Document 3
Asset Category – Cables
LPN

Asset Stewardship Report 2014

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Document History:

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2.0	07/03/2014	Final Version	Richard Gould		

Preface

UK Power Networks uses Asset Stewardship Reports ('ASR') to describe the optimum asset management strategy and proposals for different groups of assets. This optimised asset management strategy and plan details the levels of investment required and the targeted interventions and outputs needed. Separate ASRs define the most efficient maintenance and inspection regimes needed and all documents detail the new forms of innovation which are required to maximise value, service and safety for all customers and staff throughout the ED1 regulatory period. Outline proposals for the ED2 period are also included.

Each DNO has a suite of approximately 20 ASR's. Although asset policy and strategy is similar for the same assets in each DNO the detailed plans and investment proposals are different for each DNO. There are also local issues which must be taken into account. Accordingly each DNO has its own complete set of ASR documents.

A complete list of titles of the ASR's, a summary of capex and opex investment is included in '**Document 20: Asset Stewardship Report: Capex/Opex Overview'**. This document also defines how costs and outputs in the various ASR's build up UK Power Networks 'NAMP' (Network Asset Management Plan) and how the NAMP aligns with Ofgem's ED1 RIGs tables and row numbers.

Where 'HI' or asset 'Health Index' information is included please note predicted ED1 profiles are before any benefits from 'Load driven investment.'

This ASR has also been updated to reflect the feedback from Ofgem on our July 2013 ED1 business plan submission. Accordingly to aid the reader three additional appendices have been added. They are;

1. **Appendix 8 - Output NAMP/ED1 RIGS reconciliation:** This section explains the 'line of sight' between the UKPN Network Asset Management Plan (NAMP) replacement volumes contained in the Ofgem RIGS tables. The NAMP is the UKPN ten year rolling asset management investment plan. It is used as the overarching plan to drive both direct and indirect Capex and Opex interventions volumes and costs. The volume and cost data used in this ASR to explain our investment plan is taken from the UK Power Networks NAMP. Appendix 8 explains how the NAMP outputs are translated into the Ofgem RIGS tables. The translation of costs from the NAMP to the ED1 RIGS tables is more complex and it is not possible to explain this in a simple table. This is because the costs of project in the 'NAMP' are allocated to a wide variety of tables and rows in the RIGS. For example the costs of a typical switchgear replacement project will be allocated to a range of different Ofgem ED1 RIGs tables and rows such as CV3 (Replacement), CV5 (Refurbishment) CV6 (Civil works) and CV105 (Operational IT Technology and Telecoms). However guidance notes of the destination RIGs tables for NAMP expenditure and included in the table in the Section 1.1 of the Executive Summary of each ASR.

2. **Appendix 9 – Efficiency benchmarking with other DNO's:** This helps to inform readers how UK Power Networks is positioned from a benchmarking position with other DNO's. It aims to show why we believe our investment plans in terms of both volume and money is the right answer when compared to the industry, and why we

believe our asset replacement and refurbishment investment proposals are efficient and effective and in the best interest for our customers.

3. **Appendix 10 – Material changes since the July 2013 ED1 submission:** This section shows the differences between the ASR submitted in July 2013 and the ASR submitted for the re-submission in March 2014. It aims to inform the reader about the changes made to volumes and costs as a result of reviewing the plans submitted in July 2013. Generally the number of changes made is very small, as we believe the original plan submitted in July 2013 meets the requirements of a well justified plan. However there are areas where we have identified further efficiencies and improvements or recent events have driven us to amend our plans to protect customer safety and service.

We have sought to avoid duplication in other ED1 documents, such as ‘Scheme Justification Papers’, by referring the reader to key issues of asset policy and asset engineering which are included in the appropriate ASR documents.

Contents

1.0 Executive Summary Underground Cables

1.1 Scope

This document details UK Power Networks’ non-load related expenditure (NLRE) investment proposals for underground cables for RIIO-ED1 period. Where possible, indicative proposals for the ED2 period are also included.

There are 36,574 circuit kilometres of cable in LPN with an estimated MEAV of £6,936m. The intervention cost for ED1 is £127.3m across the eight year period.

The proposed investment is £15.9m per annum, which equates to an average annual 0.3% of the MEAV for this asset category. Replacement costs for these assets are held in the Networks Asset Management Plan (NAMP) and in sections of the RIGs tables identified in Table 1.

Investment type	ED1 Investment £m	NAMP line	RIGs reference (Table CV3)
Fluid-filled cable asset replacement	£13.3m	1.29.01 1.29.02 1.31.02 1.31.04 1.31.08	Additions CV3 Row 63 – 33kV UG Cable (Oil) CV3 Row 66 – 66kV UG Cable (Oil) CV3 Row 93 – 132kV UG Cable (Oil) Removals CV3 Row 191 – 33kV UG Cable (Oil) CV3 Row 194 – 66kV UG Cable (Oil) CV3 Row 221– 132kV UG Cable (Oil)
Gas cable asset replacement	£0.5m	1.07.07 1.07.90	Additions CV3 Row 64 – 33kV UG Cable (Gas) CV3 Row 67 – 66kV UG Cable (Gas) CV3Row 94 – 132kV UG Cable (Gas) Removals CV3 Row 192 – 33kV UG Cable (Gas) CV3 Row 195 – 66kV UG Cable (Gas) CV3 Row 222 – 132kV UG Cable (Gas)
Solid cable asset replacement	£113.5m	1.07.01 1.07.02 1.18.01 1.18.03 1.18.04	Additions CV3 Row 9 – LV Main (UG Consac) CV3 Row 10 – LV Main (UG Plastic) CV3 Row 11 – LV Main (UG Paper) CV3 Row 29 – 6.6/11kV UG Cable CV3 Row 30 – 20kV UG Cable CV3 Row 62 – 33kV UG Cable (Non Pressurised) CV3 Row 65 – 66kV UG Cable (Non Pressurised) CV3 Row 92 – 132kV UG Cable (Non Pressurised) Removals CV3 Row 137 – LV Main (UG Consac) CV3 Row 138 – LV Main (UG Plastic) CV3 Row 139 – LV Main (UG Paper) CV3 Row 157 – 6.6/11kV UG Cable CV3 Row 158 – 20kV UG Cable CV3 Row 190 – 33kV UG Cable (Non Pressurised) CV3 Row 193 – 66kV UG Cable(Non Pressurised) CV3 Row 220 – 132kV UG Cable (Non Pressurised)

Table 1 – Investment summary

Source: 21st February 2014 ED1 Business Plan Data Tables

1.2 Investment Strategy

The investment strategy for RIIO-ED1 is detailed in UK Power Network's Engineering Design Procedure EDP 00-009, *Asset Lifecycle Strategy-Underground Cables*. It is to ensure the lifetime cost of the underground cable assets are kept to a minimum while optimising performance and ensuring safety and regulatory compliance.

A key investment driver is the requirement to reduce the volume of fluid-filled cable top-ups, which are currently double the national average. The proposed investment plan is anticipated to reduce the current fluid-filled leakage rate by 28% over the ED1 period.

1.3 ED1 Proposals

Fluid-filled cables

Table 2 shows the planned interventions for Fluid-filled cable (FFC) assets in LPN through RIIO-ED1.

NAMP line	Description	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	ED1 total
1.29.01	EHV Cable replacement	1.30	4.70	4.30	3.30	0.00	7.20	6.60	7.20	**34.60**
1.29.02	132kV FFC replacement	0.00	2.70	3.60	0.00	0.00	9.10	0.30	19.10	**34.80**
1.31.02	Replace aluminium cable joint plumbs	3	3	3	3	3	3	3	3	**24**
1.31.04	Install remote pressure monitoring equipment	15	15	15	15	15	15	12	0	**102**
1.31.08	Replace pressurised cables ancillary equipment (tanks, gauges etc.)	8	8	8	8	8	8	8	8	**64**

Table 2 – RIIO-ED1 intervention volumes of FFC assets

Source: 19th February 2014 NAMP Table O

Gas cables

Table 3 shows the planned interventions for gas cable assets in LPN through RIIO-ED1.

NAMP line	Description	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	ED1 total
1.07.90	EHV Gas cable replacement	4	2.60	0	4.30	7.50	0	0	0	**18.40**
1.07.07	132kV Gas cable replacement	20	11	0	0	0	0	0	19	**50**

Table 3 – RIIO-ED1 intervention volumes of gas cable assets

Source: 19th February 2014 NAMP Table O

Solid Cables

Table 4 shows the planned interventions for solid cable assets in LPN through RIIO-ED1.

NAMP Line	Description	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	ED1 Total
1.07.01	ED1 EHV Solid Cable replacement provision	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	**10**
1.07.02	ED1 132kV Solid cable replacement provision	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.37	**3.03**
1.18.01	Replace HV cable (planned)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	**40**
1.18.03	Replace LV cable (planned)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	**16**
1.18.04	Replace 11kV transition joints	200	200	200	200	200	200	200	200	1600

Table 4 – RIIO-ED1 intervention volumes of solid cable assets

Source: 19th February 2014 NAMP Table O

1.4 Innovation

UK Power Networks has undertaken several initiatives to explore innovative solutions that will improve the performance of the underground cable network. Details of the various solutions are given in section 6 of the document.

Examples of innovation include online pressure monitoring, PFT leak location and partial discharge mapping.

1.5 Risks and Opportunities

	Description of similarly likely opportunities or risks arising in ED1 period	Uncertainties
Opportunity	Successful trials of self-healing fluids allow 10% of leaking fluid filled cable (FFC) sections to remain in service.	£7.4m
Risk	10 % increase in the proposed ED1 intervention volumes due to sudden degradation of fluid filled cable (FFC) sections.	£6.0m

Table 5 – Risks and opportunities

2.0 Description of Underground Cables

There are 36,574 kilometres of underground cable installed in the LPN area. There are three types of cable construction: solid cable, fluid-filled cable or gas cable. All fluid-filled cables and gas cables operate at either EHV or 132kV. Solid cables operate at all voltage levels from LV to 132kV.

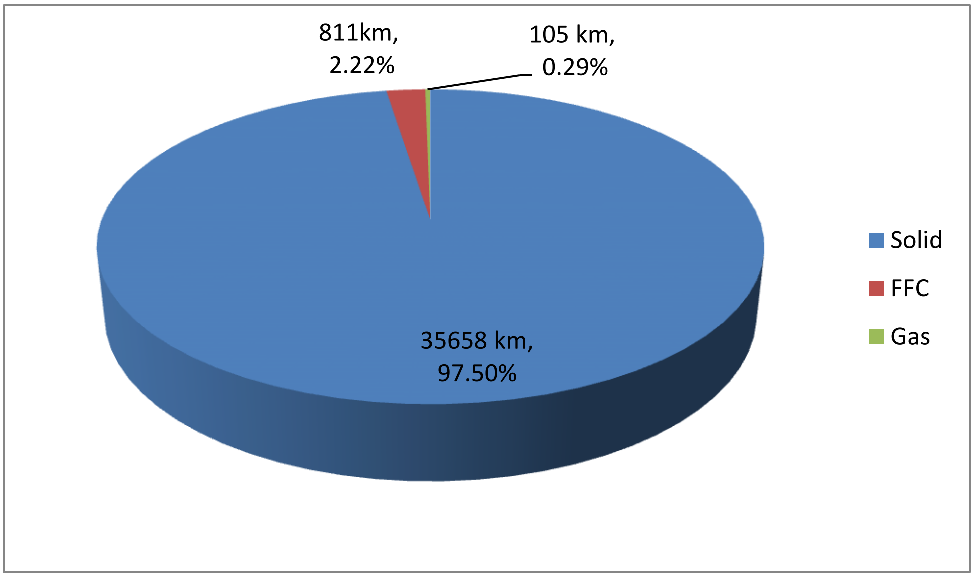


Figure 1 – Population of underground cables by type

Source: RIGs 2012 Table V5

The breakdown of the LPN underground cable network by voltage is shown in Figure 2.

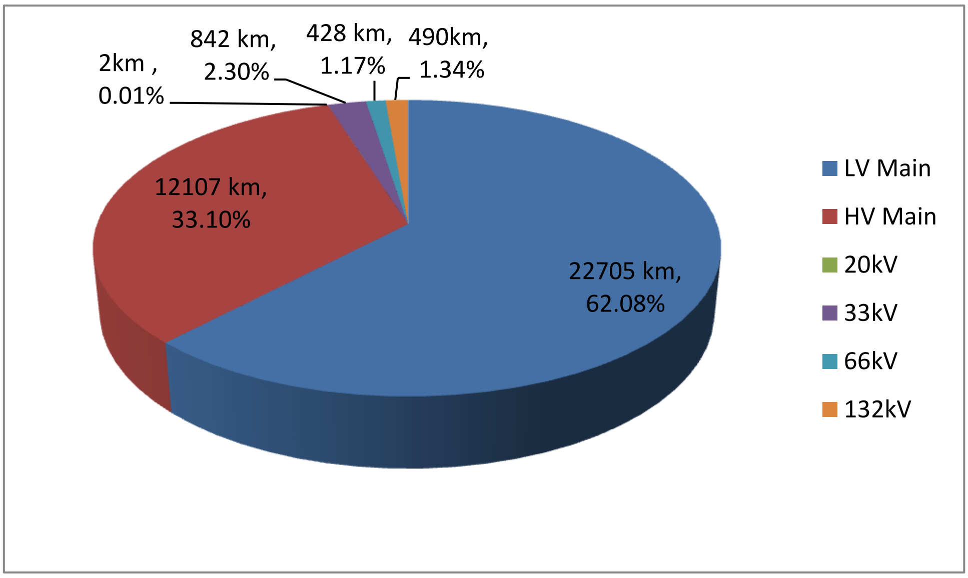


Figure 2 – Population of underground cables by voltage

Source: RIGs 2012 Table V5

The 132kV underground cable network has more fluid cable installed than any other type – refer to Figure 3.

Of the 132kV underground cable network, 59% is constructed of either fluid-filled or gas cable.

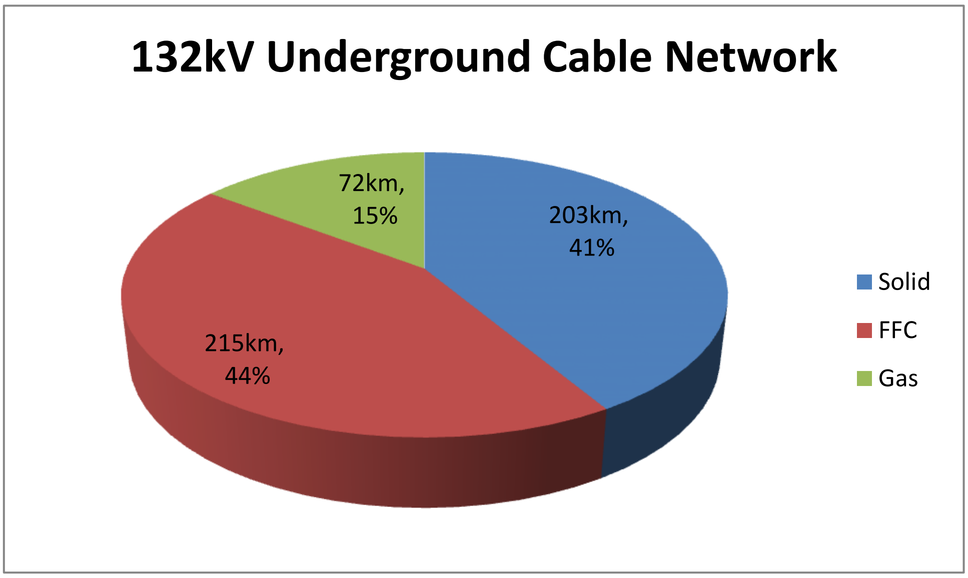


Figure 3 – 132kV underground cables by type

Source: RIGs 2012 Table V5

The EHV underground cable network also has more fluid cable installed than any other type – refer to Figure 4.

Of the EHV underground cable network, 50% is constructed of either fluid-filled or gas cable.

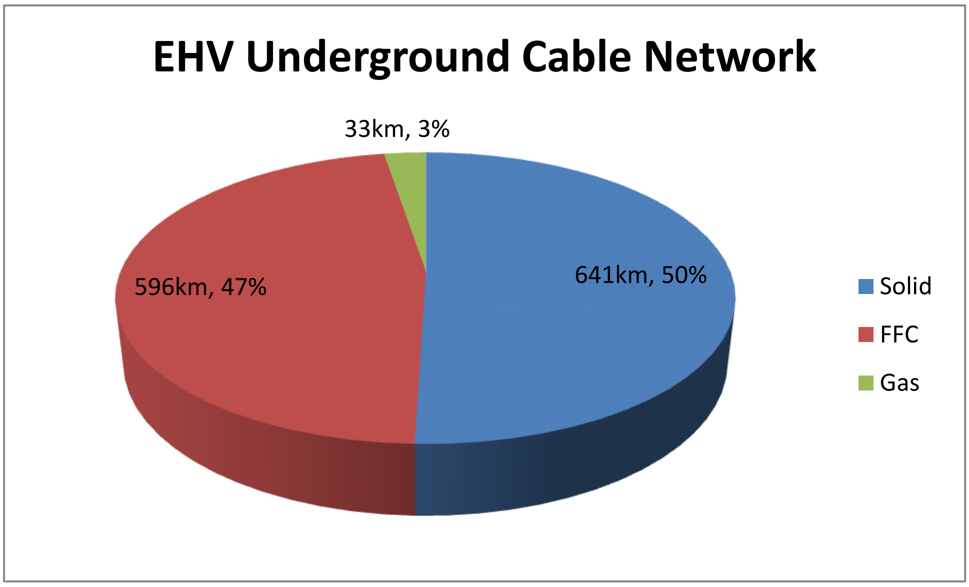


Figure 4 – EHV underground cable by type

Source: RIGs 2012 Table V5

2.1 Fluid-Filled Cables

As mentioned in section 2.0 there are more fluid-filled cables installed at 132kV or EHV than any other type of cable. The 811 kilometres of fluid filled cables installed are split evenly between 33kV, 66kV and 132kV.

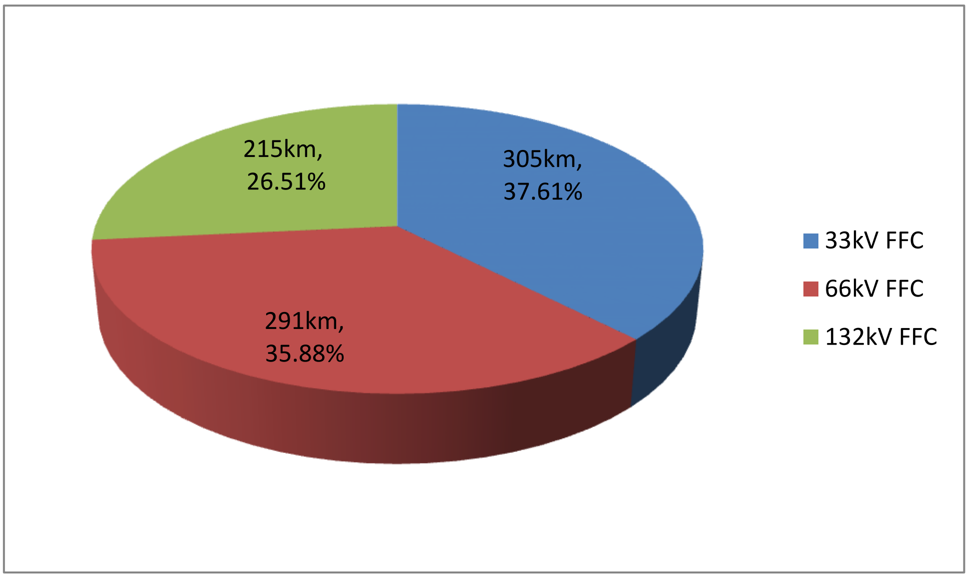


Figure 5 – Population of underground fluid-filled cable (FFC) by voltage

Source: RIGs 2012 Table V5

As can be seen in the age profile graphs, most of the fluid-filled cable at all voltages was installed in the 1960s, some 50 years ago.

The average age of the fluid-filled cable network is 52 years. The oldest 10% of these assets has an average age of approximately 80 years.

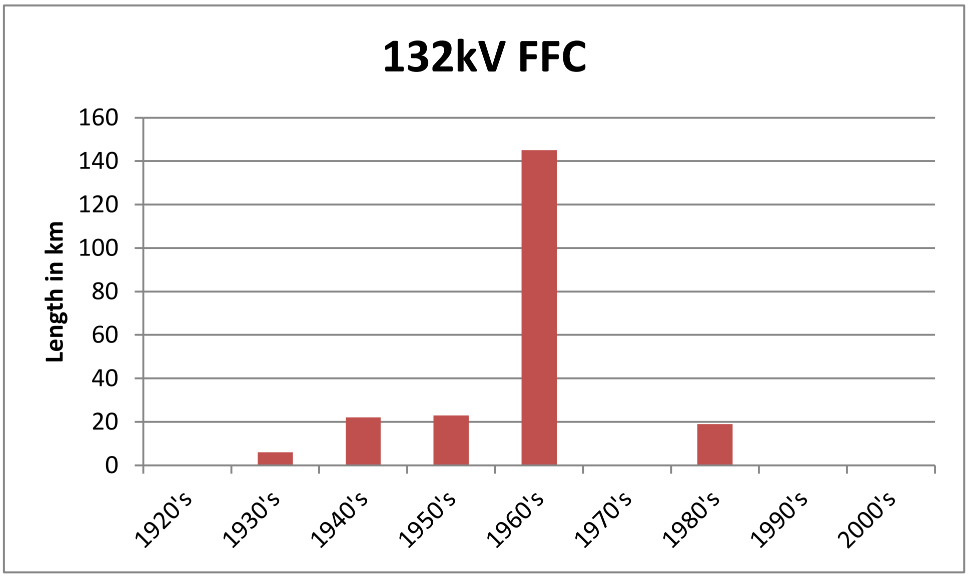


Figure 6 – Age profile of 132kV fluid-filled cable (FFC)

Source: RIGs 2012 Table V5

The average age of the 132kV fluid-filled cable network is 52 years.

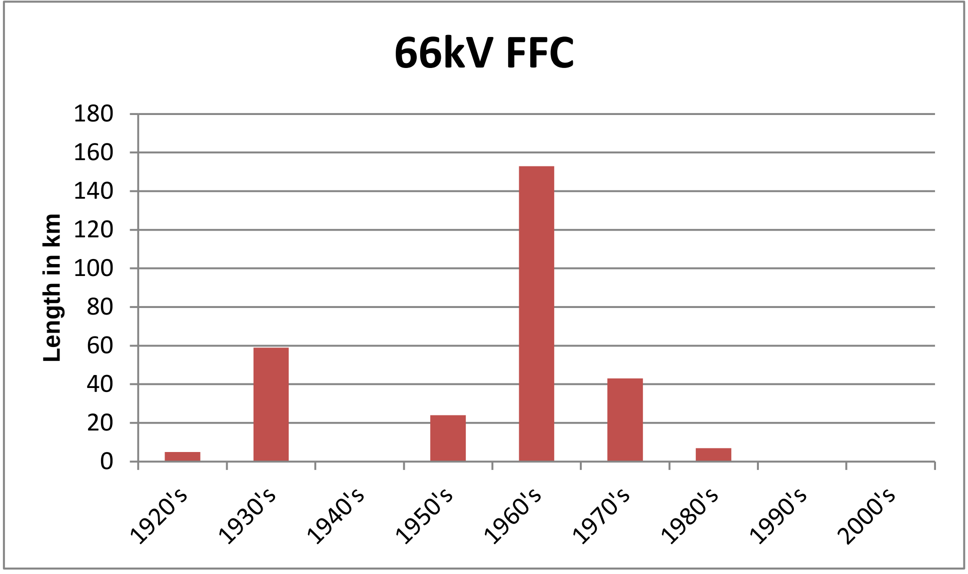


Figure 7 – Age profile of 66kV fluid-filled cable (FFC)

Source: RIGs 2012 Table V5

The average age of the 66kV fluid-filled cable network is 54 years.

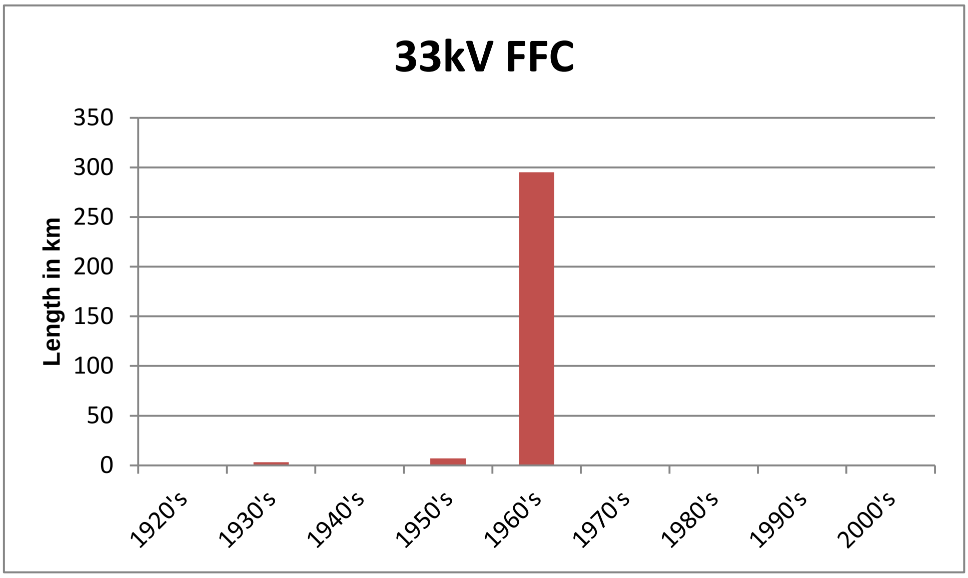


Figure 8 – Age profile of 33kV fluid-filled cable (FFC) cable

Source: RIGs 2012 Table V5

The average age of the 33kV fluid-filled cable network is 50 years.

Reference NAMP lines:

The fluid filled cable replacement provisions for ED1 are listed under following NAMP lines:

NAMP line	Description
1.29.01	Fluid Filled Cable Replacement (EHV)
1.29.02	Fluid Filled Cable Replacement (132kV)

Table 6 – NAMP reference

Reference RIGs code

The corresponding RIGs lines are shown in Table 7:

RIGs tab	Line (additions)	Line (removals)	Description
CV3	063	191	33kV UG cable (oil)
CV3	066	194	66kV UG cable (oil)
CV3	093	221	132kV UG cable (oil)

Table 7 – RIGs categories

2.2 Gas Cables

The majority of the 105 kilometres of gas cable installed is at 132kV.

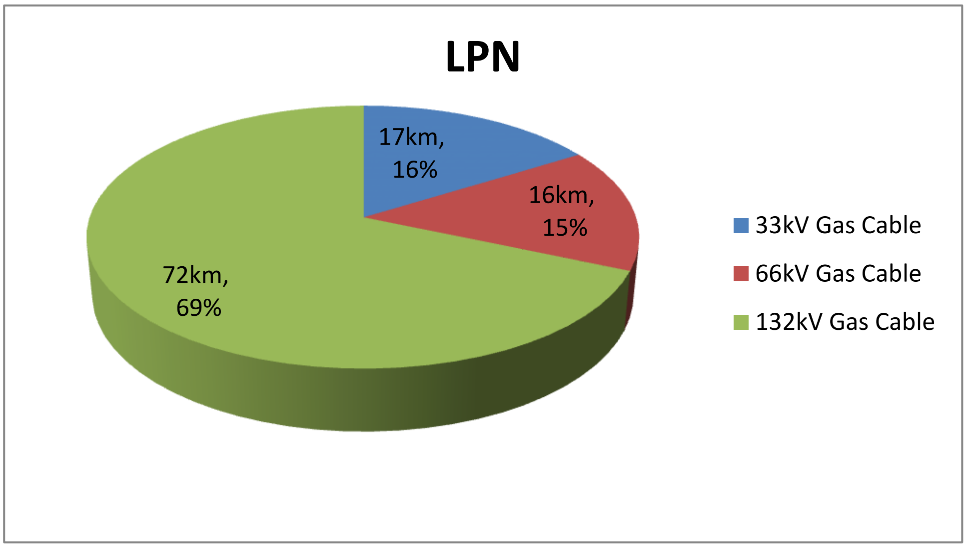


Figure 9 – Population of underground gas cable by voltage

Source: RIGs 2012 Table V5

As can be seen in the age profile graphs, most of the gas cable at all voltages was installed in the 1950s and 1960s, with some being installed up until the 2000s as a replacement of previous gas cable circuits. The average age of the gas cable network is 46 years.

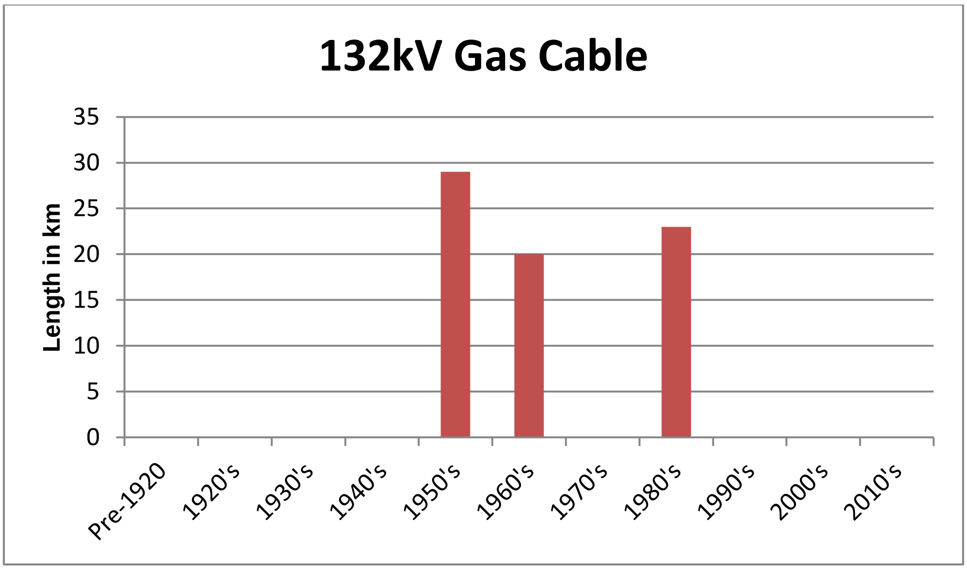


Figure 10 – Age profile of 132kV gas cable

Source: RIGs 2012 Table V5

The average age of the 132kV gas cable network is 45 years.

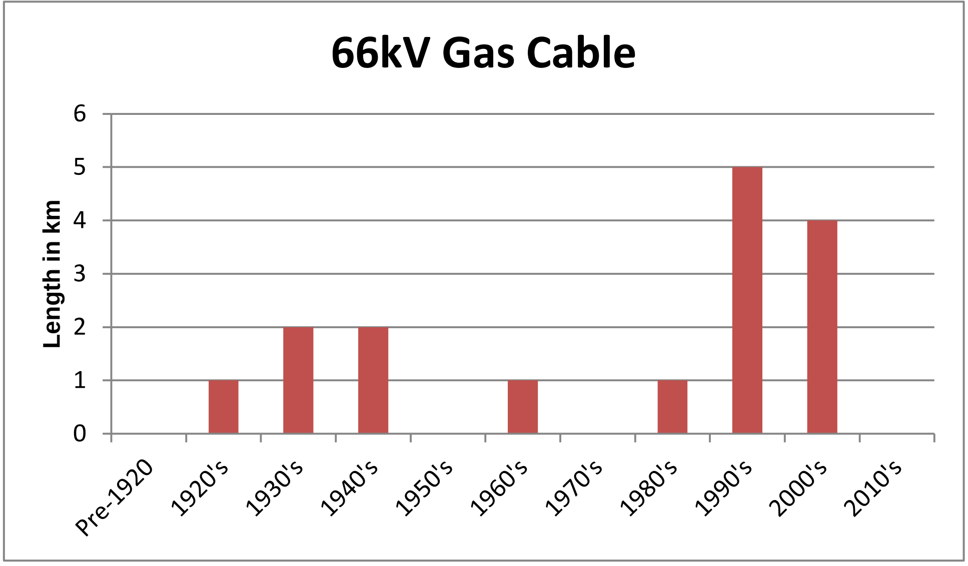


Figure 11 – Age profile of 66kV gas cable

Source: RIGs 2012 Table V5

The average age of the 66kV gas cable network is 36 years.

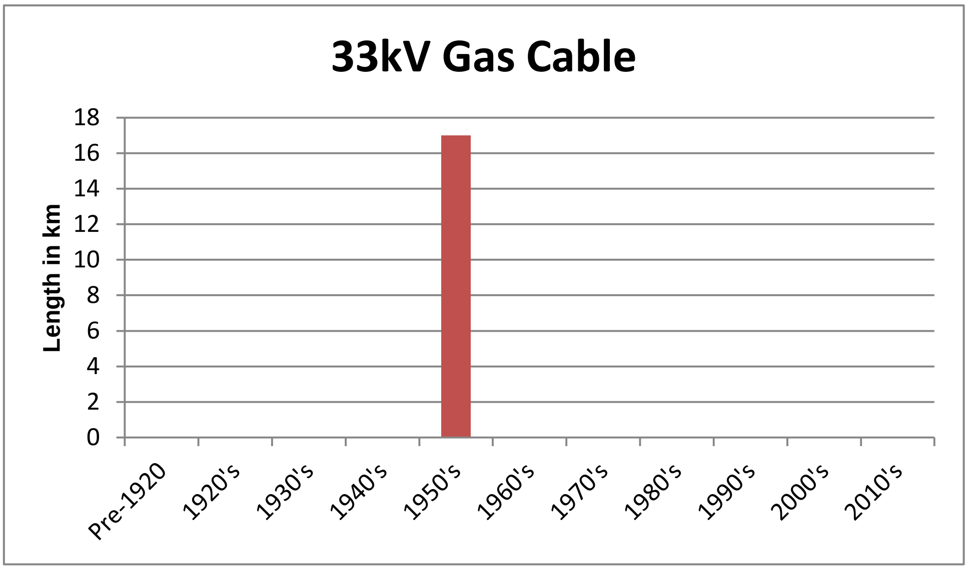


Figure 12 – Age profile of 33kV underground gas cable

Source: RIGs 2012 Table V5

The average age of the 33kV gas cable network is 57 years.

