretation and severity guidance [3]; and SOU-N EE 46.501:2006 can be used as an additional regional DGA guide with concentration limits, growth-rate logic, and relative-pattern interpretation [4]. None of these methods alone proves that the source is the core or frame.

3. DGA case evidence

The following cases show why DGA is essential and why over-localization must be avoided. Cases 11, 12, 13, and 14 [1] are ethylene-rich hot-metal patterns. Case 5 is methane/ethane-rich with very little ethylene and no acetylene. The Nevinnomyssk LV-box-to-tank example exhibits a pattern similar to a core multipoint-grounding case, demonstrating that DGA pattern similarity alone is insufficient for location.

Table 1. Diagnostic value and limitations of DGA-based methods for identifying core/frame involvement

Method/guide	Main value	Core/frame limitation
Key gases	Fast recognition of dominant stress: H2/C2H2 for discharge, CH4/C2H6/C2H4 for thermal metal stress	Gases classify energy and temperature, not the exact location.
Gas ratios / Duval methods	Classify PD, D1/D2, T1/T2/T3 or mixed thermal-discharge zones	Different metallic sources may fall in the same zone
Rate of change	Separates old stable gas from active developing stress	Requires a good sampling interval, oil volume, and repeatability
DGA, furans, methanol/ethanol	Indicates possible paper involvement and aging severity	Metallic core/frame faults may remain low in carbon oxides if cellulose is not involved
Oil quality tests: water, BDV, DDF/resistivity, IFT, acidity, particles, sulfur/passivator	Explains whether oil condition, contamination, or corrosion increases risk or confusion in DGA	Support tests; usually not a direct locator of core/frame grounding

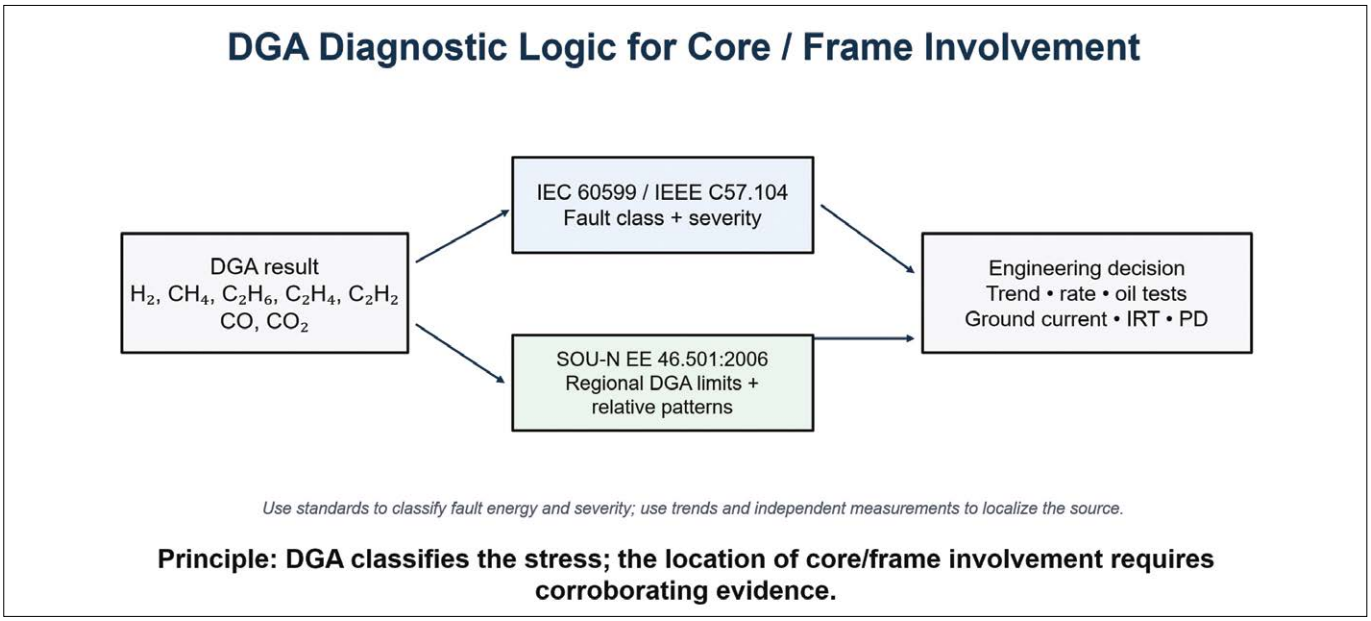


Figure 1. Compact DGA interpretation logic. IEC 60599, IEEE C57.104, and SOU-N EE 46.501:2006 are used as complementary DGA guides. Source: authors' schematic based on [2]-[5]

