PETROLEUMSTILSYNET

Investigation report

Report	
Report title Investigation of a fire in high-voltage transformer 13ET006 on Åsgard B	Activity number 001094045

Security grading		
☑ Public	☐ Restricted	☐ Strictly confidential
☐ Not publicly available	☐ Confidential	

Involved	
Team T-1	Approved by/date Kjell M Auflem/12 May 2023
Members of the investigation team [redacted]	Investigation leader [redacted]

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1 Summary

At 20.54.57 on 13 November 2022, a fire broke out in a dry-type transformer located in transformer room U54101 on the Åsgard B facility operated by Equinor. The emergency response organisation mobilised and other personnel mustered at an alternative muster point. Fire and foam pumps activated automatically. Nobody was injured during the incident. The Petroleum Safety Authority Norway (PSA) decided on 14 November 2022 to investigate the incident.

The transformer room primarily contains high-voltage equipment related to the DEH systems, which have been installed to counter hydrate and wax formation in subsea flowlines.

The direct cause of the fire in the transformation is a short circuit/arc flash resulting from impairments to and/or degradation in the winding insulation over time.

In the PSA's view, the fire in the transformer room did not have a major accident potential. The room has been designed to withstand fire, while little flammable material is present in the area. As a result, the fire is unlikely to have spread beyond it. Had there been personnel in the room when the short circuit/arc flash occurred, they are unlikely to have been directly exposed except to noise and possible smoke during the seconds it takes to leave the room.

The transformer failed after 25 years in operation (manufactured in 1998). Underlying causes of the breakdown are thought to be the following.

- Accelerated degradation of winding insulation at the fault site as a result of hot spots where the temperature exceeded the transformer's thermal insulation class.
- Local failure and partial discharges because of transient surges from the 11 kV switchboard. Since no earth fault protection is provided between the primary and secondary windings, surges can be transferred/connected directly to the secondary side.
- Possible problems with the DEH system's special configuration – phase compensation equipment (capacitance, inductance and resistance) on the secondary side and underwater cables – could have contributed over time to internal impairments in the transformer.

The investigation has identified one (1) nonconformity related to

- following up and learning from incidents

and two (2) improvement points

- barriers
- door impaired A-60 firewall.

2 Background information

Smoke and a fire occurred on 13 November 2022 because of overheating and a short circuit/arc flash in high-voltage transformer 13ET006, sited in transformer room U54. The latter is located in the utilities area (level 1, lower deck) on Åsgard B.

2.1 Description of facility and organisation

The Åsgard field lies on the Halten Bank in the central part of the Norwegian Sea, in 240-310 metres of water.

Its licensees are Equinor Energy AS (operator, 34.57 per cent), Petoro AS (35.59 per cent), Vår Energi ASA (22.06 per cent) and TotalEnergies EP Norge AS (7.68 per cent).

Åsgard was proven in 1981, with a plan for development and operation (PDO) approved in 1996.

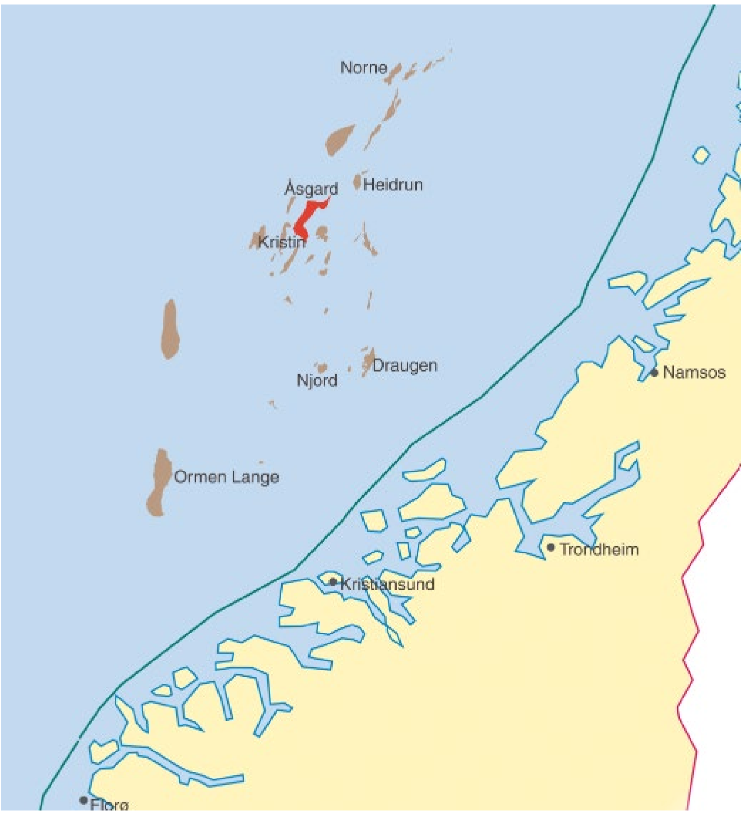


Figure 1: The Åsgard field on the Halten Bank. Source: Equinor

The field comprises the Midgard, Smørbukk and Smørbukk South deposits, while the Mikkel gas field and the Morvin and Trestakk oil fields are also tied back to its infrastructure. It has been developed with the Åsgard A production ship, the Åsgard B semi-submersible gas facility and the Åsgard C storage vessel. The field has produced oil since May 1999 and gas since October 2000.

Oil and gas reach the Åsgard facilities today from seven fields: Midgard, Smørbukk, Smørbukk South, Mikkel, Morvin, Smørbukk North-East and Trestakk. Morvin (four wells, two templates) and Mikkel (three wells, two templates) are also produced from Åsgard B. Oil, condensate and gas are produced from Åsgard itself, with the oil and gas combined to form a quality known as Åsgard blend. Liquids are pumped from storage tanks to tankers shuttling between the field and various refineries.

With the Åsgard development, the Halten Bank was tied into the gas transport systems in the North Sea. Gas from the field is piped to the Kårstø plant north of Stavanger. The main supply base for Åsgard is at Kristiansund, while its operations organisation is located at Stjørdal.

Åsgard forms part of Equinor's *Exploration and Production North* (EPN Production North) business area, with business unit *Åsgard Area* (ASG) responsible for operating and maintaining the Åsgard A and B facilities.

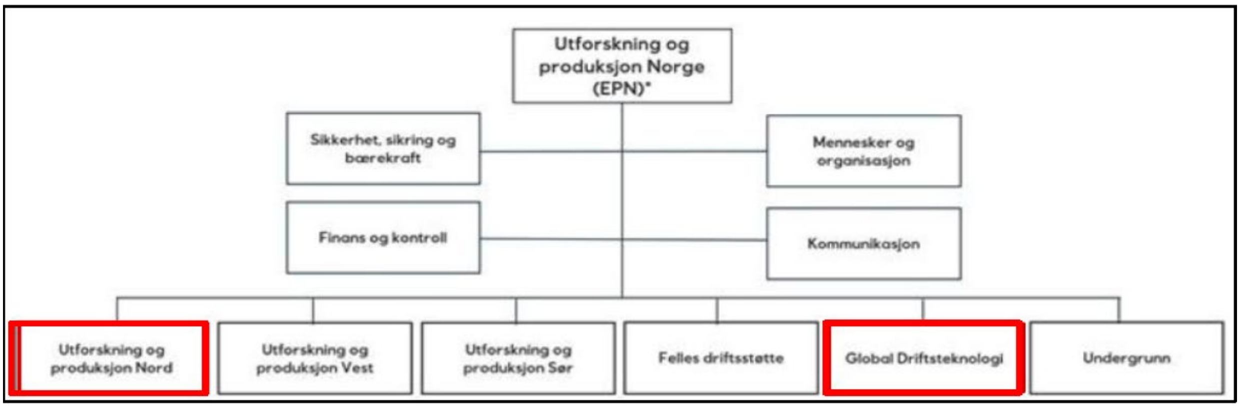


Figure 2 Organogram for Equinor Exploration and Production Norway.

