SSEN Transmission

RIIO-T2 Business Plan: T2BP-EJP-0044-Rev1.1

Scottish & Southern Electricity Networks

St Fergus Mobil 132 kV Substation and St Fergus 132 kV Switching Station Works

Engineering Justification Paper

1. Executive Summary

Our paper 'A Network For Net Zero – A Risk Based Approach to Asset Management[1]' sets out our approach to network risk and how we subsequently identify assets that require intervention to limit the rise of risk over the RIIO-T2 period.

This paper has been updated following the draft determination and addresses the comments made by Ofgem. We have also added supplementary data including more information that highlights the critical nature of St Fergus Mobil Substation and the surrounding sites, especially with regard to the UK's gas supplies. There are no changes to the scope of works or associated costs.

This paper identifies the need for intervention on the 132kV network at St Fergus Mobil Substation and St Fergus Switching Station. There are two key drivers for the work:

1. Assets at St Fergus Mobil are in poor condition – work is required to ensure they remain fit for purpose;

[redacted]

Following a process of optioneering and detailed analysis, as set out in this paper, the proposed scope of works is:

- Offline replacement of St Fergus Mobil with a new indoor substation, including replacement of existing 132 kV fluid filled cables;
- Addition of two 132 kV circuit breakers and associated switchgear at St Fergus Switching Station.

This scheme delivers the following outputs and benefits:

- Improved network reliability and resilience in line with our goal of 100% network reliability
- Use of innovative non-SF_6 solutions
- Contribution to our goal of one third reduction in greenhouse gas emissions.

The immediate monetised risk benefit is R[redacted]. The long-term benefit of this project is -R[redacted] due to the addition of new lead assets. It is also critical to recognise that a limitation of the long-term risk benefit modelling tool is that it does not consider the improvements in network resilience and the associated benefits of an improved security in supply to the critical connected customers.

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[1] A Network For Net Zero – A Risk Based Approach to Asset Management

The cost to deliver this scheme [redacted] and the works are planned to be completed within the RIIO-T2 period.

The scheme at St Fergus Mobil and St Fergus Switching Station is not flagged as eligible for early or late competition due to it being under Ofgem's £50m and £100m thresholds respectively.

Name of Scheme/Programme	St Fergus Mobil 132kV Substation Works
Primary Investment Driver	Asset Health (Non-Load)
Scheme reference/ mechanism or category	SHNLT2031 Switchgear (replacement)
Output references/type	NLRT2SH2031 Switchgear (replacement)
Cost	[redacted]
Delivery Year	Within the RIIO-T2 period
Reporting Table	C0.7 Non-Load Master Data
Outputs included in RIIO-T1 Business Plan	No

2. Introduction

This Engineering Justification Paper sets out our plans to undertake condition-related work during the RIIO-T2 period (April 2021 to March 2026). The planned work is at St Fergus Mobil substation and St Fergus Switching Station, the locations of which are shown in Figure 0-1.

The Engineering Justification Paper is structured as follows:

Section 3: Need

This section provides an explanation of the need for the planned works. It provides evidence of the primary and, where applicable, secondary drivers for undertaking the planned works. Where appropriate it provides background information and/or process outputs that generate or support the “need”.

Section 4: Optioneering

This section presents all the options considered to address the “need” that is described in Section 3. Each option considered here is either discounted at this Optioneering stage with supporting reasoning provided or is taken forward for Detailed Analysis in Section 5.

Section 5: Detailed Analysis

This section considers in more detail each of the options taken forward from the Optioneering section. Where appropriate the results of Cost Benefit Analysis are discussed and together with supporting objective and engineering judgement contribute toward the identification of a selected option. The section continues by setting out the costs for the selected option.

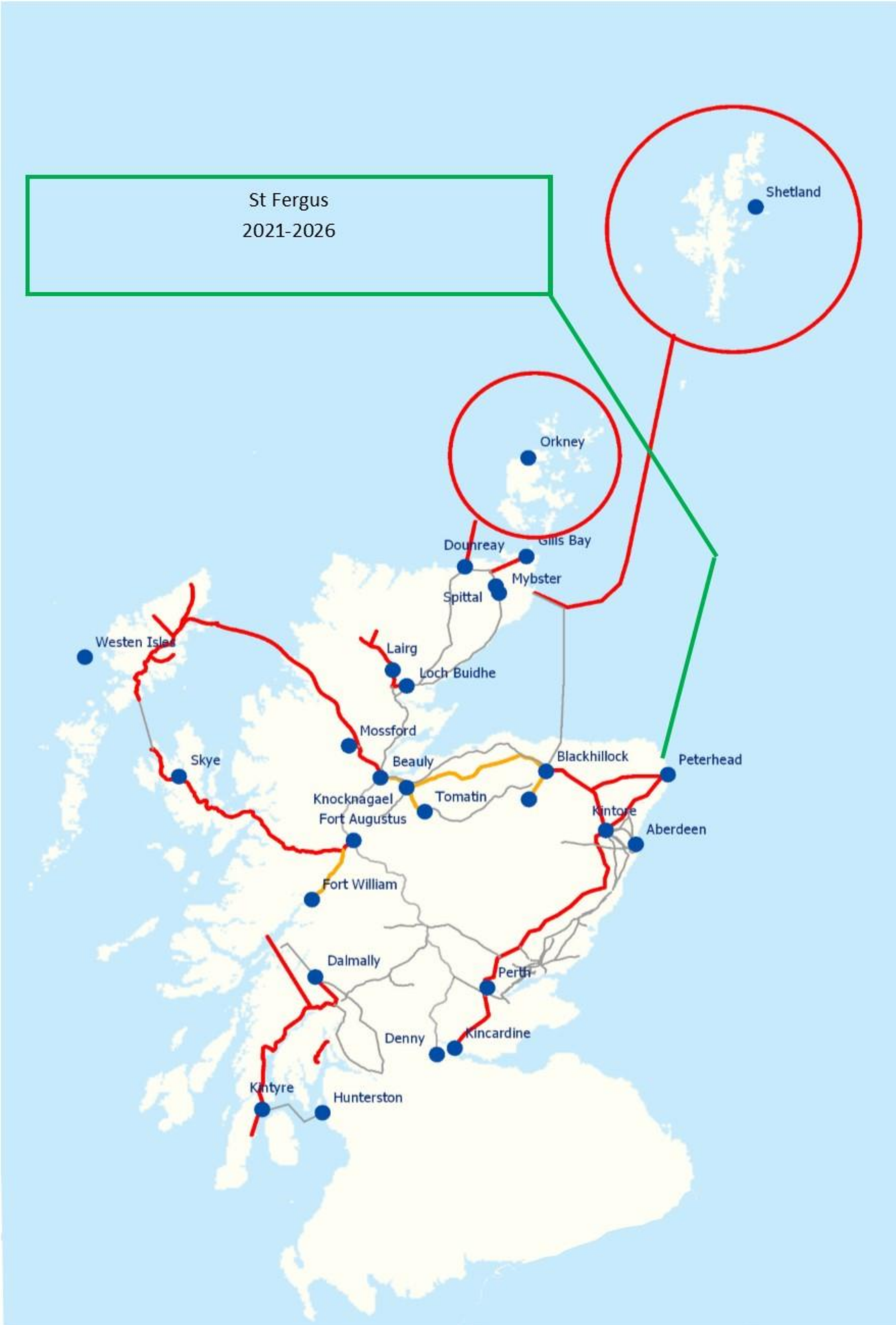
Section 6: Conclusion

This section provides summary detail of the selected option. It sets out the scope and outputs, costs and timing of investment and where applicable other key supporting information.

Section 7: Outputs included in RIIO-T1 Business Plan

This section identifies if some or all the outputs were included in the RIIO-T1 Business Plan and provides explanation and justification as to why such outputs are planned to be undertaken in the RIIO-T2 period.

Figure 0-1 - Geographical Representation



2.1. Post Draft Determination Update

Since the receipt of feedback from Ofgem as part of their draft determination, this paper has been revised to emphasise the critical nature of St Fergus Mobil Substation and the surrounding sites, to provide further information on options considered and to illustrate stakeholder support.

The option of a comprehensive refurbishment of the existing plant at St Fergus Mobil has been reviewed in detail, with input from the original plant manufacturer. While this is by some considerable margin the lowest initial cost option, it will only extend the life of the plant by up to ten years – which is only towards the normally expected end of life, as the current plant has been in service for less than 30 years.

The current maintenance regime, and associated OPEX, currently in place at St Fergus Mobil has also been included in this paper. Principally driven by corrosion, caused by the environment, St Fergus Mobil requires maintenance at double the standard interval.

The option of replacing the existing plant on a like-for-like basis has also been reviewed in detail. Again, this would not reduce exposure to the corrosive environment with the new plant expected to last only around 25 years.

[redacted]

[redacted].

