SSEN Transmission

RIIO-T2 Business Plan - T2BP-EJP-0012

Scottish & Southern Electricity Networks

Integrated Condition & Performance Monitoring Engineering Justification Paper

1 Executive Summary

SHE-Transmission has received detailed feedback from Ofgem and their consultants at draft determination stage. As an outcome of this feedback, and through the questions asked and responses provided in the SQ process this EJP has been revised. Options have been re-assessed in accordance with draft determination feedback and has been redrafted with a more incremental scope and approach in RIIO T2 based around addressing the specific identified needs cases which have been explained in more detail. The original EJP scope has been split into two separate paper since the original submission, with the Dynamic Line Rating portion being presented in a separate paper, T2BP-EJP-0050. This paper now deals solely with the substation related aspects of condition monitoring.

This Engineering Justification paper sets out the need for Integrated Condition & Performance Monitoring (ICPM) on a range of assets to address condition issues on a selection of ageing, poorly performing assets as well as those with identified type issues. It will also reduce operational and health and safety risks on specified critical assets and facilitate optimisation of TOTEX, both throughout the life of assets and at the end of their life.

SHE Transmission has outlined the following deliverables from this approach:

- Installation of online DGA :
  - 13 Multigas DGA monitors
  - 24 Single/composite gas DGA monitors
- Installation of tapchanger monitoring on
  - 20 Transformers
- Installation of bushing monitoring on
  - 16 Transformers
- Installation of Online Gas Density Monitoring on
  - 163 AIS breakers
  - 7 complete GIS substation boards.
- PD Monitoring Solutions for
  - 56 Cable Sealing Ends
  - 16 Transformers

- CB trip coil timing retrofit
    - 35 circuit breakers existing associated fault recorder installations.
- Local Environmental Monitoring
    - 11 High altitude substations
- Forensic Analysis of
    - 26 Transformers and a single reactor that are due to be removed from the network in T2.
- Deployment and Integration of Data Analytics
    - Integration with Data Analytics Platforms
    - Engagement with 3rd Party Data Analytics Providers and Academia.

The cost to deliver the preferred option stands at £16.36m. This cost is based on a detailed analysis of previous experience, actual quoted contractor prices for similar installations and a bottom up costing process where this was not possible. It would be delivered as an ongoing programme of works throughout the RIIO-T2 period.

Each individual technology proposed will produce significant benefits by addressing the needs case outlined in Section 3 Need, with section 4.1 Technical Assessment outlining how the technologies meet the needs case and shows other benefits they provide. Overall the programme of integrated condition monitoring will deliver significant benefits for the operational performance of network, reductions in health and safety risks, improved security of supply and system resilience. This investment will allow significant improvements in our asset condition data collection and analysis of this information allowing much improved future business planning, allow for reduced lifecycle cost and significant risk reduction improvements on our asset fleet. The program of works allows SHE Transmission to meet the recommendations of the EDTF in both detail and spirit. These improvements can largely be conceptualised as significant reductions in the risks present on the network and these are outlined in section 5 Detailed Analysis, with a risk benefits comparison completed as shown in section 5.1 Risk and Benefit Analysis.

The do-nothing option would not alleviate any of the specific and demonstrable condition and performance issues for the assets outlined in section 3 Needs. As shown in Section 5 where detailed analysis of the options is undertaken, doing nothing leaves unacceptable risks on the network which if unmitigated can have significant consequences as demonstrated through past experience of disruptive failures.

A key benefit provided by this paper will be an improvement to the safety of the network by avoiding catastrophic failure of porcelain sealing ends and oil filled plant, which could injure staff, members of the public or contractors or significantly damage nearby property.

Upon delivery, several benefits specifically relating to the RIIO-T2 business goals will be realised:

- Significantly improving the security of supply by reducing potential for unplanned outages, due to asset failures or faults. This comprises one of the major contributing actions towards adhering to the goal to aim for 100% transmission network reliability for homes and businesses.
- Much improved longer term planning of asset investment and subsequent risk reduction due to the availability of near real-time data. Reducing overall life time costing of the assets and contributing to the "£100 million in efficiency savings from innovation" goal in the Network for Net Zero" business plan. This will also contribute towards the provision of better data and information on asset condition to inform future price control submissions.
- Reduction of SF_6 leakage, and better analysis and information of current assets allow improved operational efficiency and asset utilisation. This helps to achieve the SHE Transmission goal of "One third reduction in our greenhouse gas emissions" stated in the RIIO T2 business plan.

This scheme 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	Integrated Condition and Performance Monitoring
Primary Investment Driver	Security of Supply
Scheme reference/ mechanism or category	SHNLT2044
Output references/type	NLRT2SH2044
Cost	£16.36m
Delivery Year	Within the RIIO-T2 period
Reporting Table	C2.25
Outputs included in RIIO-T1 Business Plan	No

2 Introduction

This Engineering Justification Paper sets out our plans to install and deploy Integrated Condition & Performance Monitoring during the RIIO-T2 period (April 2021 to March 2026).

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: Price Control Deliverables and Ring Fencing

This section provides a view of whether the proposed scheme should be ring-fenced or subject to other funding mechanisms.

Section 8: 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.

Changes from our December Submission

SHE Transmission appointed an independent specialist consultant (Kinectrics) to review the scope and contents of the original EJP. Following this review, the previous paper which requested £45.46m in funding to deliver both substation condition monitoring and dynamic line rating equipment has been split, with this paper focussing solely on the substation aspect of the paper. This new substation specific paper now proposes £16.36m in funding for the RIIO T2 period.

The paper was fully reviewed to address the issues identified in the Atkins review and the SQ's received following the submission of the business plan.

This review has consisted of re-assessing the needs case such that it is fully defined, with a specific and detailed needs case for each technology type and class deployed and outlining how this links with our wider risk based approach to asset management and our digital strategy and data analytics ambitions and requirements.

A full optioneering process was then completed for this re-defined needs case with 3 detailed options proposed – minimum requirements, responsible operator and progressive utility, as well as assessing the impact of a 'do nothing' option.

The independent specialist consultant has helped to produce a risk benefit analysis that shows the benefits of the chosen options and provides a comparative analysis to show the option that provides best value for money. This has been done using the PROSORT risk benefit analysis tool and methodology, which the paper and the appendices explain in detail.

3 Need

The SHE Transmission network is comprised of 4,904km of high voltage overhead lines and around 279km of underground and subsea cables. It is also comprised of 145 substations with 242 in service transformers ranging from 22.5MVA up to 1200MVA, and 479 circuit breakers operating at 132, 275 & 400kV.

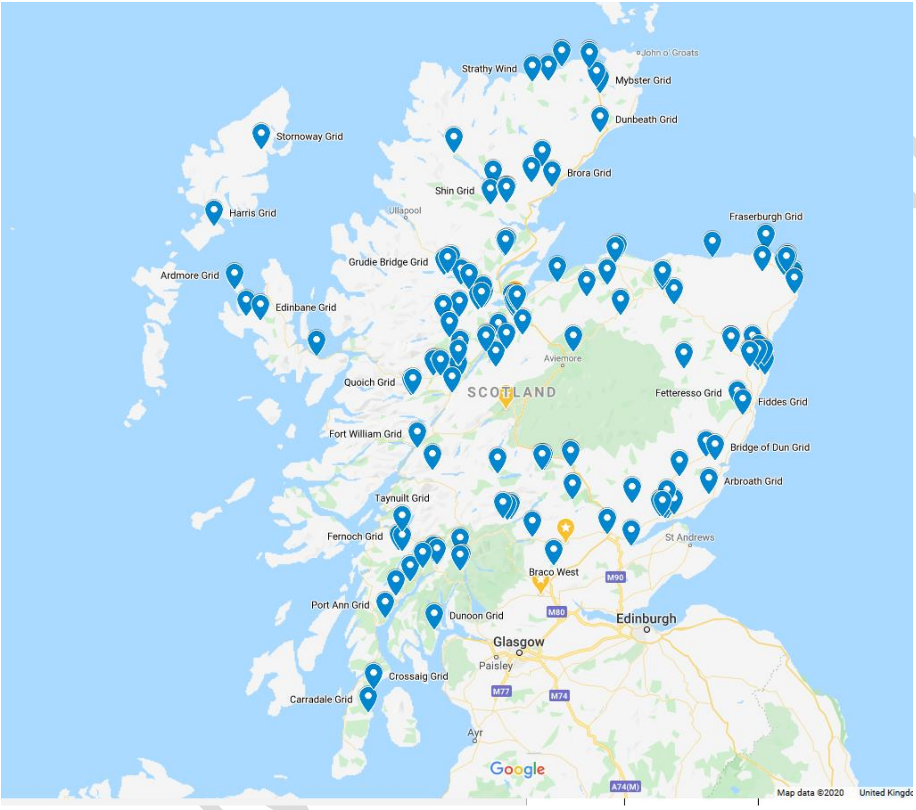

Figure 1 - Geographical Map showing SHE Transmission Substation Sites

Our licence area covers around 70% of the land mass of Scotland serving remote and, in some cases, island communities. The growth of renewables to remote areas is set to continue typically in remote areas away from dense population centres. This presents a specific set of operational challenges in managing assets that take a long time to access and requires careful planning for replacement and maintenance.

The SHE Transmission network also contains numerous assets approaching or exceeding their design life, and a number of assets with known performance and condition issues that require active monitoring in order to alleviate the risks associated with managing these assets to perform their functional duty and to the end of life.

The continued growth of the transmission electricity network in the north of Scotland, and the resultant increased pressures on ageing substation and field resources, mean that new and innovative solutions are required to operate and respond to the challenge in line with our Risk Based Approach to Asset Management.

This needs section will breakdown these assets in separate categories to describe the operational and condition requirements that necessitate active monitoring.

3.1 Drivers

3.1.1 Transformers and Reactors

SHE Transmission has a significant number of transformers that are approaching or have exceeded their design life. In total 48 transformers have now exceeded their 40 year design life, which accounts for 20% of the population.

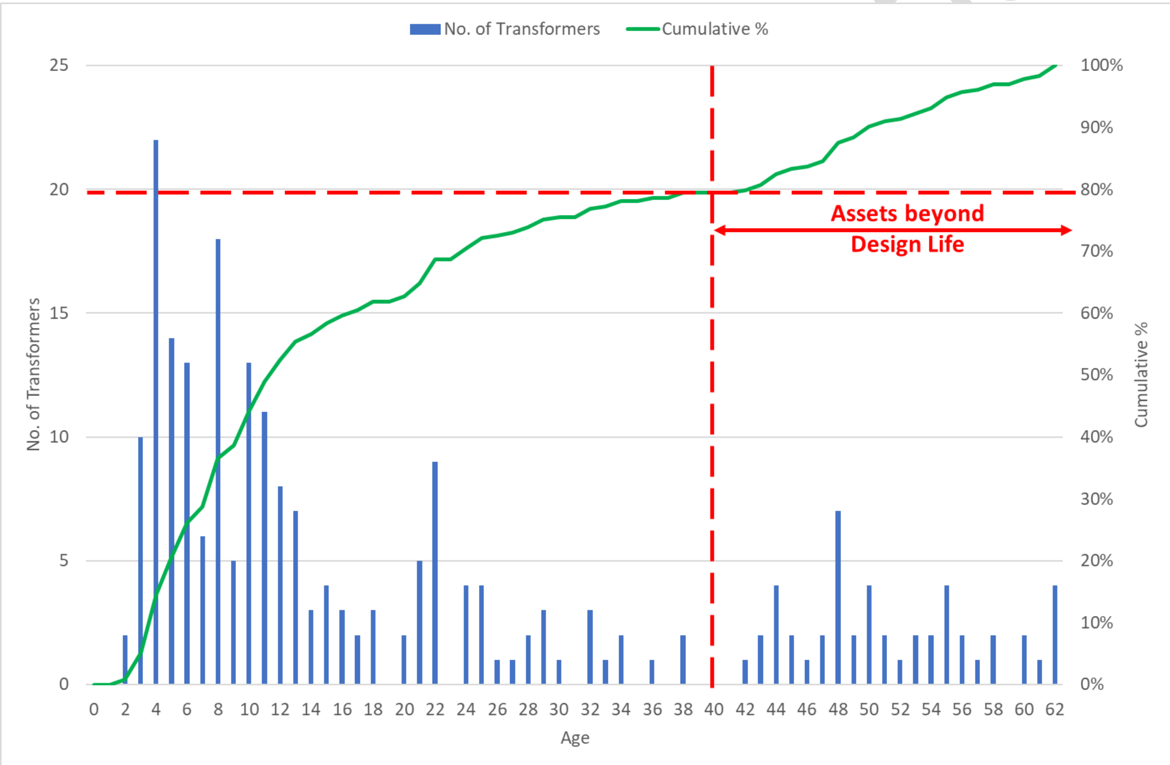

Figure 2 - Transformer Age Profile

Experience of operating transformers beyond their design life is limited and while many of these assets appear relatively healthy at present their condition will continue to deteriorate through age-based mechanisms. Therefore, it is necessary to develop an understanding of how the wear-out phase of the bathtub curve will transpire as we may begin to see the emergence of failure mechanisms that have not been commonly observed before. These concerns are not limited to the active parts of the transformers but extends to the condition of their subsystems and major components such as tapchangers and bushings, many of which are now obsolete. Developing this understanding is vital to efficiently managing the entire population in the short, medium and long-term.