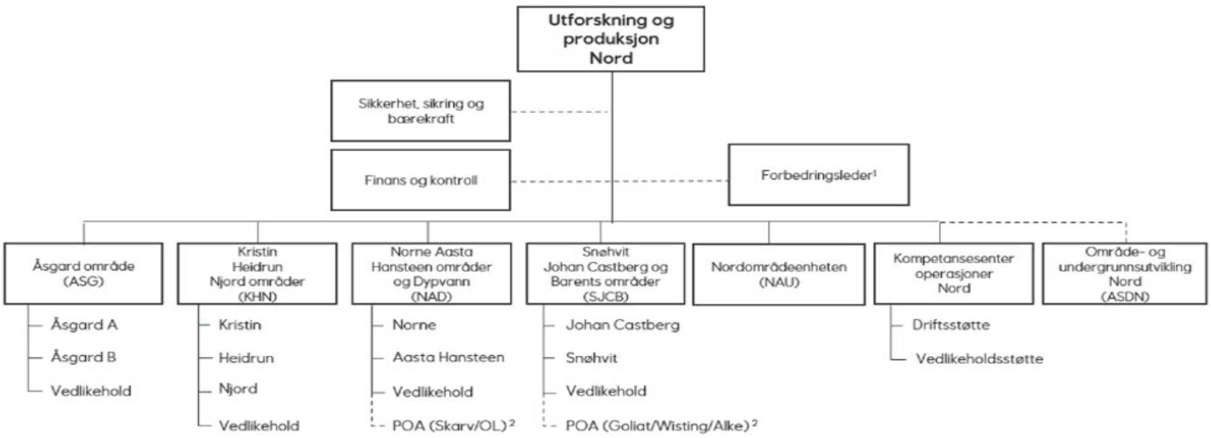


Figure 3: Organogram form Equinor Exploration and Production Norway. Source: Equinor

EPN Production North is part of Exploration and Production Norway (EPN) and has an organisation structure in line with Equinor's general operational model, where the production organisation on land is the main point of contact for the offshore organisation and coordinates with other entities.

On land, the operations organisation comprises managers for maintenance and production who report to the business unit, and an operations unit which comprises resources allocated long-term from centres of expertise.

The organisation structure on Åsgard B is presented below.

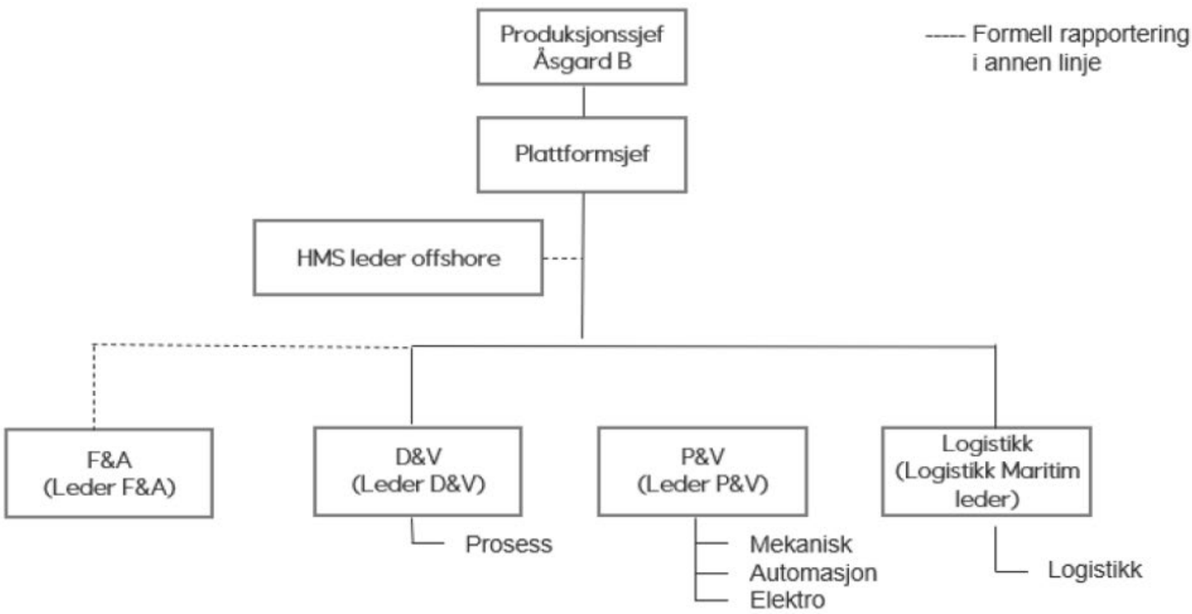


Figure 4: Organogram for Åsgard B. Source: Equinor

2.2 Position before the incident

Activity (production) on the incident day was normal, with 118 people on board. According to Equinor's response log for Åsgard B, the wind strength was 7-11 knots and wave heights were 1.7 -2.7 metres.

2.3 Abbreviations

CCR	Central control room
CM	Corrective maintenance
DEH	Direct electric heating
EPN	Exploration and Production Norway
Equinor	Equinor Energy AS
MEI	Manual electrical isolation
OBE	Operational barrier element
PM	Programme for preventive maintenance in Equinor

POB	Personnel on board
PS	Performance standard
PSA	Petroleum Safety Authority Norway
PTC	Positive temperature coefficient
SAR	Search and rescue
SSU	Safety, security and sustainability
S&R team	Search and rescue team
WO	Work order

3 The PSA's investigation

The purpose of the investigation has been to clarify the course of events, identify the direct and underlying causes, draw lessons from the incident and contribute to preventing a repetition of similar events.

Equinor notified the PSA at 21.45 on 13 November 2022 of a fire in a transformer room on Åsgard B. On the basis of this information, the PSA established its response centre to follow up Equinor's handling of the incident. However, the latter was quickly clarified and effectively handled by the first-line response on Åsgard B.

After a follow-up meeting with Equinor at 09.00 on 14 November 2022, the PSA decided to investigate the incident.

3.1 Mandate for and composition of the investigation team

The investigation team was given the following mandate.

a. *Clarify the incident's scope and course of events (with the aid of a systematic review which typically describes timelines and incidents).*
b. *Assess the actual and potential consequences:*
    1. *harm caused to people, material assets and the environment*
    2. *potential to harm people, material assets and the environment.*
c. *Assess direct and underlying causes.*
d. *Identify nonconformities and improvement points related to the regulations (and internal requirements).*
e. *Discuss and describe possible uncertainties/unclear points.*
f. *Discuss barriers which have functioned (in other words, those which have contributed to preventing a hazard from developing into an accident or have reduced the consequences of an accident).*
g. *Assess the player's own investigation report.*
h. *Prepare a report and a covering letter (possibly with proposals for the use of reactions) in according with the template.*
i. *Recommend – and normally contribute to – further follow-up.*

Composition of the investigation team:
[redacted]

3.2 Investigation of the incident

The PSA investigation has involved inspections on the facility, verifications in management systems, interviews with personnel on land and offshore, and reviews of relevant documents. A police inquiry was conducted in parallel on Åsgard B, with the PSA team participating in all interrogations carried out by the police on the facility.

Put briefly, the work has involved:

- 14 November 2022 – notice of investigation sent to Equinor
- 15-17 November 2022 – inspection, interviews and verifications on Åsgard B
- 12 January 2023 – Teams meeting with Equinor's investigation team and representatives from transformer manufacturer Hitachi (formerly ABB)
- 16 January 2023 – one member of the PSA team participated with two from the Equinor team in a investigation of the destroyed transformer at the Sintef Energy Lab in Trondheim to identify causes.

4 Description of incident site, system involved, equipment and maintenance

This chapter deals with the incident site, the system involved, the equipment and maintenance.