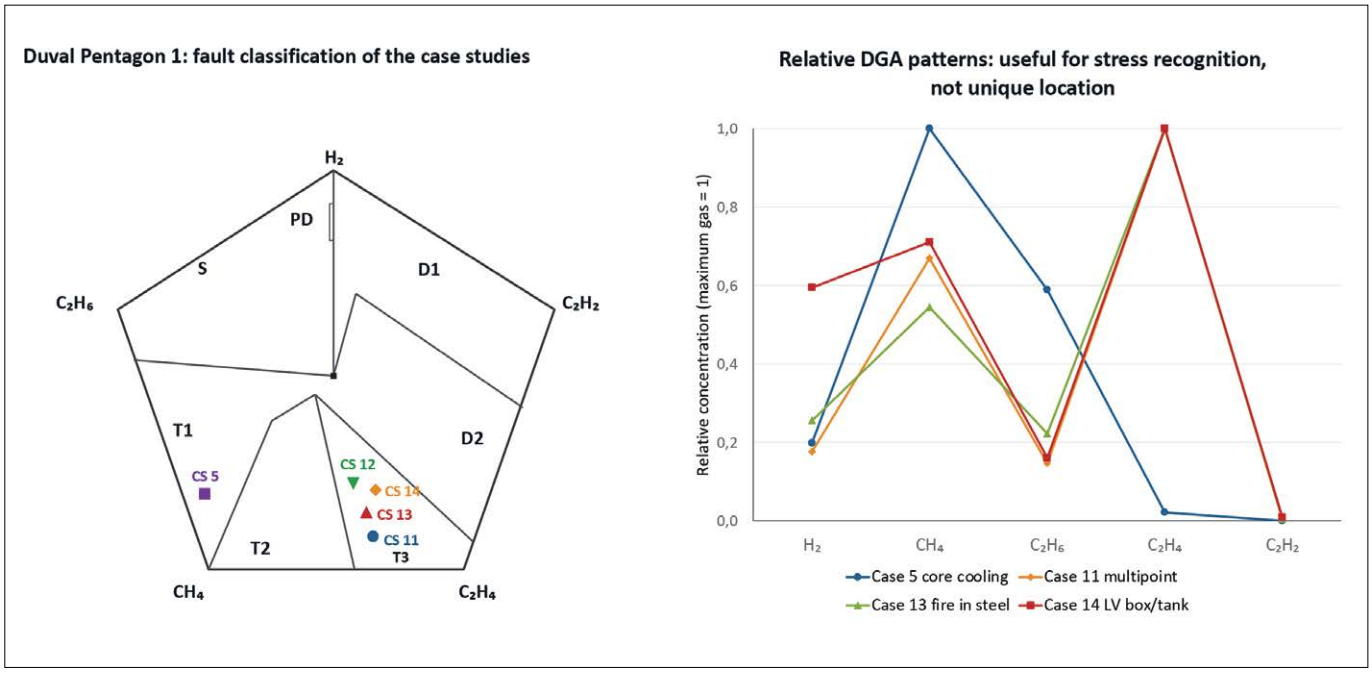
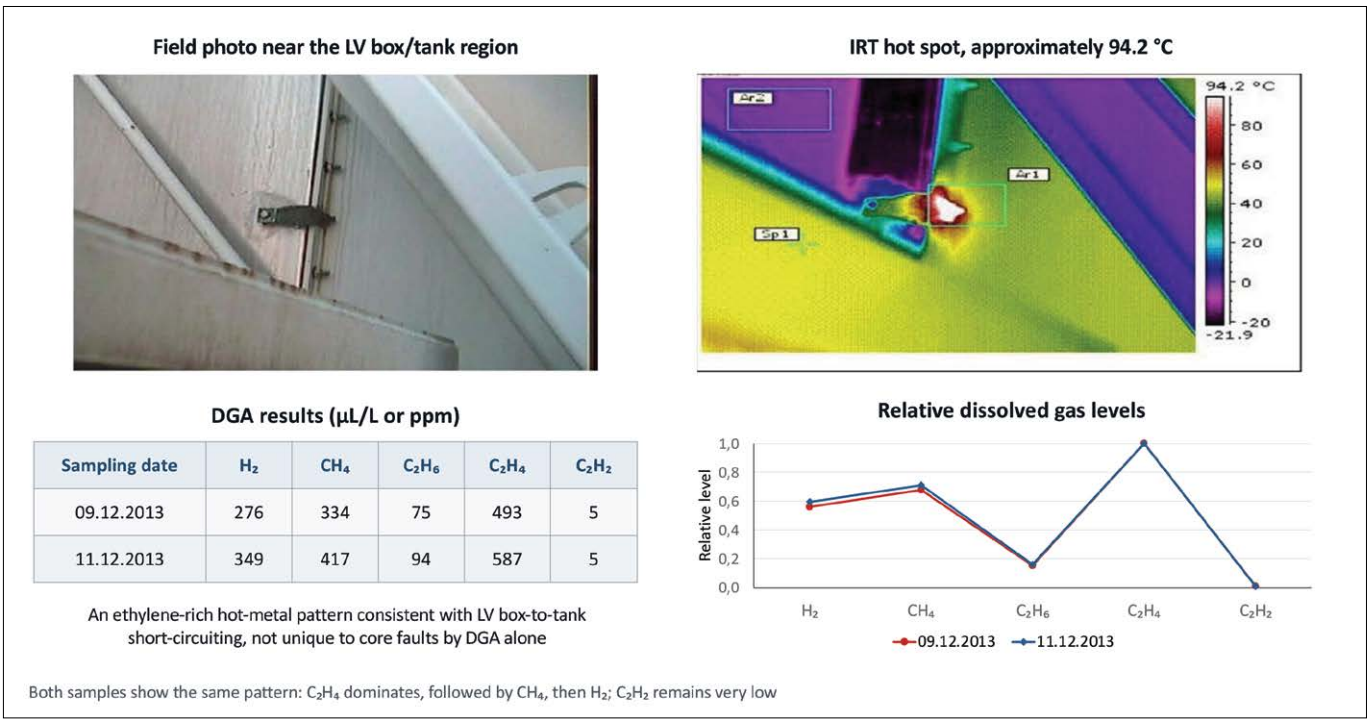