One way of increasing this knowledge base would be to perform post decommissioning forensic analysis of any transformers removed from service – whether through planned or forced replacement. As outlined in Cigre Technical Brochure TB735, when a transformer is permanently removed from service and scrapped (regardless of the underlying reasons), the opportunity arises to perform a detailed and destructive forensic examination of the transformer. From this examination direct observations and measurements can be made and material samples collected for laboratory analysis and interpretation as well as any underlying defects or flaws discovered. Any learnings from this process can then be extended directly to other units in the population.

In addition to the above, there are also a number of transformers and reactors that are exhibiting specific performance and condition issues ahead of their anticipated end-of-life. Examples of condition issues recently observed or experienced on our transformer and reactor populations include the following (this list is not exhaustive):

- A number of transformers and reactors have been observed to show gas patterns that are indicative of an underlying problem or incipient fault. This issue is not limited to assets beyond their design lives, but extends to new assets that are showing signs of potential wear-in failure.

- In some cases, these issues have been observed to occur on assets of the same type or manufacture. Potential type defects warrant further investigation to confirm whether the observed issues are part of a wider problem and to mitigate the potential effects of multiple asset failures.

- Instances of partial discharge have been identified on new and aged assets in the T1 period. As a significant proportion of the transformer assets base is starting to exceed its design life new condition issues will emerge. SHE Transmission will require enhanced capability to detect and react to these faults in the future.

- SHE Transmission has experience in recent years of operational restrictions being applied to legacy assets such as tapchangers due to identified type defects. These identified defects need to be managed over the life of the assets as it's not always possible to rectify these via corrective maintenance actions due to the volumes of affected assets.

We have specific criticality challenges for a selection of our transformers:

- Safety and proximity – we have a number of older assets located in built-up areas and in close proximity to third-party property and assets, some of which are classified as or are supplying sites of Critical National Infrastructure, are in key locations of economic importance or would cause wider societal disruption were they to fail disruptively. Many of these legacy sites were not built to current specifications and CDM design and safety standards.

- Legacy site design - Some older sites have unconventional site layouts and unique transformer designs that do not conform to current standards where there is no appropriate separation of assets, and in situ replacements or extensive refurbishment work is not possible or practical.
- Remote Locations – SHE Transmission has a number of assets in remote or difficult to reach areas. Some of these are windfarm substations which are difficult to reach in adverse (and often normal) weather conditions. SHE Transmission also has assets in areas susceptible to wild fires, flooding and land slips.

A recent example of a failure of an asset in a remote location is Nant GT1 Transformer failure in 2017, where a disruptive transformer failure occurred. Figure 3 - Nant Transformer Failure – GT1 2017 and Figure 4 - Nant Transformer Failure GT1 2017 are included to highlight the potential safety, environmental and wider societal impacts of such an event occurring at a critical location.

Figure 3 - Nant Transformer Failure – GT1 2017

Figure 4 - Nant Transformer Failure GT1 2017

3.1.2 AIS Circuit Breakers

A number of AIS SF_6 circuit breakers have exhibited very poor leak performance over the RIIO-T1 period. This has posed a significant environmental and operational challenge with a large number of forced unplanned outages required to rectify SF_6 leaks.

SHE Transmission participates in the International Transmission Operations & Maintenance Study (ITOMS). The most recent study in 2019 showed that 60% of forced and fault outages involving circuit breakers (in excess of 5 minutes) on the SHE Transmission network were caused by SF_6 leaks or alarms. As a result, the peer average performance for outages per breaker was three times better than SHE Transmission.

During five years of the current price control period SHE Transmission has exceeded the Ofgem target for SF_6 emissions. Approximately three-quarters of SF_6 gas leaks that occurred during the RIIO-T1 price control to date can be attributed to AIS circuit breakers. The proportion of leaks by asset category in RIIO-T1 is shown in Figure 5.

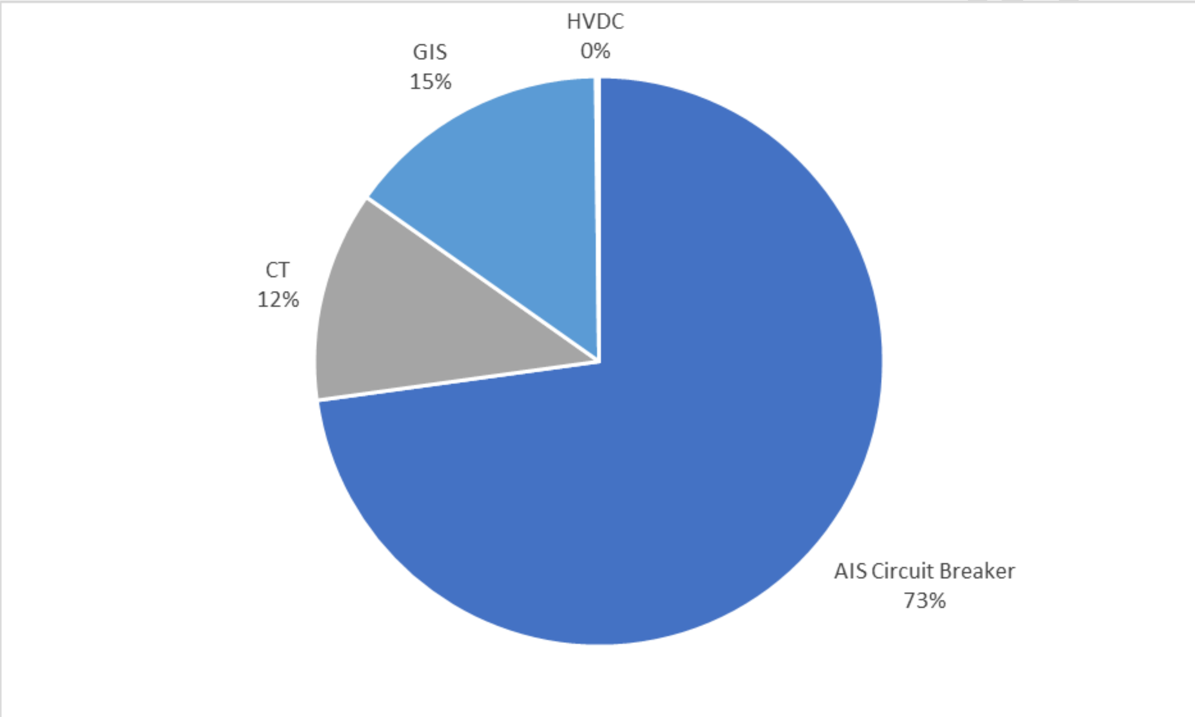

Figure 5 - SF_6 Leaks by Asset Category during RIIO-T1

To Illustrate the leak performance of the operating circuit breaker population the bubble chart shown in Figure 6 has been produced. Each bubble represents an operating SF_6 circuit breaker that has experienced a leak. The bubbles are plotted on the chart according to the number of pumping records for those assets and their leakage rate over the RIIO-T1 price control. The number of pumping records is a measure of how problematic these assets are from an operational perspective (i.e. how often corrective maintenance action is required) while the leakage rate is a measure of an assets environmental performance. The size of each bubble is relative to the amount of gas leaked during the current price control.

It is clear to see that a number of assets have required pumping activities at a rate that far exceeds their routine periodic maintenance frequency. This means that unplanned or forced outages, which place the wider network at undue risk, are often required so that inefficient reactive maintenance can take place. In addition, it is also shown that a large number of assets leak gas at more than the manufacturer's specified leakage rate.

Note that two outliers have been removed from this chart to aid the presentation of the data. The removed outliers are not considered representative of the AIS circuit breaker population.

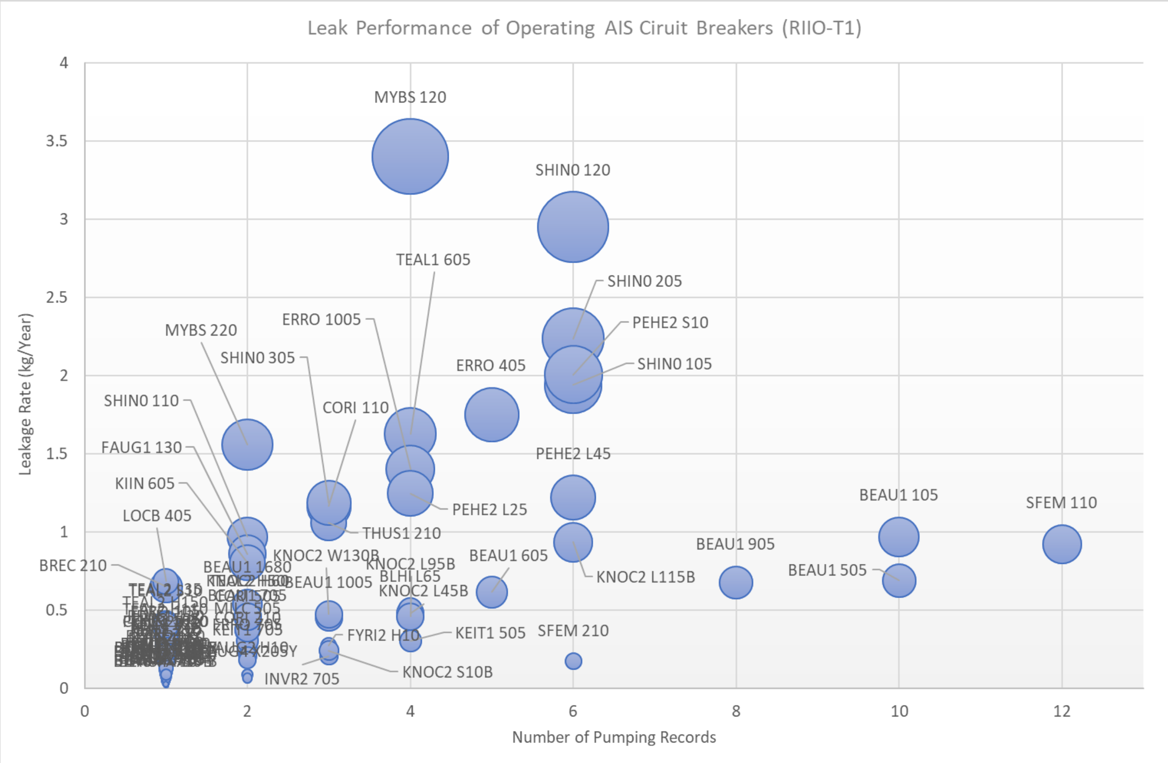

Figure 6 - AIS Circuit Breaker SF_6 Leak Performance (RIIO-T1)

A similar chart showing the performance of different AIS circuit breaker types over the RIIO-T1 price control is shown in Figure 7. In this chart the size of the bubbles is relative to the number of assets that have contributed to the amount of gas leaked on different circuit breaker types. It is shown that certain types of circuit breaker are responsible for a large percentage of overall leaks, or that they have proven to be consistently problematic and required numerous top-ups.

To further understand the performance of different circuit breaker types when they have experienced a leak, Figure 8 shows the average number of pumping records plotted against the average weight of gas pumped. This provides a means of comparing the relative performance of different types of circuit breaker.

