



# Best practice innovative transformer oils based on Shell GTL technology



## Introduction

Shell introduced in 2013, the Diala S4 range, the first and only transformer oils using unique gas-to-liquid (GTL) technology. Designed to revolutionize the reliability and lifespan of transformers, this technology has been tested and approved by OEMs and utility companies alike, and is successfully being used in thousands of power and distributions transformers globally.



## The challenge

The project-team for the development next generation of transformer oil had interviewed experts at leading OEMs, Technical Institutes, and grid companies to define the requirements and criteria; good electrical behavior and thermal properties, consistent quality, long life (high grade), recyclability, miscible with traditional oils, and not to forget; maintenance tools applicable based on industry standard Oil Condition Monitoring (OCM) techniques. This article focusses on sharing best practice OCM and field experiences.

Utility companies operate large populations of 100s or 1000s of transformers, of different types, varying ages, with different operating conditions and stresses, and which can contain different transformer oils or even mixtures. OCM and database tracking, and statistical evaluation, is an integral part of a utilities maintenance activities to ensure maximum power generation and transmission performance and reliability from its assets<sup>[1]</sup>, while seeking to control and reduce their total cost of ownership<sup>[2]</sup>. Electrical insulating oils have a specific and often unique list of OCM and other tests, when compared to conventional lubricants, such as DGA), DDF, inhibitor content, surface tension, etc<sup>[3]</sup>, and need confirmation that new oils are miscible and compatible with other similar fluids, and can use the same suite of OCM tests and alert levels.

Insulating materials in service will age due to degradation processes such as oxidation, thermal breakdown, and hydrolysis, under moderate to high electrical stresses (depending on the transformer and conditions). OCM enables the ageing process to be tracked and interventions made before it leads to transformer electrical faults and transformer failure.

## The solution

Before the Shell Diala S4 range was introduced in 2013, extensive laboratory testing was undertaken, this included miscibility and compatibility, and the resulting performance testing of mixed inhibition and unmixed, iso-paraffinic (GTL) and naphthenic hydrocarbons insulating oils, both aged and unaged, uninhibited and inhibited, and in different ratios and combinations. The data confirmed that all the tested hydrocarbon oils were fully miscible and compatible, and that mixed hydrocarbon oil systems display resultant performance properties that are an average of the type and quantity and performance of its constituent parts. The larger the proportion of GTL oil in a mixed hydrocarbon oil system, generally the greater the oxidative stability of the mixture<sup>[4],[5]</sup>.

DGA testing was also run at the University of Manchester, and the Schering Institute, University of Hannover. This involved testing Shell Diala S4 ZX-I and a conventional inhibited naphthenic fluid, transformer faults were simulated covering partial discharge (high and lower energy), and thermal hot spot faults (low and higher temperature). DGA analysis of the resultant gasses was then interpreted in terms of the Duval triangle/pentagon. It was confirmed that the DGA behavior and fault diagnosis was very similar for both fluids, and that routine DGA and interpretation could be used for Shell Diala S4 ZX-I as for conventional mineral oils as expected since they are both hydrocarbon based<sup>[6],[7]</sup>.



• **Case study:  
Switzerland**

### Customer experience

A field trial to compare the DGA performance of the Shell Diala S4 ZX-I GTL based oil back-to-back with the conventional inhibited naphthenic oil, was run with a local grid company in Switzerland. BKW operates two Siemens 132 MVA transformers, which run under the same load and similar conditions, and so were ideal for this comparison testing. Samples were taken in May and June 2016, June 2017 and April 2018, and DGA performed. DGA results for Shell Diala S4 ZX-I and the inhibited naphthenic oil were very similar in trends and concentrations, confirming that DGA is suitable and reliable for both these hydrocarbon oils (see table 1).

Transformer T1	sample Date	CO <sub>2</sub>	CO	H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>2</sub>
<b>T1 Oil: Diala S3 ZX-I (naphthenic)</b>	May 2016	70	22	0.3	0.3	0.5	0.5	0.2
	June 2016	170	50	5	2	0.5	0.5	0.5
	June 2017	280	132	2.5	1	4	5	0.5
	April 2018	280	178	2.5	2	4	2	0.5
Transformer T2	sample Date	CO <sub>2</sub>	CO	H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>2</sub>
<b>T2 Oil: Diala S4 ZX-I (GTL)</b>	May 2016	70	25	0.3	0.2	0.5	0.5	0.05
	June 2016	100	60	7	1	0.5	0.5	0.5
	June 2017	260	150	2.5	2	2	6	0.25
	April 2018	275	200	2.5	2	2	0.5	0.25
Surveillance guidelines	normal	< 350	< 100	< 120	< 65	< 50	< 2	
IEEE PC57.104 D11d	warning	350-570	100-700	120-400	65-100	50-100	2-5	
alarm	> 570	>700	> 400	> 100	> 100	>5		

Table 1.  
DGA for transformer 1 filled with conventional naphthenic oil and transformer 2 filled with GTL based oil



**Station Transformer T8 (132 kV, 90 MVA Hawker Siddeley)**

Oil type in service	Oil Surface Tension. Decreasing values indicate oil degradation.	Oil Acidity. Increasing values indicate oil degradation	DDF (Power factor). Increasing values indicate oil degradation	Dissolved gas analysis (DGA)
Original uninhibited transformer oil, Performance change after two years in service	Halved	6 times increase	20 times increase	Normal (low)
Diala S4 ZX-I performance change after being in service	No significant change (≈ 52)	No significant change (≈ 0.01 mg KOH/gr)	No significant change (< 0.001)	Normal (low)

Table 2. Station transformer T8, OCM data (previous uninhibited vs Shell Diala S4 ZX-I)

EDF (UK) had observed oil degradation issues in its 132 kV, 90 MVA Hawker Siddeley Station transformer T8, built around 1980. The operational temperatures of this transformer were trending higher, indicating future reducing of cooling performance. The transformer had last been filled with an uninhibited oil two years previously and was already showing signs of accelerated ageing. Following detailed technical discussions with Shell, the decision was made to replace the transformer's oil with Diala S4 ZX-I.