Reference NAMP lines

The gas cable replacement provisions for ED1 are listed under following NAMP lines:

NAMP line	Description
1.07.90	Gas Cable Replacement (EHV)
1.07.07	Gas Cable Replacement (132kV)

Table 8 – NAMP lines

Reference RIGs code

The corresponding RIGs lines are shown in Table 9:

RIGs tab	Line (additions)	Line (removals)	Description
CV3	064	192	33kV UG cable (gas)
CV3	067	195	66kV UG cable (gas)
CV3	094	222	132kV UG cable (gas)

Table 9 – RIGs categories

2.3 Solid Cables

There are a number of different types of solid cables in operation in the LPN region. These types are Paper Insulated Lead Covered Cable (PILC), Paper Insulated Corrugated Aluminium Sheath Cable (PICAS), Cross-Linked Polyethylene Cable (XLPE) and Waveform cable. Solid cables are operated at all voltage levels. The breakdown is shown in Figure 13.

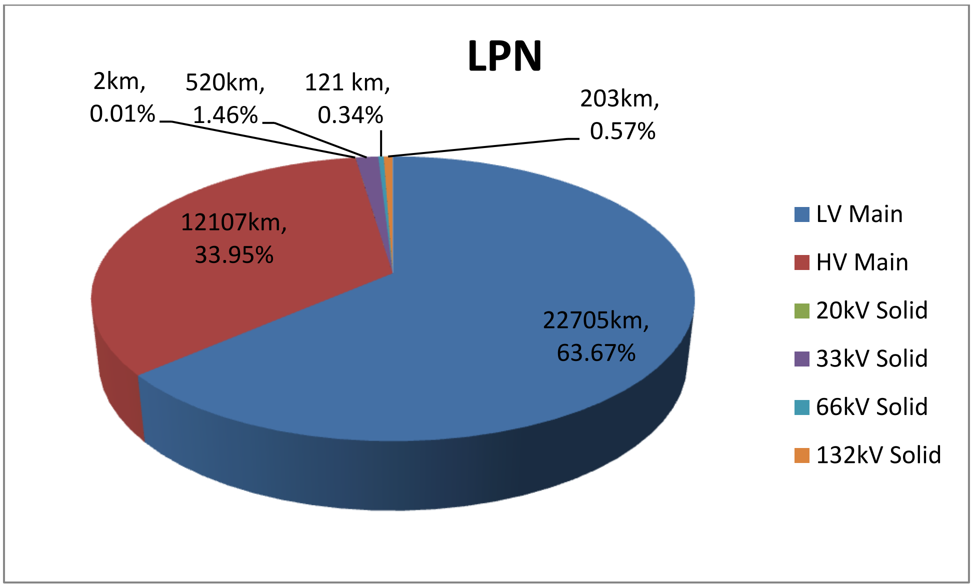


Figure 13 – Population of underground solid cables by voltage

Source: RIGs 2012 Table V5

Solid cables are now installed rather than fluid-filled cables or gas cables at higher voltages. At lower voltages, solid cables are always installed.

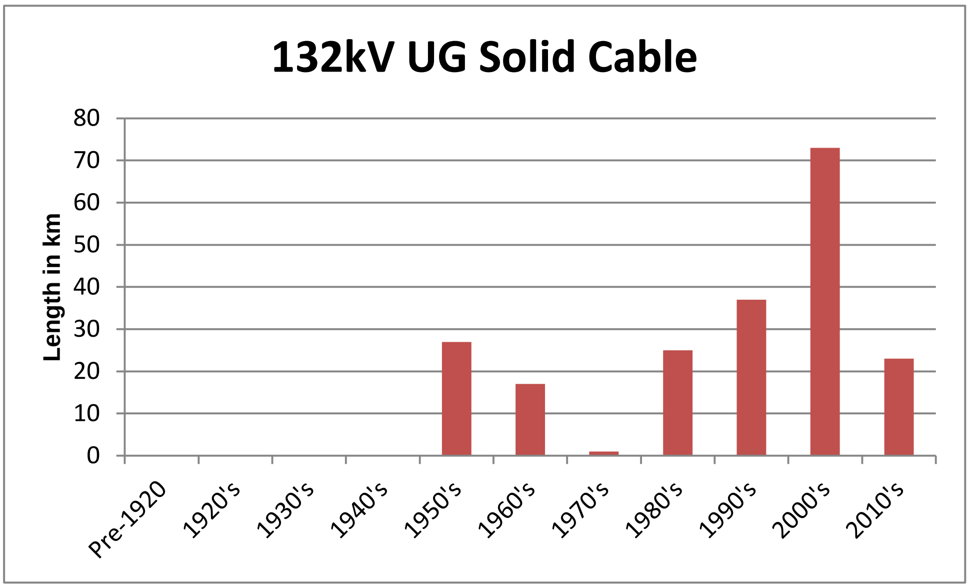


Figure 14 – Age profile of 132kV underground solid cable

Source: RIGs 2012 Table V5

The average age of the 132kV solid cable network is 21 years.

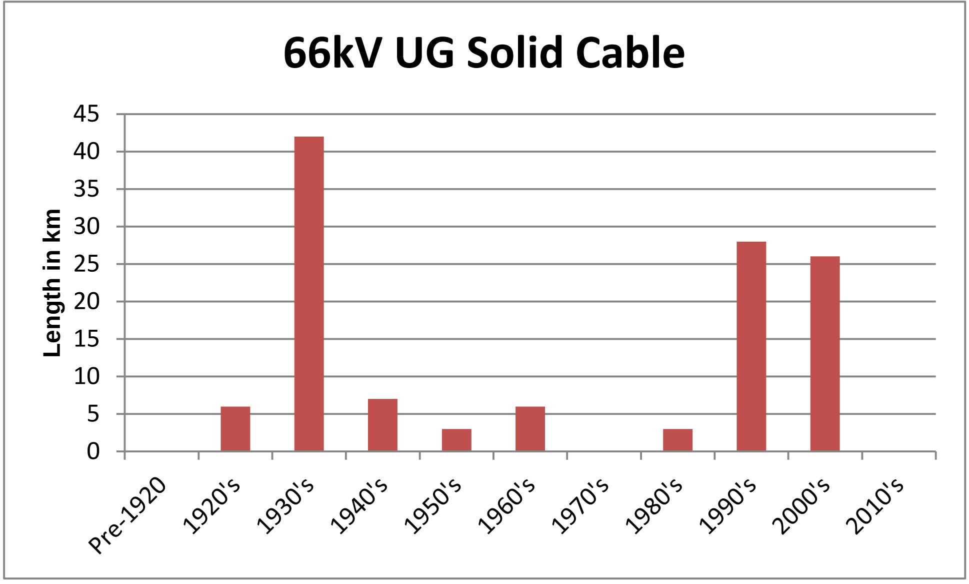


Figure 15 – Age profile of 66kV underground solid cable

Source: RIGs 2012 Table V5

The average age of the 66kV solid cable network is 47 years.

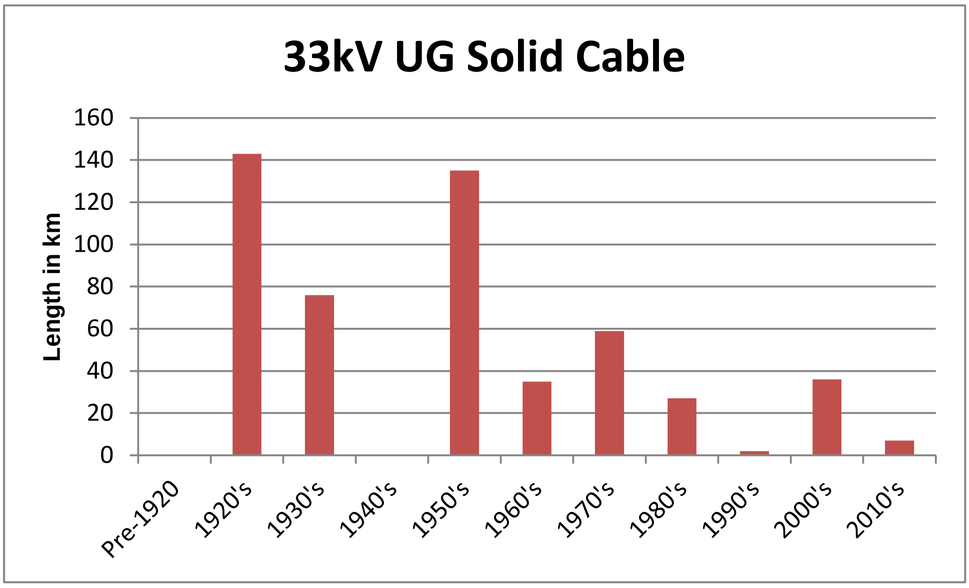


Figure 16 – Age profile of 33kV underground solid cable

Source: RIGs 2012 Table V5

The average age of the 33kV solid cable network is 61 years.

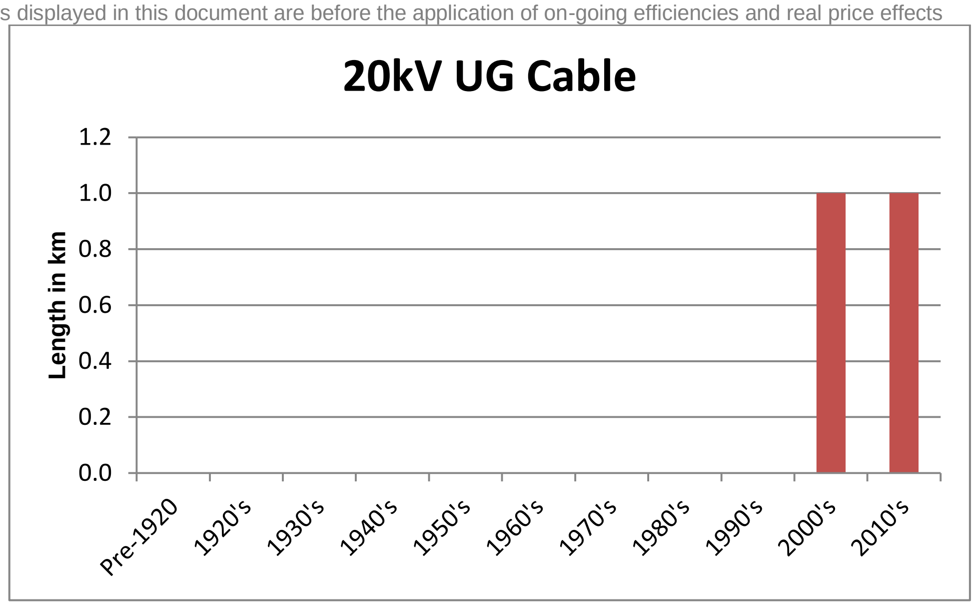


Figure 17 – Age profile of 20kV underground solid cable

Source: RIGs 2012 Table V5

The average age of the 20 kV solid cable network is 6 years.

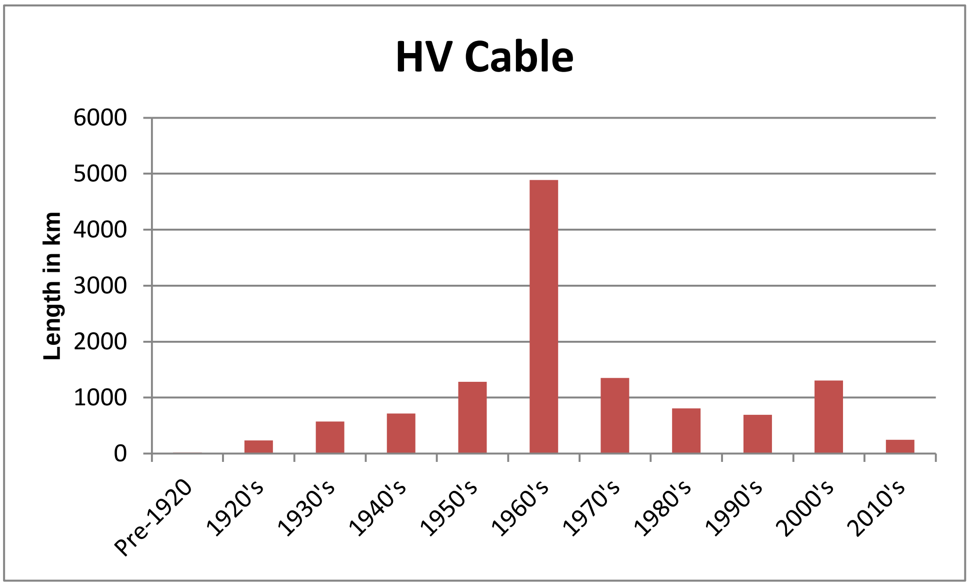


Figure 18 – Age profile of HV underground solid cable

Source: RIGs 2012 Table V5

The average age of the HV solid cable network is 43 years.

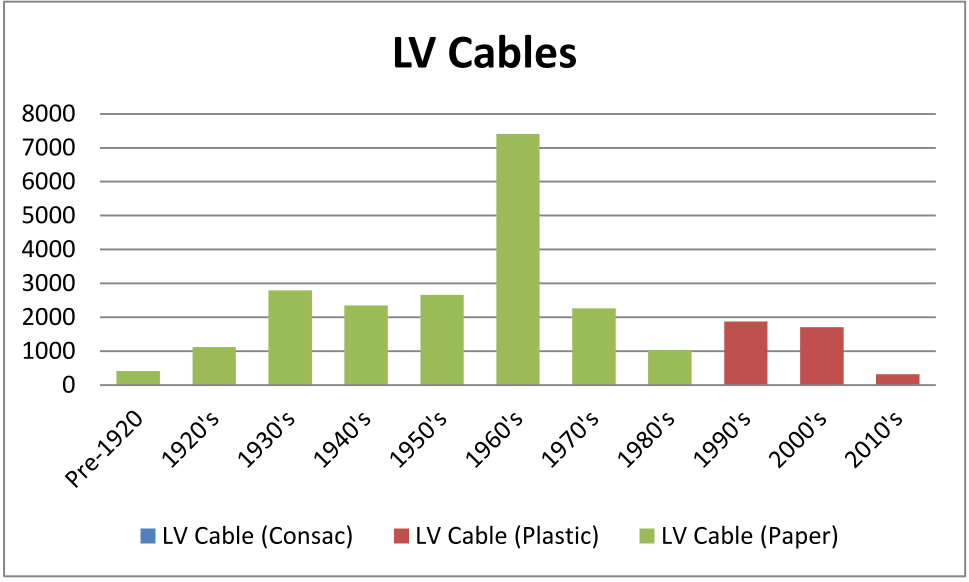


Figure 19 – Age profile of LV underground solid cable

Source: RIGs 2012 Table V5

Reference NAMP lines

The solid cable replacement provisions for ED1 are listed under following NAMP lines:

NAMP line	Description
1.07.01	Solid Cable Replacement (EHV)
1.07.02	Solid Cable Replacement (132kV)
1.18.01	HV Cable Replacement
1.18.03	LV Cable Replacement
1.18.04	11kV Transition Joint Replacement

Table 10 – NAMP lines

Reference RIGs code

The corresponding RIGs Lines are shown in Table 11:

RIGs tab	Line (additions)	Line (removals)	Description
CV3	009	137	LV Main (UG Consac)
CV3	010	138	LV Main (UG Plastic)
CV3	011	139	LV Main (UG Paper)
CV3	029	157	6.6/11kV UG Cable
CV3	030	158	20kV UG cable
CV3	062	190	33kV UG Cable (Non-Pressurised)
CV3	065	193	66kV UG Cable (Non-Pressurised)
CV3	092	220	132kV UG Cable (Non-Pressurised)

Table 11 – RIGs categories

3.0 Investment Drivers

The high-level investment drivers for underground cables are detailed in Engineering Design Procedure EDP 00-009, *Asset Lifecycle Strategy- Underground Cables*. The principal drivers for the replacement of underground cables are safety, network security, public safety, environment, condition and compliance with relevant legislation. The industry code of practice governing fluid-filled cable is ENA Engineering Technical Report (ETR) 135 – Guidance on the operation and maintenance of Fluid Filled Cables.

3.1 Investment Drivers for Fluid-Filled Cables

3.1.1 Fluid-filled cable types and known issues

Fluid-filled cables are constructed with either a lead sheath or an aluminium sheath. Both types of cables have known failure mechanisms.

Lead sheath cables suffer from crystallisation of the sheath, which results in it becoming porous and discharging cable fluid into the environment. This cause has been documented in ENA ETR135. When lead crystallisation occurs, it usually does so along large sections or the whole of a circuit. As a consequence, the replacement of short section length will not alleviate this problem. Lead sheath crystallisation results in the rapid deterioration of the integrity of the cable, which cannot be managed through repeated fault repairs.

Once lead sheath crystallisation is discovered and a repair deemed not possible or unsuccessful, the replacement of a hydraulic section will be considered initially. It is, however, sometimes necessary for the whole circuit to be replaced if the condition is similar throughout the circuit length.

Aluminium sheath cables suffer primarily from cable fluid leaks at the joint plumbs. These can often be refurbished or repaired in order to rectify leaks, although replacement of cable sections or circuits are still necessary. Tape deterioration also has an impact on the strength of the sheath that ultimately will result in fluid leakage.

Fluid-filled cables under high load conditions will subject the sheath to adverse thermo-mechanical forces resulting in higher fluid leakage rates, particularly in the winter. Leaks can be difficult to repair, because outage constraints and adverse weather often make repairs challenging to achieve during this period. Conversely, in more favourable operational conditions, cables are often leaking much less, making leak location more challenging.

Figure 20 – Crystallised lead sheath

Figure 21 – Aluminium joint

3.1.2 Cable fluid leakage

Cable fluid leakage is used in the ARP model to assist in the calculation of the overall Health Index of the fluid-filled cable population.

Fluid-filled top-up data published by Ofgem shows that LPN contributes 26% of fluid top-ups nationally, which is double the national average of 64 litres per kilometre per annum. It should be noted that the network utilisation in London is very high; one possible reason is the adverse thermo-mechanical properties of fluid-filled cables as described above.

A key investment driver for filled cables over the ED1 period is the decision to invest at a level that will reduce the fluid-filled cable top-up volumes in LPN to bring them much closer to the national average.

Using the ARP model to calculate the predicted HI4 and HI5 cable sections at the end of the ED1 period, the predicted leakage rates with and without investment have been calculated – refer to Figure 22.

This shows that the implementation of the proposed investment plan will reduce leakage rates in LPN by 28% by the end of the ED1 period. The leakage rate with intervention prediction includes a 2% year-on-year reduction in leakage due to enhanced leak location techniques, such as the PFT tracer, and an increased focus on leak repairs. Without intervention, the cable leakage rates are predicted to increase by 34% over the ED1 period.

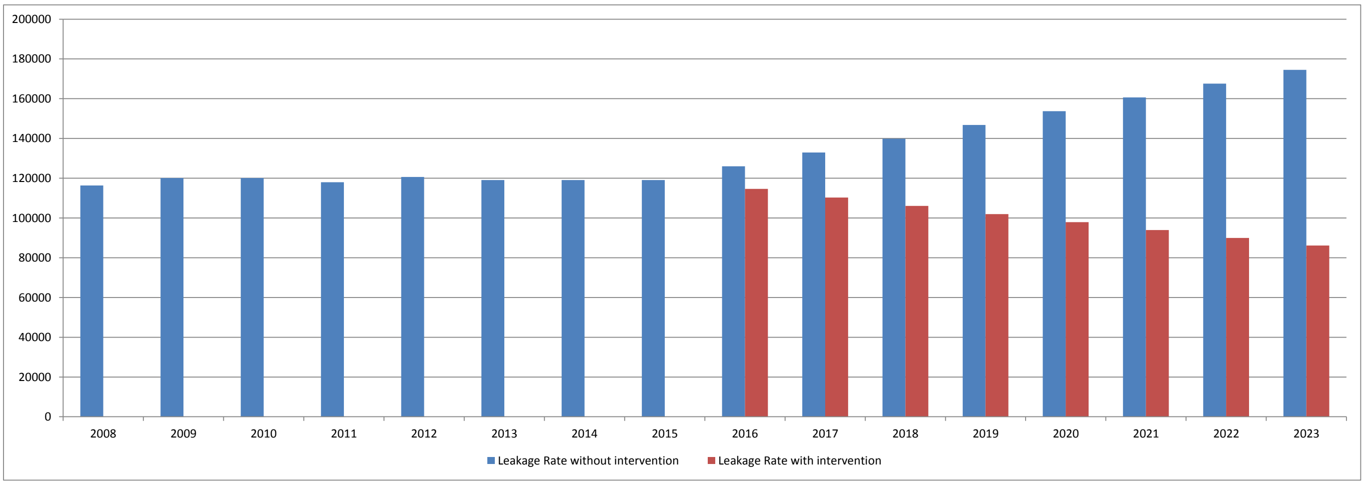


Figure 22 – Fluid-filled cable leakage with and without intervention

Source: ARP July model

3.1.3 Condition

Condition assessments of the fluid cable population are made whenever possible – for example, after a fault or cable repair. The condition assessments enable the identification of issues, such as a crystallised lead sheath, and are used in conjunction with fluid top-up records to prioritise investment. Available condition reports of proposed ED1cable schemes are attached in Appendix 10.

Should crystallised lead be discovered during a fault repair, the length of cable replaced will usually be increased to remove the length containing crystallised lead sheath.

3.1.4 Compliance with industry best practice

ENA Engineering Technical Report 135, (Guidance for the operation and management of fluid cables) forms the basis of the actions being taken by UK Power Networks to address the risks posed through the operation of fluid-filled cables. It is stated in the Operating Code that DNOs “will take all reasonably practicable steps to prevent pollution of controlled waters, taking advice from the Environment Agency as required”.

UK Power Networks implements ETR 135 through its own policy, EDP 08 306 *Leak Management Strategy for Fluid-Filled Cables*.

Pollution risk is monitored through UK Power Networks policy HSS 01 009, *Environmental Management of Fluid-Filled Cables*.

3.1.5 Environmental risk

Compliance with environmental legislation is a key investment driver for fluid-filled cables. As per the *Guidance on the National Operating Code for the Management of the Fluid Filled Cable System* produced by Energy Network Association (ENA) and Environment Agency (EA), responsibilities of Network operators are, in sensitive areas, to:

- determine the length of cable passing through the area
- report all leaks above 40 litres per month as soon as confirmed (this is the limit of leak detection/location)
- prioritise leak location and repairs in consultation with the Agency.

And in non-sensitive areas to:

- report all leaks above 100 litres per month during office hours once confirmed
- put repairs in hand without delay
- put repairs in hand within two months for leaks below 100 litres / month (subject to the practical thresholds of leak location).

The Environment Agency defines an area of environmental sensitivity as an area within 50 metres of a watercourse; a major aquifer with high or intermediate vulnerability or where groundwater is close to the surface (10 metres); or a Source Protection Zone (SPZ) around groundwater abstractions. The ARP Model uses environmental sensitivity data in the prioritisation of cable replacement.

3.2 Investment Drivers for Gas Cables

3.2.1 Gas cable types and known issues

There are two types of gas cables in use: pipeline construction and impregnated pressure type cables. Pipeline construction gas cables consist of a cable inserted into a steel pipe that is then filled with pressurised nitrogen. Pipeline construction cables are often referred to as external pressure cables.

Impregnated pressure cables are sometimes referred to as internal pressure cables and are laid directly in the ground rather than in a steel pipe.

The Skipper report[1] in 1988 highlighted a number of inherent design flaws associated with gas compression pipeline cables. These include gas leaks, cable faults, control tape fractures, lead sheath distension, thermal instability of the insulating papers and the explosive failure of sealing ends.

In particular, the issue of a double circuit outage is a significant concern, with both circuits feeding a primary substation of a similar gas cable construction.
The failure mode most commonly encountered is the migration of cable impregnate. If the cable load is increased, even within its rating, the accumulated impregnate expands, causing mechanical damage to the cable construction or joints. It is widely accepted within the industry that the issues

with gas cables are sufficiently severe to warrant their withdrawal from service.

It is UK Power Networks policy to withdraw all gas cables from service by the end of the ED1 period. It is UK Power Networks' understanding that National Grid has already completed a programme of removal of this type of cable.

[1] Gas Compression Cable Systems – A review of the current situation. D J Skipper 1988

3.2.2 Repair times and network security

In comparison to other cable types, the repair of a gas cable takes a considerable amount of time. A typical repair time could easily be 16 weeks due to the length of time taken to de-gas the cable, locate the fault, obtain spares, affect the repair and depressurise the system.

During this time, network security is severely compromised, because often the remaining healthy circuit is of an identical construction. Gas cables are also prone to failure when the load on them is suddenly increased, as is the case for a single circuit outage.

3.2.3 Availability of spares and repair costs

Spare parts for the gas pressurisation equipment, sealing ends and joints are now very difficult and expensive to source due to the lack of support offered by current cable manufacturers. There is also a lack of suitable transition joints for use with modern XLPE cables. The typical cost for a gas cable repair is £200-£250k. This is a key investment driver for the removal of these types of cable.

3.3 Investment Drivers for Solid Cables

The investment drivers for the replacement of solid cables are based primarily on a case-by-case condition assessment of faulted cable sections. It is UK Power Networks policy to collect cable samples for assessment after a cable fault, as specified in EDS 02-0043, *Solid Cable Non-Load Related Repair and Refurbishment*.

In addition, partial discharge mapping is used at HV to identify circuits on raised activity levels and any potential failure risk, although this in isolation would not be sufficient an investment driver for the replacement of a cable without further condition assessment taking place. Online partial discharge mapping has the highest penetration in LPN out of the three licence areas that UK Power Networks operates due to the congested nature of the LPN area and the high network utilisation.

3.4 Cable Fault Rates

The graphs show fault rates for cables by voltage level, but it is not possible to separate out different cable types from the data. Overall cable fault rates are relatively stable at all voltages.

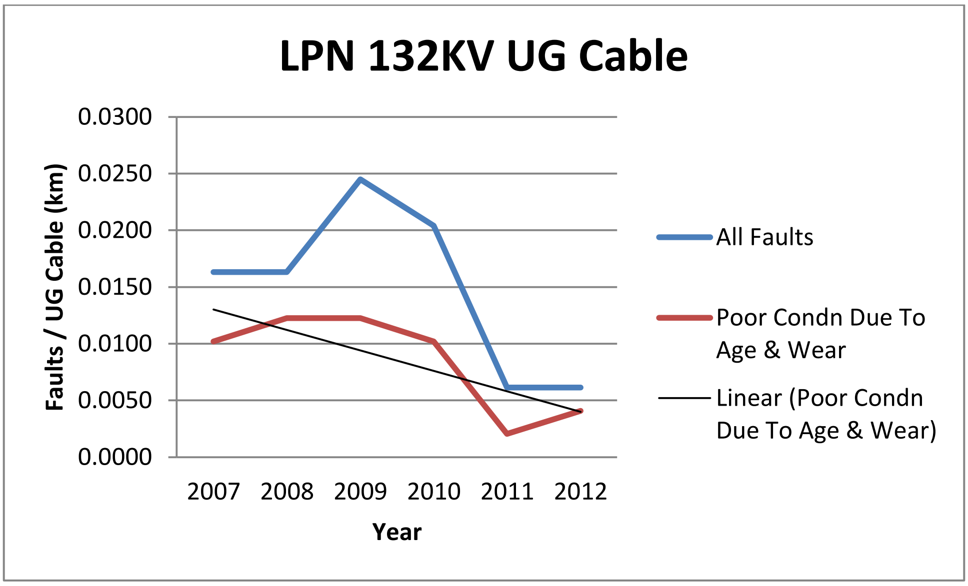


Figure 23 – Fault trends of 132kV underground cable

Source: UKPN Faults Cube

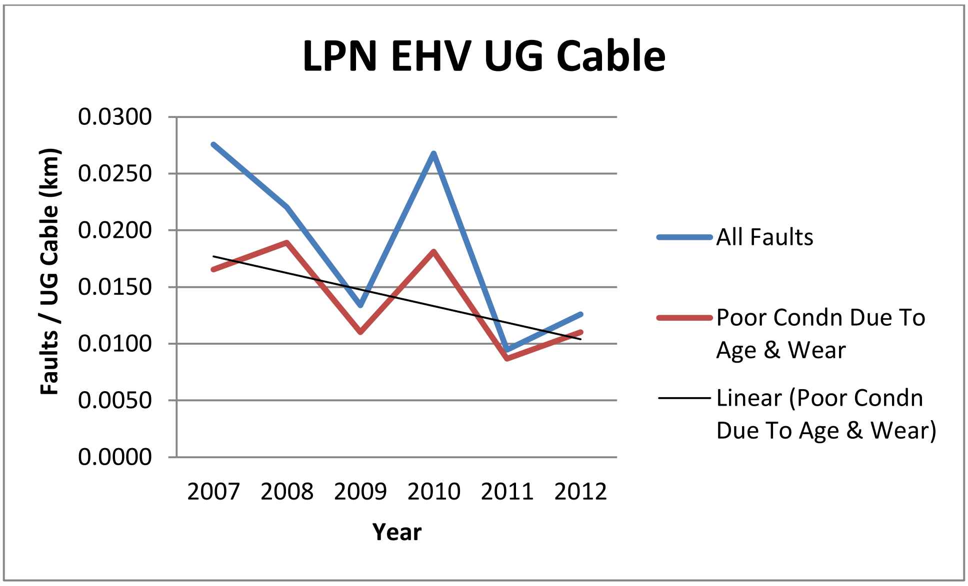


Figure 24 – Fault trends of EHV underground cable

Source: UKPN Faults Cube

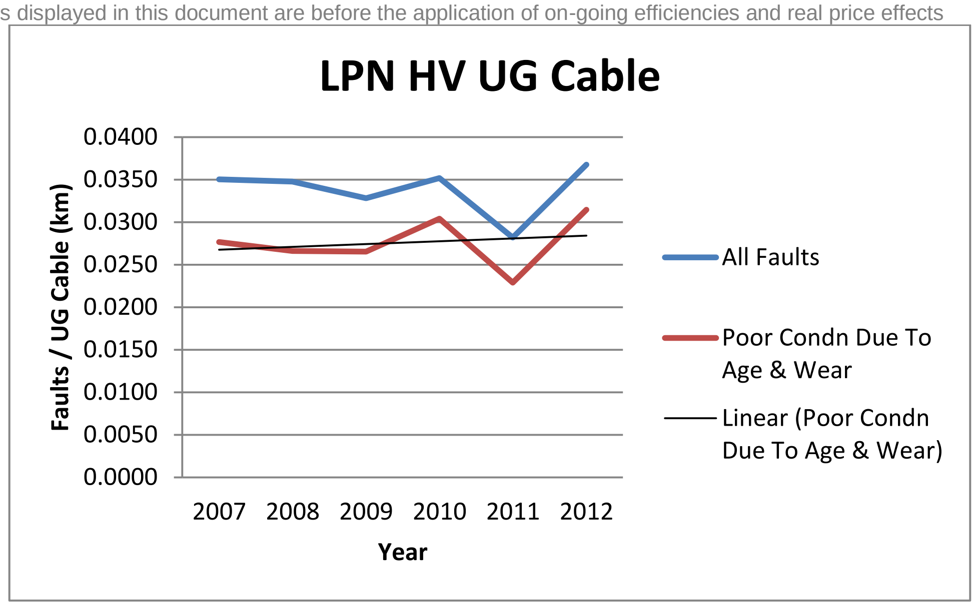


Figure 25 – Fault trends of HV underground cable

Source: UKPN Faults Cube

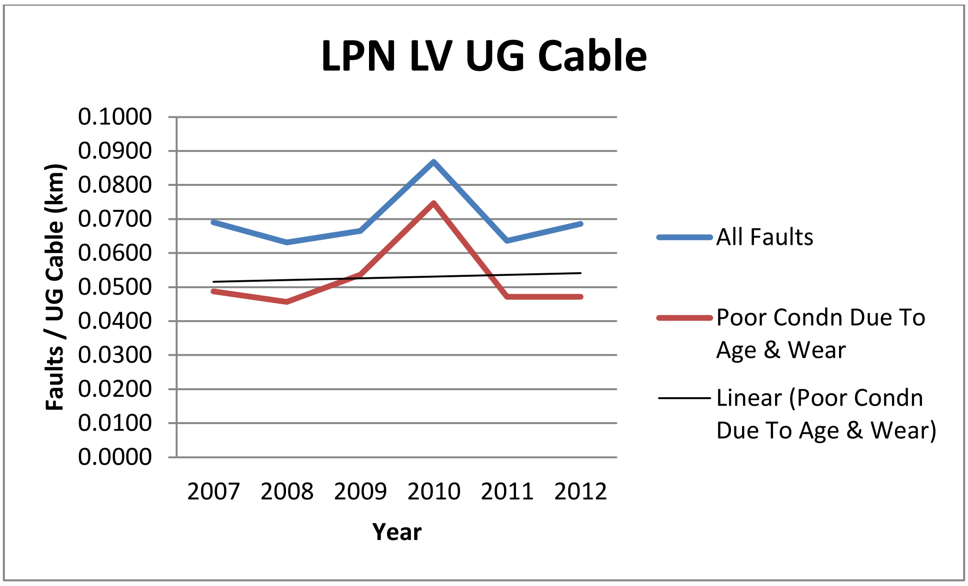


Figure 26 – Fault trends of LV underground cable

Source: UKPN Faults Cube

4.0 Asset Assessment

4.1 Health Assessment of Fluid-Filled Cables (FFC)

An innovative asset health modelling tool, the Asset Risk and Prioritisation (ARP) model, has been developed for several asset categories, including fluid-filled cables for all voltages. The methodology behind the modelling is the same for all asset categories, but the fluid-filled cable model has been tailored specifically to utilise the historical oil leak data.

4.1.1 Calculation of HI

The general methodology for the ARP model can be found in *Commentary Document 15: Model Overview*.

4.1.2 Condition information

The initial age-based health index is modified by incorporating condition assessment measurements, as well as the history of oil leaks and defects. The details of each of these factors are discussed below.

Condition factors – The fluid-filled cables model includes a number of condition points, including oversheath condition, bedding condition, screen condition, conductor condition, armour condition, metallic sheath condition, insulation condition and paper condition.

Field engineers are requested to provide condition data when repairing cables. However, this is a relatively recent initiative, so at present no comprehensive sets of condition data are available. Available data is entered into the model and set up as such that each condition point is assigned a score of 1 or 4 and then translated to a condition factor.

Oil leak history – The critical issue for fluid-filled cables is the condition of the fluid containment system. The leak history of each section is a useful proxy for this and the model includes oil leaks for up to five years. The annual oil loss per section is then estimated as the weighted average of the actual oil loss figures over the past five years.

Defect history – The rate of occurrence of defects can be considered to be an indication of both the condition of an asset and the likelihood of future defects or failure. At present, the model has no defect parameters defined, but this is a facility that could be used in the future.

Final Health Index – An overall factor value is derived for each cable section and is the highest of the following three factors:

- condition
- oil leakage history
- fault history.

An interim final health index is calculated for each section – the product of the overall factor value and the initial age-related health index.