4.1 Subsea installations tied back to Åsgard B

Production-well system 13 on Åsgard B includes flowlines from Smørbukk templates N, K, H, J, L and M. Production from these installations is routed to system 20 on Åsgard B for further processing.

The H-101/102, J-101/102 and N-101/N102 production flowlines from Smørbukk and B105 from Morvin are designed with a DEH system to protect against wax and hydrate formation.

4.2 Overview of the incident site

The incident occurred in the U54 high-voltage transformer room at level 1 in the utilities area on the lower deck. See figures 5 and 6 below. This space is normally locked and entry requires special permission. The room primarily contains high-voltage equipment related to the DEH systems.

Figure 5: Overview of Åsgard B. The incident occurred in transformer room U54A in the utilities area on the lower deck. Source: Equinor

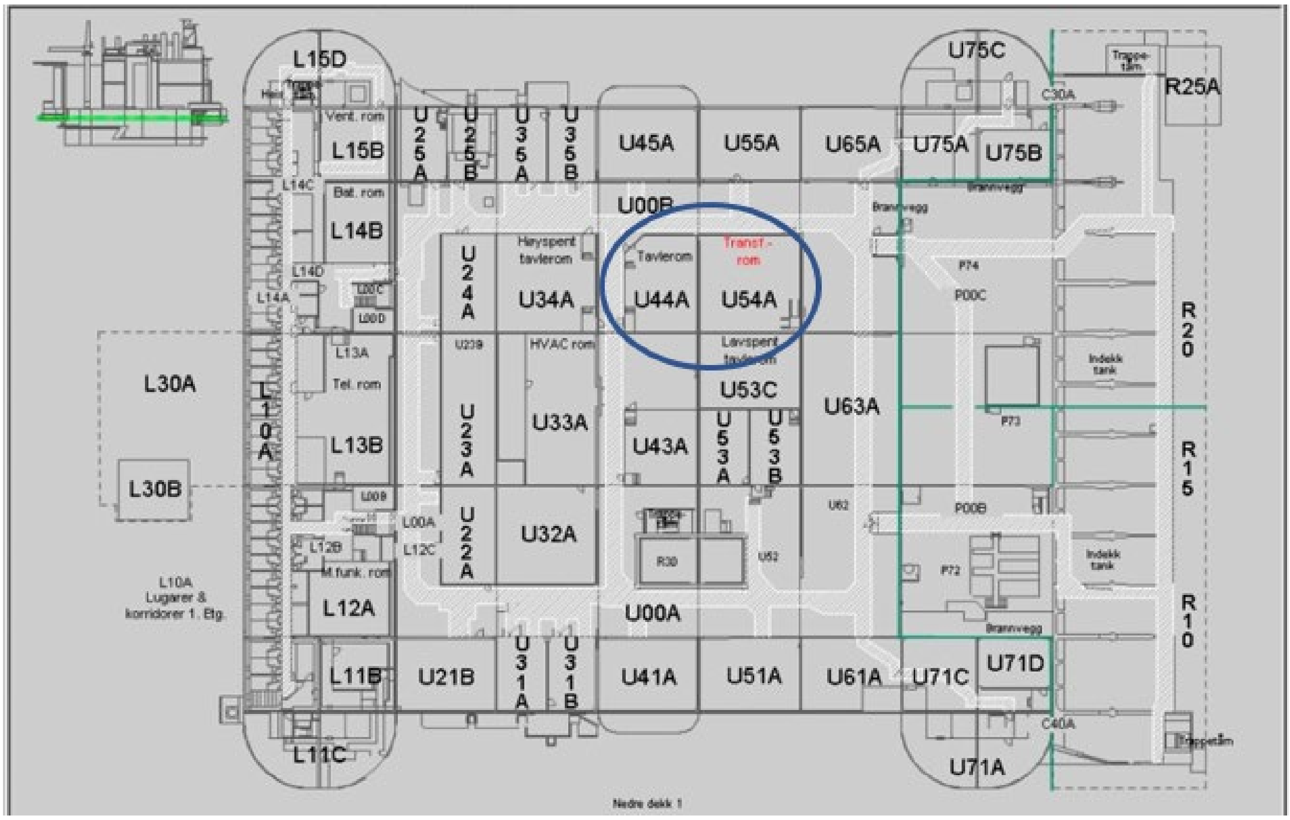


Figure 6: Layout of the utilities area, level 1, lower deck. Source: Equinor

Figure 7 shows U54 level 1 with the positions of the 13ET006 dry-type transformer and the MEI circuit breaker which was activated. To the right can be seen level 2 with the location of associated compensation equipment as well as the smoke detector which gave the first pre-alarm. U54 levels 1 and 2 are separated by a grating rather than a solid deck. A HVAC plant provides cooling for both levels in the room.

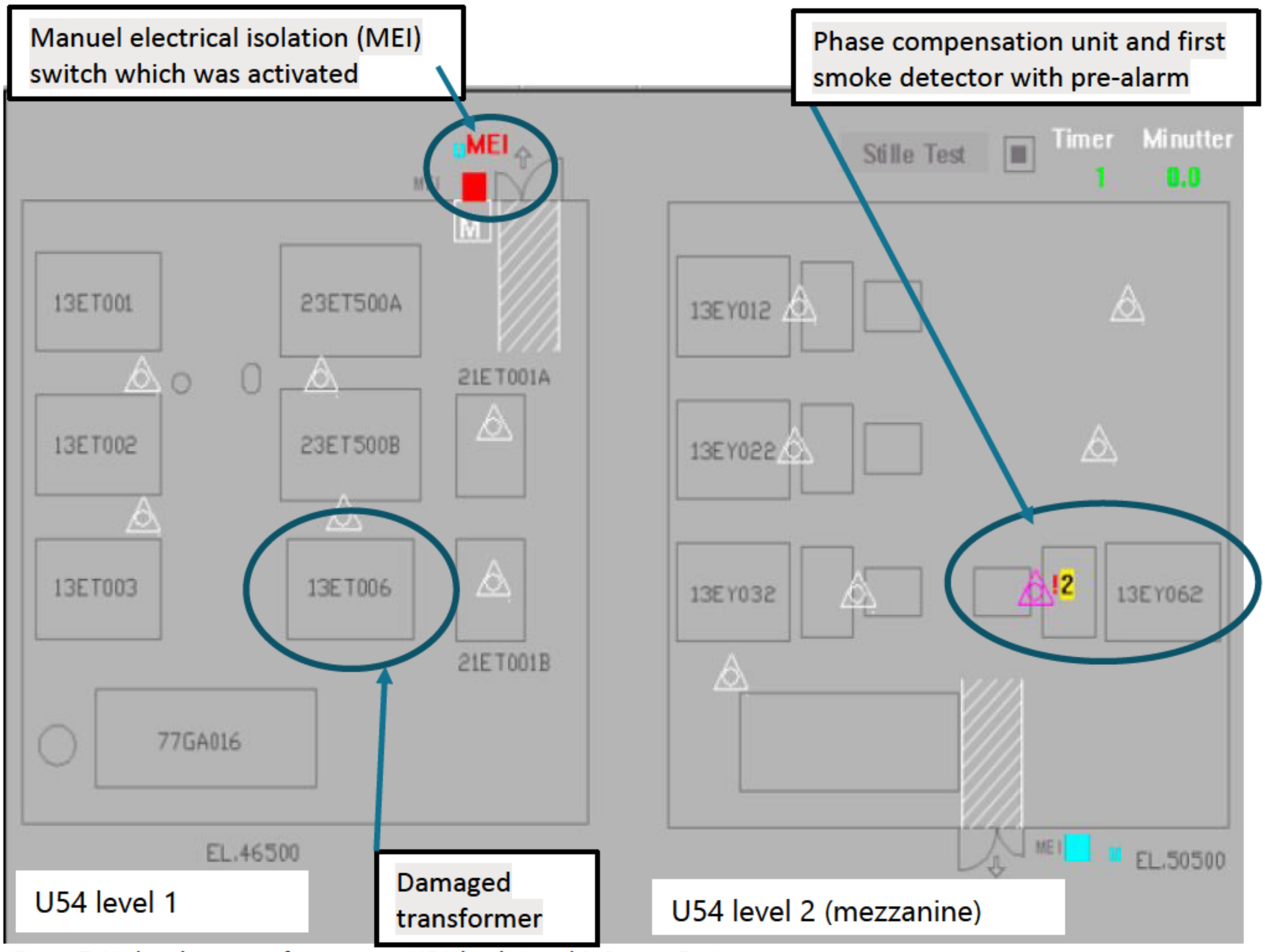


Figure 7: High-voltage transformer room U54, levels 1 and 2. Source: Equinor

4.3 The DEH system

4.3.1 Purpose and function

Hydrate and wax formation in subsea flowlines carrying oil and gas can result in undesirable fluid properties and even block the wellstream. In the worst case, this can lead to unwanted production shutdowns and extensive flowline repairs. The DEH system was developed to overcome these challenges and has also proved applicable for removing hydrate plugs.

