Report	
Report title Investigation of an electrical incident with serious personal injury at the Kårstø plant on 25 July 2020	Activity number 003912038

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

Involved	
Team T-L	Approved by/date Kjell A Anfinsen, by authority, head of supervision 10 March 2021
Members of the investigation team Jan Sola Østensen, Irene B Dahle, Eivind Sande and Bård Johnsen	Investigation leader Bård Johnsen

Contents

1 Summary

The Kårstø plant is owned by Gassled, with Gassco as operator and Equinor as technical service provider (TSP). It has about 800 employees. Shift workers are divided into six shifts.

In connection with maintenance work being carried out by Equinor at the Kårstø plant, an electrical incident involving serious personal injury occurred at 18.30 on Saturday 25 July 2020.

After earlier audits of electrical installations at Kårstø in 2016 and on the Draupner facilities in 2019, the Petroleum Safety Authority Norway (PSA) issued the following two orders of relevance to this incident:

- 2016 – order to Gassco and Equinor to initiate measures for improving personal safety when working on and operating electrical installations
- 2019 – order to Gassco to ensure electrotechnical expertise for following up electrical installations.

Equinor decided to investigate the incident at corporate investigation level 2 (incident with serious personal injury). Gassco decided to participate in this investigation. The PSA decided on 31 July to investigate the incident.

The incident happened while a work team comprising two Equinor electricians was carrying out preventive maintenance on a 690V distribution switchboard in the T200 substation for Statpipe. When inserting a starter drawer, a short circuit occurred with subsequent arc flash. The person inserting the drawer (Electrician 1) was exposed to the arc flash energy and suffered second-degree burns to face, throat area, hands and knees. The other member of the team (Electrician 2) was present in the substation but at a safe distance, and was not exposed.

A fault in an electrical installation can cause an arc flash. The incident energy will typically increase in line with the short circuit level and/or trip time in the event of faults. In the worst case, exposure to arc flashes with a high incident energy could be fatal even when the person is not in direct contact with conductive components.

The investigation team has found the potential consequence of the incident to be the loss of a human life. This is based on the worst possible outcome if the person concerned had inhaled further quantities of toxic smoke and gas liberated by the arc flash incident.

Equinor's investigation team classified the incident as severity level Red 2 – serious lost-time incident/serious personal injury.

The incident triggered a local alarm in the area, the shutdown of parts of the Kårstø plant and mobilisation of external emergency response resources. The Statpipe T-200 process train was shut down for about six days. Equinor has costed the material damage and other financial losses, repair of materials and downtime at NOK 7-8 million.

A technical fault in the circuit breaker in the starter drawer was the direct cause of the incident.

The investigation has identified the following underlying causes of the incident:

- lack of follow-up/verification of the implementation of measures following the 2016 order
- inadequate planning and execution of the work
- lack of compliance with the procedure for ensuring safety against arc flashes
- inadequate information, training and experience transfer concerning the use of the modified test panel
- ageing and residual lifetime assessments (RLAs)
- risk assessments
- capacity and ability to deliver
- other conditions related to the work.

In connection with its investigation of the incident, the PSA team has identified nonconformities in the following areas:

- management and control
- work on and operation of electrical installations
- risk and residual lifetime assessments
- information
- technical operating documents
- handling of nonconformities.

In the team's view, Equinor's investigation report describes and illustrates the actual course of the incident and its causes, both technical and operational, in a clear and thorough manner. Its observations and conclusions largely coincide with those reached in the PSA's report, but do not shed the same amount of light on key underlying causes related to overall management and control, follow-up of the 2016 order, capacity for/ability to deliver upgrading/modifications and Gassco's follow-up.

2 Definitions and abbreviations

Definitions	
Arc flash	Light and heat produced as part of an arc fault, a type of electrical explosion or discharge resulting from a connection through air to ground or another voltage phase in an electrical system. Source: Wikipedia
Aris	Part of Equinor's management system, which describes work processes
Electrician 1	Member of the work team, injured in the incident. Skilled electrician (maintenance) employed by Equinor.
Electrician 2	Member of the work team, but not injured in the incident. Skilled electrician (maintenance) employed by Equinor.
Incident energy	Amount of thermal energy on a surface at a given distance from the source, generated by an arc flash. Normally specified in calories per square centimetre (cal/cm^2)
Integrity status Concern	− Expected difficulties in ensuring a supply of spare parts and/or expert support in a time frame of four to 10 years − Concerns about vendor reliability − Rising trend for corrective maintenance − Residual lifetime assessments are needed to qualify for extended service life and/or upgrades/modifications/change-out in a time frame of four to 10 years
Integrity status Warning	− Unable to ensure a supply of spare parts and/or expert support, or expected difficulties in ensuring such a supply in a time frame of zero to four years − The vendor does not exist any more, or the equipment is obsolete − Long-lasting trend with excessive corrective maintenance − Residual lifetime assessments are needed to qualify for extended service life and/or upgrades/modifications/change-out in a time frame of zero to four years
M1 notification	Modification/technical improvement proposal (SAP term)
M2 notification	Fault report (SAP term)
M2X notification	Alternative proposal for a work operation which does not involve fault correction (such as a replacement project)
PM01	Corrective maintenance activity (SAP term)
PM02	Preventive maintenance activity (SAP term)
Radar Chart	Illustrated risk picture used by Gassco in executing its see-to-it duty and its risk-based follow-up of a TSP
Designated person responsible for electrical facilities	Person appointed to exercise overall responsibility for the electrical installations, including maintenance of electrical safety.

Definitions	
Low-voltage safety supervisor (AFA)	Person appointed to exercise responsibility for safety at a low-voltage work site
Starter drawer	Dedicated motor starter arrangement, including circuit breakers, fuses, protection, control circuit, indicator lights, etc
Test panel	Used to calibrate thermal protection, for example, in starter drawers
Thermal motor protection	Bimetal thermal protection against overloading the motor and for ensuring that it trips before reaching a surface temperature which may ignite a potentially explosive atmosphere in the process plant
Work order (WO)	Describes one or more work activities or assignments, with no special restrictions in terms of scope or type of work activity
Work permit (WP) level 1	Required for activities associated with high risk and for work which calls for coordination and clearance at plant level
Work permit (WP) level 2	Used for work where the risk requires coordination and clearance in an area or system (Equinor's definition in governing document OM105.01)

Abbreviations	
AFA	Low-voltage safety supervisor
CCR	Central control room
CM	Corrective maintenance
DL	Discipline lead
FSE	Regulations relating to the operational safety of electrical installations
HSE	Health, safety and the environment
KPI	Key performance indicator
OS	Operations supervisor
PPE	Personal protective equipment
PSA	Petroleum Safety Authority Norway
RLA	Residual lifetime assessment
SAP	System for administrative management of plant maintenance
Substation	Distribution station for electrical installations
TSP	Technical service provider
V&B list	Valve and blind list
WO	Work order
WP	Work permit

3 Background information

The incident occurred at the Kårstø plant at about 18.30 on Saturday 25 July 2020 while a work team comprising two Equinor electricians was carrying out preventive maintenance on a 690V distribution switchboard in the T200 substation for Statpipe. When inserting a starter drawer, a short circuit occurred with subsequent arc flash. The person inserting the drawer (Electrician 1) was exposed to the arc flash energy and suffered second-degree burns to face, throat area, hands and knees. The other member of the team (Electrician 2) was present in the substation but at a safe distance, and was not exposed.

3.1 Description of plant and organisation

3.1.1 About the Kårstø process plant

The Kårstø process plant plays a key role in transporting and processing gas and condensate from important areas of the Norwegian continental shelf (NCS).

Image 1 Map of Kårstø Source: Equinor

Image 2 The Kårstø plant Source: Equinor

Its purpose is to separate the hydrocarbon blends which arrive through the Statpipe and Åsgard Transport rich-gas pipelines. The plant also receives unstabilised condensate through a pipeline from the Sleipner area.

3.1.2 Organisational structure for the Kårstø process plant

The Kårstø plant is owned by Gassled, with Gassco as operator and Equinor as technical service provider (TSP). It has about 800 employees. Shift workers are divided into six shifts.

Relevant organograms for Gassco and Equinor are presented below. The chart in figure 1 shows Gassco's management team with underlying organisational units. The process plant and licence management unit is part of the asset management department and responsible for following up operation of the Kårstø process plant.

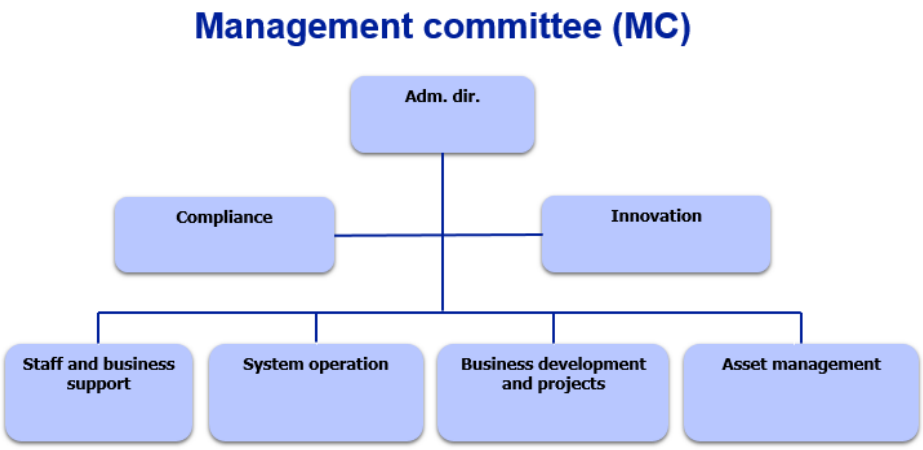


Figure 1: Organisation structure of the Gassco management team. *Source: Gassco*

The Equinor organisation responsible for day-to-day operation of the Kårstø plant is presented in figure 2. It includes operations (see figure 3) and maintenance (see figure 4) report directly to Equinor's plant manager. Technical and plant optimisation (see figure 5) reports where assignments are concerned to the plant manager, but directly to the head of OPL TPO.

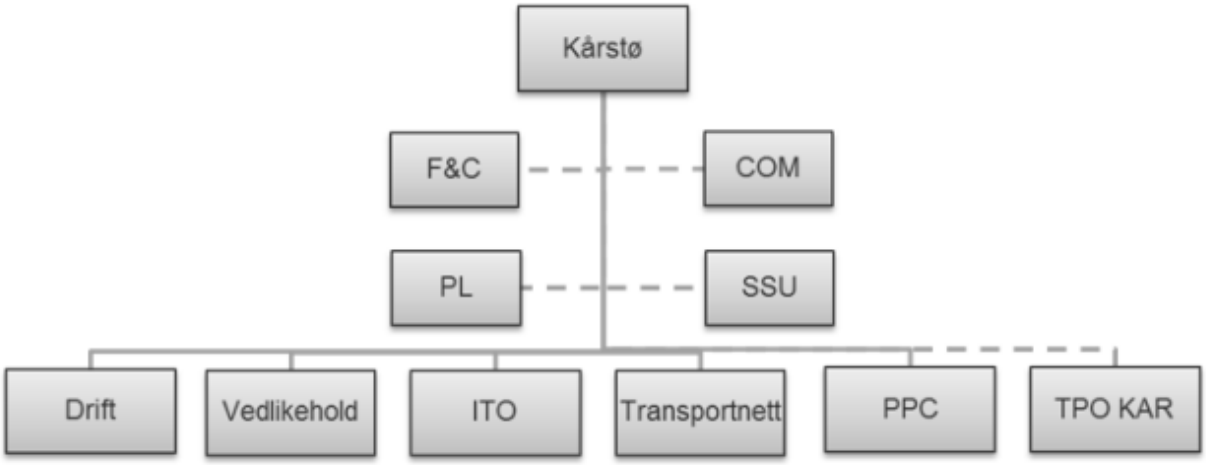


Figure 2: Organisational structure for the Kårstø process plant (PM KAR). *Source: Equinor*

Figure 3: Operations organisation (KAR OPR) for Kårstø. *Source: Equinor*

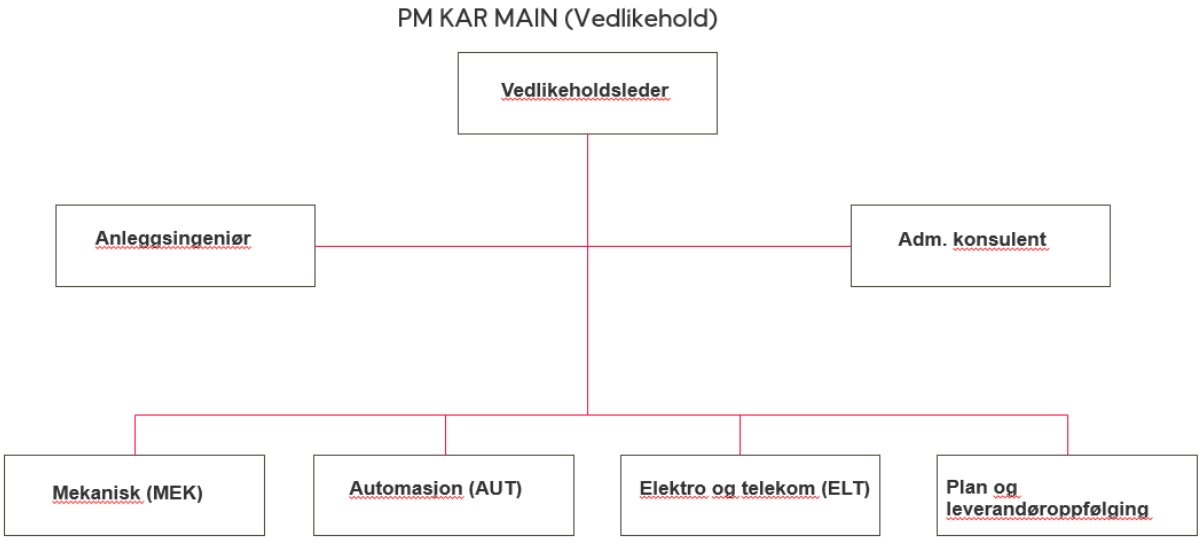


Figure 4: Maintenance department (KAR MAIN) for Kårstø. *Source: Equinor*

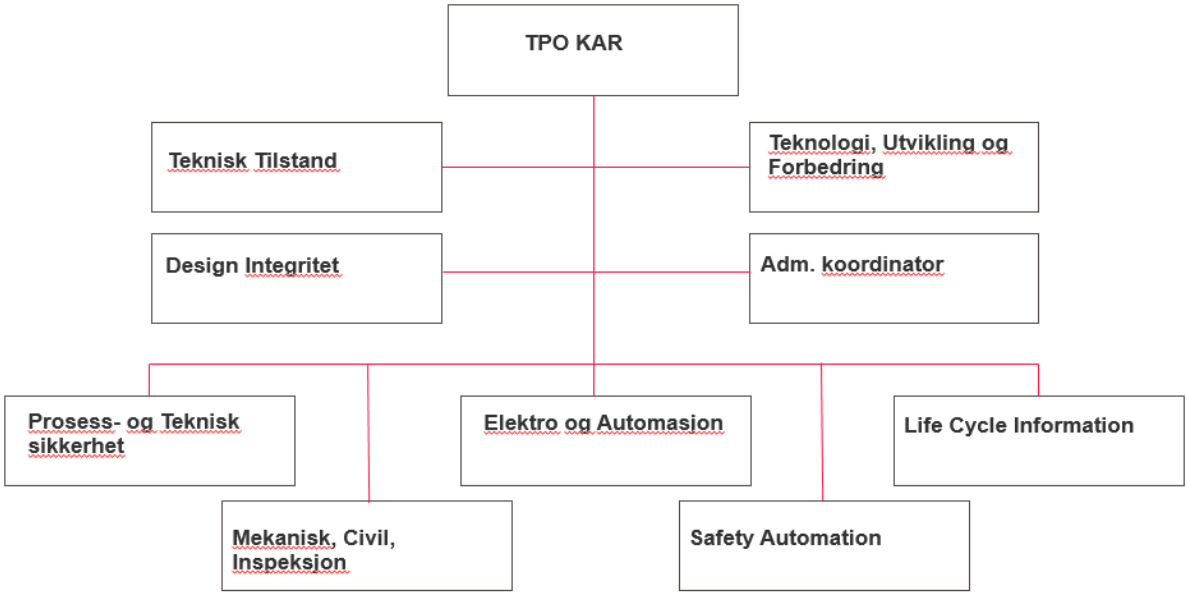


Figure 5: Technical and plant optimisation dept (TPO KAR) for Kårstø. Source: Equinor

Gassco's follow-up of Equinor as TSP is risk-based and pursued by such means as monitoring the risk picture using Radar Chart, KPIs, coordination of operations, monthly reporting, follow-up of incidents and the project/modifications portfolio, verifications, quarterly reporting of technical integrity and RLA reporting.