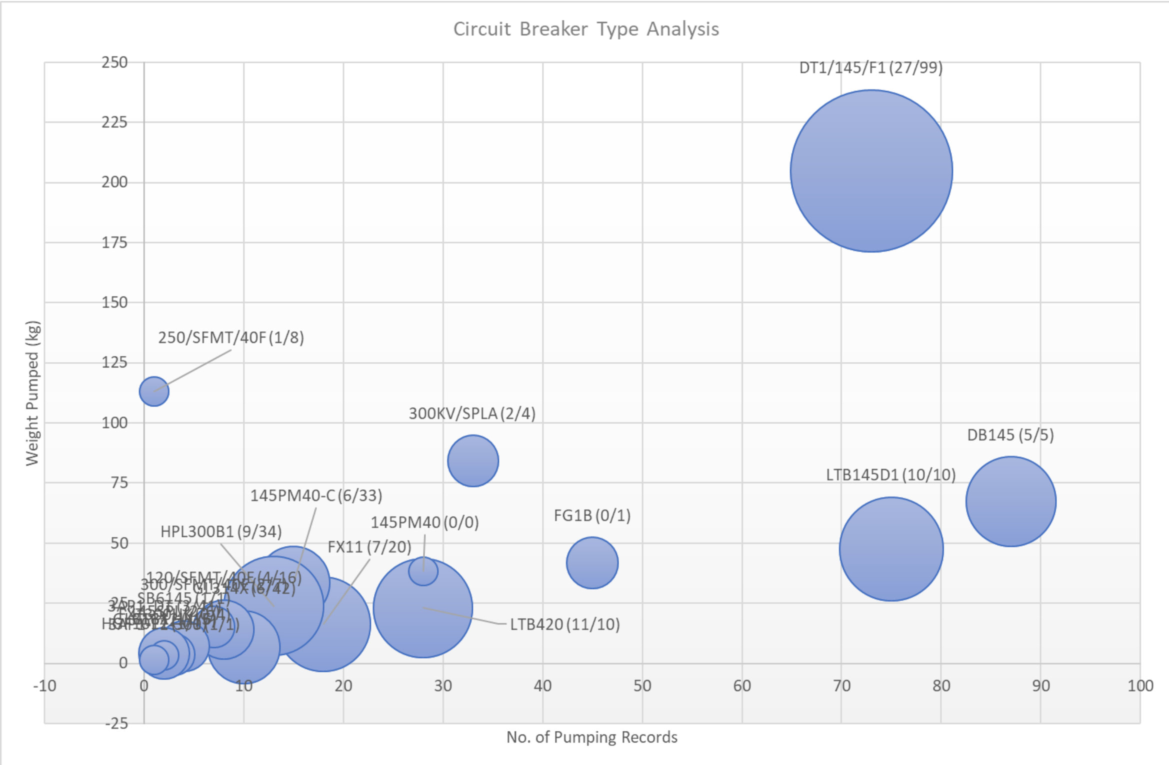

Figure 7 - AIS Circuit Breaker SF_6 Leak Performance by Type

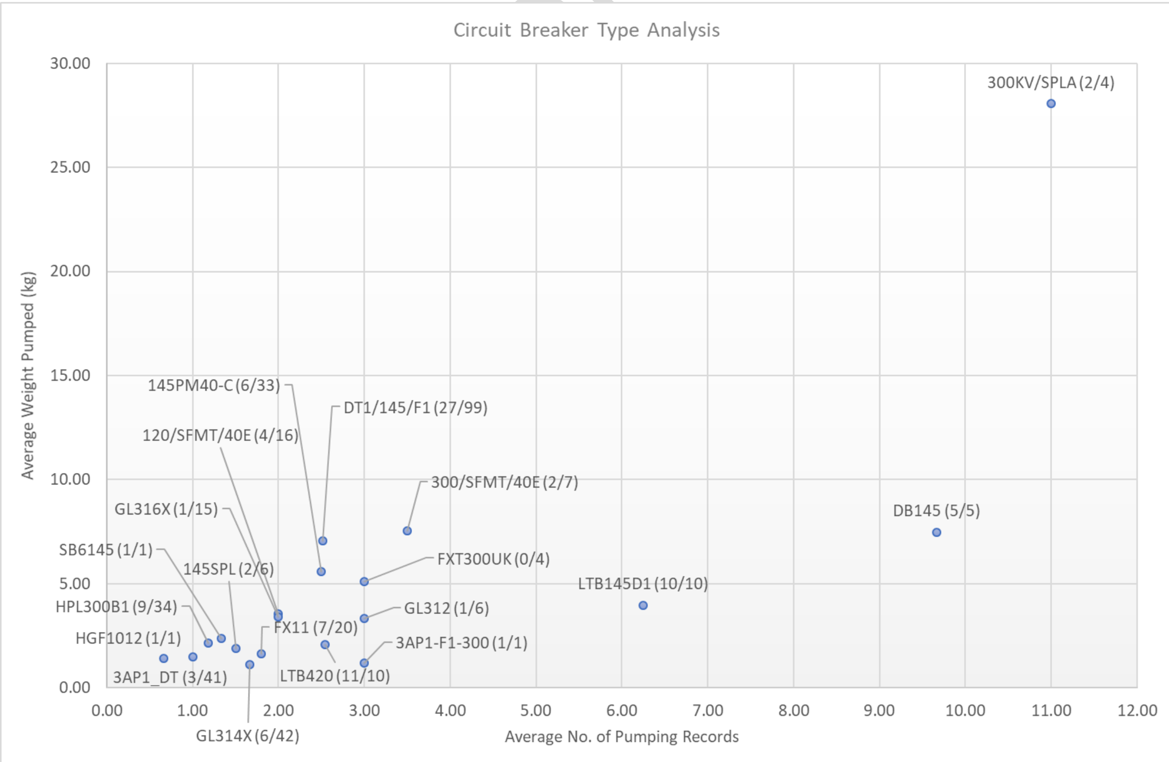

Figure 8 - AIS Circuit Breaker Average SF_6 Leak Performance by Type

3.1.3 GIS Switchgear

Gas Insulated Switchgear (GIS) was first installed on the SHE Transmission network in 2013 which makes it a relatively new technology for our network. Since this time several other GIS installations have been successfully added to the network over the course of RIIO-T1. Table 1 shows a list of these assets and the amount of SF_6 they contain. In total, the mass of gas contained in these assets accounts for 56% of our SF_6 inventory.

Table 1 - Operating GIS Sites

Substation	SF_6 Mass (kg)	Commissioning. Year
Aberdeen Bay 132kV GIS Substation*	99.84	2018
Blackhillock 132kV GIS Substation	599.10	2018
Blackhillock 400kV GIS Substation	7,618.45	2018
Crossaig 132kV GIS Substation	2,558.00	2016
Dounreay 132kV GIS Substation	894.20	2013
Dounreay 275kV GIS Substation	2,384.00	2013
Dounreay 275kV GIS Substation (extension)	1,724.00	2017
Sloy 132kV GIS Substation	1,398.00	2013
Spittal 132kV GIS Substation	1,144.00	2018
Spittal 275kV GIS Substation	2,896.80	2018
Tomatin 132kV GIS Substation	2,195.00	2020

*Single bay GIS only

Because these assets are in the early-life phase of their lifecycle we are still developing an understanding of their operational performance. To date we have experienced poor leak performance on a selection of GIS assets. Leak performance has been noted to be particularly bad on outdoor GIS assets. This has resulted in poor operational and environmental performance which has required numerous inefficient reactive maintenance activities to be taken. Rectification of leaks on GIS equipment requires specialist support personnel, often only available directly from the OEM and can have long lead times for provision of this support, particularly as the attendance of these personnel often requires international travel and specialist parts or equipment to be delivered by the OEM. Current installation leaks are only identified via low gas and lockout alarms, meaning extended forced outages can occur on the poorly performing sections of GIS, which are often in critical nodes of the network. This introduces significant operational risk and reduced capacities in the wider system.

While GIS assets only account for 15% of SF_6 emissions on the SHE Transmission network in the RIIO-T1 period, the number of GIS installations is increasing and the percentage of leaks from GIS assets is expected to increase in the future. The large quantities of SF_6 contained in these assets means that there is an increased likelihood of larger gas leaks which is detrimental from an environmental perspective. It is anticipated that our SF_6 inventory will approximately double between now and the end of the RIIO-T2 price control. This is largely due to the installation and commissioning of further GIS substations over the remainder of RIIO-T1 and over the course of RIIO-T2. Therefore, with the increasing amount of gas installed on the network there is an increased potential for gas leaks without mitigation.

A method of trending gas values is therefore required to improve operational and environmental performance. In addition, it is necessary to develop a means of condition assessing these assets to develop an understanding of their performance across the whole asset lifecycle.

3.1.4 Partial Discharge Measurement

Partial Discharge(PD) monitoring is a very well established technology and asset health assessment technique used widely across the industry, and within SHE Transmission.

PD is a small electrical discharge that can occurs across a localised area of the insulation medium of HV assets – it can be caused by discontinuities or imperfections in the insulation medium, but this discharge doesn't bridge the full insulation gap. It can be the sign of an incipient fault within the HV asset and can provide an early warning and help localise a future failure of any HV asset.

SHE Transmission currently procures periodic and targeted partial discharge surveys of our assets that will identify issues present during that 'snapshot' of time that the survey is produced.

SHE Transmission also owns a single PD 'trailer' that allows for a substation wide PD monitoring device to be deployed at a chosen substation, we also have experience with Partial Discharge Monitoring to Reduce Safety Criticality (NIA_SHET_0014) a project looking at a substation wide online PD monitoring system at Keith 275/132/33kV substation and at monitoring of cable sealing ends at Milton of Craigie 132kV/33kV.

Our current approach to targeted PD surveys of sites only allows for a very short 'snapshot' to be captured of the operation of the site at a specific time that the survey is taken. While this can at times identity issues on items of plant – allow for a repair before failure – it can only do so if it happens that the site visit has been targeted correctly, the PD is present at the time of the visit and it is of sufficient magnitude to be detected via external assessment.

PD measurement can provide much more valuable data if recorded over longer periods of time and then correlated with the prevalent system and weather conditions at the time of the recording – allowing for detecting smaller sources of PD and better health assessment of assets and not just fault/defect identification.

3.1.5 Cable Sealing Ends

SHE Transmission has recently experienced the disruptive failure of a 275kV cable sealing end at Kintor 275kV substation, as seen in Figure 9 - Kintore 275kV Cable Sealing End Failure, highlighting the risks these assets pose upon failure.

Figure 9 - Kintore 275kV Cable Sealing End Failure

In this instance no partial discharge or other indicator of impending failure was detected using the current testing regime which meant no operational restriction or exclusion zone could be applied to mitigate the risks present. This highlights a requirement to complete monitoring on similar assets to prevent similar failures and damage to adjacent plant and a long term outage to plan and action replacement activities. A method to do this is via long term PD monitoring that will allow for the early detection or identification of discontinuities or problems with the insulation or jointing in the cable sealing end structure. The failure observed within SHE Transmission was on the sealing end of a 275kV fluid filled intra-substation cable at Kintore 275kV substation.

Cigre Technical Brochure TB379 and TB560 have collated a review across multiple TO's of the failure rates of cable terminations at 220kV and above to as much as 5 times higher than those at 60-219kV. Given the recent failure, the age profile of some of our HV cables and the visibility it gives the possible risks to other assets and safety implications of these assets when installed in substations or near the public an active program of monitoring is a prudent measure to undertake. Similar reported instances of failures of this kind were identified from the NEDERs database.

SHE Transmission currently has 42 cable sealing ‘sets’ at 275kV situated within substations or dedicated cable sealing end compounds, with 8 of these planned to be removed or replaced by the end of RIIO T2. Our technical specification for any new installation mandates the installation of PD monitoring on 275kV+ cable sealing ends.

SHE Transmission has currently has 34 132kV sealing end sets for fluid filled cables at 132kV or less, with this number reducing to 14 by the end of RIIO T2 with planned replacement works. All of these cables were installed before 1980.

3.2 Risk Based Approach to Asset Management (Managing Assets to End of Life)

SHE Transmission has a large number of assets, and in particular transformers, that are approaching or have exceed their *expected* service life. We use a Risk Based Approach to Asset Management – outlined in the paper ***T2BP-PAP-0009 A Risk Based Approach to Asset Management,*** and through this approach apply a risk and condition based approach to asset replacement.

As these asset age their condition will deteriorate, and with this the probability of failure increases as illustrated in Figure 10. (Reproduced from ***T2BP-PAP-0009).***

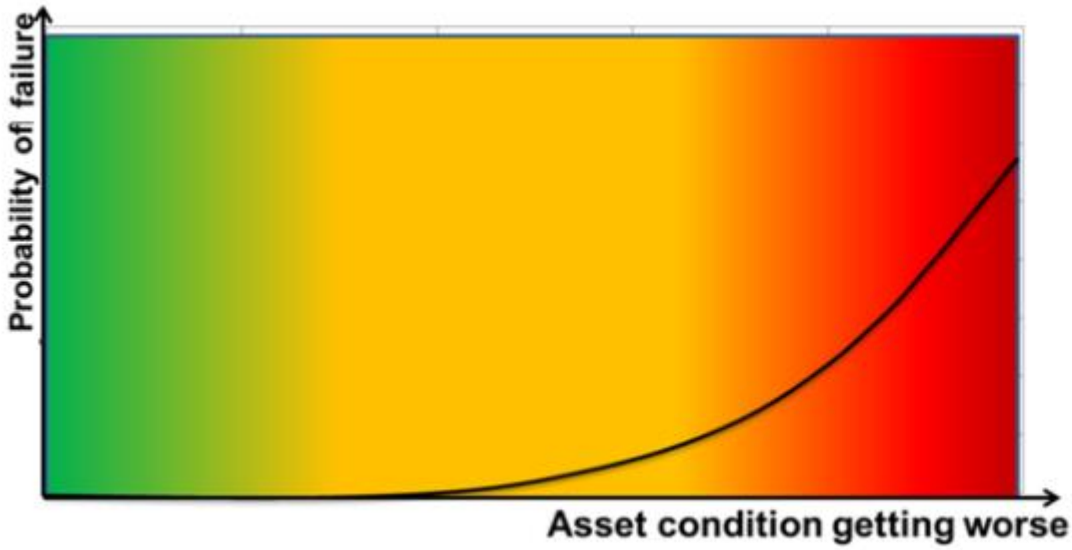

Figure 10 - Typical asset condition deterioration cover time

T2BP-PAP-0009 also outlines our approach to assessing non-load interventions, reproduced here for additional context:

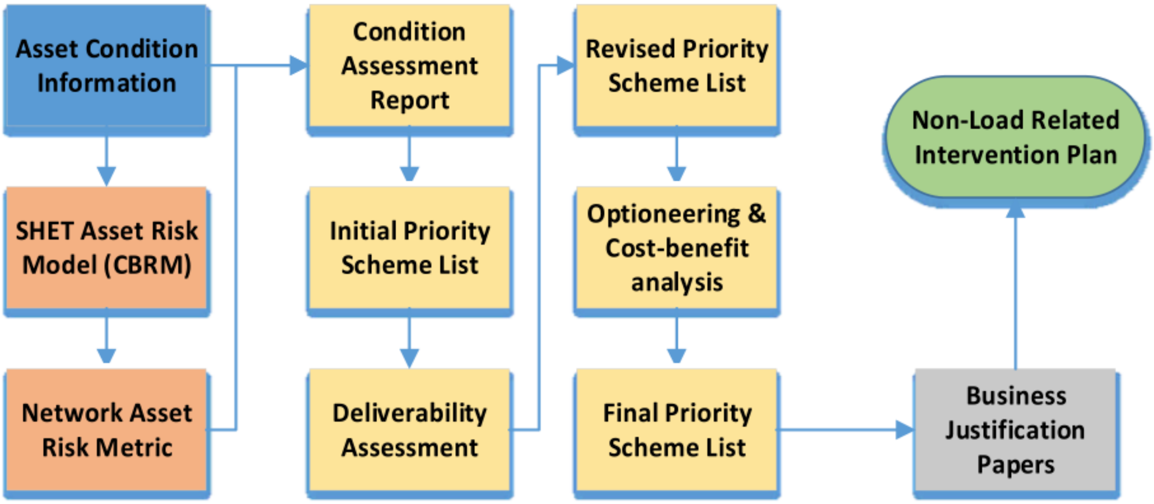

Figure 11 - SHET Non-Load Intervention Planning Process

Phase 1 – Data Gathering underpins our approach to cost-effective, intervention decision-making by ensuring that accurate, up to date, asset condition information is the starting point for all projects.

