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NSP/009/003 – Network Service Procedure for Laboratory Analysis of Transformer Insulating Oil

1. Purpose

The purpose of this document is to set out the level of service that would be required by the service provider through this contract.

This document supersedes the following documents, all copies of which should be destroyed;

Document Reference	Document Title	Version	Published Date
NSP/009/003	Network Service Procedure for Laboratory Analysis of Transformer Insulating Oil	2.0	Nov 2022

2. Scope

The scope of this work is principally the laboratory analysis of insulating oil from the following asset groups:

- Transformers with a primary voltage of 132, 66 and 33kV and the associated tapchanger selector where the selector and diverter compartments are separate.
- Current transformers of nitrogen sealed/hairpin design with a primary voltage of 66 and 132kV.

Laboratory analysis of oil from other assets including switchgear rated at 11kV to 132kV, distribution transformers and oil-filled instrument transformers may be required on an ad-hoc basis.

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3. Technical Requirements

3.1. General

Northern Powergrid is responsible for delivering electricity to over 3.9 million properties across the North East of England, Yorkshire and northern Lincolnshire, operating through the subsidiary companies Northern Powergrid (Northeast) PLC in the North East and North Yorkshire, and Northern Powergrid (Yorkshire) PLC in West, South and East Yorkshire and northern Lincolnshire.

Northern Powergrid owns more than 200 transformers with a primary voltage of 132kV and more than 1000 transformers with a primary voltage of 66 or 33kV. It is current policy to carry out the analysis of oil samples from 132kV transformers on an annual basis and 66 and 33kV transformers biennially. Samples are also analysed from transformers with separate tapchanger selectors on the same basis.

In addition, Northern Powergrid has a population of more than 120 sets of nitrogen sealed/hairpin CTs that are currently subject to a 3-year sample frequency.

Mineral insulating oil in use includes; unused mineral insulating oil to IEC 60296, recycled mineral insulating oil to BS148 and synthetic organic esters IEC 61099. Oil in use is generally uninhibited; however, following on-site regeneration of insulating oil, inhibitor may be added to achieve the required oxidation stability.

Transformer insulating oil effectively holds a blueprint of the transformer condition. Oil test results and the concentration of dissolved hydrogen and hydrocarbons in the oil are used to inform asset management investment decisions. Testing requirements are provided in section 3.7.

3.2. Sampling Process

Samples will be taken by experienced Northern Powergrid personnel, or their nominated contractors, in accordance with BS EN IEC 60475 Method of sampling insulating liquids.

The Service Provider shall provide gas-tight sample flasks (1000ml for transformer samples and 30ml for PCB / CT samples) to a design and specification determined as appropriate by the Service Provider and agreed with Northern Powergrid. Typically these will be of dark glass to reduce the effect of light on the sample and the vessel sealed with a plastic screw cap holding a gas-tight conical polyethylene seal.

The Service Provider shall provide suitable containers to protect the bottles during transport.

The Service Provider shall supply labels pre-printed with the following fields for completion by the Maintenance Engineer:

- Customer name NPg Northeast / NPg Yorkshire
- Date sampled
- Substation name (and number in the case of NPg Yorkshire sites)
- Northern Powergrid Operational Engineer
- Asset description (type of unit)
- Asset serial number
- Rating (MVA)
- Primary Voltage (kV)
- Year of Manufacture
- Oil Volume
- Sample point
- Oil temperature (°C)
- Air temperature (°C)

The label will also provide a series of tick boxes to identify the tests to be carried out:

- Routine (to include basic oil tests, DGA and Furans), or
- Special investigative tests (PCBs/Corrosive sulphur), or
- Tests to be carried out following a transformer buchholz operation (Oil tests, DGA).

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- Other – specific requirement stated

Samples will be made available for collection by the Service Provider from the following Northern Powergrid depots:

NPg Northeast

- Ashington
- Northallerton
- Middlesbrough
- Stockton
- Penshaw
- Scarborough
- Shiremoor

NPg Yorkshire

- Brigg
- Dewsbury
- Castleford
- Hellaby
- Hull
- Keighley

The Service Provider shall be responsible for the collection of batches of samples from Northern Powergrid locations.