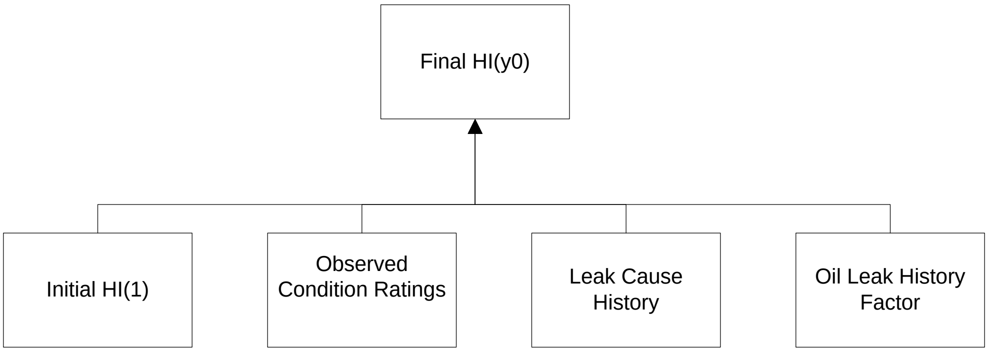


Figure 27 – Flowchart showing calculation of Health Index from ARP model

4.2 Asset Criticality

The ARP model can also be used to calculate the criticality of a particular hydraulic section of the FFC asset. This is then output in the form of a Criticality Index 1 to 4, with 1 being the least critical and 4 being the most. A detailed methodology for calculating the criticality index can be found in *Commentary Document 15: Model Overview*.

In the FFC ARP model, there are five main areas considered when calculating the criticality of an asset: network performance, safety, operational expenditure, capital expenditure and environment. A number of key factors are considered in each of these areas.

This area of the model is still in its infancy and in the process of being further developed.

4.3 Network Risk

The network risk in monetary terms can also be calculated in the ARP model. This is done using the probability of failure, the criticality and the consequence of failure. The probability of failure is calculated using the current Health Index of the item of FFC and the criticality is calculated as described in the previous section. The consequence of failure is the average cost to either repair or replace the section of cables following one of three failure modes.

This area of the model is still in its infancy and in the process of being further developed.

4.4 Data Validation

All data used in the ARP model is subject to validation against a set of data requirements. The requirements ensure data is within specified limits, up to date and in the correct format for use in the model. On completion of the validation process, an exception report is issued, providing details of every non-compliance and allowing continual improvement of data quality to be achieved.

4.5 Data Verification

A sampling approach to data verification follows each data upload to ensure accurate transfer into the models.

4.6 Data Completeness

The completeness, accuracy and timeliness of the data used in the ARP model are routinely checked. For the results of the data used in the fluid-filled cable model, refer to Table 12.

Area	Result
Completeness	88.83 %
Accuracy	Not available
Timeliness	Not available

Table 12 – Data CAT scores

Source: Decision Lab report “CAT Scoring” 8th February 2013
* Not available: quality standards are under review

The completeness score is a combination of fluid filled name plate data and pumping information in asset register. The completeness of any data used in the network risk section, such as customer numbers, is also used in the overall completeness score.

The accuracy and timeliness scores are a measure of how reliable and correct the condition data stored in Ellipse is. As condition data is not collected for fluid-filled cables on a planned basis, this analysis has not been completed.

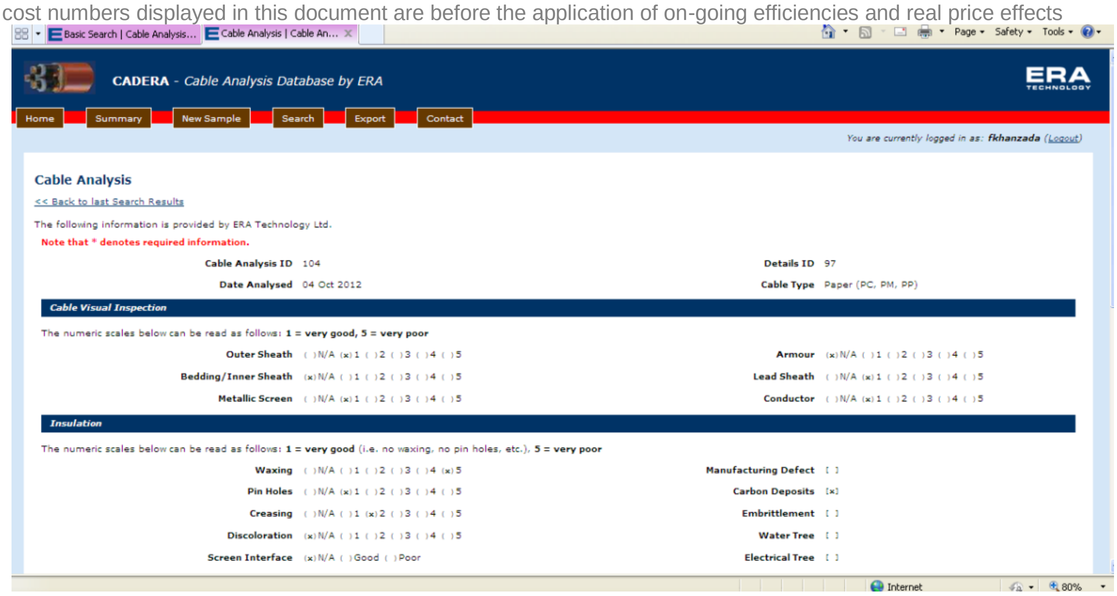
4.7 Health Assessment of Gas Cables

Due to issues described in section 3, all gas cables operated by UK Power Networks have been assessed as being at end-of-life and it is UK Power Networks policy to remove these cables from service by the end of ED1.

4.8 Health Assessment of Solid Cables

Individual solid cables are not assessed for health on a planned basis. However, UK Power Networks has a policy to collect cable samples for assessment, as specified in EDS 02-0043, *Solid Cable Non-Load Related Repair and Refurbishment*. As part of the policy, field engineers provide relevant samples for condition assessment. Over time, this will enable a fuller picture of the health of solid cables to be built up, which can then be used as a future investment driver. Figure 28 shows the snapshot of the CADERA (Cable Analysis Database By ERA), which consists of assessment results.

Results show that the main failure mode is due to the drying out of the impregnate, especially for cables installed on slopes. Oil migration in insulation papers also appears to play a significant role in the premature ageing of solid cables.



You are currently logged in as: **fkhanzada** (Logout)

Cable Analysis

<< Back to last Search Results

The following information is provided by ERA Technology Ltd.

Note that * denotes required information.

Cable Analysis ID 104
Date Analysed 04 Oct 2012
Details ID 97
Cable Type Paper (PC, PM, PP)

Cable Visual Inspection

The numeric scales below can be read as follows: **1 = very good, 5 = very poor**

Outer Sheath ( ) N/A (x) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5
Bedding/Inner Sheath (x) N/A ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5
Metallic Screen ( ) N/A (x) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5
Armour (x) N/A ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5
Lead Sheath ( ) N/A (x) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5
Conductor ( ) N/A (x) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

Insulation

The numeric scales below can be read as follows: **1 = very good** (i.e. no waxing, no pin holes, etc.), **5 = very poor**

Waxing ( ) N/A ( ) 1 ( ) 2 ( ) 3 ( ) 4 (x) 5
Pin Holes ( ) N/A (x) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5
Creasing ( ) N/A ( ) 1 (x) 2 ( ) 3 ( ) 4 ( ) 5
Discoloration (x) N/A ( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5
Screen Interface (x) N/A ( ) Good ( ) Poor
Manufacturing Defect [ ]
Carbon Deposits [x]
Embrittlement [ ]
Water Tree [ ]
Electrical Tree [ ]

Figure 28 – Snapshot of the cable analysis database

5.0 Intervention Policies

5.1 Intervention Options

5.1.1 Interventions for fluid-filled cables

Interventions on fluid-filled cables consist of the replacement of a complete circuit, the replacement of a hydraulic section or leak repair. The type of intervention used is driven by application of the investment drivers highlighted in section 3.

If possible, a leak repair is carried out. However, if crystallised lead is discovered, consideration will be given to the replacement of a hydraulic section or possibly the circuit depending on leak rate history and the extent of the sheath degradation.

5.1.2 Interventions for gas cables

UK Power Networks policy is to replace all gas cables before the end of ED1 due to the issues described in section 3. Hence the only planned intervention option is the replacement of the circuit with a solid XLPE cable. In an unplanned outage situation, a repair or partial overlay may have to be considered in the context of restoring the security of the network for customers.

5.1.3 Interventions for solid cables

Interventions on solid cables consist of either a cable repair or the replacement of faulted cable sections. A reactive replacement of cable may also be considered if the cable in poor condition is discovered during other work. This decision is usually based on a condition assessment by a field engineer in consultation with Asset Management as required.

6.0 Innovation

UK Power Networks has undertaken several initiatives to explore innovative solutions in order to improve the performance of the underground cable network.

6.1 Fluid-Filled Cables

6.1.1 Online pressure monitoring

The use of pressure transducers to monitor fluid-filled cable operating pressures remotely has a potential to provide a more holistic approach to maintenance and inspection, based on real-time condition against the current regime of periodic-based scheduled tasks. The topping-up of fluid reservoirs could be done based on trends rather than planned ‘milk runs’. This equipment is in the process of installation and is expected to be complete by end of DPCR5 period.

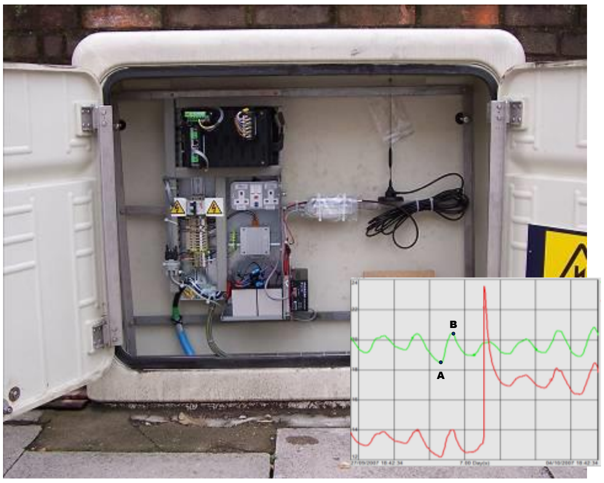


Figure 29 – Online pressure-monitoring system

6.1.2 PFT leak location

In order to offset the long-term leakage from fluid-filled cables, an innovative solution has been developed and deployed. A minute amount of Perflurocarbon Tracer (PFT) is added to the cable fluid. PFT introduced in this way is vented to the atmosphere at the point where a leak in the cable is present – where it can be detected using highly sensitive mobile equipment. This method greatly improves performance in the detection and resolution of leaking cable incidents – reducing cost of work, outage time and environmental impact.

Figure 30 – PFT leak-location system

6.1.3 FFC self-healing

This project will identify, develop and assess self-repairing systems for fluid-filled cable sheath, such that the damage to the sheath will self-heal by avoiding oil leakage and the subsequent environmental clean-up.

This is an IFI project currently at the R&D stage. Phase 1 is due to complete in January 2015 and is an exercise to identify potentially suitable additives. Depending on the success of this phase, there would potentially be subsequent laboratory and field trial phases.

6.2 Solid Cables

6.2.1 Innovative design of 132kV and 66kV solid cables

Design modification opportunities are being explored to reduce the cost of the 132kV and 66kV solid cables by eliminating copper and reducing insulation thickness without comprising the integrity and quality of the cables.

This is a UK Power Networks-led initiative in conjunction with cable manufacturers.

6.2.2 Innovative design of 33kV and 11kV solid cables

Design modifications are being developed that will remove all copper, reduction in cost still to be determined but in the region of 10% to 20% and less susceptible to theft.

This is a UK Power Networks lead initiative in conjunction with cable manufacturers.

6.2.3 Partial discharge-monitoring system on HV cable network

The use of partial discharge (PD) measurement is a well-known method of checking the condition of electrical insulation. Over the past 10 years, UK Power Networks has been actively involved in the development of online partial-discharge monitoring and mapping techniques. Opportunities to improve the existing technology have been identified. This project has developed equipment to continuously monitor PD activity in 11kV underground cables. Further work is in progress in order to improve algorithms for early fault detection.

Figure 31 shows typical screen shots from the online PD monitoring system showing partial discharge activity on an 11kV cable at Fairlop substation. A trace with this level of discharge activity would prompt an offline PD assessment to be made in order to determine more accurately the issue.

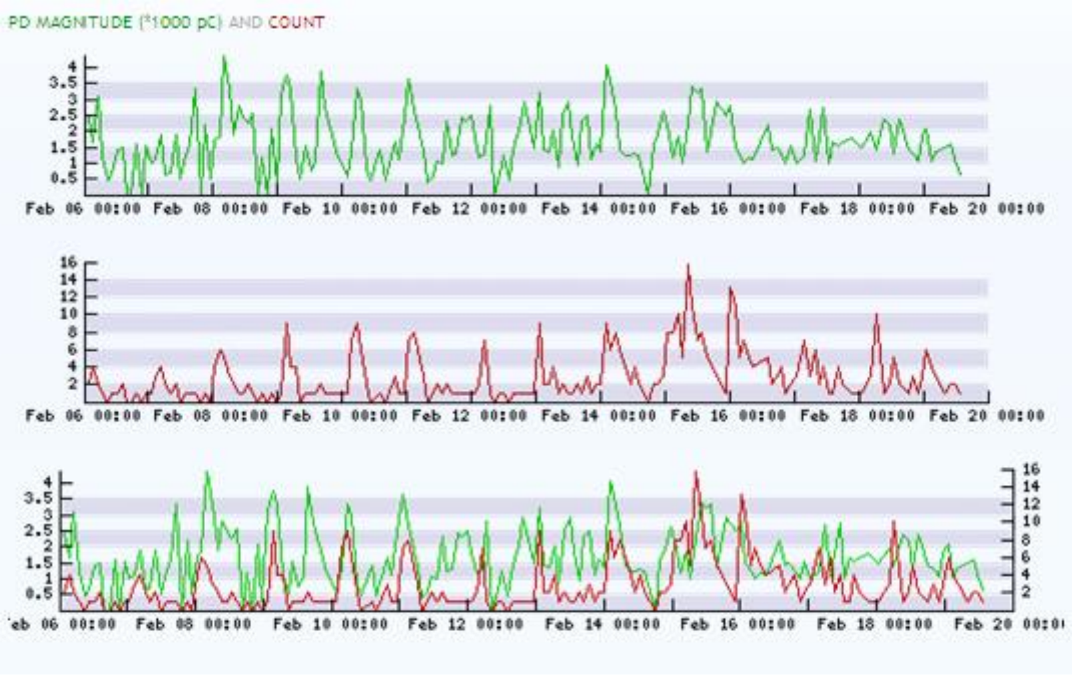


Figure 31 – Partial discharge activity of 11kV cables at Fairlop Rd substation (LPN)

UK Power Networks has led this innovative work from the start and is unique in the scale of deployment of this capability.

One example of the usefulness of this technology was the successful detection of a discharging cable bushing at Amberley Road Primary substation. The faulty equipment was replaced prior to failure and saved serious and costly damage to the primary transformer.

7.0 Expenditure Requirements for Underground Cables

7.1 Method

7.1.1 Fluid-filled cables

An overview of the method used to construct the ED1 plan is shown in Figure 32. This programme has been produced with the assistance of the Asset Replacement Prioritisation Tool (ARP).

1. Cable sections with a Health Index of HI4 and HI5 were identified by the ARP tool.
2. Internal Stakeholders such as Network Operations, Infrastructure Planning and Capital Programme were consulted on the identified cable sections.
3. Identified cable sections were prioritised based on the location sensitivity.
4. After the consultation process, schemes were raised for inclusion in the ED1 plan

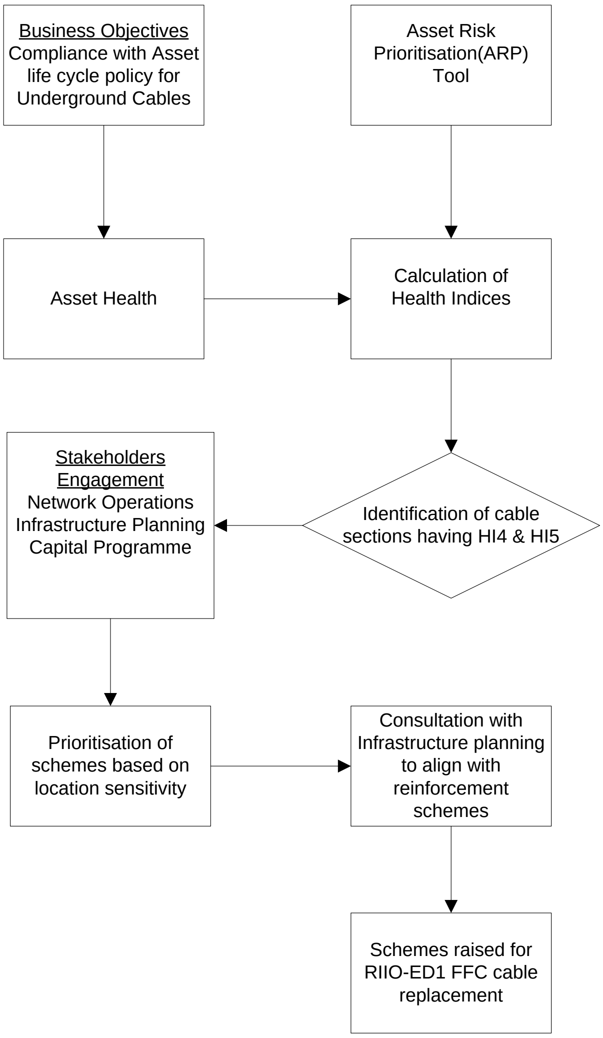


Figure 32– Construction of NLRE plan for FFC replacement

7.1.2 Gas cables

UK Power Networks has made a strategic decision to replace all the gas cable circuits before the end of the ED1 period, as detailed in section 3, Investment Drivers. This is in line with nationally accepted industry best practice in the UK.

All gas circuits currently in commission in the LPN licence area have been included for removal before the end of the ED1 period.

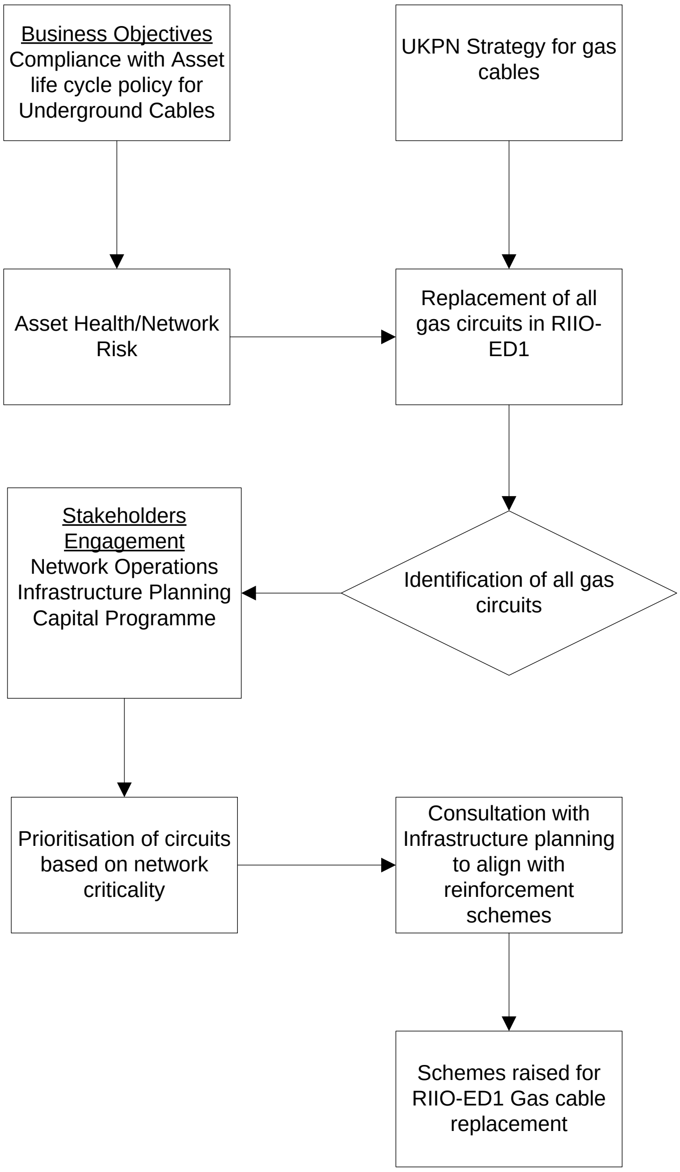


Figure 33 – Construction of NLRE plan for gas cable replacement

7.1.3 Solid cables

This programme is compiled on the basis of historical replacement levels. Post-fault analysis is carried out on historical faults. Solid cables are replaced with a modern XLPE cable, but only when their condition is found to be poor. Solid cable condition is not recorded in Ellipse, but partial discharge mapping can be used on short lengths of circuit where poor fault history is found.

The following process has been adopted for the ED1 solid cable replacement plan.

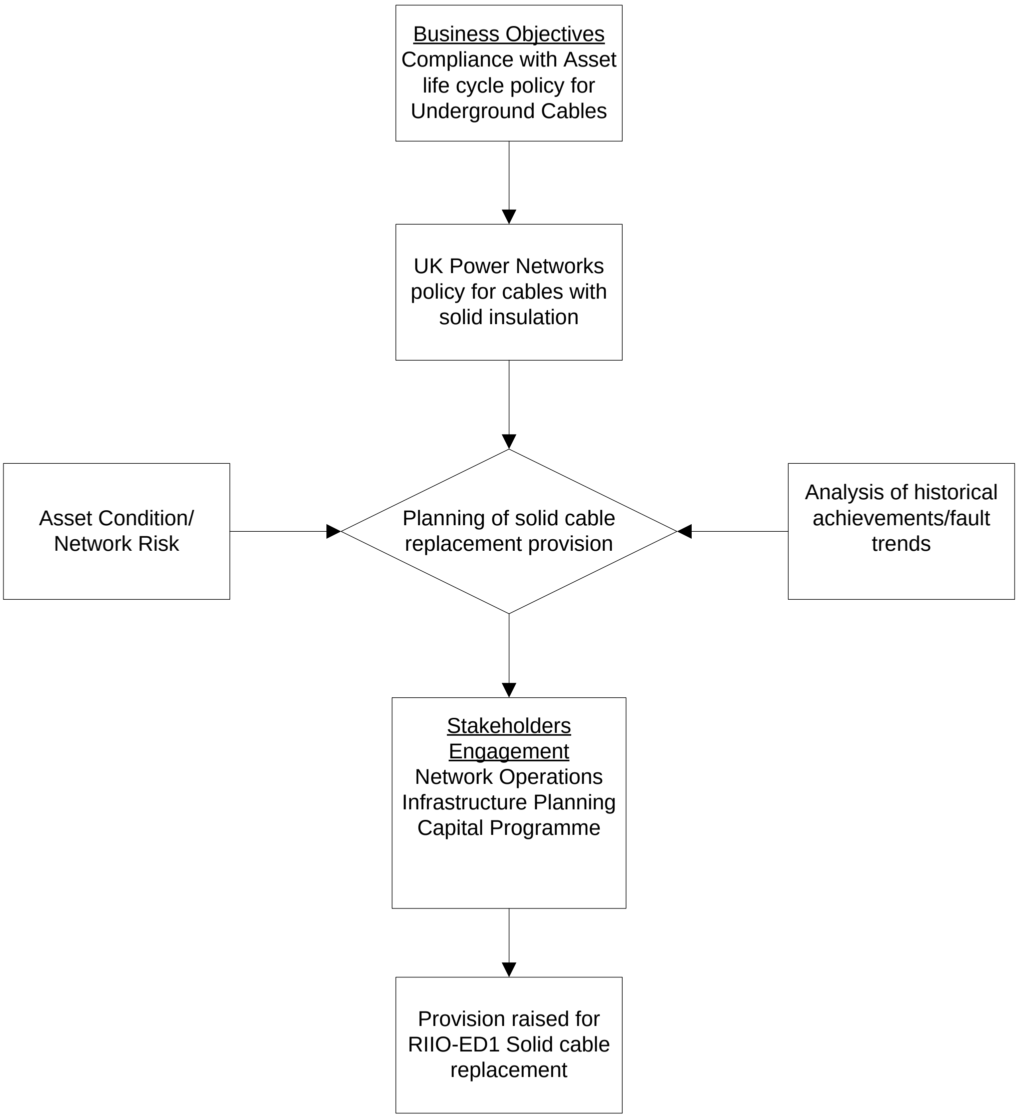


Figure 34 – Construction of NLRE plan for solid cable replacement

7.2 Constructing the Plan

7.2.1 Fluid-filled cables

Intervention volumes – The business objective throughout the planning process for ED1 was to invest at a level that will reduce the fluid filled cable top up volumes in LPN to bring them much closer to the national average. To achieve this, the ARP model was used to determine the HI profiles for 132kV, 66kV and 33kV FFC cable sections at the end of DPCR5 and at the end of ED1 to project how the number of HI4s and HI5s would increase without investment.

LPN fluid filled cable top-ups are double the national average. The proposed investment plan will reduce fluid-filled cable top-up volumes by 28% by the end of the ED1 period. The reduction in top-up rates will also enhance the company's environmental reputation.

Figure 35 and Figure 36 show how the lengths of HI4 and HI5 fluid-filled cable is projected to change over the remaining period of DPCR5 and ED1 both with and without investment.

HI profiles:

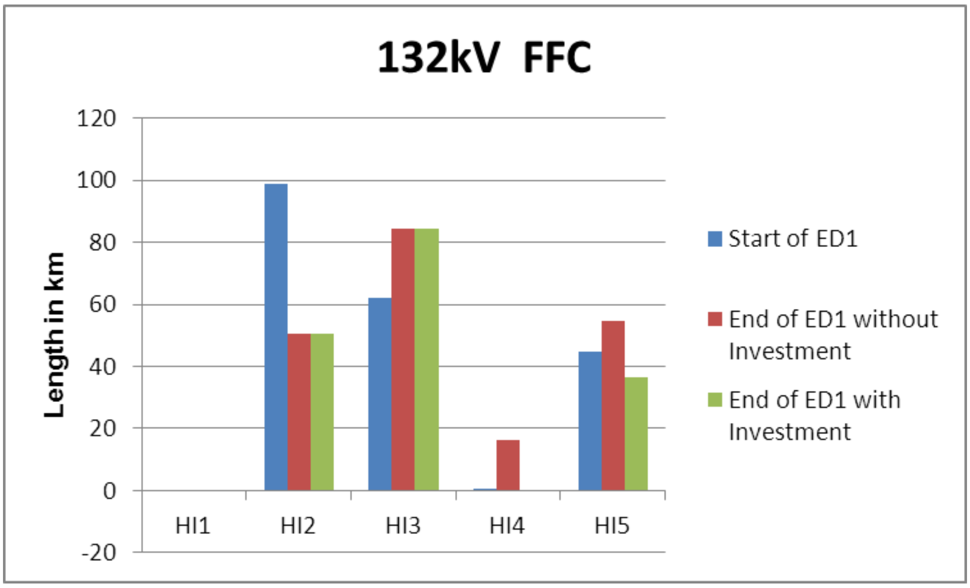


Figure 35 – HI profiles of 132kV fluid-filled cables (FFC)

Source: ARP Model W_FFC_25Jul2012_March 2014 submission

Note: The drop in the number of HI5s at the end of the period is due to the additional focus on the reduction of fluid-filled cable leaks in ED1.

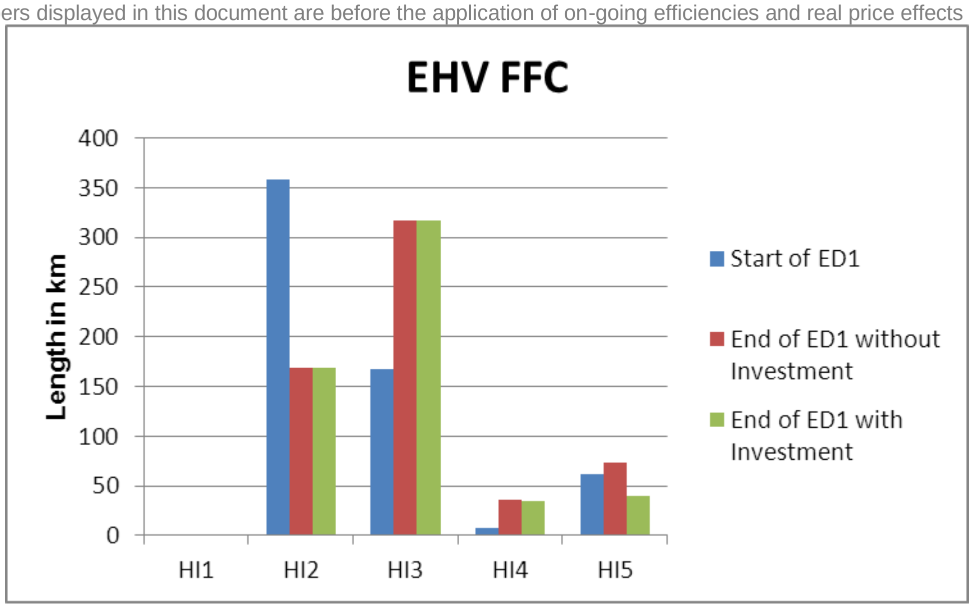


Figure 36 – HI profiles of EHV fluid-filled cables (FFC)

Source: ARP Model W_FFC_25Jul2012_March 2014 submission

Intervention types – Interventions on fluid-filled cables consist of the replacement of a complete circuit, the replacement of a hydraulic section or leak repair. The type of intervention used is driven by application of the investment drivers highlighted in section 3.

If possible, a leak repair is carried out. However, if crystallised lead is discovered, consideration will be given to the replacement of a hydraulic section or possibly the circuit, depending on leak-rate history and the extent of the sheath degradation.

7.2.2 Gas cables

Intervention volumes – The business objective throughout the planning process for ED1 for gas cable replacement was to implement UK Power Networks policy to replace all the gas cable circuits before the end of the ED1 period, as detailed in section 3. This is in line with nationally accepted industry best practice in the UK.

All gas circuits currently in commission in the LPN licence area have been included for removal before the end of the ED1 period.

Intervention types – UK Power Networks policy is to replace all gas cables before the end of ED1 due to the issues described in section 3. Hence, the only planned intervention option is the replacement of the circuit with a solid XLPE cable. In an unplanned outage situation, a repair or partial overlay may have to be considered in the context of restoring the security of the network for customers.

7.2.3 Solid cables

Intervention volumes – The business objective throughout the planning process for ED1 solid cable replacement plans was to use historical replacement trends to inform the future replacement programme.

HIs are not calculated for solid cables and hence HI graphs are not available.

Intervention types – Interventions on solid cables consist of either a cable repair or the replacement of faulted cable sections. A reactive replacement of cable may also be considered if the cable in poor condition is discovered during other work or a circuit with an unacceptably high fault rate is identified.

7.3 Additional Considerations

The Network Asset Management Plan (NAMP) has been used to ensure that the proposed underground cable projects are not duplicated in the Non Load Related Expenditure and Load Related plans.

Stakeholder engagement was an important part of the process to finalise the ED1 plan. Network Operations, Infrastructure Planning and Capital Programme were consulted through formal peer review sessions and various informal discussions during the construction of ED1 plan.

7.4 Asset Volumes and Expenditure

7.4.1 132kV Fluid-Filled Cables

In total, there are 34.8 kilometres of 132kV fluid-filled cables proposed for intervention during ED1. This represents 16.2% of the installed population of 132kV FFC in LPN. The ED2 figures shown in the chart below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2. Further work will be done in ED1 to explore additional intervention options that can be used to extend asset life.

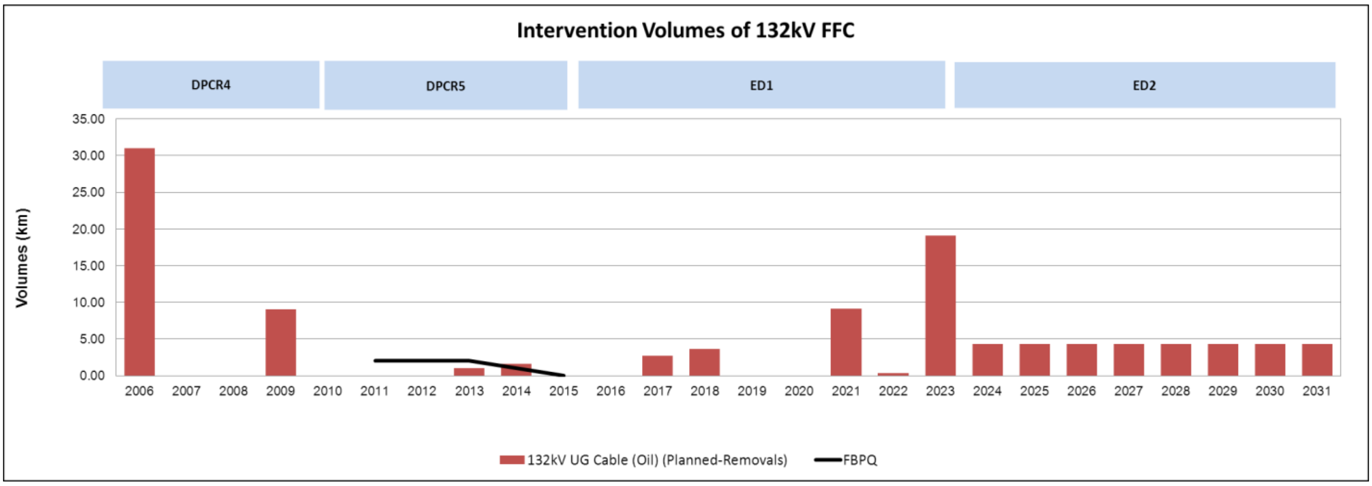


Figure 37 – Intervention volumes of 132kV fluid-filled cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table
ED2 - Similar rate of investment in ED1 assumed

The estimated cost of the proposed investment plan in ED1 is £48.36m.