3. Need

3.1. Background

[redacted]

[redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

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2 [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[6] http://www.ancalamidstream.com/technical/

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

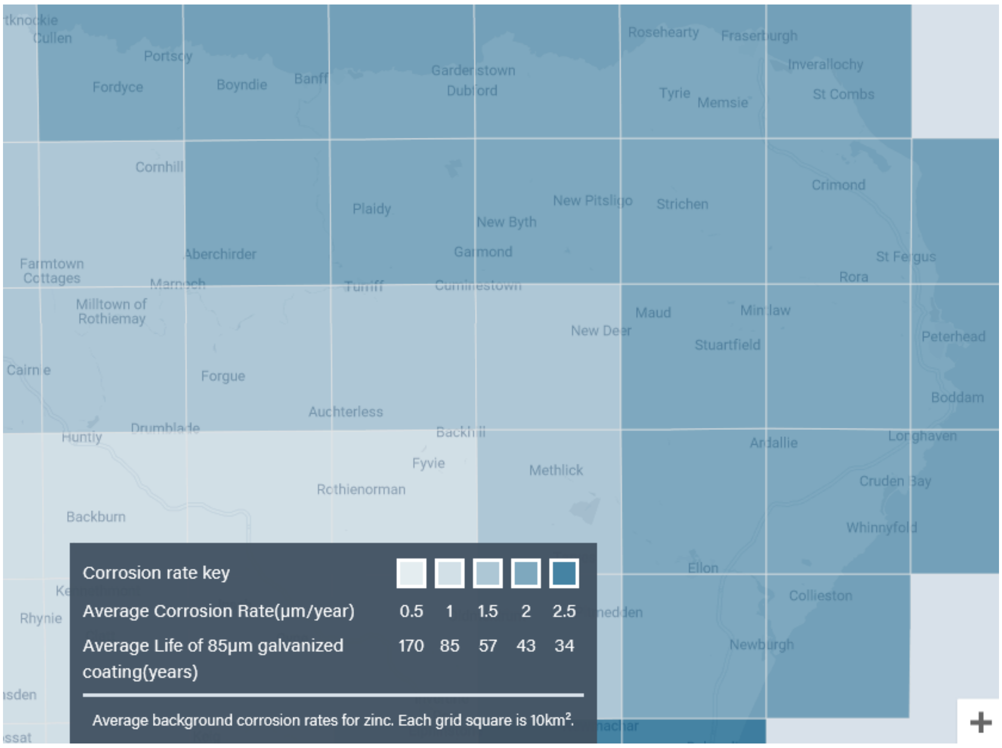
[redacted]

[7] https://www.galvanizing.org.uk/

[redacted]

Figure 3-2 - Aerial photograph showing location of St Fergus Mobil Substation

Figure 3-3 - Galvanisation Corrosion Rate for St Fergus Area (Courtesy of the Galvanisers' Association)



3.2. Asset Need

Ongoing site inspections provide detailed condition assessment of the plant along with the data gathered from testing and analysis. The resulting asset condition report provides, in detail, the condition of existing assets and recommendations for intervention in the RIIO-T2 period. This section includes information on the condition of the plant at St Fergus Mobil and the arrangement of the network around the St Fergus Switching Station, together with the implications of these.

3.2.1. Switchgear

The key condition related issues with the 132kV switchgear at St Fergus Mobil are as follows; for further details refer to condition report T2BP-ACR-030:

- There are significant corrosion issues across the substation well beyond what would be expected for their c.30 years' time in service. The figures below show some examples of this. This is attributed to the substation being outdoors, and in extreme proximity to the North Sea, and therefore exposed to a highly saline, aggressive environment.
- The circuit breakers both have a visual condition score of four, this is the worst score that can be attributed and is for "serious deterioration or damage that requires specific action in the short term".
- There is high concern for the level of corrosion on the circuit breakers' vermin meshes and the SF_6 pipes between the phases. It is unclear how much can be done about the SF_6 pipes without an intrusive survey, which would require outages to inspect. The vermin mesh could be replaced during site maintenance. Failure of the SF_6 pipes would result in total loss of SF_6 from the circuit breaker with associated interruption to supply, environmental impact and possible disruptive failure. See Figure 3-6 for detail.
- Both disconnectors and earthing switches show extensive rusting on their support structures – with clear holes in some parts – and to parts of the disconnectors / earthing switches themselves. See Figure 3-7, Figure 3-8 and Figure 3-9.
- The two marshalling kiosks also show significant corrosion – again there are holes in the steel work. See Figure 3-10 and Figure 3-11.
- Both circuit breakers are ABB type LTB145D1 have had significant issues with SF_6 leakage in the RIIO T1 period – 8.1 kg of gas has been pumped into the circuit breakers which contain only 5 kg of gas each.
- A repair was performed on circuit breaker 110 in 2018 in an attempt to reduce the leakage – this involved replacement of the covers on the top of each pole of the circuit breaker, together with the associated seals. While this repair appears, after only two years in service, to have been successful, the results of the work done showed that the leakage was

attributed to oxidation of the top cover of the circuit breaker. It is reasonable to conclude that the aggressive coastal environment was, as minimum, a contributary factor to this, and we cannot preclude this reoccurring. While the environment at the other site where SHE Transmission have this type of circuit breaker installed is not as extreme as at St Fergus Mobil it is in a location only one classification lower according to the Galvaniser's Association.

- The other circuit breakers of this type installed on the SHE Transmission Network also exhibit SF_6 leakage – across the ten circuit breakers of this type 45.8 kg of SF_6 has been pumped during the RIIO T1 period; all circuit breakers have leakage rates in excess of the natural leakage, with half of them having a leakage rate in excess of ten times the natural leakage rate. Full details for the type of circuit breaker are given in Table 3-1.
- Figure 3-4 and Figure 3-5 show the ABB LTB145D1 is comparison to other circuit breakers on the SHE Transmission network:
    - Figure 3-4 shows the total number of pumping records against the total amount of gas pumped for different circuit breaker types. The size of the bubbles is relative to the number of circuit breakers. The data labels contain details of the number of operating circuit breakers that have experienced a leak. It can be seen that ten out of ten LTB145D1 circuit breakers have experienced a leak, and the quantity of gas and number of pumping operations is large compared to circuit breakers that are many times more numerous on our network.
    - Figure 3-5 is a scatter plot of the same thing but for 132 kV and the values have been averaged using the number of circuit of breakers of each type to have experienced a leak. It shows the LTB145D1 to be the second worst performing 132 kV circuit breaker type on our network, and substantially worse than all bar one of our 132 kV circuit breaker types. (The worst performing circuit breaker type is proposed to be removed as part of other T2 works.)
- Neither disconnector is remote tele-controllable, with only manual operation possible. This requires site attendance and manual local operation. This poses a particular difficulty at St Fergus Mobil due to the additional steps required to gain access to the substation as it is located within the secure gas terminal. This increased the time required to operate the disconnectors by several hours compared to remotely operable disconnectors.
- The manual operation is stiff and difficult to perform on both disconnectors, with one disconnector requiring two-person operation despite best efforts to rectify during maintenance. Corrosion, attributed to the plant being installed outdoors in immediate proximity to the North Sea, is likely to be the cause of this.

[redacted]

[redacted]

Table 3-1 - SF_6 Pumping and Leakage for ABB LTB145D1 Circuit Breakers

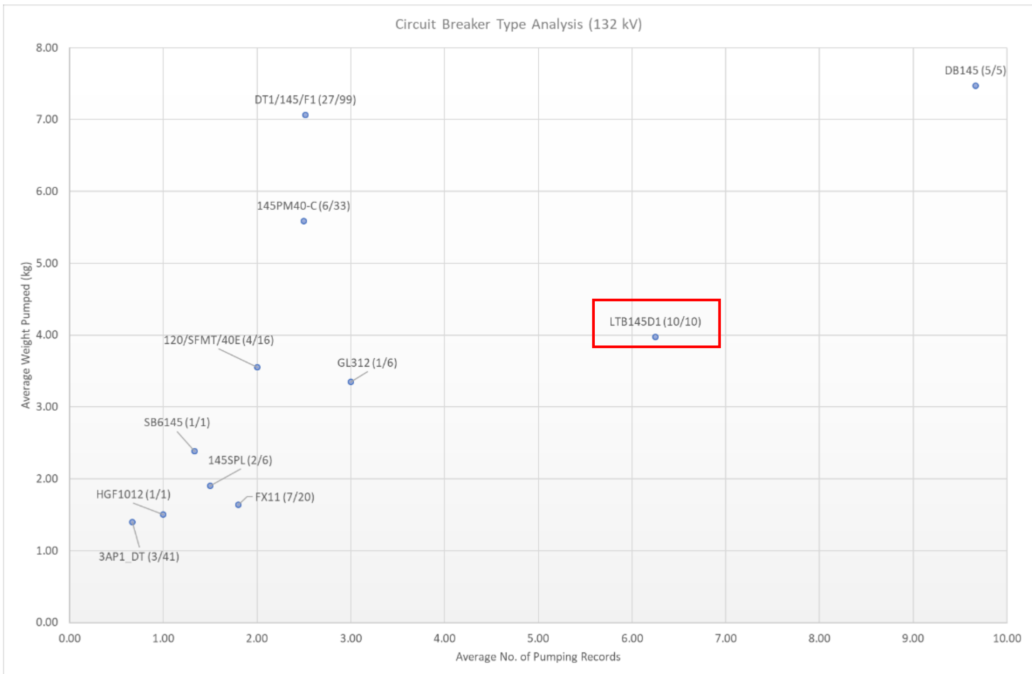
Site	ID	Year of Manufacture	Age at First Intervention	No. Pumping Records	No. Pumping Records (RIIO-T1)	First Intervention (MM/YYYY)	Last Intervention (MM/YYYY)	Time between First & Last Intervention	Time since Last Intervention (years)	Total Weight Pumped (kg)	Total Weight Pumped (kg) (RIIO-T1)	Annual Leakage Rate (kg/year) (RIIO-T1)	**% Annual Leakage Rate (kg/year) (RIIO-**
Beauly	105	1993	14	13	10	05/2007	04/2020	12.90	0.92	8.65	7.15	0.98	**19.57**
	505	1995	14	12	10	12/2009	04/2020	10.31	0.92	6.8	5.1	0.70	**13.96**
	605	1995	12	10	5	10/2007	02/2018	10.33	1.21	8.45	4.55	0.62	**12.46**
	705	1993	18	3	2	04/2011	02/2018	6.86	1.18	3.6	2.8	0.38	**7.67**
	905	1995	13	13	8	03/2008	04/2020	12.12	0.99	8.5	5	0.68	**13.69**
	1105	1994	18	2	1	10/2012	10/2016	3.95	2.58	1.1	0.7	0.10	1.92
	1205	1994	20	1	1	07/2014	07/2014	0.00	4.78	0.4	0.4	0.05	1.10
St Fergus Mobil	110	1993	24	12	12	09/2017	02/2018	0.46	1.18	6.8	6.8	0.93	**18.62**
	210	1993	21	6	6	08/2014	09/2019	5.08	0.38	1.3	1.3	0.18	**3.56**

Notes:

- Each circuit breaker contains 5 kg of SF_6
- This type of circuit breaker has an expected natural annual leakage rate of 1%
- This table is like Table 5-4 of T2BP-ACR-030 but includes most up to date records, showing continued leakage of this type of circuit breaker.

