national gas transmission

NGT_AH2_03 St Fergus HV Transformers

Engineering Justification Paper

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Version control

Version/revision number	Date of issue	Notes
1.0	30 h June 2023	Submission to Ofgem
1.1	29 H September 2023	Detail of the three bundled scopes included in project scope and costs updated to reflect change in material costs. See section 7. Preferred Option Scope, cost, and Project Plan. Additional Survey report included. See Appendix B – [redacted] report. Changes compared to the EJP submitted in June 2023 are highlighted in yellow.
1.2		
1.3		
1.4		
2.0		
2.1		
3.0		

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1. Executive summary

1. National Gas Transmission, (hereafter referred to as 'NGT'), are submitting the needs case and funding request in accordance with the RIIO-T2 Engineering Justification Paper (EJP) Guidance v2 document. The purpose of this stage of the process is to justify the project need, set out the different options considered along with the preferred strategic options, and request funding for the preferred option justified within this paper.

2. This Engineering Justification Paper (EJP) details the investment for the replacement of six defected and non-compliant High Voltage (HV) transformers at the St Fergus Gas Terminal.

3. This is part of a suite of documents, shown in Figure 1, and should particularly be read in conjunction with the St Fergus Site Strategy and its appendices. The St Fergus Site Strategy describes the gas terminal's function, its criticality to the network and the proposed investments in line with the site strategy.

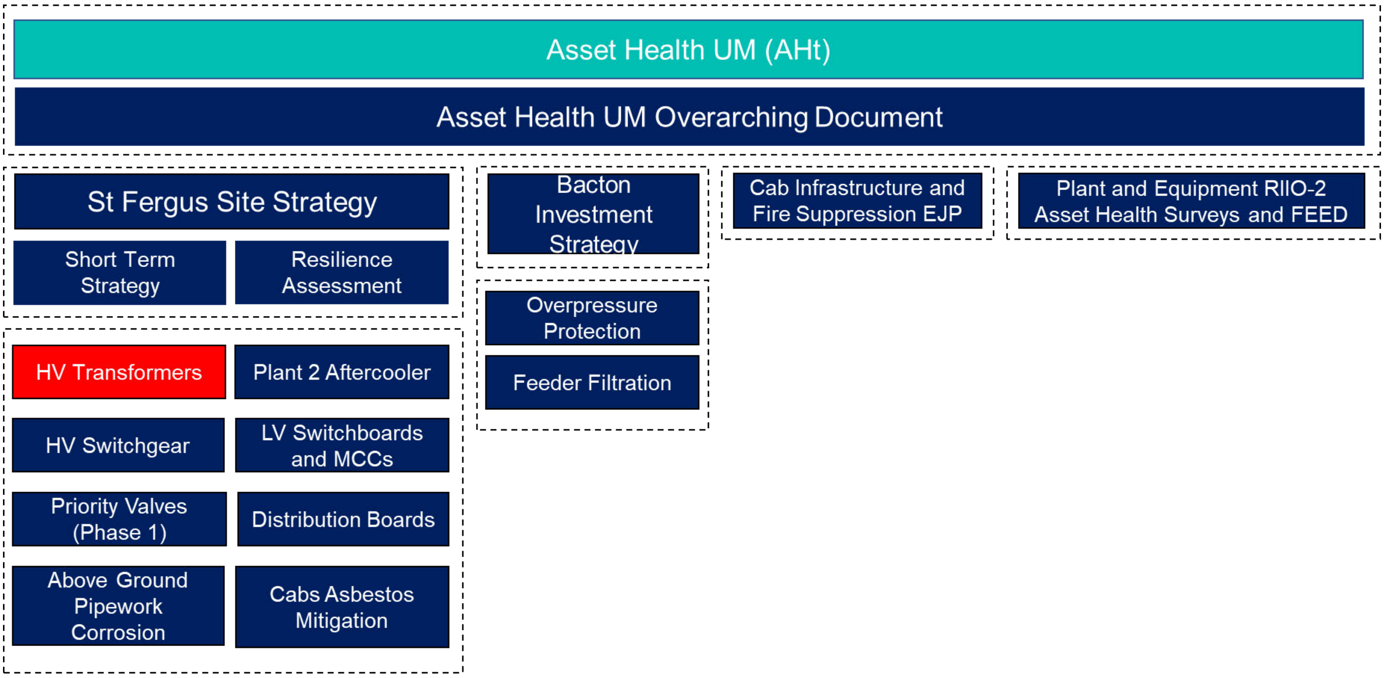

Figure 1: St Fergus Submission Documents Structure

1. The St Fergus Gas Terminal handles between 25% and 50% of the UK's gas supplies, dependent on supply and demand patterns. The site has been in continuous operation for over 45 years and is now moving beyond the design life of the critical original assets. The site is one of two upper tier COMAH sites on our network and as such is a major accident hazard site, subject to regular HSE and SEPA inspections and significant health, safety, and environmental legislation.

4. The high voltage transformers on the site step down the electrical supply from the Scottish and Southern Electricity Network (SSEN) Substation. This takes 11kV down to a 3-phase 415V supply suitable for the Terminal.

5. Six of the eight transformers which serve the Main Terminal Building (MTB), Plant 1 and 2 were installed when the site was commissioned in 1977. The remaining two were installed in 2008 as part of the works for the Plant 3 Variable Speed Drive (VSD) compressors.

6. The legacy transformers, installed as part of the original construction, are currently operating past their useful design life and site inspections on the assets have reported multiple condition related defects and risks associated with their continual operation.

7. Three of the six legacy transformers (one on each area) have had to be electrically isolated as they suffered from oil leakage caused by severe corrosion of the tanks. This has left each area currently running on its back-up option and therefore more reliant on the use of a standby generator for back up should any of the transformers fail.

8. Reliance on standby generation as back up presents a significant risk to the operation and resilience of the site as they are not designed to run for long durations and could result in a potential outage of the terminal should they fail.

9. The legacy transformers also do not conform to current industrial standards and regulations on electrical equipment which poses various safety, operational and environmental risks.

10. The St Fergus Short-Term Strategy confirms the requirement for investing in the six transformers at the site for it to remain operational until 2030. This is because three of six transformers are currently out of service due to condition related defects such as corrosion and the remaining three in service are also in poor condition and in need of replacement. The need for immediate intervention on these assets is further supported by asset condition surveys carried out by a contractor.

11. Failure of the remaining transformers could result in either of the affected plants relying on standby generation for prolonged durations which would break environmental permits and compromise the site's resilience.

12. The RIIO-T2 business plan included all asset health works associated with Plant 1 and Plant 2 under the Compressor Emissions Re-opener as the uncertainty about the future solution affected all those assets. NGT is submitting this investment proposal in the June 2023 asset health submission window as funding is needed immediately to ensure safe and continued operation of the site in the short-term out to 2030.

13. The options considered for the transformers are:
    - Refurbishment
    - Replacement

14. The above options were assessed against a wide range of criteria and the replacement of all six transformers was deemed to be the most efficient solution that delivers the best value to both NGT and consumers.

15. The indicative cost of this investment is [redacted] (18/19 price base). The estimated RIIO-T2 cost profile is shown in the Table 1. This project is at Stage 4.2 in the ND500 process: Option Selection. Therefore, the cost accuracy is estimated at +30/-15% in accordance with the Infrastructure and Projects Authority (IPA) cost estimating guidance.

Table 1 Current estimated RIIO-T2 spend profile

£m 18/19	FY2023	FY2024	FY2025	FY2026	Total	Comments
HV transformers replacement	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	

16. NGT are making this funding application for the HV transformer replacement Programme RIIO-T2 investment costs through the Asset Health Re-opener, in line with Special Condition 3.14, requesting an adjustment to the value of the NARMAHOt term for costs incurred in RIIO-T2.
17. This is summarised, along with other investments, in the Asset Health Overarching Document provided as NGT_AH2_03 of the June 2023 Asset Health Re-opener Submission.