Phase 2 – Risk-based Analysis demonstrates our commitment to risk-based intervention decision-making by using our accurate asset condition information, within the complex CBRM risk modelling tool to calculate a monetised risk NARM score for all SHET lead assets.

Phase 3 – Optioneering is the lengthiest & most complex phase in our asset intervention decision-making process. It involves the exercise of engineering & commercial judgement to develop the outputs of our Data Gathering & Risk-based Analysis phases into a portfolio of asset intervention options and associated lifetime benefits for consideration in our T2 Business Plan.

Phase 4 – Non-Load Plan involves the development of the 28 Business Justification Papers that comprise the T2 Non-load Intervention Plan. These papers summarise the outputs of the complex and rigorous assessments undertaken in Phases 1, 2 & 3 and propose the intervention that provides the most cost effective, safe & deliverable solution that delivers the highest lifetime benefit to consumers.

Our risk based asset management approach therefore relies on having good quality, up to date and informative condition information. Currently the majority of our condition information is gathered through periodic inspection, maintenance and testing of our asset fleet.

This information is used to identify assets and sites that require further investigation and analysis, which along with specialist studies and review by the Asset Condition and Engineering team is used to produce detailed condition reports and is also then used within our CBRM (Condition Based Risk Management Tool) tool to calculate NARM risk values.

At the present time input data/information used in this *Phase 1* is "static" in nature, i.e. include periodic testing and inspection results as well as maintenance records and inputs. This requires that something has triggered the process of gathering new data – this can be a planned periodic inspection or test, a system fault or observations from O&M staff. However, as the probability of failure increases faults and degradation can develop at rates faster than any form of periodic inspection could capture, or would require infeasible numbers of O&M visits to monitor.

The current approach allows SHE Transmission to use the CBRM system Health Indexing (HI) approach to assess condition of their assets based on these inputs and this results in a "snapshot" in time HI (and monetised risk) scores. SHE Transmission updates these scores within CBRM at periodic intervals to incorporate changes from the previous assessment, such as removals, replacements, refurbishments and repairs, new test and inspection records, etc.

Nevertheless, the changes that occur between reviews are not processed until the next assessment and, thus, it is possible to have assets in poor condition stay in service and potentially fail in the meantime. This can result in unplanned/emergency replacements or repairs/refurbishments and therefore we are forced to bypass most of *Phase 3*, meaning more costly and less efficient replacements, as well as potentially severe outages and impacts on the local communities and environments of these sites. This also then has a significant knock on effects on our investment planning approach – *Phase 4* of our asset management system, both from capital and maintenance perspectives.

It is therefore required to have some means of actively monitoring assets approaching the end of life – preferably in as close to real time as possible to allow for the identification of specific issues that would lead to failures – minimising the risk of a fast-developing fault causing an unplanned and potentially disruptive failure.

It can be a very time consuming to gather the quantity of information required to compile the comprehensive asset condition reporting which allows us to predict asset failure timescales. An automated system that pulls in the required information, and can provide early identification of trends or issues would reduce the chance of assets adversely degrading faster than expected between planned review cycles. This would allow for better investment planning and more accurate end of life predictions. It would also allow these end of life predictions to be made with lower margin of error – extracting the full possible usable lifespan from each asset.

3.3 Extracting value from collected data

SHE Transmission currently collects a vast amount of data on all of our assets and the transmission system itself through a multitude of disparate data sources and systems. To provide a conceptual basis for this challenge – much of our data is split between our OT (Operational technology) and IT (Information technology) networks. Combining data in systems within these boundaries is often challenging, but working across these boundaries is an even more challenging process at present, often using a manual 'swivel chair' process or in many cases simply not practical. The OT network is the highly cyber secure SCADA and telecoms network that communicates directly with asset monitoring and control systems – this includes our PowerOn network control system as well as operational technology tools such as our fault locators and recorders as well as the PI data historian, which stores historical SCADA information. Our IT systems comprise our asset management and asset registration systems such as Maximo, iSIM, iHawk.

Currently extracting information from this multitude of existing data/information sources to perform a condition assessment review is a rather labour intensive and time-consuming exercise. It is also simply not possible to extract the full value of data analysis from these systems because possible correlations and automated analyses cannot be completed. Experience with limited forms of data analysis through an Innovation project Networks-07: Predictive Analytics for Transmission Networks Research has proven the value of data analytics in allowing for identification of trends and possible faults. There is the potential to open our data sets to wider key stakeholders such as academia, manufactures, developers and system operators in a way that allows for a more holistic view to be created.

Experience on previous projects has shown that in order to fully correlate asset information an accurate source of local weather data is an incredibly useful tool – however regionally aggregated data available is not fully suitable for use at some more remote SHE Transmission locations, where a localised reading would provide much better accuracy – as well as allow for operational use of this data to remotely assess the weather at sites before travelling.

To extract a full benefit from ICPM investment SHE Transmission needs to integrate with an Asset Analytics platform often referred to as an Asset Performance Management (APM) platform. This APM allows utilities to extract relevant data and information from a multitude of enterprise and standalone systems, process these data and information using built in analytics, as well as transferring the data to other relevant analytics and reporting tools such as CBRM. The system will also be used to generate desired outputs, such as reports, dashboards, graphs, etc, with dashboards and visualisation tools for both the control room and asset engineering and operational usage.

The APM will provide capability to incorporate inputs not only from static sources, such as periodic testing or inspections typically stored in IT domain, but also from real time inputs typically coming from OT domain, such as on-line monitoring data to be provided as a result of ICPM investment. Finally, with enough data accumulated, APM could generate AI based analytics based on the machine learning techniques.

A Data analytics platform will be key to meeting the five recommendations of the EDTF report outlined in Table 2 - Energy Data Task Force Recommendations.

Having a functional APM is an essential element of the ICPM project which will enable SHE Transmission to effectively utilise data and information being collected from on-line monitoring. It is therefore a requirement across all optioneering options, except the ‘Do Nothing’ case. Specifically, APM will allow SHE Transmission to improve decision making and existing processes as follows:

- Refine the existing analytics used in determining condition of assets which is an integral part of investment planning
- Facilitate transition from time-based maintenance to condition-based or risk-based maintenance when required or feasible to allow for improved asset management performance – as measured by ITOMS/ITAMS scores.
- Generate alerts in real time to identify assets that need to be replaced or refurbished/repaired before they fail, i.e. moving to proactive actions which are more cost effective
- Advance R&D initiatives related to data analytics, extracting

On-line monitoring capabilities from the ICPM project, and the data analytics platform envisaged will allow for updating condition of assets in "near real time". Additionally, since condition information updates will be generated in "near real time" this will allow proactive mitigation and rectification of issues prior to failure and will result in more economical capital expenditures by having more proactive interventions. ICPM will also allow to improve maintenance processes depending on the current condition of assets thus optimising life cycle cost and useful life of assets. Furthermore, combining "static" inputs currently available with "near real time" inputs collected from on-line monitoring will generate a more accurate and credible CBRM scoring and calibration as more relevant and most current inputs will be considered in quantifying assets' condition.

A conceptual diagram showcasing the position of the proposed asset analytics platform, but which also is useful in understanding this issue can be seen in Appendix B

The Energy Data Taskforce report A Strategy for a Modern Digitalised Energy System was used to help frame SHE Transmission thinking in regards as to the possible benefits to improved analysis, as well as what the regulatory requirements will be in forthcoming years:

Table 2 - Energy Data Task Force Recommendations

EDTF Recommendation	SHE Transmission Challenges
Recommendation 1: Digitalisation of the Energy System	Large parts of the network are not 'digitally enabled' and have no provision for online or digitised condition information to be collected.
Recommendation 2: Maximising the Value of Data	Current Data is difficult or impossible to share and perform correlative analysis due to the design of current OT and IT systems. Full value of data analysis requires integration of data sources and meaningful analysis parameters applied.
Recommendation 3: Visibility of Data	Current systems are not built with external sharing in mind – making sharing a very time-consuming manual process.
Recommendation 4: Coordination of Asset Registration	RIIO T1 Asset Register project provides an opportunity to allow more consistent collection of third-party data, but significant challenges still exist in current IT systems in producing shareable data.
Recommendation 5: Visibility of Infrastructure and Assets	SHE Transmission Digital strategy looks to address this challenge through the introduction of new GIS (Geographic information systems) and BIM (Building information modelling) tools – but integration of existing assets and sites into BIM can be challenging in terms of model creation.

4 Optioneering

The first stage of the optioneering process was to complete a technical assessment of the available solutions to address the needs cases outlined above. This section of the report will provide the technical details of any solutions considered within the optioneering process, the risks they mitigate and the benefits they provide.

4.1 Technical Assessment

4.1.1 Transformer Online Dissolved Gas Analysis (DGA)

Online DGA allows the dissolved gas content of transformer oil to be continuously monitored. It is a well understood and established monitoring practise that provides users with the ability to quickly detect faults and prevent unplanned failure. This provides inherent benefits for managing critical assets and can, in some cases, provide improved asset utilisation and life extension.

There are a wide variety of online DGA products on the market and these can be broadly divided into two categories; multi-gas and single/composite gas monitors.

Multi-gas DGA monitors provide high accuracy monitoring of all key fault gases plus moisture. The ability to monitor all key fault gasses allows identification of a wide range of fault types. As such these installations are best suited for intensive monitoring of highly critical assets or assets with known or confirmed condition issues.

Single or composite DGA monitors are a simpler variations of the multi-gas monitors which provide early warning of incipient faults. These devices typically provide measurements of either a single gas (hydrogen) or composite gas plus moisture. They are compact in nature and can usually be installed on a single oil valve which does not require the installation of any additional pipework. These installations are best suited for surveillance or screening of critical assets where it is not deemed worthwhile of installing a multi-gas device. Where issues are subsequently detected and confirmed it may then be necessary to upgrade to a multi-gas solution.

Both types of monitor complement periodic oil sampling that is required to monitor insulation ageing performance and oil quality which can only be done off-line (e.g. acidity, breakdown voltage, dielectric dissipation factor, etc.).

4.1.2 Tapchanger and Bushing Monitoring

Tapchanger monitoring products are available in many forms. They include data acquisition modules, that allow a variety of inputs to be monitored and utilised to predict the condition of the tapchanger (e.g. contact wear), and DGA devices for tapchangers with separate oil tanks. Both types of device provide advanced warning of impending issues and allow trending and analysis to improve performance and reliability.

Bushing monitoring devices allow changes in capacitance and power factor to be detected using devices that attach to the test tap of the bushings. These devices operate by continuously monitoring changes in these parameters, which are indicative of insulation deterioration, to provide advanced warning of failure.

4.1.3 Forensic Analysis

Learning from the experiences outlined in Cigre Technical Brochure TB735, as well as from the best practices of other utilities it is possible to define the scope, goals and benefits of forensic analysis.

For transformers specifically, while the transformer is in active service the main source of data used within SHE Transmission's risk based approach to asset management comes from the analysis of oil samples, along with temperature measurements where available and a review of loading profiles combined with external condition assessments. In addition, off-line electrical condition tests are occasionally completed, and the data recorded and analysed. This data is very useful as a method for detecting and diagnosing problems allowing an insight into the condition of the transformer. However because it involves compiling multiple indirect measurements across the lifetime of the asset it does not provide positive confirmation of root cause of defects/failure. This makes it difficult to draw solid conclusions that can then be extended directly to other units in the population.