3.2 Relevant orders following earlier audits of electrical installations

After earlier audits of electrical installations at Kårstø in 2016 and on the Draupner facilities in 2019, the PSA issued the following two orders of relevance to this incident:

- 2016 – order to Gassco and Equinor to initiate measures for improving personal safety when working on and operating electrical installations (ref 2016/1065)
- 2019 – order to Gassco to ensure electrotechnical expertise for following up electrical installations (ref 2019/1023).

These are described in more detail below.

3.2.1 Order to Gassco and Equinor – inadequate personal safety when working on and operating electrical installations at Kårstø

Following audits of major accidents and electrical installations in 8-10 November 2016, the PSA issued an order on 16 November 2016 to Gassco and Equinor (ex Statoil) to initiate measures for protecting personal safety when working on and operating electrical installations. This was prompted by a lack of risk perception and follow-up of identified high levels of arc flash energy and PPE for electrical installations at the Kårstø plant.

The companies were ordered to adopt the following measures to ensure the necessary protection of personnel when exposed to short circuits with arc flash.

- *Clearly inform all relevant personnel of the identified PPE levels and what hazards these can pose in an accident. At the same time, the companies must ensure that personnel receive the necessary information about the required PPE when working on and operating electrical installations/equipment in accordance with identified PPE levels.*
- *Incorporate work processes and routines to protect personal safety when working on and operating electrical equipment in accordance with identified PPE levels.*
- *Adequately highlight, mark and make known the electrical equipment where PPE which exceeds the normal level will be required.*

The PSA received a letter on 29 December 2016 from Gassco which reported, on behalf of Equinor and itself, that the order had been complied with and corrective measures were implemented.

3.2.2 Order to Gassco – lack of electrotechnical expertise when following up electrical installations

Following an audit of electrical and associated installations on the Draupner facilities, the PSA issued an order to Gassco on 15 November 2019. Part 2 of the order read as follows.

Prepare a realistic and binding plan to ensure the following [...]

2. Ensure that Gassco is in possession at all times of the necessary electrotechnical expertise related to electrical installations. See section 5.1.1 of the report.

The PSA received a response from Gassco on 15 January 2020 that the order had been complied with and that the deadline for corrective measures related to part 2 of the order was set at 1 October 2020. Gassco reported that it would acquire electrotechnical expertise as and when required as a compensatory measure in anticipation of a permanent solution.

3.3 Arc flash short circuits and incident energy

A fault can cause an arc flash in an electrical installation. The incident energy will typically increase in line with the short circuit level and/or trip time in the event of faults. In the worst case, exposure to arc flashes with a high incident energy could be fatal even when the person is not in direct contact with conductive components.

An arc flash occurs with an explosive release of energy from electricity flowing through ionised air. Its energy is converted to light and heat with temperatures up to 19 000°C, a powerful flash (welding flash) and a loud noise up to 160 dB. A pressure wave and toxic gasses from vaporised metal may occur.

Figure 6 illustrates an arc flash incident in an electrical distribution switchboard.

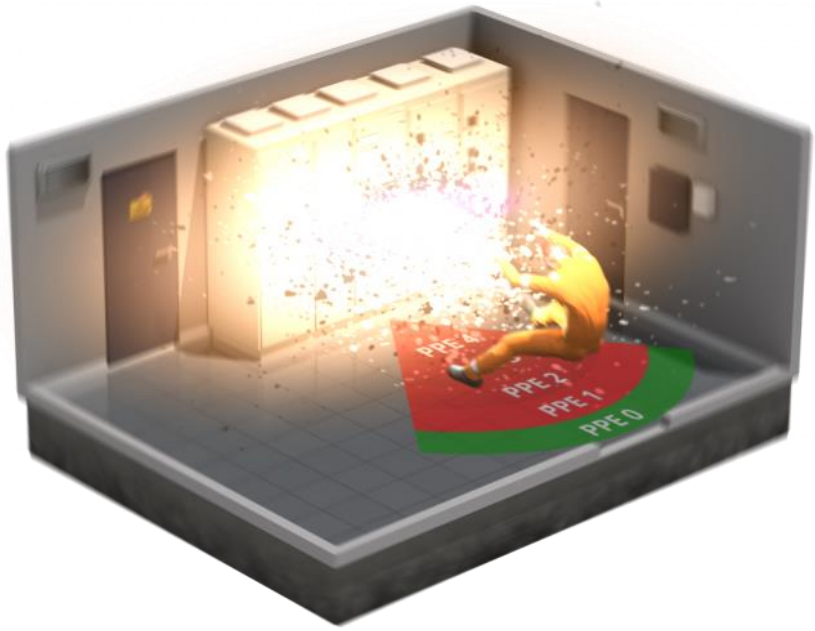


Figure 6 Incident with short circuit and arc flash in a switchboard (illustration). Source: Trainor

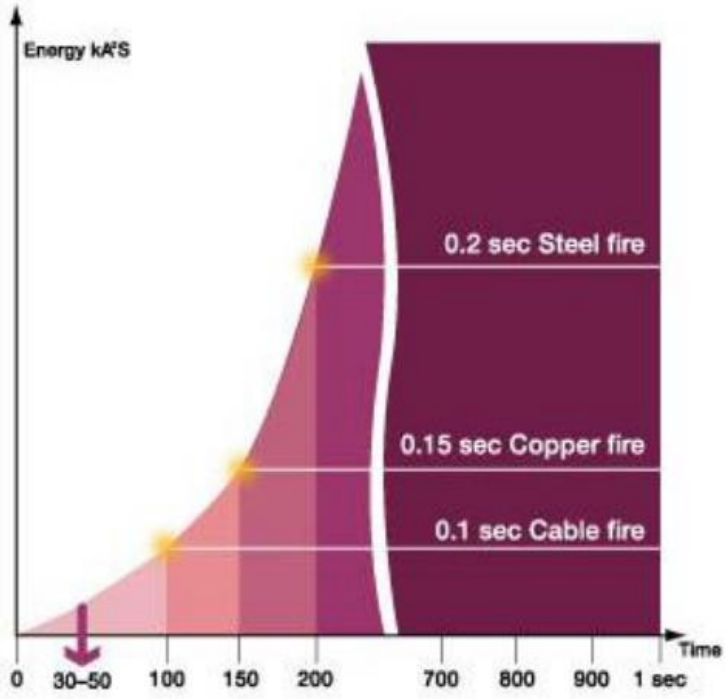


Figure 7 Incident energy as a function of time. Source: ABB[1]

Figure 7, which presents incident energy as a function of time, shows that it rises exponentially from t=0 to about t=0.5 seconds, where it reaches its peak value.

[1] https://new.abb.com/medium-voltage/apparatus/arc-fault-protection/evaluate-the-risk-of-arc-faults-in-your-power-distribution-installation

The term incident energy, expressed in calories per square centimetre (cal/cm^2), is used when specifying PPE requirements. It is the result of the amount of energy liberated in the duration of the arc flash and how far the person is from it.

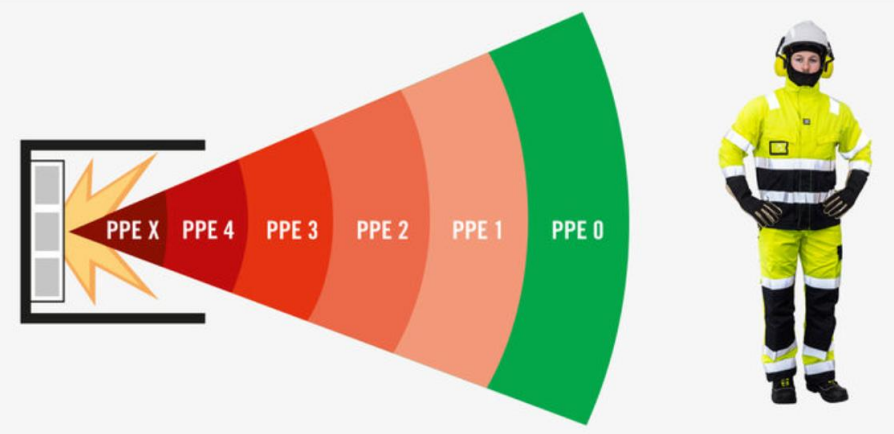


Figure 8 Arc flashes and PPE levels. *Source: www.wenaas.com*[2]

Categorisation of incident energy in arc flashes and PPE requirements is as follows.[3]

PPE 0 ≤ 1.2 cal/cm² (no clothing to protect against arc flash required)
PPE 1 ≤ 4 cal/cm²
PPE 2 ≤ 8 cal/cm²
PPE 3 ≤ 25 cal/cm²
PPE 4 ≤ 40 cal/cm²
PPE x > 40 cal/cm² (extreme hazard)

Calculations are based on voltage level, short circuit current and protection settings. The duration of the arc flash is decisive for the size of the incident energy.

3.4 Position before the incident

Although the summer holidays were under way, the Kårstø plant was operating normally ahead of the incident. Maintenance personnel normally work daytime hours at Kårstø but, because of the Covid-19 pandemic, a three-shift schedule (split into three teams) was introduced in March 2020 for such employees.

A new WP system called Permit Vision was adopted at Kårstø in February/March 2020.
Capacity and expertise in the electrical discipline was somewhat weakened because the designated person responsible for electrical facilities and their deputy were both

---

[2] https://mediacdn6.fristadskansas.com/v-637471288152900775/c7/6a/87a5-44c0-4f56-8dee-4bffb14e8c1b/lysbue-article-2.jpg.

[3] See IEEE 1584, NFPA 70E and IFEA's guideline *Lysbuerisiko, krav til og bruk av bekledning*.

off sick. A couple of days before the incident, the OS for the electrical installations was given the temporary role as designated person in addition to the OS role.

The work team (Electricians 1 and 2) began its working week on Monday 20 July from 14.45 to 23.00 until the Thursday, had the Friday off and was due to work from 06.45 to 19.00 on Saturday and Sunday. The week before, it had worked the day shift and was due to have the following week off.

4 The PSA's investigation

The incident occurred at about 18.30 on Saturday 25 July, and the PSA was notified of it by phone at 19.00. A report in writing was sent to the PSA the following day.

On Monday 27 July, the PSA called Gassco and Equinor to a virtual meeting to receive a more detailed briefing on the incident. Equinor decided that week to investigate the incident at corporate investigation level 2 (incident with serious personal injury). Gassco decided to participate in this investigation.

Based on information from the briefing, the PSA initially decided to conduct a site inspection on Wednesday 29 July, but took the decision on Friday 31 July to also launch its own investigation of the incident.

On Monday 3 August, the PSA received the mandate for Equinor's investigation team as well as a copy of safety alert no 1 (appendix C), which had been prepared and distributed internally in the companies.

4.1 Investigation team's mandate

The following mandate was provided for the PSA investigation.

The investigation team is to do the following.

a) Clarify the incident's scope and course of events (with the aid of a systematic review which typically describes time lines and incidents).
b) Assess the actual and potential consequences
    1. harm caused to people, material assets and the environment.
    2. the potential of the incident to harm people, material assets and the environment.
c) Assess direct and underlying causes.
d) Assess the incident in light of the orders issued to Gassco and Equinor after an audit at Kårstø in 2016 and to Gassco (point 2) after a Draupner audit in 2019.
e) Identify nonconformities and improvement points related to the regulations (and internal requirements).

f) Discuss and describe possible uncertainties/unclear points.
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 accordance with the template.
i) Recommend – and normally contribute to – further follow-up.

4.2 The investigation team

Composition of the investigation team.

- Jan Sola Østensen - process integrity discipline
- Eivind Sande - process integrity discipline
- Irene B Dahle - occupational health and safety discipline
- Bård Johnsen - process integrity discipline (investigation leader)

4.3 Investigation methodology

The investigation has been conducted in the form of interviews with relevant Equinor personnel in the Kårstø operations organisation and key personnel at operator Gassco in Bygnes. Technical investigations and inspections have been carried out at the plant, plus reviews of governing documents and other documentation relevant to the incident. Equinor's investigation report has also been reviewed and assessed. See chapter 13.

4.4 Inspections, interviews and document reviews

From 27 July to 10 August 2020, the PSA investigation team conducted the following inspections, technical investigations, interviews and document reviews at the Kårstø plant and at operator Gassco in Bygnes.

Table 1 – Overview of meetings, inspections and interviews conducted

Time	Place	Purpose
27 Jul 2020	On line	Information meeting with Equinor and Gassco
29 Jul 2020	Kårstø	Site inspection and preliminary conversations
5 Aug 2020	Kårstø	Kick-off meeting for PSA investigation with interviews and inspections at the site and in the electrical workshop
18 Aug 2020	Kårstø	Inspection, interviews with Equinor operations personnel
19 Aug 2020	Kårstø	Inspection, interviews with Equinor operations personnel
25 Aug 2020	On line	Information exchange with Equinor's investigation team in connection with technical investigation of starter drawers
8 Aug 2020	Kårstø	Interviews and technical investigations
9 Aug 2020	Bygnes	Interviews with key personnel at Gassco

5 Course of events

The incident occurred during a planned maintenance job on a 690V motor starter drawer in a substation for the Statpipe part of the plant. Electrician 1 was squatting in front of the switchboard to replace the starter drawer after conducting a function test of the thermal motor protection. A short circuit with subsequent arc flash occurred inside the drawer. Electrician 1 was hit by the incident energy and suffered second-degree burns to face, throat area, hands and knees. Electrician 2 was standing by the entrance door about seven metres away (see figure 14).

Electrician 2 went straight to the vehicle and notified the Kårstø CCR. The emergency response team and external emergency resources were mobilised. On returning, Electrician 2 met the injured person, who was on their feet and heading out of the substation. Electrician 1, who was conscious at all times and had no need for respiratory assistance, was met by the response team and taken to shower and cool down in the CCR before being flown by air ambulance to Stavanger University Hospital for medical treatment. Electrician 2 was looked after by colleagues in the CCR.