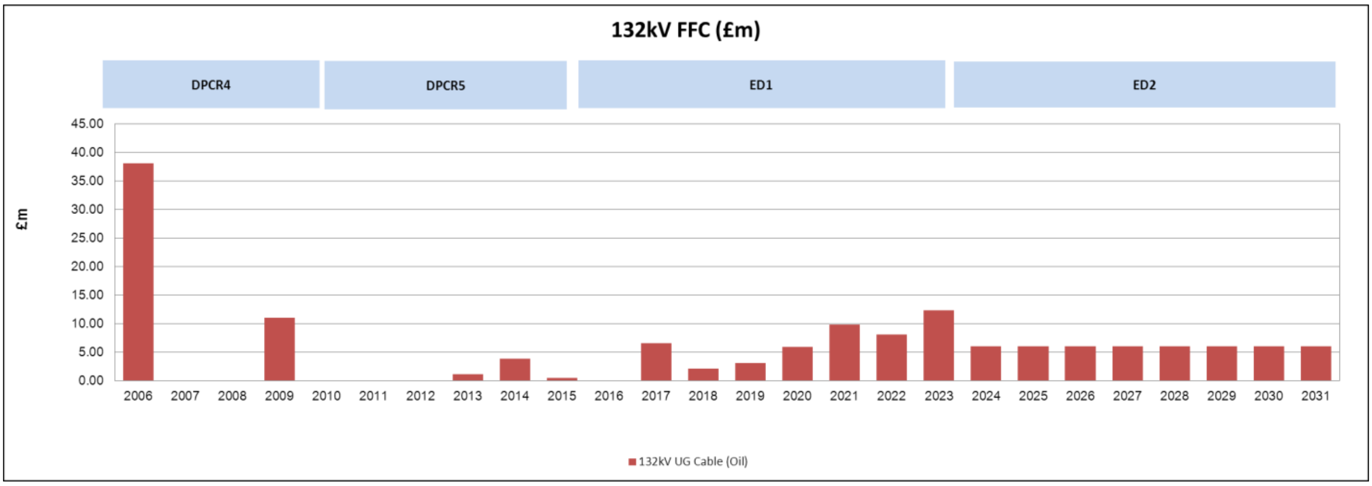


Figure 38 – Intervention cost of 132kV fluid-filled cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)
ED2 - Average from ED1 costs

7.4.2 EHV fluid-filled cables

In total, there are 34.6 kilometres of EHV hydraulic sections proposed for intervention during ED1. This represents 5.8% of the installed population of EHV FFC in LPN. The ED2 figures shown in the chart have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2. Further work will be done in ED1 to explore additional intervention options that can be used to extend asset life.

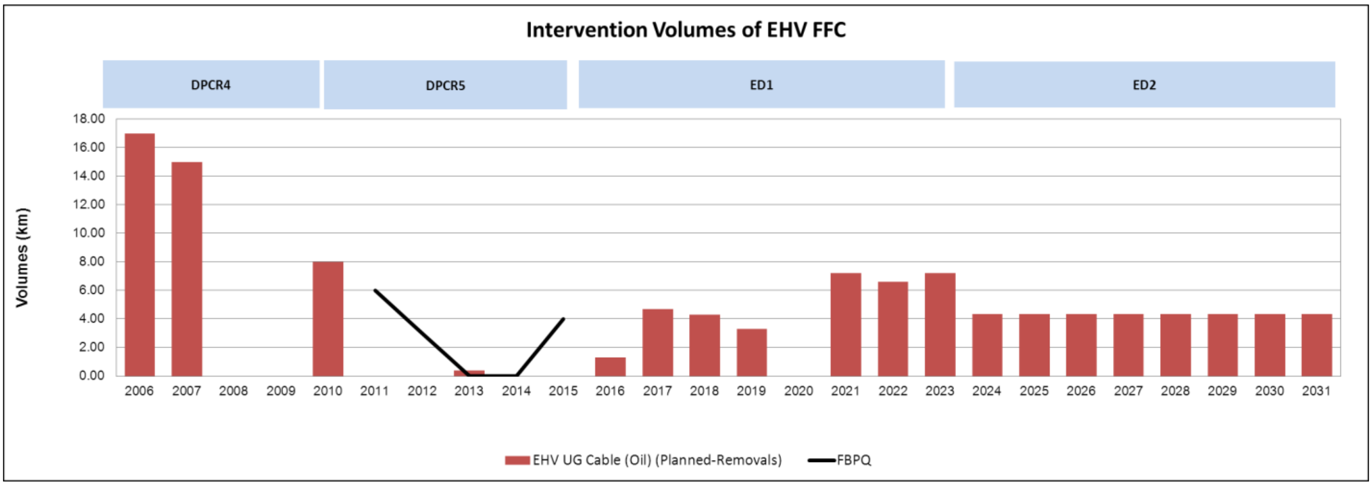


Figure 39 – Intervention volumes of EHV fluid-filled cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table
ED2 - Similar rate of investment in ED1 assumed

The estimated cost of the proposed investment plan in ED1 is £25.42m.

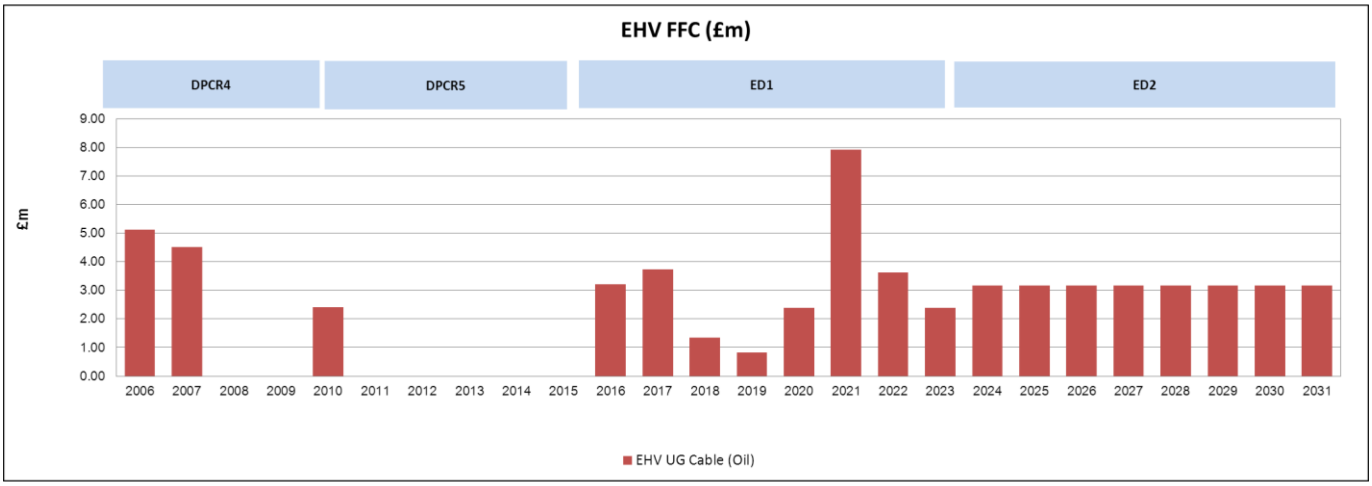


Figure 40 – Intervention cost of EHV fluid-filled cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)
ED2 - Average from ED1 costs

7.4.3 132kV gas cables

In total, there are 50 kilometres of 132kV gas cables proposed for intervention during ED1.

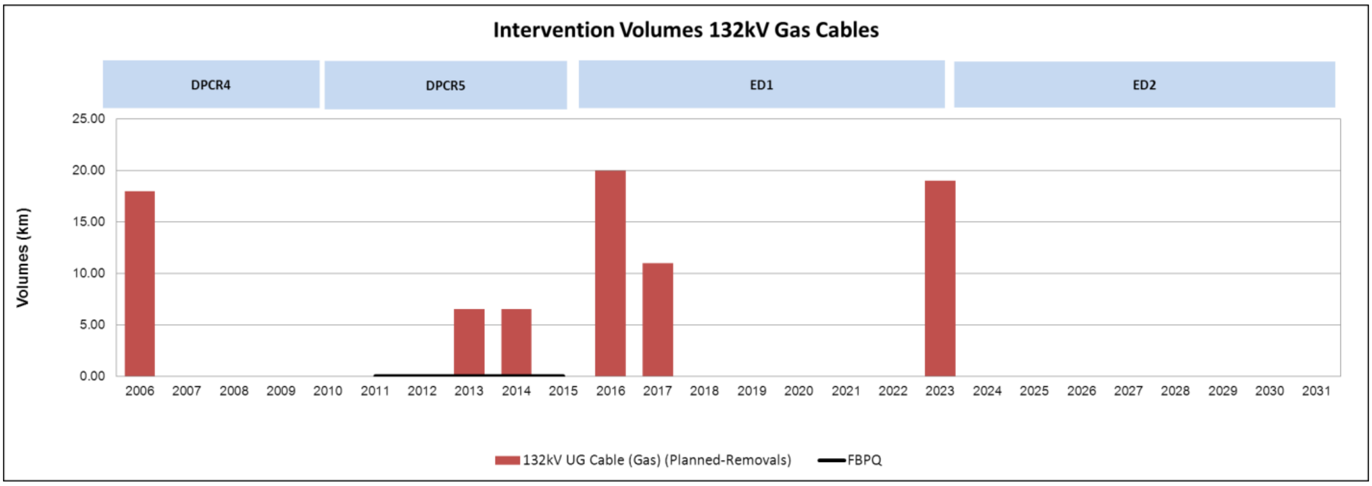


Figure 41 – Intervention volumes of 132kV gas cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table

The estimated cost of the proposed investment plan in ED1 is £39.76m.

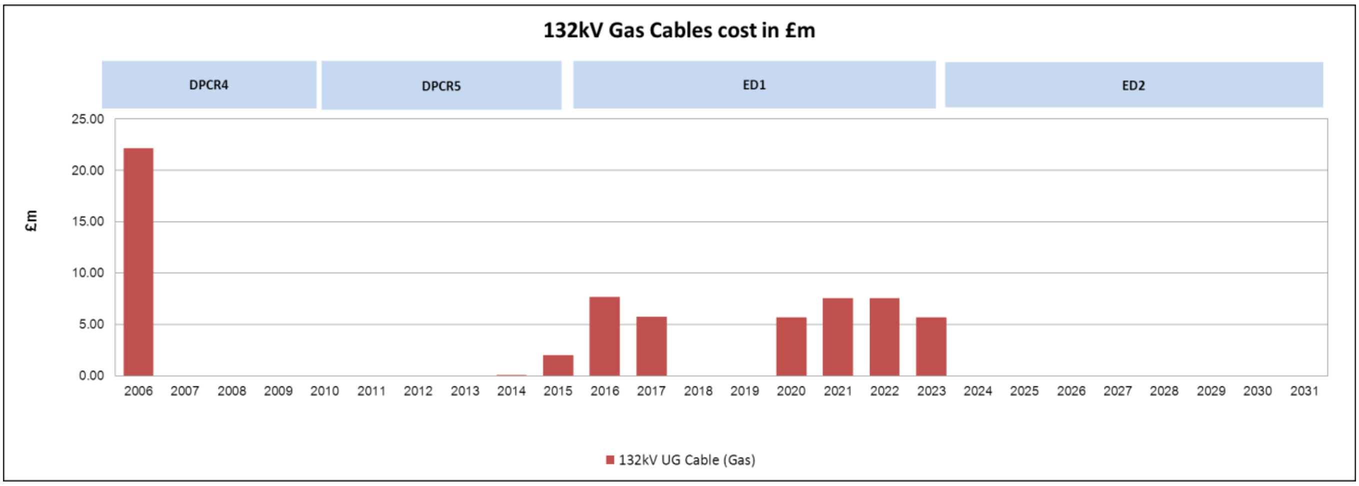


Figure 42 – Intervention cost of 132kV gas cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)

7.4.4 EHV gas cables

In total, there are 18.40 kilometres of EHV gas cables proposed for interventions during ED1.

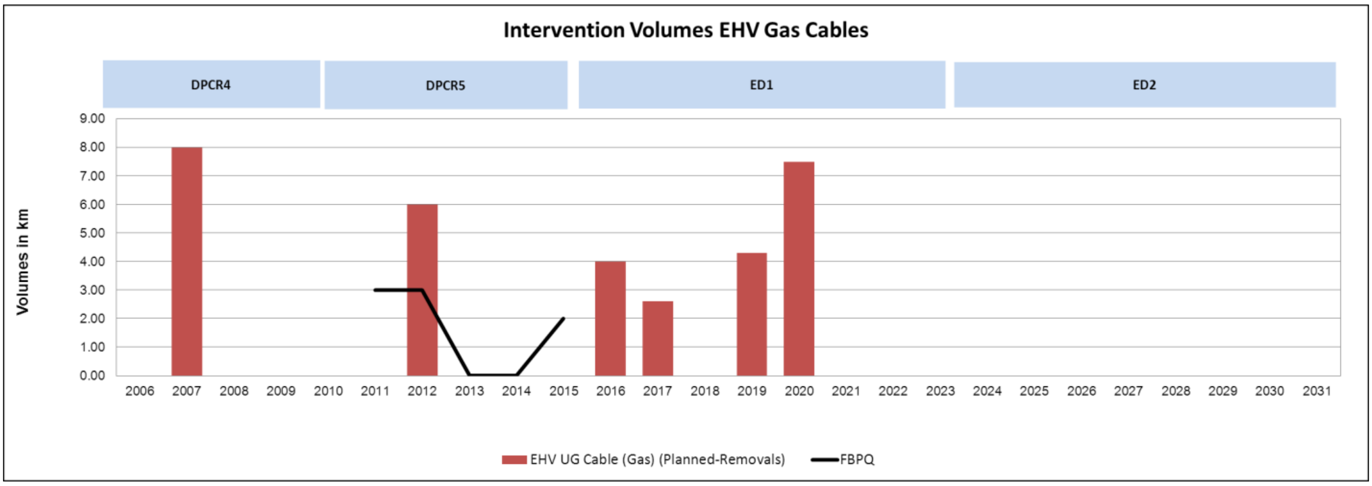


Figure 43 – Intervention volumes of EHV gas cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table

The estimated cost of the proposed investment plan in ED1 is £13.39m.

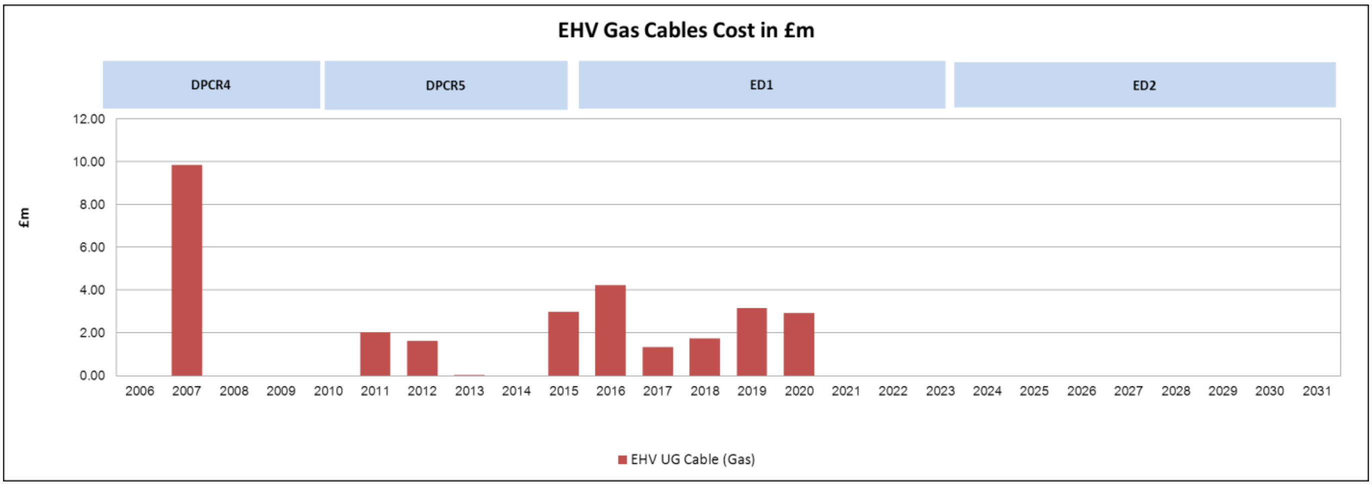


Figure 44 – Intervention cost of EHV gas cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)

7.4.5 132kV solid cables

In total, there are 3.03 kilometres of 132kV solid cables proposed for intervention during ED1. This represents 1.6% of the installed population of 132kV solid cables in LPN. The ED2 figures shown in the chart below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2.

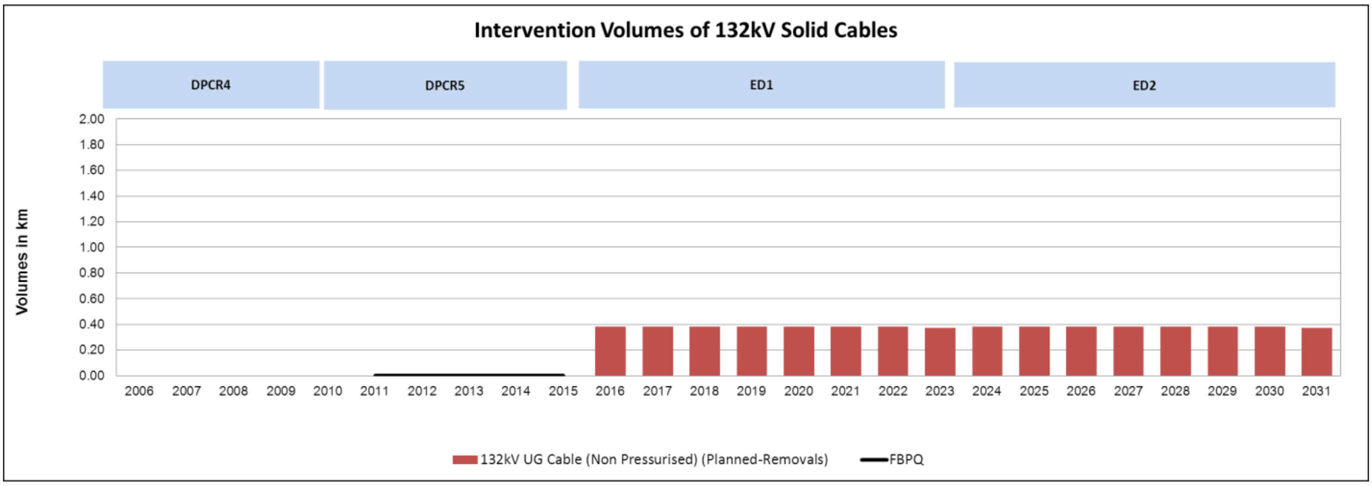


Figure 45 – Intervention volumes of 132kV solid cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table
ED2 - Similar rate of investment in ED1 assumed

The estimated cost of the proposed investment plan in ED1 is £4.39m.

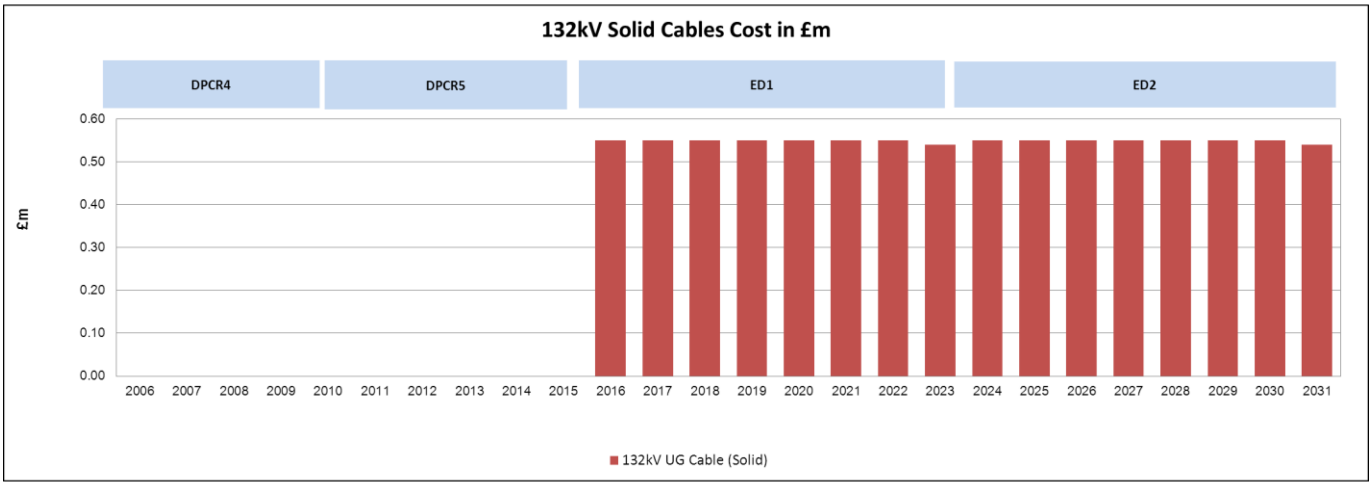


Figure 46 – Intervention cost of 132kV solid cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)
ED2 - Average from ED1 costs

7.4.6 EHV solid cables

In total, there are 10 kilometres of EHV solid cables proposed for intervention during ED1. This represents 1.6% of the installed population of EHV solid cables in LPN. The ED2 figures shown in the chart below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2.

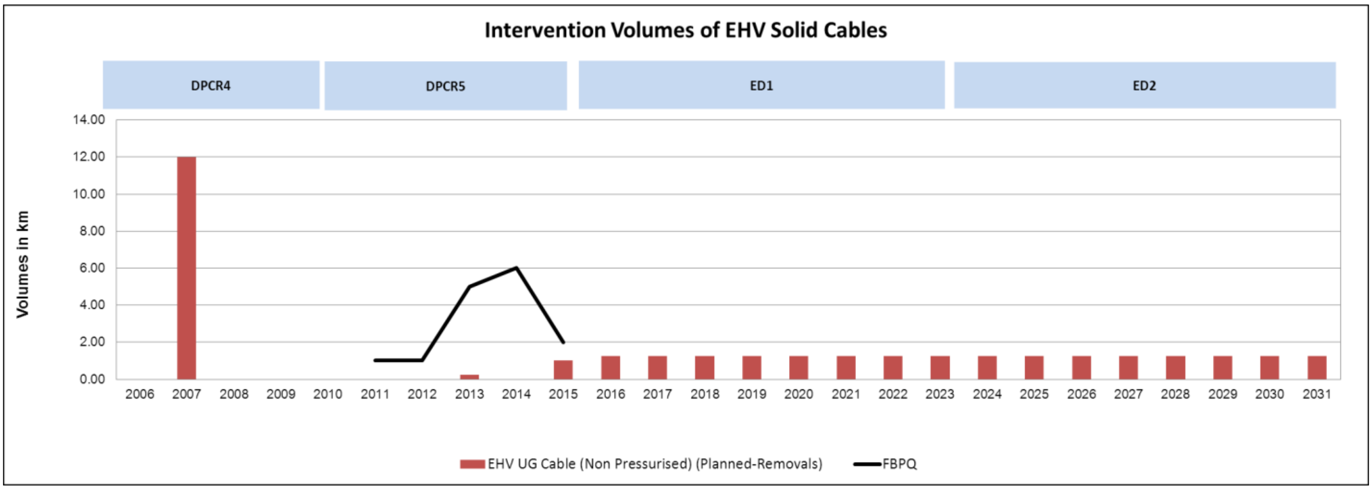


Figure 47 – Intervention volumes of EHV solid cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table
ED2 - Similar rate of investment in ED1 assumed

The estimated cost of the proposed investment plan in ED1 is £3.20m.

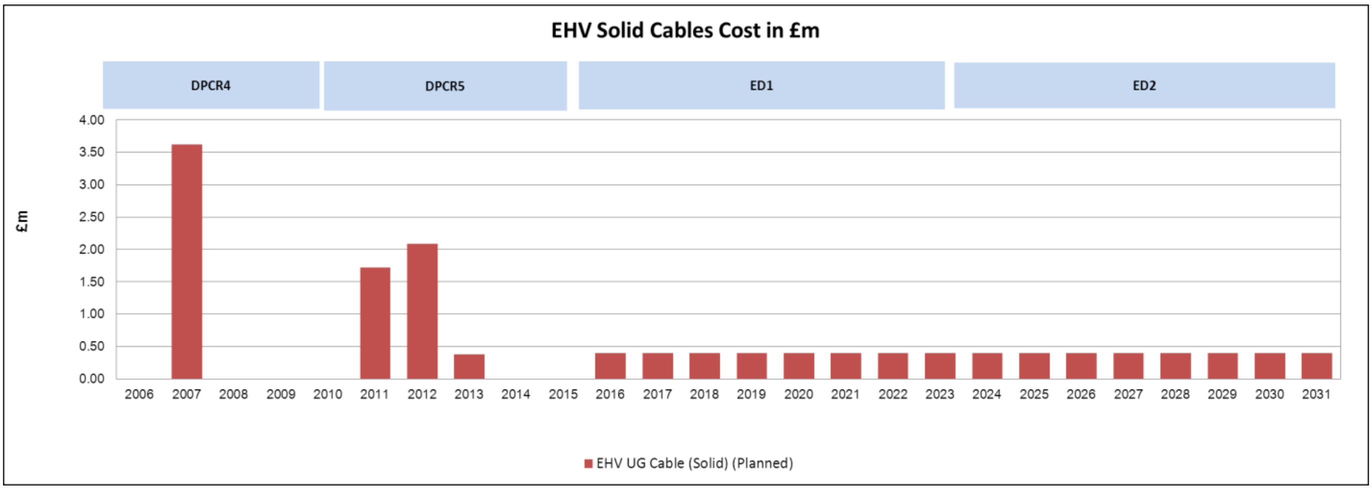


Figure 48 – Intervention cost of EHV solid cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)
ED2 - Average from ED1 costs

7.4.7 HV solid cables

In total, there are 40 kilometres of HV solid cables proposed for intervention during ED1. This represents 0.3% of the installed population of HV solid cables in LPN. The ED2 figures shown in the chart below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2.

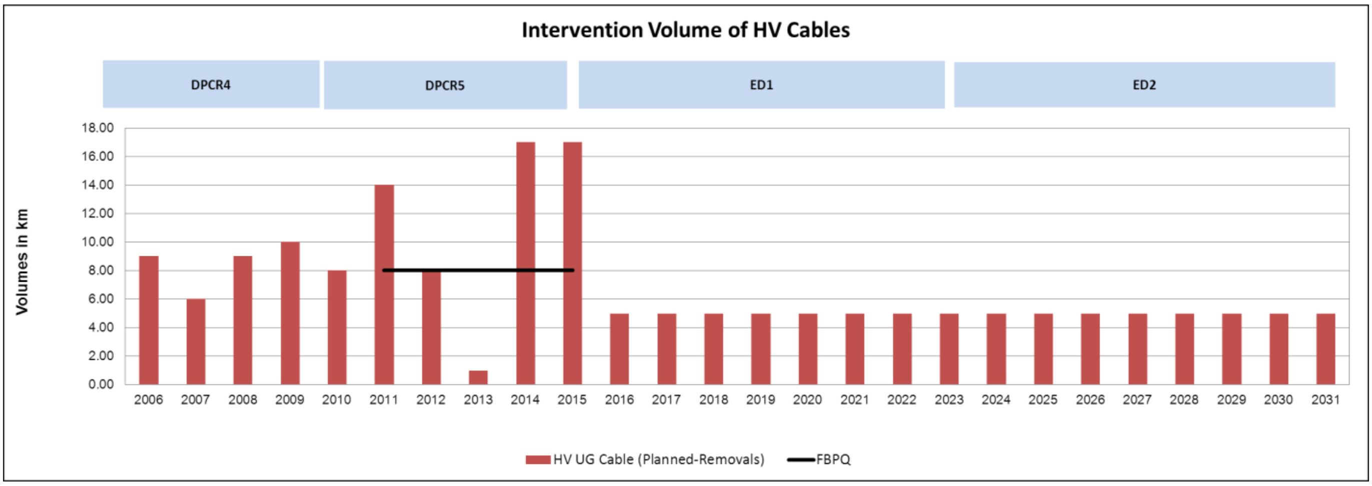


Figure 49 – Intervention volume of HV solid cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table
ED2 - Similar rate of investment in ED1 assumed

The estimated cost of the proposed investment plan in ED1 is £3.68m.

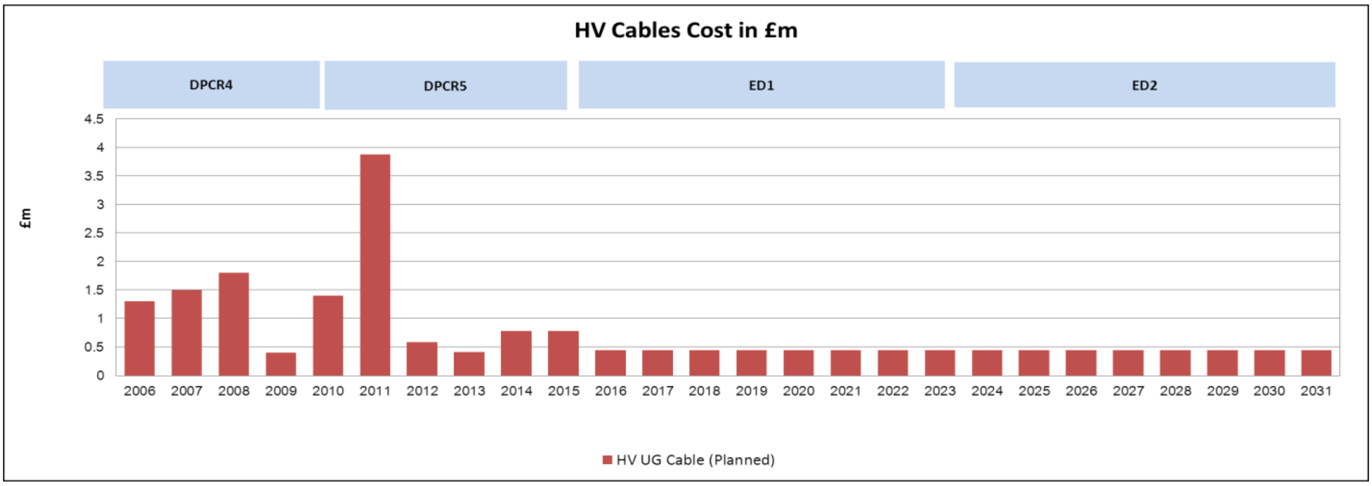


Figure 50 – Intervention cost of HV solid cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)
ED2 - Average from ED1 costs

7.4.8 LV solid cables

In total, there are 16 kilometres of LV solid cables proposed for intervention during ED1. This represents 0.1% of the installed population of EHV solid cables in LPN. The ED2 figures shown in the chart below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2.

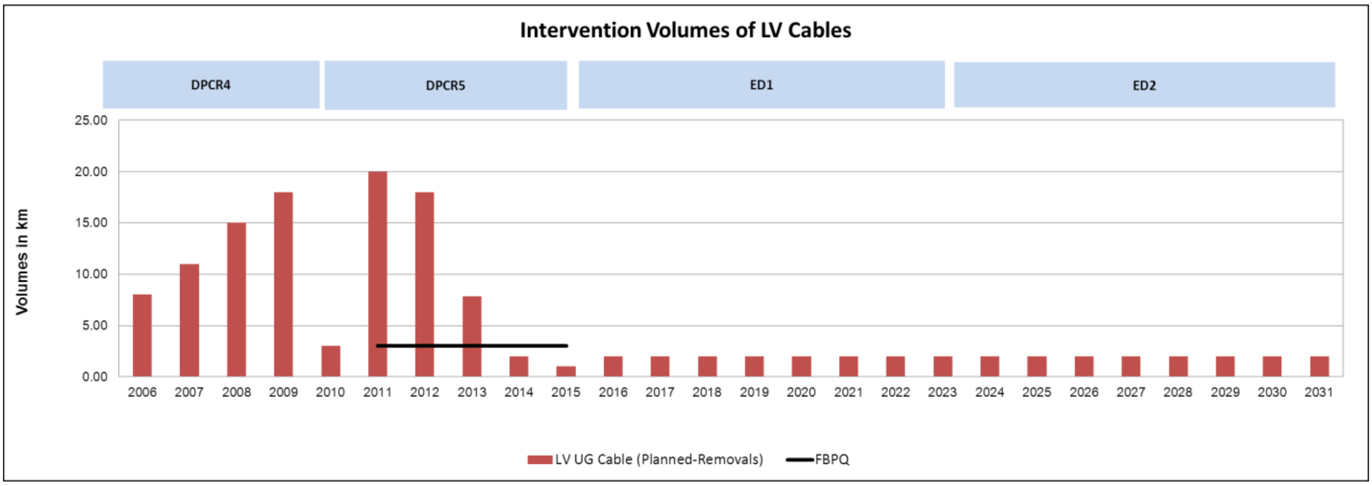


Figure 51 – Intervention volume of LV solid cables

Sources:
DPCR4 & DPCR5 FBPQ - Table NL3 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) - 2013/2014 RIGS CV3 table
ED1 - 2013/2014 RIGS CV3 table
ED2 - Similar rate of investment in ED1 assumed

The estimated cost of the proposed investment plan in ED1 is £2.08m.

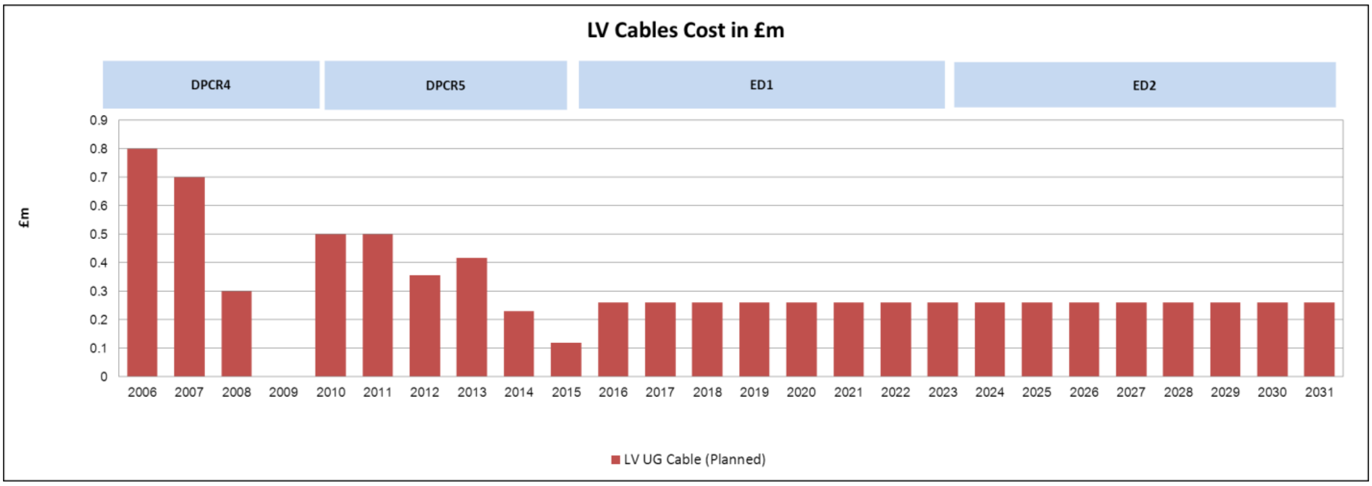


Figure 52 – Intervention cost of LV solid cables

Sources:
DPCR4 - Table NL1 (DPCR5 FBPQ)
DPCR5 (First three years) - 2013/2014 RIGS CV3 table
DPCR5 (Last Two years) – 14thJune NAMP (Table JLI)
ED1 – 19th February NAMP 2014 (Table J Less Indirect)
ED2 - Average from ED1 costs

7.4.9 FFC joints and ancillary equipment

Intervention volumes								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace aluminium cable joint plumbs	3	3	3	3	3	3	3	3
Install remote pressure-monitoring equipment	15	15	15	15	15	15	12	0
Replace pressurised cables ancillary equipment (tanks, gauges, etc)	8	8	8	8	8	8	8	8

Table 13 – Intervention volumes of joints and ancillary equipment

Intervention cost in £m								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace aluminium cable joint plumbs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Install remote pressure-monitoring equipment	0.15	0.15	0.15	0.15	0.15	0.15	0.12	0.00
Replace pressurised cables ancillary equipment (tanks, gauges, etc)	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19

Table 14 – Intervention cost of joints and ancillary equipment in £m

The FFC joints and ancillary equipment interventions are based on historical levels of activity.