Shell Diala S4 ZX-I has now been in successful continual service in this transformer, stable and reliable performance, and as well as the reduction in transformer operating temperature, the rate of oil ageing has also declined as shown in table 2.

Based on the good experiences with the Hawker Siddeley Station transformer, EDF (UK) decided to select Shell Diala S4 ZX-I for their new generator transformers, scheduled to supply in 2014 - 2016. Per block, 3x GE-Alstom, single phase 400 kV (800 MVA) Generator Transformers. (Video: [Shell Diala case study with EDF - YouTube](#))

EDF Energy Heysham has an extended condition monitoring program in place; critical transformers are equipped with on-line DGA monitoring (Kelmann), and oils samples are taken on a regular basis.

"The obvious improvements in reliability and performance Shell Diala S4 ZX-I has produced, have prompted Heysham 2 to specify the high-performance oil for all future tap changer maintenance and in transformers above 23 kV"

*Douglas Barker, Electrical Engineer, Heysham 2*

Based on the good experiences, the EDF Nuclear department approved the filling of 3 single phase generator transformers at Chinon Nuclear Power plant (900 MW) with Shell Diala S4 ZX-I in 2020.

- **Case study:**  
**EDF Heysham 2**  
**Power Station, UK<sup>[6]</sup>**



### OEM experiences and acceptance

During the pre-launch phase, Shell technical experts have been in contact with leading OEMs, and get input on their nowadays and future requirements, and confirmation on market trends. Multi test programs have been agreed upon with OEMs (Siemens, HE (ABB), GE, etc.) and Universities <sup>[1],[7]</sup> to confirm the typical performance test data sets. These collaborations supported a smooth market acceptance of the GTL based Shell Diala S4 ZX-I.

Country	Transformer type	notes/comments
Nigeria	Power Transformers	340 KV
Vietnam	Power Transformers	220 KV
India	Power Transformers	1200 KV
Ethiopia	Power Transformers	500 KV
Kenya	Power Transformers	220 KV
Germany	Power /Distributions	220 KV and below
China	Reactors	500 KV
Malaysia	Power/Distributions	275 KV / 340 MVA
Heilongjiang province, China	HVAC, reactor	500 KV / 50000 kvar
Netherlands	Power Transformers	380 KV
UAE	Power transformers	500 KV / 882 MVA
Germany	Power transformers	400 KV
Saudi-Arabia	GSU (Generator Set-up)	400 KV / 864 MVA
Germany / Belgium	HVDC link project	380 KV
Netherlands / Denmark	HVDC link project	320 KV
Belgium	Power transformers	380 KV
UK / France	HVDC link project	320 KV
UK	HVDC link project	400 KV
Germany	Power transformers	380 / 110 KV
France	Power transformers	235 KV / 660 MVA
Italy / France	HVDC link project	400 KV

Table 3.  
compact overview with reference projects



**SHELL Diala S4 blending facilities**



Figure 1. Global coverage, with local production facilities has been realised within a decade.



**Summary**

Shell is already active in the Power generation and distribution market for over 80 years, historically the product portfolio was based on traditional mineral oils (Diala AX, Diala B, Diala DX, etc.). With the introduction Shell Diala S4 ZX-I, based on GTL technology, the performance scope was pushed to the next level; higher flash point (safety), Sulphur free formulation (eliminate corrosive Sulphur risk), lower density (weight saving), superb oxidation resistant (long oil life/cost reduction) and easy recyclability (sustainability).

Obviously, for smooth the market introduction and acceptance, easy handling and continuity in oil condition monitoring best practices are important key points. Leading OEMs and customers have collaborated to closely monitor the important oil condition parameters (physical, chemical and DGA) and share the positive findings. Standard oil condition best practice remains valid with Diala S4 ZX-I.

**References**

- [1] 'Condition monitoring and diagnostic assessment of transformers' Z. D. Wang, Q. Liu, P. Jarman, G. Wilson, R. Hooton, D. Walker, P. Dyer, CH. Krause, P. W. R. Smith, A. Gyore, R. Martin, P. Mavrommatis, J. Noakes. Paper given at the Cigre, Paris, 2016 conference, as part of A2-109
- [2] Shell lubricants white paper 'Unlocking, efficient, reliable power' 2016
- [3] IEC 60422:2013 Mineral insulating oils in electrical equipment – Supervision and maintenance guidance
- [4] 'Fact or fiction benefits of inhibited versus uninhibited hydrocarbon oils for transformers', P. Smith, B. Lohmeyer, A. Hilker, Cigre A2 & D1 colloquium, 2011, Kyoto
- [5] 'The benefits of inhibited transformer oils using GTL technology', Dr J. Friedel, Transformer Life Symposium (TLM) 2014, Neuss
- [6] 'Benefits and experiences of GTL transformer oil', Euro TechCon, Nov 2016, Bristol, Dr J. Friedel, Dr P Smith
- [7] 'DGA of a GTL hydrocarbon transformer oil under thermal faults', X. F. Wang, Z. D. Wang, Q. Liu, Ch. Krause, P. W. R. Smith, D. Walker, 19<sup>th</sup> International Symposium on high voltage engineering, Pilzen, Czech republic, Aug 2015
- [8] 'Application experience with GTL based transformer oils', Euro TechCon, Dec 2018, Cardiff, Dr V Null