2. Introduction

18. This paper provides the justification for the replacement of six High Voltage transformers at the St Fergus Gas Terminal.

19. In developing our investment programmes at the St Fergus Gas Terminal since the RIIO-T2 Final Determinations, we have adopted a two-phase strategy to ensure clarity between short-term asset health and long-term site operating strategy.

20. Our St Fergus Short-Term Strategy provides certainty on the terminal operation requirements, including minimum compression across Plant 1 and 2, for operation out to 2030. The long-term strategy will deliver the enduring terminal solution, including compression, required for operation beyond 2030.

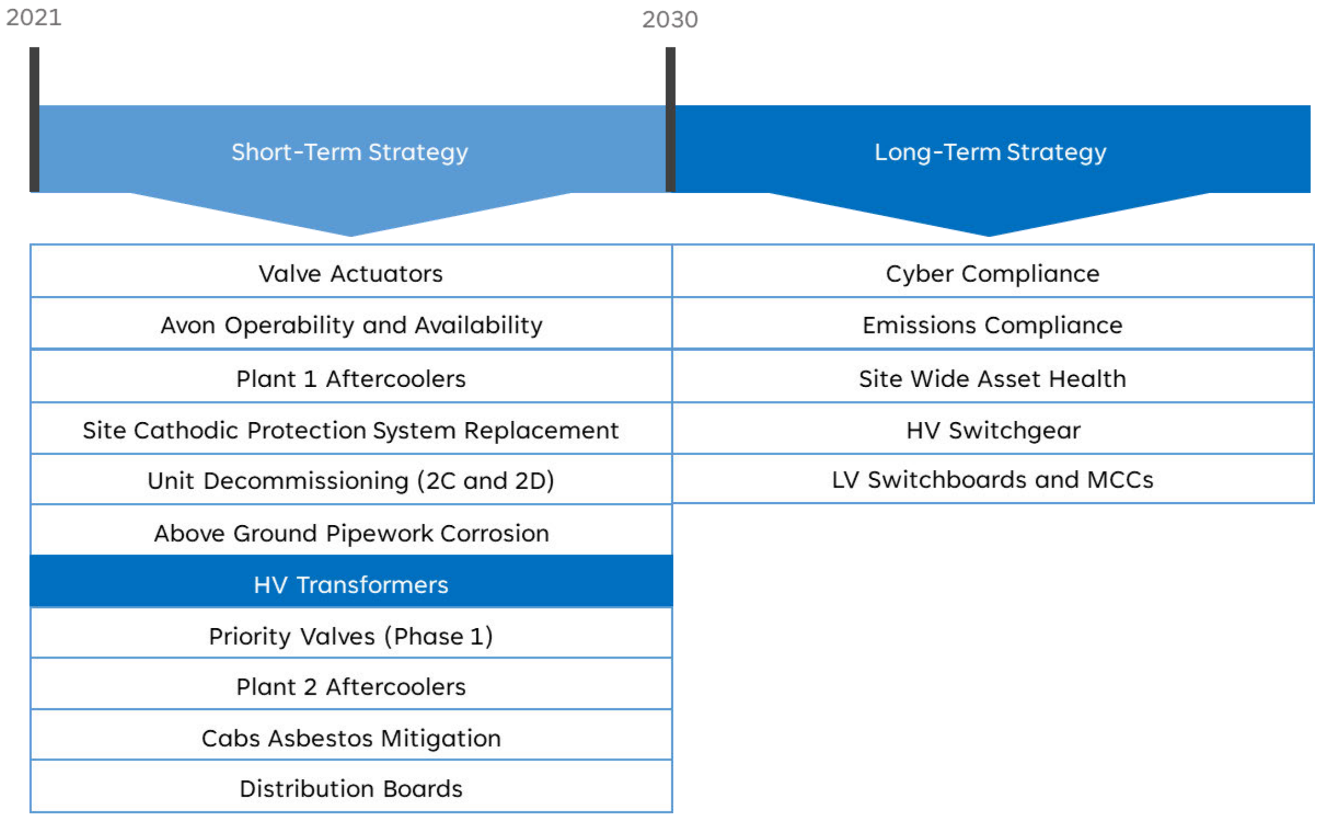

Figure 2 St Fergus Site Strategies Summary

21. The St Fergus Short-Term Strategy supports the decision to rationalise the compression units across Plant 1 and 2 to four Avon units (1A, 1B, 1D and 2B) and maintain these in operation to at least 2030. That recommendation is fundamental to the proposals in this paper; therefore, it is important that these two documents are considered in parallel.

22. The investment outlined in this justification paper concerns transformers which are used to provide low voltage supply (415V) by stepping down high voltage (11kV) supplied from the nearby Scottish and Southern Electricity Network (SSEN) Substation.

[redacted]

Figure 3 Site layout

23. As shown in Figure 3, the terminal is electrically dived into four main areas which are:

- Main terminal building (MTB)
- Plant 1 – shown in green
- Plant 2 – shown in yellow
- Plant 3 – shown in red

24. Six of the eight transformers serve the MTB, Plant 1 and Plant 2. These were installed when the site was built in 1977. These areas are equipped with two transformers that can handle the full load of the area and provide back up in case of a failure.

25. The remaining two were installed in 2008 as part of the works for the Plant 3 Variable Speed Drive (VSD) compressors. Plant 3 is equipped with one transformer for each of the two compressors.

26. The legacy transformers are currently operating past their useful design life (25 years) and site inspections on the assets have reported multiple condition related defects and risks associated with their continual operation.

27. Three of the six legacy transformers (one on each area) have had to be electrically isolated as they suffered from oil leakage caused by severe corrosion of the tanks.

28. This has left each area currently running on its back-up option and therefore more reliant on the use of a standby generator for back up should any of the transformers fail.

29. The Plant 1 and 2 gas turbine standby generator units are original from 1977 (these will be included for investment in a future submission) with aged and obsolete components. The MTB diesel standby generator was installed in 1995, has recently had the acoustic enclosure replaced but is otherwise original.

30. Historical data shows that the standby generator has been used for an average of 30 hours per year. The equipment is not designed to run for long durations and its historic low utilisation and age makes it highly susceptible to failure if required to run for long durations as its performance under such conditions is unknown.

31. Therefore, it is not sustainable to rely on standby generation should a transformer fail as this will most likely result in a total plant outage in the extended period until a new transformer could be specified, ordered and installed.

32. As mentioned later in the document, running a standby generator (which utilises fuel gas) for extended periods may also breach the United Kingdom Emissions Trading Scheme (UKETS) permit.

33. The legacy transformers also do not conform to current industrial standards and regulations on electrical equipment which poses various safety, operational and environmental risks.

34. Not investing on the transformers would significantly impact the site's resilience and increase the risk to security of supply as there is an increased risk of a plant outage should the terminal rely on standby generation for long durations.

35. This document seeks to highlight the needs case for investment together with the benefits associated with the replacement of the transformers which supports the site's short-term strategy.

3. Equipment Summary

36. The main power supplies for the National Gas St Fergus Gas Terminal originate from a Scottish and Southern Electricity Network (SSEN) Substation located within the National Gas terminal perimeter fence line.

37. The SSEN Substation is supplied by two 132kV/11kV transformers connected to the overhead lines and contains 11kV switchgear. This interfaces with National Gas Transmission (NGT) 11kV electrical switchgear with Oil Circuit Breakers (OCBs) and Vacuum Circuit Breakers (VCBs).

