XH & XJ ROUTE 400kV OHL MAJOR REFURBISHMENT	
Name of Scheme/Programme	XH & XJ Route 400kV OHL Major Refurbishment
Primary Investment Driver	Asset Health
Scheme reference/ mechanism or category	SPNLT205/Overhead (Tower) Line
Output references/type	NLRT2SP20111/400kV OHL (Tower) Conductor, NLRT2SP20111/400kV OHL Fittings, NLRT2SP20111/400kV OHL Tower
Cost	£39.1M
Delivery Year	2026
Reporting Table	C0.7/5.18
Outputs included in RIIO T1 Business Plan	Yes

Issue Date	Issue No	Amendment Details
July 2019	Issue 1	First issue of document
December 2019	Issue 2	Gross cost, NPV, Monetised Risk, Long Term Risk Benefit and Delivery Year values updated.

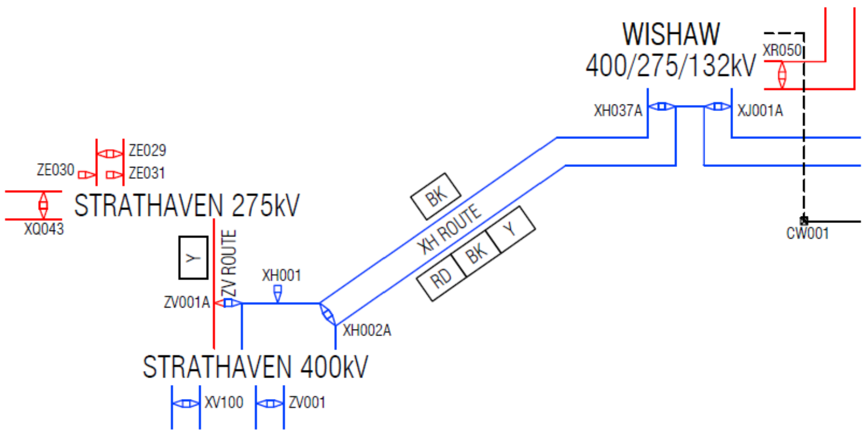
Table of contents

1. Introduction

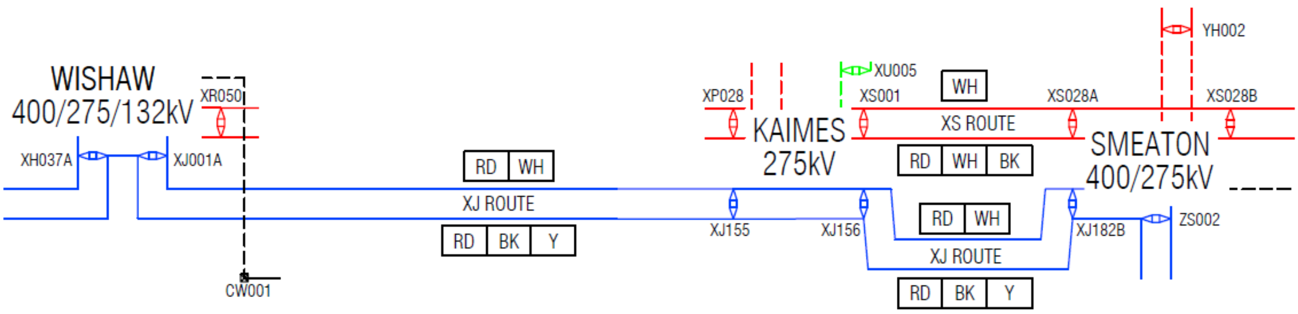
This justification paper supports a proposal to carry out a major refurbishment of the XH and XJ routes:

- XH Route: 400kV transmission double circuit overhead line between Strathaven and Wishaw substations consists of a twin ACSR 400mm2 'Zebra' phase conductor installed in 1960. Earthwire consists of a single ACSR 175mm2 'Lynx' conductor with fibre wrap installed in 1960. XH route (XH001-XH037A) is supported on 39 steel lattice towers (L2 design) with an approximate route length of 11.60km and circuit length of 23.20km.
- XJ Route: 400kV transmission double circuit overhead line between Wishaw, Kaimes and Smeaton substations consists of a twin ACSR 400mm2 'Zebra' phase conductor installed in 1963. Earthwire consists of a single AACSR 190mm2 'Keziah' equivalent OPGW conductor. XJ route (XJ001-XJ182B) is supported on 183 steel lattice towers (L2 design) with an approximate route length of 62.06km and circuit length of 124.12km.