There are a number of transformers due to be permanently removed from service and scrapped within the RIIO T2 period, and with this the opportunity arises to perform a detailed and destructive forensic examination of these units, allowing the collection of direct observations and measurements to be made and material samples collected for analysis. This direct analysis will give measurements that provide the most conclusive possible results regarding the condition of the transformer, and being able to inspect the internal parts makes it possible to capture valuable information on its design and construction as well.

On a high level for all asset types, post-mortem analysis of planned or forced replacement assets will be used to inform the health indexing and CBRM scoring for SHE Transmission assets and consequently the asset management decision making process. This learning will also be used to inform future standards and specifications. A post-mortem analysis program will allow SHE Transmission to be in a good position to:

- Identify the root cause (in case of failure).
- Capture information about the design and construction.
- Understand the condition of the asset as a whole or parts of special interest.
- Identify problems which have developed in service, owing to weakness in the design and construction or otherwise (regardless of whether or not the unit has failed in service).
- Correlate all findings with the operating and maintenance regime.

The information that can be extracted from a post-mortem analysis goes far beyond the asset being studied, it will give an indication of the health of the remaining family types as well as reveals how various operating and maintenance regimes have performed.

4.1.4 Circuit Breaker Monitoring

4.1.4.1 Online SF_6 Gas Density Monitoring

This involves the monitoring of the interrupting gas tank of AIS breakers with an online digital reading, which allows for the remote identification of CB gas leaks (SF_6 or alternatives) as well as trending and prediction of when filling would be required. This allows for a reduction in unplanned outages for gas top up. It also allows for the proactive identification and then planning of mitigation works on leaking breakers, a reduction in SF_6 emissions by proactively spotting leaking assets and for proactive maintenance and repairs to be undertaken.

4.1.4.2 Online Trip Coil Current/Timing Monitoring

This involves online monitoring the current draw of the trip coil during circuit breaker operation. An online system allows for all routine circuit breaker operations to be captured. Current circuit breaker maintenance regimes capture this information as part of a wider and more detailed assessment of the asset health. Online and automated capture of timing information allows for every operation recorded automatically to build a more detailed operating profile than is currently possible by recording data at the point of periodic maintenance only. This will allow improved knowledge of circuit breaker performance and identify any changes more quickly and allow for trending over time and other factors. It will also allow the ‘first trip’ to always be captured during maintenance process – this can’t always be captured due to the switching requirements with current maintenance testing and issues can be masked for subsequent operations by this breaker operation ‘freeing’ the mechanism for a short time. This system can be retrofitted into existing system fault recorder installations, and this solution has been fitted to several recent new build substations.

4.1.4.3 Comprehensive Online Breaker Health Assessment (CB Watch)

These solutions provide both online SF_6 monitoring, and online trip coil timing solutions outlined above in a single package. This state of the art monitoring solution also allows for recording the exact contact operation times, arcing time and contact wear as well as recording the operating parameters of the charging motors and local temperature. This provides a more in depth understanding of breaker performance and health than other available monitoring solutions.

4.1.5 GIS Gas Density Monitoring

Online GIS Gas Density monitoring allows for precise early detection of even small leaks in GIS systems. It allows for remote identification of leaks, and trending allows for forecasting refilling needs to allow for reduced outage times and early leakage mitigation measures to be investigated and deployed.

The system(s) use temperature compensated gas density and pressure detection sensors with integrated digital outputs. Retrofits of these systems are specific to the GIS board considered, but are of similar design and use similar technologies.

SHE Transmission has a gas density monitoring system installed at the Blackhillock 400kV and 132KV GIS sites – which has been very beneficial in allow for the proactive identification and mitigation of leaks, however this system operates only on a local basis with an access terminal within the substation itself. Remote access and integration with wider SHE Transmission data systems would allow the full value of the data produce by this system to be extracted.

4.1.6 Partial Discharge (PD) Monitoring

There is a wide variety of PD monitoring products and solutions on the market. SHE Transmission's previous experience with partial discharge monitoring, and the specific needs that require addressed, along with recent failures have informed the technologies assessed and proposed here:

4.1.6.1 Portable Online Partial Discharge Monitoring

The assessed solution allows for a portable online PD monitoring solution to be deployed where required to provide online and long-term readings from the assets assessed. Multiple sensor accessories can be procured and installed for different assets and their components. The two major use cases proposed and assessed in this paper are explored below:

HV Cable Terminations (Sealing End) and Joints Monitoring

Using high-frequency current transformers allows for the identification of PD from the earth connection of HV sealing ends to identify PD generated not just at the sealing end but also along the length of the cable upon which the system is deployed.

Transformer Monitoring

Using an Ultra High frequency (UHF) valve sensor connected into the vent of an oil drain valve allows for identification of UHF PD within the tank of a transformer.

4.1.7 Weather Monitoring

The assessed solution allows for the installation of permanent weather stations measuring pressure, humidity and temperature, UV Radiation, Wind Speed and Direction, Rainfall, Cloud Height, Snow Depth and other values, with remote logging of values, and real-time online communication of these to SHE Transmission data systems.

4.2 Options

When reviewing our options in this area, we produced a three-tier approach to our development (in addition to a "Do Nothing" option:

- ***Minimum Requirements***
    - The bare minimum required to "keep the lights on" & maintain legal/regulatory compliance

- ***Responsible Operator***
  - A more resilient network for longer term customer benefit
- ***Progressive Network Enabler***
  - An adaptable, sustainable and flexible network providing enhanced value to current and future customers

In this workstream, "Do Nothing", "Minimum Requirements", "Responsible Operator" and "Progressive Network Enabler" options are considered. The thinking and process behind how each of these options was developed is laid out in this section.

A summary table of the proposed installations is shown in Table 3. The optioneering process and basis for the numbers proposed is expanded upon in sections 4.2.1, 4.2.2, 4.2.3 and 4.2.4.

Table 3 - Optioneering Outputs - Number of Assets Monitored by Technology Type

Monitoring Technology	Unit Count		
	Minimum	Responsible	Progressive
DGA (multi-gas)	7	13	36
DGA (2-gas)	13	24	65
Tapchanger	16	20	33
Bushing	7	16	27
GIS SF6	5	7	7
CB SF6	94	163	294
CB Watch	0	0	50
CB Timing	25	35	100
PD Monitoring Base	25	36	42
PD Monitoring Cable	42	56	56
PD Monitoring Transformer	7	16	27
Environmental Monitoring	11	11	24
SCADA and Integration Per Site	33	55	72
Analytics Platform Research and Algorithm Development	5	5	10
Forensic Anlaysis	27	27	27

4.2.1 Do Nothing

This option would include only installing condition monitoring on new assets in line with updated technical specifications, with no provision made for currently installed assets. The costs for the provision of monitoring technology would be covered within the specific projects. This will provide benefits in future price controls periods – but these will not be realised in the short or medium term and will probably not start to be accrued until at least RIIO T4 and RIIO T5 periods.

This would not alleviate any of the specific and demonstrable condition and performance issues for the assets outlined in the needs section, that apply now and in the RIIO T2 period, and as shown in Figure 3, Figure 4 and Figure 9 leaving these unmitigated can have significant consequences. As subsequently shown in the detailed analysis section this does not remove all risks from the 'severe' zone, and leaves multiple severe risks unmitigated.

It would not be possible to comply with the letter and spirit of the EDTF recommendations and harness the benefits of increased asset condition visibility for the assets on the network where this would drive most value.

4.2.2 Minimum Requirements

The Minimum Requirements option would focus on retrofit installations of monitoring only on alleviating the worst performing and highest risk assets, and those with health and safety implications doing the minimum required to 'keep the lights on'.

In each asset class the following approach has been taken in line with the needs identified in Section 3:

4.2.2.1 Transformer Monitoring

Online DGA monitoring has been identified for transformers with observed condition issues using a combination of laboratory oil results from the last five-years and CBRM health index calculations. Multi-gas installations have been selected for assets displaying the most concerning or severe gas trends, as identified from the above two data sources, while single/composite gas devices have been identified for critical assets showing early signs of deterioration or where assets have far surpassed their 40 year design life (in excess of 50 years).

Similarly tapchanger and bushing monitoring has been identified for critical assets using the same age criteria (in excess of 50 years). Tapchanger monitoring has also been identified for tapchanger models that are subject to active operational restrictions due to known type issues.

In the above assessment critical assets are those that are situated at sites deemed to have a 'Very High' criticality according to the NOMs/NARM methodology. These sites are identified because they are situated in built-up areas with high or constant levels of activity.

4.2.2.2 Forensic Analysis

In order to allow SHE Transmission to learn from transformers removed, and the relatively low cost of the process compared to the benefits provided, it is proposed to subject every scrapped transformer in the RIIO T2 period to a forensic analysis during the scrapping process. This amounts to 27 transformers and reactors as per current planning.

4.2.2.3 Circuit Breaker Monitoring

SF_6 monitoring of AIS circuit breakers at 132kV and above was identified by performing leak analysis of different circuit breaker types over the RIIO-T1 period. The worst performing circuit breakers from an operational and environmental perspective were identified from Figure 8 by setting thresholds for the average number of pumping records and the average weight of gas leaked from each circuit breaker type. For the Minimum Requirement option these thresholds were set at 5 pumping interventions and 7kg of SF_6 leakage. Any circuit breaker type that exceeded these thresholds was identified for monitoring and the appropriate assets were subsequently identified.

4.2.2.4 GIS Monitoring

GIS monitoring has been identified for five multi-bay GIS sites that contain outdoor gas compartments. These assets are specifically targeted based on current operating experience which indicates that these assets are more prone to leakage. This would include monitoring at Tomatin 132kV, Spittal 132kV and 275kV, Crossaig 132kV and Dounreay 275kV.

4.2.2.5 PD Monitoring

Optioneering for the installation of PD monitoring was focused on two use cases: cable sealing ends for cable PD monitoring and transformer internal UHF PD monitoring.

The monitoring option proposed consists of 3 parts – a portable PD monitoring measurement equipment base station, the sensors and fixings required for permanent installation on cable sealing ends, and the sensors and fixings required for permanent installation on transformers.

The intention would be for permanent installation of the sensors and terminations to be made on the proposed sites, with 'base stations' procured for a half of the permanent installations and to be moved between these sites as required for short, medium or long term observations.

In this minimum requirement option permanent cable monitoring is proposed for all 275kV cable sealing ends located within substations or sealing end compounds. This is proposed because of the recent failures within SHE Transmission, and the higher probability of failure seen with 275kV assets in the large scale study in TB379 and TB560.

It is proposed to install PD monitoring on transformers using the same criteria as that for bushing monitoring, using an age and criticality based rule. For the minimum requirement this is transformers over 50 years of age situated at a site with a very high reported criticality.

4.2.2.6 Environmental Monitoring

Environmental monitoring is proposed at sites to improve the accuracy of weather data and to allow remote real time online identification of the weather at remote sites. Therefore, the criteria used to assess which sites to install was to choose sites at particularly high altitudes. For the minimum requirement and responsible operator option this was taken to be sites at over 300m of altitude, with this comprising of a total of 11 sites.

4.2.2.7 Analytics Platform Research and Algorithm Development

The integration and analytics work required will be to ensure all the above monitoring technologies are integrated into an analytics platform as part of SHE Transmission's wider digital strategy, as well as to ensure the development of analytical algorithms and tools that ensure we learn as much as possible from the data we collect. The optioneering has been based on the experience SHE Transmission has had in this field with the Networks-07: Predictive Analytics for Transmission Networks Research project with the University of Strathclyde. This proof of concept project has helped us define what would be required in order to build predictive algorithms from PD monitoring data and how this would be implemented. It is proposed for the minimum requirement that 5 similarly scaled projects would be required to produce predictive algorithms and assessment techniques for the data collected.

PROGRESSED TO DETAILED ANALYSIS

4.2.3 Responsible Operator

The Responsible Operator option includes the requirements of the Minimum Requirements option and expands upon this, in line with responsible asset management practice, to include assets that show early signs of deterioration and have performance issues that are not quite as severe as those identified in the minimum requirements option. This is further expanded to include unique and remote assets that are deemed to present an enhanced risk because they will be difficult to replace due to their bespoke nature or difficult location.

It has been scoped to try and maximise the cost per risk reduction achieved by the installation of monitoring options. This option will allow for a greater level of risk reduction than the minimum requirements option, and allow for greater efficiencies and improvements in medium and long-term planning for RIIO-T3 and beyond as asset condition information for assets included will be greatly improved, as well as allowing for better information on all asset classes.

4.2.3.1 Transformer Monitoring

In this option critical assets showing early signs of deterioration are identified for multi-gas monitors as opposed to a single/composite gas monitor. The installation of single/composite gas monitors is then extended to provide coverage of unique assets (e.g. non-standard assets such as SVC transformers), assets located at remote sites and assets with a disproportionately high monetised risk value. The age criteria used for DGA, tapchanger and bushing monitoring is reduced to 40 years to reflect the design lives of these assets. In addition, tapchanger and bushing monitoring is also extended to assets with a disproportionately high monetised risk value.