38. Developments by SSEN, for the relocation of their Substation which is currently within the NGT Site and is the same age as NGT's switchboard, are in progress. The new SSEN Substation will be located to the west of the St Fergus site outside the site perimeter.

39. SSEN will install a modern Substation and switchgear to meet with the latest standards and HSE Regulations. The present SSEN General Electric Company (GEC) OCB switchgear is obsolete and does not meet with modern switchgear standards and HSE requirements.

40. The two 11kV supplies (Feeder 1 and 2) from SSEN to the NGT Substation are routed separately from each other and terminate at Panel A7 and A9 on the NGT Substation 11kV Switchboard as shown in Figure 4.

HV transformers primary distribution

41. From the 11kV Switchboard A, the outgoing power is directed via feeder OCBs and VCBs to 11kV/415V transformers for onward Low Voltage (LV) distribution at 415V to LV switchboards and Motor Control Centres (MCCs) in the Main Terminal Building (MTB) area, Plant 1 switch room, Plant Area 2 switch room and Plant 3 switch rooms.

42. This document covers the integrity of the six 11kV/415V transformers highlighted in Figure 4 (see drawing 6011/03/01/03/0033). Unit 3A and 3B transformers were installed in 2008 and do not require intervention at this time.

[redacted]

Figure 4 HV Single line diagram extract from 6011/03/01/03/0033 (see Appendix D – Single line diagrams for full drawing)

Table 2 Equipment summary

Description	MTB	Plant 1	Plant 2	Plant 3
Tag number	BGC/T1 and BGC/T2	P1/T1 and P1/T2	P2/T1 and P2/T2	3201A-TF2 and 3201B-TF2
Manufacturer	Bonar Long and Co Ltd	Bonar Long and Co Ltd	Bonar Long and Co Ltd	Transformers and rectifiers
Rating	800kVA, 11kV/415V	1250kVA, 11kV/415V	1250kVA, 11kV/415V	630kVA, 11kV/415V
Installation date	1977	1977	1977	2008
No. of equipment	2	2	2	2
Condition	T1 isolated, T2 is in service but badly corroded	T1 isolated and oil drained down from tank, T2 is in service but badly corroded	T1 isolated, T2 is in service but badly corroded	Both operating and in good condition

43. Currently the terminal is reliant on three of the six transformers, one on each plant. The T1 transformers on each plant have been isolated because of severe corrosion which has led to leakage of the oil from the transformers. The remaining transformers in service are badly corroded and require replacement (see Appendix J – Transformers maintenance reports).

HV transformers secondary distribution

MTB 800kVA Transformers LV secondary

[redacted]

Figure 5 BG sub-LV distribution extract from 6011/03/01/03/0036 (see Appendix D – Single line diagrams for full drawing)

44. The main switchboard is located in the south side of the BGC LV switch room. It contains 13 panels, 6 on one side and 7 on the other plus the 2 incomer and bus section Air Circuit Breakers (ACB).

45. The switch board is energised from T1 or T2 respectively via Incomer ACB to the Left-Hand Side (LHS) of the board. The incomers are equipped with Castel Key interlocking so that only one ACB is closed at any time. The bus section circuit breaker is normally closed and the Standby Generator is connected to the Right-Hand Side (RHS) of the board .

46. The switchboard incorporates two undervoltage relays connected to the transformer side of the ACBs and on failure of the mains supply will open the ACB, start the Standby Generator, close the generator ACB and supply power to the switchboard.

47. In addition to the Castell Key locking, there is electrical interlocking between each of the three incomers which prevents inadvertent paralleling of transformers and generator supplies.

48. The original design philosophy is that if a transformer is removed for overhaul or replacement there will still be one unit remaining along with the Standby Generator to provide any LV power distribution. This is not the case at this time due to BGC/T1 being isolated.

Plant 1 and 2, 1250 kVA transformers

[redacted]

Figure 6 Plant 1 LV distribution extract from 6011/03/01/03/0034 (see Appendix D – Single line diagrams for full drawing)

49. The switch boards for Plant 1 and 2 are energised from T1 or T2 respectively via Incomer ACB to the Left-Hand Side (LHS) of the board. The incomers are equipped with Castel Key interlocking so that only one ACB is closed at any time. The bus section circuit breaker is normally closed and the Standby Generator is connected to the Right-Hand Side (RHS) of the board .

50. The switchboard incorporates two undervoltage relays connected to the transformer side of the ACBs and on failure of the mains supply will open the ACB, start the Standby Generator, close the generator ACB and supply power to the switchboard.

51. In addition to the Castell Key locking, there is electrical interlocking between each of the three incomers which prevents inadvertent paralleling of transformers and generator supplies

52. If a transformer is removed for overhaul or replacement, there will still be one unit remaining along with the Standby Generator to provide power distribution. This is not the case at this time due to P1/T1 and P2/T1 being isolated.

53. To enhance the provision of Standby Power to either board as required, there is also a crossover power link between the two RHS sections of the Plant 1 and Plant 2 boards so that Standby Power can be provided to both boards by either Stand-by Generator should the other generator be unavailable (**see** Appendix E – Change sequence).

4. Problem Statement

54. The St. Fergus transformers are more than 45 years old and have been exhibiting an increased number of defects throughout their operation. The current defects operational risk assessment and maintenance (ORAM) score of the asset is at 16 out of 25, where the main hazard is the loss of oil containment leading to transformer failure. (See Appendix K – HV transformer risk score)

55. The key drivers for investment are:

56. Asset deterioration:

    - Multiple corrosion defects have been identified on the transformer tanks and cooling fins. This results in major oil leakages which leads to overheating of the transformers and poses a safety risk in its operation and to the environment.
    - Deterioration and heavy corrosion of connecting power which could result in short circuits which would trip the transformer.
    - This would result in the plant being supported by standby generation. See **Appendix G - Dangerous incident notification** where corrosion was the root cause of failure on a similarly aged transformer.

57. Compliance:

    - When the transformers were installed in 1977, they complied with BS 171-March 1970. However, they do not comply with the latest standards BS EN 60076-2018. The main design issue is the thermal and dynamic ability to withstand short circuits.
    - There is also a requirement to meet with the recent ECODESIGN specifications (2021) which looks at the minimum losses and efficiency associated with the equipment.

58. Reliability and resilience:

- As **all** the transformer units are displaying severe corrosion and leakage there is a high probability of them becoming unavailable. If that happens, standby generation will be required while the units are repaired or replaced which is costly due to the long periods the standby generators are expected to run.
- The existing P1 and P2 standby generators are approaching 50 years old with an average running time of 30 hours per year. At this age and with the limited running history these generators have, they are unlikely to provide reliable running 24/7 for at least 6 months whilst a replacement transformer is sourced.
- The MTB standby generator is almost 30 years old with again limited running so is also unlikely to prove reliable running 24/7.
- Therefore, it is highly likely that a hired standby generator will be temporarily connected to the electrical distribution system with fuel being an ongoing cost. In the event of a failure of multiple transformers then multiple standby generators would be required.

59. This investment aims to:

- achieve the restoration of the terminal's resilience across the compression plant's and thus reduce the risk on security of supply.
- ensure that the installed assets are safe, fit for purpose, secure by design, reliable and maintainable by complying to the latest standards and regulations

60. The impact of not intervening on the transformers is covered later in the document (Consequence of Failure section)

Example of the Problem

61. Site inspections by the [redacted] provided the following condition assessments of the transformers in support of the drivers for investment.

Severe corrosion and leakage

62. Currently BGC/T1, P1/T1 and P2/T1 have been isolated from plant operating service. P1/T1 oil was drained after severe corrosion on the transformer body caused an oil leak in 2020. This transformer was inspected and deemed damaged beyond repair as the internal components of the transformers were also severely corroded.