Figure 3-4 - Circuit Breaker Type Analysis (all voltages)

Figure 3-5 - Circuit Breaker Type Analysis (132 kV circuit breakers)[8]



[8] A single outlining circuit breaker type, with a higher numbering of pumping records, of which we have only one remaining in service, is not shown in this graph as it is to be removed by a current in progress works.

Figure 3-6 - Example of corrosion of circuit breaker at St Fergus Mobil - note hole in mesh that protects SF_6 pipes

Figure 3-7 - Example of corrosion of disconnector at St Fergus Mobil – note holes in the steel cross member

Figure 3-8 - Example of corrosion of disconnector at St Fergus Mobil – detail on holes from Figure 3-7

Figure 3-9 - Example of corrosion of disconnector at St Fergus Mobil – note the corrosion on the safety critical earth braid

Figure 3-10 - Example of corrosion of marshalling kiosk at St Fergus Mobil – note holes through the steel work

Figure 3-11 - Example of corrosion of marshalling kiosk at St Fergus Mobil – note top of kiosk and gas plant in background

3.2.2. Power Cables

The two circuits SM1 and SM2 from St Fergus Switching Station to St Fergus Mobil each contain cable for approximately 1.07 km of route length between St Fergus Mobil and a Sealing End Compound to the West of the A90, the remainder of the route to St Fergus Switching Station being overhead line carried on lattice towers.

These cables were installed in 1992 using the fluid-filled cable technology that was widely used at the time. In this system, the lapped paper tape primary insulation of the cables is impregnated with a low-viscosity synthetic fluid retained by a metallic cable sheath, continuously pressurised from external tanks to maintain the performance of the insulation system. The cable fluid feed tanks and monitoring equipment are situated at the St Fergus Mobil terminations. The metallic sheath is protected from corrosion by an extruded polymeric oversheath which forms the largest part of an overall secondary or outer insulation system.

Any works requiring diversion or modification of the cables would need to consider the issue inherent with fluid-filled cables, together with the design and condition of these cables.

Issues with fluid-filled cables

Fluid-filled cables inherently bring a risk of fluid leakage into the environment and also have maintenance requirements for the fluid feed and monitoring system. The fluid itself is presumed to be synthetic straight-chain alkylbenzene, which is usually considered to be biodegradable under aerobic conditions; however, leakage into the environment is clearly to be avoided. There is an Operating Code for the Management of Fluid-Filled Cable Systems promulgated by the Energy Networks Association, which gives guidance on the reporting and repair of leaks once detected. The monitoring system for these circuits includes alarms to detect a low-pressure condition which may be an indication of loss of fluid from the system. In this event, or whenever a more modest loss of pressure is detected during routine maintenance, the feed tanks are topped up from an external supply.

Leaks developing in the middle to late life of a previously healthy fluid-filled cable system typically result from

- Metallurgical changes in the cable sheath, accessory (joint or termination) metalwork, fluid feed pipework, and metal-to-metal (typically plumbed) joins between them;
- Corrosion due to localised failure of the secondary insulation system that insulates the metallic cable sheath, associated pipework and bonding connections from earth; or
- Failures of flexible seals between rigid components.

Having said all that, the risk of leakage from a properly-maintained fluid-filled cable system is generally considered low. This low risk prevails as long as the cable system is regularly monitored, and above all is decommissioned as soon as or preferably before it becomes problematic.

Routine inspection and maintenance of the cables at St Fergus is made a longer, more complex and higher risk process by the network configuration – this is explained in the section 3.2.3.

The cables under consideration have a fairly good performance record for their age, having been pumped with a modest amount of additional fluid in 2009. A leak was detected in 2018 from one termination of circuit SM2, as a result of which the O-ring seals in all six terminations on that circuit were replaced, rectifying the problem.

Issues with porcelain terminations

The cables are terminated at both ends in outdoor terminations. The external insulation of the terminations consists of a hollow glazed porcelain insulator with metal fittings at both ends, which was the system in general use at the time of their installation. This insulator simultaneously provides mechanical support to the HV connector, retains the pressure of fluid to maintain the performance of the stress control system within, excludes moisture and has insulation performance sufficient to maintain the insulation of the system in the ambient conditions.

The glazed surface of electrical porcelain has generally good surface insulation properties, even in the presence of moisture and pollution. These properties, combined with an external profile providing sufficient creepage length protected from the weather, are designed to be sufficient for the weather and pollution experienced at the location. “Pollution” in this case refers mainly to deposits of marine salt, which has a deleterious effect on the performance of the external insulation.

Porcelain has a long track record as the external insulation of high-voltage equipment but suffers from a significant risk: the fragmentation hazard in the event of an electrical fault. An internal fault followed by passage of fault current leads to rapid over-pressurisation and disruptive failure of the insulator. Razor-sharp and heavy fragments of porcelain are formed and ejected at considerable speed, causing a hazard to personnel and other equipment over a wide area, often exceeding the boundaries of any substation.

Modern designs of termination replace the porcelain insulator with a composite design, usually consisting of a rigid fibre-reinforced vacuum-formed polymer tube and a profiled elastomeric weather-protection layer. As with porcelain, this composite is bonded to metal fittings at both ends. A number of considerations have driven this change of material, significantly

- Reduced weight and fragility in transport and installation;
- Improved resistance to external impact in service; and
- Greatly reduced fragmentation hazard in the event of internal electrical failure.

Composite housings for the external insulation of equipment has a good track record, having been widely used for cable termination insulators in UK for some 30 years and for other equipment for even longer.

Issues with obsolescence

The fluid-filled insulation system of HV cables has largely been superseded by other insulation systems. This transition has been driven mainly by the issues of fluid leakage and of maintenance, referred to above. For systems above 33 kV in the UK, the XLPE (cross-linked polyethylene) insulation system is now almost universally used for new installations. This system involves a solid (but somewhat flexible) extruded polymeric insulation structure, with no requirement for pressurisation.

Most cable manufacturers have discontinued manufacture of fluid-filled cables and accessories, and many cable installers and other service providers no longer support their installation and maintenance. Thus, any diversion or repair of an existing fluid-filled installation becomes problematic. Supplies of compatible fluid-filled cable and joints are generally not available. It is possible to divert or repair using modern XLPE cable by the use of transition joints to adapt between the two systems. Issues with this are considered in a section 4.6.

3.2.3. Network Configuration – Operation and Protection

[redacted]

[redacted]

[redacted]

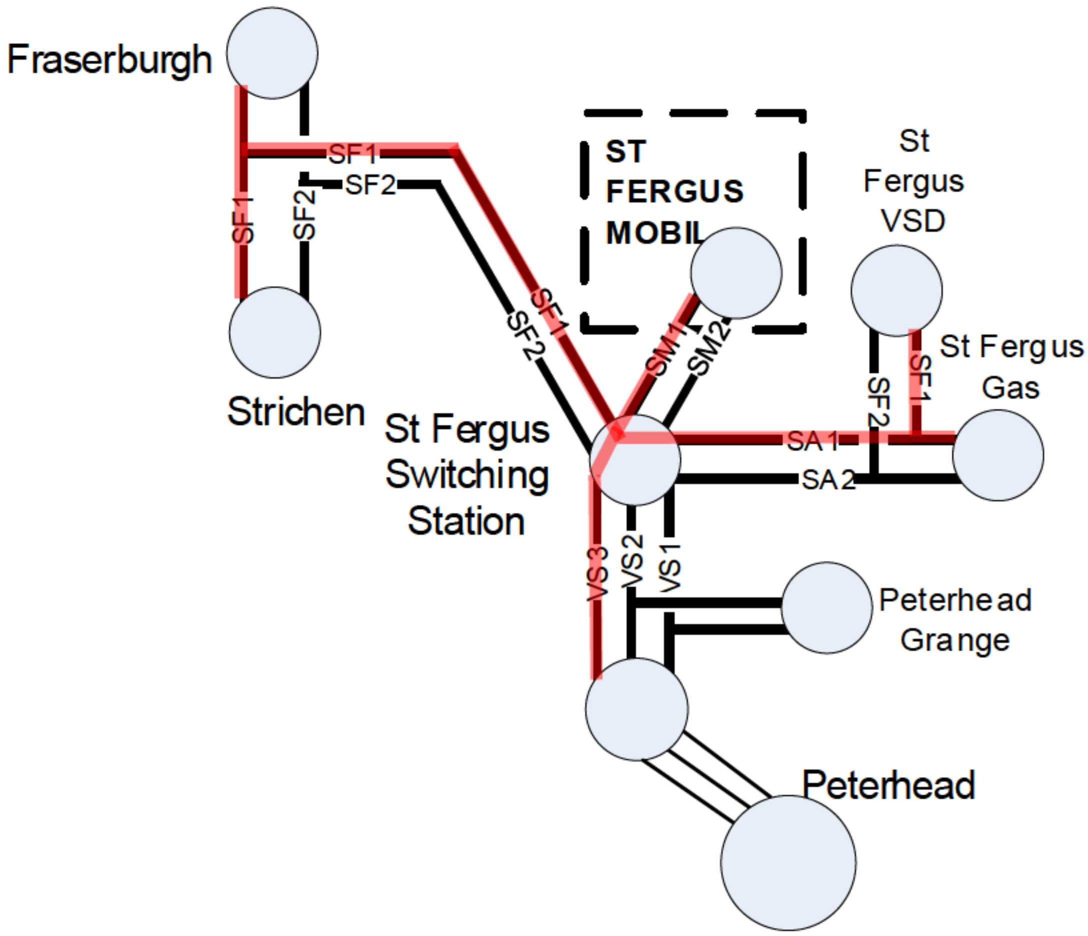
[redacted]

[redacted]

[redacted]

[redacted]

Figure 3-12 - Circuits connected to St Fergus Switching Station - showing outage on SM1 (current configuration)