4.2.3.2 Forensic Analysis

As per minimum requirements – all transformers and reactors removed within RIIO T2 and scrapped.

4.2.3.3 Circuit Breaker Monitoring

Similar to the Minimum Requirement option a set of thresholds were used to target the worst performing circuit breakers. In this option the thresholds were set more conservatively to ensure a greater coverage of poorly performing circuit breaker types. The thresholds were set at an average of 3 pumping interventions and 5kg of SF_6 leakage. A threshold of three pumping records was set on the basis that, over the course of an eight year price control, an asset should not require more than three interventions in line with current maintenance timescales.

4.2.3.4 GIS Monitoring

In this option monitoring of GIS assets is extended to the two remaining multi-bay GIS sites that do not currently have any form of monitoring and are not captured under the Minimum Requirement option. This provides full coverage of all existing multi-bay GIS sites with the aim of improving operational and environmental performance.

4.2.3.5 PD Monitoring

In the responsible operator option permanent cable monitoring is proposed for all 275kV cable sealing ends located within substations or sealing end compounds. It is also proposed to include the 14 remaining fluid filled sealing ends at 132kV – with all of these assets having been installed before 1980.

It is proposed to install PD monitoring on transformers using the same criteria as that for bushing monitoring, using an age and criticality based rule. For the responsible operator option this is for transformers over 40 years of age with a very high reported criticality and with a high monetised risk value.

4.2.3.6 Environmental Monitoring

Environmental monitoring is proposed at sites to improve the accuracy of weather data and to allow remote real time online identification of the weather at remote sites. Therefore, the criteria used to assess which sites to install was to choose sites at particularly high altitudes. For the minimum requirement and responsible operator option this was taken to be sites at over 300m of altitude, with this comprising of a total of 11 sites.

4.2.3.7 Analytics Platform Research and Algorithm Development

The proposal for the responsible operator option utilises the same technologies as the minimum requirement option. It is judged that a similar amount of algorithm and analytics work would be required as the minimum requirement to deliver the benefits.

PROGRESSED TO DETAILED ANALYSIS

4.2.4 Progressive Network Enabler

The Progressive Network Enabler option includes the requirements of the Minimum Requirements, and Responsible Operator options and expands upon these, in line with leading asset management practice, to include assets that show very early signs of deterioration and have performance issues that are not quite as severe as those identified in the previous options. It also includes more older assets with no criticality based driver. This is further expanded to include more unique and remote assets that are deemed to present an enhanced risk because they will be difficult to replace due to their bespoke nature or difficult location. It also includes more detailed and intrusive CB monitoring techniques.

It has been scoped to try and maximise the risk reduction possible by the installation of monitoring options. This option will allow for a greater level of risk reduction than the minimum requirements and responsible operator options, and allow for even greater efficiencies and improvements in medium and long-term planning for RIIO-T3 and beyond as asset condition information for assets included will be greatly improved, as well as allowing for better information on all asset classes.

4.2.4.1 Transformer Monitoring

Multi-gas monitors are extended out to all transformers showing early signs of deterioration regardless of their criticality. Single/composite gas monitors are extended to all critical, unique and remote assets, in addition assets beyond their 40-year design life are also captured.

Tapchanger and bushing monitoring is extended to all 'Very High' criticality sites regardless of their age.

As per the responsible operator option, all assets with a disproportionately high monetised risk value were also included for single/composite gas, tapchanger and bushing monitoring.

4.2.4.2 Forensic Analysis

As per minimum requirements – all transformers and reactors removed within RIIO T2 and scrapped.

4.2.4.3 Circuit Breaker Monitoring

SF_6 monitoring of AIS circuit breakers is extended to all assets that are of a type that has previously experienced a leak, irrespective of whether individual assets of those types have previously experienced a leak.

4.2.4.4 GIS Monitoring

Full coverage of all existing multi-bay GIS assets is achieved under the responsible operator option; therefore, this option remains the same as before.

4.2.4.5 PD Monitoring

The same criteria as used for responsible operator was considered for progressive utility for the choice of cable sealing ends.

It is proposed to install PD monitoring on transformers using the same criteria as that for bushing monitoring, using an age and criticality based rule. For the progressive enabler option this is for all transformers with a very high reported criticality or a disproportionately high monetised risk value.

4.2.4.6 Environmental Monitoring

Environmental monitoring is proposed at sites to improve the accuracy of weather data and to allow remote real time online identification of the weather at remote sites. Therefore, the criteria used to assess which sites to install was to choose sites at particularly high altitudes. For the progressive enabler option this was taken to be sites at over 200m of altitude, with this comprising of a total of 24 sites.

4.2.4.7 Analytics Platform Research and Algorithm Development

The proposal for progressive enabler, while utilising the same technologies as the minimum requirement and responsible operator, is that the algorithm development would be significantly expanded to allow for more esoteric or unpredictable algorithmic correlations and gains to be investigated as part of a progressive look forward to future issues on the network, this has been scoped at double the other options, with provision for the equivalent work of Networks-07: Predictive Analytics for Transmission Networks Research projects.

PROGRESSED TO DETAILED ANALYSIS

5 Detailed Analysis

This section considers in more detail each of the options taken forward from the Optioneering section. It examines three comparative factors in order to determine the preferred option:

- Risk,
- Stakeholder Requirements, and
- Cost.

5.1 Risk and Benefit Analysis

Due to the nature of this project, risks and benefits involved are not easily quantifiable and, as agreed with Ofgem, are not suitable for traditional Cost Benefit Analysis.

In order to demonstrate the benefits of delivering this project, we have carried out a Risk and Benefit Analysis. For each option taken forward to Detailed Analysis, it looks at the existing risks, the likelihood of these risks being realised, and the severity should that happen. The likelihood and severity combine to give an overall Unmitigated Risk Rating.

Mitigation actions delivered by each option are then identified, and the likelihood and severity are reappraised, resulting in a Mitigated Risk Rating. This exercise was carried out for all options with "Do Nothing" representing unmitigated risks.

In order to deal with the challenge of quantitively comparing the different options proposed and to ensure consistency in assessing the three options progressed to detailed analysis, SHE Transmission used Kinectrics PROSORT tool. This tool has been used by several utilities in North America for three purposes:

1. To compare different alternatives for meeting identified need(s)
2. To prioritise "one off" major projects
3. To allocate funds to annual programs across different lines of business

The approach used in PROSORT for all these applications involves first assessing existing Total Risk Score (TRS) to Corporate Business Values, and then normalising investment cost over the total amount of risks this investment mitigates and additional benefits it provides as compared to the exiting situation. This allows SHE Transmission to prioritise options based on the ratio of their cost vs mitigated risk plus incremental benefits, from the lowest to the highest, so that the option with the lowest cost per mitigated unit of TRS is selected as the most cost-effective. Additionally, options are deemed feasible only if ALL the resultant individual Business Value risks move outside of the defined "red zone" representing unacceptable level of risk.

Table 4 - Prioritised Risk Benefits

Rank	Option		Description	Cost	Savings	CRBF
1	2	**Responsible Operator**	Meeting min requirements for "keeping lights on" and meeting all regulatory/legal requirements	£16,355,099	£0	25,495
2	1	**Minimum Requirements**	A more resilient network for longer term customer benefit	£11,528,184	£0	26,251
3	3	**Progressive Network Enabler**	An adaptable, sustainable and flexible network providing enhanced value to current and future customers	£25,113,367	£0	38,056

Table 4 - Prioritised Risk Benefits shows the three options proposed ranked in order which the lowest CRBF (Cost per Risk Benefit Factor) at the top – i.e. the most risk reduction achieved for the amount of money spent. This shows that the responsible operator option provides the most risk benefit improvement per pound of investment. Table 5 - PROSORT Cost and Risk Benefit Outcome Summary shows a summary of this risk assessment and comparison process. The full detail of the Risk & Benefit Analysis, and details on the PROSORT tool and its usage is contained within Appendix A.

Table 5 - PROSORT Cost and Risk Benefit Outcome Summary

PROSORT OPTIONS ANALYSIS	0 Do Nothing		1 Minimum Requirements		2 Responsible Operator		3 Progressive Network Enabler	
	Cost	£0	Cost	£11,528,184	Cost	£16,355,099	Cost	£25,113,367
PROJECTS ASSESMENT			Δ TRS	439.16	Δ TRS	641.51	Δ TRS	659.91
			CRBF	26,251	CRBF	25,495	CRBF	38,056

Business Values			Risk Assessment															
#	%	Description	Conseq	Likely	Score	WS	Conseq	Likely	Score	WS	Conseq	Likely	Score	WS	Conseq	Likely	Score	WS
1	12	**Cost Efficiency**	Major	Likely	994	119.3	Major	Possible	366	43.92	Major	Hardly Ever	49	5.88	Major	Hardly Ever	49	5.88
2	10	**Environment**	Major	Likely	994	99.4	Serious	Likely	366	36.6	Serious	Unlikely	49	4.9	Serious	Unlikely	49	4.9
3	15	**Health and Safety**	Severe	Possible	994	149.1	Severe	Unlikely	366	54.9	Severe	Hardly Ever	134	20.1	Severe	Hardly Ever	134	20.1
4	10	**System Reliability**	Major	Likely	994	99.4	Major	Possible	366	36.6	Major	Unlikely	134	13.4	Major	Unlikely	134	13.4
5	11	**Stakeholder Engagement**	Serious	Likely	366	40.26	Serious	Possible	134	14.74	Serious	Unlikely	49	5.39	Serious	Unlikely	49	5.39
6	10	**Sustainability**	Major	Possible	366	36.6	Major	Unlikely	134	13.4	Major	Unlikely	134	13.4	Serious	Hardly Ever	18	1.8
7	14	**Compliance**	Major	Possible	366	51.24	Major	Unlikely	134	18.76	Major	Hardly Ever	49	6.86	Major	Hardly Ever	49	6.86
8	8	**Reputation**	Severe	Unlikely	366	29.28	Severe	Unlikely	366	29.28	Major	Unlikely	134	10.72	Major	Hardly Ever	49	3.92
9	10	**Innovation**	Major	Likely	994	99.4	Major	Possible	366	36.6	Minor	Unlikely	18	1.8	Minor	Unlikely	18	1.8
								Change in Risk		439.2		Change in Risk		641.5		Change in Risk		659.9

5.1.1 Chosen Option – Responsible Operator

As it reduces all risks from out of the 'severe' category, and delivers the best cost per risk benefit score, it is proposed to deliver the Responsible Operator Option within the RIIO T2 period at a cost of £16.36m.

5.2 Stakeholder Engagement

Throughout the stakeholder engagement process there was strong support for ensuring that security of supply 'is the most critical factor' as outlined in the SHE Transmission RIIO-2 User Group Business Plan Report. However, stakeholders also wanted cost control and consideration of wider environmental and societal issues to be taken into account. In addressing the clear needs cases outlined in this paper, and through the risk and benefits analysis process, SHE Transmission has taken these into account in compiling the RIIO T2 plan and this submission. This paper has also been designed to help deliver the 'five clear goals' that were developed through our stakeholder engagement process – helping deliver "100% transmission network reliability for homes and businesses", "£100 million in efficiency savings from innovation" and our target of "one third reduction in our greenhouse gas emissions".

5.3 Costs – All Options

A detailed description of the costing methodology, as well as costs for all options is found in Appendix C. A summary of the costs for all options is seen in Table 6 - Summary of Costs: All Options**.**

Table 6 - Summary of Costs: All Options

Monitoring Technology	Unit Count			Cost Per Option		
	Minimum	Responsible	Progressive	Minimum	Responsible	Progressive
DGA (multi-gas)	7	13	36	£ 305,900.00	£ 568,100.00	£ 1,573,200.00
DGA (2-gas)	13	24	65	£ 166,894.00	£ 308,112.00	£ 834,470.00
Tapchanger	16	20	33	£ 177,568.00	£ 221,960.00	£ 366,234.00
Bushing	7	16	27	£ 213,500.00	£ 488,000.00	£ 823,500.00
GIS SF6	5	7	7	£ 3,453,292.97	£ 4,829,575.70	£ 4,829,575.70
CB SF6	94	163	294	£ 208,586.00	£ 361,697.00	£ 652,386.00
CB Watch	0	0	50	£ -	£ -	£ 2,040,000.00
CB Timing	25	35	100	£ 9,755.00	£ 13,657.00	£ 39,020.00
PD Monitoring Base	25	36	42	£ 1,290,600.00	£ 1,858,464.00	£ 2,168,208.00
PD Monitoring Cable	42	56	56	£ 246,797.04	£ 329,062.72	£ 329,062.72
PD Monitoring Transformer	7	16	27	£ 74,124.40	£ 169,427.20	£ 285,908.40
Environmental Monitoring	11	11	24	£ 225,357.00	£ 225,357.00	£ 491,688.00
SCADA and Integration Per Site	33	55	72	£ 1,364,892.87	£ 2,274,821.45	£ 2,977,948.08
Analytics Platform Research and Algorithm Development	5	5	10	£ 1,333,345.00	£ 1,333,345.00	£ 2,666,690.00
Forensic Anlaysis	27	27	27	£ 270,000.00	£ 270,000.00	£ 270,000.00
SUB TOTAL				**£ 9,340,612.28**	**£ 13,251,579.07**	**£ 20,347,890.90**
Pre-Construction				£ 326,921.43	£ 463,805.27	£ 712,176.18
Regulatory & Consent				£ -	£ -	£ -
SSE Staff				£ 467,030.61	£ 662,578.95	£ 1,017,394.55
Commisioning				£ 46,703.06	£ 66,257.90	£ 101,739.45
Insurance				£ 93,406.12	£ 132,515.79	£ 203,478.91
Outages				£ -	£ -	£ -
SUB TOTAL - including procurement & construction				**£ 10,274,673.51**	**£ 14,576,736.98**	**£ 22,382,679.99**
Risk				£ 842,523.23	£ 1,195,292.43	£ 1,835,379.76
Scope Developmenet				£ 410,986.94	£ 583,069.48	£ 895,307.20
TOTAL				**£ 11,528,183.68**	**£ 16,355,098.89**	**£ 25,113,366.95**

6 Conclusion

This paper outlines the needs case, optioneering and detailed analysis for the installation of a program of integrated condition and performance monitoring. This cost is based on a detailed analysis of previous experience, actual quoted contractor prices for similar installations and a bottom up costing process where this was not possible. It is proposed this would be delivered as an ongoing roll-out of project works throughout the RIIO-T2 period.