This method regulates the internal flowline temperature by transmitting alternating electric current through the steel pipe wall – in other words, supplying direct electrical heating which thereby hampers hydrate and wax formation. See figure 8 below.

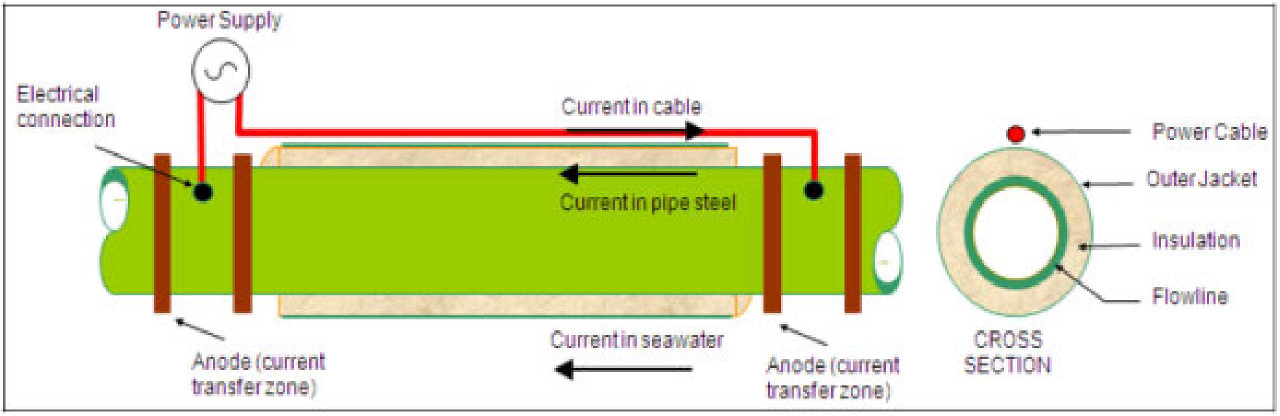


Figure 8: Direct electric heating (DEH) system – open loop (wet insulated)

A DEH system has three primary operating modes:
a) maintain temperature during production shutdowns
b) heating from ambient to operating temperature during production start-up
c) continuous heating under specified operating conditions.

The N-102 DEH system involved in this incident is not in continuous operation, but activated primarily in connection with production start-up and/or when redirecting wellstreams and production flows.

Equipment components in the DEH system for N-102 are shown in figure 9.

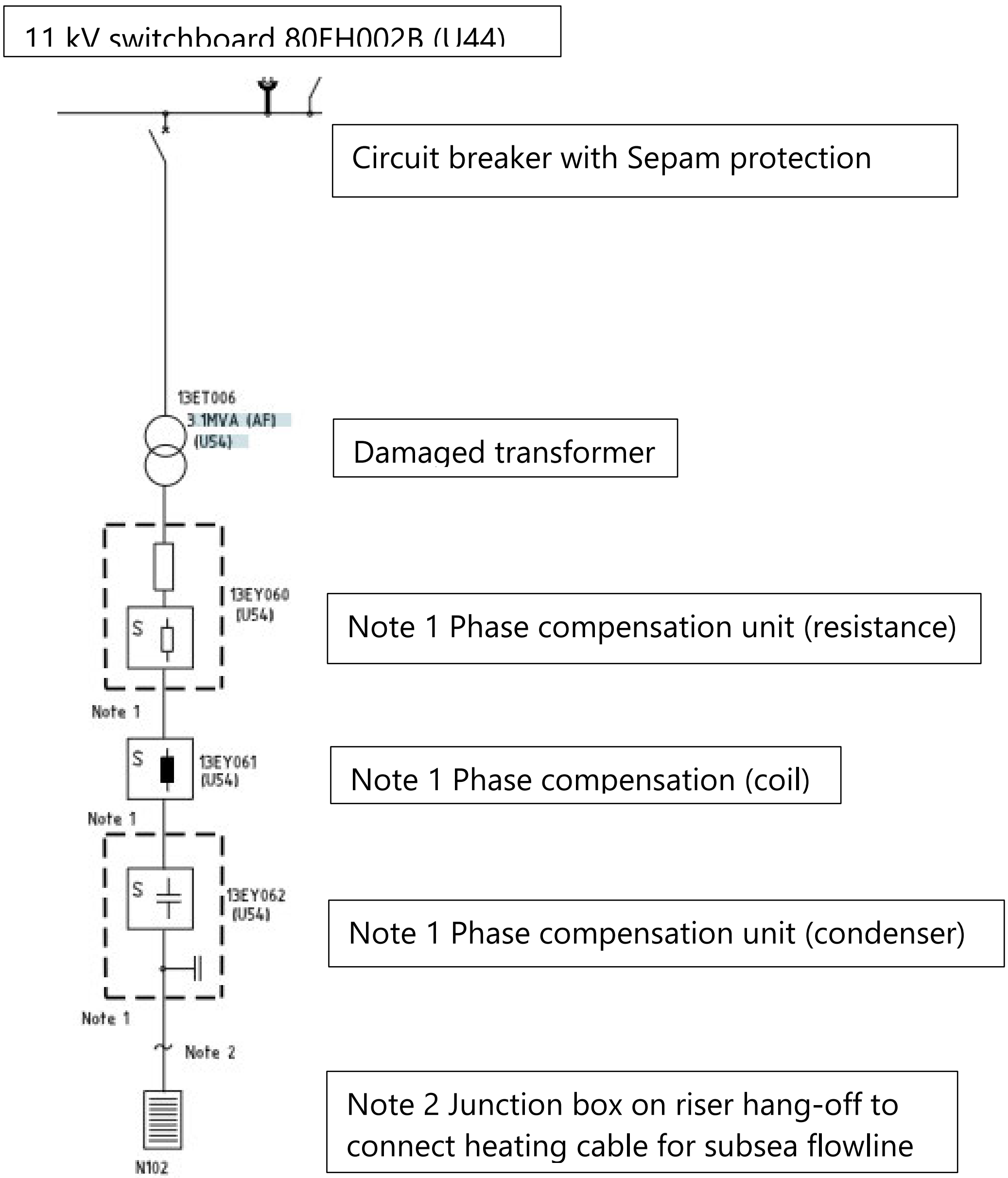


Figure 9: Extract from single-line diagram for the DEH system.

4.3.2 High-voltage switchboard 80EH002B

The 80EH002B 11 kV high-voltage switchboard in switchboard room U44 is supplied from the 11 kV 80EH001A/B main switchboard in U34. See figure 6 above. Outgoing circuit breaker (cubicle +H73) supplies transformer 13ET006 and the downstream phase compensator unit and cable to flowline N-102 for Smørbukk and Morvin. See figure 9 above.

4.3.3 Merlin Gerin Fluarc FG2 circuit breaker

The Merlin Gerin Fluarc FG2 is a 630A withdrawable SF_6 breaker. Information received from the counter on the relevant device shows that it has operated 381 times since start-up in 2000, which is a relatively low number given the breaker's design capacity.