The driver proposal is the asset health of phase conductors and earthwire which will be approaching the end of the operational life by end of RIIO-T2 without intervention after site specific investigations and data analysis.



SYSTEM DIAGRAM EXTRACT: XH ROUTE 400kV



SYSTEM DIAGRAM EXTRACT: XJ ROUTE 400kV

In line with above, the proposed 400kV outputs to be delivered in this project for the replacement option are:

Asset	Type of Activity	Disposal (cct. Km/sets/each)	Addition/Activity (cct. Km/set/each)
400kV OHL (Tower Line) Conductor	Replacement	135.7 cct. Km	135.7 cct. Km
400kV OHL Fittings	Replacement*	405 sets	405 sets
400kV Tower	Refurbishment Major	-	222 each

**OHL Fittings outputs refer to spacers and vibration dampers and not to the replacement of the whole insulator set.*

The delivery of the project is characterised by multiple wiring gangs (2) working concurrently in order to minimise access and constraints on the network.

2. Background Information

The existing system (XH and XJ Routes) is a double circuit overhead line that forms a 400kV connection between Strathaven, Wishaw, Kaimes and Smeaton substations which travels predominately through agricultural land with some residential buildings in close proximity. No alterations to the system configuration have been proposed.

The existing conductors are 400mm2 ACSR 'Zebra' (core only greased) manufactured with a configuration of two conductors per phase. The existing earth wire is a 175mm2 ACSR 'Lynx' (core only greased) conductor with optical fibre wrap installed between towers XH003 to XH035 and single "Keziah" 190mm^2 AACSR equivalent OPGW installed along sections XH001 to XH003, XH035 to XH037A and XJ Route.

<u>XH Route 400kV:</u>

Circuits are twin conductor as follows:

- Phase Conductor Type (Strathaven-Wishaw cct.): twin ACSR 400mm2 'Zebra' core only greased installed in 1960.
- Phase Conductor Type (Strathaven-Torness cct.): twin AAAC 425mm2 'Totara' installed in 2014.
- Earth wire Conductor Type (XH003 to XH035): single ACSR 175mm2 'Lynx' core only greased installed in 1960 with optical fibre wrap installed.
- Earth wire Conductor Type (XH001 to XH003 and XH035-XH037A): single "Keziah" 190mm^2 AACSR equivalent OPGW installed in 2012 and 2015.
- Insulators Type: porcelain-grey installed in 2004.
- Tower Type: steel lattice L2 design except for towers XH002A, XH002B, XH036A and XH037A which are L8 designs.

XH route presents a number of critical locations adjacent to railways, main roads and HV OHLs, namely:

- 1no. 33kV OHL crossings.
- 5no. 11kV OHL crossings.
- 1no. Motorway (M74).
- 3no. A Roads crossings.
- 1no. Railway line crossing.
- Close proximity to urban areas.
- Terrain comprising of urban areas, open undulating farmland with some locations in excess of 200m high (A.O.D.).

XJ Route 400kV:

Circuits are twin conductor as follows:

- Phase Conductor Type: twin ACSR 400mm2 ‘Zebra’ installed in 1966.
- Earth wire Conductor Type: single “Keziah” 190mm^2 AACSR equivalent OPGW installed in 2010.
- Insulators Type: porcelain-grey installed in 2009.
- Tower Type: steel lattice L2 design except for towers XJ001A, XJ180, XJ181B and XJ182B which are L8 designs.

There are 3 operating circuits on XH and XJ route. Circuit nomenclatures and colours are:

- STHA-WISH-1 (XH001 – XH037A). Circuit colour: Black.
- TORN-STHA (XH001 – XJ182B). Circuit colour: Red / Black / Yellow.
- WISH-SMEA (XJ001A – XJ182B). Circuit colour: Red / White.