When 10 samples have accumulated at a single location, Northern Powergrid will contact the Service Provider to make arrangements for collection. The number of samples awaiting collection at a single location will not exceed 20 units. Regardless of the number of samples, the maximum time any sample shall await collection is two weeks.

A label will be attached to each sample by the Operational Engineer with all relevant fields completed.

3.3. Testing and Reporting Requirements

The Service Provider shall carry out the required tests indicated on the sample label. A full list of tests that may be requested are included in section 3.7.

The Service Provider shall be responsible for holding and maintaining a database of current and historical results. Northern Powergrid will provide static asset data and historical results to be imported into the database.

The Service Provider shall be responsible to ensure that data on the sample label is validated against static data provided, and shall query information that does not align. Where necessary the Service Provider shall contact the Maintenance Engineer or Policy & Standards for clarification.

The tests shall be carried out in accordance with the appropriate standards listed in table 4.

The tests results shall be recorded on the database.

The Service Provider shall make available to Northern Powergrid an on-line test report within a maximum of one calendar month from receipt of the oil sample. In the event that one or more of the tests carried out on the sample exceed the limits specified by the relevant British Standard, or internal limits set by Northern Powergrid, the Service provider shall communicate the test results directly to the Maintenance Engineer and associated Programme Manager, and to the nominated Policy & Standards representative within 24 hours of the test being carried out.

The report shall state the main findings of the analysis and highlight any defects in the oil sample and suggest possible causes based on the evidence available.

The Service Provider shall assess the condition of oil samples by comparing individual test results against the relevant BS, IEC or Northern Powergrid internal thresholds.

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The Service Provider shall provide interpretation of the oil test results and summarise the oil condition with a simple 'traffic light' metric.

Following the production of the oil test report, the Service Provider shall take the action described in table 1.

Status	Test Outcome	Action	
Red	One or more oil test results significantly over the limits.	Contact the Maintenance Engineer within 24 hours	Forward report to Policy & Standards
Amber	One or more oil test results marginally over the limits.	Forward report to Maintenance Engineer	Forward report to Policy & Standards
Green	No oil results over the limits.	Report to be accessible on line.	

Table 1: Action to be taken by the Service Provider following the test results

3.4. Database Specification

The Service Provider shall create and maintain a database of test results against each asset for which oil samples are provided.

The following static data shall be provided by Northern Powergrid for inclusion in the database against each asset:

- Substation Name
- Asset Name
- NPg unique asset identifier
- Serial Number
- Year of Manufacture
- Voltage (kV)
- Rating (A)
- Total Oil Volume

Northern Powergrid will furnish the Service Provider with static asset data including the unique plant identifier number and historical oil test data. The Service Provider shall import this data into their database.

The cost of administrating the database, including minor modifications or enhancements, shall be the responsibility of the service provider.

The database shall have the following functionality:

- The database will provide the source information for the oil test report. The report shall be produced for each oil sample in pdf format. The report shall state the three most recent oil test results to enable comparison between tests. A list of the fields to be included in the form is included in Appendix 1.
- The database will be accessible via the internet by Northern Powergrid personnel. Northern Powergrid will provide a list of nominated users.
- Usernames and passwords for Northern Powergrid users shall be provided by the Service Provider.
- All oil data held shall be available for Northern Powergrid users to download in Excel format.
- Allow NPg users to interrogate it to establish assets that require intervention.
- Present a 'dashboard' of the assets that present the greatest risk to the business.
- The provision of multiple comments field for each oil sample that is editable by NPg users.

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3.5. Asset Populations

Table 2 below states the transformer and tapchanger separate selector populations broken down by DNO and primary operating voltage.

Asset	NPg Northeast	NPg Yorkshire	Total
Grid transformers (main tank)	79	134	213
Primary transformers (main tank)	334	676	1010
Tapchanger separate selector	175	307	482
Auxiliary transformers	68	92	160
Nitrogen sealed/ hairpin CTs (single phase units)	360	12	372

Table 2 Transformer population

3.6. Sampling Frequency

Based on the asset populations as of 2010, the average number of routine samples required each year is broken down in Table 3 below based on the frequency of routine tests.