Figure 2. Selected DGA evidence from core/frame-related and similar hot-metal cases [1]



Sampling date	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2
09.12.2013	276	334	75	493	5
11.12.2013	349	417	94	587	5

Figure 3. Nevinnomyssk GSU example: field photo, IRT hot spot, and relative DGA pattern for an LV-box-to-tank short.

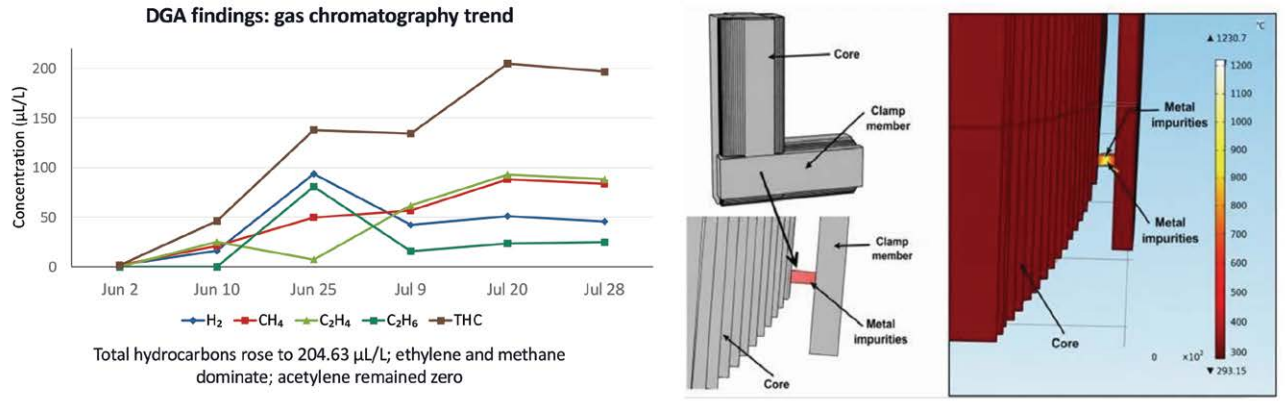
Table 2. Selected case DGA evidence and interpretation for core/frame-related or similar hot-metal faults