4.3.4 Sepam, imbalance (Megacon) and impedance (PC) protections

The Sepam protection for transformer 13ET006 incorporates overcurrent, short circuit, and earth fault as well as *temp high alarm* and *temp high, high trip* functions. See the Sepam control logic diagram [82]. According to the information received, the Sepam alarm and trip functions are not connected to SAS or the CCR operator stations, nor is it possible to extract trends or incident logs.

In addition comes an imbalance protection which measures a negative sequence. Both the Sepam and imbalance protections are positioned in the switchboard cubicle – in other words, on the primary side of the transformer.

An impedance protection (PC tool) also safeguards the subsea installations.

Table 1 shows the protection functions with set points for alarm and disconnection.

Table 1 Overviev of protection functions for transformer and DEH system. Source: Equinor

Sepam-vern	Alarm	Utkobling	Innstilling	Kommentar
Temp. høy transformator	x		100°C	
Temp. høy-høy transformator		x	120°C	
Temp. høy induktor (13EY061)	x		135°C	
Temp. høy høy induktor(13EY061)		x	150°C	
Overstrøm		x	125A/ 0,2 sec	*Very invers curve*
Kortslutning I>		x	1500A/0,05 sec	*Definite time curve*
Jordfeil		x	2A/0,2 sec	
Ubalansevern (Megacon KPC110)				
Negativ sekvens høy	x		80 %, 15 sec	
Negativ sekvens høy-høy		x	90 %, 5 sec	
Impedansevern-PC				
Impedansevern overstrøm		x	1287 A, 0,55 sec	Beskytter installasjoner subsea
Impedansevern høy	x		Vinkel >69,10, <68,10	Beskytter installasjoner subsea
Impedansevern høy høy		x	Vinkel > 69,25, < 67,25	Beskytter installasjoner subsea

4.3.5 Transformer 13ET006

The transformer which broke down was manufactured in 1998 in connection with the Åsgard B development project. It is a three-phase dry-type Resibloc (glassfibre reinforced epoxy resin) high-voltage unit with fan cooling. The model type is KTHP 12 C 2500 (3150 kVA, 11 kV/5424 V – 9x136.7 V), with manual stepping points for secondary voltage selection.

Figure 10: Transformer 13ET006 (left) and an illustration (right) which shows that the incident began at the top of middle spool. Sources: Equinor and Sintef

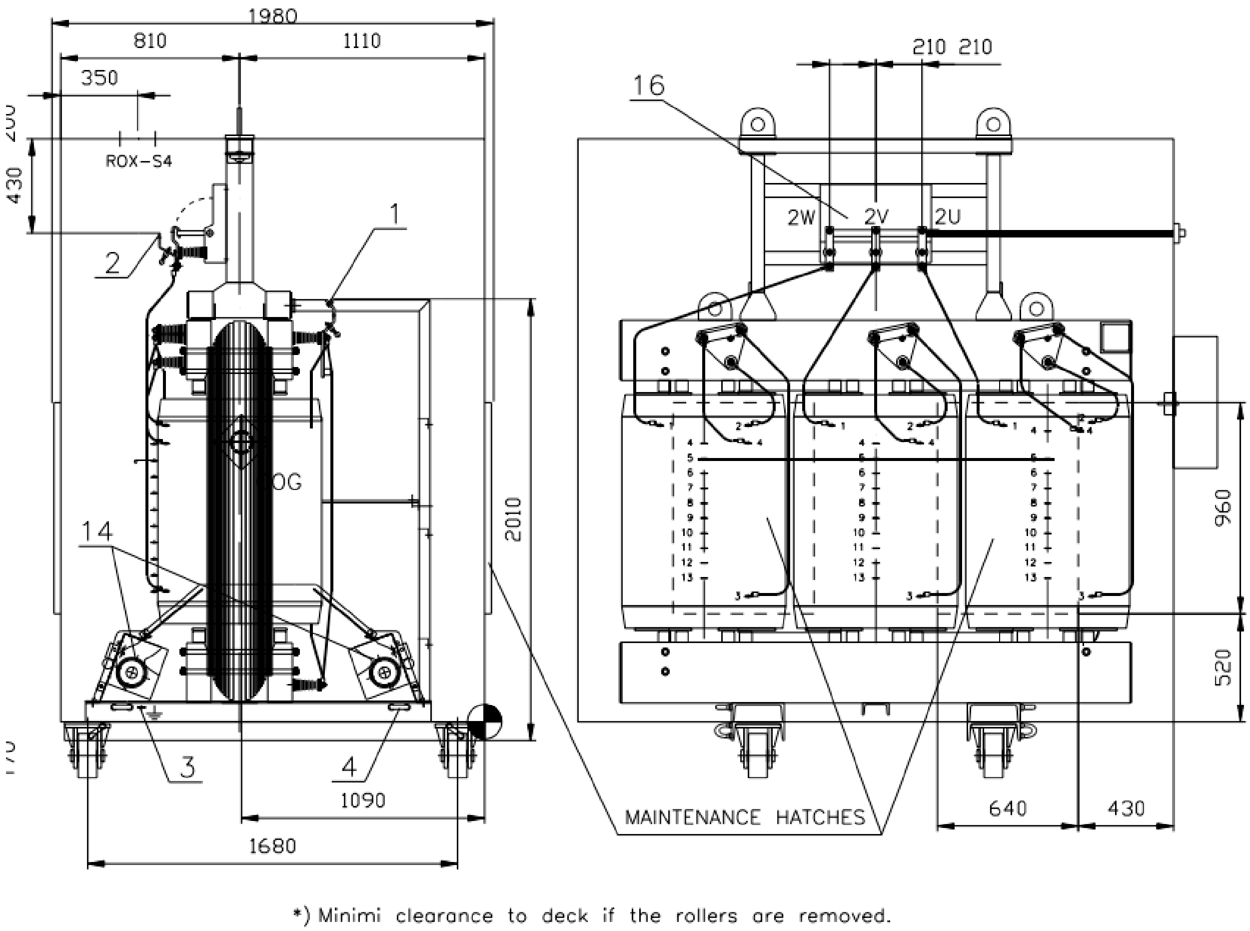


Figure 11: Arrangement drawing of the transformer. Source: Equinor

The transformer, with such components as cooling fans and temperature sensors, is installed in a removable metal housing. It has fire class F1, which means limited flammability with emissions of toxic substances and smoke reduced to a minimum.

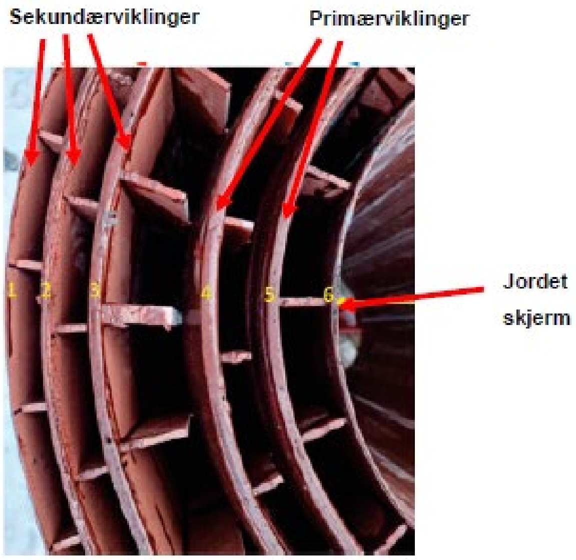


Figure 12: Images of the transformer with windings and core. Source: Sintef
Key: Secondary windings Primary windings Earthing screen

The data sheet (appendix A) specifies that the transformer windings (insulation class F) should withstand the mechanical forces associated with on/off connection of the phase compensation unit (condenser, resistance and coil) on the secondary side of transformer, with the following limitations:

- two connections per day
- maximum 40 connections per annum for 25 years.