XJ route presents a number of critical locations adjacent to railways, main roads and HV OHLs, namely:

- 3no. 33kV OHL crossings.
- 6no. 11kV OHL crossings.
- 14no. A Roads crossings.
- 5no. Railway line crossing.
- Close proximity to urban areas.
- Terrain comprising of urban areas, open undulating farmland with some locations in excess of 350m high (A.O.D.).

2.1 Data Collection

As part of the SP Energy Networks (SPEN) OHL inspection regime, aerial photographic information in conjunction with site specific investigations such as conductor corrosion monitoring and conductor damages have been employed to provide a detailed condition analysis of the OHL components.

- Aerial photographic inspection (2011 and 2014).
- Corrosion monitoring testing:
  - Earth wire along XH Route in 1992.
  - Earth wire along XJ Route in 1993/1993.
  - Phase conductor on spans XJ067-068 and XJ070-071-072 in 2007-2010.
- Conductor damages records from 2016 to 2018.

2.2 Data Analysis and Interpretation

The collected condition data has been analysed following “ASSET-01-030 Overhead Lines Technical Asset Life and CBRM Methodology” before condition ratings (1 to 5) per asset are defined and subsequently input to the SPEN Condition Based Risk Management (CBRM) tool.

The “ASSET-01-030 Overhead Lines Technical Asset Life and CBRM Methodology” document covers the model describing how overhead line conductors’ condition is expected to change over time and its calculated technical asset life based upon a condition data approach, conductor types, grease levels and environment type. It also defines a common way on how condition data is interpreted, removing subjectivity and providing a clear view on how condition ratings have been concluded.

<u>Phase and Earth wire conductors:</u>

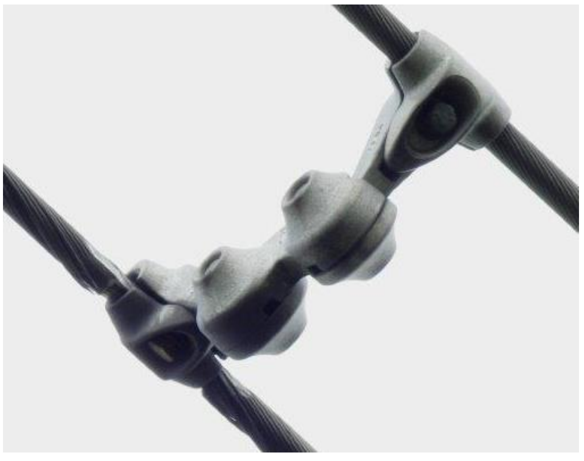
XH and XJ route conductors from condition information gathered in January 2014 and October 2011 respectively indicate conductor to be in good external condition however, it generally recognised that conductor degradation is age related and cormon test measurements would provide a more reliable indicator of conductor condition. Cormon testing was carried out along XH route earthwire conductor over several span locations (XH006-007, XH007-008, XH011-012, XH012-013, XH022-023, XH023-024, XH031-32, XH032-33) in 1992 indicating a negligible deterioration of the steel wires galvanic protection (zinc layer) from readings recorded. Similarly, cormon testing was also carried out along the XJ route primarily on the earthwire conductor over numerous span locations in 1992 and 1993 also indicating a negligible deterioration of the steel wires galvanic protection (zinc layer) from readings recorded.

The availability of network access of these circuits is very onerous and therefore information on the condition of the conductor is very limited, however previous conductor samples collected from moderately polluted areas over the SP Network indicate that the anticipated life following an ageing profile (internal galvanic corrosion) of a ACSR ‘Zebra’ (core-only greased) conductor is between 50-60 years. Consideration of this and additional factors including quality, manufacturing, design and fatigue at clamps and spacer locations can accelerate the typical ageing profile of the conductors giving a CBRM projection for the conductor approaching the end of the operational life by end of RIIO-T2.

In addition to the above, corrosion monitoring results collected at XP Route (OHL in close proximity to XJ Route along spans XJ140-XJ150) over several span locations throughout the route in 2007 indicated a significant deterioration of the steel wires' galvanic protection (zinc layer) from 'partial' to 'severe' readings along the phase conductor (400mm2 ACSR 'Zebra' installed in 1964) and earthwire (175mm2 ACSR 'Lynx' installed in 1964).