Case	Main DGA evidence, µL/L	Interpretation for this paper
5. Insufficient cooling channels in the core	H2 166, CH4 837, C2H6 493, C2H4 18, C2H2 0	The thermal/PD-related core problem can be CH4/C2H6-rich, not necessarily C2H4/C2H2-rich
11. Multipoint grounding	H2 41, CH4 156, C2H6 34, C2H4 233, C2H2 1	Ethylene-dominant hot-metal pattern compatible with core multipoint grounding but not unique
12. Poor core-ground contact	CH4 245, C2H6 20, C2H4 300, C2H2 0 H2 not reported	Hot contact can generate C2H4 without measurable acetylene
13. “Fire” in steel	H2 230, CH4 490, C2H6 200, C2H4 900, C2H2 5	Severe metallic heating; low but present C2H2 suggests possible dynamic sparking
14. LV box short to tank	09-Dec: H2 276, CH4 334, C2H6 75, C2H4 493, C2H2 5; 11-Dec: H2 349, CH4 417, C2H6 94, C2H4 587, C2H2 5	DGA looks like hot metal; IRT/photo evidence located the source outside the core itself

The strongest examples in the literature are those in which DGA is linked to an independent physical finding

4. Focused literature examples

The strongest examples in the literature are those in which DGA is linked to an independent physical finding. The 220 kV Feng et al. [6] case is directly relevant: DGA suggested high-temperature thermal stress, grounding current reached 8.26-8.59 A, core-to-clamp resistance was zero, and inspection found discharge traces and metal impurities between core and clamp. Naderian Jahromi et al. [7] show that DGA/Duval/DFR, combined with inspection, identified oxidation of the core-ground connection and related deposits. Mahankali et al. [8] are not core- or frame-specific, but their field cases demonstrate the value of validating DGA severity through physical inspection.



DGA measurements: gas chromatography data (µL/L)

Date	H_2	CO	CO_2	CH_4	C_2H_4	C_2H_6	C_2H_2	THC
Jun 2	1.79	2.48	181.25	1.70	0.00	0.00	0.00	1.70
Jun 10	16.12	21.48	195.87	21.05	25.09	0.00	0.00	46.14
Jun 25	93.61	34.76	172.39	49.76	7.30	80.76	0.00	137.82
Jul 9	42.22	39.28	203.02	56.64	61.87	15.72	0.00	134.23
Jul 20	51.11	61.79	273.95	88.07	92.88	23.68	0.00	204.63
Jul 28	45.70	62.56	268.07	83.56	88.22	24.89	0.00	196.67

Source: adapted from Feng et al. [6], as supplied in TM 57 Gurin v3, p. 78, Figure 4

Figure 4. Integrated diagnostic evidence for the 220 kV core-to-clamp multipoint grounding case: DGA trend, gas chromatography data, finite-element fault model, and current–temperature relation. adapted from Feng et al. [6]