A review of current measurements and overcurrent detection during the time frame from 18.29.41.190 to 18.29.42.220 (1.03 seconds) shows that at least three short circuits occurred during the incident. They happened in less than a second, and the current feeding the arc flash varied in strength within that time frame. The measurements were taken from the 22kV circuit breaker supplying the switchboard via a transformer. This is a relatively long duration for an electrical fault in this type of installation. The protection was set to a disconnect time of (td=0.4 seconds). See figure 13. Equinor's calculation of the switchboard's PPE level was based on that trip time, which would normally apply for this type of incident. Equinor has recalculated the potential arc flash energy based on the actual trip time and current measurements from the incident. The incident energy is calculated to have been up to 70 cal/cm^2, corresponding to PPE level X. See also chapter 12 on uncertainties.

Overcurrent detection in the protection device shows that the latter began counting down to disconnect three times, when the current exceeded the set trip value. On the first two occasions, however, the current value sank below the set point before 0.4 seconds had passed. The overcurrent in the third short circuit retained its value until the protection device cut in. It is assumed that the first fault occurred in the starter drawer's circuit breaker between the phase (L1) and the switching rod (earth). See figure 21. It is furthermore uncertain where the second fault arose. The third short circuit, which caused the circuit breaker to disconnect, is assumed to have been on the switchboard's distribution busbars in the section where the incident occurred. See figure 19.

5.1 Timeline

The timeline below specifies in chronological order the activities/sub-incidents which are relevant for the course of events and the investigation of the incident.

Table 2 – Timeline

Time	Activity/sub-incident	Comment
1984-85	Installation and start-up of Siemens S-404 switchboard 82-EN-520A/B – Statpipe development project	Originally 660V, but upgraded to 690V
1984-85	Installation of test panel for S404 starter drawers – Statpipe development project	Tailored to first-generation starter drawers
1990s	Replacement of 25-PA-201M, refrigerant transfer pump motor (68 kW and 68A)	Replaced with rather larger motor (80 kW and 81.6A). Documentation not updated
1999	Installation of test panel for S404 starter drawers – Åsgard development	Tailored to latest generation of starter drawers
19 July 2006	Fatal arc-flash accident during work on electrical substation at ConocoPhillips' Seal Sands plant in Teesside, UK	Also attracted great attention in Norway
17 Sep 2009	M1 41039376: established for modification/replacement of S404 starter drawers	Total of 48 defective motor starters registered between 2007 and 2009
26 May 2010	M1 41039376: handled and extended at the recommendation of the electrical specialists	
17 Feb 2012	M1 41039376: technical handling – *Study for new starters on Statpipe and Sleipner switchboards*	
2012	RLA for S404 switchboards in Statpipe in 2012	"... need to be handled in 2012-2013"
2013	RLA for S404 switchboards in Statpipe, 2013	"... need to be handled in 2013-2014"
20 March 2013	M1 41039376: technical proposal. "Service life expired, spare parts no longer available – recommend replacement/ upgrading of all starter drawers"	Possible consequences: • more breakdowns • heating/fire/short circuit • ignition source in the field because of inaccuracies in motor protection.
4 April 2013	M1 41039376: "Recommended that switchboard system supplier Siemens carries out a definition study to front-end engineer the job and come up	Estimated improvements: • improved regularity • increased Ex safety (ignition source control)

Time	Activity/sub-incident	Comment
	with a more exact price estimate following from the possible need to change drawer sizes"	• increased fire safety, • opportunity for more efficient maintenance
2013	Documented calibration of motor starters in the 25 system (WO-24782540)	Ref PM 24052378 – four-year interval for this
18 July 2014	From harmonisation meeting: "Based on the definitions for maintenance/ replacement/modification, we recommend cancellation of M1 and establish M2s for the future in the OM02/M2 process"	This was M2x notifications for technical clarification from the technical and plant optimisation unit (TPO)
23 Sep 2014	M1 41039376: Notification replaced by two M2x notifications – 43806861 and 43807074 (east/west)	No priority set for these, and both get «Required end date 18 September 2015»
24 Sep 2014	M1 41039376: Notification cancelled	M2x notifications to take care of further investigations/studies.
2014	RLA for S404 switchboards in Statpipe in 2014: "There are some concerns that need to be handled in the near future"	"Siemens will not support this application after 31 December 2014"
2015	Siemens prepares RLA report for S404 switchboards at Kårstø (51CO-0007807.000-D-004, rev 1)	Corporate evaluation – Siemens will continue to ensure spare part supplies
15 Nov 2016	Notice of order after audit of electrical installations, 8-10 November 2016	Initiate measures to ensure personal safety when working on and operating electrical installations
16 Nov 2016	Order to both Equinor and Gassco	As above
18 Nov 2016	Procurement of two sets of PPE 4 for arc flash protection	An extra set (70 cal/cm^2) is acquired rather later
2016	Measures after audit and order • calculation of PPE level • marking of switchboards • preparing routine/procedure to ensure personal safety	
2016	RLA for S404 switchboards in Statpipe in 2016: "Top 10 risks: switchgears/ switchboards and distribution boards"	
2016	Arc flash/PPE course held by Gassco/ Equinor, documented by signed	Decided to repeat course every four years, but not

Time	Activity/sub-incident	Comment
	participant lists	documented
September 2017	Original planned execution date for WO 24899587	All sub-activities were implemented except four-year calibration of S404 starter drawers
17 January 2018	M6 45118539: Established to assess robustness of S404 switchboards.	Technical clarification. Responsible unit TPO.
22 March 2018	Original WO 24899587 closed (completed) in SAP	Even though starter drawers were not calibrated
2018	Procedure requirement that executing work team must contact OS electrical for information on the PPE level and reduction of protection was dropped	Executing work teams ceased to practise this procedure
2018	RLA for S404 switchboards in Statpipe in 2018: design life of S404 switchboard is 2014 and residual life (RL) is 2022	- Integrity status: Warning
14 August 2019	Established WO 24899587 (PM02), notification 45821051, V&B list 0010012327 (CM job)	Discovered that calibration had not been done as PM01 in 2017. No priority specified
24 October 2019	Job status changed from "Prep" (preparation) to "Red ex" (ready for execution)	Since this job went from PM01 to PM02, it had to be planned
2019	Åsgard test panel moved to electrical workshop in the V building. After its conversion, only the procedure for Åsgard was updated and no procedure was established for Statpipe	The converted test panel did not fit the Statpipe starter drawers, and a wrench/ gripping pliers were used to operate the circuit breaker during testing
February 2020	Introduction of new Permit Vision system for WPs. Interviewees reported that the tool box talk form was not used	PSA team's understanding is that the tool box talk form applied only to suppliers and contractors
March 2020	Covid-19 measures adopted: • shift working for maintenance • physical signing of WPs ceases	Shift system increased the load on the OS electrical. Equinor's practice is that the person who signs the WP is the AFA for the job
19 May 2020	M1 46178817 established for making switchboards more robust (part 2)	Includes arc flash protection device and circuit breakers
17 July 2020	WP (1) application established by authorised electrician and approved	The WP was not activated and the job postponed

Time	Activity/sub-incident	Comment
	for execution at 15.00-23.00 on 20-24 July	
22 July 2020	WP (2) – established and entered in the system for execution	Executing team contacted area operator for access and rerouting of critical pumps
23 July 2020	Appointment of acting designated person responsible for the electrical facilities because of sickness	This person also acted as head of the electrical department and has operational responsibility for electrical systems as well
23-24 July 2020	Electrician 2 applied for WP (2) – WP approved. Regarded as a routine job	
25 July 2020	**Incident day**	
About 16.16	Electricians 1 and 2 drove to substation T200 to start the job.	Permission to drive in confirmed by CCR.
About 16.16	WP activated by area operator. Valid until 19.00 on 26 July. WP covers calibration of six S404 starter drawers in Statpipe substation T200 (WO 24899587).	Two of the six drawers were not made available that day, and only four were removed for testing.
About 16.16-17.00	One of the electricians in the team discussed the work with the area operator in relation to activating the WP. Four starter drawers were also taken out and placed in the vehicle	The routine requires the AFA role to be clarified when the WP is signed. However, it emerges that the work team pays very little attention to the AFA role, risk assessment and choice of work method
About 17.00-18.00	The drawers were taken to the electrical workshop for testing. Problems were faced with the first one, and much time had to be spent identifying the electrical connections	Procedure and wiring diagrams were not established for calibrating this type of starter drawer
About 18.00-18.15	Only one drawer had been calibrated when the working day approached its end	The four drawers had to be returned to substation T200 and replaced before time ran out
About 18.15	The work team consulted with the responsible area operator and agreed that the WP could be completed. They reported that they would only replace the four drawers before going home	

Time	Activity/sub-incident	Comment
About 18.20	Electricians 1 and 2 began to carry the drawers into the substation	
About 18.20	Each electrician took two drawers from the vehicle. Electrician 2 put a drawer down outside in order to open the doors in the air lock, and held the door open so that Electrician 1 could enter with two drawers	
About 18.25	Electrician 2 deposited the first drawer in the substation and went out again to fetch the last drawer, which he had left outside the air lock	
About 18.29	Electrician 1 went directly to switchboard section 14 to install the first drawer	
About 18.30	As Electrician 1 put in the drawer and before it had slid completely home, crackling was heard and followed by a flash of light. Electrician 1 immediately felt sharp pains, particularly in the left hand, and was thrown backwards	
About 18.30	Smoke detector 20-SD-7111 in the T200 substation activated and gave an immediate alarm to the CCR. Then 20-SD-7112 also activated and the two gave “confirmed fire train 200 substation” to the CCR	
About 18.30	Electrician 2 was re-entering the substation from the air lock with the last drawer when they heard crackling and saw the light flash. They turned quickly, went to fetch the radio from the vehicle and immediately notified the CCR	
About 18.30	When Electrician 2 re-entered the substation, they met the injured Electrician 1 who had got up and was on their way to the exit	
About 18.30	Electricians 1 and 2 went together from the substation towards the CCR. They were met by emergency response personnel and taken to a changing	

Time	Activity/sub-incident	Comment
	room below the CCR, where the injured person took a shower to cool down	
18.32	The electrical duty officer was notified by phone	
About 19.00	Ambulance and air ambulance arrived at Kårstø, and the latter flew the injured person to hospital	

6 Plant, systems and equipment involved in the incident

The following sections provide a brief description of plant, systems and equipment relevant to the incident.

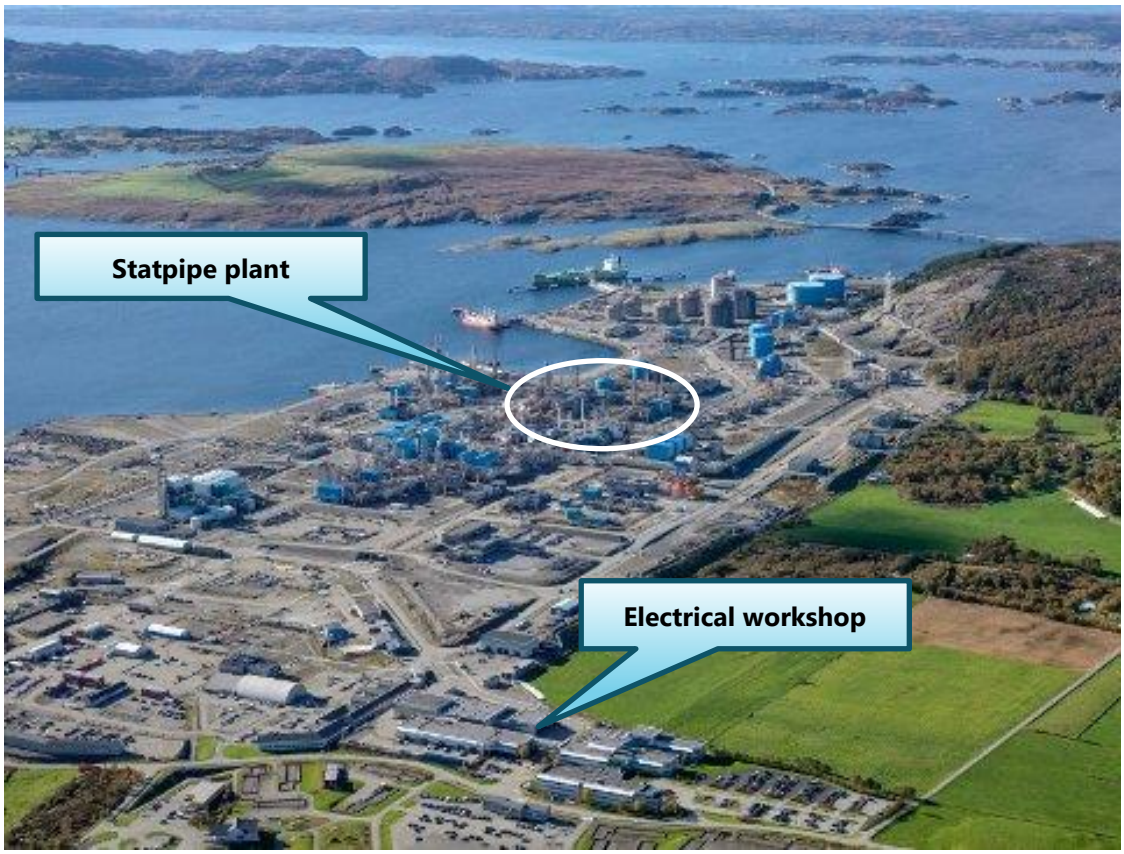


Figure 9 Aerial view of the Kårstø process plant. *Source: Gassco*

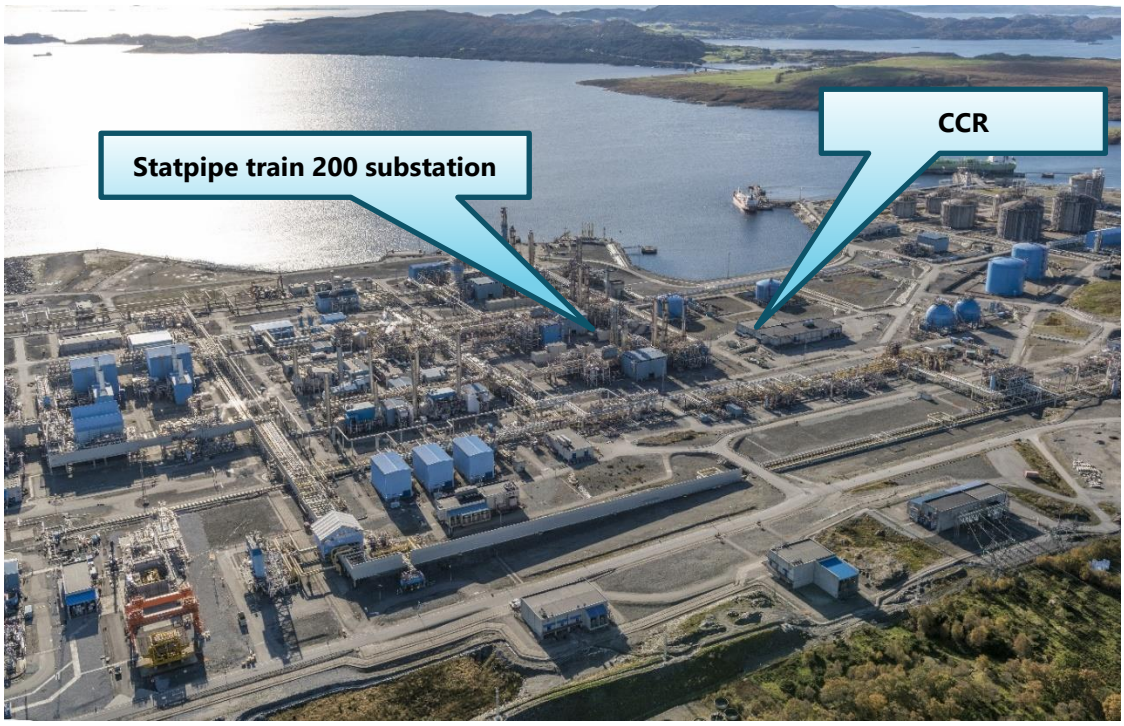


Figure 10 Aerial view of part of the Kårstø process plant. *Source: Gassco*

6.1.1 Statpipe process train T200 and substation T200

Statpipe T200 is one of two process trains installed and put into service in 1984-85 when the Statfjord field in the North Sea came on stream. It primarily processes and fractionates rich gas from the Statpipe pipeline into sales gas and liquid products.