Further evidence also indicates that 'end of life' for some ACSR conductor OHL routes operating in certain environments is caused by fatigue due to wind induced damage at conductor to conductor component fitting locations and not through corrosion. Damage mostly occurs around fittings and spacers affecting the conductor aluminium strand wires with a number of incidents related to wind induce effects having been reported along XH and XJ Routes:

- Conductor damages noted at spacer locations within the last 3 years, spans: XH003-004, XH018-019, XJ075-076, XJ088-089, XJ101-102, XJ121-122.



Conductor damage at span XH003-004

Conductor damage at span XJ088-089

There was also a previous need for works on XH and XJ routes to be carried out within the RIIO-T1 regulatory period however, through outage constraints were never completed and therefore have now become a necessary requirement within the RIIO-T2 regulatory period.

In addition, a requirement to increase the level of generation has resulted in a proposal to re-conductor both circuits on XH and XJ routes with a AAAC 425mm2 "Totara" conductor (TORI130) to facilitate an increase in the thermal rating capability of the OHLs.

2.3 CBRM Summary

CBRM extract is shown below indicating End of Life (EoL) for each of the identified asset for replacement:

XH Route 400kV:

Asset Description	Year of Installation	EoL*	Monetised Risk (R£m)*
Phase Conductor (TORN-STHA cct.) XH Route 400kV	1960	8.50	7,617,584.30

**Values at the end of the RIIO-T2 period with no intervention as per NOMs methodology.*

XJ Route 400kV:

Asset Description	Year of Installation	EoL*	Monetised Risk (R£m)*
Phase Conductor XJ Route 400kV	1966	9.72	40,073,220.70
Steel Tower XJ Route 400kV	1966	13.74	789,098.41

**Values at the end of the RIIO-T2 period with no intervention as per NOMs methodology.*

3. Optioneering

Three options have been considered based on the requirements identified within the condition assessments produced for the existing XH and XJ route overhead line, where Option 1 has been recognised as the only viable option which meets the project objectives.

Option	Status	Reason for rejection
Baseline - Do Minimum: • Deferral of the major refurbishment intervention to RIIO-T3 (2026).	Considered but Rejected	This option is unacceptable due to the overall condition of the OHL conductor being at their end of life and no intervention will add considerable risk to two of the most critical 400kV circuits within the SPT Network. In addition, deferring the investment will accelerate the continual deterioration of the OHL components, in particular the OHL conductor which strength will be compromised preventing its use as pulling bond, significantly increasing the costs for conductor stringing activities.
Option 1 - Conductor and Earthwire Replacement: • Major refurbishment intervention (replacement of phase conductor and earth wire) in RIIO-T2 (2026).	Considered and Proposed	-

Option	Status	Reason for rejection
Option 2 - Full Refurbishment • The replacement of phase conductor, earth wire and insulators in RIIO-T2 (2026).	Rejected	Insulators along XH and XJ Routes were installed in 2004 and 2010 respectively with an anticipated life of 50 years.
Option 3 - Full Replacement	Rejected	Replacement of the existing OHL towers is unacceptable due to its condition and anticipated remaining life. Full Replacement will incur in a more onerous cost and delivery timescales due to environmental planning constraints (which is not in the best interests of system security or consumers).

4. Detailed analysis

Option 1 achieves the main objective of replacing phase conductor, earth wire and fittings/insulators while refurbishing the OHL Towers and thereby reducing the overall risks to the network and costs. Baseline and Option 1 have been considered for a CBA analysis including whole life monetised benefits and comparison of respective project option costs.