Each individual technology proposed will produce significant benefits by addressing the needs case outlined in Section 3 Need, with section 4.1 Technical Assessment outlining how the technologies meet the needs case and shows other benefits they provide. Overall the programme of integrated condition monitoring will deliver significant benefits for the operational performance of network, reductions in health and safety risks, improved security of supply and system resilience. The paper would allow significant improvements in our asset condition data collection and analysis of this information allowing much improved future business planning, allow for reduced lifecycle cost and significant risk reduction improvements on our asset fleet. The program of works allows SHE Transmission to meet the recommendations of the EDTF in both detail and spirit. These improvements can largely be conceptualised as significant reductions in the risks present on the network and these are outlined in section 5 Detailed Analysis, with a risk benefits comparison completed as shown in section 5.1 Risk and Benefit Analysis.

The do-nothing option would not alleviate any of the specific and demonstrable condition and performance issues for the assets outlined in section 3 Needs. As shown in Section 5 where detailed analysis of the options is undertaken, doing nothing leaves unacceptable risks on the network which if unmitigated can have significant consequences as demonstrated through past experience of disruptive failures.

A key benefit provided by this paper will be an improvement to the safety of the network by avoiding catastrophic failure of porcelain sealing ends and oil filled plant, which could injure staff, members of the public or contractors or significantly damage nearby property.

Upon delivery, several benefits specifically relating to the RIIO-T2 business goals will be realised:

- Significantly improving the security of supply by reducing potential for unplanned outages, due to asset failures or faults. This comprises one of the major contributing actions towards adhering to the goal to aim for 100% transmission network reliability for homes and businesses.

- Much improved longer term planning of asset investment and subsequent risk reduction due to the availability of near real-time data. Reducing overall life time costing of the assets and contributing to the “£100 million in efficiency savings from innovation” goal in the Network for Net Zero” business plan. This will also contribute towards the provision of better data and information on asset condition to inform future price control submissions.

- Reduction of SF_6 leakage, and better analysis and information of current assets allow improved operational efficiency and asset utilisation. This helps to achieve the SHE Transmission goal of “One third reduction in our greenhouse gas emissions” stated in the RIIO T2 business plan.

This scheme is not flagged as eligible for early or late competition due to it being under Ofgem’s £50m and £100m thresholds respectively.

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. At the project level this means that if we don't deliver the output, or a materially equivalent outputs, we commit to returning the ex-ante allowance for the output not delivered.

This means that if the funding for Integrated Condition Performance Monitoring should be ring-fenced and if it does not go ahead, we will return the allowances of £16.36m in full (minus any justified preconstruction expenditure).

It also means that we commit to delivering the output specified above for the costs of £16.36m. If we do not deliver the output, or a materially equivalent output, we commit to returning a proportion of the ex-ante allowance. The detailed methodology should be decided at when developing the Close Out methodologies but should apply the same principles of uncertainty mechanisms - that any under delivery should be material.

8 Outputs included in RIIO-T1 Plans

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

Appendix A – PROSORT Tool and Risk Benefit Analysis Detail

Due to the nature of this project, risks and benefits involved are not easily quantifiable and, as agreed with Ofgem, are not suitable for traditional Cost Benefit Analysis. To deal with this challenge and to ensure consistency in assessing the 3 options progressed to the detail analysis, SHE Transmission used Kinectrics PROSORT tool. This tool has been used by several utilities in North America for 3 purposes:

- To compare different alternatives for meeting identified need(s)
- To prioritize "one off" major projects
- To allocated funds to annual programs across different lines of business

The approach used in PROSORT for all these applications involves first assessing existing Total Risk Score (TRS) to Corporate Business Values, and then normalizing investment cost over the total amount of risks this investment mitigates and additional benefits it provides as compared to the exiting situation. This allows SHE Transmission to prioritize options based on the ratio of their cost vs mitigated risk plus incremental benefits, from the lowest to the highest, so that the option with the lowest cost per mitigated unit of TRS is selected as the most cost-effective. Additionally, options are deemed feasible only if ALL the resultant individual Business Value risks move outside of the defined "red zone" representing unacceptable level of risk.

The PROSORT methodology ensures that all feasible options are assessed using a consistent approach by comparing their cost-effectiveness in reducing overall Corporate Risk and, at the same time, ensures that individual Corporate Risks are reduced to acceptable levels.

PROSORT STEPS

Identifying Corporate Values and their Weights

SHE Transmission has identified 9 Core Business Values and these Business Values along with the corresponding weights representing their relative importance to SHE Transmission are shown in the Table 7 – SHE Transmission Corporate Values and Weights below. These were developed as part of SHE Transmissions ITAMS submission.

Table 7 – SHE Transmission Corporate Values and Weights

Number	Weight	Business Value	Description of Risk
1	12	**Cost Efficiency**	Impact of unplanned failures leading to reactive replacement work.
2	10	**Environment**	Impact of SF6 Leakage, and of environmental impact of unplanned failures.
3	15	**Health and Safety**	Impact of Disruptive Failure, And Reduced Reactive Fault Work.
4	10	**System Reliability**	Impact on wider system reliability e.g. System Constraints, Energy Not Supplied and DNO CI/CML
5	11	**Stakeholder Engagement**	Impact on Stakeholders - Generators, DNO, Local Communities, ESO, Other TO's of unreliable or failed assets.

6	10	**Sustainability**	Impact on SHE Transmission Business sustainability and Business Planning, wider societal sustainability (net-zero)
7	14	**Compliance**	Impact on compliance with our license conditions and statutory and legal requirements (e.g. ESQCR) and delivery of agreed price control items and new connections.
8	8	**Reputation**	Impact on SHE Transmission Reputation of Failure of Assets leading to ENS, Generation Constraints, Disruption to Public and/or wider negative media coverage.
9	10	**Innovation**	Impact on SHE Transmission Innovation Goals, Identifying and integrating new ways of working. Becoming a Leader in Asset Management as measured by ITAMS/ITOMS, Delivery of Smart Grid and EDTF Goals.

Determining Risk Scores Using Risk Matrix

Risk Score for each of these Business Values is determined using the Risk Matrix shown below in Table 8 - Risk Scoring Matrix. This Risk Matrix is designed so that Consequences increase exponentially from “Minor” to “Catastrophic” depending on the expected impact. Likelihoods increase from exponentially from “Hardly Ever” to Almost Certain” depending on the expected likelihood of a consequence. The intersection of expected Consequence and its Likelihood determines the resultant Risk Score. Additionally, the “red zone” of the Risk Matrix highlights unacceptable levels of risk that need to be lowered. This exercise is repeated for each of the Business Values in Table 7 – SHE Transmission Corporate Values and Weights.

Table 8 - Risk Scoring Matrix

	Almost Never	**Hardly Ever**	**Unlikely**	**Possible**	**Likely**	**Almost Certain**
Catastrophic	134	366	994	2701	7342	19958
Severe	49	134	366	994	2701	7342
Major	18	49	134	366	994	2701
Serious	7	18	49	134	366	994
Minor	2	7	18	49	134	366
Incidental	1	2	7	18	49	134

Table 9 - Risk Scoring Matrix with SHE Transmission Risks

	Almost Never	Hardly Ever	Unlikely	Possible	Likely	Almost Certain
Catastrophic	High	High	Severe	Severe	Severe	Severe
Severe	Medium	High	High	Severe	Severe	Severe
Major	Medium	Medium	High	High	Severe	Severe
Serious	Low	Medium	Medium	High	High	Severe
Minor	Low	Low	Medium	Medium	High	High
Incidental	Low	Low	Low	Medium	Medium	High

<u>Comparing Different Options</u>

The TRS is then calculated by first multiplying each Risk Score by its corresponding weight to calculate Weighted Risk Score (WRS) and then adding up all the WRSs. This was done for the existing situation which represents “Do Nothing” and for the 3 options that progressed to the detail analysis.

For each of these 3 options a change in the TRS or ΔTRS as compared to the “Do Nothing” option was then calculated by subtracting its TRS from the “Do Nothing” TRS and adding incremental weighted benefit (which for this project was associated with innovations capabilities). Finally, Cost per Risk Benefit Factor (CRBF) was determined for each option using the following equation:

$$CRBF = \text{Project Cost} / \Delta TRS$$

The outcomes of these calculations are detailed in Table 10 - Prioritised CRBF Scores and Table 11 - Tabulated Outcomes Summary.

Table 10 - Prioritised CRBF Scores

Rank	Option		Description	Cost	Savings	CRBF
1	2	**Responsible Operator**	Meeting min requirements for "keeping lights on" and meeting all regulatory/legal requirements	£16,355,099	£0	25,495
2	1	**Minimum Requirements**	A more resilient network for longer term customer benefit	£11,528,184	£0	26,251
3	3	**Progressive Network Enabler**	An adaptable, sustainable and flexible network providing enhanced value to current and future customers	£25,113,367	£0	38,056

Table 11 - Tabulated Outcomes Summary

PROSORT OPTIONS ANALYSIS	0 Do Nothing		1 Minimum Requirements		2 Responsible Operator		3 Progressive Network Enabler	
	Cost	£0	Cost	£11,528,184	Cost	£16,355,099	Cost	£25,113,367
PROJECTS ASSESMENT			Δ TRS	439.16	Δ TRS	641.51	Δ TRS	659.91
			CRBF	26,251	CRBF	25,495	CRBF	38,056

#	%	Description	Conseq	Likely	Score	WS	Conseq	Likely	Score	WS	Conseq	Likely	Score	WS	Conseq	Likely	Score	WS
1	12	Cost Efficiency	Major	Likely	994	119.3	Major	Possible	366	43.92	Major	Hardly Ever	49	5.88	Major	Hardly Ever	49	5.88
2	10	Environment	Major	Likely	994	99.4	Serious	Likely	366	36.6	Serious	Unlikely	49	4.9	Serious	Unlikely	49	4.9
3	15	Health and Safety	Severe	Possible	994	149.1	Severe	Unlikely	366	54.9	Severe	Hardly Ever	134	20.1	Severe	Hardly Ever	134	20.1
4	10	System Reliability	Major	Likely	994	99.4	Major	Possible	366	36.6	Major	Unlikely	134	13.4	Major	Unlikely	134	13.4
5	11	Stakeholder Engagement	Serious	Likely	366	40.26	Serious	Possible	134	14.74	Serious	Unlikely	49	5.39	Serious	Unlikely	49	5.39
6	10	Sustainability	Major	Possible	366	36.6	Major	Unlikely	134	13.4	Major	Unlikely	134	13.4	Serious	Hardly Ever	18	1.8
7	14	Compliance	Major	Possible	366	51.24	Major	Unlikely	134	18.76	Major	Hardly Ever	49	6.86	Major	Hardly Ever	49	6.86
8	8	Reputation	Severe	Unlikely	366	29.28	Severe	Unlikely	366	29.28	Major	Unlikely	134	10.72	Major	Hardly Ever	49	3.92
9	10	Innovation	Major	Likely	994	99.4	Major	Possible	366	36.6	Minor	Unlikely	18	1.8	Minor	Unlikely	18	1.8
								Change in Risk		439.2		Change in Risk		641.5		Change in Risk		659.9

(Column groups: Business Values; Risk Assessment — 0 Do Nothing, 1 Minimum Requirements, 2 Responsible Operator, 3 Progressive Network Enabler)

Risk Maps

Unmitigated Consequence	Unmitigated Likelihood	Almost Never	Hardly Ever	Unlikely	Possible	Likely	Almost Certain
	Catastrophic	High	High	Severe	Severe	Severe	Severe
	Severe	Medium	High	8	Severe 3	Severe	Severe
	Major	Medium	Medium	High	6 7	1 2 4 9	Severe
	Serious	Low	Medium	Medium	High	5	Severe
	Minor	Low	Low	Medium	Medium	High	High
	Incidental	Low	Low	Low	Medium	Medium	High