63. BGC/T1 and P2/T1 were isolated early in 2023 due to corrosion. These have not been drained at this time as they are not leaking but are severely corroded. Provided a transformer is oil filled, repair is still an option as the internal components of the transformer are protected from the environment.

Figure 7 Plant 1 T1 transformer 1 currently isolated

64. All remaining transformers are also in severely bad condition where corrosion and leakage can be identified on the tank and radiator fins. Paintwork on the transformers is very rusty and flaking off as seen in figure 8 and 9.

65. The visual inspection concluded that where the HV cables have been exposed to the environment, the cable insulation sheath is showing deterioration and cable glands were showing corrosion.

Figure 8 Corrosion on the radiator fins and connecting cables

Figure 9 Leaking oil from conservator tank and corrosion

Civil and structural issues

66. The design did not adhere to current National Gas electrical specifications (ref T/SP/EL/50 – section 8.7.4) on containment systems for bulk oil containing equipment which states that:

- All bulk oil containing equipment, including transformers, shall be provided with oil containment facilities capable of capturing and holding the entire oil content in the event of an oil leak, without contaminating the surrounding environment
- The oil containment facilities shall incorporate suitable measures to cope with rainwater accumulation.
- The oil containment bund design shall allow for fire limitation and suppression

67. The drainage system of the current design does not comply with any of the clauses. This creates an environmental risk in the event of a loss of containment resulting in contaminated materials escaping into the environment via the site drainage system.

68. The environmental impact is discussed later in the document (consequence of failure section)

Spend Boundaries

69. This investment covers only the transformers on the terminal and does not include any other low voltage distribution assets.

- Six Auxiliary transformers have been identified for replacement, affected assets include:
- 2 x 800 KVA transformers supplying the main terminal building (MTB / BGC Sub-Station),
- 2 x 1250 KVA transformers supplying Plant 1 Switchboard and
- 2 x 1250 KVA Transformers supplying Plant 2 switchboard.
- Cabling from the HV switchgear to the (Plant 1, Plant 2 and MTB) transformers to the LV switchboard including protection cabling
- Civil and drainage assets associated with the above transformers. This does not impact drainage assets associated within the rest of the site boundary.

70. This does not include the 2 transformers in plant 3.

5. Probability of Failure

71. A transformer can fail from any combination of electric, mechanical, or thermal factors. While it is difficult to define a typical failure mode for transformers due to their complexity, most failures result from the breakdown of the transformer's insulation system.

Table 3 shows industrial data on the main causes of transformer failure (**See**

72. Appendix F – IEEE Gold book).

Table 3 Failure initiating causes for transformers (figures have been rounded to the nearest whole number**)**

Failure-initiating cause	**Percentage (%)**
Winding insu ation breakdown	29%
Transient overvo tage disturbance (switching surges, arcing ground fau t, etc.)	16%
Insu ation bushing breakdown	14%
Mechanica breaking, cracking, oosening, abrading, or deforming of static or structura parts	7%
Loose connection or termination	7%
Other insu ation breakdown	6%
Ma function of protective re ay contro device or auxi iary device	5%
Improper operating procedure	4%
Overheating	3%
Mechanica burnout, friction, or seizing of moving parts	3%
Mechanica y caused damage from foreign source (digging, vehicu ar accident, etc.)	3%
Shorting by birds, snakes, rodents, etc.	3%
Shorting by too s or other meta objects	1%
Others	1%

73. Corrosion is expected given the saliferous environment. This is not reflected in the data above as it applies to general transformer locations and not specifically those in coastal environments.

74. Three of the six High voltage transformers at St. Fergus have failed because of oil leaks and severe corrosion deeming them inoperable. The three transformers have been isolated but are yet to be repaired or replaced. The root cause for the three failures was corrosion which resulted in leakage of the transformer oil (see figure 5 and 6).

75. The three remaining transformers that are still in operation have been identified as being severely corroded and in need of repair or replacement (see Appendix J – Transformers maintenance reports). Remediating the corrosion defects and painting of the transformers is NGT's current method of mitigating against this failure mode. However, this intervention does not improve the performance of the asset as the inner electrical components deteriorates due to ageing making the above failure modes in **Table 3** likely.

76. However, translating this into a failure rate (0.006 Failures per unit-year) aligns with the data shown in Table 4**.**

Table 4 Failure rate vs. age of power transformers

Equipment subclass (kVA)	Age (years)	Failure rate (failures per unit-year)
Liquid fi ed 300 to 10 000	1 to 10	0.0072
Liquid fi ed 300 to 10 000	11 to 25	0.0053
Liquid fi ed 300 to 10 000	>25	0.0060

77. It can be seen that slightly higher failure rates for transformer units aged 1 year to 10 years and for units greater than 25 years may be attributable to “infant mortality” and to units approaching the end of their life, respectively.

Probability of Failure Data Assurance

78. The data is taken from Institute of Electrical and Electronic Engineers (IEEE) Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems which is the only standard dedicated solely to the reliability analysis of industrial and commercial power systems.

Consequence of Failure

79. There are multiple consequences should the transformers fail:

80. Impact on site resilience:

- Currently one transformer in each of Plant 1, Plant 2 and British Gas Corporation substation (BG sub) are isolated due to corrosion causing oil leaks.
- Failure of the remaining transformer in the BG Sub would put the BG Sub, MTB, Electrical Distribution Building (EDB) onto standby generator supply for an extended period up to 6 months as previously described. This would be the last available source of power so any failure of these temporary generators would leave these buildings without an electricity supply. These buildings supply the critical power to control the whole Terminal as well as the fire pumps to deal with an incident onsite which requires firewater.
- Plant 1 and 2 can be interconnected and either transformer can supply both plants. However, these plants are designed to operate separately with this interconnector closed for specific works e.g., if the standby generator is isolated or half the main switchboard isolated for maintenance, there is additional risk of a trip of the entire compression plant if both plants are operating on a single transformer.
- Plant 1 and 2 also have their own emergency shutdown systems which are tied into the electric system isolating the power in the event of a full plant Emergency shutdown system (ESD). This would isolate both plants if the electrical interconnector is closed.
- The requirement to have both transformers on each plant available and reliable is also key to the strategy of changing out the aged electrical switchgear in each plant which is covered under the LV Switchboards and MCCs EJP.
- Despite resiliency built into the design of Plants 1 and 2, reliance on old and defected assets for back up presents a high risk to the operation of the plant which is not acceptable given the terminal's criticality to the NTS.

81. Safety impact of failure:

- There have been recorded incidents of catastrophic failure of assets in the electricity supply network that have been commissioned at the same period and the root cause of failure was determined to be corrosion.
- This type of failure could lead to the destruction of property and loss of life should site personnel be in the vicinity. Please refer to **Appendix G - Dangerous incident notification**for a NEDeRS (National Equipment Defect Reporting Scheme) report on the failure mode
- As stated earlier the transformers on site have not suffered catastrophic failure as result of breakdown of the transformers insulation system. Although that has not happened so far at St Fergus the root cause was identified to be corrosion which is prevalent at St Fergus making it a high-risk location for a similar failure

- The currently isolated transformers were isolated based on the visual assessment of their condition. One had already an active oil leak, the other two corrosion was of such a condition that an oil leak was deemed likely and were therefore disconnected before that could happen.

82. Environmental impact:

- The environmental impact from failure of the transformers mainly stems from leakage of the oil from the transformer's tanks via the site drainage potentially leaving site via the site fire pond to the Blackwater Burn which flows through the Terminal.
- This could cause damage to the flora and fauna which live on and near the watercourse which flows into the North Sea approx. 1.5 km downstream. Severe leakage has been reported and one of the units had to be drained down and taken out of service as a result.
- It has been noted that the transformers containment system does not conform to current National Gas standards (ref T/SP/EL/50 – section 8.7.4). This increases the risk of environmental contamination should there be a loss of containment.
- Reliance on standby generators in the interim will have increased carbon emissions

83. Financial impact:

- Transformer failure will require use of standby Diesel generators for long term operation, as explained above, which are costlier to run than the existing electrical system.
- Running a standby generator for extended periods will also breach the United Kingdom Emissions Trading Scheme (UKETS) permit by raising the unit from de-minimis to a major emissions source which would incur significant emissions cost and requirements.