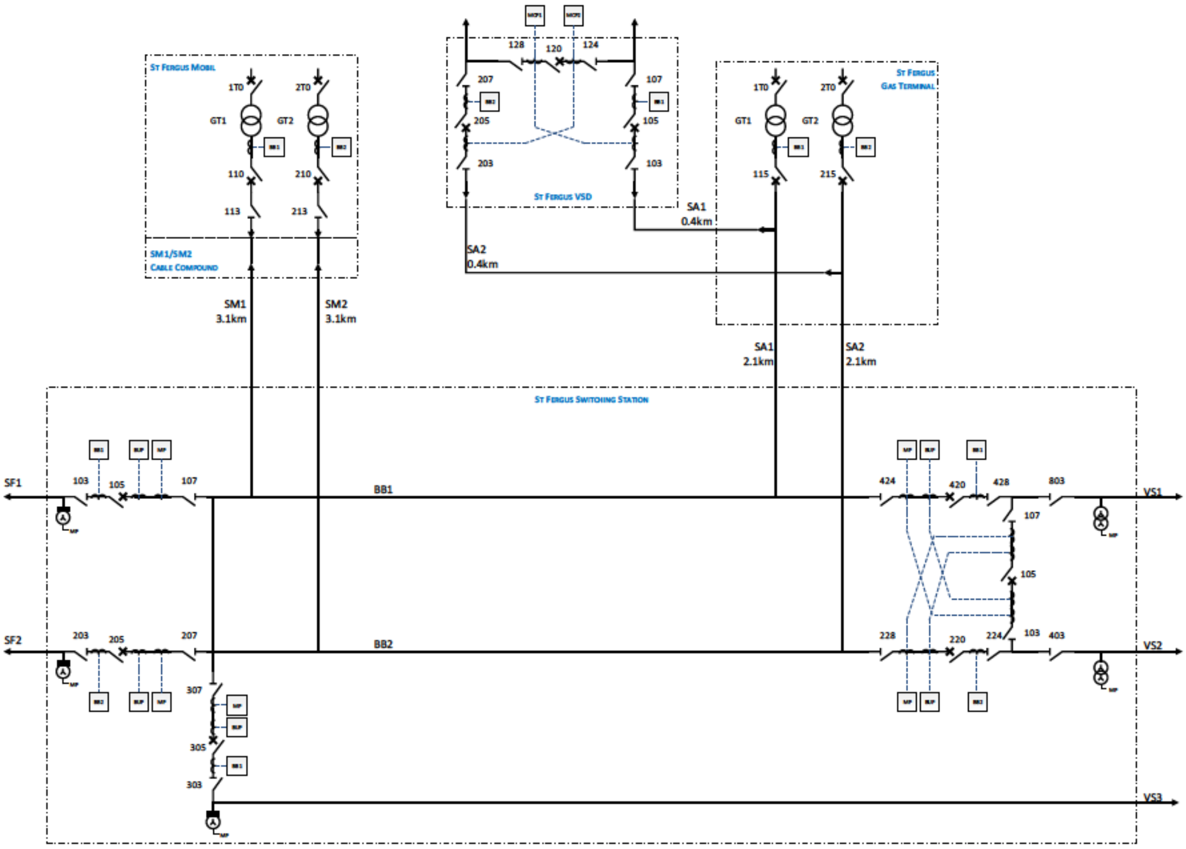


[redacted]

[redacted]

[redacted]

Figure 3-13 - Existing Arrangement



[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Figure 3-16 - Busbar Protection with telecoms infrastructure

[redacted]

- [redacted]

- [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

3.2.5. LVAC and DC Supplies

The batteries, chargers and LVAC at St Fergus Mobil are located within the customer (Ancala) owned control building and provide all LVAC and LVDC supplies at the site.

The LVAC board is owned and maintained by the customer but serves both the customer and SHE Transmission requirements. It is fed from two customer owned earthing and auxiliary transformers. There is no standby generator located at St Fergus Mobil.

There are two 110 V DC systems with SHE Transmission and the customer owning a set each. In addition, SHE Transmission own a 48 V DC system. This single 48 V DC system presents a risk due to the cascade impact of a failure – the protection ring requires all ends to be intact to allow the differential protection to operate correctly, and so the loss of a single 48V supply at St Fergus Mobil will affect all sites in the St Fergus 'ring'. The implications of this on the wider network are the same as a failure to the protection relay as have been explained in section 3.2.4.

The standby batteries for St Fergus Mobil are PowerSafe cells type. They are stored within the control building on racks. This is room does not comply with intrinsically safe installation practices. While the batteries are sealed, they have pressure relief valves fitting for the expulsion of excessive gas build up, which presents a potential safety hazard.

[redacted]

[9] Source: National HVDC Centre https://www.hvdccentre.com/wp-content/uploads/2020/03/HVDC-Grid-Code-Challenges_Cardiff_200320_v1.0.pdf / National Grid Interconnector Register 01 08 2019

3.2.6. Summary

[redacted]

Table 3-2 - Summary of Actions Required in RIIO T2 in St Fergus Area

Asset	Concern	Principal Risks	Intervention Required
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

3.3. Growth Need

A summary of the latest demand and generation capacity connected via these GTs to the wider network is summarised in the tables below:

Table 1: St Fergus Mobil Demand & Generation Summary

Demand		Generation		
Winter Peak (MW)	Summer Min (MW)	Connected (MW)	Contracted (MW)	Total (MW)
9.06	0.24	N/A	N/A	N/A

Demand is not projected to significantly rise in the medium term, thus there is no growth need to be considered for the site.

4. Optioneering

This section presents all the options considered to address the "need" that is described in Section 3. Each option considered here is either discounted at this Optioneering stage with supporting reasoning provided or is taken forward for Detailed Analysis in Section 5.

The need section identified that all 132kV switchgear requires intervention, or it will reach the end of its operational life during the RIIO-T2. This will increase the risk of a supply interruption to the [redacted]

The recommendation from the need, outlined in section 3, means that intervention is required in the RIIO-T2 price control period so the "do nothing" option is not valid.

A summary of the options is presented in the table below:

Table 3: Options Summary

Option	Option Detail	Cost (£m)	Taken forward to Detailed Analysis?
0	Do nothing	-	No
1	Refurbish existing switchgear at St Fergus Mobil in situ in RIIO-T2 – with subsequent replacement by offline build of new indoor substation in RIIO-T3	[redacted] [redacted] [redacted]	Yes
2	Offline build of new indoor substation in RIIO-T2 to replace current St Fergus Mobil	[redacted]	Yes
3	As option 2, with the installation of 2 x 132 kV Circuit Breakers at St Fergus Switching Station on SM1/SM2	[redacted]	Yes
4	Replace switchgear at St Fergus Mobil in situ in RIIO-T2 – with subsequent replacement by offline build of new indoor substation beyond RIIO-T3	[redacted] [redacted] [redacted]	No

With regards to interfacing projects that need to be considered when reviewing these options, any outages taken for these proposed works must be coordinated with the outages under the Peterhead to Inverugie overhead line works in order to secure supplies on the 132kV MITS.

4.1. Option 0: Do nothing

From section 3.2.1, it has been demonstrated that, despite being less than 30 years old, the condition of the switchgear at St Fergus Mobil is such that no intervention is not an option. The switchgear is already subject to a high frequency of [redacted]

NOT PROGRESSED TO DETAILED ANALYSIS

4.2. Option 1: Refurbish existing switchgear at St Fergus Mobil in-situ in RIIO-T2 – with subsequent replacement by offline build of new indoor substation in RIIO-T3

This option considers the refurbishment of the 132kV switchgear at the existing substation. While this option would improve the current state of the plant, it has the following limitations:

- This option would improve the current state of the plant but would not reduce exposure to the marine environment. Therefore, any refurbishment carried out would be under the same environmental pressures caused by the salt air corrosion.
- Based on this, and experience from other similar sites, it is estimated that the refurbishment activity will extend the life of the switchgear by not more than ten years from the current date. The currently installed switchgear has been in service for less than 30 years, so this refurbishment would simply delay the requirement for replacement. This replacement would have to take place in RIIO-T3.
- This option would continue to require maintenance at double the standard interval, with the associated high OPEX costs.
- In contrast, for a new site both exposure to corrosion would be mitigated and the increased maintenance would no longer be required, as current specifications require plant within such proximity to the coast to be indoors. Plant in SHE Transmission substations in locations with similar environments, but where the plant is installed indoors, do not show any deterioration due to corrosion.
- [redacted].

- The outage time for this works would approximately five to seven days (per circuit); including the time taken to establish isolations, by means of disconnecting jumpers as described above.

- This option would require separate work on substation auxiliary supplies – LVAC and batteries – to be carried out. This is covered under a separate non-core, non-load scheme paper. This work is significantly more challenging to deliver on the existing site footprint due to space constraints, limitation of access etc. as outlined elsewhere in this paper.

PROGRESSED TO DETAILED ANALYSIS

4.3. Option 2: Offline build of new indoor substation in RIIO-T2

This option considers an offline rebuild of the St Fergus Mobil substation indoors. The benefits of this solution would be as follows:

- Newly installed switchgear would be protected from the saline atmosphere and therefore would not be subject to the accelerated corrosion seen on the existing switchgear.
    - Therefore, the switchgear would last its full design life rather than requiring replacement or extensive refurbishment in approximately 25 years as would apply if the switchgear was replaced in situ outdoors.
    - The normal maintenance interval could be applied – approximately halving the maintenance related OPEX cost compared to refurbishment or in situ replacement.
    - Plant in SHE Transmission substations in locations with similar environments, but where the plant is installed indoors, do not show any deterioration due to corrosion nor require additional maintenance.

- Outage requirements would be much lower than compared to an in-situ replacement. This would reduce the time that the gas terminals connected to the St Fergus ring were exposed to single circuit risk. As explain in section 3.1, SHE Transmission are not privity to sufficient information to allow us to calculate the macroeconomic consequences of an interruption in gas supply caused by a failure to the electricity supply, but it is reasonable to assume that these would be substantial.

- Acceptable ERTS times could be accommodated compared to an in-situ replacement where this is not to be possible. This would mean that, in the event of a fault on the circuit not being worked on, supplies could be restored to the St Fergus ring much more rapidly.

- LVAC and DC batteries would be according to the requirements for a resilient substation; this would reduce the risk of failure in the supply to control and protection system with an associated possible interruption to supply to sites in the St Fergus ring.