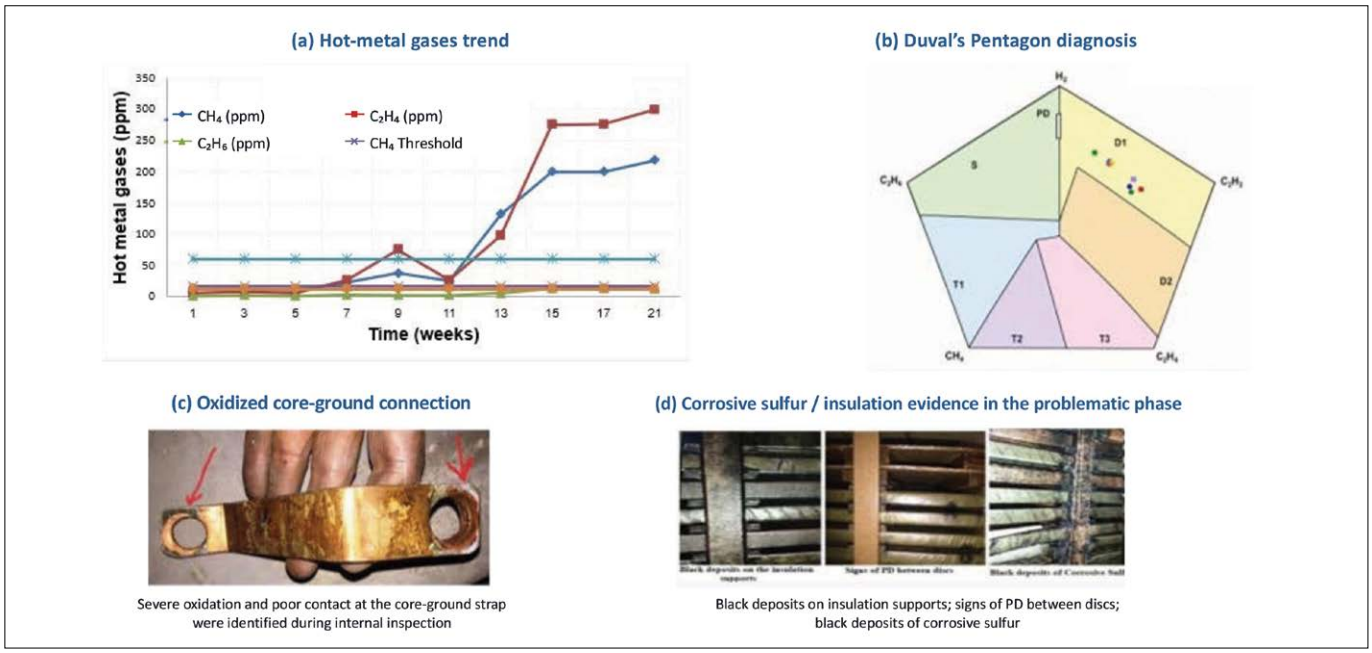


Figure 5. Integrated diagnostic evidence used to identify the core-ground issue in Case Study 1: (a) hot-metal gas trend over 22 weeks, (b) Duval's Pentagon 1 indicating a D1 low-energy discharge pattern, (c) severe oxidation at the core-ground connection, and (d) physical evidence of corrosive sulfur/insulation distress in the problematic phase [7]

5. Oil tests that should accompany DGA

Oil tests do not usually locate a core/frame fault, but they indicate whether the oil system can lead to discharges, contamination, corrosion, or misleading gas production. A compact oil-test package is recommended whenever core/frame DGA suspicions arise: water by Karl Fischer, BDV, DDF, or resistivity; acidity IFT; particles; inhibitor/passivator content; corrosive sulfur/DBDS, where relevant; and cellulose markers such as furans, methanol, and ethanol. Stray gassing should be considered [2] when H2, CH4, or C2H6 increase without corroborating thermal, electrical, or current evidence.