Substation T200, located on the outer edge of the T200 process train, handles such tasks as transforming voltage (22kV/690V) to distribution switchboards supplying electricity to consumers in the T200 process train.

The substation's location close to an Ex area (zone 2) means that the entrance to the building has an overpressure air lock to prevent intrusion of explosive atmospheres in the event of plant leaks. It is equipped with fire and gas detectors connected to the Kårstø plant's fire and gas detection system, with control and monitoring functions in the CCR.

Figure 11 below shows a simplified single-line diagram with voltage levels and electrical equipment and components relevant to the incident.

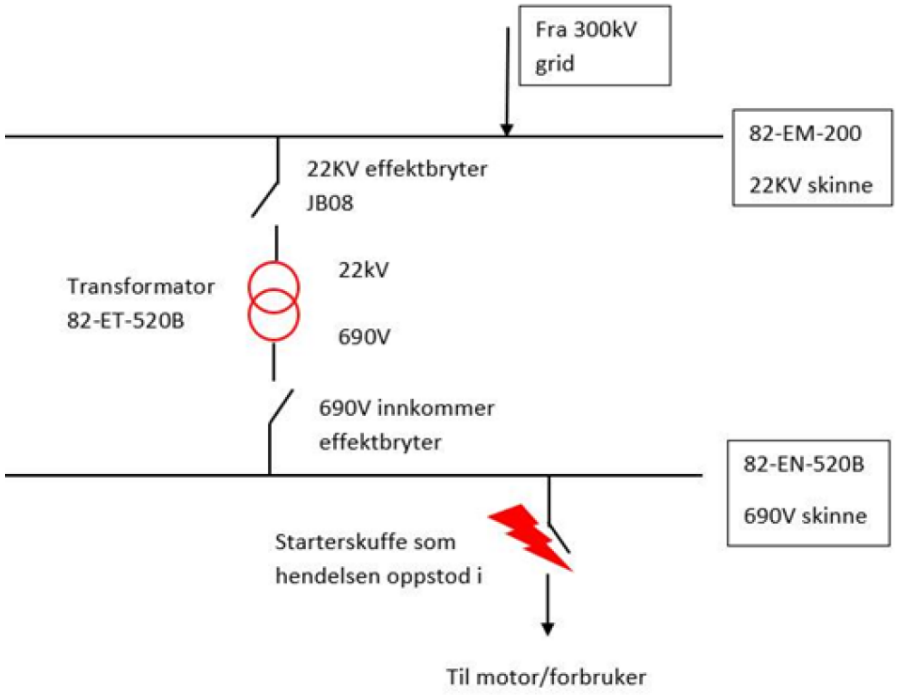


Figure 11 Simplified single-line diagram relevant to the incident. *Source: Equinor*
Key: From 300kV grid; 22kV circuit breaker; 22kV busbar; 690V incomer busbar; Starter drawer where the incident occurred; To motor/consumer

6.1.2 Incomer circuit breaker for 82-EN-520B

To compensate for the high level of incident energy from a fault while operating/ working on the switchboard, jobs to be done before the operation/work began were incorporated in the WO. These involved adjusting down the protection device in the incomer circuit breaker for the relevant switchboard, so that it would trip the circuit breaker faster than normal to limit the incident energy. See figure 7.

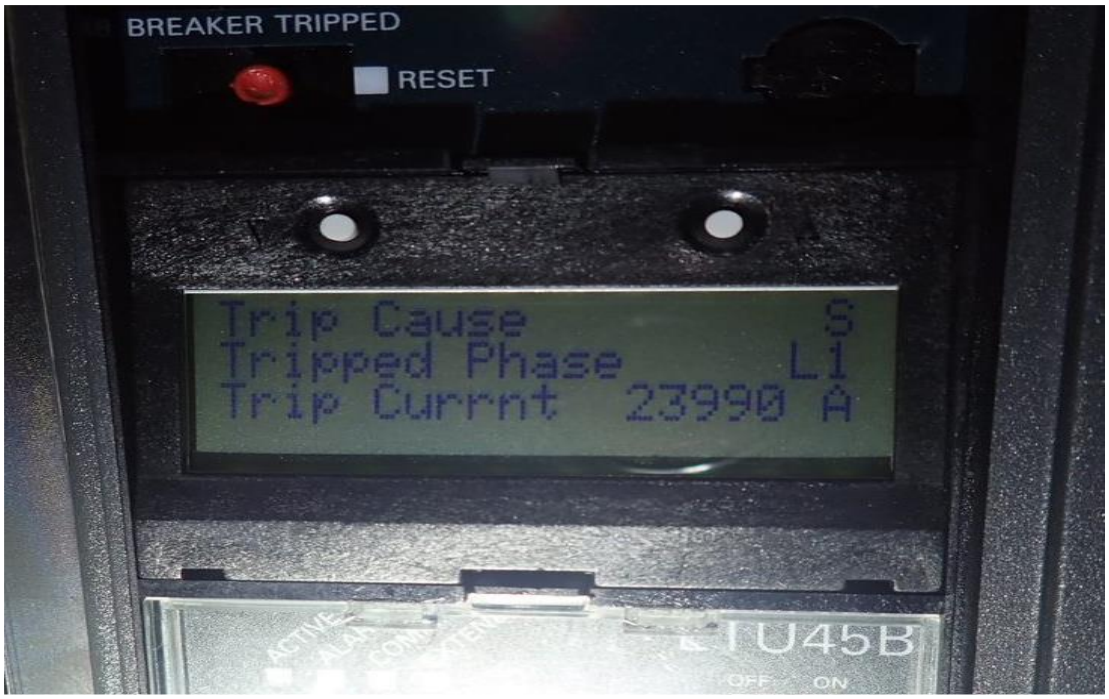


Figure 12 Trip status for incomer circuit breaker. Source: Equinor

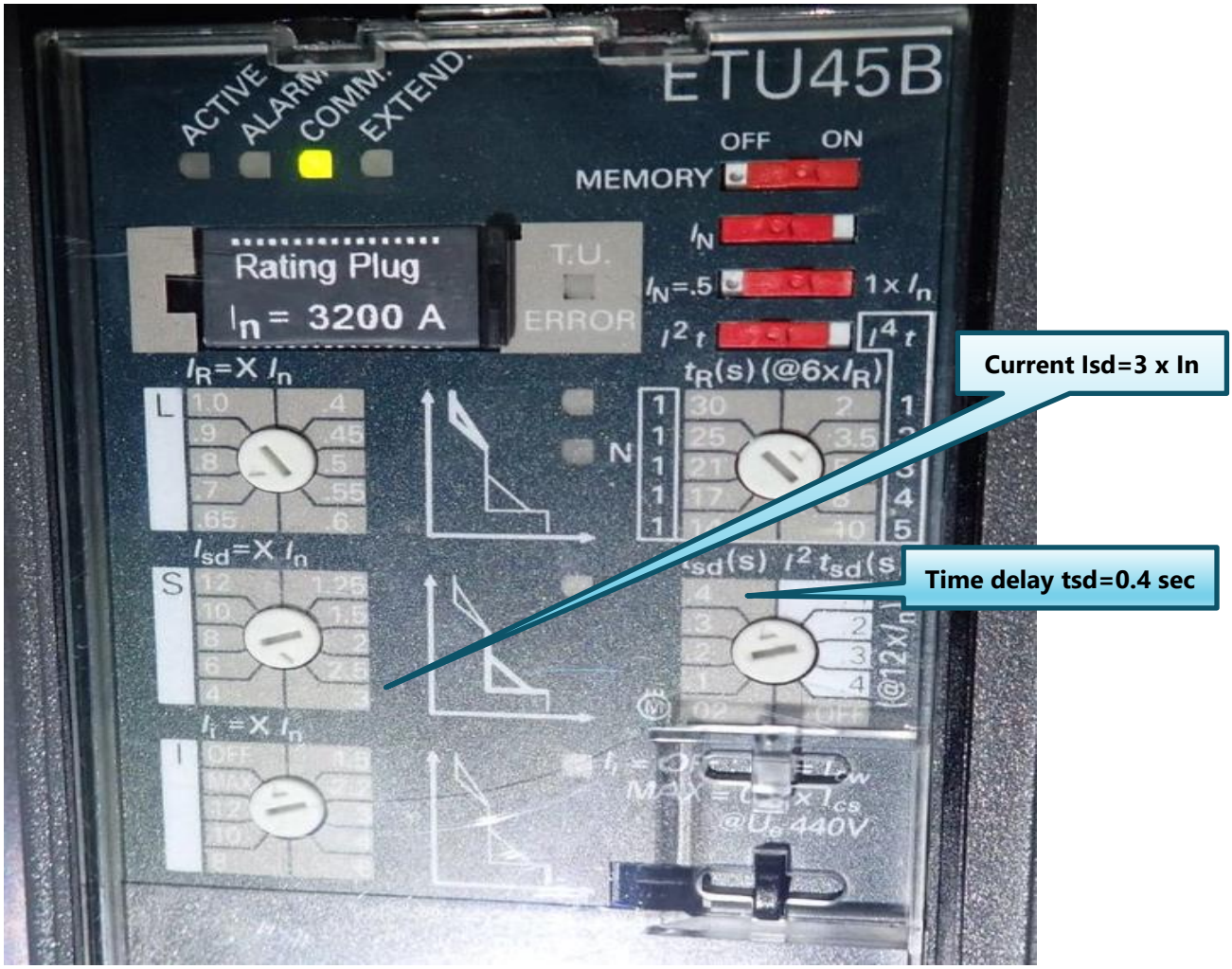


Figure 13 Settings for incomer breaker protection at the time of the incident. Source: Equinor

The set point for the overcurrent value (Isd) which would activate the protection was 3. In other words, if short-circuit current Isd exceeded 3 x 3200A = 9.6kA, the protection device would activate after a delayed trip time (tsd), which was set to 0.4 seconds. See figures 12 and 13.

Pursuant to the WO, trip time was to be adjusted down ahead of operating/working on the switchboard to zero/0.2 seconds in order to reduce the calculated incident energy level from PPE 4 to PPE 2. See figures 7 and 8 on incident energy.

6.1.3 Siemens S404 low-voltage switchboard 82-EN-520 (690V)

The Siemens S404 switchboard 82-EN-520 was installed and put into service during the Statpipe development project in 1984-85. Widespread at the time, this type of low-voltage switchboard was installed in a number of onshore plants and on offshore petroleum facilities.

This Siemens S404 switchboard contains first-generation starter drawers.

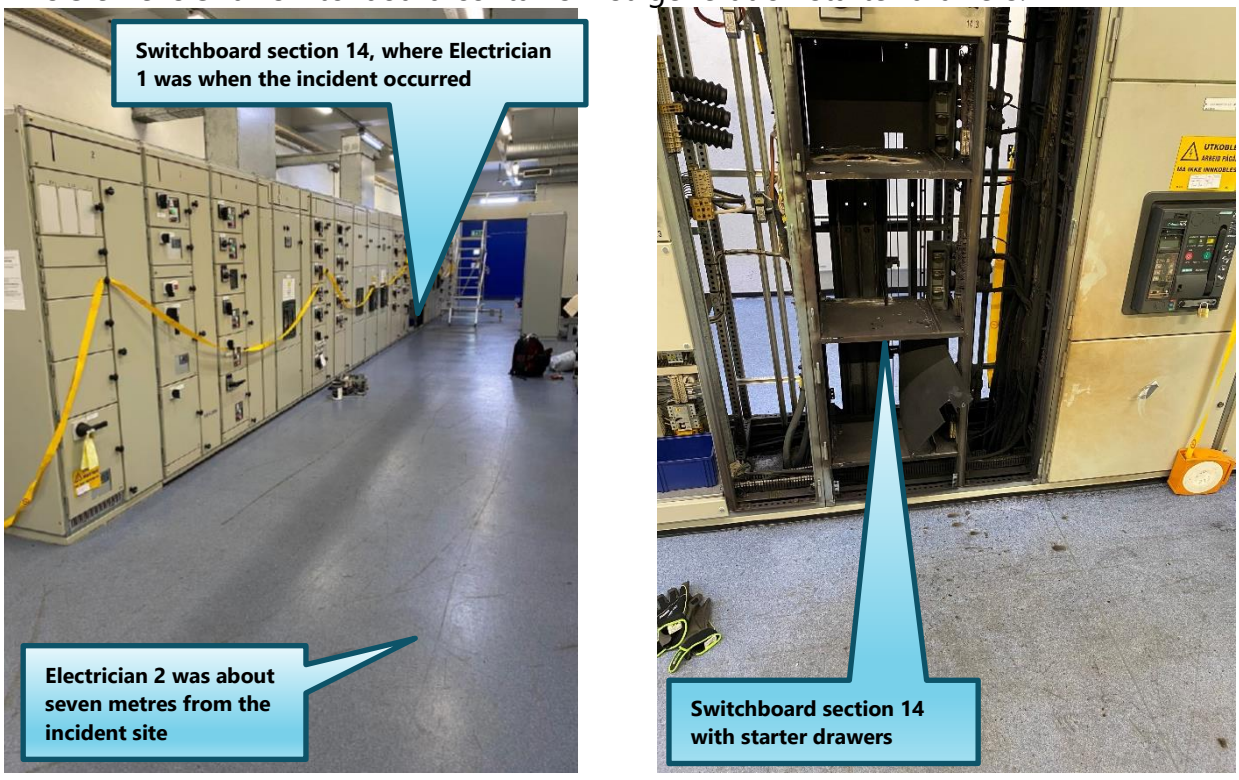


Figure 14 Front of switchboard 82-EN-520B and the switchboard section after the incident. Source: Equinor

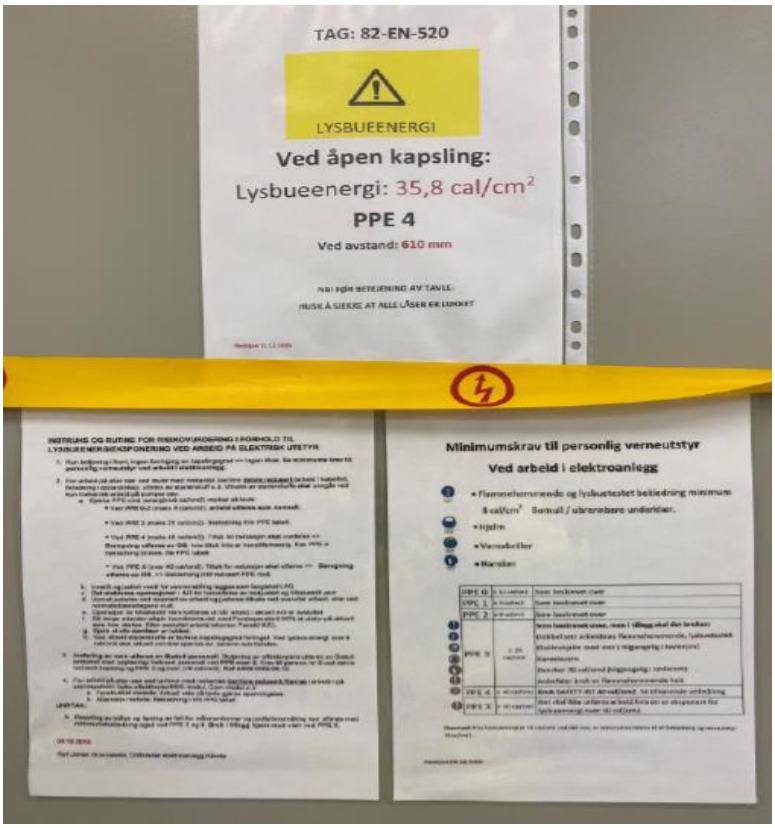


Figure 15 Arc flash information and procedure on the short wall of switchboard 82-EN-520. Source: Equinor

6.1.4 Starter drawers in section 14.5 of switchboard 82-EN-520B

Figures 16 and 17 below show the damaged starter drawer, while clear signs of the three-phase short circuit can be seen in figures 18 and 19 over the fuse elements and on the copper busbars. The neighbouring starter drawers were also heavily exposed and damaged by the short circuits and the incident energy.