Figure 12 - Unmitigated Risk Map

		Minimum Requirements Likelihood					
		Almost Never	Hardly Ever	Unlikely	Possible	Likely	Almost Certain
Minimum Requirements Consequence	Catastrophic	High	High	Severe	Severe	Severe	Severe
	Severe	Medium	High	3 8	Severe	Severe	Severe
	Major	Medium	Medium	6 7	1 4 9	Severe	Severe
	Serious	Low	Medium	Medium	5	2	Severe
	Minor	Low	Low	Medium	Medium	High	High
	Incidental	Low	Low	Low	Medium	Medium	High

Figure 13 - Minimum Requirements Risk Map

		Responsible Operator Likelihood					
		Almost Never	Hardly Ever	Unlikely	Possible	Likely	Almost Certain
Responsible Operator Consequence	Catastrophic	High	High	Severe	Severe	Severe	Severe
	Severe	Medium	3	High	Severe	Severe	Severe
	Major	Medium	1 7	4 6 8 9	High	Severe	Severe
	Serious	Low	Medium	2 5	High	High	Severe
	Minor	Low	Low	Medium	Medium	High	High
	Incidental	Low	Low	Low	Medium	Medium	High

Figure 14 - Responsible Operator Risk Map

Progressive Network Enabler Consequence		Progressive Network Enabler Likelihood					
		Almost Never	Hardly Ever	Unlikely	Possible	Likely	Almost Certain
	Catastrophic	High	High	Severe	Severe	Severe	Severe
	Severe	Medium	High 3	High	Severe	Severe	Severe
	Major	Medium	Medium 1 7 8	High 4	High	Severe	Severe
	Serious	Low	Medium 6	Medium 2 5	High	High	Severe
	Minor	Low	Low	Medium 9	Medium	High	High
	Incidental	Low	Low	Low	Medium	Medium	High

Figure 15 - Progressive Network Enabler Risk Map

Appendix B Asset Analytics Platform Map

Figure 16 - Asset Analytics Platform Map can be provided as a separate file upon request.

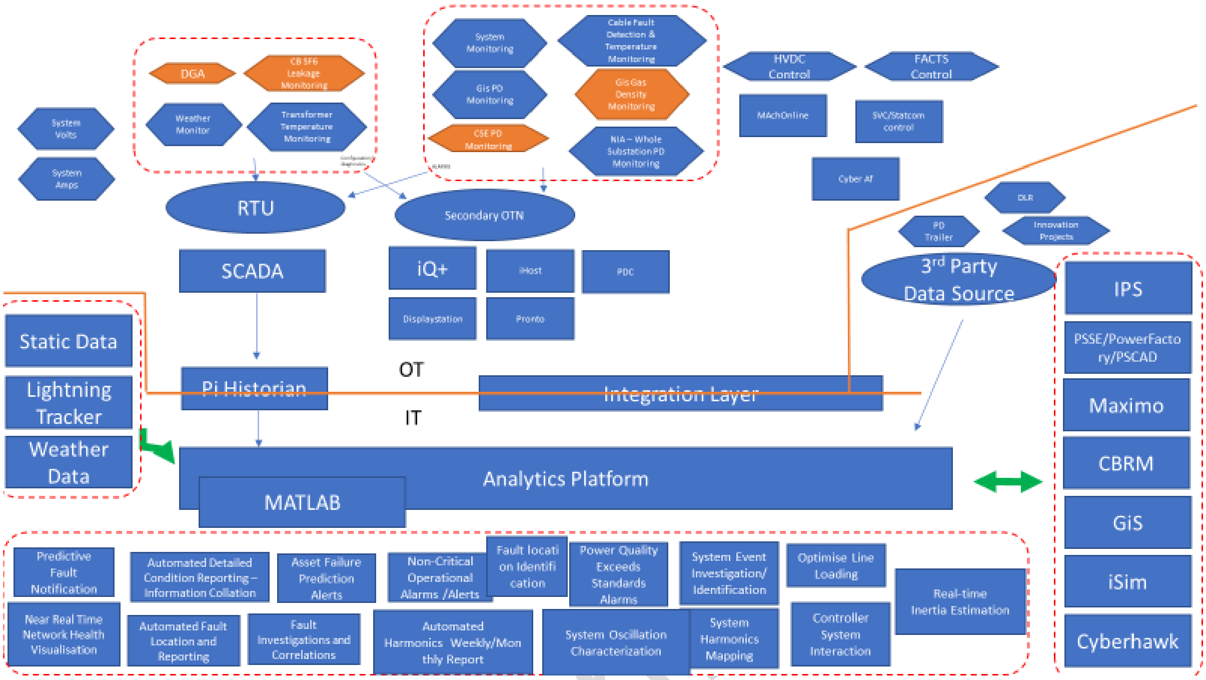

Figure 16 - Asset Analytics Platform Map

Appendix C Costing Methodology

The costing for deployment of these smart monitoring technologies has been derived been from previous experience, contractor quotes and where neither was possible, a bottom up costing methodology was employed to calculate the costs of each technology deployed.

For each proposed monitoring installation quotes from vendors that provide known solutions produced for installations at specific sites, and then averaged where similar technologies are available from multiple vendors – or the most appropriate quote taken where a single vendor supplies the exact technology scoped.

For SCADA and Integration Costs per site, specific vendor quotes are not the appropriate method and a bottom up costing methodology's similar to that used in the Substation SCADA Replacement T2BP-EJP-0007 – this has been developed with respect to previous installation experience as well as costs associated with the appropriate contractors. For each integration scheme there is a generic associated cost for the hardware upgrades and changes required including the RTU CPU upgrades, control and data input cards, cablings, filters, enclosures, consumable materials.

For the Analytics Platform Research and Algorithm Development costs have been taken from SHE Transmission work on Networks-07: Predictive Analytics for Transmission Networks Research project undertaken with University of Strathclyde, and the required time for seconded/contracted data scientist support to source, supply and interpret the findings for integration with the business wide data analytics platform.

The SHE Transmission internal costs have been calculated using the same methodology as for a standard project, with allowance for Risk and Scope development but with any requirement for regulatory and consenting costs omitted.

Table 12 - Costing Table

Monitoring Technology	Unit Cost	Predominant Costing Apporach and Rationale	Unit Count			Cost Per Option		
			Minimum	Responsible	Progressive	Minimum	Responsible	Progressive
DGA (multi-gas)	£ 43,700.00	Quote from Supplier	7	13	36	£ 305,900.00	£ 568,100.00	£ 1,573,200.00
DGA (2-gas)	£ 12,838.00	Quote from Supplier	13	24	65	£ 166,894.00	£ 308,112.00	£ 834,470.00
Tapchanger	£ 11,098.00	Quote from Supplier	16	20	33	£ 177,568.00	£ 221,960.00	£ 366,234.00
Bushing	£ 30,500.00	Quote from Supplier	7	16	27	£ 213,500.00	£ 488,000.00	£ 823,500.00
GIS SF6	Cost Sheet	Quote(s) from Supplier and assumed similar costs on 2 sites	5	7	7	£ 3,453,292.97	£ 4,829,575.70	£ 4,829,575.70
CB SF6	£ 2,219.00	Quote from Supplier	94	163	294	£ 208,586.00	£ 361,697.00	£ 652,386.00
CB Watch	£ 40,800.00	Quote from Supplier	0	0	50	£ -	£ -	£ 2,040,000.00
CB Timing	£ 390.20	Quote from Supplier	25	35	100	£ 9,755.00	£ 13,657.00	£ 39,020.00
PD Monitoring Base	£ 51,624.00	Quote from Supplier	25	36	42	£ 1,290,600.00	£ 1,858,464.00	£ 2,168,208.00
PD Monitoring Cable	£ 5,876.12	Quote from Supplier	42	56	56	£ 246,797.04	£ 329,062.72	£ 329,062.72
PD Monitoring Transformer	£ 10,589.20	Quote from Supplier	7	16	27	£ 74,124.40	£ 169,427.20	£ 285,908.40
Environmental Monitoring	£ 20,487.00	Quote from Supplier	11	11	24	£ 225,357.00	£ 225,357.00	£ 491,688.00
SCADA and Integration Per Site	£ 41,360.39	Fully Bottom up costed as per SCADA Paper	33	55	72	£ 1,364,892.87	£ 2,274,821.45	£ 2,977,948.08
Analytics Platform Research and Algorithm Development	£ 266,669.00	NIA Project + 100 days Data Scientist Support	5	5	10	£ 1,333,345.00	£ 1,333,345.00	£ 2,666,690.00
Forensic Anlaysis	£ 10,000.00	Forensic Analysis of Removed Items of Plant	27	27	27	£ 270,000.00	£ 270,000.00	£ 270,000.00
SUB TOTAL						**£ 9,340,612.28**	**£ 13,251,579.07**	**£ 20,347,890.90**
Pre-Construction	3.50%	SSE Baseline				£ 326,921.43	£ 463,805.27	£ 712,176.18
Regulatory & Consent	0.00%	Removed from Baseline - No consents or regulatory barriers.				£ -	£ -	£ -
SSE Staff	5%	SSE Baseline				£ 467,030.61	£ 662,578.95	£ 1,017,394.55
Commisioning	0.50%	SSE Baseline				£ 46,703.06	£ 66,257.90	£ 101,739.45
Insurance	1%	SSE Baseline				£ 93,406.12	£ 132,515.79	£ 203,478.91
Outages	0%	SSE Baseline				£ -	£ -	£ -
SUB TOTAL - including procurement & construction						**£ 10,274,673.51**	**£ 14,576,736.98**	**£ 22,382,679.99**
Risk		8.2% of Initial and SSE Costs for Risk - SSE Baseline				£ 842,523.23	£ 1,195,292.43	£ 1,835,379.76
Scope Developmenet		4% of Initial and SSE Costs for scope development - SSE Baseline				£ 410,986.94	£ 583,069.48	£ 895,307.20
TOTAL						**£ 11,528,183.68**	**£ 16,355,098.89**	**£ 25,113,366.95**

Table 13 - SCADA and Integration Per Site - Costing Table

Asset Monitoring

Asset Monitoring					
Hardware Costs					
Hardware Description		Cost	Qnt.	Sub Total	**Total**
RTU CPU		£ 1,900.00	1	£ 1,900.00	
48Vdc Digital Input Card		£ 900.00	1	£ 900.00	
Analogue Input Card		£ 1,600.00	1	£ 1,600.00	
Modbus to DNP3 converter		£ 472.00	1	£ 472.00	
PSU for Converter		£ 84.00	1	£ 84.00	
I/O Termination		£ 200.00	8	£ 1,600.00	
48Vdc Filter Module		£ 100.00	2	£ 200.00	
RS232-RS485 Serial Interface Adaptor		£ 210.00	1	£ 210.00	
Ribbon Cables and Connectors		£ 50.00	8	£ 400.00	
DC Cabling - inc. glanding [m]		£ 72.00	30	£ 2,160.00	
Multi pair Cabling - inc glanding [m]		£ 108.00	100	£ 10,800.00	
Welfare Facilities Van - inc. mileage [week]		£ 480.00	2	£ 960.00	
Consumable materials - installation		£ 500.00	2	£ 1,000.00	
Sensor Module		£ 1,000.00	4	£ 4,000.00	
			Sub-total	£ 26,286.00	
			Oncosts	£ 3,022.89	
			Total	£ 29,308.89	
Personnel Costs					
Job Title	**Description per Charging Statement**	Rate	Qnt.	Sub Total	
Transmission Manager	Section Manager or internal solicitor	£ 990.00	0	£ -	
Senior PM	Principal Power Systems Engineer	£ 833.00	0	£ -	
Project Manager	Senior Power Systems Engineer, Project Manager or Senior Wayleave Of	£ 695.00	0.5	£ 347.50	
Commercial Manager	Power Systems Engineer or draughtsman	£ 554.00	0	£ -	
Project Engineer	Power Systems Engineer or draughtsman	£ 554.00	5	£ 2,770.00	
Wayleave Officer	Power Systems Engineer or draughtsman	£ 554.00	0	£ -	
Civil PE	Power Systems Engineer or draughtsman	£ 554.00	0	£ -	
Environmental PM	Power Systems Engineer or draughtsman	£ 554.00	0	£ -	
H & S Manager	Power Systems Engineer or draughtsman	£ 554.00	0	£ -	
QS	Power Systems Engineer or draughtsman	£ 554.00	0	£ -	
CAD Design	Power Systems Engineer or draughtsman	£ 554.00	1	£ 554.00	
Land Agent	Graduate Engineer	£ 468.00	0	£ -	
Environmental Advisor	Graduate Engineer	£ 468.00	0	£ -	
Site Construction Manager	Graduate Engineer	£ 468.00	0	£ -	
Craftsman	Craftsman (linesman, cable jointer, substation fitter)	£ 419.00	20	£ 8,380.00	
Admin Support	Admin Support	£ 366.00	0	£ -	
			Personnel Total	£ 12,051.50	
				Project Total	**£ 41,360.39**
				Asset Monitoring	**£ 41,360.39**