4.1 Option 1: Full Refurbishment

This option considers replacement of the replacement of all phase conductors, fittings/insulators assets as identified earlier through condition data, data analysis and interrogation. The following interventions are proposed to be replaced in a staged manner in this option:

XH Route 400kV:

- Re-conductor TORN-STHA cct. with twin 'Totara' 425mm2 All Aluminium Alloy Conductor (AAAC) EHC at maximum 90C for operation.
- Replace earthwire with a single "Keziah" 160mm2 AACSR equivalent OPGW.
- Replace all tension and suspension conductor end fittings.
- Replace earthwire fittings.
- Replace tower muff foundations as required per condition.
- Upgrade foundations as required per condition.
- Replace downleads and fittings at Strathaven and Wishaw substations.
- Steelwork modifications as per TGN161 and TGN163.
- Replace heavily corroded or damaged steelwork (above category 4).
- Update all OHL records to reflect the works carried out.
- Carry out condition assessments on sections of removed conductor.
- Provide report to the Asset manager to include condition of all redundant conductors, steelwork and foundations along with associated tests logs for existing/new concrete.

XJ Route 400kV:

- Re-conductor all with twin 'Totara' 425mm2 All Aluminium Alloy Conductor (AAAC) EHC at maximum 90C for operation.
- Replace all tension and suspension conductor end fittings.
- Replace tower muff foundations as required per condition.
- Upgrade foundations as required per condition.
- Replace downleads and fittings at Wishaw, Kaimes and Smeaton substations.
- Carry out tower painting.
- Steelwork modifications as per TGN161 and TGN163.
- Replace heavily corroded or damaged steelwork (above category 4).
- Update all OHL records to reflect the works carried out.
- Carry out condition assessments on sections of removed conductor.
- Provide report to the Asset manager to include condition of all redundant conductors, steelwork and foundations along with associated tests logs for existing/new concrete.

The standard replacement minimum twin conductor 425mm^2 AAAC (Totara) EHC system thermal ratings*:

Season / State	Amps	MVA
Winter Pre Fault	2430	1680
Winter Post Fault	2890	2000
Spring/Autumn Pre Fault	2330	1610
Spring/Autumn Post Fault	2770	1920
Summer Pre Fault	2170	1500
Summer Post Fault	2580	1790

**at 90C Maximum Operation Temperature*

Specific factors attributable to this option which results in additional costs are listed below:

- Works also include for exploratory ground investigations to assess the condition of the tower foundations below ground level. Above ground foundation and/or muffs will be repaired or replaced where required by their condition.

  The majority of SPT towers use foundations of the pyramid block and chimney design, with most of the rest being piled. For the majority of well-constructed foundations using the appropriate materials there are no significant means of degradation but workmanship and past design details do give rise to potentially serious problems. Insufficient embedment of stubs into the block and a lack of cleats can result in uplift failures where the pyramid block remains in the ground. Corrosion of the tower steel stub can occur when moisture and oxygen come into contact with it. The corrosion is usually only found at the chimney/muff interface where poor construction has left the joint open exposing the bare steel.

  SPT has developed a methodology (applied in RIIO-T1) based upon a comprehensive desktop/site intrusive study to undertake a quantified risk assessment (QRA) approach to determine the foundation sites that require any type of refurbishment:

  - Importance of the circuits.
  - Ground investigation desktop study. Misalignment of installed foundation type with soil type identified on the British Geological Survey (BGS) maps.
  - Tower lean and towers required to have wind stays removed under the contract.
  - Highly loaded towers (in relation to new and design loads).
  - Access difficulties.
  - Proximity to crossings, residential areas, etc.
  - Other high risk factors (e.g. existing damage, relative location to highly distressed towers, etc.).
  - Primary investigations (Level 1 inspection): non-intrusive surveys.
  - Secondary investigations (Level 2 inspection): foundation intrusive.

  Once the above aspects have been considered, a risk rating will be applied grading the perceived suitability. This in turn will form the basis for any recommendation of foundation refurbishments.

  Based on the experience gathered in RIIO-T1 for the same type of towers and age, an allowance of 10% of the suspension towers and all pulling positions have been allocated to the project for foundation intrusive investigation and refurbishment.

- Consideration for body extension modifications and replacement of the suspension insulator cross-arm channels following TGN161 and 163 respectively.
- Allowances for the undergrounding of distribution crossing have also been made.
- Temporary ADSS Telecom conductor along XH Route to provide diversion to the existing earthwire fibre wrap.

- Large number of critical locations adjacent to railways, main roads and HV OHL's
- Terrain comprising of urban areas, open undulating farmland with some locations in excess of 350m high (A.O.D.).