According to the supplier, the average expected working life of such transformers is 20-30 years in normal environmental and operating conditions. Where isolation class F is concerned, this is based on an average winding temperature of 120°C. Other factors will also affect the working life of a transformer, such as ambient temperature, its load, environmental conditions such as dust, humidity and vibration, and external events in the network, such as surges. It is therefore difficult to predict the working life of an individual transformer.

Given that the secondary windings on this transformer are also high voltage (5.7 kV), Equinor maintains that measuring the winding temperature directly is not possible. An indirect method has therefore been used which measures airflows through the windings. The set points for fan start, alarms and disconnection are set below the specified limits for isolation class F, which are 80°C/100°C/120°C respectively.

The transformer is equipped with three PTC sensors in each phase/coil for fan start (80°C), alarm high temperature (100°C) and disconnection at high temperature (120°C). These sensors are installed on the upper coil edge, and will be heated by air flowing through the various winding layers.

The 13ET006 unit also has a PT-100 temperature sensor, which has not been taken into use. However, the PT-100 element can be connected to the SAS system for logging temperature. An analogue thermometer is also installed locally on the transformer.

Four fans installed in the base of the transformer housing are dedicated to internal cooling. In addition, transformer room U54 has its own HVAC system for cooling the interior.

The transformer is also fitted with surge arresters to deal with undesirable/damaging surges, which can arise when circuit breakers are activated, for example.

4.4 Maintenance programme for transformer 13ET006

A generic concept for preventive maintenance (PM) of transformers is established in Equinor's SAP maintenance system. This is based on supplier recommendations and established practice in the industry. Maintenance requirements for such transformers are limited. Their PM programme describes procedures like cleaning and visual inspection to identify possible external impairment/damage. It also specifies function tests for circuit breakers and protection.

Based on documents received, the following PM programmes have been performed on the relevant DEH system.

- <u>48-monthly PM programme</u> for system 13, production manifold flowlines
  Carried out in 2001, 2016 and 2020
    - check condition, function test of breakers and protection, thermostrips for 13ET001-006
- <u>24-monthly PM programme</u> for flowline heating system N102
  Carried out in 2002, 2004, 2006, 2008, 2010, 2012, 2014, 2018 and 2022.
    - test of Sepam protection
    - inspection of transformer
    - test of temperature element (13TE5801 A/B/C)
    - check and test of transformer control panel, cooling fan
    - condition of capacitor bank (13EY062)
- <u>six-monthly PM programme</u> for direct electrical heating N101/N102
    - function test of direct electrical heating

Technical feedback of PM jobs was introduced in connection with the plant integrity programme in 2015-16. Faults were previously only reported in M2 notifications.

Work order WO 25151286, 48M PM N102 – 14.8.2020 received for 1191-13ET006 includes operation 050 *Functional test alarm and trip signals* (TH0200-0004), which specifies that the temperature elements must be simulated when verifying trip and alarm functions. The corresponding operation 050 is also included in WO 25884051, 24M PM N102 – 16.8.2022 received.

Based on information received, the following WOs for CM were carried out on transformer 13ET006:

- 2004 flowline heating assistance (Notification 40280138)
- 2006 fault on cooling fan for transformer 13ET006 (Notification 40516239)
- 2011 flowline heating N102 tripping because of high impedance during start-up (Notification 42690301)

The PSA team was informed that thermography of the transformer has been carried out in recent years but that, in order to shield personnel from danger, this was done immediately after turning off the transformer – in other words, in no-load condition. It is uncertain whether this thermography method would identify that the incident was developing.

4.5 Earlier incidents with dry-type high-voltage transformers

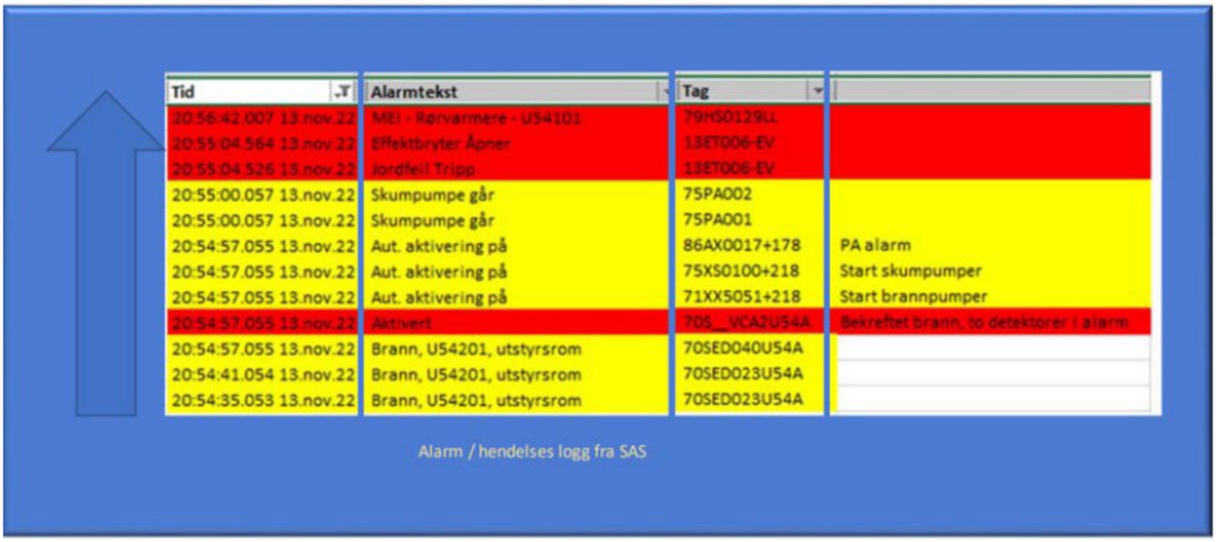
Equinor has earlier experienced incidents of short circuiting/arc flash in similar dry-type transformers which were very probably caused by impairment/deterioration of insulation between winding turns.

The following incidents can be mentioned.

- 1998 Sleipner A: incident with transformer 81-ET01A, a 13.8/6 kV unit with an output of 12.5 MVA.
- 2003 Sleipner A: incident with transformer 82-ET01A, a 13.8/0 kV unit with an output of 3.5 MVA.
- 2004 Sleipner T: incident with transformer G-81-ET02, a 13.8/6 kV unit with an output of 8 MVA.
- 2011 Åsgard B: incident with converter transformer 23-ET500, a 11 kV/2 x 2 866 V unit with an output of 2 x 7035 KVA.
- 2021 Sleipner A: incident with transformer 16-ET02A, an 13.8 kV/400 V unit with an output of 2.5 MVA.

5 Course of events

At 20.54.34 on Sunday 13 November 2022, the CCR received a pre-alarm from smoke detector 70SED023U54A at level 2 in transformer room U54 on Åsgard B. An alarm was received from the same detector six seconds later. At 20.54.47, an alarm also arrived from neighbouring detector 70SED040U54A. Detector voting 2ooN in alarm gives confirmed fire, automatic start-up of fire pumps and mustering alarm on Åsgard B.