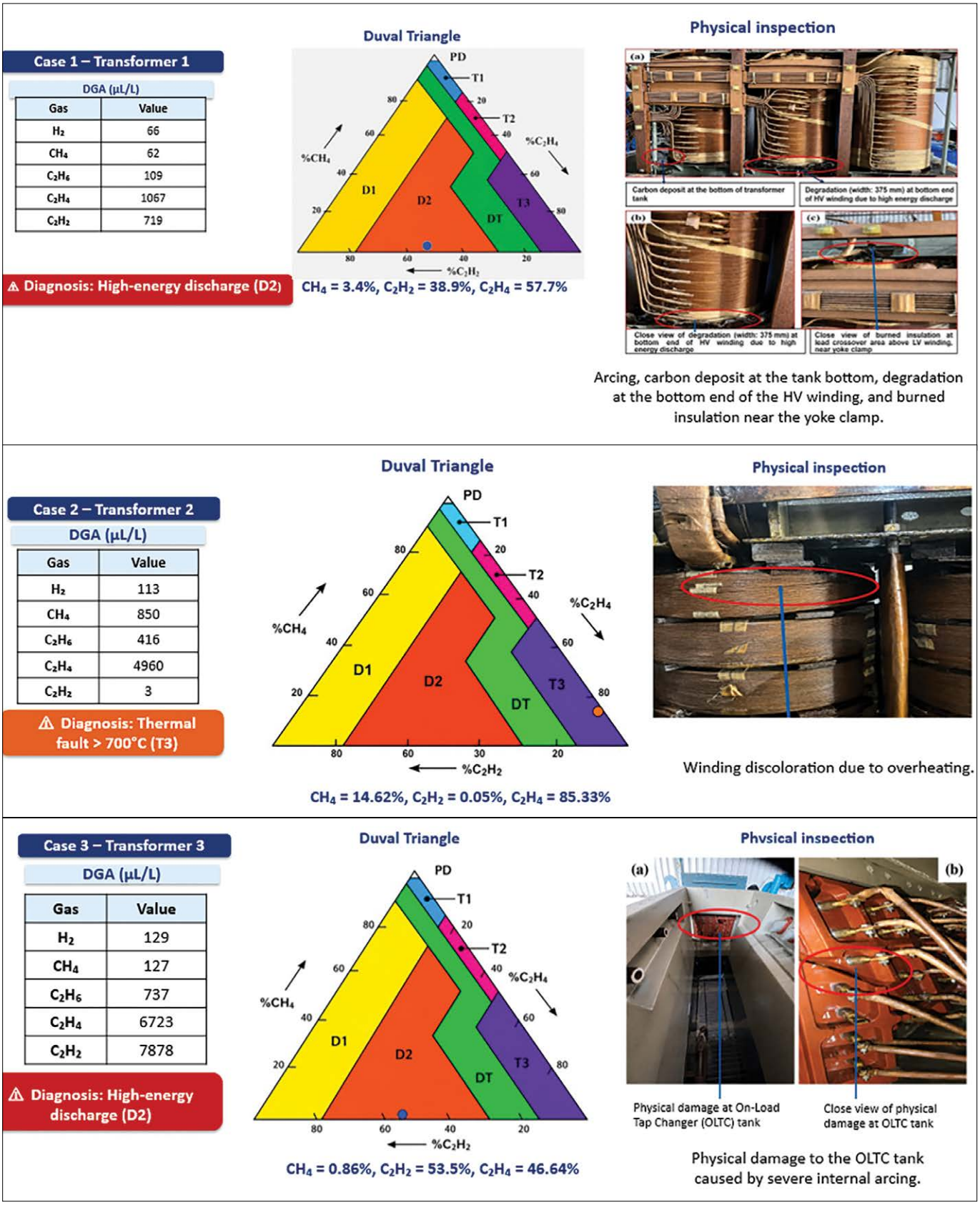


Figure 6. Field-validated DGA examples from Mahankali et al.; DGA severity was checked against inspection evidence. Source: adapted from [8]

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6. Diagnostic pattern and action levels

A DGA-only diagnosis should stop at stress classification: thermal metal, discharge, mixed thermal-discharge, or cellulose-involving. A core/frame diagnosis should be assigned only when DGA is supported by one or more of the following: abnormal core/frame grounding current, IRT hot spot in a relevant region, PD/acoustic localization near the core/frame/bottom tank, de-energized core-to-clamp or frame-to-tank resistance abnormality, DFR evidence consistent with core-ground configuration, or physical inspection (more details will be available in Part III of the article).

7. Conclusions

1. DGA is the principal screening and severity-trending method for suspected core/frame insulation defects, but it is not a component locator.

2. IEC 60599, IEEE C57.104, and SOU-N EE 46.501:2006 should be used as com-

Table 3. Recommended oil tests to support the interpretation of suspected core/frame faults

Oil test	Why is it relevant to core/frame suspicion	How to use
Water + BDV	Moisture and particles lower dielectric strength and may support PD or intermittent discharge	Use as a risk modifier, not as proof of a core defect
DDF / resistivity	Sensitive to polar contamination, oxidation products, and conductive paths	Check whether the oil condition can explain abnormal insulation behavior
IFT + acidity + inhibitor	Indicate oxidation and surface-active products that can affect bubbles, discharge behavior, and general oil condition	Support maintenance decisions and oil treatment needs
Particles	Metal powder or carbon particles can create intermittent bridges or PD-like behavior	High particle/metal evidence increases suspicion of moving conductive bridges
Sulfur / passivator / DBDS	Core/frame faults may coexist with corrosion risks; sulfur can damage contacts and windings	Use when copper/silver corrosion or passivated oil history is possible
Furans, methanol, ethanol, DGA	Decide whether cellulose is involved	Raises severity if paper insulation is affected