[redacted]

The relocated substation would require revision of the existing cables between St Fergus Mobil and the Sealing End Compound. A number of possible ways to achieve this have been considered, with the support of an independent specialist power cable consultant; these options are explained in detail in section 4.6:

1. Relocate the existing cables.
2. Divert with new cable and terminations at the St Fergus Mobil end,
    a. Using compatible fluid-filled cable and accessories, or
    b. Using XLPE (or other solid polymeric system) cable, transition joints, and terminations to suit the new cable.
3. Leave the existing cables and terminations in situ and add a new route from the existing St Fergus Mobil substation to the new one.
    a. Replace entirely with new cable and terminations,
    b. Largely on the existing route, or
4. As far as possible on a new route.

The following options for power cable connections from St Fergus Switching Station to the relocated St Fergus Mobil substation have been considered:

Table 4-1 - St Fergus Mobil Cable Options

Option	Option Detail	Outcome
1	Relocate the existing cables.	NOT feasible.
2 a	Divert with new cable and terminations at the St Fergus Mobil end, Using compatible fluid-filled cable and accessories	NOT feasible.
2 b	Divert with new cable and terminations at the St Fergus Mobil end,	Feasible but fails to address the issues with the existing cables, resulting in a

	Using XLPE cable, transition joints, and terminations to suit the new cable.	mixed-age system which will require revision in coming years.
3	Leave the existing cables and terminations in situ and add a new route from the existing St Fergus Mobil substation to the new one.	Feasible but fails to address the issues with the existing cables, requiring revision in coming years. Minimum disruption to existing circuits. The existing St Fergus Mobil substation would be partly retained.
4 a	Replace entirely with new cable and terminations, Largely on the existing route	Completely removes the aged cable system. Feasible but disruptive, requiring extensive outages and long ERTS times.
4 b	Replace entirely with new cable and terminations, As far as possible on a new route.	Completely removes the aged cable system. Minimum disruption to existing circuits. Consents for a new route would be required. The preferred option.

This option would also require further planning consent for the new building footprint. No major issues with this are foreseen.

PROGRESSED TO DETAILED ANALYSIS

4.4. Option 3: Offline build of new indoor substation in RIIO-T2 to replace current St Fergus Mobil and installation of two 132 kV CBs at St Fergus Switching Station in RIIO-T3

This option includes option two plus work at St Fergus Switching Station to add circuit breakers, and associated switchgear, on the SM1 and SM2 circuits to St Fergus Mobil. Appropriate modifications to the protection are also included.

A high-level single line diagram of this solution is shown in Appendix E.

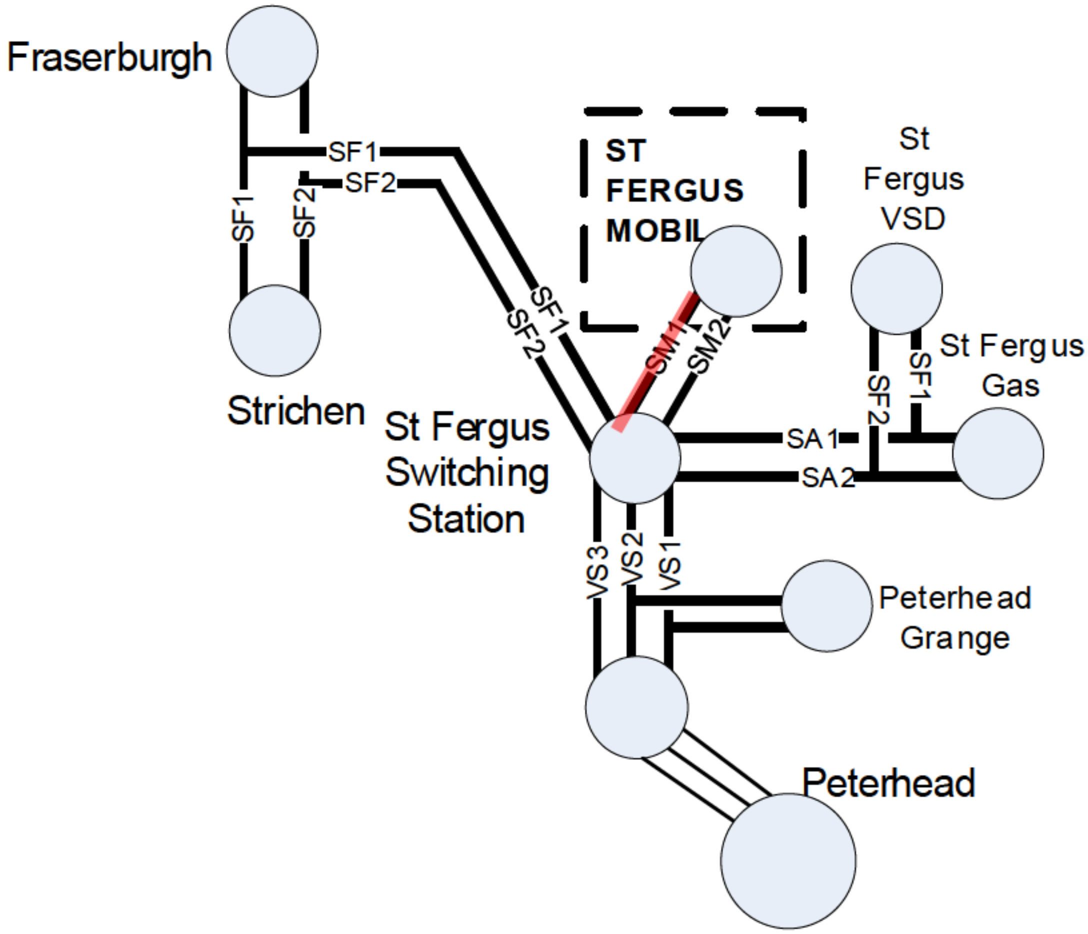
This option brings all the advantages of option two and also has the [redacted]

The effect of these modifications on network outages is shown in Figure 4-1 – it shows no other circuits have to be out of service for a planned outage or fault on the SM1 circuit between St Fergus

Switching Station and St Fergus Mobil, therefore no other connected customers are at single circuit risk, dramatically reducing the risk of an interruption to their supply.

[redacted]

Figure 4-1 - Circuits connected to St Fergus Switching Station - showing outage on SM1 (option 3)



This option would include the modification of the protection accordingly; Figure 4-2 shows the proposed setup with circuit breakers, and associated switchgear, installed to control circuits SM1/SM2:

[redacted]

With the as proposed new plant installed, 2 separate zones of protection are now formed (shown in Figure 4-3). OHL circuits SM1/2 are now protected by dedicated line protections. The busbar protection zone is now limited to the confines of St Fergus Switching Station and SA1/2.

[redacted]

The advantages of this approach are as follows:

[redacted]

PROGRESS TO DETAILED ANALYSIS

4.5. Option 4: Replace switchgear in-situ in RIIO-T3 – with subsequent replacement by offline build of new indoor substation beyond RIIO-T3

This option considers the in-situ replacement of the switchgear, including their supporting structures, at St Fergus Mobil substation. While this option would resolve the immediate problems associated with the condition of the asset, this option suffers from the following limitations:

- This option would not reduce exposure to the marine environment. Therefore, the new plant would be under the same environmental pressures caused by the salt air corrosion.
- This means the replaced plant would have a lifetime of approximately 25 years. This is based on experience at St Fergus Mobil and other SHET substations in similar costal locations; further supported by the Galvanisers Association. In contrast, for a new site, with the plant located indoors, the plant would last the full design life.
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

NOT PROGRESS TO DETAILED ANALYSIS

4.6. Power Cables

This section is relevant to options two and three. It expands on the possible solutions for the 132 kV cables the form the connection into St Fergus Mobil from sealing end compound on the circuit to St Fergus Switching Station:

1. Relocate the existing cables
It is not considered feasible to recover and re-use the existing cables and accessories for a number of reasons.

- The terminations would have to be removed and re-made with new internal components. The successor company to the original manufacturer would be unlikely to support this.
- The cable would have to be excavated and lifted. This is highly likely to cause problems in three subsystems.
    a. The oversheath would be damaged by the process of excavation and handling.
    b. The metallic sheath would be damaged by movement.
    c. The internal arrangement of the lapped paper tapes forming the insulation system is very susceptible to wrinkling of the paper caused by uncontrolled bending.
- Pressure of the fluid within the cable would have to be maintained to prevent the ingress of moisture, air and other contaminants. Any operations involving the insulation being exposed to air would be carried out under conditions of continuous flow of fluid from a temporary fluid feed arrangement at the Sealing End Compound.
- The existing terminations are equipped with porcelain housings, with all the problems that that entails.
- There would be no possibility of manufacturer’s warranty support for a “new” system which is over 28 years old.
- The remaining life of the cable, even if not shortened by the processes involved, would necessitate further complete replacement in the near future.

2. Divert with (a) new fluid-filled cable and accessories
There are very limited options for the supply of new paper-insulated (including fluid-filled) cable and accessories for land applications. New installations are now confined to subsea routes at the highest operating voltages where extruded systems do not yet have much of a track record. Some network operators maintain limited stocks of spare cable for emergency repairs. Former manufacturers and installers are very unlikely to have stocks of suitable cable available.

An added difficulty is that the existing fluid feed arrangement is at St Fergus Mobil; this would have to be dismantled, refurbished, relocated and recommissioned at the relocated substation. A temporary fluid feed arrangement would have to be provided at the sealing end compound during the works. A small number of UK cable installers maintain the expertise and equipment to support the operations.

Diversion with new cable would leave the bulk of the aged cable and the porcelain-housed terminations at the Sealing End Compound in service, with a limited remaining life. It might be possible to re-use the metalwork and porcelain insulator of the existing terminations at St Fergus Mobil, but this would depend on new internal components being designed and manufactured. Sourcing a new joint to connect the new cable to the existing would be highly problematic.

Any diversion of the circuit would involve a lengthy single-circuit outage, likely to be in weeks. During the outage, the emergency return-to-service (ERTS) time in the event of failure of the remaining circuit would be similarly lengthy. This would adversely affect the security of the highly critical supply to the customer.