Asset	Sampling Frequency (years)	Total Units	Samples per year
Grid transformers (main tank)	1	213	213
Primary transformers (main tank)	2	1010	505
Grid separate selector	1	96	96
Primary separate selector	2	386	193

Table 3 Sampling frequency and volume

In the event that one or more test results are marginally greater than the established limits, the action will be to increase the sampling frequency. The increased sampling rate will remain in place until remedial action has been executed or subsequent results fall below the established limits.

If the results are significantly over the established limits, remedial action may be taken.

If the oil results fall outside the criteria, the Service Provider shall document appropriate recommendations in the report and shall provide interpretation of the oil results to assist in determining the root cause of the abnormal result.

In the event of abnormal results, the Service Provider shall give consideration to all the oil analysis data available including the Rogers Ratio to establish the characteristics of the fault. The level of monitoring/mitigating action will be determined by Northern Powergrid, following discussion between EHV Maintenance, Control, Policy & Standards, and the Service Provider.

For each oil sample report, the Service Provider shall carry out trend analysis to identify significant changes from the previous two sets of results. The Service Provider shall provide a summary of trends in the test report including significant rates of change, which may be indicative of a developing fault.

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3.7. Testing Requirements

3.7.1. Routine Tests

The routine tests shall be carried out to the appropriate standard stated in Table 4 below.

Test	Method
Colour and appearance	ISO 2049
Breakdown voltage	IEC 60156
Water content	IEC 60814
Acidity (neutralisation value)	BS EN 62021-1
Resistivity/ Dielectric dissipation factor	BS EN 60247
Concentration of 2-furfural	IEC 61198
Particle count	BS EN 60970
Inhibitor content (for inhibited oil only)	BS EN 60666

Table 4 Routine Tests

Test results shall be categorised 'good', 'fair' or 'poor' based on the limits stated in Table 5 of BS EN 60422. Oil sample results which fall into the 'poor' category will be deemed to be below the required standard.

Based on the concentration of 2-furfural, the degree of polymerisation shall be calculated based on a methodology agreed with NPg. Presently the Chendong model is used, but alternatives will be considered based on latest research and best industry practice.

3.7.2. Dissolved Gas Analysis

Sampling of insulating oil to determine dissolved gas concentrations shall be carried out in accordance with IEC 60567 Oil-filled electrical equipment – Sampling of gases and of oil for analysis of free and dissolved gases – Guidance.

90% typical values have been established for the Northern Powergrid 132kV/EHV transformer population based on the methodology set in BS EN IEC 60599 Mineral oil-filled electrical equipment in service - Guidance on the interpretation of dissolved and free gases analysis. These values are established as threshold values and are stated in Table 5. Thresholds for current transformers are based on BS EN IEC 60599 table A.8 – Maximum admissible values for sealed instrument transformers (with the exception of acetylene which has the lower threshold of 0.3ppm).

	Hydrogen H ₂	Methane CH ₄	Ethylene C ₂ H ₄	Ethane C ₂ H ₆	Acetylene C ₂ H ₂
threshold values for power transformers, ppm	45	20	20	20	10
threshold values for current transformers, ppm	300	30	10	50	0.3

Table 5 NPg Threshold Values

Test results greater than the threshold values established for Northern Powergrid power transformers shall be identified as such and recommended action proposed, for example primary transformers may become subject to annual (rather than biennial) testing.

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The analysis will determine the concentration of the following gases:

Nitrogen	N ₂
Oxygen	O ₂
Hydrogen	H ₂
Carbon monoxide	CO
Carbon dioxide	CO ₂
Methane	CH ₄
Ethane	C ₂ H ₆
Ethylene	C ₂ H ₄
Acetylene	C ₂ H ₂

3.7.3. Furanic Compounds

Concentrations of furanic compounds shall be determined in accordance with BS EN 61198 Determination of 2-Furfural and Related Compounds.

Test results indicating the concentration of total furanic compounds to be greater than 3.0mg/kg or a rate of increases equivalent to 0.1 mg/kg per annum shall be identified by the Service Provider and communicated to Northern Powergrid in the report recommendations to initiate increased monitoring in the first instance.