7.4.10 Solid cable joints

Intervention volumes								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace 11kV Transition Joints	200	200	200	200	200	200	200	200

Table 15 – Intervention volumes of HV transition joints

Intervention cost in £m								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace 11kV Transition Joints	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43

Table 16 – Intervention cost of HV transition joints in £m

The solid cable joints and ancillary equipment interventions are based on historical levels of activity.

7.5 Commentary

7.5.1 Fluid-filled cables

As previously discussed in section 3, Investment Drivers, LPN has a leakage rate of double the national average per kilometre of installed fluid-filled cable. By virtue of its large numbers installed, Fluid-filled cables account for 26% of all national fluid-filled cable leakage.

The hydraulic sections and circuits identified for replacement in ED1 with the assistance of the ARP model represent 8.6% of the total fluid-filled cable population and yet are responsible for 48% of the fluid leakage.

In DPCR5, the strategy was to maintain leakage rates at existing levels. However, by using a targeted approach to the replacement of specific hydraulic sections wherever possible and only replacing complete circuits when necessary, this programme has the potential to reduce the fluid-filled cable leakage in LPN by 28% by the end of the ED1 period.

The health indices calculated with the assistance of the ARP model are based primarily on age and leakage history of the hydraulic circuit. These identified circuits were then investigated in detail based on the available condition information, which is gathered when available during fault repairs.

7.5.2 Gas cables

As previously discussed in section 3, Investment Drivers, it is UK Power Networks policy to withdraw all gas cables from service by the end of ED1. Following the Skipper report in 1988, there has been industry-wide support for the phased decommissioning of the gas cables.

This was justified on the basis of the potential for explosive sealing end failures, gas leaks which require an immediate and prolonged circuit outage, a higher than average cable fault rate and inherent design flaws.

It is understood that all of the DNOs in the UK are currently completing or have completed gas cable replacement programme, with National Grid completing a replacement programme in 2001. These issues are discussed fully on section 3.2.1.

The work to comply with this policy decision has already commenced in DPCR5, with interventions on gas cables well in excess of FBPQ levels. The plan will require a further increase in activity within ED1.

7.5.3 Solid cables

The replacement of solid cables is based on a case-by-case condition assessment of faulted sections. Named schemes are not identified in advance and the planned provision is based primarily on historical levels of activity in each of the voltage level areas as can been seen in the graphs in section 7.4.5 to 7.4.8. This is considered to be a prudent approach in line with decreasing or flat fault rate.

7.6 Sensitivity Analysis and Plan Validation

An independent report has been carried out by Decision Lab to understand how the Health Index profile of assets may change if the average asset life does not turn out as predicted. The full results are shown in Appendix 6.

Average life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	17.1	38.8	30.0	2.4	11.2
-2	17.1	44.7	24.7	2.4	11.2
-1	17.1	45.9	23.5	2.4	11.2
0	17.1	45.9	23.5	2.4	11.2
1	17.1	45.9	25.9	0.0	11.2
2	17.1	47.6	24.1	0.0	11.2
4	17.1	50.6	21.2	1.2	10.0

Average life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	11.8	21.8	47.1	5.3	14.1
-2	11.8	24.1	47.1	2.9	14.1
-1	11.8	27.1	44.1	2.9	14.1
0	11.8	28.2	42.9	3.5	13.5
1	12.9	28.8	44.1	0.6	13.5
2	12.9	28.8	44.1	0.6	13.5
4	12.9	34.7	38.8	0.0	13.5

Table 17 – Results of sensitivity analysis 132kV FFC

Average life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	2.6	63.2	28.5	2.4	2.9
-2	2.6	66.0	26.1	2.9	2.4
-1	2.6	67.6	24.8	2.3	2.4
0	2.6	69.4	24.1	1.5	2.4
1	2.6	69.5	23.9	1.3	2.4
2	2.9	70.4	22.8	1.5	2.3
4	3.7	72.6	19.7	2.3	1.5

Average life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	1.5	30.9	55.9	5.7	6.0
-2	1.5	36.5	50.5	5.5	6.0
-1	2.6	45.6	40.1	5.5	6.0
0	2.6	46.1	41.0	4.1	5.9
1	2.6	51.5	36.2	4.4	5.4
2	2.6	55.7	32.4	4.6	4.7
4	2.6	58.8	29.8	4.9	3.7

Table 18 – Results of sensitivity analysis of EHV FFC

In Table 19 and Table 20, each average asset life change of years +/- 1, 2 and 4 are represented as a percentage of the current population. With each change in average asset life, there is a subsequent movement in the percentage of population in each Health Index. An average asset life at 0 represents the current population split within each Health Index with intervention strategies applied. The two tables range from the start of ED1 (2015) and the end of ED1 (2023).

These tables show the percentage population movements over the eight-year period and the impact any change in average asset life will have on the asset group's HI profile.

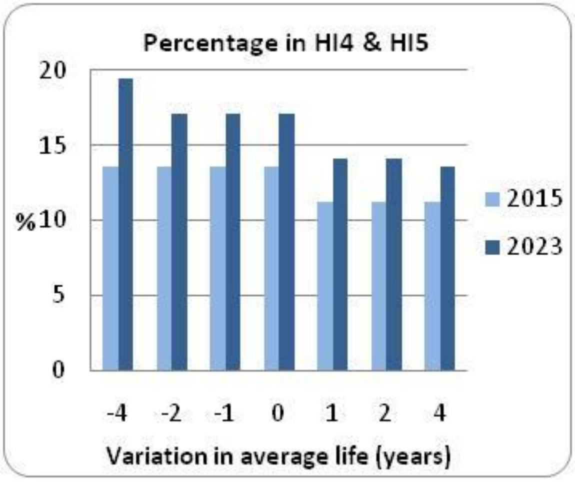


Figure 53 – Effect of average asset life variation on volumes of HI4 and HI5 of 132kV FFC

Figure 53 represents the summed HI4s and HI5s as a percentage of the population, showing the change at each average asset life iteration, comparing 2015 and 2023. In 2015, if average asset life is four years longer, the proportion of HI4 and HI5 will reduce from 13.6% to 11.2%; but if four years shorter, it will increase to 13.6%. In 2023, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 17.0% to 13.5%; but if four years shorter, it will increase to 19.4%.

It is concluded from the above observations that the ED1 replacement plan for LPN 132kV UG Cable (Oil) is slightly sensitive to a variation in average asset life up to four years.

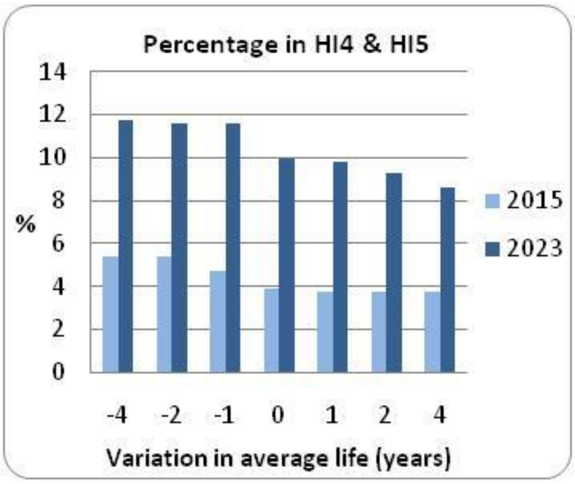


Figure 54 – Effect of average asset life variation on volumes of HI4 and HI5 of EHV FFC

Figure 54 represents the summed HI4s and HI5s as a percentage of the population showing the change at each average asset life iteration comparing 2015 and 2023. In 2015, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 3.9% to 3.8%; but if four years shorter, it will increase to 5.3%. In 2023, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 10.0% to 8.6%; but if four years shorter, it will increase to 11.7%.

It is concluded from the above observations that the ED1 replacement plan for LPN EHV UG Cable (Oil) is fairly insensitive to a variation in average asset life of up to four years.

7.7 Model Testing

The ARP model had undergone rigorous testing to ensure it met the defined requirements prior to acceptance. There were four distinct subsets to the testing process: algorithm testing, software testing, data-flow testing and user and methodology testing. Each test was designed to capture potential errors in specific parts of the system. The completion of all tests provides assurance that a thorough evaluation has been carried out to ensure correctness and validity of the outputs.

7.7.1 Algorithm testing

The ARP model comprises a set of algorithms implemented within the database code. The tester in a spread sheet mimics each algorithm, with the results compared with those of the ARP algorithm for a given set of test data inputs. The test data comprised data within normal expected ranges, low-value numbers, high-value numbers, floating point numbers, integers, negative numbers and unpopulated values. In order to pass the test, all results from the ARP algorithm are required to match the spread sheet calculation.

7.7.2 Software testing

A number of new software functions used in the model required testing to ensure they performed correctly. A test script was created to identify the functional requirement, the method to carry out the function and the expected outcome. In order to pass the test, the achieved outcome had to match the expected outcome.

7.7.3 Data-flow testing

Data flow testing was carried out to ensure that data presented in the ARP upload files passes into the model correctly. Data counts from the ARP model upload files were compared to data successfully uploaded to the model. To pass the test, counts of the data had to match within specified tolerances.

7.7.4 User and methodology testing

The aim of the user and methodology testing is to ensure that the models are fit for purpose. A test script has been created to check that displays operate correctly and that outputs respond appropriately to changes in calibration settings.

7.8 Network Risk

Table 21, Table 22, Table 23 and Table 24 illustrate the asset health and criticality of the assets in LPN at the beginning and end of RIIO-ED1 with interventions.

Asset Category	Criticality	Units	Estimated Asset Health and Criticality Profile 2015					2015
			Asset Health					
			HI1	HI2	HI3	HI4	HI5	
132kV FFC	Low	circuit km	0	23	15	0	11	49
	Average	circuit km	0	19	11	1	8	39
	High	circuit km	0	33	21	0	15	69
	Very high	circuit km	0	23	15	0	11	49

Table 19 – Estimated Asset Health and Criticality Profile 2015

Asset Category	Criticality	Units	Estimated Asset Health and Criticality Profile 2023					2023
			Asset Health					
			HI1	HI2	HI3	HI4	HI5	
132kV FFC	Low	circuit km	0	12	20	0	13	45
	Average	circuit km	0	9	16	0	11	36
	High	circuit km	0	18	28	1	10	57
	Very high	circuit km	0	12	20	0	1	33

Table 20 – Estimated Asset Health and Criticality Profile 2023

Asset Category	Criticality	Units	Estimated Asset Health and Criticality Profile 2015					2015
			Asset Health					
			HI1	HI2	HI3	HI4	HI5	
EHV FFC	Low	circuit km	0	38	17	1	6	62
	Average	circuit km	0	22	10	0	4	36
	High	circuit km	0	31	15	1	6	53
	Very high	circuit km	0	267	125	6	46	444

Table 21 – Estimated Asset Health and Criticality Profile 2015

Asset Category	Criticality	Units	Estimated Asset Health and Criticality Profile 2023					2023
			Asset Health					
			HI1	HI2	HI3	HI4	HI5	
EHV FFC	Low	circuit km	0	17	33	4	8	62
	Average	circuit km	0	11	19	2	2	34
	High	circuit km	0	15	28	3	3	49
	Very high	circuit km	0	126	237	26	26	415

Table 22– Estimated Asset Health and Criticality Profile 2023

Source: 21st February 20144 ED1 Business Plan Data Tables

8.0 Deliverability

The volume of work proposed in ED1 is a significant increase on that in DPCR5 and an appropriate use of both internal and external resources will be necessary to successfully deliver the plan. Consultation with internal stakeholders responsible for the delivery of the plan was taken at an early stage and will continue throughout the process.

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Appendices

Appendix 1 – Age Profiles

Fluid-filled cables (FFC)

The age profiles of 132kV FFC cables are shown in Figure 55.

1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
0	6	22	23	145	0	19	0	0

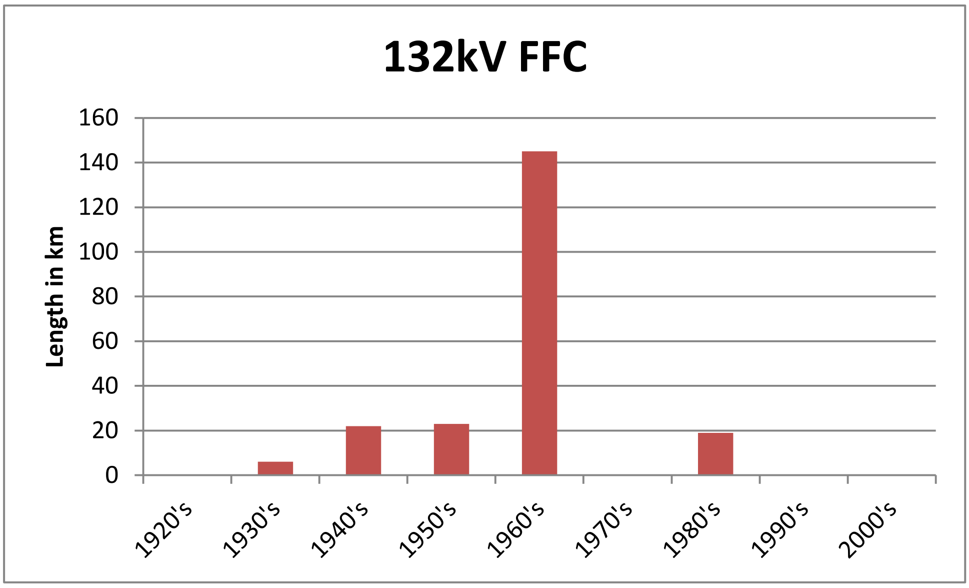


Figure 55 – Age profile of 132kV FFC

The age profiles of 66kV FFC cables are shown in Figure 56.

1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
5	59	0	24	153	43	7	0	0

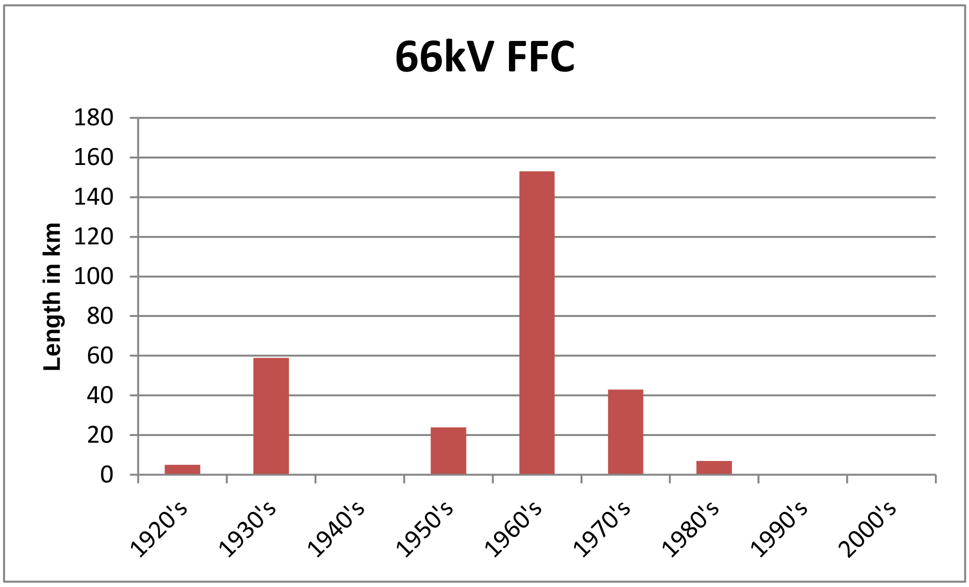


Figure 56 – Age profile of 66kV FFC

The age profiles of 33kV FFC cables are shown in Figure 57.

1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s
0	3	0	7	295	0	0	0	0

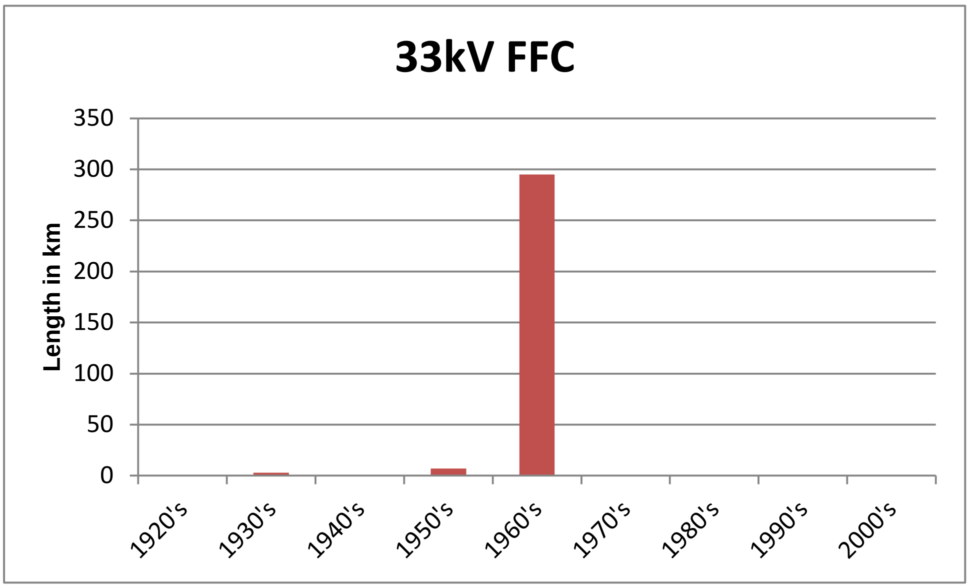


Figure 57– Age profile of 33kV FFC

Gas cables

The age profile of 33kV gas cable in LPN is shown in Figure 58.

Pre-1920	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0	0	0	0	17	0	0	0	0	0	0

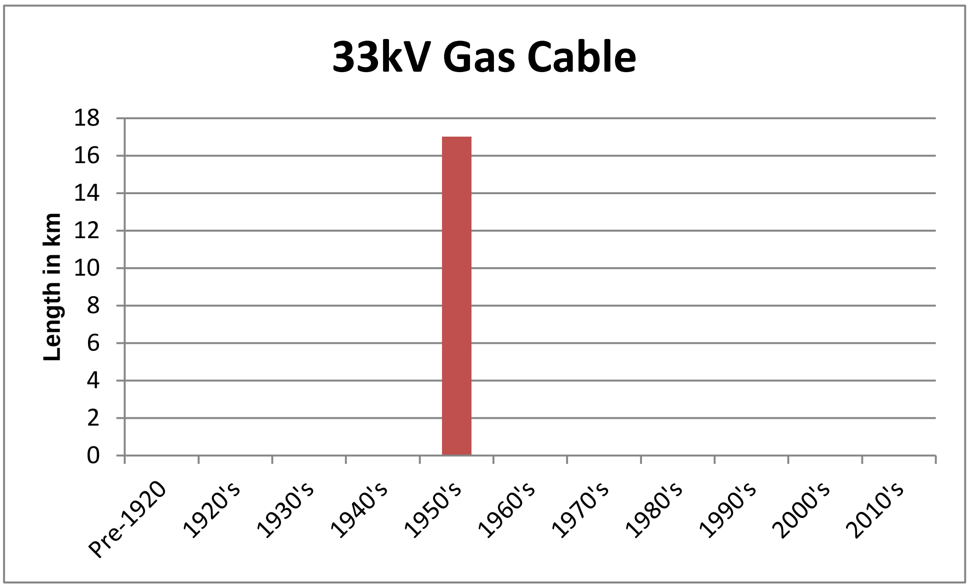


Figure 58 – Age profile of 33kV underground gas cable

The age profile of 66kV gas cables in LPN is shown in Figure 59.

Pre-1920	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0	1	2	2	0	1	0	1	5	4	0

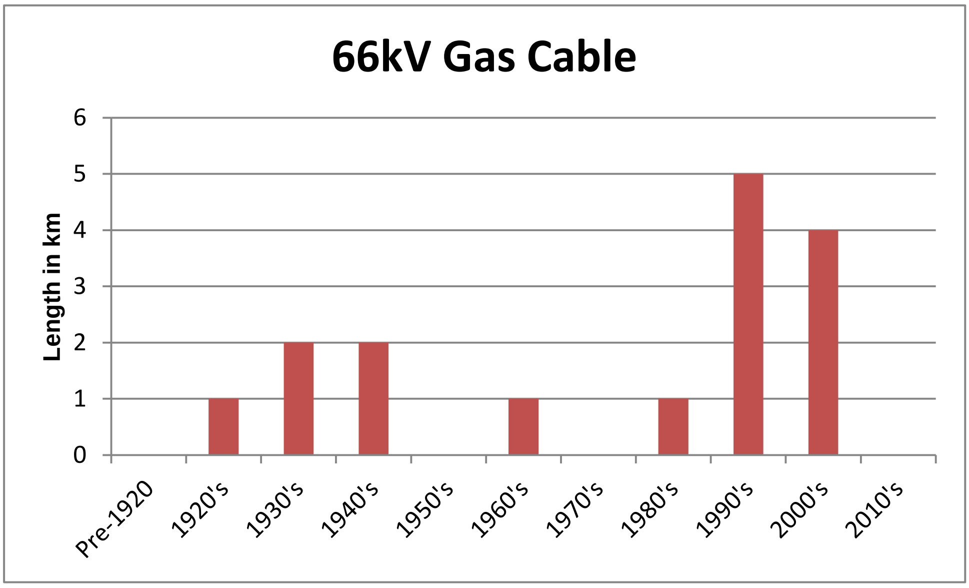


Figure 59 – Age profile of 66kV underground gas cable

The age profile of 132kV gas cables in LPN is shown in Figure 60.

Pre-1920	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0	0	0	0	29	20	0	23	0	0	0

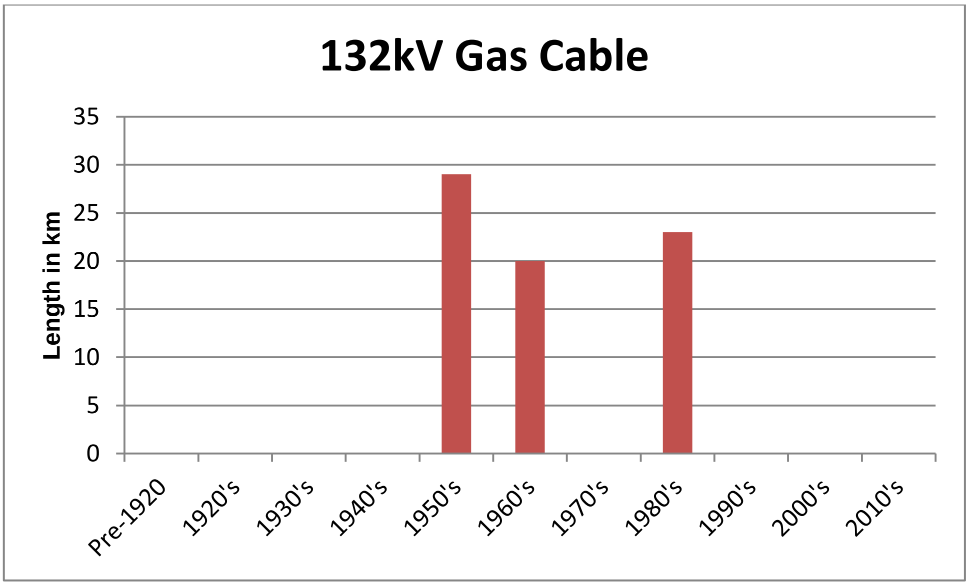


Figure 60 – Age profile of 132kV underground gas cable

Solid cables

The age profiles of 132kV solid cables are shown in Figure 62.

Pre-1920	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0	0	0	0	27	17	1	25	37	73	23

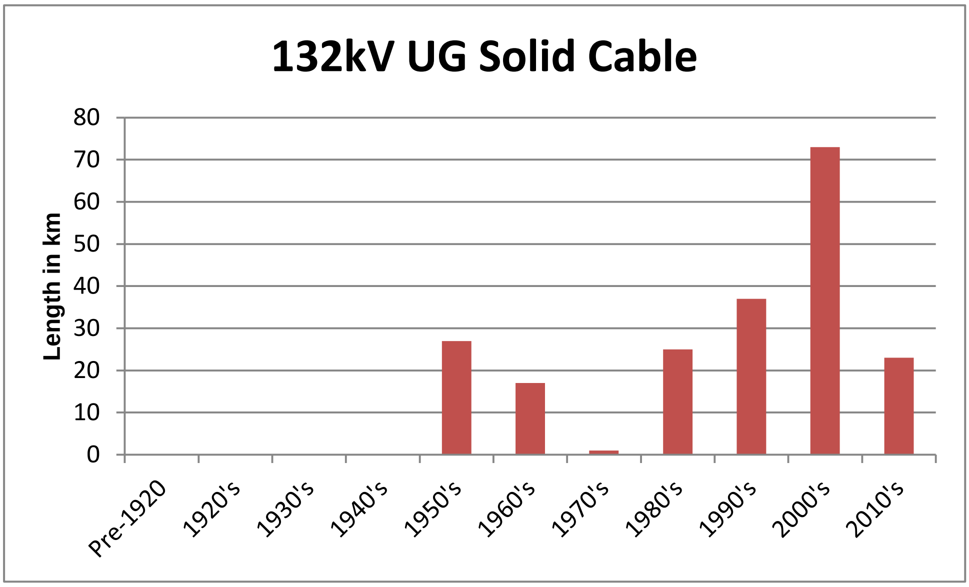


Figure 61 – Age profile of 132kV underground solid cable

The age profiles of 66kV solid cables are shown in Figure 62.

Pre-1920	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0	6	42	7	3	6	0	3	28	26	0

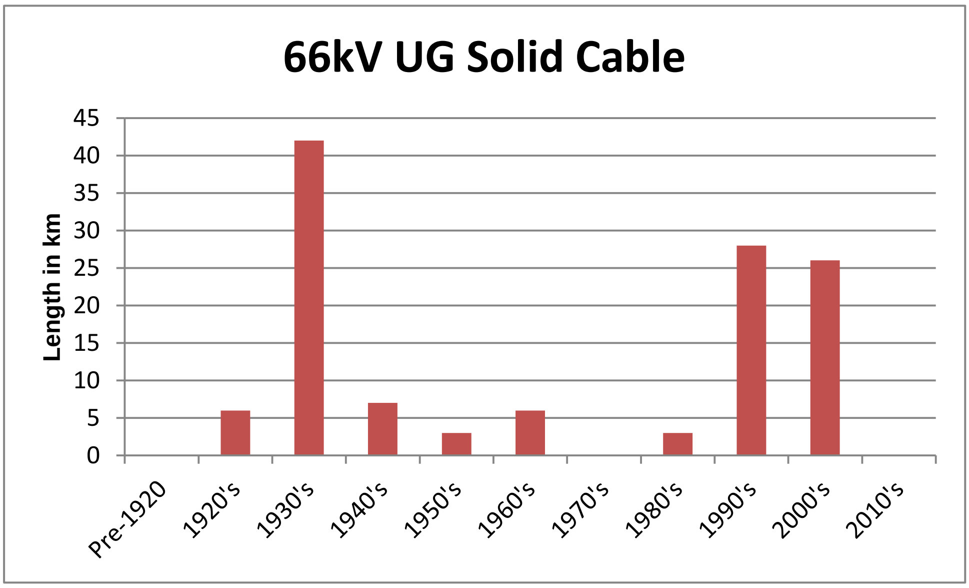


Figure 62 – Age profile of 66kV underground solid cable

The age profiles of 33kV solid cables are shown in Figure 63.

Pre-1920	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0	143	76	0	135	35	59	27	2	36	7

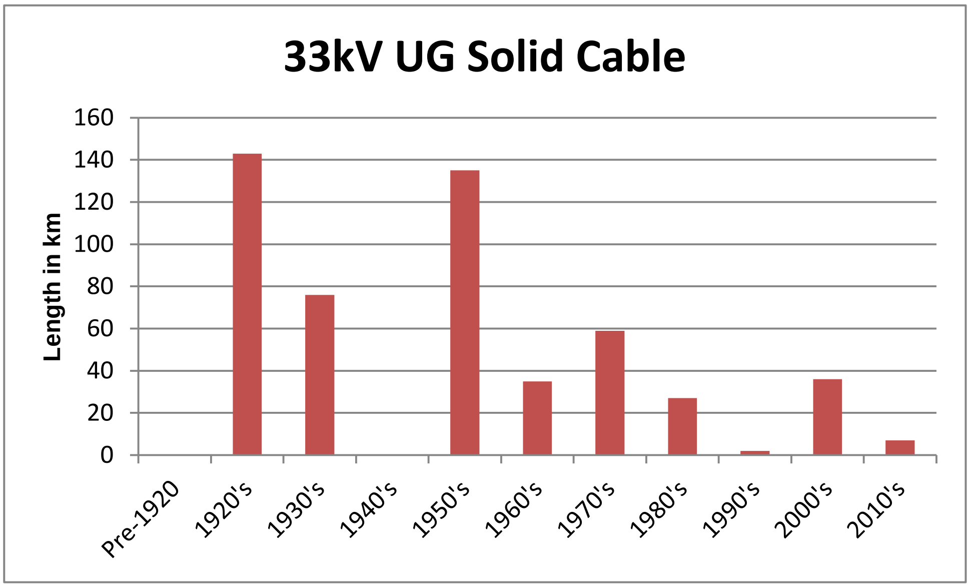


Figure 63 – Age profile of 33kV underground solid cable

The age profiles of 22kV solid cables are shown in Figure 64.

Pre-1920	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s
0	0	0	0	0	0	0	0	0	1	1

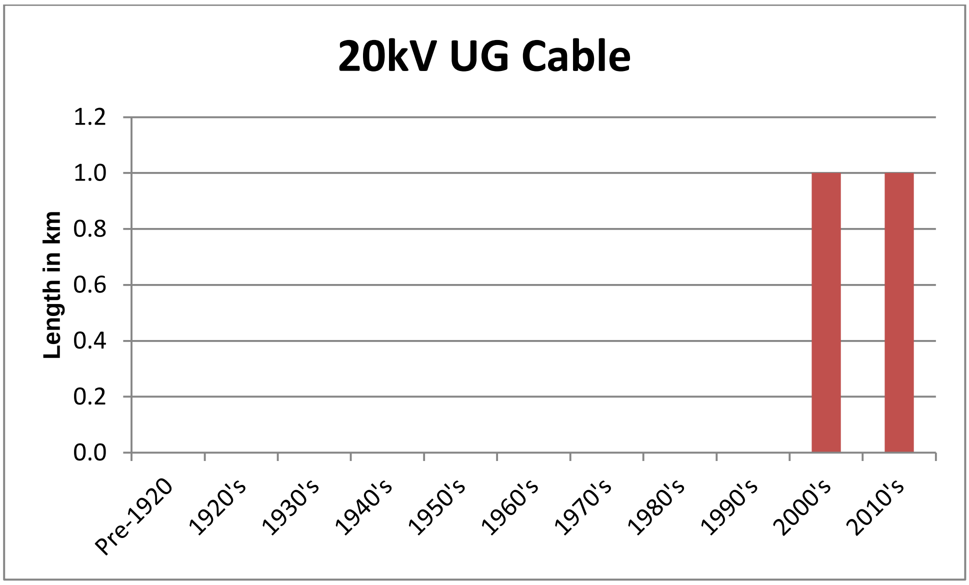


Figure 64 – Age profile of 20kV underground solid cable

The age profiles of HV solid cables are shown in Figure 65.

Pre-1920	**1920s**	**1930s**	**1940s**	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**2010s**
15	234	570	714	1,281	4,890	1,351	808	691	1305	248

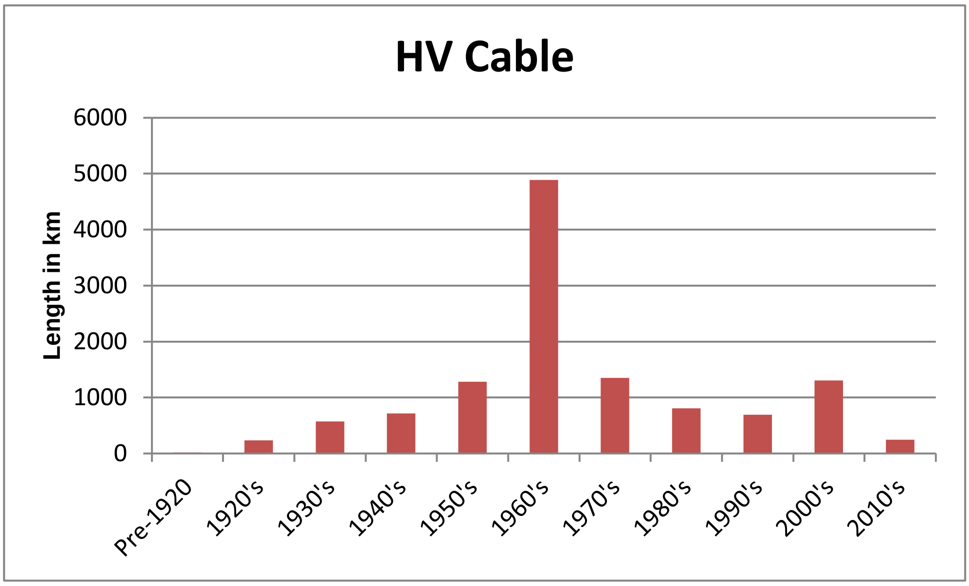


Figure 65 – Age profile of HV underground solid cable

The age profiles of LV solid cables are shown in Figure 66.