2. Divert with (b) new XLPE cable, transition joints and terminations

It is possible to cut the existing cable below the St Fergus Mobil terminations and insert a transition joint to a modern extruded cable system, presumably XLPE. The new cable would be terminated into the new substation. In view of the short lengths of new cable required, a custom cable build would NOT be economic; however, cable installers have a flow of similar projects, and an over-length of suitable cable designed for a different contract could be provided. This would probably mean using a more-common conductor size, likely to be 300 mm^2. Consideration would have to be given to the short-circuit rating of whatever sheath design is chosen, to ensure that it meets SSEN requirements.

It would be preferable in many ways for the transition joint to be located very close to the existing terminations within St Fergus Mobil. In this option, the existing fluid feed arrangement could be retained, with the fluid pipes diverted to feed at the fluid side of the new transition joint. However, if the joint were placed elsewhere, further down the route, a new fluid feed arrangement would be required adjacent to the new joint, the existing feed arrangement being decommissioned along with the old terminations. As before, a temporary fluid feed arrangement would have to be provided at the opposite end (at the sealing end compound) to maintain the fluid supply during the works.

A new link box would be provided adjacent to the new joint to accommodate the sheath earth connections to the existing and new cables. The link box could be installed in a pit (under an inspection cover flush with the ground surface) or could alternatively consist of an above-ground kiosk. In either case, the link box would remain accessible for future testing and maintenance of the cable systems on both sides.

Diversion with new cable of any technology would leave the bulk of the aged fluid-filled cable and the porcelain-housed terminations at the sealing end compound in service, with a limited remaining life. Thus, one of the key benefits of the re-built substation would not fully be realised.

Any diversion of the circuit would involve a lengthy single-circuit outage, likely to be in weeks. During the outage, the emergency return-to-service (ERTS) time in the event of failure of the remaining circuit would be similarly lengthy. This would adversely affect the security of the highly critical supply to the customer.

3. Leave in situ and add new route

It would be possible to leave the entire existing circuits as they are, reducing the existing St Fergus Mobil substation to a sealing end compound. At this new compound, new terminations adjacent to the old ones would connect to new cables on a very short route to the new substation. This would minimise disturbance to the existing cables. However, the existing substation arrangement at St Fergus Mobil may NOT provide sufficient space to erect new terminations and install new cable alongside the existing without extensive disruption to other equipment in the substation. Dependent on these considerations, an extensive outage of parts of the substation could be required. Furthermore, this solution would involve retaining the existing cable system in its entirety, doing nothing to address the issues of ageing, corrosion, and porcelain terminations. The existing St Fergus Mobil substation would be reduced to a second Sealing End Compound, which would remain until the existing cables are eventually replaced. These existing aged circuits would require replacement in due course, with the accompanying disruption. If the new very short route were retained and diverted with new cable to the sealing compound, the result would still be circuits of mixed age incorporating an XLPE-XLPE transition joint. The joint would be a significant vulnerability in the final configuration.

4. Replace entirely with new cable and terminations, (a) largely on the existing route

The only solutions that satisfactorily address the issues of ageing, corrosion and porcelain insulators of the existing circuits involve replacing the entire cable system with a new construction. This would consist of modern XLPE cables between new terminations. For this cable requirement totalling some 6 km of single-core cable, a custom-built cable fully meeting SSEN specifications and with optimised conductor size would be procured. The issues of ageing, corrosion and porcelain terminations of the existing circuits would be fully addressed by their total removal:

- Brand new cable system with full warranty
- Composite-housed terminations with greatly reduced fragmentation hazard.

The new route would be entirely ducted; that is, polymeric ducts are first installed along the entire route, and then the cable is pulled into the ducts from one end. This method brings certain advantages including:

- The crossing under the A90 would be achieved by horizontal directional drilling, with no need to trench across the road: in fact, no disruption to road traffic at all;
- On the remainder of the route the ducts would be installed progressively, with no need to have a trench open along the entire route length at any one time;
- The cable is never at any time exposed to view, and thus to theft, at any point along the route outside the two compounds.

One option is to re-use the existing cable corridor for the new cables. This would NOT require new consents for the route, but it would involve extensive physical disruption. It seems likely that the existing cables would have to be drained of cable fluid and entirely removed to allow for the new cables to be installed. This would reduce some of the advantages of the ducted method of installation. However, more critically, it would require both circuits to be out of service for a considerable period of time during the entire process of removal and replacement.

The existing cables are also believed to be installed in ducts along part of the route, including the crossing under the A90. This brings the possibility of re-using the existing ducts for the new cables. However, XLPE cables are generally of larger diameter than fluid-filled cables of the same rating, which may make that difficult. In this case, the bulk of the route is believed to be in the form of one three-phase cable per circuit, so there will be a single duct, which will not be large enough for three single-core cables. Therefore, new ducts would be installed, using horizontal directional drilling where required. The configuration of the new duct arrangement would be designed to suit the new cable system, possibly including separate ducts for the three single-phase power cables and one associated pilot cable for each circuit, or else the power cables and/or the pilot cable could be carried in sub-ducts within one larger duct.

4. Replace entirely with new cable and terminations, (b) largely on a new route

In many ways, the most advantageous solution is to install a new replacement cable system consisting of new cable and terminations on an entirely new route. This would retain the advantages of new cable on the old route:

- Fully compliant modern extruded cable with optimised conductor size;
- Complete removal of the aged, corroded and porcelain-housed equipment;
- Brand new cable system with full warranty;
- Composite-housed terminations with greatly reduced fragmentation hazard.

It would also bring the further advantage that the existing cables would be left in service during the entire installation process. Set against this is the requirement to obtain new consents for the new route, which is likely to be time-consuming.

There is believed to be sufficient space at the Sealing End Compound for the new replacement terminations to be installed alongside the existing. This means that the existing terminations would NOT have to be removed to allow installation of the new ones. If, dependent on the detailed design, more space turns out to be required, it should be possible to extend the Sealing End Compound in such a way that the new cable terminations can be accommodated without disruption to the existing equipment, especially given that the new cables will presumably approach from a new direction. This becomes the least disruptive of all options in terms of the outage requirement. On commissioning of the new circuits, the existing terminations would be decommissioned and removed.

Once the existing cables are out of service, there are options for their decommissioning. The most comprehensive option is to physically remove the existing cables. The fluid content would first be drained out to avoid significant leakage during the process. The cables would be pulled out of the existing ducts, where fitted. On the remainder of the route, a combination of pulling and excavation would be required.

The alternative to complete removal is to drain the cable of fluid, remove the terminations and adjacent cables down to below ground level, permanently end-cap the cables and "abandon" them *in situ*. This method does not entirely eliminate the risk of small volumes of fluid escaping from the low point of the route as the cable degrades in the future. This risk can be addressed by prior treatment of the fluid with an additive: in the event of future leakage, contact with ambient oxygen causes the treated fluid to congeal into an impermeable gel. This blocks off the leak, a process that is actually improved by contact with the surrounding granular backfill material. This solution is also available for leak protection of in-service fluid-filled cables, as the additive has no adverse effect on the electrical or other properties of the fluid.

5. Detailed analysis

5.1 Cost Benefit Analysis

We have carried out a Cost Benefit Analysis (CBA) using counterfactual Net Present Value (NPV) analysis to demonstrate the potential benefits of each of the shortlisted options, with Option 1 presented as the baseline option for comparison purposes. Our CBA Methodology[10] sets the process and mechanics of our approach to CBA.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[10] Cost Benefit Analysis Methodology

Table 5-1 - CBA Summary

CBA reference	Description of Option	Total Forecast Expenditure (£m)	Total NPV	Delta (Option to Baseline)	Total NPV (inc. Monetised Risk)
Baseline (Option 1)	Refurbish existing switchgear at St Fergus Mobil in situ in RIIO-T2 – with subsequent replacement by offline build of new indoor substation in RIIO-T3	[redacted]	[redacted]	[redacted]	[redacted]
Option 2	Offline build of new indoor substation in RIIO-T2 to replace current St Fergus Mobil	[redacted]	[redacted]	[redacted]	[redacted]
Option 3	As option 2, with the installation of 2 x 132 kV Circuit Breakers at St Fergus Switching Station on SM1/SM2	[redacted]	[redacted]	[redacted]	[redacted]

5.2 Proposed solution

All options taken forward for detailed analysis – options one, two and three – return similar levels of NPV. However, once monetised risk is included, only options two and three should be considered. Given the additional benefits to customer security of supply for this critical site, option three is proposed.

The scope of the selected solution is to build an offline 132kV building to house the new 132kV switchgear, along with the addition of two new circuit breakers at St Fergus Switching Station. A copy of the Single Line Diagram (SLD) is shown in Appendix E. The project will be energised within the RIIO-T2 period. The table below details the outputs.

The scheme at St Fergus Mobile is not flagged as eligible for early or late competition due to it being under Ofgem's £50m and £100m thresholds respectively.