Tid	Alarmtekst	Tag	
20:56:42.007 13.nov.22	MEI - Rørvarmere - U54101	79HS0129LL	
20:55:04.564 13.nov.22	Effektbryter Åpner	13ET006-EV	
20:55:04.526 13.nov.22	Jordfeil Tripp	13ET006-EV	
20:55:00.057 13.nov.22	Skumpumpe går	75PA002	
20:55:00.057 13.nov.22	Skumpumpe går	75PA001	
20:54:57.055 13.nov.22	Aut. aktivering på	86AX0017+178	PA alarm
20:54:57.055 13.nov.22	Aut. aktivering på	75XS0100+218	Start skumpumper
20:54:57.055 13.nov.22	Aut. aktivering på	71XX5051+218	Start brannpumper
20:54:57.055 13.nov.22	Aktivert	70S__VCA2U54A	Bekreftet brann, to detektorer i alarm
20:54:57.055 13.nov.22	Brann, U54201, utstyrsrom	70SED040U54A	
20:54:41.054 13.nov.22	Brann, U54201, utstyrsrom	70SED023U54A	
20:54:35.053 13.nov.22	Brann, U54201, utstyrsrom	70SED023U54A	

Alarm / hendelses logg fra SAS

Figure 13: Alarm log from SAS. Source Equinor

Shortly afterwards (20.55.04), Sepam protection activated the circuit breaker for an earth fault. Emergency shutdown (ESD) level 2 was activated at 20.56.42 when the MEI button outside the room was pressed. This included shutdown of main power and automatic start-up of emergency generators as well as automatic ESD and partial pressure relief in accordance with the ESD logic.

Temperature high alarm and temperature high-high trip in Sepam protection for transformer 13ET006 was first activated at 21.02.42. These are alarm and trip locally in the Sepam protection, and not accessible in the CCR alarm system.

No work was under way in the room, nor were any personnel present. The room was locked.

Further information on the course of events is provided in the timeline below.

5.1 Timeline

The timeline for the incident is presented in the table below. Times for Sunday 13 November 2022 are taken from Equinor's response and alarm logs.

Table 2 Timeline

Time	Description
1998	Production year of the transformer
2000	Transformer installed and started up on Åsgard B
2001	48-monthly PM programme for flowline heating system N102
2002	24-monthly PM programme for flowline heating system N102
2004	24-monthly PM programme for flowline heating system N102 CM – flowline heating assistance

2006	24-monthly PM programme for flowline heating system N102 CM – fault on cooling fan for transformer 13ET006
2008	24-monthly PM programme for flowline heating system N102
2010	24-monthly PM programme for flowline heating system N102
2011	CM – flowline heating system N102 tripping because of high impedance during start-up
2012	24-monthly PM programme for flowline heating system N102
2014	24-monthly PM programme for flowline heating system N102
2016	48-monthly PM programme for flowline heating system N102
2018	24-monthly PM programme for flowline heating system N102
14 Aug 2020	48-monthly PM programme for flowline heating system N102
22 Sep-5 Oct 2020	Service of MG high-voltage breakers by supplier – no serious findings – next service recommended for 2025
16 Aug 2022	24-monthly PM programme for flowline heating system N102 Thermography and visual inspection of transformer 13ET006 carried out (WO 25884051)
13 Nov 2022	Transformer 13ET006 in normal operation before the incident
16.41.23	Alarm impedance protection DEH system for N102 – phase angle < alarm value
17.31.52	Alarm impedance protection DEH system for N102 – phase angle < alarm value
17.31.52	Trip/disconnection impedance protection DEH system for N102 – phase angle < disconnection value, also disconnects transformer 13ET006
20.54.34	CCR receives pre-alarm from smoke detector 70SED023U54A located on level 2 in U54
20.54.40	CCR receives alarm from detector 70SED023U54A, and requests check and reports from process operators – then in HSE meeting on inside
20.54.57	CCR receives another alarm from detector 70SED040U54A, also at level 2 in U54. This initiates confirmed fire in U54
20.54.57	Automatic activation of fire and foam pumps
20.54.57	Emergency response organisation mobilises and other personnel muster at alternative muster point on fifth storey
20.55.04	Earth fault protection trips flowline heating system for N-102 Breaker opens and cuts out transformer 13ET006
20.56.42	MEI button 79HS0129LL outside the door to flowline heater U54101 activated by plant operator, isolating all 690 V and high-voltage equipment in the room and activating NAS2.2 ESD
21.14	Two electricians sent to the emergency generator room to start up the HVAC plant for U54 manually because main power is shut down
21.17	POB check. POB 118. Electricians manually cut out all high-voltage breakers and activate earth fault protection
21.18	No spread to other areas. Check of smoke detectors.

21.30	Begin planning and deciding on partial evacuation by helicopter: first contingent, 21.56 second contingent, 22.26 third contingent, 22.44 A total of 56 people evacuated to Åsgard A
21.35	Report of smoke in U53, the neighbouring room to U54
21.45	S&R team in action in U54. Naked flames seen through hatch in transformer housing 13ET006. Manual extinguishing with CO_2. Close to 300°C measured at the top of middle transformer coil
21.54	Fire extinguished
22.06	U54 secured for investigation
23.55	Cooling of transformers completed, but patrols with thermography equipment conducted through the night
	Normalisation: information to and debriefing of personnel on board
14 Nov 22, 00.11	Equinor's second line demobilised
14 Nov 22, 00.15	PSA emergency response centre demobilised

6 Potential of the incident

6.1 Actual consequences

Great heat developed in connection with the short circuit/arc flash, but damage was confined to the actual transformer, which is built into a metal enclosure with inspection window. Apart from a large amount of soot, no visible damage occurred outside that enclosure.

Material damage and financial consequences:

1. transformer breakdown
2. consequent loss of production

No people were injured.

6.2 Potential consequences

Since little flammable material is present in the area, the fire is unlikely to have spread out of the transformer room. This is surrounded by an A-60 firewall against adjacent rooms/areas.

Had personnel been present in the room when the fire broke out, they are unlikely to have been directly exposed except to noise and possible smoke during the seconds it takes to escape.

7 Direct and underlying causes

7.1 Direct causes

The most probable direct cause of the fire in the transformer is a short circuit/arc flash caused by impairment and/or degradation of the insulation between the copper windings over time.

Figure 14: Defective/melted copper winding on the secondary side located at the top of the middle coil.

7.2 Underlying causes

The broken-down transformer failed almost 25 years after its manufacture in 1998.

Technical conditions

One or more of the following failure mechanisms could have been underlying causes for the transformer breakdown. See the Sintef report.

- Accelerated degradation of winding insulation at the fault site because of hot spots which exceed the transformer's thermal insulation class.
- Degradation of the insulation material on internal windings caused by local partial discharges owing to transient surges on activating the breaker in the 11 kV board. Since no earthing screen is in place between the primary and secondary windings, such surges can be transferred/connected directly to the secondary side.
- Potential issues related to the DEH system's special load configuration with phase compensation equipment on the secondary side, settings for the impedance protection, and possible uneven loading of the subsea cable, which could have contributed over time to internal weaknesses in the transformer.
- The PTC temperature sensors failed to function as intended (slow response time)
    - faulty positioning
    - faulty design
    - defective or impaired sensor.
- The PT-100 temperature element was available, but was not taken into use.

According to the supplier, the following factors could have a negative effect on the transformer's working life.

- Inadequate cooling which causes overheating in the transformer is the most prominent cause of degradation in the insulation material and causes breakdown over time. A rise in operating temperature of just 10°C over the recommended level can reduce working life by up to 50 per cent.
- Inadequate cleaning, with the accumulation of dust and dirt on cooling surfaces, can reduce the cooling effect and cause a gradual temperature rise over time.
- Surges in the transformer's high-voltage internal winding when operating the breaker.

Operational conditions

- Despite a number of incidents with similar transformers at Equinor and others, a perception in industry has been that such units are operationally reliable, have a relatively long working life and require little maintenance.
- Equinor has established a generic maintenance programme for dry-type transformers, but the type of failure mechanism described here is difficult to detect through PM.
- Continuous condition monitoring, able to detect emerging degradation and hot spots in the winding insulation, has not been established practice for this type of transformer.
- Equinor lacks a replacement strategy and working-life programme for this type of transformer.

Interviews and documentation received indicate that Equinor has initiated the implementation of a working-life programme for selected types of equipment on

Åsgard B. The need for such a programme for this type of transformer had been identified, but not initiated.

8 Emergency response

8.1 Notification

A general alarm sounded on Åsgard B at 20.54.57 with a subsequent public address (PA) announcement of a fire in U54. The emergency response leadership and personnel mobilised as planned, while remaining personnel mustered to the alternative muster point on the fifth storey of the living quarters. There were 118 people aboard and no personal injuries.