Pre-1920	**1920s**	**1930s**	**1940s**	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**	**2010s**
418	1,122	2,795	2,353	2,663	7,409	2,270	1,035	1,884	1,705	317

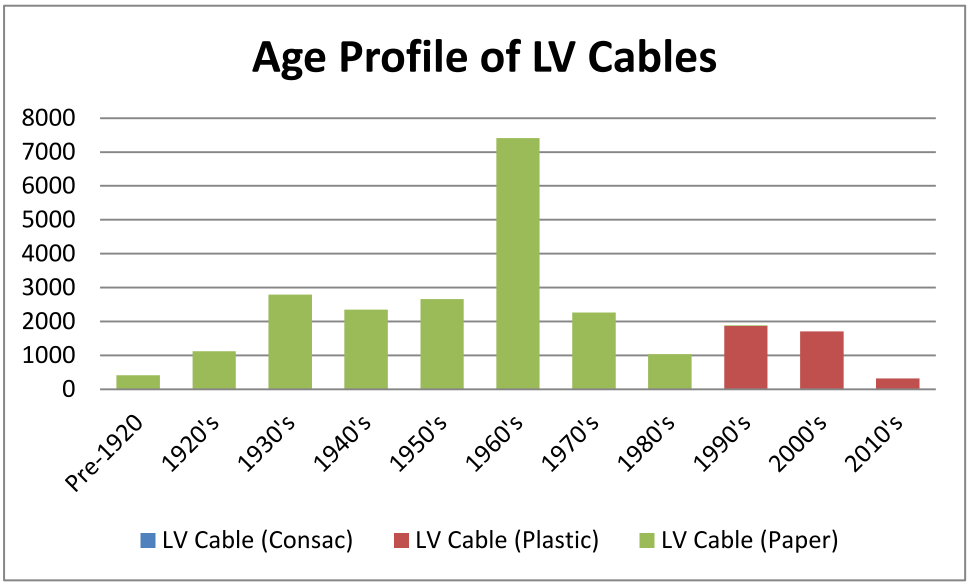


Figure 66 – Age profile of LV underground solid cable

Appendix 2 – HI Profiles

Fluid-filled cables (FFC)

132kV	HI1	HI2	HI3	HI4	HI5
Start of ED1	0	98	62	1	45
End of ED1 without Investment	0	51	84	16	55
End of ED1 with Investment	0	51	84	1	36

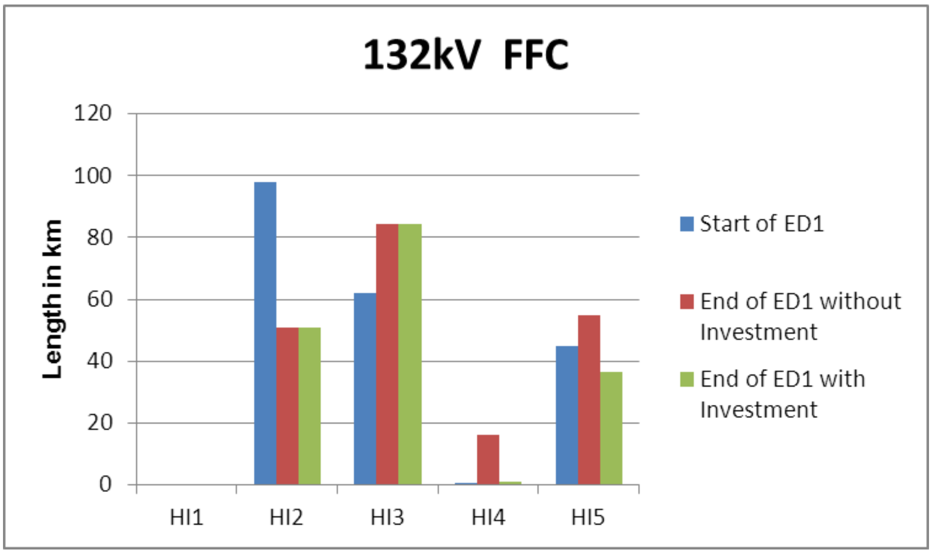


Figure 67– HI profiles of 132kV fluid-filled cables (FFC)

Source: ARP Model W_FFC_25Jul2012_March 2014 submission

EHV	HI1	HI2	HI3	HI4	HI5
Start of ED1	0	358	167	8	62
End of ED1 without Investment	0	169	317	36	73
End of ED1 with Investment	0	169	317	35	39

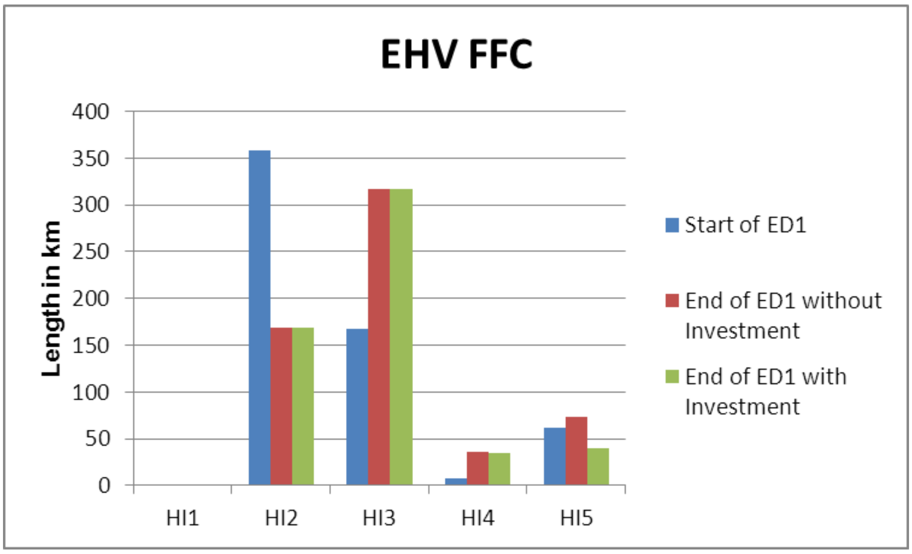


Figure **68 – HI profiles of EHV fluid-filled cables (FFC)**

Source: ARP Model W_FFC_25Jul2012_March 2014 submission

Appendix 3 – Fault Data

132KV UG Cable	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
All Faults	0.0163	0.0163	0.0245	0.0204	0.0061	0.0061
Poor Condn Due To Age & Wear	0.0102	0.0122	0.0122	0.0102	0.0020	0.0041

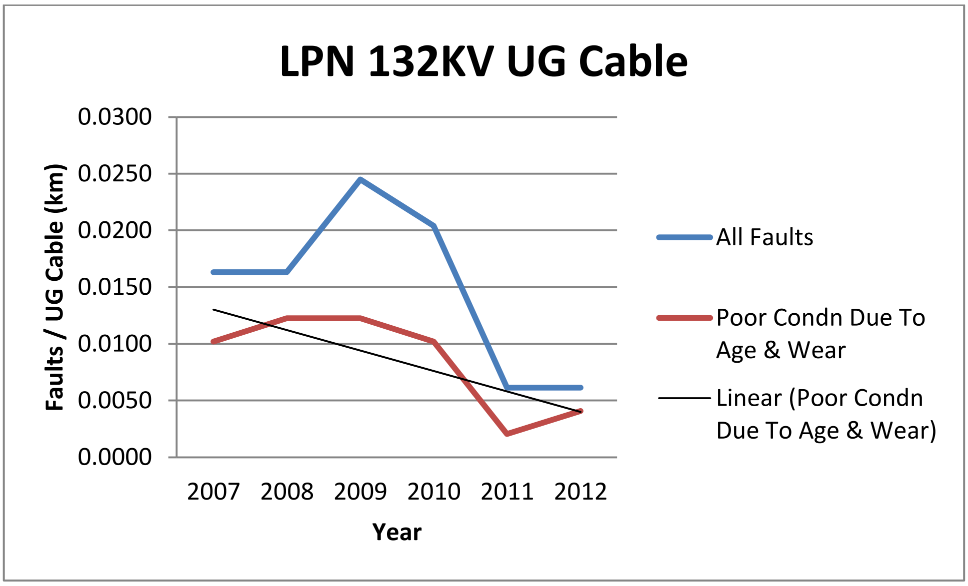


Figure 69 – Fault trends of 132kV underground cable

EHV UG Cable	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
All Faults	0.0276	0.0220	0.0134	0.0268	0.0094	0.0126
Poor Condn Due To Age & Wear	0.0165	0.0189	0.0110	0.0181	0.0087	0.0110

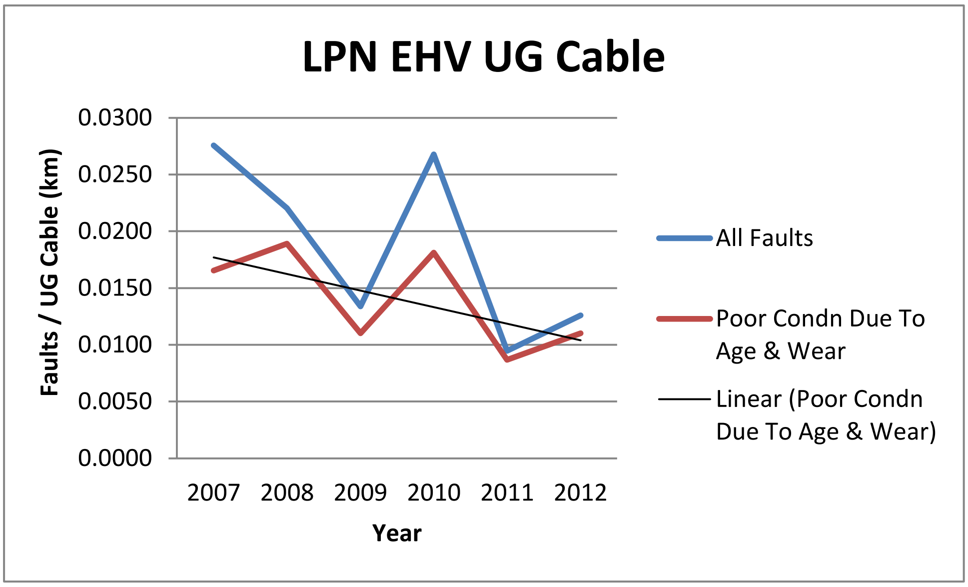


Figure 70 – Fault trends of EHV underground cable

HV UG Cable	2007	2008	2009	2010	2011	2012
All Faults	0.0350	0.0348	0.0328	0.0352	0.0282	0.0368
Poor Condn Due To Age & Wear	0.0277	0.0266	0.0265	0.0304	0.0229	0.0315

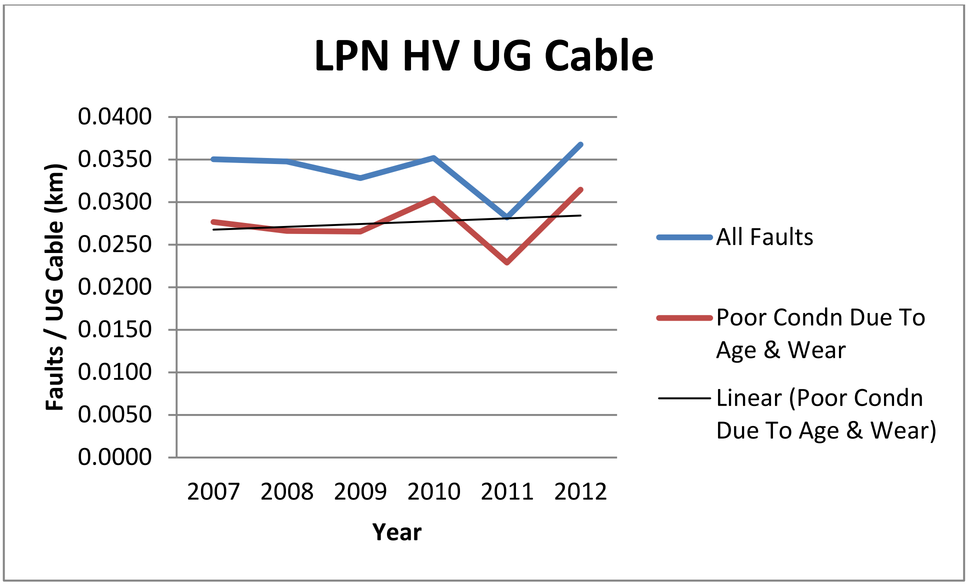


Figure 71 – Fault trends of HV underground cable

LV UG Cable	2007	2008	2009	2010	2011	2012
All Faults	0.0690	0.0631	0.0665	0.0868	0.0636	0.0686
Poor Condn Due To Age & Wear	0.0487	0.0456	0.0536	0.0747	0.0472	0.0471

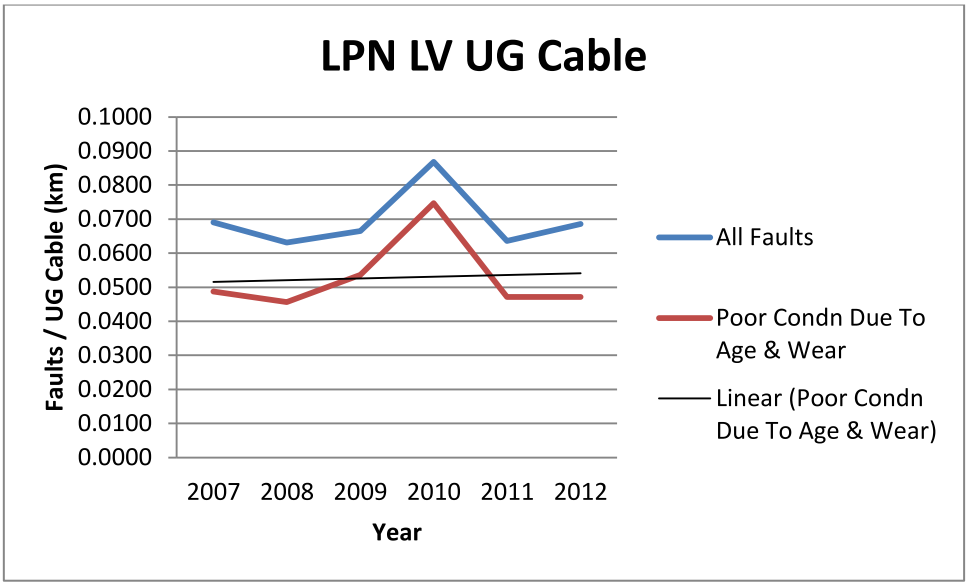


Figure 72 – Fault trends of LV underground cable

Source: UKPN Faults Cube

Appendix 4 – WLC Case Studies

Whole life cost description	**132kV Fluid Filled Cable**
Starting assumption (same for all scenarios)	It is assumed the 132kV Fluid Filled Cable is 60 years old at the beginning of the scenario, that the current replacement cost is £1.3M per km and that it has an average useful operating life of 80 years. The average life used for a solid cable is 100 years.

Scenario 1	End of life of a 132 kV Fluid Filled Cable with a replacement Solid Cable purchased at 70 years
Assumptions specific to this scenario	60 year old fluid filled cable requiring £1k of inspection and maintenance activity per annum per km

Description of costs/(income) items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Totals
Notional purchase cost of a 60 year fluid filled cable (1km) (i.e.: 20 years remaining service life)	300																														300
Annual inspection & maintenance costs of initial fluid filled cable	1	1	1	1	1	1	1	1	1	1																					10
Purchase of replacement cable in year 10 (Solid Cable Installed)										1,200																					1,200
Annual inspection & maintenance costs of replacement cable (which will be solid)																															0
Residual value of replacement solid cable at end of scenario (i.e.: 80 years remaining life)																														-1,040	-1,040
Net cash flow	301	1	1	1	1	1	1	1	1	1201	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1040	470

Discount rate: Select 6.85%	6.85%
Discounted whole life cost	764

Scenario 2	End of life of a 132 kV Fluid Filled Cable with a replacement Solid Cable purchased at end of life
Assumptions specific to this scenario	60 year old fluid filled cable requiring £1k of inspection and maintenance activity per annum per km

Description of costs/(income) items	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24	Year 25	Year 26	Year 27	Year 28	Year 29	Year 30	Totals
Notional purchase cost of a 60 year old fluid filled cable (i.e.: 20 years remaining service life)	300																														300
Annual inspection & maintenance costs of initial fluid filled cable	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1											20
Purchase of replacement cable in year 20 (Solid Cable Installed)																				1,200											1,200
Annual inspection & maintenance costs of replacement cable (which will be solid)																															0
(blank)																															0
(blank)																															0
Residual value of replacement solid cable at end of scenario (i.e.: 90 years remaining life)																														-1,040	-1,040
Net cash flow	301	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1201	0	0	0	0	0	0	0	0	0	-1040	480

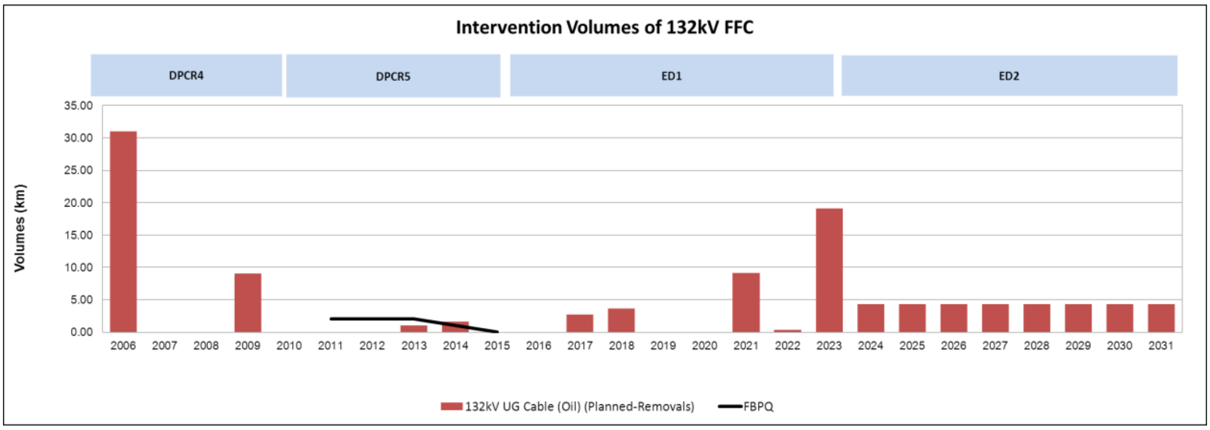
Discount rate: Select 6.85%	6.85%
Discounted whole life cost	468

Appendix 5 – NLRE Expenditure Plan

132kV fluid-filled cables volumes:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
132kV UG Cable (Oil) FBPQ (Removals only)						2.00	2.00	2.00	1.00	0.00
132kV UG Cable (Oil) (Planned-Removals)	31.00	0.00	0.00	9.00	0.00	0.00	0.00	1.00	1.60	0.00

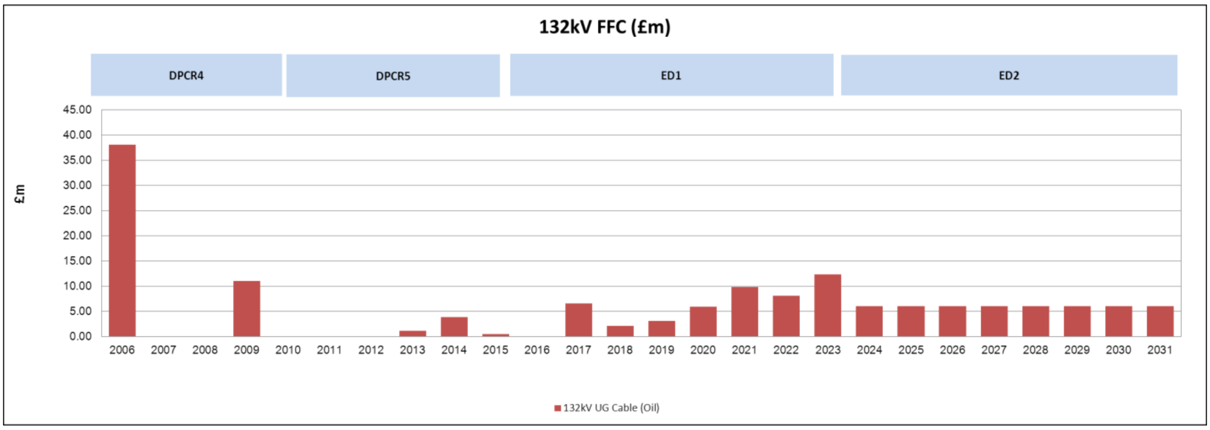
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Oil) FBPQ (Removals only)																
132kV UG Cable (Oil) (Planned-Removals)	0.00	2.70	3.60	0.00	0.00	9.10	0.30	19.10	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35



132kV fluid-filled cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
132kV UG Cable (Oil)	38.11	0.00	0.00	11.06	0.00	0.00	0.00	1.23	3.86	0.51

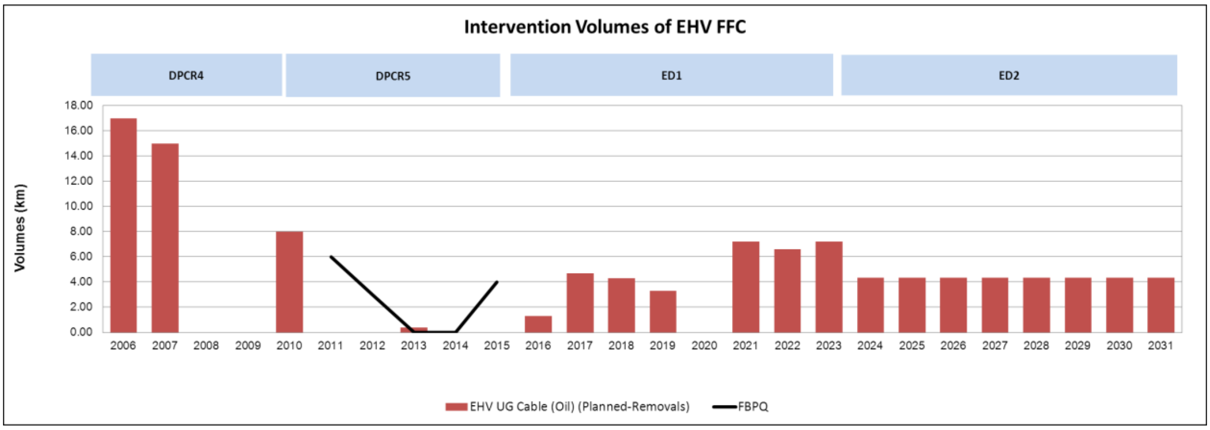
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Oil)	0.00	6.60	2.14	3.19	5.97	9.89	8.15	12.42	6.05	6.05	6.05	6.05	6.05	6.05	6.05	6.05



EHV fluid-filled cables volumes:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
EHV UG Cable (Oil) FBPQ (Removals only)						6.00	3.00	0.00	0.00	4.00
EHV UG Cable (Oil) (Planned-Removals)	17.00	15.00	0.00	0.00	8.00	0.00	0.00	0.40	0.00	0.00

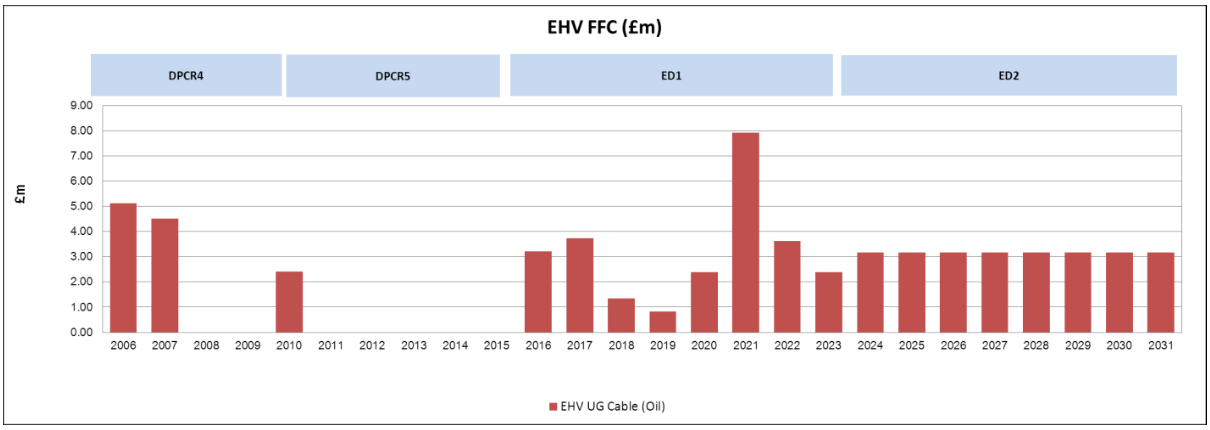
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Oil) FBPQ (Removals only)																
EHV UG Cable (Oil) (Planned-Removals)	1.30	4.70	4.30	3.30	0.00	7.20	6.60	7.20	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33



EHV fluid-filled cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
132kV UG Cable (Oil)	38.11	0.00	0.00	11.06	0.00	0.00	0.00	1.23	3.86	0.51

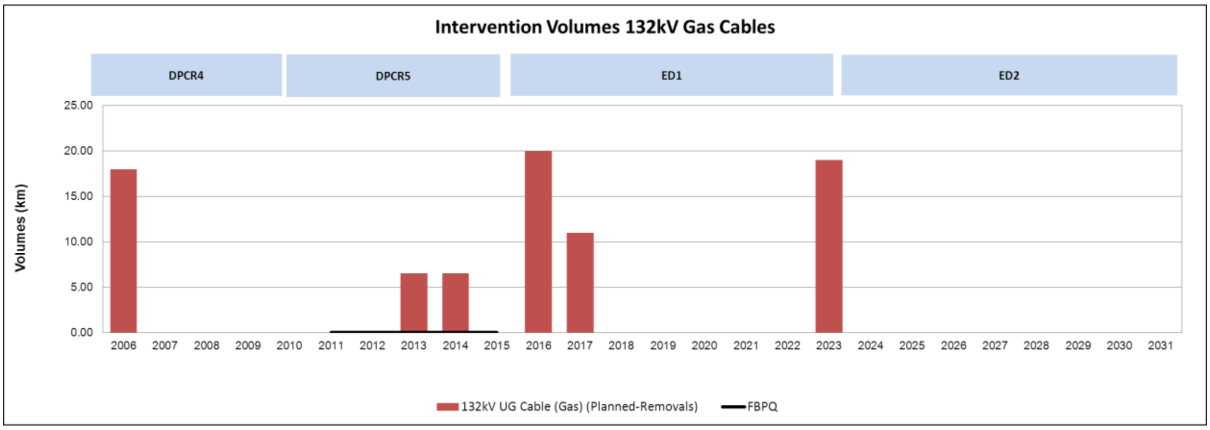
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Oil)	0.00	6.60	2.14	3.19	5.97	9.89	8.15	12.42	6.05	6.05	6.05	6.05	6.05	6.05	6.05	6.05



132kV gas cables volumes:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
132kV UG Cable (Gas) FBPQ (Removals only)						0.00	0.00	0.00	0.00	0.00
132kV UG Cable (Gas) (Planned-Removals)	18.00	0.00	0.00	0.00	0.00	0.00	0.00	6.50	6.50	0.00

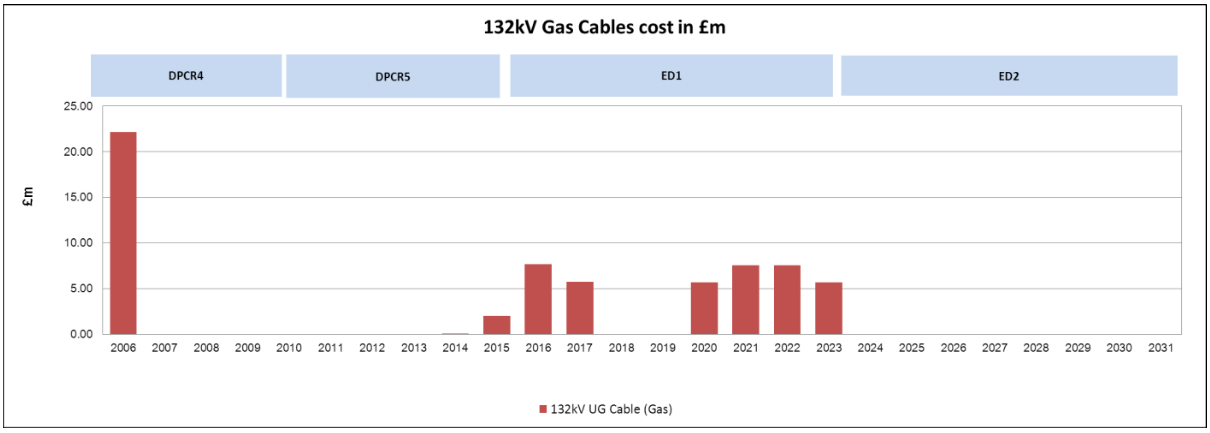
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Gas) FBPQ (Removals only)																
132kV UG Cable (Gas) (Planned-Removals)	20.00	11.00	0.00	0.00	0.00	0.00	0.00	19.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



132kV gas cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
132kV UG Cable (Gas)	22.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	1.98

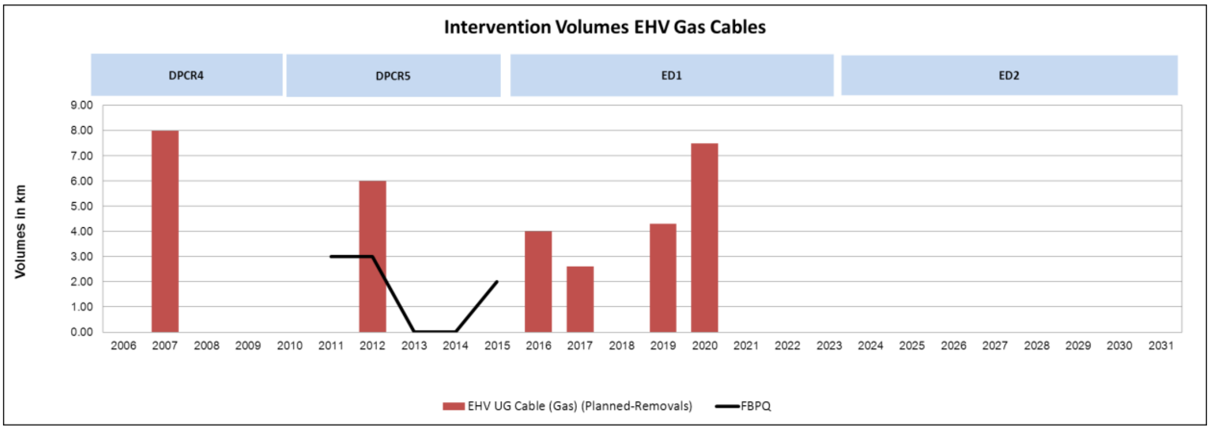
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Gas)	7.68	5.72	0.00	0.00	5.65	7.53	7.53	5.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



EHV gas cables volumes:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
EHV UG Cable (Gas) FBPQ (Removals only)						3.00	3.00	0.00	0.00	2.00
EHV UG Cable (Gas) (Planned-Removals)	0.00	8.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00

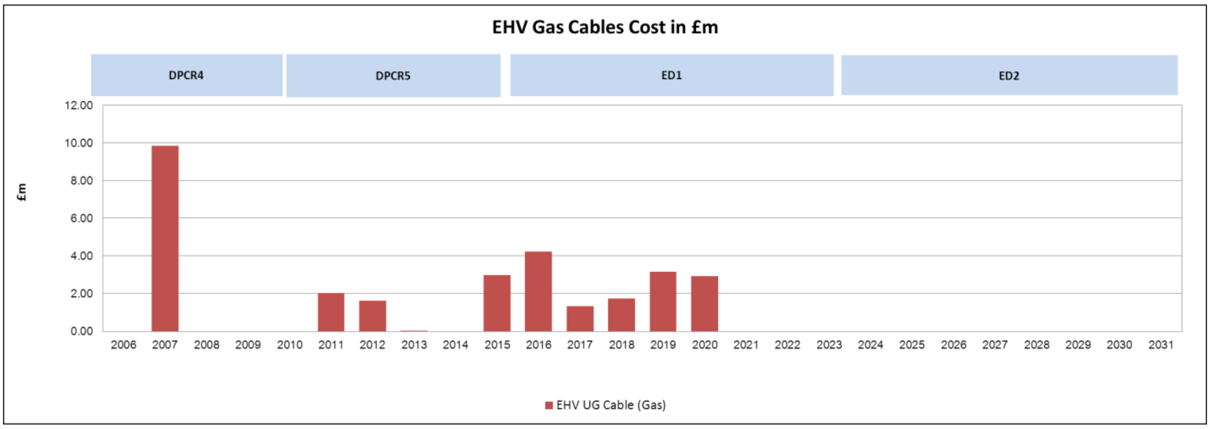
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Gas) FBPQ (Removals only)																
EHV UG Cable (Gas) (Planned-Removals)	4.00	2.60	0.00	4.30	7.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



EHV gas cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
EHV UG Cable (Gas)	0.00	9.83	0.00	0.00	0.00	2.03	1.63	0.02	0.00	2.98

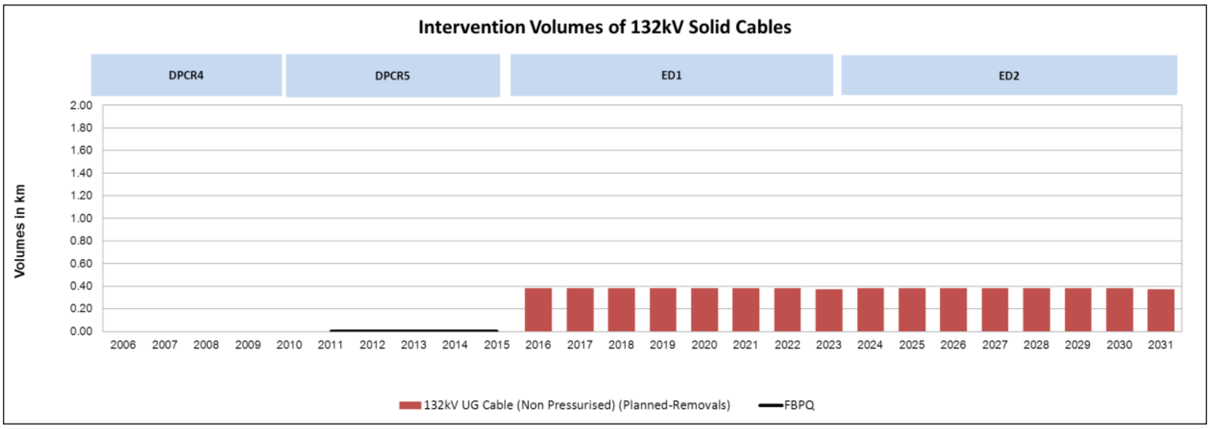
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Gas)	4.22	1.34	1.73	3.17	2.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



132kV solid cables volumes:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
132kV UG Cable (Non Pressurised) FBPQ (Removals only)						0.00	0.00	0.00	0.00	0.00
132kV UG Cable (Non Pressurised) (Planned-Removals)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