6. Options Considered

84. In total, five options are considered here for management of the condition issues and associated risks as outlined in the previous section. Of these five options, four are immediately discounted as they are not viable for compliance reasons, the reasoning being outlined below. Options 4 and 5 are then expanded upon to outline the pros and cons to support the final option selection.

Options discounted.

85. Option 1: Continue to operate without resolving transformers defect risk (do nothing):

- This option is not viable due to requirements to operate a safe plant in compliance with COMAH and other safety regulations.
- To date 3 of the 6 transformers on site have already had to be isolated due to issues with corrosion and oil leakage. All transformers are the same age therefore the likelihood of the remaining transformers degrading and requiring isolation is high.

86. Option 2: Proactive risk assessment and rolling mitigation of defects (minor refurbishment):

- Undertake continuous risk assessments of transformer defects, intervening proactively to mitigate defect risk. This is mainly done by removing corrosion and painting the tanks. This will reduce the transformers efficiency over time.
- Whilst this will mitigate against the corrosion issues being experienced, due to the makeup of the cooling fins (thin wall tube and difficult access for preparation and painting) it is not possible to fully protect the transformer against corrosion. The inner electrical components also deteriorate due to ageing and this option does not rectify this issue.
- Plant 1, 2 and BG sub are already operating on the back up transformer therefore any further failures will lead to reliance on standby generators which are also past their design life and unreliable as they not designed for long duration operation.

87. Option 3: Operate with a reactive maintenance approach to transformer defects on a "fix on fail" basis (Repair/Replace on failure):

- This option is not viable due to requirements to operate safe plant in compliance with COMAH and other safety regulations.
- P1/T1 must be replaced as the transformer is damaged beyond repair. Plant 1, 2 and BG sub are already operating on the back up transformer therefore any further failures will lead to reliance on standby generators which are also past their design life and unreliable as they are not designed for long duration operation.
- Fixing on failure would therefore have major impacts on the site's resilience and is not only viable but also does not deliver the best value for the consumer.

88. Option 4: Major Upgrade of the existing transformer and repair of components (Major refurbishment)

- Involves the removal of corrosion, repair of windings, internal connections and tap changers. Replacement of the control system with smart technology, replacement of the protection system and oil.

Advantages:

- Reduces the risk of equipment failure for the short term as the key internal components have been refurbished.

Disadvantages:

89. High initial cost and potentially higher cost than a replacement due to added complexity of modifications required to match the design e.g., Accommodating of digital Protection relays into the existing switchboard
90. Difficulty in obtaining quotations and costs: Obtaining accurate quotations and costs for refurbishing outdated transformers is a challenging task. The availability of specialized contractors or service providers experienced in refurbishing such legacy equipment is limited, resulting in fewer options for obtaining competitive quotations
91. Does not comply with current standards such as T/SP/EL/50, BS EN 60076-2018
92. Not in line with the site's future operating strategy and does not deliver the best value for the consumer as they will need to be replaced to operate until 2050
93. Lack of OEM support: With equipment commissioned in 1977, the OEM is no longer available to provide support for the specific transformer model. This makes it challenging to access technical expertise, spare parts, and documentation necessary for a comprehensive refurbishment. This lack of OEM support can significantly impede the refurbishment process and potentially compromise the overall reliability and safety of the asset
94. Reduced long term reliability: The asset has been in operation for over 45 years, refurbishment might address immediate concerns, but it may have a limited lifespan which impacts on the risk of failure or breakdowns.

Do nothing, minor and major refurbishment options were deemed not viable and therefore not costed. This is because they present significant limitations that do not address the major investment drivers and would also not guarantee long term reliability of the assets to 2050.

Options progressed

95. Option 5: Replace transformers (replacement)

- Involves replacement of all transformers with new units to meet present BS standards. The new transformers can be type tested at works and installed at site, one out one in with short duration
- The civil and drainage assets will also be upgraded and/or redesigned to comply with NGT standards thereby addressing the environmental impact of the transformers

Advantage:

- This option is safer and complies with all the standards and regulations

- This option will meet the terminal's long-term strategy where the transformers will be functional to 2050
- This option integrates seamlessly with newer technology/upgrades being done on other electrical assets on the terminal (See St Fergus site strategy chapter 4: Electrical assets)
- This option significantly reduces the likelihood of equipment failure leading to inability to flow gas through the terminal. The option returns the terminal to its original resilient design configuration with back up transformers on each plant. See Appendix I – 6 Transformers justification
- Sufficient availability of spares and OEM lifecycle support reduces the turnaround time after failure which is cost effective and minimises risk to operations.
- Resetting the asset life reduces the overall operational expenditure required to maintain the assets throughout and eliminates the current challenges brought about by lack of OEM support, obsolescence, and lack of spare parts.
- Provides the best value to the consumer due to the economies of scale when designing, procuring, and installing the transformers and cross site cabling

Disadvantages:

- High initial cost. However, current assets are past their design life (25 years) and from a whole life costing perspective replacement delivers the most value for money due to increased reliability of the asset and reduced maintenance costs
- As a result of the long lead times associated with acquiring and installing the new assets, minor refurbishment (fixing corrosion defects and coating the transformer surfaces) will be required to remediate the existing transformers in the meantime to manage security of supply risks.

Options Cost Details

Options	Programme element	Cost evidence	Volume	Price base conversion	Investment value (£m 18/19 price base)
Option 1	Do nothing				
Option 2	Minor refurbishment				
Option 3	Replace/Fix on failure				
Option 4	Major refurbishment				
Option 5	Replacement		[redacted]		[redacted]

Option analysis and selection

96. Considering the above rationale and options assessment, the following table provides a summary of the options considered.

Solution considerations		**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**
		Do Nothing	**Minor refurbishment**	**Replace/Fix on failure**	**Major refurbishment**	**Replace transformers**
Compliance	**COMAH**	Non-comp aint	Non-comp aint	Non-comp aint	Comp iant	Comp iant
	T/SP/EL/50	Non-comp iant	Non-comp iant	Non-comp iant	Non-comp iant	Comp iant
	BS EN 60076-2018	Non-comp iant	Non-comp iant	Non-comp iant	Non-comp iant	Comp iant
	ECODESIGN	Non-comp iant	Non-comp iant	Non-comp iant	Non-comp iant	Comp iant
Environmental Impact		Non-comp iant with (T/SP/EL/50) on containment systems for bu k oi containing equipment which might ead to contamination	Non-comp iant with (T/SP/EL/50) on containment systems for bu k oi containing equipment which might ead to contamination	Non-comp iant with (T/SP/EL/50) on containment systems for bu k oi containing equipment which might ead to contaminate	Non-comp iant with (T/SP/EL/50) on containment systems for bu k oi containing equipment which might ead to contaminate	Comp iant with (T/SP/EL/50) on containment systems for bu k oi containing equipment
Maintenance	**Ongoing Maint. need**	High - Introduces ongoing inspection and maintenance programme for the high-risk transformers	High - Introduces ongoing inspection and maintenance programme for the high-risk transformers and reactive expensive repairs	High - Introduces ongoing inspection and maintenance programme for the high-risk transformers and reactive expensive repairs	Medium - continuous OPEX cha enge to maintain	Low - removes significant effort for ongoing defect management of the transformers
Operational Resilience	**Security of Supply**	Very high risk of fai ure. Site current y running on p ant back up assets	High risk of fai ure. Site current y running on p ant back up assets	High risk of fai ure. Site current y running on p ant back up assets	Low. As the site has been returned to run as designed with redundancy in each p ant	Low. As the site has been returned to run as designed with redundancy in each p ant
Cost		No cost. However, the associated risk from fai ure of the assets and re iance on aged and defected assets for back up is high. This wi resu t in high constraint costs if we are unab e to meet our f ow ob igations.	Option not viab e therefore not costed	Option not viab e therefore not costed	Option not viab e therefore not costed	High cost, current assets are past design ife and from a who e ife costing perspective rep acement de ivers the most va ue for money due to increased re iabi ity of the asset and reduced maintenance costs
Overall viability		Not viab e	Not viab e	Not viab e	Not viab e	Viab e

7. Preferred Option Scope, cost, and Project Plan

97. The assessments outlined in this paper and the associated discounting and costing of options demonstrates there is only one cost effective and logical option to take forwards: Option 5 - Replace all transformers with new fit for purpose units and upgrade of associated civil and structural assets to meet national gas specifications and current standards and regulations.