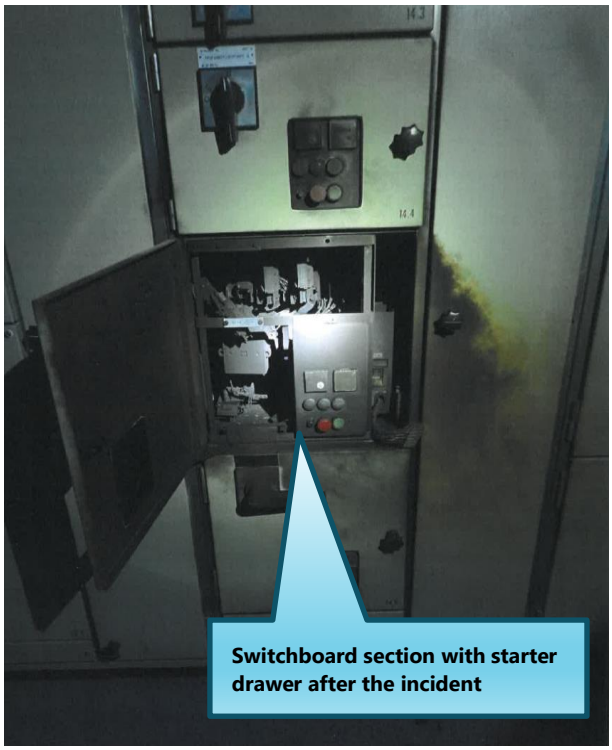


Figure 16 Switchboard section with starter drawers. Source: Equinor

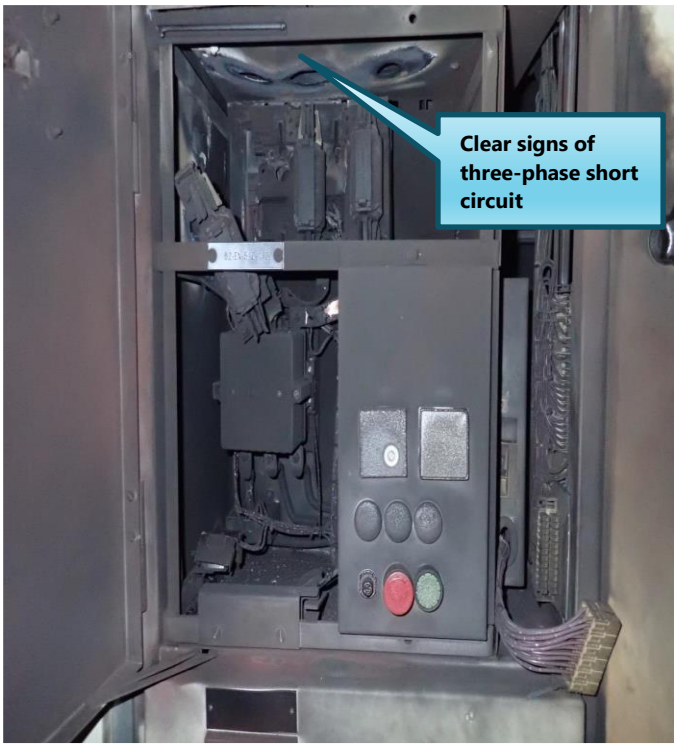
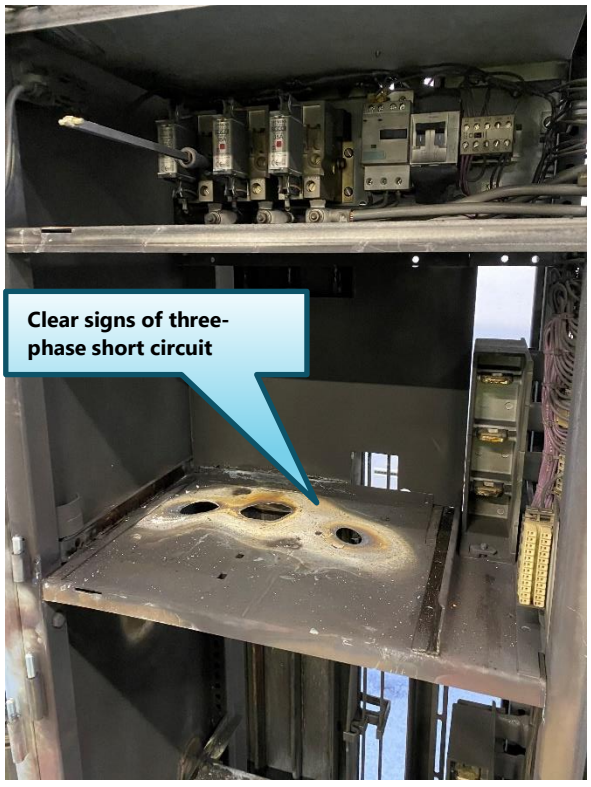


Figure 17 Starter drawer 14.5. Source: Equinor



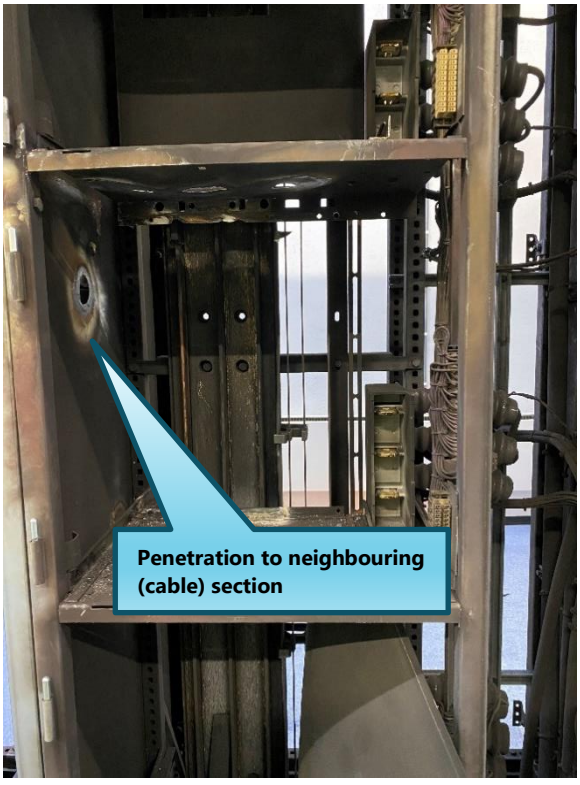


Figure 18 Frames for starter drawers and marks from short circuits. Source: Equinor

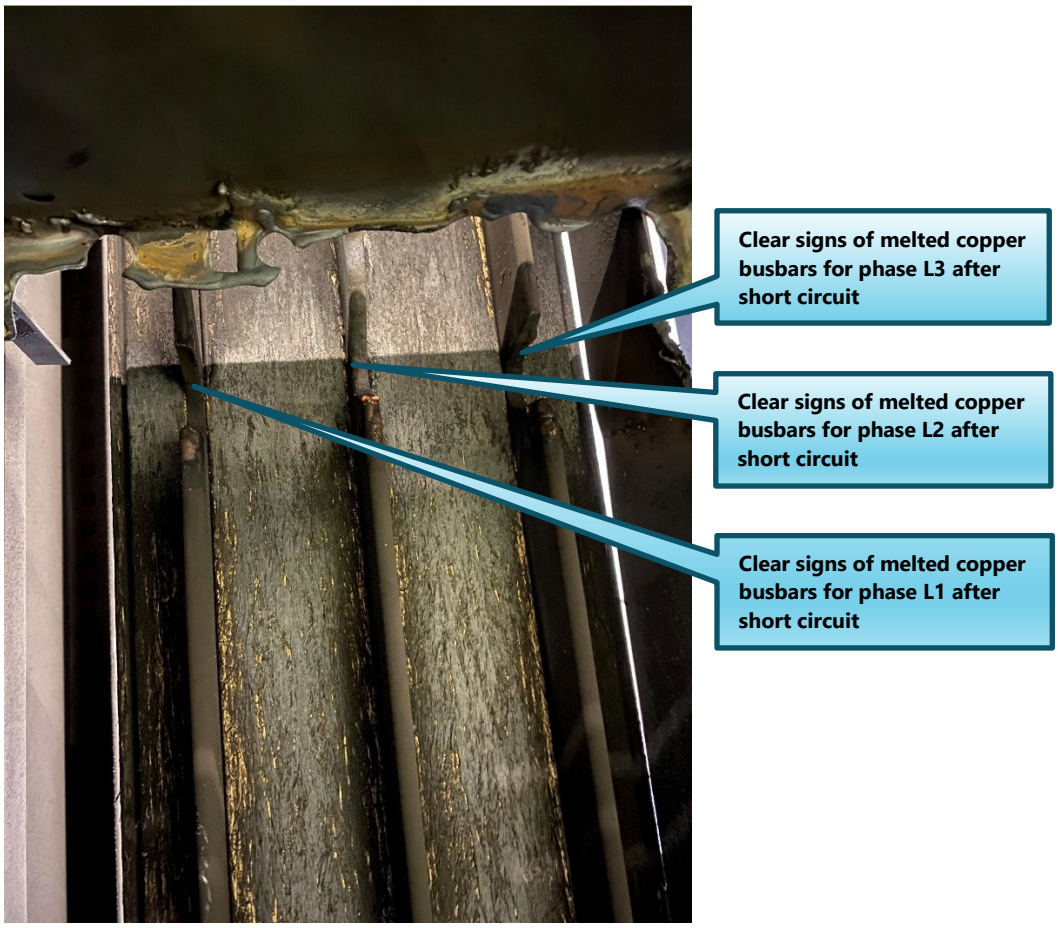


Figure 19 Clear signs left by melting of copper busbars after the short circuits.
Source: Equinor

Figure 19 above shows the switchboard's copper busbars for phases L1, L2 and L3 in the field below the damaged starter drawer. Clear signs of melted busbars as a result of the incident can be seen.

Figure 20 below, left, shows internal details of a disassembled spare circuit breaker with phases L1, L2 and L3, earthed switching rod and extinguishing chamber. Corresponding details from the damaged circuit breaker are shown on the right.

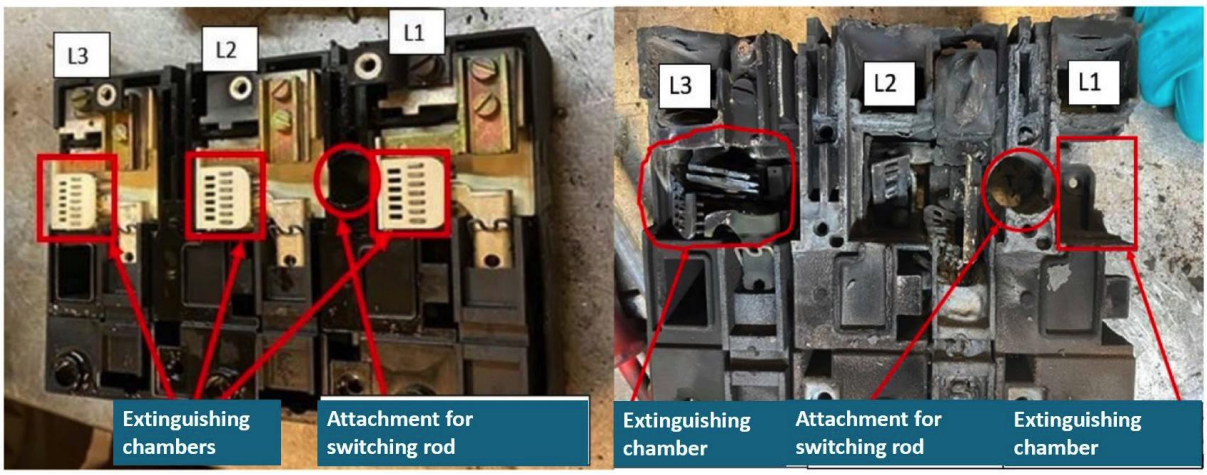


Figure 20 Comparison of disassembled spare breaker and damaged breaker. Source: Equinor

Figure 21 shows further details of the disassembled spare breaker with phase L1, earthed switching rod and extinguishing chamber. This also shows the area where the short circuit and arc flash are assumed to have occurred.