Table 4. Diagnostic evidence patterns and recommended actions

Evidence pattern	Probability of active stress	Probability core/frame source	Recommended action
DGA abnormal only; no current/ IRT/PD evidence	Moderate to high, depending on rate	Low to moderate	Repeat sample, check lab quality, investigate other hot-metal sources
Hot-metal DGA + abnormal grounding current >300 mA	High	High	Increase DGA frequency; perform IRT and PD/acoustic; plan outage confirmation.
Grounding current >1 A, fast gas growth, or C2H2	Very high	Very high if the current path is the core/frame lead	Immediate engineering review; consider de-loading and urgent outage tests
DGA pattern points to T3/D2, but IRT locates bushing, lead box, or tank accessory	High	Low for core/frame unless separate evidence exists	Do not label as core/frame; investigate the indicated component
Low/zero core-to-clamp or frame-to-tank resistance plus inspection evidence	Confirmed	Confirmed	Repair, clean contamination, restore insulation, and establish a new DGA/current baseline

plementary DGA diagnostic guides; none should be used alone to declare core/frame involvement.

3. Ethylene-rich hot-metal patterns are common in severe metallic heating cases. Still, similar patterns can arise from core loops, frame/tank contacts, lead boxes, bushings, OLTC contamination, or leakage-flux heating.

4. As will be shown in the next Part III of the article, grounding-current measurement is the most direct energized confirmation method when external core/frame leads are accessible; abnormal current without DGA should still be trended because gas formation may lag.

5. Oil quality tests are necessary to judge whether moisture, particles, oxidation, sulfur/corrosion, cellulose involvement, or stray gassing affects the interpretation.

6. Immediate action is justified when high grounding current, fast DGA growth, acetylene, PD/acoustic localization, or IRT hot spots converge; internal inspection is then normally required.

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Authors



Vitaly Gurin graduated from Kharkov Polytechnic Institute (1962) and graduated from school at the Leningrad Polytechnic Institute. Candidate of technical sciences in the Soviet scientific system (1970). For 30 years, he tested transformers up to 1,150 kV at ZTZ, including the largest one of that time in Europe, and statistically analysed the test results. For over 25 years, he was the Executive Director of Trafoservis Joint-Stock Company in Sofia (the diagnosis, repair, and modernisation in the operating conditions of transformers 20–750 kV). He has authored about 150 publications in Russian and Bulgarian and is the main co-author of GOST 21023.



Marius Grisaru holds an MSc in Electro-Analytical Chemistry from the Israel Institute of Technology. He has almost 30 years of intense experience in almost all transformer oil test chains, from planning, sampling, and diagnosis to recommendations and treatments, mainly in Israel but also in other parts of the world. He is responsible for establishing test strategies and procedures and creating acceptance criteria for insulating liquids and materials based on current standardization and field experience. In addition, he trains and educates electrical staff on insulating matrix issues from a chemical point of view. He is an active member of relevant Working Groups of IEC, CIGRE, and a former member of ASTM. He is also the author and co-author of many papers, CIGRE brochures, and presentations at prestigious international conferences on insulation oil tests, focusing on DGA, analytical chemistry of insulating oil, and advantageous maintenance policy for oil and new transformers.



Oleg Svyrydenko , with over 24 years of expertise in the transformer industry, previously led the field repair and damage investigation department at the Zaporizhzhya Transformer Plant in Ukraine. He is now part of the service department at the International BEZ Group, which oversees transformer plants in several countries: ETD Transformers (Power Transformers) in Plzeň, Czech Republic; BEZ Transformers (Distribution Transformers) in Bratislava, Slovakia; and Elprom Heavy Industries (Power Transformers and Tap Changers) in Sofia, Bulgaria. Oleg possesses extensive international experience in installation, complex field repairs, diagnostics, and investigations into the causes of damage to power transformers up to 765 kV.