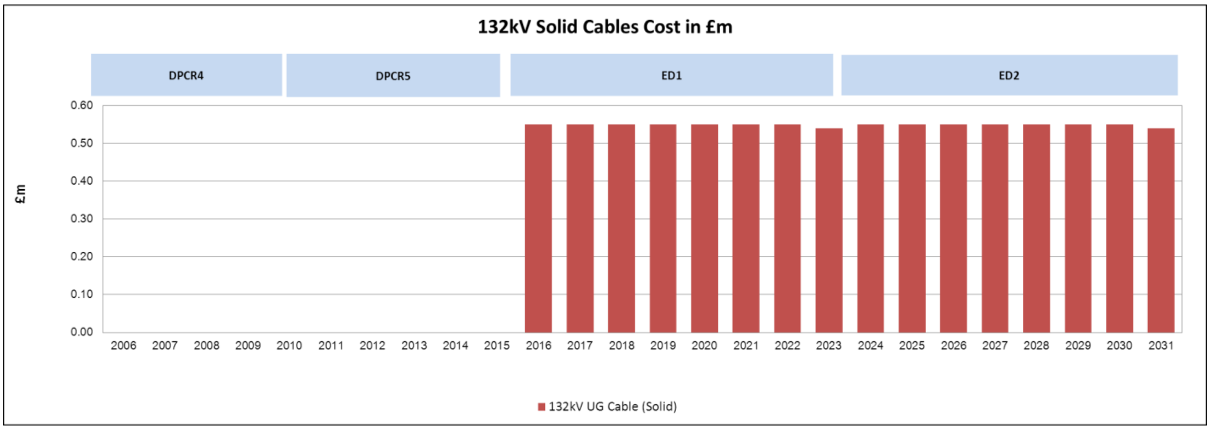
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Non Pressurised) FBPQ (Removals only)																
132kV UG Cable (Non Pressurised) (Planned-Removals)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40



132kV solid cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
132kV UG Cable (Solid)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

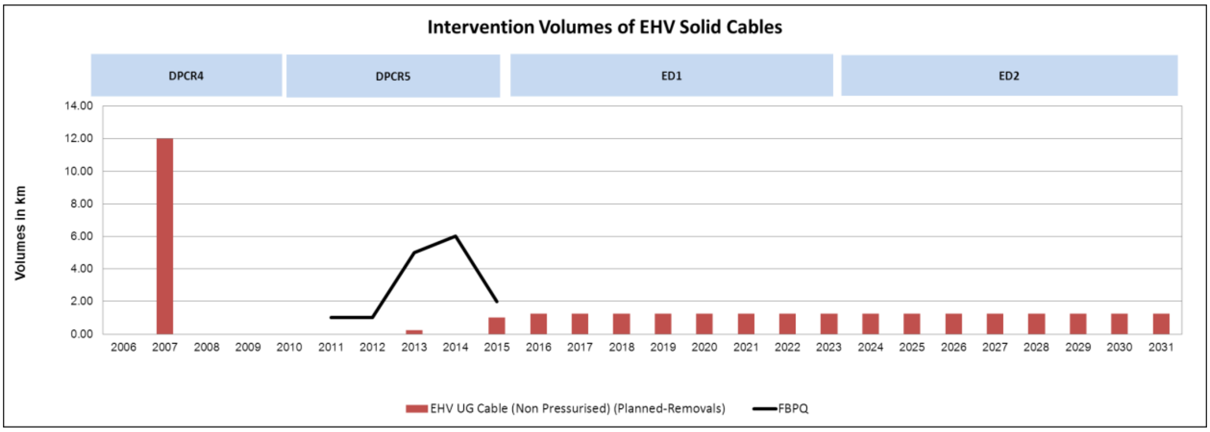
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Solid)	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.54	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.54



EHV solid cables volumes:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
EHV UG Cable (Non Pressurised) FBPQ (Removals only)						1.00	1.00	5.00	6.00	2.00
EHV UG Cable (Non Pressurised) (Planned-Removals)	0.00	12.00	0.00	0.00	0.00	0.00	0.00	0.22	0.00	1.00

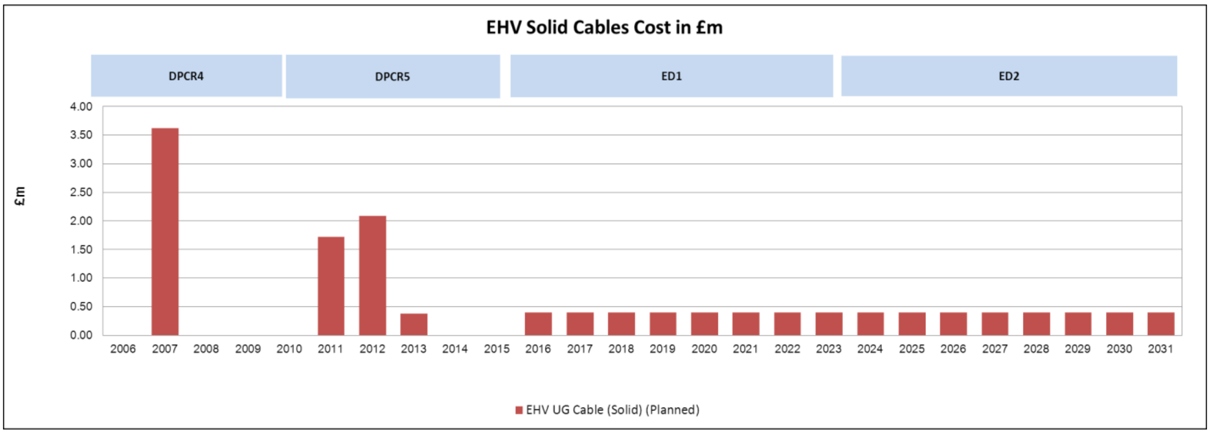
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Non Pressurised) FBPQ (Removals only)																
EHV UG Cable (Non Pressurised) (Planned-Removals)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25



EHV solid cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
EHV UG Cable (Solid) (Planned)	0.00	3.62	0.00	0.00	0.00	1.72	2.08	0.38	0.00	0.00

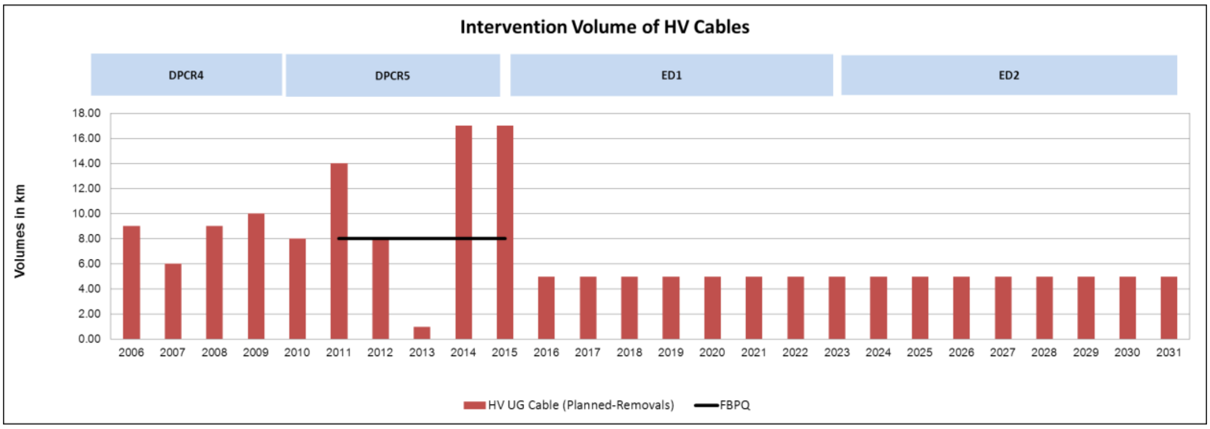
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Solid) (Planned)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40



HV solid cables volume:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
HV UG Cable FBPQ (Planned-Removals only)						8	8	8	8	8
HV UG Cable (Planned-Removals)	9.00	6.00	9.00	10.00	8.00	14.00	8.00	0.99	17.00	17.00

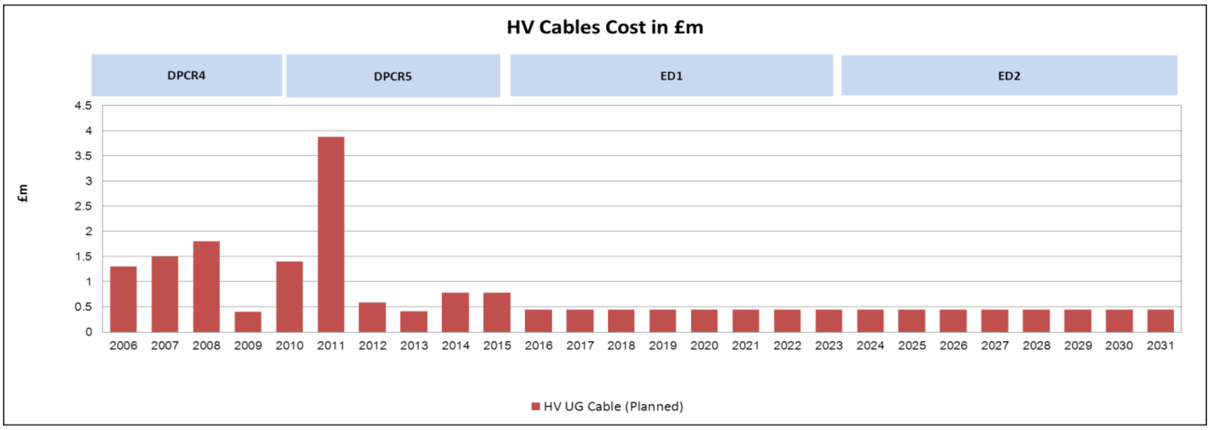
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
HV UG Cable FBPQ (Planned-Removals only)																
HV UG Cable (Planned-Removals)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00



HV solid cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
HV UG Cable (Planned)	1.3	1.5	1.8	0.4	1.4	3.88	0.58	0.41	0.78	0.78

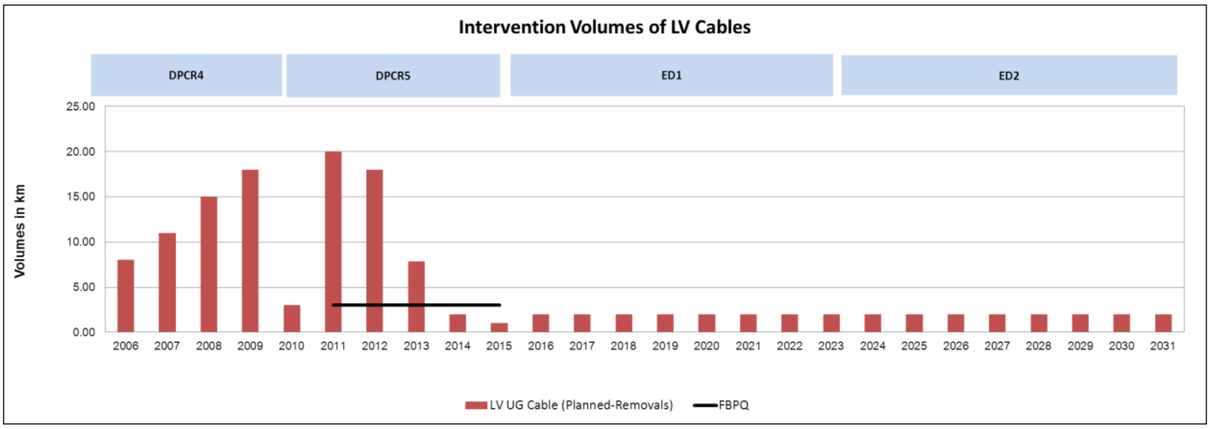
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
HV UG Cable (Planned)	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45



LV solid cables volume:

Volumes	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
LV UG Cable FBPQ (Removals only)						3.00	3.00	3.00	3.00	3.00
LV UG Cable (Planned-Removals)	8.00	11.00	15.00	18.00	3.00	20.00	18.00	7.83	2.00	1.00

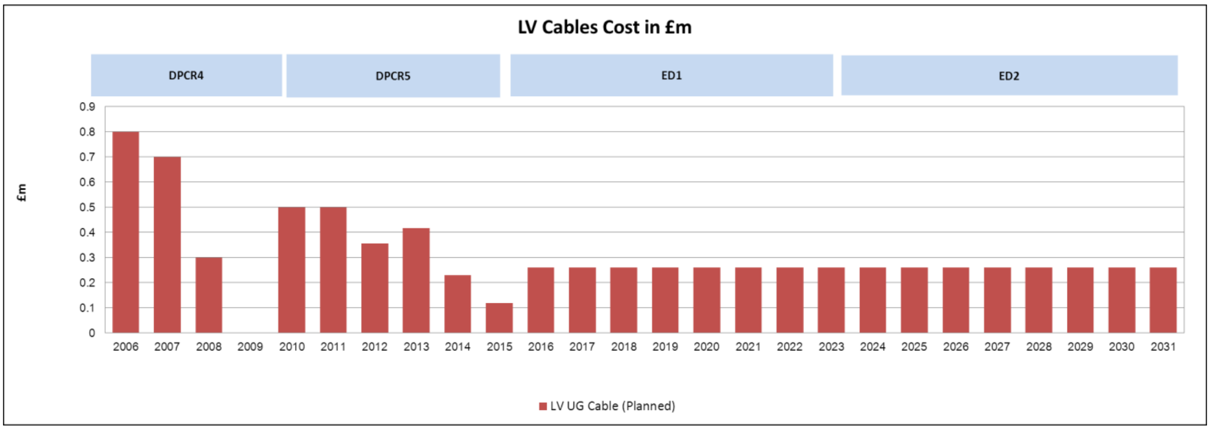
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
LV UG Cable FBPQ (Removals only)																
LV UG Cable (Planned-Removals)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00



LV solid cables cost:

Investment £'m	DPCR4 (FBPQ)					DPCR5 (Actual and Forecast from RIGs)				
Year end	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
LV UG Cable (Planned)	0.8	0.7	0.3	0	0.5	0.50	0.36	0.42	0.23	0.12

Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
LV UG Cable (Planned)	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26



FFC joints and ancillary equipment

Intervention volumes								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace aluminium cable joint plumbs	3	3	3	3	3	3	3	3
Install remote pressure-monitoring equipment	15	15	15	15	15	15	12	0
Replace pressurised cables ancillary equipment (tanks, gauges, etc)	8	8	8	8	8	8	8	8

Intervention cost in £m								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace aluminium cable joint plumbs	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Install remote pressure-monitoring equipment	0.15	0.15	0.15	0.15	0.15	0.15	0.12	0.00
Replace pressurised cables ancillary equipment (tanks, gauges, etc)	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19

Solid cable joints

Intervention volumes								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace 11kV Transition Joints	200	200	200	200	200	200	200	200

Intervention cost in £m								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**2021**	**21/22**	**22/23**
Replace 11kV Transition Joints	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43

Appendix 6 – Sensitivity Analysis

Sensitivity Analysis

Asset Risk and Prioritisation Model for LPN 132kV UG Cable (Oil) (written by Decision Lab)

Introduction

This is a report on the sensitivity analysis conducted on the Asset Risk and Prioritisation (ARP) Model, developed by EA Technology and used to support the asset replacement and investment strategy for LPN 132kV UG Cable (Oil), which is included in the ED1 plan.

The objective is to understand how the Health Index profile of assets may change if the average asset life does not turn out as predicted.

An input to the ARP model is the starting asset population in each Health Index, which is different in each region. Therefore, sensitivity analysis has been done on a region-by-region basis.

The Asset Risk and Prioritisation Model

The ARP model uses database information about each individual asset, and models many parameters to predict the Health Index of each asset in the future. Significant parameters are age, location, loading and current average asset life.

Sensitivity Analysis

Variation in average asset life can occur, but this is significantly less than the variation in individual asset lives.

Standard average asset lives are used in the ARP model. These are 70, 80 and 95 years. In 2012, about 81% had a current average asset life of 80 years and about 19% of 70 years. This study covered the full population of LPN 132kV UG Cable (Oil).

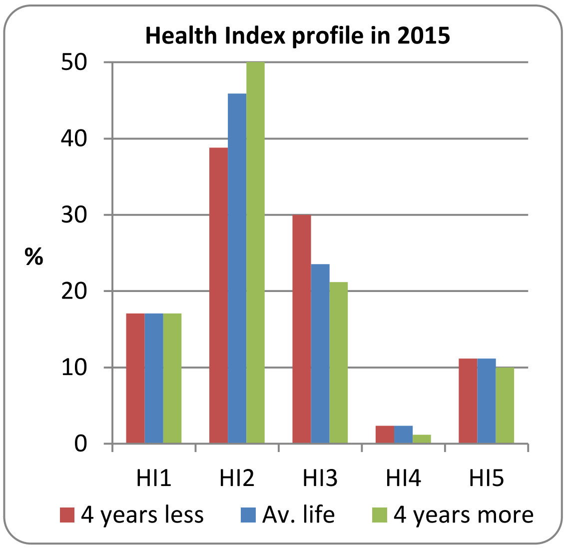
Using 2012 asset data and the replacement plans up to 2023, the ARP model was used to predict the Health Index of each asset at the beginning and end of ED1. This was then repeated, varying each current average asset life by +/- 1, 2 and 4 years.

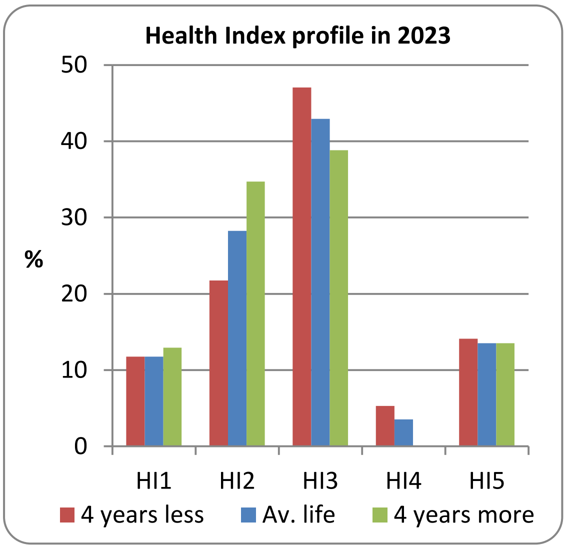
All results are shown below as the percentages of the population.

Average life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	17.1	38.8	30.0	2.4	11.2
-2	17.1	44.7	24.7	2.4	11.2
-1	17.1	45.9	23.5	2.4	11.2
0	17.1	45.9	23.5	2.4	11.2
1	17.1	45.9	25.9	0.0	11.2
2	17.1	47.6	24.1	0.0	11.2
4	17.1	50.6	21.2	1.2	10.0

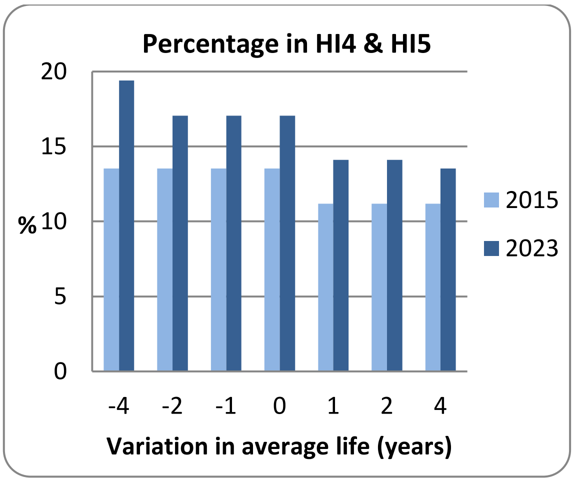
Average life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	11.8	21.8	47.1	5.3	14.1
-2	11.8	24.1	47.1	2.9	14.1
-1	11.8	27.1	44.1	2.9	14.1
0	11.8	28.2	42.9	3.5	13.5
1	12.9	28.8	44.1	0.6	13.5
2	12.9	28.8	44.1	0.6	13.5
4	12.9	34.7	38.8	0.0	13.5

As the percentages above are rounded, the sum of a row may be 0.2% above or below 100%. The upper and lower and current average asset life cases are charted below.





For all cases modelled, the sums of assets in Health Indices HI4 and HI5 are plotted below.



The results show:

- A variation in asset life will affect the proportions of HI4 and HI5 assets in 2015 and 2023.
- In 2015, if average asset life is four years longer, the combined proportion of HI4 and HI5 will reduce from 13.6% to 11.2%; but if four years shorter, it will increase to 13.6%.
- In 2023, if average asset life is four years longer, the combined proportion of HI4 and HI5 assets will reduce from 17.0% to 13.5%; but if four years shorter, it will increase to 19.4%.

Conclusion

The ED1 replacement plan for LPN 132kV UG Cable (Oil) is slightly sensitive to a variation in average asset life of up to four years.

Sensitivity Analysis

Asset Risk and Prioritisation Model for LPN EHV UG Cable (Oil) (written by Decision Lab)

Introduction

This is a report on the sensitivity analysis conducted on the Asset Risk and Prioritisation (ARP) Model, developed by EA Technology and used to support the asset replacement and investment strategy for LPN EHV UG Cable (Oil), which is included in the ED1 plan.

The objective is to understand how the Health Index profile of assets may change if the average asset life does not turn out as predicted.

An input to the ARP model is the starting asset population in each Health Index, which is different in each region. Therefore, sensitivity analysis has been done on a region-by-region basis.

The Asset Risk and Prioritisation Model

The ARP model uses database information about each individual asset, and models many parameters to predict the Health Index of each asset in the future. Significant parameters are age, location, loading and current average asset life.

Sensitivity Analysis

Variation in average asset life can occur, but this is significantly less than the variation in individual asset lives.

Standard average asset lives are used in the ARP model. These are 70, 80, 85 and 95 years. In 2012, about 84% had a current average asset life of 80 years and about 11% of 95 years. This study covered the full population of LPN EHV UG Cable (Oil).

Using 2012 asset data and the replacement plans up to 2023, the ARP model was used to predict the Health Index of each asset at the beginning and end of ED1. This was then repeated, varying each current average asset life by +/- 1, 2 and 4 years.

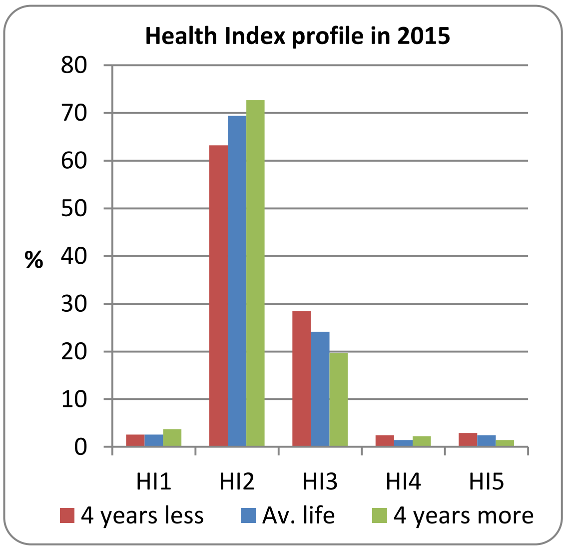
All results are shown below as the percentages of the population.

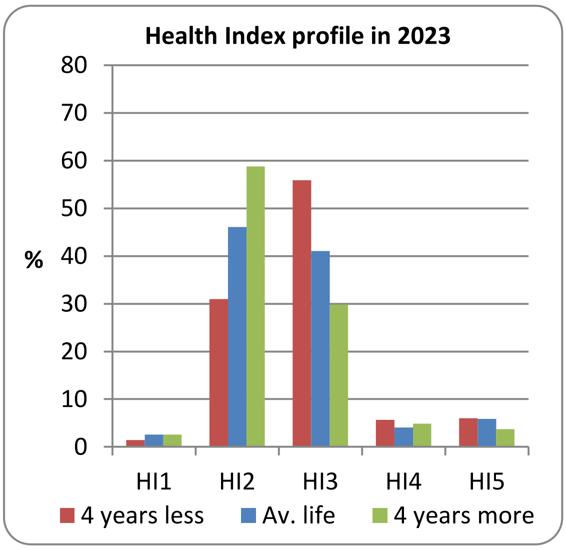
Average life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	2.6	63.2	28.5	2.4	2.9
-2	2.6	66.0	26.1	2.9	2.4
-1	2.6	67.6	24.8	2.3	2.4
0	2.6	69.4	24.1	1.5	2.4
1	2.6	69.5	23.9	1.3	2.4
2	2.9	70.4	22.8	1.5	2.3
4	3.7	72.6	19.7	2.3	1.5

Average life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	1.5	30.9	55.9	5.7	6.0
-2	1.5	36.5	50.5	5.5	6.0
-1	2.6	45.6	40.1	5.5	6.0
0	2.6	46.1	41.0	4.1	5.9
1	2.6	51.5	36.2	4.4	5.4
2	2.6	55.7	32.4	4.6	4.7
4	2.6	58.8	29.8	4.9	3.7

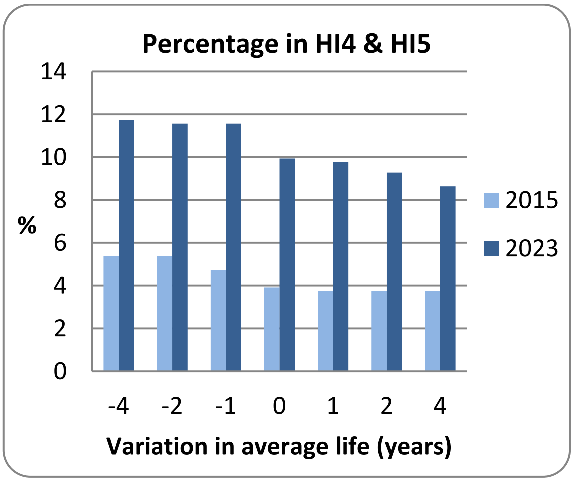
As the percentages above are rounded, the sum of a row may be 0.2% above or below 100%.

The upper and lower and current average asset life cases are charted below.





For all cases modelled, the sums of assets in Health Indices HI4 and HI5 are plotted below.



The results show:

- A variation in asset life will affect the proportions of HI4 and HI5 assets in 2015 and 2023.
- In 2015, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 3.9% to 3.8%; but if four years shorter, it will increase to 5.3%.
- In 2023, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 10.0% to 8.6%; but if four years shorter, it will increase to 11.7%.

Conclusion

The ED1 replacement plan for LPN EHV UG Cable (Oil) is fairly insensitive to a variation in average asset life of up to four years.

Appendix 7 – Named Schemes

Fluid-filled cables

Ref	Project ID	DNO	Description	Volume (km)	Cost (£m)
1.29.01.7947	7947	LPN	Back Hill-Kingsway St (Circuit 1A) - 33kV FFC Replacement	1.30	0.45
1.29.01.7946	7946	LPN	Barking West 33kV-Axe St (Circuit 1-A) - 33kV FFC Replacement	0.50	0.17
1.29.02.7955	7955	LPN	Beddington - Sydenham (Circuit 2 A-B) - 132kV FFC replacement	9.10	12.63
1.29.02.7954	7954	LPN	Bromley Grid-Hurst (Circuit 1-B-C & Circuit 2 B-C) - 132kV FFC Replacement	8.10	11.24
1.29.01.7945	7945	LPN	Buckhurst Hill to Fairlop Rd (Circuit 3-C-F) - 33kV FFC Replacement	3.30	1.14
1.29.02.7953	7953	LPN	Deptford Grid 132kV-Bengeworth RD 33kV(Circuit 1-F) - 132kV FFC Replacement	2.70	3.75
1.29.02.4096	4096	LPN	Hackney-Exeter Rd 66kV-Replace FFC (Mollerhoj)	4.30	1.96
1.29.02.7957	7957	LPN	Lodge Rd 66kV-Duke Street (Circuit 4-A) - 66kV FFC Replacement	2.00	2.56
1.29.02.7950	7950	LPN	Moscow Rd 22kV-Townmead Rd (Circuit 1-A,Circuit M2, Circuit 1-L-M1, Circuit 2-A & Circuit M2) - 66kV fluid filled cable replacement	2.00	2.56
1.29.02.7958	7958	LPN	New Cross 66kV-South Bank (Circuit 1B) - 66kV FFC replacement	2.20	2.82
1.29.02.7951	7951	LPN	New Cross- South Bank (Circuit 3B & Circuit 5A) - 66kV FFC replacement	5.20	6.66
1.29.01.7943	7943	LPN	Redbridge Supergrid 33kV-Grove Lodge (Circuit 2-B) - 33kV FFC Replacement	1.50	0.52
1.29.01.7942	7942	LPN	Redbridge Supergrid 33kV-Perth Road 33kV (Circuit 3-B)- 33kV FFC Replacement	1.20	0.41
1.29.02.7952	7952	LPN	St John’s Wood 132kV-Aberdeen Place-B (Circuit 5A & Circuit 5B) - 132kV fluid filled cable replacement	0.30	0.42
1.29.01.7944	7944	LPN	Sydenham Park 33kV-Churchfield (Circuit 4-A) - 33kV FFC Replacement	2.30	0.79
1.29.02.7949	7949	LPN	Wandsworth 66kV-Carslake (Circuit 3-B) - 66kV FFC replacement	1.60	2.05
1.29.02.7956	7956	LPN	Wandsworth 66kV-Lombard (Circuit 2-B) - 66kV FFC replacement	0.90	1.15
1.29.02.7948	7948	LPN	Wimbledon 132kV SEC 1&2-Bengeworth Rd 33 (Circuit 2-J) - 132kV FFC Replacement	3.60	4.99
1.29.02.7939	7939	LPN	Wimbledon 132kV SEC 1&2-Kingston 132kV (Circuit 1-B,Circuit 2-B & Circuit 2-C) - 132kV FFC replacement	11.00	15.35
1.29.01.7940	7940	LPN	Wimbledon Grid-Trinity Crescent (Circuit 2-A) - 33kV FFC Replacement	2.90	1.00
1.29.01.7941	7941	LPN	Wimbledon-Merton (Circuit 3-A) - 33kV FFC Replacement	3.40	1.17

Gas cables

Ref	Project ID	DNO	Description	Volume (km)	Cost (£m)
1.07.07.8401	8401	LPN	Eltham-Sydenham 132kV gas cable replacement	19.00	26.36
1.07.02.2587	2587	LPN	Hackney to Exeter Road 66kV gas cable replacement	4.30	2.07
1.07.07.8301	8301	LPN	Hackney-King Henrys Walk 66kV gas cable scheme	4.00	2.56
1.07.07.8303	8303	LPN	Norroy Rd Tee Point-Barnes 66kV gas cable replacement	3.50	4.48
1.07.90.8305	8305	LPN	Perth Rd-Fairlop 33kV gas cable replacement	4.00	1.38
1.07.07.8304	8304	LPN	Wandsworth Grid-Norroy Rd Tee Point 66kV gas cable replacement	2.60	2.91
1.07.07.8400	8400	LPN	Barking-Brunswick Wharf 132kV gas cable replacement	11.00	13.35
1.07.07.8300	8300	LPN	Barking-West Ham 132kV gas cable (decommissioning)	20.00	0.05

Solid cables

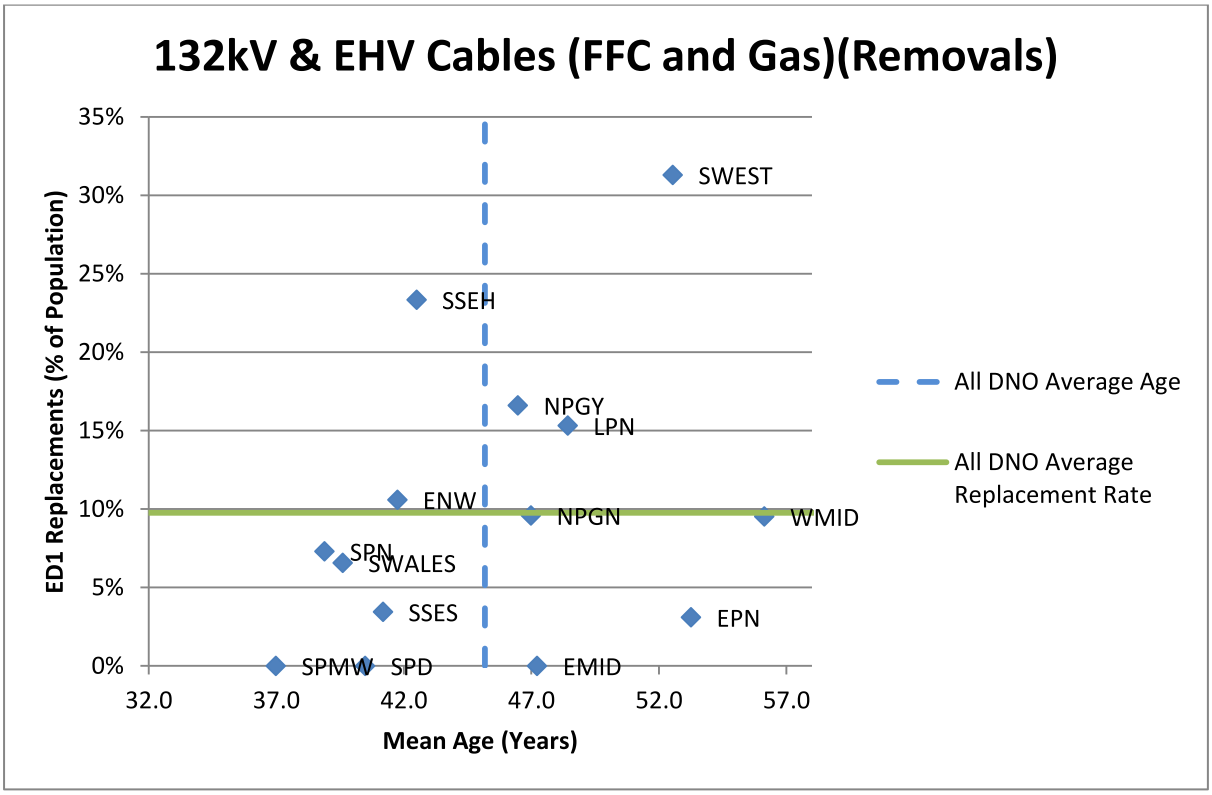
Ref	Project ID	DNO	Description	Volume (km)	Cost (£m)
1.07.01.8531	8531	LPN	ED1 33kV solid cable replacement provision	5	1.48
1.07.02.8532	8532	LPN	ED1 66kV solid cable replacement provision	5	1.73
1.07.02.8407	8407	LPN	ED1 132kV solid cable replacement provision	3	4.39
1.18.01.9404	9404	LPN	Replace HV cable (planned)	40	3.56
1.18.03.9405	9405	LPN	Replace LV cable (planned)	16	2.06

Appendix 8 – Output NAMP/ED1 Business Plan Data Tables

Outputs	**Asset Stewardship reports**										**RIG Table**										
Investment description	**NAMP Line**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**2021/22**	**2022/23**	**Total**	**RIG Table**	**RIG Row**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**2021/22**	**2022/23**	**Total**
132kV FFC replacement	1.29.02	0.00	2.70	3.60	0.00	0.00	9.10	0.30	19.10	34.80	CV3	221	-	2.70	3.60	-	-	9.10	0.30	19.10	**34.80**
EHV FFC replacement	1.29.01	1.30	4.70	4.30	3.30	0.00	7.20	6.60	7.20	34.60	CV3	191	1.30	0.50	-	3.30	-	-	5.00	6.30	**16.40**
											CV3	194	-	4.20	4.30	-	-	7.20	1.60	0.90	**18.20**
132kV Gas replacement	1.07.07	20.00	11.00	0.00	0.00	0.00	0.00	0.00	19.00	50.00	CV3	222	20.00	11.00	-	-	-	-	-	-	**31.00**
											V4a	94	-	-	-	-	-	-	-	19.00	**19.00**
EHV Gas replacement	1.07.90	4.00	2.60	0.00	4.30	7.50	0.00	0.00	0.00	18.40	CV3	192	-	-	-	-	4.00	-	-	-	**4.00**
											CV3	195	4.00	2.60	-	4.30	3.50	-	-	-	**14.40**
Replace 132kV solid cable	1.07.02	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.37	3.00	CV3	220	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.37	**3.00**
Replace EHV solid cable (planned)	1.07.01	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	10.00	CV3	190	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	**5.00**
											CV3	193	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	**5.00**
Replace HV cable (planned)	1.18.01	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	40.00	CV3	157	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	**40.00**
Replace LV cable (planned)	1.18.03	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	16.00	CV3	137	-	-	-	-	-	-	-	-	**0.00**
											CV3	138	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	**1.71**
											CV3	139	1.79	1.79	1.79	1.79	1.79	1.79	1.79	1.79	**14.29**
Total		**33.93**	**29.63**	**16.53**	**16.23**	**16.13**	**24.93**	**15.53**	**53.92**	**206.80**			**33.93**	**29.63**	**16.53**	**16.23**	**16.13**	**24.93**	**15.53**	**53.92**	**206.80**

Source: 19th February 2014 NAMP Table O
21st February 2014 ED1 Business Plan Data Tables

Appendix 9 – Efficiency benchmarking with other DNO's



This graph shows how in LPN there is a higher level of investment than average due to the strategy to reduce leakage rates in LPN downwards towards the industry average.