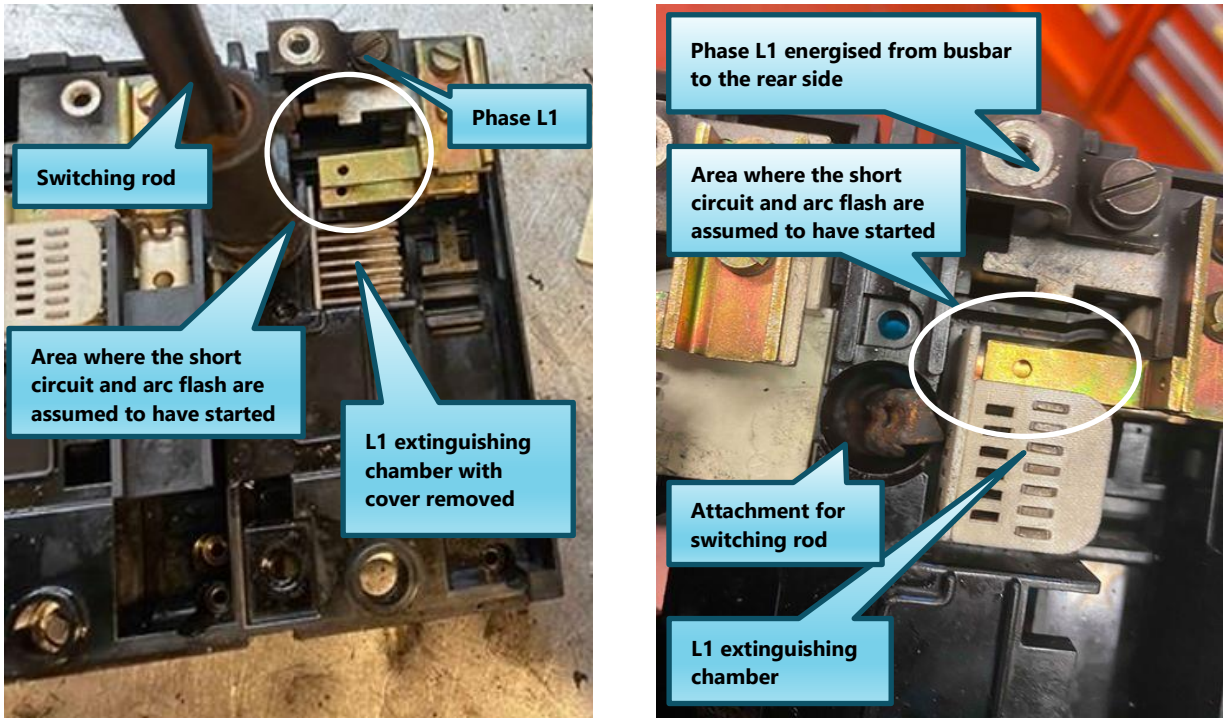


Figure 21 Information from disassembly of spare breaker. Source: Equinor

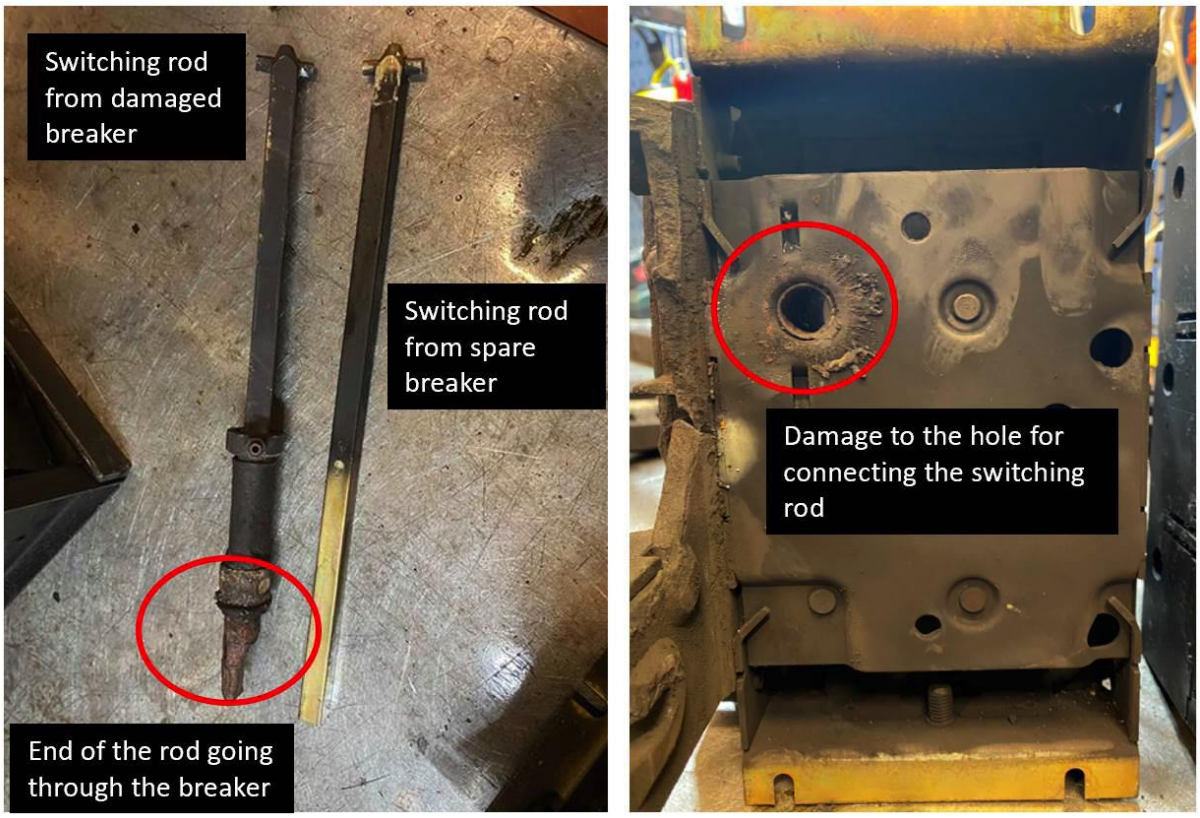


Figure 22 Switching rods and image of the rear of the damaged breaker. *Source: Equinor*

Figure 22 compares the switching rods for the damaged and spare circuit breakers. The one for the damaged breaker shows considerable melting at the end, just where the rod goes through the rear of the breaker. This rod had reportedly come loose and lay on the floor after the incident.

Figure 23 below shows a simple wiring diagram of the starter drawer with circuit breaker, fuses and contactors.

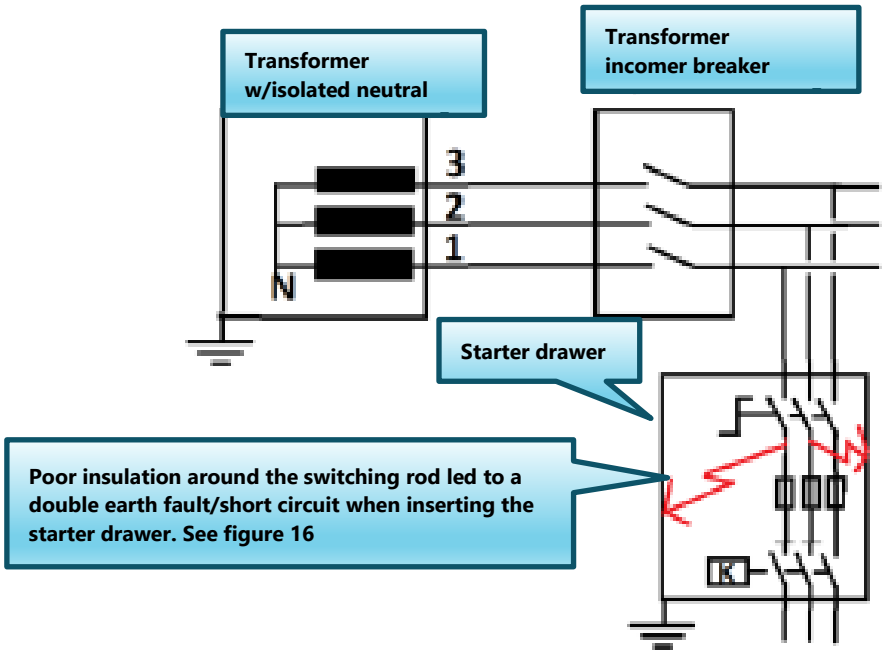


Figure 23 Simple wiring diagram relevant to incident *Source: Equinor*

6.1.5 Siemens test panel for calibrating S404 starter drawers

A dedicated test panel for calibrating the first-generation S404 starter drawers was originally delivered and installed in the Butane substation.

In connection with the Åsgard development in 2000-01, a dedicated test panel was delivered for a newer generation of S404 starter drawers. This was moved to the electrical workshop in 2019.

Later the same year, the panel was modified so that it could calibrate the starter drawers in the Butane and Statpipe substations, since the Butane panel was partly defective. This modified panel proved to be not fully compatible with the first-generation starter drawers. The circuit breaker handles in the test panel doors, for example, did not fit with the switching rod in the Statpipe starter drawers. This meant that the panel doors would not close and that the circuit breaker had to be operated using tools (gripping pliers or wrench).

6.1.6 Refrigerant transfer pump motor 25-PA-201(M)

The starter drawer in section 14.5 which was damaged in the incident supplies refrigerant transfer pump motor 25-PA-201 (M) and is part of system 25 – a closed cooling circuit in the T200 process train with propane as the coolant. The original motor was a Loher eA 315 SC-2 type in Exe design (68 kW, 68A), but this was replaced in the 1990s with a larger Siemens motor type – 1MA6 (EExe), 80kW, 81.6A.

Associated drawings, such as E002-82-EQ-30141, rev A and E002-XX-82-EE-334.04, rev G, received during the investigation were not updated with technical data after

the change to an 80kW motor. The thermal (bimetal) protection (-F4), for example, has the nominal range of 55-80A. Following the incident, Equinor has confirmed that this protection was replaced by a new version (70-100A) matching the motor.

7 Potential of the incident

7.1 Actual consequences

The incident triggered a local alarm in the area, the shutdown of parts of the Kårstø plant and mobilisation of external emergency response resources.

Electrician 1 suffered second-degree burns to face, throat area, hands and knees and was hospitalised for several days. In all probability, they have also inhaled fumes as a result of the arc flash.

Electrician 2 was not physically injured by the incident, but was off sick for a time afterwards.

The Statpipe T-220 process train was shut down for about six days. Equinor has estimated the cost of the material damage and other financial losses, repair of materials and downtime at NOK 7-8 million.

7.2 Potential consequence

The investigation team has assessed the potential consequence of the incident as the loss of a human life. This is based on what could have been the worst-case outcome if the person concerned had inhaled further quantities of toxic smoke and gas generated by the arc flash incident.

This is also based on experience from similar arc flash incidents in other comparable electrical installations. A fatal arc flash accident occurred in 2006 during work on the electrical facilities at Seal Sands in Teesside, UK. The cause of death here was a combination of burns and lung damage from inhaling toxic fumes. Comparable exposure was also present in this incident.

8 Direct and underlying causes

8.1 Direct cause

The direct cause of the incident was a technical fault in the circuit breaker in the starter drawer.

8.2 Underlying causes

The investigation has identified a number of underlying causes of the incident. These are described in more detail in the following sections.

8.2.1 Lack of follow-up/verification of the implementation of measures following the 2016 order

It emerged during the investigation that follow-up by Gassco and Equinor of measures introduced as a result of the 2016 order has been deficient. Neither company could demonstrate that their formal response to this order, with its associated nonconformities, included measures or actions to follow up and evaluate the effect of the measures taken. Nor has Equinor's systematic supervision of electrical safety ensured that work on electrical installations accords with procedures.

Although the 2016 order was issued to both Equinor and Gassco, it emerged from the latter's handling of nonconformities that no dedicated measures were adopted to follow up the order. Gassco's follow-up has been based on dialogue with Equinor and onward transmission of information to the PSA. In all, the handling of the order by the companies has been deficient. The PSA team was also informed that Gassco's own internal control in 2019 identified that its tools and systematic methods for following up nonconformities had been deficient. As a result, the company initiated corrective measures.

It was found in 2019 that Gassco had not acquired necessary electrotechnical expertise. The company's follow-up of electrical installations on facilities and at plants it operates had also been deficient. On that basis, the PSA ordered Gassco in 2019 to ensure that it had access at all times to the necessary electrotechnical expertise related to electrical installations. The company sees the relationship between the order with associated nonconformities issued in connection with the 2019 audit and the inadequate follow-up of the 2016 order. As a result, Gassco was planning further follow-up of its plants in the future. This covered audits of electrical installations and safety at several plants in 2020. Such an audit was planned at Kårstø that spring.

The PSA team takes the view that the planned audit of the Kårstø plant was staffed with relevant electrotechnical expertise and could potentially have identified relevant underlying causes of this incident. However, the Covid-19 pandemic meant this audit could not be conducted as planned, and it was postponed until the autumn of 2020. Given these factors, the team takes the view that Gassco lacked the necessary follow-up of electrical installations at the Kårstø plant in relation to the order from 2016 until the incident occurred. At the same time, the team notes that the 2019 order prompted the company to establish a follow-up which ensures greater compliance with the regulations.

8.2.2 Inadequate planning and execution of the work

The investigation has identified inadequate planning and execution of the work. This shows signs of a failure to acquire the necessary information on the equipment and plant, and that risk assessments ahead of the work were deficient. Risk assessments were reportedly carried out when establishing the WP and outside the substation when the WP was activated.

Activating the WP involved the area operator and only one of the executing electricians. There is no evidence of any risk assessment involving both electricians in the work team. The area operator who took part in the risk assessment lacked electrotechnical expertise. On the other hand, the risk assessment made was directed at technical process conditions rather than electrical safety. Nothing has emerged to show that the work team conducted its own risk assessment for electrical safety before starting the job.

Such a risk assessment is intended to ensure, for example, that an AFA is appointed, a suitable working method has been chosen, safety measures are identified (such as adjusting the protection device down and ensuring necessary PPE), and relevant procedures have been reviewed. The procedure posted on the short wall of the distribution switchboard was not reviewed before the job. See figure 15. Necessary information on such aspects as potential incident energy was not acquired or assessed. Nor was the work team aware that the test panel was not fully compatible with the relevant starter drawers.

No unambiguous division of responsibilities when doing the work had been ensured. The AFA role was not established pursuant to the FSE or internal company requirements and procedures. Nor was it clarified during the work who was to establish, manage and remove the safety measures. The precaution of adjusting down the incomer circuit breaker's trip time (protection) was forgotten.

Adjusting trip time for protection was described as two work operations in the WO along with a work operation on calibrating starter drawers. These operations are checked as "performed" or "not performed" in SAP once the work is done. No criteria were specified for which value the protection should be adjusted down or up to. The work operation of adjusting protection was not done while executing the job. Another finding by the investigation is that the practice described in the WO was not coordinated with the procedure for ensuring arc flash protection.

Nor was the role of second person practised as assumed in Equinor's governing documents. They are meant to be present in order to intervene or notify should an accident occur. The job was not organised in that way, but rather so that the second person served as an additional work resource. In the team's view, failure to practise

this role had limited significance for the incident and its outcome. The person who was not exposed during the incident quickly notified the CCR.

8.2.3 Lack of compliance with the procedure for ensuring safety against arc flashes

Following the 2016 order, the companies implemented instructions and routines for risk assessments in relation to arc flash energy exposure when working on electrical equipment. The investigation found that the person injured lacked adequate PPE at the time of the accident. This was partly because the company's procedure for ensuring arc flash safety was not fully practised at the plant.

A separate practice which deviated from the procedure had become established. This involved electricians adjusting the protection device in the distribution facility to the lowest trip time. The perception has been that, providing this is done, standard PPE for electricians will provide sufficient protection. This is also why the work team did not have PPE which accorded with the distribution facility's PPE level. Adjusting down the protection device was forgotten in this case.

In the team's view, the established practice of adjusting down protection does not represent a robust operational measure for ensuring personal safety. It has a major potential for human error should executing personnel forget to make the adjustment. The procedure accepts protection adjustment as a relevant risk-reduction measure, but also requires executing personnel to conduct a risk assessment with the OS before making the adjustment. Such an assessment would have helped to focus greater attention on establishing the safety measures. Interviews with several executing personnel at the plant have confirmed that cases exist where adjusting the protection device down and back up again has been forgotten.

8.2.4 Inadequate information, training and experience transfer concerning the use of the modified test panel

No evidence has emerged that information, experience transfer or training was given on using the converted Åsgard test panel. Separate instructions existed for testing Åsgard and Butane circuit breaker drawers. When the Åsgard test panel was moved and modified, only its instructions were updated. However, they did not cover calibration of the first-generation drawers in Statpipe.

It emerged that the work team involved in the incident had not participated in earlier testing of Statpipe S404 starter drawers with the converted panel. Nor had it been informed that no instructions existed for testing Statpipe drawers with this panel.

Since neither instructions nor drawings which showed electrical connections were available, the work team used extra time to map the electrical wiring of the control signals between test panel and starter drawer.

This meant the job took longer than planned, and the work team only managed to calibrate one of the four drawers it took to the workshop.

8.2.5 Ageing and assessment of residual lifetime

Ageing as a result of thermal and mechanical stresses during operation and maintenance can cause material fatigue over time, particularly deterioration of plastic.