The following specific risks have been identified for this option:

- Conductor condition monitoring before works starts to allow an early indication of the suitability of the conductor and earth wire to be used as pulling bonds.
- Working over existing distribution overhead lines to be addressed by diverting or undergrounding on a temporary basis.
- Railway and road crossings to be mitigated through scaffolding and traffic management systems or deployment of a catenary support system.
- Utilities within working areas to be addressed through procurement of records for duration of the project.
- Access routes to be addressed through early engagement with landowners, employing low bearing pressure ground vehicles and trackway where possible to minimise extents of stone tracks.
- Foundation condition and shape not being able to provide necessary uplift/compression capacity.
- Optimisations of Network access by the introduction of multiple gangs.
- Network operability/wayleave/environmental restrictions which impact on the progression of works as planned.

4.2 Selected Option

Baseline and Option 1 have been considered for a CBA analysis where whole life monetised benefits and comparison of respective project option costs.

Option No.	Description Of Option	Preferred Option	Total NPV (£m) *(Incl. Monetised Risk)*	Delta *(Option to baseline)*
Baseline	Baseline	N	£ 2,731.42	£ -
1	Conductor and Earthwire Replacement	Y	£ 2,910.81	£ 179.39

5. Conclusion

The 2 options proposed have been reviewed in terms of scope feasibility, cost, timescales and construction risks with Option 1 demonstrating the primary objective of lead assets replacement whilst affording greatest reduction in risk to the network.

In line with the costs prepared, the proposed scope of works and CBA analysis, option 1 (replacement of phase conductor, earth wire and insulator/fittings) is the selected option:

- Scheme Total Cost: £39.1M
- Timing of investment: 2021 – 2026
- Declared outputs:

Asset	Type of Activity	Disposal (cct. Km/sets/each)	Addition/Activity (cct. Km/set/each)
400kV OHL (Tower Line) Conductor	Replacement	135.7 cct. Km	135.7 cct. Km
400kV OHL Fittings	Replacement	405 sets	405 sets
400kV Tower	Refurbishment Major	-	222 each

- Longer term risk benefit (LR£m):

XH Route:

Asset	Long Term Risk Benefit (LR£m)
400kV OHL (Tower Line) Conductor	528.50

XJ Route:

Asset	Long Term Risk Benefit (LR£m)
400kV OHL (Tower Line) Conductor	2,786.31
400kV OHL Tower	11.48

- Price control period of outputs: 2026

6. FUTURE PATHWAYS – NET ZERO

6.1 Primary Economic Driver

The primary driver for this investment is asset condition and risk. The investment does not have a strong reliance on environmental benefits.

6.2 Payback Periods

The CBA indicates that a positive NPV results in all assessment periods (10, 20, 30 & 45 years) which is consistent with the lifetime of the intervention. Consumers benefit from reduced network risk immediately on completion of the project.

6.3 Pathways and End Points

The network capacity and capability that result from the proposed option has been tested against and has been found to be consistent with the network requirements determined from the ETYS and

NOA processes. Additionally, the proposed option is consistent with the route-specific capacity requirements from SPT's Energy Scenarios.

6.4 Asset Stranding Risks

Electricity generation, demand and system transfers are forecast to increase under all scenarios. The stranding risk is therefore considered to be very low.

6.5 Sensitivity to Carbon Prices

The CBA inputs are not sensitive to carbon prices.

6.6 Future Asset Utilisation

It has been assessed that the preferred option is consistent with the future generation and demand scenarios and that the risk of stranding is very low.

6.7 Whole Systems Benefits

The supergrid voltage proposals do not inhibit whole system solutions but are more remote from the interfaces.

7. OUTPUTS INCLUDED IN RIIO T1 PLANS

XH and XH Routes were included as a 'best view' scheme in RIIO-T1. There have been a small number of substitutions of the overhead line portfolio and XH and XJ routes were deferred as part of this. The overall position for overhead lines is that the schemes substituted in are forecast to meet the targets for this category. The full funding allocated to XH and XJ routes in RIIO-T1 has been transferred to other schemes through substitution.