3.7.4. Special Investigative Tests

It may be necessary to carry out the non-routine tests identified in Table 6. A framework of charges shall be agreed.

Test	Method
Polychlorinated biphenyls (PCBs)	BS EN 61619
Corrosive Sulphur	BS EN 62535
Dibenzylidissulfide (DBDS)	BS EN 62697-1

Table 6 Non-routine tests

3.8. Emergency Service

When requested, the Service Provider shall offer an emergency testing facility and tests shall be carried out within 12 hours of receipt of the oil sample to meet operational requirements. Northern Powergrid will take responsibility for delivery in the case of samples requiring emergency testing. The Service Provider shall provide a verbal report to the relevant EHV engineer or relevant Policy and Standards engineer within 12 hours of receipt of the sample and provide a written report within 24 hours.

When required under exceptional circumstances, test results shall be forwarded directly to Control Operations. In the event of such an incident, a named contact in Control Operations will be given to the Service Provider.

3.9. Laboratory Certification

The Service Provider shall ideally be certified to the following standards:

- ISO 9001 Quality management systems
- ISO 14001 Environmental management systems
- ISO 45001 Occupational health and safety management systems
- BS EN 17025 General requirements for the competence of testing and calibration laboratories

The Service Provider shall grant access to Northern Powergrid to undertake an audit of their Quality Management System.

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3.10. Data Security

The Service Provider shall maintain the security and integrity of data.

The Service Provider shall be responsible for the database for the duration of the contract.

The Service Provider shall issue Northern Powergrid with all data in an agreed format on an annual basis and at the end of the contract duration at no additional cost.

3.11. Ownership of Data and Intellectual Property Rights

All data held by the Service Provider relating to Northern Powergrid assets, including test results, shall remain the sole property of Northern Powergrid and is to be treated as commercially confidential. It shall not be divulged to any third parties without formal permission from Northern Powergrid.

The Service Provider shall meet any request by Northern Powergrid to provide data for individual assets within 48 hours during working hours and in exceptional cases may include out of hours requirements.

Northern Powergrid shall make available historical data and it shall be the responsibility of the Service Provider to import into their database.

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4. References

4.1. External Documentation

Reference	Title
BS 148	Recycled mineral insulating oil for transformers and switchgear.
BS EN 60247	Method for the measurement of relative permittivity, dielectric dissipation factor and d.c. resistivity of insulating liquids.
BS EN 60422	Mineral insulating oils in electrical equipment. Supervision and maintenance guidance.
BS EN 60567	Oil-filled electrical equipment. Sampling of gases and analysis of free and dissolved gases. Guidance.
BS EN 60666	Method for detection and determination of specified antioxidant additives in insulating oils.
BS EN 60970	Insulating liquids. Methods for counting and sizing particles.
BS EN 61099	Insulating liquids. Specifications for unused synthetic organic esters for electrical purposes.
BS EN 61198	Mineral insulating oils. Methods for the determination of 2-furfural and related compounds.
BS EN 61619	Insulation liquids. Contamination by polychlorinated biphenyls (PCBs). Method of determination by capillary column gas chromatography.
BS EN 62021-1	Insulating liquids. Determination of acidity. Automatic potentiometric titration.
BS EN 62535	Insulating liquids. Test method for detection of potentially corrosive sulphur in used and
BS EN 62697-1	Test methods for quantitative determination of corrosive sulphur compounds in unused and used insulating liquids. Test method for quantitative determination of dibenzyl disulfide
BS EN IEC 60296	Fluids for electrotechnical applications. Mineral insulating oils for electrical equipment.
BS EN IEC 60296	Fluids for electrotechnical applications. Mineral insulating oils for electrical equipment.
BS EN IEC 60475	Method of sampling insulating liquids.
BS EN IEC 60599	Mineral oil-filled electrical equipment in service. Guidance on the interpretation of dissolved
IEC 60156	Insulating liquids. Determination of the breakdown voltage at power frequency. Test method
IEC 60814	Insulating liquids. Oil-impregnated paper and pressboard. Determination of water by automatic coulometric Karl Fischer titration.
ISO 45001	Occupational health and safety management systems.
ISO 14001	Environmental Management Systems.
ISO 17025	General requirements for the competence of testing and calibration laboratories.
ISO 2049	Methods of test for petroleum and its products. Petroleum products. Determination of colour.