Project scope

98. In total all six transformers are severely corroded and leaking oil, with BGC/T1, P1/T1 and P2/T1 isolated from plant operating service and drained down. These transformers are over 45 years old and considered end of life and require replacement.

99. A high-level project scope is detailed below:

100. Replacement of six Auxiliary transformers. These include:

- 2 x 800 KVA transformers supplying the Main Terminal Building (MTB / BGC Sub-Station)
- 2 x 1250 KVA transformers supplying Plant 1 Switchboard
- 2 x 1250 KVA Transformers supplying Plant 2 switchboard.

101. Decommissioning of existing transformers. These include:

- BGC/T1 and T2 supplying the MTB,
- P1/T1 and T2 supplying Plant 1,
- P2/T1 and T2 supplying Plant 2.

102. Replacement of Paper-insulated lead-covered (PILC) cables with new cross linked polyethylene steel wire armour (XLPE SWA) 11KV cables - estimated 3000m - that supply the 6 transformers. (See Appendix B – [redacted] report)

103. Civil and structural works:

- Decommission and destruct of existing civil works (groundworks and "bunding")
- Installation of 3 new sets of containment systems (piling and bunding/kerb/localised containment area), with fire barriers, close to the individual buildings,
- Localised building works for high level penetration and/or underground ducting and the associated enabling works,
- Underground services infrastructure works and the associated enabling works,
- Drainage systems to suit regulatory accepted site-based and site-wide philosophies and the associated enabling works.

104. Low Voltage (LV) cabling replacement - estimated 3,000m - between the transformers and associated switchboards is also to be bundled with the HV transformer replacement works which brings efficiencies in cost and delivery.

105. The following is a summary of the project scope deliverables:

- Provide safe, fit for purpose, secure by design, reliable and maintainable HV Auxiliary Transformers and associated equipment, suitable for present and future operations, while sustaining operational capability of the St Fergus Terminal, in line with T/SP/EL/50 and T/SP/COMP/30.
- The replacement Auxiliary Transformer and associated equipment should have a minimum 25-year design life (ref T/SP/EL/50 – section 1.4) with sufficient availability of spares and OEM lifecycle support to maintain acceptable reliability and availability for this period. The Supplier or OEM shall provide, if possible, a premature obsolescence management plan, detailing the future availability of spares, repairs, and technical support.
- Upgrading and/or redesign of the civil and drainage assets associated with the transformers to comply with current NGT electrical specifications (ref T/SP/EL/50 – section 8.7.4) on containment systems for bulk oil containing equipment.
- The replacement assets shall be implemented in a phased approach, allowing flexibility for operational constraints, outage dates / requirements, other Asset Health projects and providing commissioning stage fallbacks to ensure no significant impact on operations and planned gas flow through the site.
- The replacement assets will integrate with retained systems and provide capacity for foreseeable future modifications. Where possible, to assist with the integration of new Transformer related assets with existing site installed infrastructure, the use of marshalling panels shall be considered to act as a termination point, including capacity for future proofing and additional redundancy for existing or new network interfacing systems, in line with T/SP/EL/50 and T/SP/COMP/30.
- Meet the COMAH Competent Authority (Health & Safety Executive) expectations and Critical National Infrastructure security requirements.

Final cost and programme

106. Table 5 provides a breakdown of the final costs for the project split by several categories.

Table 5 Project cost breakdown

	Cost Category	Outturn Costs (£m)	Costs (£m) 2018/19 Price Base
	OEM costs	[redacted]	[redacted]
Direct	EPC Estimate	[redacted]	[redacted]
Indirect	EPC PM	[redacted]	[redacted]
Direct	EPC Site Establishment	[redacted]	[redacted]
Direct	NGGT Direct Company Costs	[redacted]	[redacted]
Indirect	NGGT Indirect Company Costs	[redacted]	[redacted]
	Contractor Risk	[redacted]	[redacted]
Direct	NG Project Risk	[redacted]	[redacted]
	FEED	[redacted]	[redacted]
	Development / Optioneering	[redacted]	[redacted]
	Land / Easements	[redacted]	[redacted]
	TOTAL	[redacted]	[redacted]
		[redacted]	[redacted]
	Direct	[redacted]	[redacted]
	Indirect	[redacted]	[redacted]

107. Table 6 shows the spend profile for our preferred option in 2018/19 pricing.

Table 6 Spend profile of preferred option

£m 18/19	FY2023	FY2024	FY2025	FY2026	Total	Comments
HV transformers replacement	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	

RIIO-T2 Volume UIDs

108. Costs associated with this project have been assigned against the RIIO-T2 Unique Identifier (UID) [redacted] **- ST FERGUS TERMINAL – Transformer Replacement.**

109. Table 7 provides a summary of the UIDs and associated funding for the scope of works proposed in this paper.

Table 7 UID Details

UID	Baseline volume of Intervention (By PP) (by unit of measure)	Baseline total funding available (£ 18/19)	Current volume of intervention (by unit of measure)	ECC total funding required (£m 18/19)	Output Year	UID funding requested through UM (£m)
[redacted] - ST FERGUS TERMINAL – Transformer Replacement	[redacted]	Nil	[redacted]	[redacted]	2026	[redacted]

110. The cost accuracy at this stage of the project is estimated at +30/-15% in accordance with the Infrastructure and Projects Authority (IPA) cost estimating guidance.

111. This report has explained the safety concerns NGT has regarding the defected transformers and the implications of these on terminal operations. The intervention is necessary to ensure the safety of site personnel and ongoing 24/7/365 operation of the terminal facility.

NARMs Benefit

112. Following discussions with Ofgem in the NARM Development Monthly Meetings, it is proposed that for simplicity all the investments that arise from the UMs are collated and one NARMs update is provided after the Plant & Equipment submission.

113. For further details and a summary of UIDs please see the Asset Health UM Overarching document.

Conclusion

114. This report has explained the asset health and compliance shortcomings of the HV transformers at St Fergus and their implications to the safe and reliable operation of the terminal.

115. As detailed in this justification paper, it is of paramount importance to secure the necessary investment to address the highlighted investment drivers.

116. Removal and the subsequent replacement of transformers, upgrade of associated civil and structural assets and the LV cable replacement program at the St Fergus gas terminal totals [redacted] (18/19 Prices).