Area response resources mobilised: SAR Heidrun, *Havila Troll* (with FiFi) positioned itself outside the 500-metre zone, and SeaKing HRS Ørland was stand-by on the Kristin facility. According to Equinor's response log, wind strength on Åsgard B was 7-11 knots and wave heights were 1.7 -2.7 metres. Weather conditions were favourable for evacuation by helicopter.

Notification to the PSA accorded with the applicable response plan for Åsgard B. The PSA established its own response centre to supervise Equinor's handling of the incident. The impression is that Equinor's first line handled the incident in a good way, and the PSA received adequate and updated information from the company's second-line response. Its impression is that the response on Åsgard B was good.

8.2 Fighting the fire

S&R teams 1 and 2 mobilised at the incident command centre, where team 1 was reinforced with an electrician. It was then sent to heating transformer room U54101 to extinguish the fire in high-voltage transformer 13ET006. Team 2 backed it up and was ready with water hoses. The on-scene commander and the S&R team leader then mobilised.

The fire was extinguished with several CO_2 extinguishers, but repeatedly flared up again before it was decided to cool with water. Cooling of high-voltage transformer 13ET006 continued until midnight.

8.3 Rescue

POB of 118 were quickly accounted for within 22 minutes, and no personal injuries had been suffered on board.

8.4 Evacuation

The offshore installation manager decided on a partial evacuation, and SAR Heidrun began transferring personnel from Åsgard B to Åsgard A at 21.56. A total of 56 people were received on Åsgard A.

8.5 Normalisation

From 22.07, the response organisation and the remaining personnel were demobilised, debriefed and informed. Personnel evacuated to Åsgard A returned to Åsgard B in the course of Tuesday 14 November 2022. Those involved in the incident commented that communication between all response personnel involved was good throughout the incident, while good information was provided to the remaining personnel at the alternative muster point. Patrols equipped with a thermograph visited the fire site and checked the transformer throughout the night.

The PSA demobilised its response centre at 00.15 on 14 November 2022. In the investigation team's view, the partial evacuation, the normalisation phase with cooling, patrols, debriefing and information for personnel on board functioned as planned.

The fire site was secure for investigation and the police inquiry.

9 Observations

The PSA's observations are generally divided into two categories.

- **Nonconformities:** This category encompasses observations where the PSA has established a breach of the regulations.
- **Improvement points:** Relate to observations where deficiencies are identified, but the PSA lacks sufficient information to establish a breach of the regulations.

9.1 Nonconformities

9.1.1 Following up and learning from incidents

Nonconformity
Equinor has failed to ensure that data acquired from earlier incidents with similar transformers have been processed and used to initiate preventive measures.

Grounds
Equinor has earlier experienced short circuit/arc flash incidents in similar dry-type transformers. See section 4.5. Processing data and learning from such events could have helped to prevent degradation/impairment developing into a breakdown.

It emerged from interviews that Equinor lacks a replacement strategy and working-life programme for preventing breakdowns with this type of transformer.

Requirement
Section 19, litera e of the management regulations on collection, processing and use of data.

9.2 Improvement points

9.2.1 Barriers

Improvement point
Technical barriers, in the form of condition monitoring and protection able quickly to detect and prevent the development of rapidly rising internal temperatures in the transformer beyond its design limits, do not appear to have been established.

Grounds
Temperature is an important measurement parameter for transformer operation. The supplier of the transformer has provided both temperature alarm and trip functionality for connection to circuit breakers and the overall control and safety system. This functionality does not seem to have been fully utilised.

The transformer is equipped with three PTC sensors in each phase/coil, for fan start (80°C), for alarm high temperature (100°C) and for disconnection at high temperature (120°C). In this incident, the PTC sensors failed to function optimally in that earth fault protection disconnected before the sensor alarm/disconnection limits were exceeded.

A PT-100 temperature sensor installed on the transformer was not taken into use. The PT-100 element can be connected to the SAS system for temperature logging.

An analogue thermometer is installed locally on the transformer for manual reading. It is unclear to the PSA team how information from this device has been utilised in operating and maintaining the transformer.

Requirement
Section 5, paragraph 1, litera a and b of the management regulations on barriers

9.2.2 Door impaired A-60 firewall

Improvement point
The door between U54 and U53 appears to have impaired the A-60 firewall.

Grounds
During the fire, smoke was reported from U53, the neighbouring room to U54. On inspection, the PSA team also observed clear soot deposition on the top frame of A-60 firedoor 76AD-53201 between U54 and U53. Smoke detectors a few metres from the relevant door in U53 were not activated during the incident. All detectors at this level in U53 have been tested after the incident without finding faults. Nevertheless, the PSA team takes the view that door 76AD-53201 is not completely smoke-proof and thereby impaired the A-60 firewall around transformer room U54.

Requirement
Section 82, number 2 of the facilities regulations on entry into force, see section 22 of the regulations on explosion and fire protection of facilities in the petroleum industry (1995) on technical requirements for firewalls

10 Barriers which have functioned

The following barriers functioned as intended:

- early detection of smoke in U54
- MEI button outside U54
- ESD (NAS2.2) with partial pressure relief
- PA alarm, automatic fire pump start and start-up, of emergency generators
- transformer’s earth fault protection.

11 Emergency response

The response organisation, with the response leadership, on Åsgard B notified, mobilised and fought the fire in accordance with the response plan. Active extinguishing work had been initiated by the first-line S&R team about 50 minutes after the fire was confirmed. The PSA team’s impression is that partial evacuation of Åsgard B functioned as intended.

12 Discussion of uncertainties

If the direct cause was fabrication weaknesses in the insulation system for internal windings introduced during the manufacturing process, it is reasonable to assume the transformer would have failed much earlier. That assumes the transformer has been in continuous operation. However, this unit has not been operated continuously.

Uncertainty relates to whether degradation of the insulation material in the internal windings could have been caused by transient surges arising from breaker activation over time. This depends on the number of breaker operations. However, the counter on the breaker shows that the number of operations has been relatively small.

13 Assessment of the player's investigation report

Equinor has conducted its own investigation of the incident, which was allocated to assignment level 2 in the company's investigation categorisation. We received the report on 21 March 2023.

The causes identified by Equinor's investigation team and described in its report coincide with those described in the PSA team's report. Recommendations in the Equinor report are systematised and well grounded, and accord well with the PSA investigation's findings.

Immediately after the incident, the Equinor entity investigation initiated the following risk-reduction measures.

- Taking care of personnel involved in the partial evacuation
- Transformer 13ET006 was removed and sent for technical examination
- Continuing to review OBEs for all relevant teams.
- PA announcements were heard on UHF channel 4, which is intended to be a closed channel for the response team. Established notification 47330112 to correct this.
- The foam pump did not start up when the emergency generator activated. Established notification 47373032 to correct this.
- Corrected fault which meant some cabins failed to receive important reports transmitted over the PA system (notification 47240873).
- Assessing automatic start-up of HVAC after blackout in an incident.
- Producing a notice outside all rooms with an external MEI button to describe what cut-outs the electrical department must activate during an incident in addition to the button.
- Assessed optimal lifeboat allocation.
- Clarified the assignment level for the investigation, established its mandate and appointed an investigation team.
- Established a task force team for normalisation of U54.

As an immediate measure, the investigation team also proposed to assess and establish a safety alert. However, the PSA team is not aware that such an alert has been prepared and distributed.

Equinor's report observes that the incident has identified a need for learning and improvement in five areas, with the most important being:

- in order to detect degradation or degradation mechanisms before equipment faults arise, the maintenance concept for dry-type transformers needs to be updated and the quality of documentation for their condition over time in SAP improved.

- in order to detect faults early and reduce their consequences, further protection functions need to be assessed.

14 Appendices

A: List of documents received
B: List of personnel interviewed