The starter drawer involved in the incident was one of the first-generation Siemens S404 drawers from 1984-85. It had thereby been in operation for more than 35 years, which exceeds the estimated service life of 25-30 years. Where the first-generation drawers in the Statpipe plant are concerned, this lifetime expired in 2014 (see section 5.18.1.4 of the RLA report for 2014).

In collaboration with Equinor, Gassco has conducted regular RLAs of plant, systems and equipment at Kårstø on the basis of biennial (previously annual) RLA reporting. The investigation has received RLA reports from 2010 to the present.

As noted in section 6.1.5, the Åsgard test panel located in the electrical workshop was modified so that it could also test Butane and Statpipe starter drawers. However, it was not fully compatible with the Statpipe drawers, and tools therefore had to be used to operate the circuit breaker during testing.

Combined with thermal stresses during operation and testing, mechanical stresses resulting from the using tools and from transporting the starter drawers between substation and electrical workshop have probably caused deterioration/material fatigue over time. These effects are regarded as the direct cause of the incident.

8.2.6 Risk assessments

The matrix used by Equinor in its risk assessments has been based on probabilities and consequences related to personal injury, gas leaks, production and cost respectively in a major accident perspective. Assessment of uncertainty is not visualised in this matrix.

Results from these risk assessments provide part of the decision basis for the RLAs.

Results from the latest RLA for the Statpipe plant show that the overall risk was assessed as yellow (medium), despite the integrity status for the electrical distribution systems being assessed as red (warning). One reason for the yellow status could be that the risk of personal injury finds little expression in the assessments, and that uncertainty related to the significance of ageing and deterioration for personal safety was not adequately assessed.

Furthermore, uncertainty related, for example, to the reliability of thermal motor protection, weakened ignition source control and major accident risk in the form of fire/explosion in the process plant was not adequately discussed, understood and expressed in the risk assessments.

According to Gassco, failure to give expression to HSE risk is one reason why it has not given priority to maintenance/replacement.

The result has been that upgrading/increasing the robustness of S404 starter drawers has been postponed and/or cancelled. See also the timeline in appendix A.

8.2.7 Capacity and ability to deliver

During interviews, personnel in Gassco reported that Equinor's capacity was regarded as one of the most important factors when approving the upgrade portfolio. This has meant in many cases that insufficient capacity has been available to implement, for example, upgrading projects where the overall risk is classified as yellow.

Combined with inadequate risk assessments, Equinor's ability to deliver/capacity appears to have been an important reason why maintenance/replacement of S404 switchboards has been postponed over time.

Costs in the industry have been under heavy pressure. That may have influenced the organisation's capacity and ability to deliver.

8.2.8 Other conditions related to the work

Efforts were made when the Covid-19 pandemic broke out to prevent the possible spread of infection among personnel in the maintenance department at Kårstø.

Maintenance personnel normally worked daytime hours. To help control infection, Equinor wanted to split this department into three groups – day, evening, off – in order to segregate and free up personnel in the event of a possible disease outbreak at the plant. The working time schedule adopted meant that personnel were on days in week 1, with Saturday and Sunday off, then worked in week 2 from 14.45-23.00 on Monday-Thursday, had Friday off, and worked from 06.45-19.00 on Saturday and Sunday. They were then off work in week 3.

Table 3 – Overview of working time arrangement

	Mandag	Tirsdag	Onsdag	Torsdag	Fredag	Lørdag	Søndag	Timer
uke 1	0645 - 1500	0645 - 1500	0645 - 1500	0645 - 1500	0645 - 1500	Fri	Fri	41,25
uke 2	1445 - 2300	1445 - 2300	1445 - 2300	1445 - 2300	Fri	0645 - 1900	0645 - 1900	57,5
uke 3	Fri	Fri	Fri	Fri	Fri	Fri	Fri	0
								98,75

Gj.snitt pr uke: 32,9

The incident occurred on Saturday when the work team had been working for almost 12 hours. According to Norway's National Institute for Occupational Health (Stami),[4] a number of studies have found that accident risk increases when a work session lasts beyond eight hours (Dembe et al 2005, Dong 2005, Weaver et al 2015). Research has also shown that the risk of sleepiness in the last part of a shift increases with daily overtime working/long working days (Son et al 2008).

The job to be done was regarded as routine. It became clear along the way that the work team would not manage to test all four starter drawers because of the testing challenges encountered. See section 8.2.4.

A long working day/week, combined with delays to the job and a desire to finish, could have contributed to the work team failure to establish the necessary safety measures. It emerged from interviews that the team did not feel it was under pressure of work.

9 Emergency response

How emergency response was handled in connection with this incident is not part of the investigation team's mandate, and has therefore not been reviewed and assessed in this report.

10 Observations

The PSA's observations fall generally into two categories.

- Nonconformities: this category embraces observations where the PSA has identified breaches of the regulations.
- Improvement points: these relate to observations where deficiencies are seen, but insufficient information is available to establish a breach of the regulations.

10.1 Nonconformities

10.1.1 Management and control

Nonconformity
Management at operator Gassco and TSP Equinor had failed to ensure that risk management for electrical installations covered the activities, resources, processes and organisation required to secure prudent operation and continuous improvement.

[4] Stami report no 1 (2014), ISSN no 1502 0932.

Grounds
Upgrading the switchboard installation had been postponed beyond the equipment's service life, without the associated risk being adequately assessed and handled. Reference is also made to following conditions which support the nonconformity:

a) lack of follow-up/verification concerning implementation of measures after the 2016 order (see section 8.2.1)
b) inadequate planning and execution of the work (see section 8.2.2)
c) failure to comply with procedures for ensuring arc flash safety (see section 8.2.3)
d) inadequate information, training and experience transfer on use of the modified test panel (see section 8.2.4.)
e) risk associated with mechanical stress combined with deterioration of the plant over time was inadequately assessed or handled (see section 8.2.5)
f) inadequate risk assessments (see section 8.2.6)
g) indications that Equinor lacked sufficient capacity and ability to deliver (see section 8.2.7.)

Requirements
Section 6 of the management regulations on management of health, safety and the environment
Section 21 of the management regulations on follow-up
Section 22 of the management regulations on handling of nonconformities

10.1.2 Work on and operation of electrical installations

Nonconformity
Gassco and Equinor have failed to ensure that the measures introduced under the 2016 order have been followed up and practised in such a way that personal safety is ensured when working on and operating electrical installations.

Their implementation of necessary measures to avoid hazards and accidents related to working on and operating electrical installations has been deficient. They have not ensured that procedures for securing arc flash safety have been formulated and utilised in a way which fulfils their intended function.

Grounds
Reviewing the incident and inspecting the accident site revealed deficiencies which support the view that a systematic approach to securing personal safety relevant to the job in question and similar work was absent.

a) Following the 2016 order, the companies implemented instructions and routines for risk assessment in relation to arc flash energy exposure when working on electrical equipment. Where work on equipment classified as PPE

4 is concerned, the procedure requires that risk reduction measures are assessed and that the calculations must be made by the OS. Executing personnel reportedly ceased to contact the OS over such work in late 2018/early 2019. A practice was also established where executing personnel at the plant adjusted protection down when doing relevant work without contacting the OS. This practice has not been updated in the company's management system, nor was there any marking on the distribution facility about how far the protection should be adjusted down. In the team's view, moreover, the practice is a poor operational measure, with a big potential for human error. Conversations with executing personnel at the plant have confirmed that it has been forgotten at times, so that the protection was not adjusted. This indicates that systematic breaches of the company's procedures have existed over a long period without being picked up. The companies have thereby failed to ensure that measures introduced after the 2016 order are followed up and practised so that personal safety is secured when working on and operating electrical facilities. See also nonconformity 10.1.6 on handling of nonconformities.

b) PPE tailored to the plant's potential arc flash energy was not used with the relevant operating parameters at the time of the incident. Marking on the distribution facility required PPE 4 unless risk-reducing measures were taken.

c) Work planning was deficient in that risk assessments were inadequate and the necessary information about the installation was not obtained. The following examples show that no appropriate risk assessment related to electrical safety was carried out before the work started.
   I. A risk assessment was not carried out at the work site. Such evaluations were reportedly done when establishing the WP and when outside the substation while activating the WP. The area operator and only one of the executing electricians took part in the latter. There is no evidence of any risk assessment involving both electricians in the work team.
   II. As part of preparations for the job, the work team applied for a WP which included some risk assessments. These were picked from a list in the WP system, and should have been assessed by the OS pursuant to the WP approval process for electrical installations. There can reportedly be 30-40 WPs per day related to such installations. This comes in addition to the OS role's other duties. It has emerged that the OS lacks the time/capacity to review all these in detail for their risk assessments, and that many evaluations must therefore be superficial.
   III. The conduct of the risk assessment when activating the WP lacked quality. Reportedly, the area operator whose responsibility includes substations has no electrotechnical expertise. The risk assessment made was therefore directed at technical process conditions rather than

electrical safety. No further electrical safety assessments were done before the work started.

IV. No evidence has emerged that the choice of work method was clearly defined when conducting the risk assessment. It is unclear whether the work method was discussed before the job started.

V. No information was obtained or assessment made of the relevant distribution facility when planning the work. The work team did not know, for example, about the PPE level for potential arc flash energy (cal/cm^2) in the distribution facility in connection with possibly adjusting down protection. Nor did it know in advance that the test panel was not fully compatible with the relevant starter drawers.

VI. The procedure for arc flash safety, mentioned under litera a) above, was not assessed/reviewed when planning the work.

d) Inadequate measures to ensure an unambiguous divisions of responsibility for work on low-voltage installations. Authority for planning and responsibility for establishing, leading and discontinuing safety measures at the work site are not clarified. It has been explained that the person who signs the WP has the AFA role. This role had not been clarified or practised for the work done here. Conversations revealed that awareness of the role and its responsibilities were inadequate. The PSA team was also told that it was a matter of chance which member of the work team took responsibility for establishing safety measures, such as adjusting protection. The company's procedures and work processes described the role, but the investigation found that it was not adequately implemented in work done at the plant. Relevant personnel have also noted that greater attention was paid to the AFA role for third-party workers at the plant than when the company's own employees were doing the work.

e) Where the job which was to be done is concerned, Equinor has defined that the work team should have two members. In such work, the second person should be present partly to intervene or notify if an accident occurs. Nevertheless, the job was not organised in that way, but rather with the second person used as an extra work resource. They thereby did not supervise the work and were not equipped with the rescue gear and radio equipment required by Equinor's governing document.

f) The company's systematic supervision of electrical safety has failed to ensure that work is planned in accordance with requirements and procedures. That covers, for example, the use of and compliance with procedures/work routines and the conduct of risk assessments. Nor has internal control ensured that substation checks have been conducted regularly in accordance with internal requirements. See litera h).

g) Inadequate formulation and use of WO. This was not coordinated with the applicable procedure for ensuring arc flash safety. Nor was the job planned and executed in accordance with the WO for this work.

h) During its initial inspection of the accident site on 29 July 2020, the team noted safety equipment in the switchboard room (hard hat with visor) which was past its expiry date. It also observed that gloves in the PPE 4 set had a lower level of protection (32.8 cal/cm^2) than the rest of the gear (40 cal/cm^2). Equinor has earlier introduced a system of appointing a person responsible for substations, who is meant to conduct regular checks of such facilities in their plant area. The team also noted that such checks had only been signed off as conducted once during 2020 in the substation where the incident occurred. Equinor's required them to be carried out monthly.

Requirements
Section 60, paragraph 1 of the technical and operational regulations on work on and operation of electrical installations with guidelines, which refers to sections 6, 7, 10, 12 and 19 of the regulations relating to the operational safety of electrical installations (FES) on organisation, on overall planning, on planning of work, on safety in the workplace and on carrying out maintenance respectively, and to chapter IV of the FES on work methods.
Section 45, paragraph 2 of the technical and operational regulations on procedures
Section 8 of the management regulations on internal requirements

10.1.3 Risk and residual lifetime assessments

Nonconformity
Deficiencies existed in risk and RLAs, which are individually and collectively intended to provide the necessary decision basis for safeguarding HSE.

Grounds
Uncertainty related to the link between ageing problems and risk was not adequately assessed and expressed (see section 8.2.6).

a) The matrix used by Equinor in its risk assessments has been based on probabilities and consequences related to personal injury, gas leaks, production and cost respectively in a major accident perspective. Assessment of uncertainty does not find expression in this matrix.

b) It emerged from the RLAs that the S404 switchboards in the Statpipe plant have been highlighted as a concern at least as far back as 2010. Results from the latest RLA for the Statpipe plant show that the overall risk was assessed as yellow (medium), despite the integrity status for the electrical distribution system being assessed as red (warning). One reason for the yellow status could

be that the risk of personal injury is little expressed in the assessments, and that uncertainty related to the significance of ageing and deterioration for personal safety was not adequately assessed (see sections 8.2.5 and 8.2.6, and appendix A).

c) Furthermore, uncertainty related, for example, to the reliability of thermal motor protection, weakened ignition source control and major accident risk in the form of fire/explosion in the process plant was not adequately discussed, understood and expressed in the risk assessments.

d) It emerged from interviews that the electrical discipline at the Kårstø plant has had the S404 switchboards at the top of its list of high-risk equipment. This found little expression in the risk assessments used to reach decisions on postponing replacements/upgrades.

Requirements
Section 11 of the framework regulations on risk reduction principles
Section 16 of the management regulations on general requirements for analysis, see section 17, paragraph 2 of the management regulations on risk analyses and emergency preparedness assessments
Section 11, paragraphs 1 and 3 of the management regulations on the basis for making decisions and decision criteria

10.1.4 Information

Nonconformity
Equinor had failed to identify the information required to plan and execute testing of starter drawers in the modified test panel. It was not certain that the necessary information had been obtained, processed and communicated to relevant users ahead of the work.

Grounds
No evidence has emerged that information or training was provided on the use of the converted Åsgard test panel. Separate instructions existed for testing Åsgard and Butane circuit breaker drawers. When the Åsgard test panel was moved and modified, only its instructions were updated. However, they did not cover calibration of the first-generation drawers in Statpipe.

It emerged that the work team involved in the incident had not previously tested Statpipe S404 starter drawers with the converted panel, nor were they informed that no instructions existed for testing Statpipe drawers with this panel. The work team was also unaware that the panel was not compatible with the relevant drawers.

Since no instructions or drawings existed which showed electrical connections, the work team had to work this out on the job. It devoted a lot of time to checking and connecting control signals between test panel and starter drawer.

The circuit breaker handles in the test panel doors did not fit the switching rod in the Statpipe starter drawers. This meant that the panel doors could not be closed and the circuit breaker had to be operated using gripping pliers or a wrench. No information was obtained, processed and communicated to the work team on the potential risk associated with mechanical damage from using tools to operate a circuit breaker, for example, combined with ageing and deterioration of plastic materials.

Requirements
Section 15 of the management regulations on information
Section 40, litera c, of the technical and operational regulations on the start-up and operation of onshore facilities

10.1.5 Technical operating documents

Nonconformity
Inadequate updating of technical operating documents after modifications.

Grounds
The following conditions provide examples which illustrate the nonconformity.

a) Instructions for calibrating protection and other relevant technical operating documents were not updated in connection with the modification of the Åsgard test panel. Separate instructions were available for testing Åsgard and Butane starter drawers, but not for Statpipe drawers.
b) A review of the technical operating documents for the starter drawer for refrigerant transfer pump motor 25-PA-201 (M) in field 14.5, which was destroyed in the incident, found that drawings E002-82-EQ-30141, rev A and E002-XX-82-EE-334.04, rev G had not been updated with technical data after the change to an 80 kW motor. See also section 6.1.5.