8. Appendices

Appendix A – Project Summary table

Table 8 Project summary table

Name of project	T2_St Fergus_2021_St Fergus RIIO-2 Asset Health Programme		
Scheme reference	PAC1051320		
Primary investment driver	Asset Deterioration/Obsolescence		
Project initiation year	2023		
Project close out year	2026		
Total installed cost estimate 18/19	[redacted]		
Cost Estimate accuracy (%)	+30/-15		
Project spend to date Outturn	[redacted] (all St Fergus T2 AH UM development)		
Current project stage gate	F2		
Reporting table ref	RRP Table 6.3 (Asset Health) and 6.4 (Asset Health Projects)		
Outputs included in RIIO-T1 business plan	No		
Spend apportionment 18/19	T1	T2	T3
	[redacted]	[redacted]	[redacted]

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Appendix B – [redacted] report

1. File: 5210385-001-EL-REP-022, 22-HV Transformers, [redacted], Rev 03,2023

2. File: 5210385-001-EL-REP-009, 09- Electrical Distribution (Excl. Distribution Boards), [redacted], Rev 03,2023

Appendix C – Abbreviations

ACB - Air Circuit Breakers

BGC sub - British Gas Corporation substation

EDB - Electrical Distribution Building

GEC - General Electric Company

HV – High Voltage

IEEE - Institute or Electrical and Electronic Engineers

MCC - Motor Control Centres

MTB - Main Terminal Building

OCB - Oil Circuit Breakers

ORAM - Operational Risk Assessment and Maintenance

SSEN - Scottish and Southern Electricity Network

VCB - Vacuum Circuit Breakers

VSD - Variable Speed Drive

Appendix D – Single line diagrams

1. File: Single line diagram switchboard A BGC 11kV substation main HV switchboard - 6011/03/01/03/0033
2. File: MTB single line diagram 6011/03/01/03/0036
3. File: Plant 1 LV SLD 6011/03/01/03/0034 and
4. File: Plant 2 LV SLD 6011/03/01/03/0035

Appendix E – Change sequence

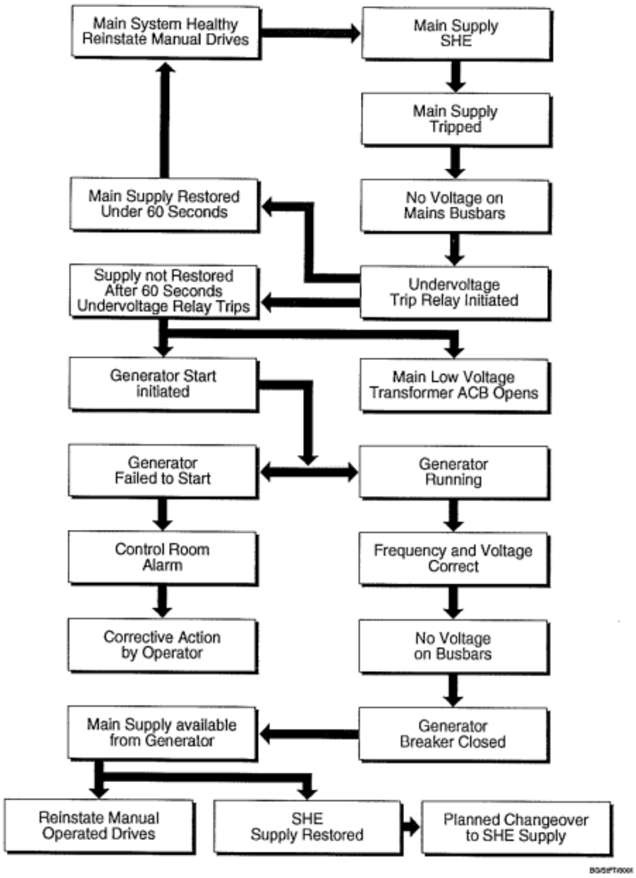

Figure 10 change sequence

Appendix F – IEEE Gold book

1. File: IEEE Gold book Std-493-2007, IEEE Recommended Practice for the Design of Reliable Industrial Commercial Power Systems, IEEE ,2007

Appendix G - Dangerous incident notification

1. File: NEDeRS report Dangerous incident notification (DIN) 2019001801

Appendix H - Eco-design Directive

Link: [Commission Regulation (EU) 2019/1783 of 1 October 2019 amending Regulation (EU) No 548/2014 on implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to small, medium and large power transformers (Text with EEA relevance) (legislation.gov.uk)]

An Eco-design Directive from the European Commission, (COMMISSION REGULATION (EU) No 548/2014 implementing Directive 2009/125/EC) for small, medium, and power transformers to save energy and reduce network losses is approaching the second stage of the regulation.

Published in the Official Journal of the European Union, the regulation imposes, for supply into the EU, the maximum level of losses and minimum efficiencies for transformers placed on the market / put into service.

The regulation detailed two stages of introduction

- Stage 1 “Tier 1”, imposing maximum loss levels and minimum efficiencies came into force on 1st July 2015.
- Stage 2 “Tier 2”, imposing reduced maximum loss levels and increased minimum efficiencies commencing 1st July 2021
- As such from 1st July 2021, small, medium and large power transformers must meet the requirements of Tier 2 losses / efficiency, with transformer manufacturers being fully responsible in applying the law.

Appendix I – 6 Transformers justification

1. Multiple scenarios were analysed to determine whether rationalisation of the transformers within Plant 1 and 2 would be cost effective while also ensuring that the resilience of the terminal remains within an acceptable level.
2. The analysis, shown in Table 9, demonstrates the limitations of reducing the number of transformers as all scenarios introduce a single point of failure (SPOF), additional civil costs and significant risks to security of supply. These limitations greatly outweigh the cost savings from rationalisation of the transformers.
3. As BG Sub switchboard C has no facility to connect to another switchboard, reducing the number of transformers is not possible without putting the BG Sub/MTB onto generator supply whilst carrying out maintenance on Switchboard C or the transformer, therefore 2 transformers are required for this part of the plant.

Table 9 Plant 1 & Plant 2 transformer comparison

#	Scenario	Total number of transformers in Plant 1 and 2	SPOF	Advantages over current design	Disadvantages over current design
1	P1/T1 and P2/T2 with an automatic transfer scheme for the interconnector between D1 and D2	2	YES	• Reduced CAPEX on transformers. • Reduced OPEX on maintenance.	• Greatly reduces the resilience of Plant 1 and 2 as a single transformer is used as a backup for either plant. • During maintenance on the LHS of Sw/Bd D1 or D2 or Sw/Bd A Plant 1 and 2 is reliant on a single transformer. If the backup trips both plants are reliant on standby generation. • The LV switchboards do not currently have this functionality so would require replacement with this design included.
2	P1/T2 on Plant 1 and P2/T1 + P2/T2 on Plant 2	3	YES	• Reduced CAPEX on transformers. • Reduced OPEX on maintenance.	• During emergency shut down or electrical isolation of Plant 2, Plant 1 will operate without any back up. • When Plant 2 stand by generator is isolated for maintenance or a fault, the whole plant is reliant on Plant 1 T2. If P1/T2 trips, both plants will be supported by Plant 1 standby generator. • Reduced resilience from current design
3	P1/T1 and P2/T2 with transformer in new location with cabling and circuit breakers to connect T3 to both RHS and LHS of switchboard A	3	YES	• Eliminates the cost associated with acquiring a 4th transformer however costs associated with additional circuit breakers to allow isolation from either side of the	• Added cost due to new location, civils, cabling, and further civils associated drainage system will be required which may outweigh saving in purchasing additional transformer • This option will require modifications to the switchgear which will incur added costs • During maintenance of one side of the HV Switchboard A, two of the transformers will be isolated which will reduce the

				switchboard may outweigh this saving.	resilience of the plant as Plant 1 and will be reliant on a single transformer
4	P1/T1 + P1/T2 on Plant 1 and P2/T1 + P2/T2 on Plant 2	4	NO	• Current design	• Current design

[redacted]

Figure 11 Scenario 3 Normal operation

[redacted]