Table 5-2: Outputs from preferred option

Plant	Size of new plant	Replacement for
Offline build of new indoor substation, replacement of existing 132kV fluid filled cables plus the installation of 2 new 132kV circuit breakers at St Fergus Switching Station.	4x 132kV circuit breakers 4x 132kV disconnectors 6x 132kV earth switches 2km 132kV cable Building, DC & AC systems	Existing 132kV AIS switchgear and cables at St Fergus Mobil

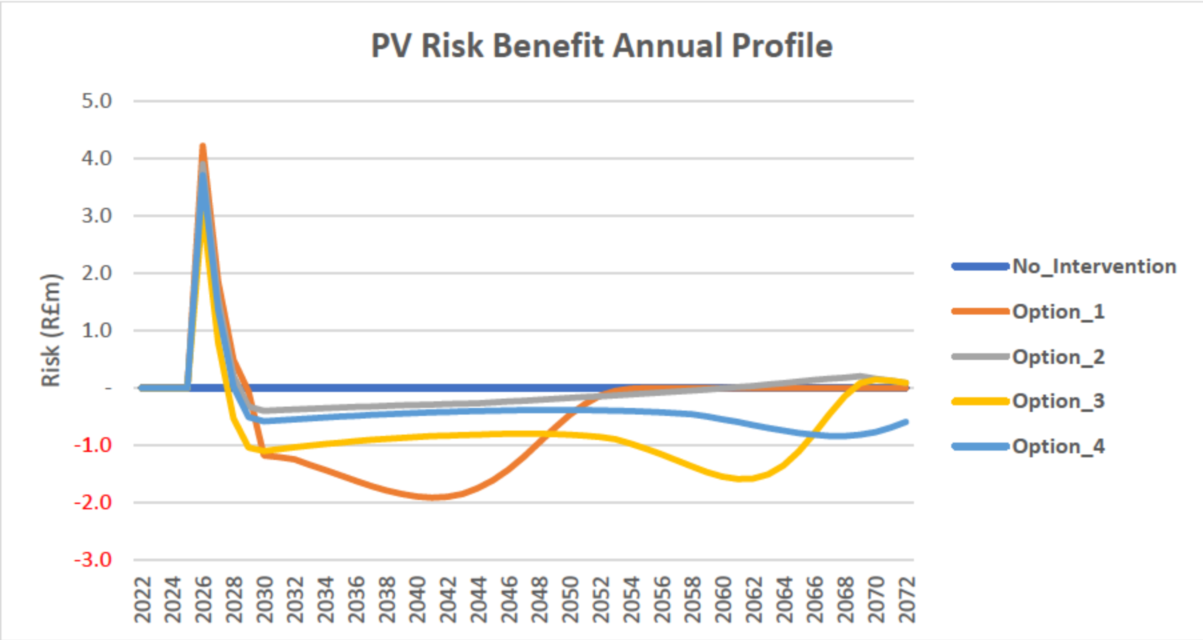
5.3 Risk Benefit

A Risk Benefit Analysis has been carried out in order to compare "no intervention" against the selected "with intervention" option. Please note that while monetised risk is denoted as a financial figure, it is important to note that it is not "real" money and does not correspond to the cost that SHE Transmission would incur if an asset was to fail and these values are thus identified with R£ prefix (for more details please refer to A Network For Net Zero – A Risk Based Approach to Asset Management).

The immediate monetised risk benefit which would be realised through the completion of this project is R[redacted]

In addition to assessing the immediate risk reduction achieved, a long-term benefit has also been determined. The long-term benefit is derived by consideration of the risk of the asset experiencing a catastrophic failure weighted by the probability that the asset will survive for the Options and "no intervention" scenarios. The long-term benefit is an aggregation of the risk of all assets being considered within the option. The risk of each Option is then compared with the "no intervention" scenario. The "no intervention" scenario assumes that when the asset experiences a catastrophic failure the asset is replaced. The long-term benefit of this project is [redacted]. It is critical, however, to recognise that a limitation of the long-term risk benefit modelling tool is that it does not consider the improvements in network resilience, and the associated benefit to the critical connected customers, that the addition of the circuit breaker at St Fergus Switching Station brings. Rather the tool sees this as a disadvantage as the scheme would replace two circuit breakers with four circuit breakers and hence an increased risk over the 50-year LTB model. It is therefore more appropriate to see the output of option three as providing additional benefit to option two, as it provides better security of supply and more network reliability. This benefit is particularly important due to the nature of the critical connection as set out in the needs case.

Figure 5-1 - PV Risk Benefit Annual Profile



5.4 Innovation & Sustainability

Also considered is the use of alternatives to mitigate the use of the greenhouse gas sulphur hexafluoride (SF_6) on SHE Transmission's network. The installation of new CBs at St Fergus Mobil and St Fergus Switching Station will employ a non-SF_6 filled solution. At 132kV there are non-SF_6 alternatives market ready, one of which is being deployed at Dunbeath during RIIO-T1. During the RIIO-T2 period, and in support of our Sustainability and Environmental policies, all 132kV CB replacements will consider the use of non-SF_6 filled technology.

5.5 Carbon Modelling

We are committed to managing resources over the whole asset lifecycle – i.e. including the manufacturing of assets, construction, operations and decommissioning activities – to reduce our greenhouse gas emissions in line with climate science and become a climate resilient business. It is our aspiration that the carbon lifecycle cost of investment options plays a key role within our project development and is considered in the selection of a preferred solution. We have therefore developed an internal carbon pricing model that estimates a carbon cost deriving values for:

1. Embodied carbon, which relates to the carbon emissions associated with the manufacturing and production of the materials use in production of the lead assets (transformer, reactors, underground cables and Overhead lines. Overhead line is made up of tower/wood pole/composite pole, conductor and fittings) procured and installed as part of the project.
2. The carbon emissions associated with the main stages of the project lifecycle (construction, operations and decommissioning).

It is our vision to embed carbon considerations within our strategic optioneering and project development processes, which will require us to determine a way of flagging high carbon options within our CBA outputs. We will continue to develop our thinking in this space, which will involve our model being validated by a third party, so the results included in this EJP are indicative and subject to change.

In terms of the results of analysis for this project, which are captured in the carbon footprint results table,

Table 6: Carbon Calculation Summary

Project Information		1	2	3	4
Project info	Project Name/number	0	0	0	0
	Construction Start Year	2026	2026	2026	2026
	Construction End Year	2026	2026	2026	2026
Cost estimate £GBP	Embodied carbon	£8,868	£110,841	£119,709	£8,868
	Construction	£11,376	£223,109	£234,485	£11,376
	Operations	£39,754	£39,755	£79,509	£39,754
	Decommissioning	£5,249	£102,949	£108,199	£5,249
	Total Project Carbon Cost Estimate	£65,247	£476,654	£541,901	£65,247

Carbon footprint tCO2e	Embodied carbon	118	1,480	1,598	118
	Construction	152	2,979	3,131	152
	Operations	183	183	367	183
	Decommissioning	15	298	313	15
	Total Project Carbon (tCO2e)	469	4,940	5,409	469
Project Carbon Footprint by Emission Category	Total Scope 1 (tCO2e)	76	76	152	76
	Total Scope 2 (tCO2e)	107	107	215	107
	Total Scope 3 (tCO2e)	286	4,757	5,043	286
SF_6 Emissions	Total SF_6 Emissions 3 (tCO2e)	68	68	137	68

5.6 Cost Estimate

The cost of the preferred option for works at St Fergus Mobil has been developed using rates from existing substation framework contracts and benchmarks from delivered RIIO-T1 projects. These have been applied to indicative quantities obtained from layout drawings. The total cost for delivering the scope of works for the proposed solution [redacted]

6. Conclusion

This paper identifies the need for intervention on the 132kV switchgear at St Fergus Mobil substation and St Fergus Switching Station. The primary drivers for this scheme are the asset conditions and security of supply.

Four intervention options were identified for this scheme, which were all considered for detailed analysis.

The proposed scope of work has been selected as a result of the site's criticality and will improve the security of supply to several important customers in the area. It is option three and includes:

- Offline replacement of the 132 kV AIS switchgear at St Fergus Mobil with new switchgear;
- Installation of this new switchgear and other required equipment in a building, in order to remove the effects on the harsh costal environment on asset life;
- Suitable 132 kV cable to connect this new substation to the overhead lines at the existing cable compound;
- The installation of AIS switchgear as St Fergus Switching station in order to improve security of supply to critical customers and increase operational resilience;
- Associated control and protection modifications also required in order to improve security of supply to critical customers and increase operational resilience.

The cost to deliver this scheme [redacted] the works are planned to be completed within the RIIO-T2 period.

The scheme at St Fergus Mobile is not flagged as eligible for early or late competition due to it being under Ofgem's £50m and £100m thresholds respectively.

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[11] £12.7m at 2018-19 costs – previous edition of the paper had included out turn costs in error.

7. Price Control Deliverables and Ring Fencing

As set out in our Regulatory Framework paper (section 1.12 and Appendix 3) we support a key principle from Citizens Advice – one that guarantees delivery of outcomes equivalent to the funding received - to ensure that RIIO-T2 really deliver for consumers.

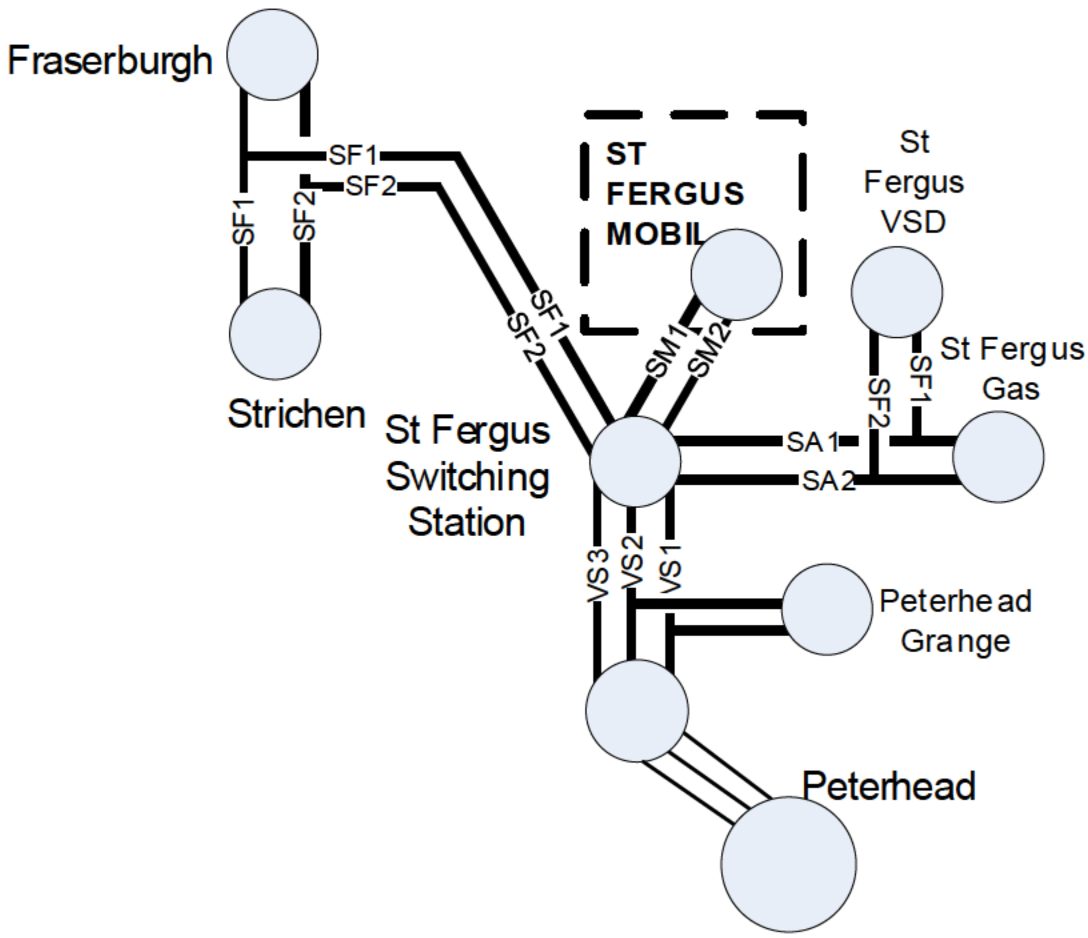
For our core non-load projects this means that we commit to delivering our overarching NARMs target. If we do not deliver the NARMS target, or a materially equivalent target, then we should be subject to a penalty. Equally, if we over-deliver against our target and are able to justify that the over-delivery is in the consumers interests and could not have been reasonably factored into our business plan at the time of target setting then we should be made cost neutral for this work.