Requirement
Section 40, litera c, of the technical and operational regulations on the start-up and operation of onshore facilities

10.1.6 Handling of nonconformities

Nonconformity
Inadequate follow-up of nonconformities covered by the 2016 order to take measures to protect personal safety when working on and operating electrical installations.

Grounds
A review of nonconformity handling by the companies and interviews found that no activities were conducted to evaluate the effect of measures. There was thereby no verification of compliance with the measures or whether they had the desired effect.

It was also found that Gassco's handling of nonconformities did not involve measures or actions on its part. The PSA team was told that internal control by Gassco in 2019 had identified that its tools and systematics for handling nonconformities were deficient. As a result, the company had initiated a number of actions to improve its practice and compliance with the regulations. This work was under way during the investigation.

Requirement
Section 22 of the management regulations on handling of nonconformities

11 Barriers which have functioned

The following barrier functions/elements have functioned as intended:

- emergency shutdown function for the Statpipe process plant
- trip function for protection on the incomer circuit breaker, even though the time delay had not been adjusted down during the work operation
- electrical disconnection function for the T200 substation from the CCR
- smoke detection in the T200 substation activated the alarm and confirmed fire to the CCR.

12 Discussion of uncertainties

Current measurements in the plant during the incident indicate that a minimum of three short circuits occurred. See chapter 5. Inspection of the incident site and witness statements suggest the possibility that the second short circuit could have created an electric current path (earth fault) through Electrician 1's left hand.

It is unlikely that Electrician 1 was exposed to the whole incident energy which arose (around 70 cal/cm^2). When a short circuit of this kind occurs, the incident energy will spread in different directions to achieve the fastest possible discharge.

Nevertheless, Electrician 1 is assumed to have been exposed to a large part of the incident energy which arose. This is because they were positioned with direct exposure to the short-circuit site without major obstacles between themselves and the fault location. The injuries suffered by Electrician 1 also bear that out. Actual personal exposure to the incident energy cannot be determined for this type of incident, so some uncertainty exists about the degree of such exposure.

13 Assessment of the player's investigation report

Equinor investigated the incident with participation from Gassco, and its investigation report was submitted to the PSA on 29 October 2020. This describes and illustrates the actual course of events and both technical and operational causes in a thorough and comprehensible manner.

Equinor's investigation team classified the incident as severity level Red 2 – serious lost-time incident/serious personal injury. Material damage and other financial loss is estimated at NOK 7-8 million and is classified in accordance with Equinor's system as severity level Green 4.

The PSA team has assessed the potential consequence of the incident to be the loss of one human life. This is based in particular on the worst case in terms of burn injuries combined with inhalation of toxic smoke and gas liberated by arc flash incidents.

Equinor's investigation has not managed to determine the direct cause of the incident. But witness statements and technical investigations suggest that technical failure in the circuit breaker is highly likely, probably because of mechanical stresses combined with ageing/material fatigue. That also accords with the PSA's conclusions.

The most important underlying causes named in Equinor's report are:

- misunderstanding of requirements and consequent errors in the local training programme, procedures and signage concerning the use of PPE to protect against arc flash
- inadequate follow-up related to whether procedures are being observed/have an effect, both at Kårstø locally and by Equinor centrally
- risks associated with operating time and the ageing issue with equipment, and for personal injury, have been underappreciated.

The most important learning points in the report concerned understanding of:

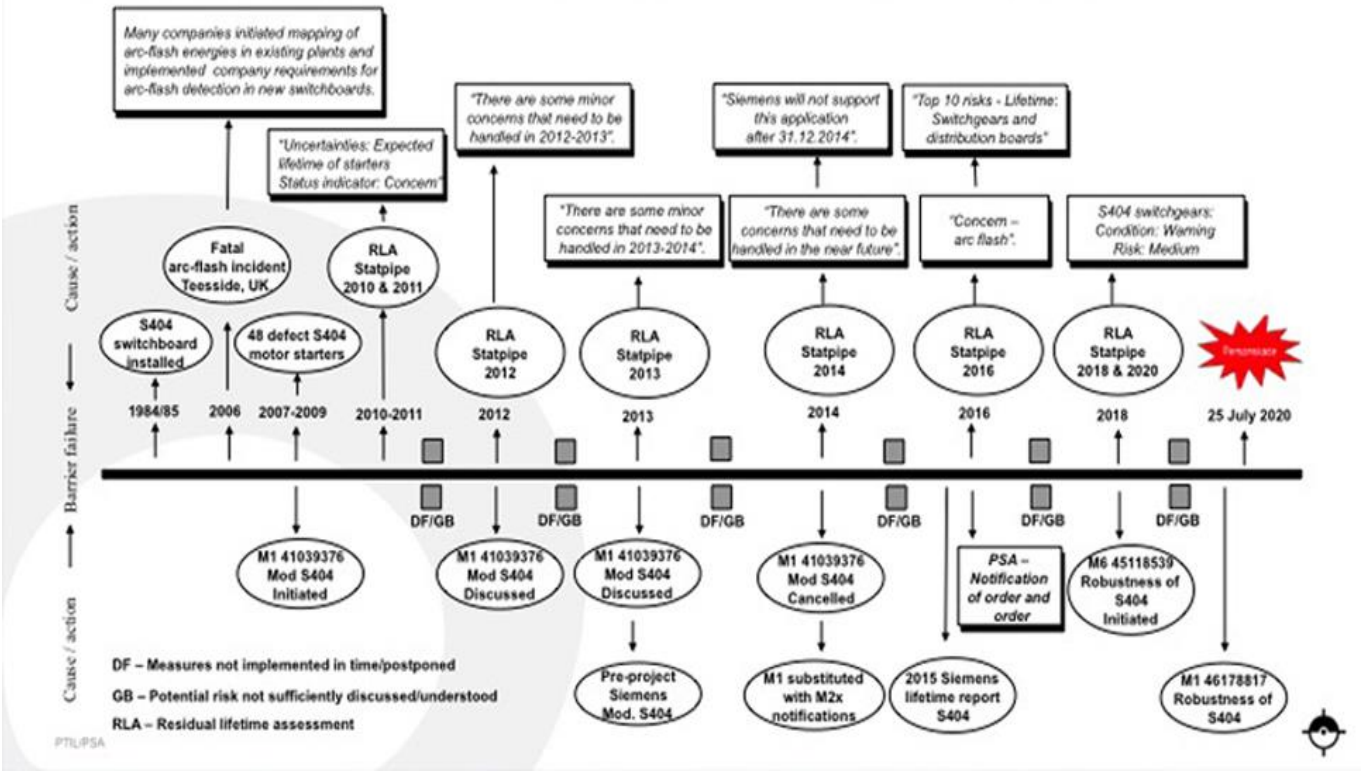
- requirements related to the need to use PPE against arc flash
- personal risk related to arc flash risk and possible ageing problems for equipment
- following up that new procedures are observed and have the desired effect.

In the PSA's view, observations and conclusions in Equinor's investigation report largely coincide with those in this report, but do not shed the same amount of light on key underlying causes related to overall management and control, follow-up of the 2016 order, capacity for/ability to deliver upgrading/modifications and Gassco's follow-up.

14 Appendices

A. Timeline for lifetime assessments and upgrade/ robustness of Siemens S404 switchboard
B. Instructions and routines for risk assessment related to arc flash exposure when working on electrical equipment
C. Safety alerts
D. Documents utilised in the investigation (separate document)
E. Overview of personnel interviewed (separate document)

Appendix A – Timeline for lifetime assessments and upgrade/robustness of Siemens S404 switchboard



Appendix B – Instructions and routines for risk assessment related to arc flash exposure when working on electrical equipment

INSTRUKS OG RUTINE FOR RISIKOVURDERING I FORHOLD TIL LYSBUEENERGIEKSPONERING VED ARBEID PÅ ELEKTRISK UTSTYR

1. Kun betjening i front, ingen forringing av kapslingsgrad => Ingen tiltak, **Se minimums krav til personlig verneutstyr ved arbeid i elektroanlegg.**

2. For arbeid på eller nær ved tavler med mekanisk barriere **delvis redusert** (arbeid i kabelfelt, feilsøking i apparatskap, uttrekk av starterskuff o.l). Uttrekk av starterskuffe **skal** unngås ved kun mekanisk arbeid på pumper osv.
   a. Sjekke PPE-nivå (energinivå cal/cm2) merket på tavle.
      - Ved **PPE 0-2** (maks 8 cal/cm2): **arbeid utføres som normalt.**
      - Ved **PPE 3** (maks 25 cal/cm2): Bekledning ihht PPE tabell.
      - Ved **PPE 4** (maks 40 cal/cm2): Tiltak for reduksjon **skal** vurderes => **Beregning utføres av OS**, hvis tiltak ikke er hensiktsmessig. Kan PPE 4 bekledning brukes. Se PPE tabell.
      - Ved **PPE X** (over 40 cal/cm2): Tiltak for reduksjon **skal** utføres => **Beregning utføres av OS**, => Bekledning ihht redusert PPE nivå.
   b. Innstilt og justert verdi for verninnstilling legges som langtekst i AO
   c. **Det etableres operasjoner i AO** for bekreftelse av nedjustert og tilbakestilt vern
   d. Vernet justeres ved oppstart av arbeid og justeres tilbake ved avsluttet arbeid, eller ved normalarbeidsdagens slutt.
   e. Operasjon for tilbakestilt vern kvitteres ut når arbeid i aktuell AO er avsluttet.
   f. Så lenge arbeider pågår koordineres det med Paneloperatør(HKR) at utstyr på aktuell side ikke startes. Etter avsluttet arbeid informer Panel(HKR).
   g. Sjekk at alle **dørlåser er lukket.**
   h. Ved uttrekt starterskuffe er tavlens kapslingsgrad forringet. Ved lysbue-energi over 8 cal/cm2 skal aktuelt område sperres av, dersom sub forlates.

3. **Justering av vern utføres av Statoil personell**. Betjening av effektbrytere utføres av Statoil personell med opplæring/ instruert personell ved **PPE over 2**. Krav **til person nr 2** ved delvis redusert kapsling og PPE 3 og over (>8 cal/cm2). **Ref ARIS OM2.05.12**.

4. For arbeid på eller nær ved tavlene med mekanisk **barriere redusert /fjernet** (arbeid i på skinnepakker, bytte effektbryter/BSS-modul, Com-modul o.l)
   a. Foretrukket metode; Aktuell side på tavle gjøres spenningsløs
   b. Alternativ metode; Bekledning i hht PPE tabell.

UNNTAK:

5. Resetting av blålys og åpning av felt for måleromformer og jordfeilovervåking kan utføres med minimumsbekledning også ved PPE 3 og 4. **Bruk i tillegg hjelm med visir ved PPE X.**

02.12.2016

Operations leader electrical installations Kårstø

Appendix C – Safety alerts

Safety alert

Sted:	Kårstø	Tittel:	Lysbue i T-200 substasjon medførte alvorlig personskade	Dato:	25.07.2020

equinor

Konsekvenser:	Faktisk:	Potensiell
Personskade	2	2
Synergi nr.: 1623679		

Beskrivelse av hendelse

Arbeidslag på 2 personer utførte planlagt vedlikehold på 690 V starteskuffer i substasjon i T-200.
Det oppsto lysbue ved innsetting av starterskuffe i garasje i driftsposisjon.
1 person i arbeidslaget ble eksponert for lysbue.
Hendelsen har ført til en personskade måtte behandles gjennom innleggelse på sykehus med sykehusopphold av flere dagers varighet for å behandle brannskader.

Årsaker og barrierer

Årsak til at det oppstod kortslutning og lysbue er foreløpig ikke kjent.
Feilen ble utkoblet av forankoblet vern.

Tiltak og lærdom

Umiddelbare tiltak:

Kårstø har midlertidig stoppet tilsvarende arbeider på spenningsatte tavler av typen Siemens S404.
Det anbefales at andre anlegg med denne type tavler i påvente av resultater fra granskingen vurderer begrenset aktivitet og arbeid som krever åpning av kapsling til startere/brytere.

Ved nødvendig arbeid/betjening som krever at kapsling åpnes, benyttes verneutstyr for lysbue i henhold til lysbueenergi-nivå for tavla. Det bør være to personer tilstede.

Prosess for å innlede gransking iverksettes mot COA/MMP SSU CC.

Equinor's safety alert no 1 ***Source: Equinor***

Safety Alert, Flere hendelser med kortslutning og påfølgende lysbue

Beskrivelse av hendelse

Det har i løpet av de siste 4 ukene vært 2 alvorlige hendelser med kortslutning og påfølgende lysbue, med personskader i begge tilfellene. Kårstø, 25.07.2020 synergi 1623679 Statfjord B, 18.08.2020 synergi 1625866
Det er derfor et behov for økt fokus på å følge styrende dokumentasjon, med tanke på bruk av personlig verneutstyr for lysbue.
Ref ARIS
- OM105.12.02 R-102183 og OM105.12.07 R-21836
- OM205.12.02 R-109247 og OM205.12.07 R-107520

Årsaker og barrierer

Riktig bruk av personlig verneutstyr for lysbue vil redusere sannsynlighet for personskade dersom det oppstår utstyrsfeil og havari ved betjening av brytere og starterskuffer. Mer informasjon om hendelsene kan finnes i synergien for de enkelte hendelsene.

Tiltak og lærdom

Umiddelbare tiltak:

Sikre etterlevelse av krav i ARIS iht OMX05.12.02 og OMX05.12..07

Minimum bruke personlig verneutstyr mot lysbue ved arbeid på/betjening av brytere med åpen kapsling i tavler med lysbue energi nivå fra PPE 1 (1,2 cal/cm2) og høyere.

Det må være spesiell fokus på merking av lysbueenergi for tavler og å benytte personlig verneutstyr for lysbue iht aktuelle lysbueenerginivå i tavlen. Merking av aktuell lysbue energi nivå for tavler skal være tilgjengelig i aktuelt tavlerom

NB! For tavler med vern i innkommer bryter kan lysbue-energinivå være mye høyere foran og i bryter enn for resten av tavlen (etter bryter)

Når granskingene er fullført, vil det bli sendt ut link til rapportene, slik at alle kan lese tiltak som må iverksettes eller etableres.

R-109247/R-102183
Verneutstyr ved betjening av brytere med åpen kapsling

Benytt egnet verneutstyr ved betjening av uttrekkbare brytere i tavle med åpen dør/kapsling. Normalt er dette:
- Hjelm elektro
- Visir elektro
- Hørselvern (bør også benyttes ved lokal betjening av effektbrytere med lukket kapsling)
- Hansker for beskyttelse mot lysbue
- Bekledning, for elektro personell

Bilde på siden inneholder følgende verneutstyr som bør benyttes fra
PPE 3 fra Wenaas :
- El Pakke MSA Prem Hjelm/Visir STK
- Hørselvern MSA High Hjelm 14
- Glove Dehncare APG
- Gore-Tex Jakke Arctic pro

Utarbeidet av fagnettverket på elektro.
Ved behov for avklaringer, kontakt:
Lennart Jardstål lelle@equinor.com, 90774064
Roy Eystein Murberg rmur@equinor.com, 99160512
Arne Nossum anos@equinor.com, 48034595

Equinor's safety alert no 2 ***Source: Equinor***