Figure 12 Scenario 3 Right hand side of Switchboard A isolated

[redacted]

Figure 13 Scenario 3 Left hand side of Switchboard A isolated

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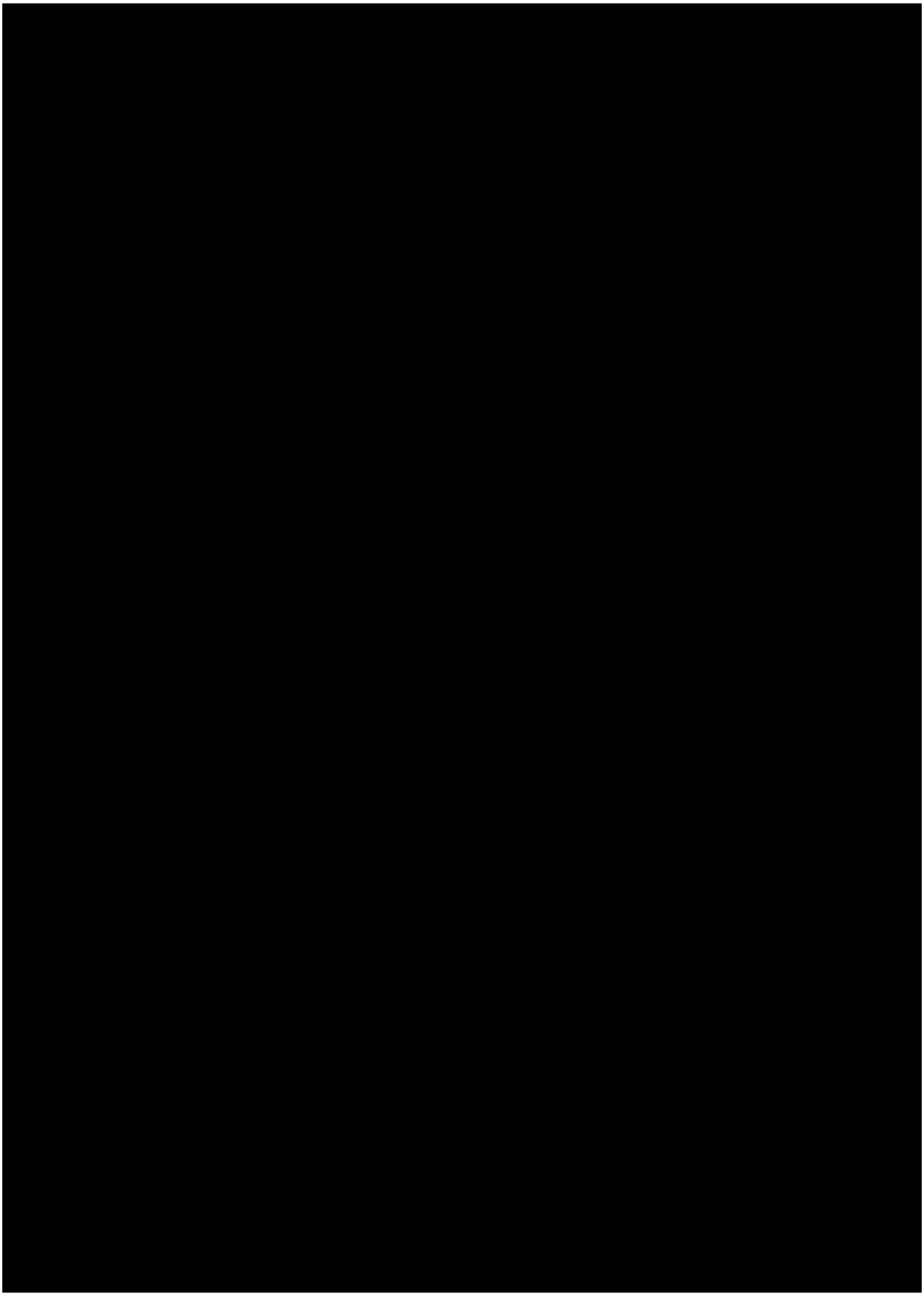
Appendix J – Transformers maintenance reports

[redacted]



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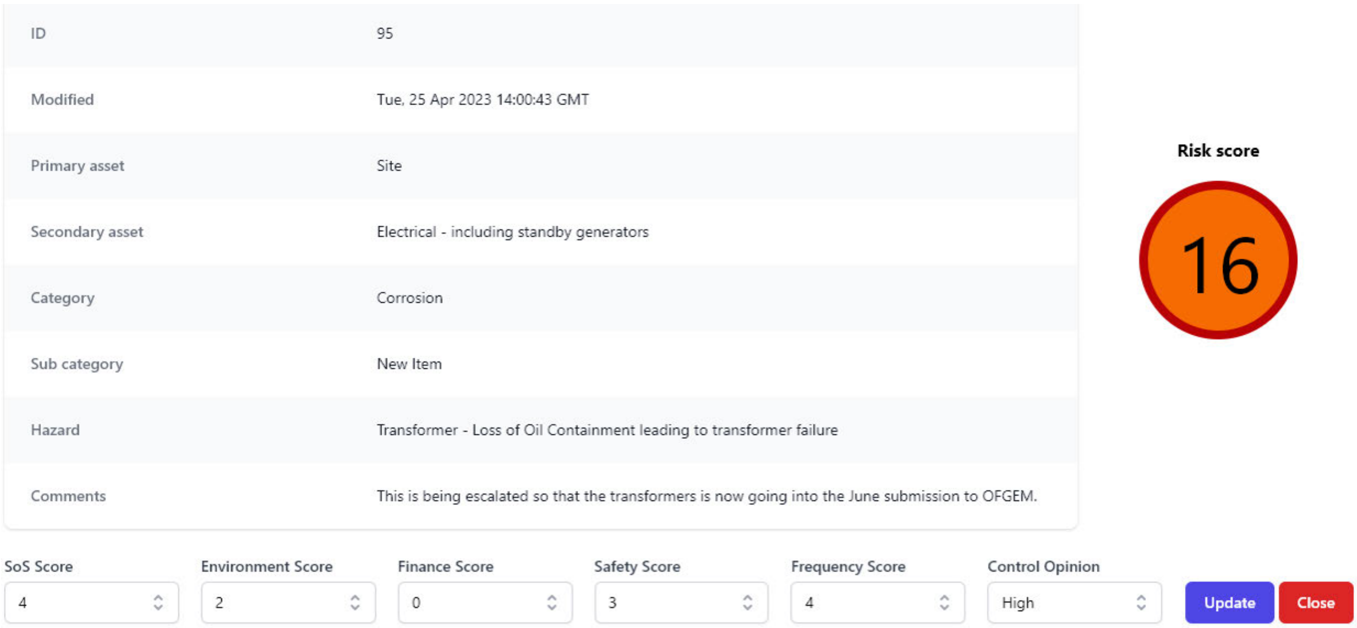
Appendix K – HV transformer risk score



ID	95
Modified	Tue, 25 Apr 2023 14:00:43 GMT
Primary asset	Site
Secondary asset	Electrical - including standby generators
Category	Corrosion
Sub category	New Item
Hazard	Transformer - Loss of Oil Containment leading to transformer failure
Comments	This is being escalated so that the transformers is now going into the June submission to OFGEM.

Risk score

16

SoS Score	Environment Score	Finance Score	Safety Score	Frequency Score	Control Opinion
4	2	0	3	4	High

Update Close

Figure 14 HV transformers risk score in NGT's ORAM

A score of 16 is made up by multiplying the frequency and the highest number in all categories.

A frequency score of 4 indicates - Likely – Not certain to happen but any one additional unforeseen factor may result in an Incident.

A Security of supply score of 4 indicates the consequence: Distribution Network disrupted / Major outage for significant period