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4.2. Internal Documentation

Reference	Title
n/a	

4.3. Amendments from Previous Version

Reference	Description
3.1	Change Northern Powergrid (Northeast) Ltd to Northern Powergrid (Northeast) PLC
3.1	Hairpin CT population has now reduced from circa 200 to 120 sets
3.1	Specifically state synthetic organic esters for clarity
3.1	The revised BS148 refers to recycled rather than reclaimed mineral oil
3.2	BS EN IEC 60475 is stated as most relevant to sampling of oil from transformers
3.4	Inclusion of the requirement to provide a 'dashboard' of the assets that present the greatest risk to the business.
3.5	Asset populations revised to reflect the replacement of a number of hairpin CTs
3.7.1	Removal of the test for 'sludge' as a routine test
3.7.1	State the requirement to model the degree of polymerisation based on a methodology agreed with NPg, presently the Chendong model
3.7.2	Reflect change in BS EN IEC 60599 title

5. Definitions

Reference	Title
n/a	

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6. Authority for Issue

6.1. CDS Assurance

I sign to confirm that I have completed and checked this document and I am satisfied with its content and submit it for approval and authorisation.

		Date
Liz Beat	Governance Administrator	19/06/2023

6.2. Author

I sign to confirm that I have completed and checked this document and I am satisfied with its content and submit it for approval and authorisation.

Review Period - This document should be reviewed within the following time period;

Standard CDS review of 3 years?	Non Standard Review Period & Reason	
No	Period: 5 years	Reason: To align with procurement cycles
Should this document be displayed on the Northern Powergrid external website?		Yes
		Date
Joe Helm	Lead Policy and Standards Engineer	19/05/2023 email

6.3. Technical Assurance

I sign to confirm that I am satisfied with all aspects of the content and preparation of this document and submit it for approval and authorisation.

		Date
Paul McAdoo	Lead Policy and Standards Engineer	19/05/2023 email

6.4. Authorisation

Authorisation is granted for publication of this document.

		Date
Paul Black	Head of System Engineering	19/05/2023 email

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Appendix 1

Report Specification

The following fields shall be included in the reporting sheet. The reporting sheet shall state the three most recent test results to enable comparisons to be made.

Customer Name:	NPg Yorkshire/NPg Northeast
NPg Unique asset identifier:	
Substation Name	
Unit Description	e.g. GT1 or GT2
Manufacturer	
Manufactured Year	
Serial Number	
Category (BS EN 60422)	e.g. B
Rating (A)	
Voltage (kV)	
Oil Volume (litres)	

Sample Point	Main Tank	Main Tank	Main Tank
Sample Date	05/07/21	01/07/22	12/07/23
Sample Number			
Date of receipt			
Sampling Date			
Oil Temperature (°C)			
Interfacial Tension mN/m			
Resistivity (20°C) GΩm			
Dissipation Factor (20°C)			
Resistivity (90°C) GΩm			
Dissipation Factor (90°C)			
Acidity mg KOH/g			
Breakdown Voltage kV			
Water Content mg/kg			
Colour			
Appearance			
Fibres			
Furans (2-furfural) mg/kg			
Estimated DP (Chendong)			
Polychlorinated Biphenyls (PCB) mg/kg			
Passivator Content mg/kg			
Inhibitor Content % Mass			
Corrosive Sulphur IEC			
Dissolved Gas Analysis:			
Hydrogen µl/l			
Methane µl/l			
Ethane µl/l			
Ethylene µl/l			

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Acetylene µl/l			
Carbon Monoxide µl/l			
Carbon Dioxide µl/l			
Oxygen µl/l			
Nitrogen µl/l			
TDCG µl/l			
Total Gas µl/l			
DGA Interpretation			
Comments			
Recommendation			
Next Sampling Date			