Non-core non load projects should not be ring fenced. This is to allow for substitution of projects in order to meet that NARMs target. We need flexibility to respond to up to date asset data information or external influences on our network during the price control; this information might drive us to substitute one project for another in order to ensure a reliable and resilient network. Ring fencing projects may result in sub-optimal decisions, having adverse consequences for the health of our network, which will ultimately be reflected in the NARMs target.

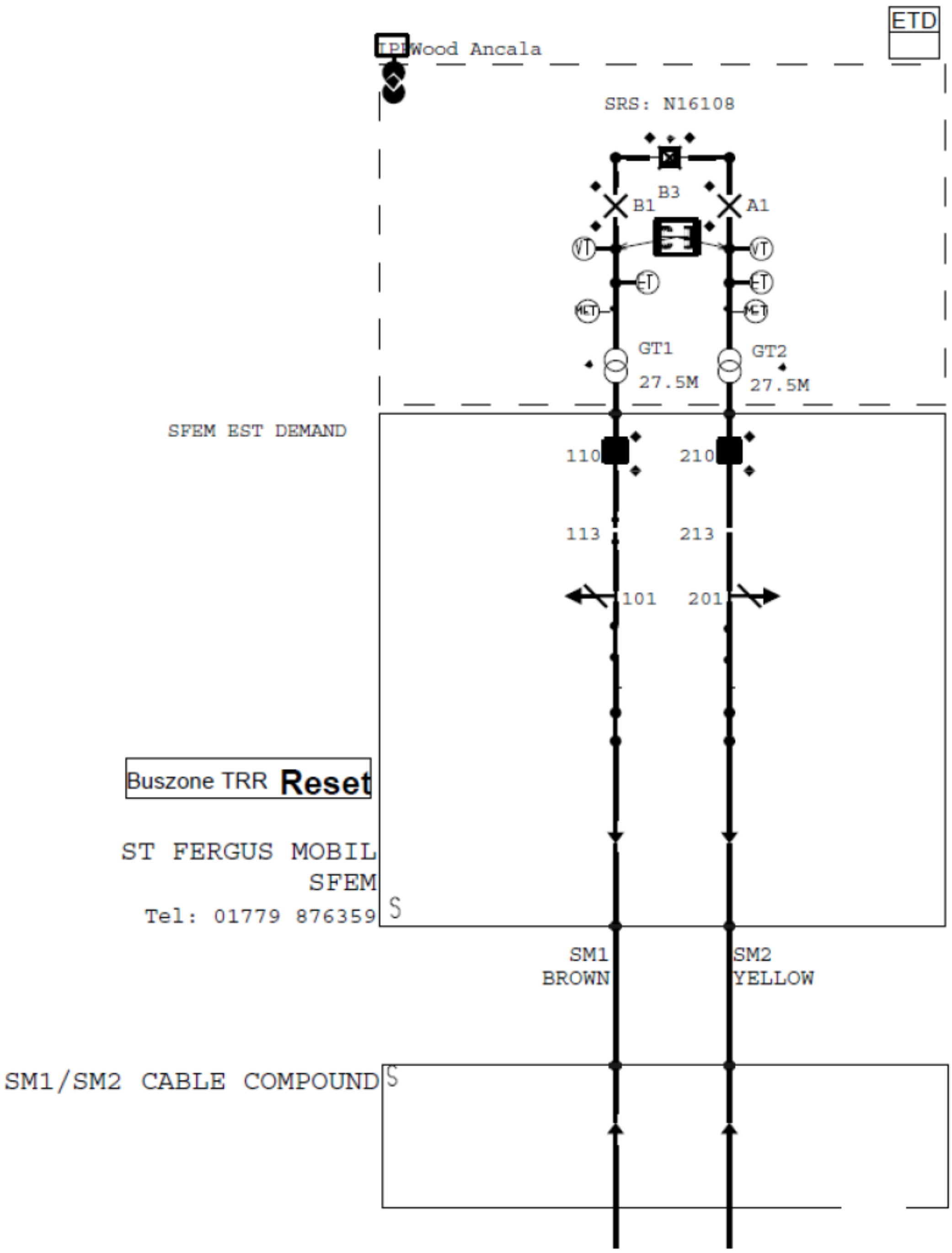
8. Outputs included in RIIO-T1 Plans

There are no outputs associated with this scheme included in our RIIO-T1 plans.

Appendix A: Overall MITS Network Diagram

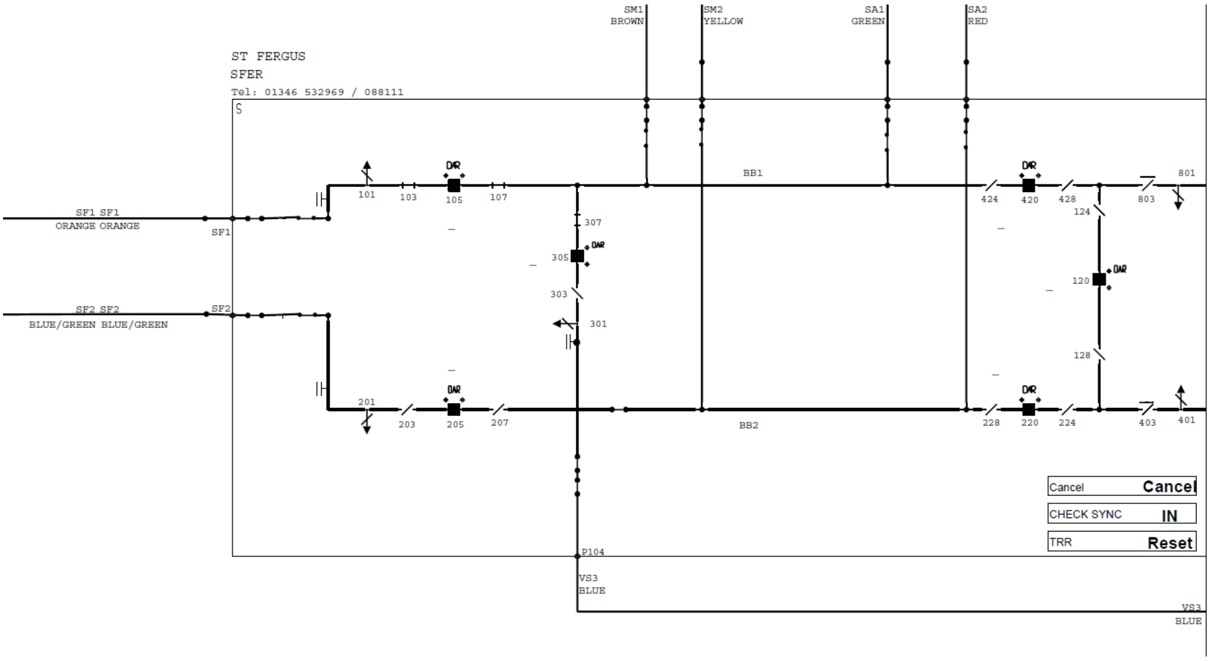


Appendix B: St Fergus Mobil Substation Network Configuration

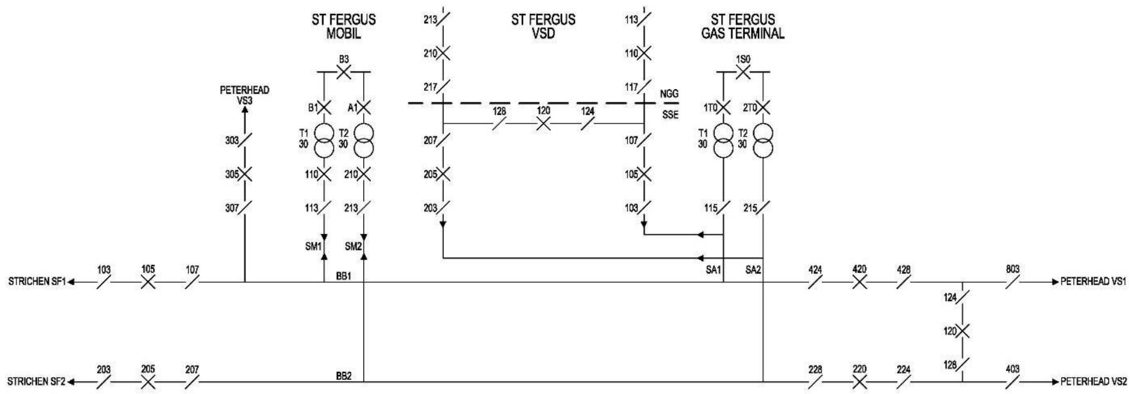


Appendix C: St Fergus Switching Station Network Configuration

Note the absence of circuit breakers or disconnectors on the SM1 / SM2 circuits to St Fergus Mobil and on the SA1 / SA2 circuits to St Fergus VSD and St Fergus Gas.



Appendix D: St Fergus Area Network Configuration



Appendix E: SLD for St Fergus Mobil / St Fergus Switching Station Works