Appendix 10 – Material changes since the July 2013 ED1 submission

This document now only includes costs relevant to *asset replacement (CV3)* and. Unplanned replacements (NAMP lines 2.50) are now included in the *Inspection and Maintenance Asset Stewardship reports.*

There are no changes to our proposed fluid filled cables (FFC) investment at 132kV and EHV as the business objective throughout the planning process for ED1 was to invest at a level that will reduce leakage rates in LPN downwards towards the industry average.

Changes between the July 2013 submission and the March 2014 re-submission are summarised and discussed below.

Asset type	Action	Change type	2013	2014	Difference (Reduction)	Comment
6.6/11kV UG Cable	Replace	Volume (Addition)	40km	40km	-	-
		Volume (Removals)	120km	40km	80 (no. of services)	-
		Investment (£m)	£12.55m	£10.38m	£2.17m	-
		UCI (£k)	£313.8k	£259.4k	£54.4	-

Source: ED1 Business Plan Data Tables following the OFGEM Question and Answer Process / 21st February 2014 ED1Business Plan Data Tables

6.6/11kV UG Cable

Correction has been made in 6.6/11kV solid cable removal volumes as redundant HV services (no. of services) removal volumes were reported by mistake in the July 2013 ED1 submission.

Appendix 11 – Case Study

Summary

The fluid-filled cable repair on the Back Hill – Fisher Street No4 circuit in 2011 cost in excess of £150k to repair.

Particular issues encountered on this job were the depth of the excavation – 7 metres (23ft) – the requirement to close the entire road for an extended period and the requirement to stop work whenever an examination was in progress at the adjacent College for the Law Society. Such issues are typical for work of this nature anywhere in Central London.

Discussion

Fisher Street is a four-transformer 33/11kV primary substation fed via four 33kV fluid-filled cables from Back Hill. The circuits are 1km in length and were installed in 1960.

In February 2011, following leaks on the No4 circuit for some time, the leak rate increased significantly to a point where an urgent leak location and repair was necessary.

UK Power Networks employs two primary methods of leak location. The first technology is a system developed by EA Technology that uses the pressure drop at either end of the fluid-filled cable circuit to calculate an approximate leak location position. This is often accurate to within 50 yards. UK Power Networks also uses the PFT Cable Sniffer device, which is able to detect a unique tracer added to the cable oil to provide a more accurate position.

Using these techniques, the cable leak was determined to be somewhere in the vicinity of Princeton Street in London WC1. The road is a narrow two-way street containing offices, shops and the College for the Law Society. The area is part of London's 'legal district' – home to many of the top lawyers and barristers in the country.

Due to the depth of the cable at this point of the route, three excavations and 'cable freezes' were required to determine the precise position of the fault.

In order to repair the fault, negotiations were required with the London Borough of Camden to close the road and to rent all of the affected parking bays. The excavation required a repair of the cable (refer to the pictures at the end of the case study) and was 7 metres (23ft) deep.

At the time of the fault, examinations were taking place at the adjacent Law Society. It was agreed with them that works would not take place during the times of the examinations due to the noise disturbance. This increased the duration and cost of the fault repair.

The lead sheath on the cable was found to be crystallised and a 10-metre section of cable required replacement.

Figure 73 – Excavation required for fluid-filled cable repair at the Back Hill Fisher Street No 4 circuit

Figure 74 – The excavation was 7 metres deep (23 feet) below the ground and required a significant excavation

Figure 75 – The lead sheath was found to be crystallised

Figure 76 – The replacement fluid-filled cable is delivered to site by a specialist contractor

Appendix 12 – Condition Information

Back Hill-Kingsway St 33kV FFC

Asset condition (Field report)

UNDERGROUND CABLES

Circuit title:	Backhill – Kingsway No:3				
Date of fault:	Dec 10 – Jan 11	Airline ref No:		Environment Agency incident No:	
Date of repair:	04 Jan 11	Report completed by:	Paul Crook Contact No: 07875116001		
Cable Section:	A	Voltage kV:	33kv	FFC , Gas or Solid	FFC
Location:	Hatton grd				
Cable construction:	3 core lead sheath				

Fault due to leaking from: Please X	Lead sheath Crystallised	x	Access constraints: Please X	Traffic-managed routes	x
	Reinforcing tape corrosion			Red Routes	
	CSA Sheath			Bridges	
	Plumbs			Tunnels/Cables/Services	x
	Sealing ends			Rail trackside	
	Connections			Arable land	
	Pipe-work			Restricted Hours working	
	Third party damage/other	x		Other – Landowner etc	

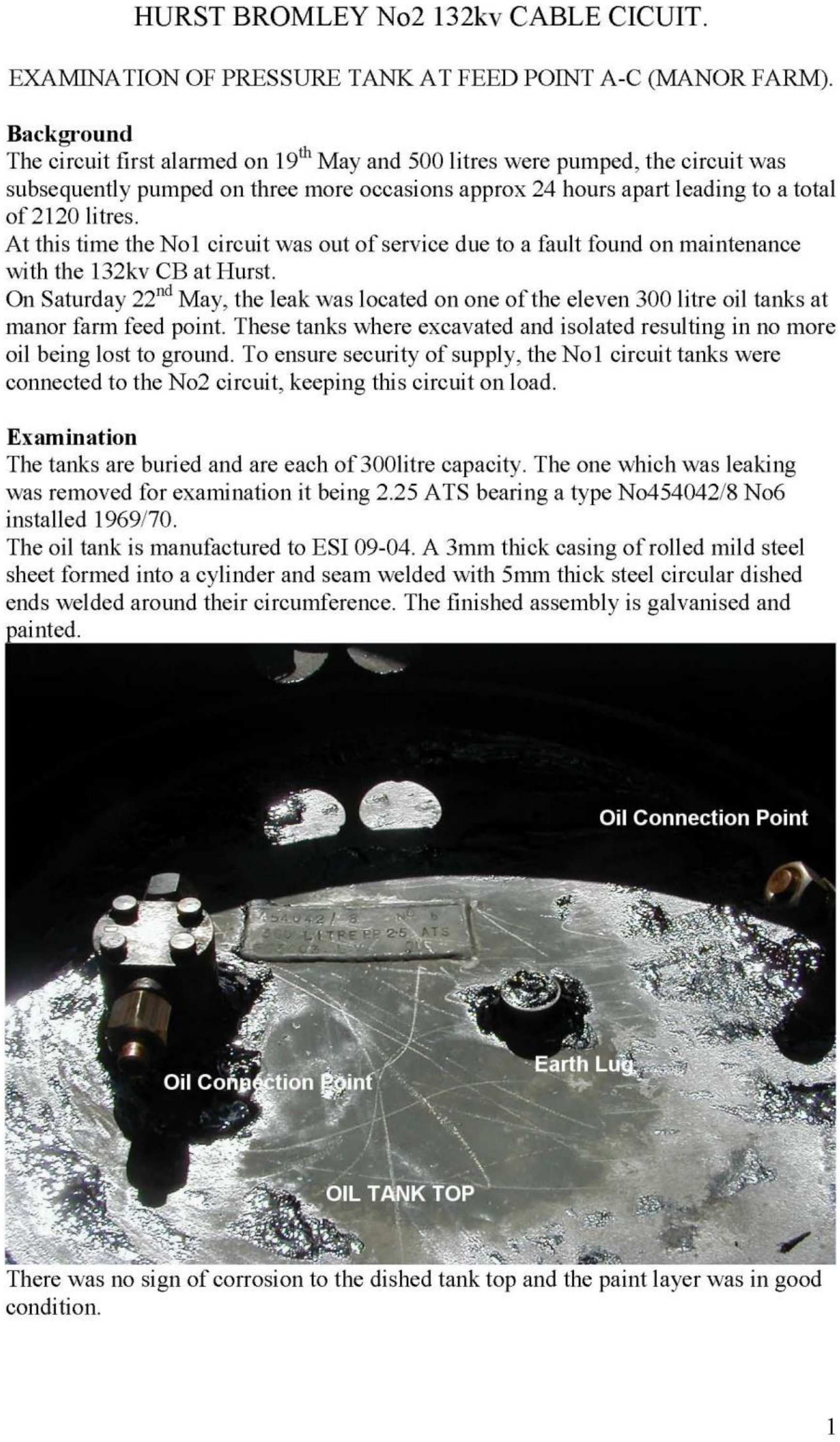
Additional:	SAP No	60578879	Photographic evidence attached	x
General comments, e.g. Fluid loss: Leak located by using PFT or Other: Type of repair/work undertaken: Estimate of cost of repair etc: Access difficulties, and any comments you consider relevant.	The Backhill – Kingsway circuits have a history of leaking. The no:3 circuit was connected to booster tanks to keep the pressure up. These boosters were also used for other circuits out of Backhill. So an average of 70 ltrs a week was feeding into this circuit. A EA technology leak location was performed along with a PFT location. The PFT was unsuccessful this time. The EA Tec was 10 mtrs out. The ground was disturbed by a new water main laid directly on top and along side the Backhill – Kingsway circuits along Hatton grd. The movement and small strikes on the cable along with the crystallised lead caused the fault/leak. When repairing the cable a small movement on the circuit caused a leak further on. This denotes crystallised lead. Jointer reported that the cable/lead was not in a very good condition.			

Thank you. The information you provide is invaluable in understanding the overall condition of the asset.

Please submit this electronically to Asset Management C/O ..... alan.archer@ukpowernetworks.co.uk

Backhill - Kings 3 Page 1 of 1

Bromley Grid-Hurst 132kV FFC:



HURST BROMLEY No2 132kv CABLE CICUIT.

EXAMINATION OF PRESSURE TANK AT FEED POINT A-C (MANOR FARM).

Background

The circuit first alarmed on 19th May and 500 litres were pumped, the circuit was subsequently pumped on three more occasions approx 24 hours apart leading to a total of 2120 litres.

At this time the No1 circuit was out of service due to a fault found on maintenance with the 132kv CB at Hurst.

On Saturday 22nd May, the leak was located on one of the eleven 300 litre oil tanks at manor farm feed point. These tanks where excavated and isolated resulting in no more oil being lost to ground. To ensure security of supply, the No1 circuit tanks were connected to the No2 circuit, keeping this circuit on load.

Examination

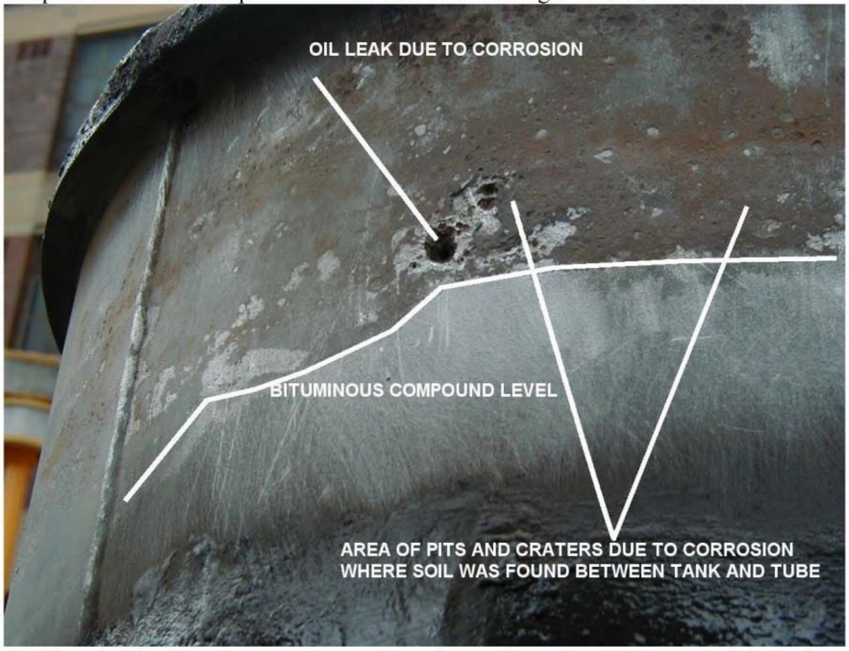
The tanks are buried and are each of 300litre capacity. The one which was leaking was removed for examination it being 2.25 ATS bearing a type No454042/8 No6 installed 1969/70.

The oil tank is manufactured to ESI 09-04. A 3mm thick casing of rolled mild steel sheet formed into a cylinder and seam welded with 5mm thick steel circular dished ends welded around their circumference. The finished assembly is galvanised and painted.

There was no sign of corrosion to the dished tank top and the paint layer was in good condition.

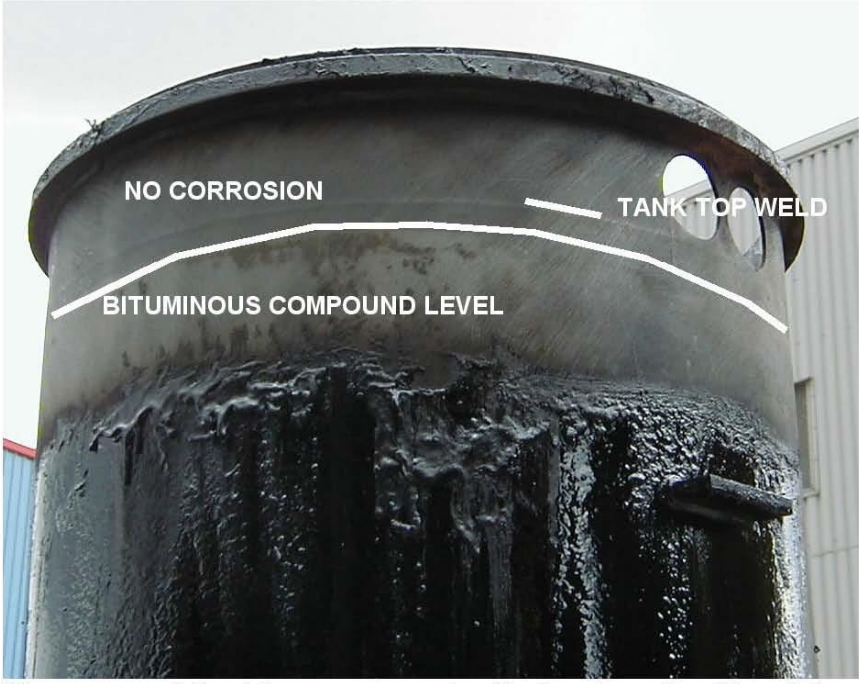
1

An area of corrosion was found on the cylindrical surface approx 100 mm from the tank top but below the weld line of the dished tank top an area 100mm by 350mm. This was composed of small 5 to 10mm pits and one large area 20mm across with steep sides and this had penetrated the side wall causing a 4mm hole and the leak.

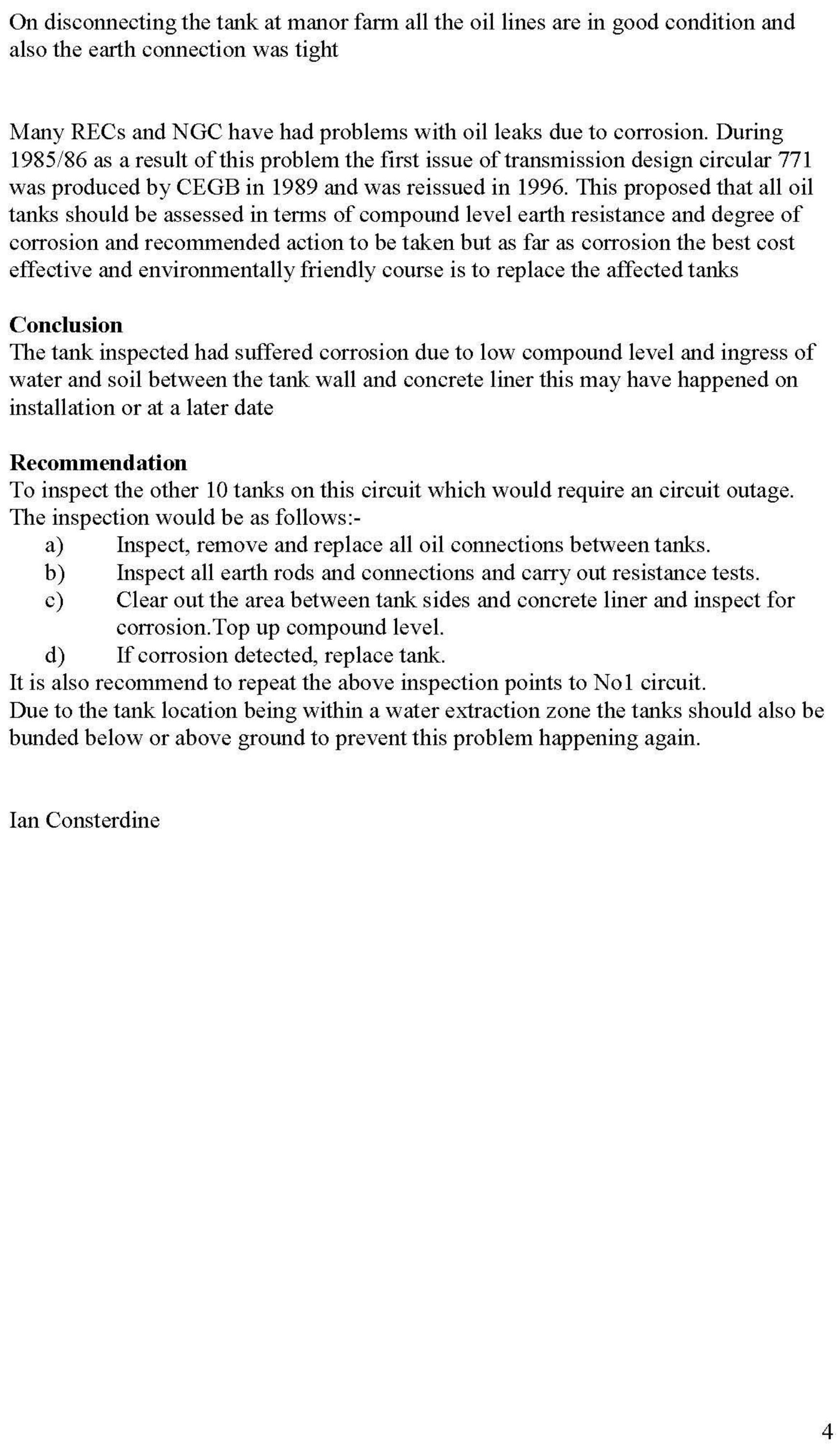


At this point the bituminous compound was lower than other points around the tank, soil had entered this area and had been a catalyst for the corrosion due to where the compound level was low.

2



Where no was soil found there was no corrosion. On closer inspection of the soil it contained sharp small flint stones that over time may have cut into the paint and zinc galvanising



On disconnecting the tank at manor farm all the oil lines are in good condition and also the earth connection was tight

Many RECs and NGC have had problems with oil leaks due to corrosion. During 1985/86 as a result of this problem the first issue of transmission design circular 771 was produced by CEGB in 1989 and was reissued in 1996. This proposed that all oil tanks should be assessed in terms of compound level earth resistance and degree of corrosion and recommended action to be taken but as far as corrosion the best cost effective and environmentally friendly course is to replace the affected tanks

Conclusion
The tank inspected had suffered corrosion due to low compound level and ingress of water and soil between the tank wall and concrete liner this may have happened on installation or at a later date

Recommendation
To inspect the other 10 tanks on this circuit which would require an circuit outage. The inspection would be as follows:-

a) Inspect, remove and replace all oil connections between tanks.
b) Inspect all earth rods and connections and carry out resistance tests.
c) Clear out the area between tank sides and concrete liner and inspect for corrosion.Top up compound level.
d) If corrosion detected, replace tank.

It is also recommend to repeat the above inspection points to No1 circuit.
Due to the tank location being within a water extraction zone the tanks should also be bunded below or above ground to prevent this problem happening again.

Ian Consterdine

4

Buckhurst Hill to Fairlop Rd:

Page 1 of 12

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COBHAM

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Author:	Barry Knox
Client:	EDF Energy
Client Reference:	4500413132
Report Number:	2010-0483
Project Number:	7F0626701
Report Version:	Final Report
Document Control:	Commercial-in-Confidence

Report Checked by:	**Approved by:**
M.W. Coates	
Mark Coates Senior Cable Consultant	Bob Dean Head of Forensic Engineering

August 2010

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ERA Technology Report 2010-0483
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Summary

Cobham Technical Services have carried out an examination of a 33kV cable sample.

It had been reported to Cobham that;

> the cable sample was taken from Horns Road, on the Perth to Fairlop leg, the circuits being teed in the transformer end box at Fairlop.

It is considered that the cable probably faulted due to thermal degradation of the impregnant caused by partial discharge activity at the interface between the paper insulation and the stranded conductor. The cable is 50 years old and is nearing the end of its working life.

It is Cobham's opinion that the cable must be considered for replacement in the near future.

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Contents

Figures List

1. Introduction

Cobham Technical Services have carried out an examination of a 33kV cable sample.

It had been reported to Cobham that the cable sample was taken from Horns Road, on the Perth to Fairlop leg, the circuits being teed in the transformer end box at Fairlop.

This report describes the results of the strip down and examination of the cable.

2. Examination

2.1 Faulted Core

The as received condition and fault site of the sample sent to Cobham Technical Services is shown in Figs. 1 & 2.

Figure 1 As received condition

Figure 2 Fault site

Removal of the lead sheath showed it to be in a good condition with no obvious cracks or crazing seen. The cable compound on the internal surface of the lead sheath was discoloured and starting to harden, Fig. 3.

Figure 3: Lead sheath

Removal of the CWFT binder showed that the fault site was on only one core, Fig. 4. The fault was at the edge of the shaped conductor.

Figure 4 Fault site

Stripdown of this core showed extensive waxing at the butt gaps of the insulation papers and hardened discoloured cable compound on the conductor strands, Figs. 5 & 6.

Figure 5 Wax at butt gaps

Figure 6: Hardened cable compound on conductors

A cable marker tape was found with the legend:

Johnson & Philips Ltd, Charlton, XNW.

XNW is a reference date for 1960.

2.2 Unfaulted core

A section of cable away from the fault site was removed and stripped to assess the general condition of the cable. A core (core 2) was chosen that was seen to not have any of the carbon blown from the fault or be overly affected by the fault, Fig. 7.

Figure 7: Unfaulted cores

The core insulation papers were found to be oily on the outer heads of papers but minor waxing at the butt gaps was seen after half of the insulation papers had been removed, Figs. 8 & 9. Examination of the conductors revealed hardened and discoloured cable compound, evidence of partial discharge activity, at the conductor surface and between the strands, Fig. 10.

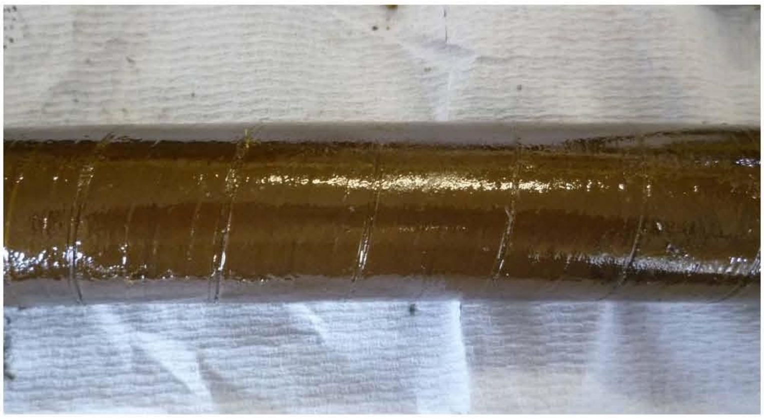


Figure 8: Oily outer insulation papers

Figure 9: Minor waxing on inner insulation papers

Figure 10 Hardened cable compound on strands

3. Discussion

The position of high electrical stress in a screened shaped conductor cable would be at the narrowest side of the shaped conductor. This cable had faulted at this position.

It could be seen that the paper cable was showing signs of waxing and discolouration due to partial discharge activity. The degradation within the bulk of the paper insulation was not severe. However, at the interface between the insulation and the stranded conductor there was evidence of more severe thermal degradation of the impregnant due to partial discharge activity. This degradation is considered to be a sign of ageing.

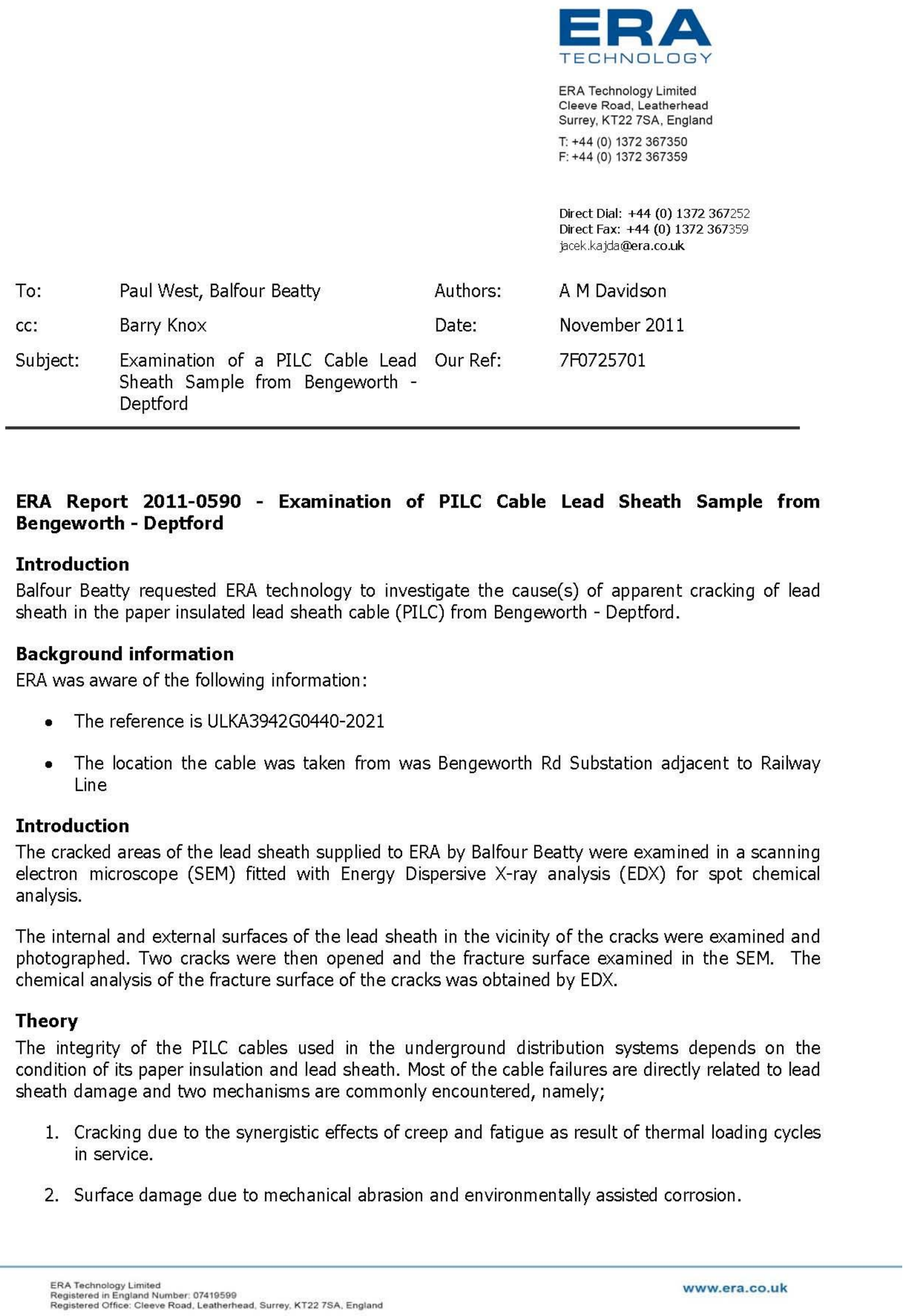
There was no evidence of any other possible cause of failure and therefore it is considered that the failure was probably due to thermal ageing of the impregnant at the interface between the insulation and the conductor.

4. Conclusions

It is considered that the cable faulted due thermal ageing of the impregnant caused by partial discharge activity at the interface between the paper insulation and the conductor. The cable is 50 years old and is nearing the end of its working life.

It is Cobham's opinion that the cable must be considered for replacement in the near future.

Deptford Grid 132kV-Bengeworth Road 33kV:



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To:	Paul West, Balfour Beatty	Authors:	A M Davidson
cc:	Barry Knox	Date:	November 2011
Subject:	Examination of a PILC Cable Lead Sheath Sample from Bengeworth - Deptford	Our Ref:	7F0725701

ERA Report 2011-0590 - Examination of PILC Cable Lead Sheath Sample from Bengeworth - Deptford

Introduction

Balfour Beatty requested ERA technology to investigate the cause(s) of apparent cracking of lead sheath in the paper insulated lead sheath cable (PILC) from Bengeworth - Deptford.

Background information

ERA was aware of the following information:

- The reference is ULKA3942G0440-2021
- The location the cable was taken from was Bengeworth Rd Substation adjacent to Railway Line

Introduction

The cracked areas of the lead sheath supplied to ERA by Balfour Beatty were examined in a scanning electron microscope (SEM) fitted with Energy Dispersive X-ray analysis (EDX) for spot chemical analysis.

The internal and external surfaces of the lead sheath in the vicinity of the cracks were examined and photographed. Two cracks were then opened and the fracture surface examined in the SEM. The chemical analysis of the fracture surface of the cracks was obtained by EDX.

Theory

The integrity of the PILC cables used in the underground distribution systems depends on the condition of its paper insulation and lead sheath. Most of the cable failures are directly related to lead sheath damage and two mechanisms are commonly encountered, namely;

1. Cracking due to the synergistic effects of creep and fatigue as result of thermal loading cycles in service.
2. Surface damage due to mechanical abrasion and environmentally assisted corrosion.

Results

Visual Examination

- The thickness of the lead sheath appeared to be uniform measuring approximately 2.5 mm.
- Although the internal and external surfaces did not show any significant mechanical damage, there were some light grooves/depressions in line with two of the cracks.
- Three cracks could be seen, which appeared to extend through the entire thickness of the lead sheath.

SEM Images

- Plates 1 and 2 show the condition of the outside surface of the lead sheath material around one of the cracks. The crack which could be visually identified was prominent and was approximately 3 mm long.
- Plates 3 and 4 show the condition of the outside surface a distance away form the crack. Intergranular cracks around the grains at the surface are clearly visible. The average grain size is of the order of 100 to 250 microns.
- The fracture surface of the through wall crack is shown in images in Plates 5 to 8. The fracture path was predominantly intergranular as indicated by the facetted topography of the crack surface. Distinct regularly spaced lines reminiscent of fatigue striations were identified however at high magnifications as shown in Plates 7 and 8.

EDX Analysis

- EDX analysis of the external surface showing intergranular cracks were carried out on the as received lead sheath material in Plate 9. The bulk material is high purity lead, with a small amount of tin present (~1%). No aggressive species such as chlorides were detected on the external surface. The surface is covered by lead oxide and lead carbonate as revealed by the presence of significant concentrations of oxygen and carbon.
- EDX analysis of the fracture surfaces of the crack, revealed presence of tin (Sn) in Plate 10, most likely as an impurity element. This is a significant finding suggesting that part of the fracture path traverses along the grain boundaries as intergranular cracks. Preferential segregation of impurity tramp elements Sn "weakened" the grain boundaries and allowed them to be attacked by the external environment. However, no aggressive species such as chlorides were detected on the fracture surfaces.

Discussion

- The experimental evidence gathered suggests that the apparent through wall cracks in the lead sheath were caused by a mixed mechanism of both the simultaneous effects of creep and fatigue as well as environmentally assisted corrosion.
- Preferential oxidation of the grain boundaries initiated surface intergranular cracks. Tin (Sn) the "tramp" element migrated to the grain boundaries and provided the driving force for the environmentally assisted corrosion.
- The thermal loading cycles allowed the simultaneous effects of creep and fatigue which was most likely the predominant mechanism of failure in the later part of the lead sheath life in service.
- The cracks have been exposed to the atmosphere for significant length of time as revealed by presence of lead oxide and lead carbonates.

Conclusions

- It may be concluded that normal aging processes were ultimately responsible for the observed failure.

Report by:	A M Davidson Metallurgist
Checked by:	Dr. N Wright Head of Forensic Engineering

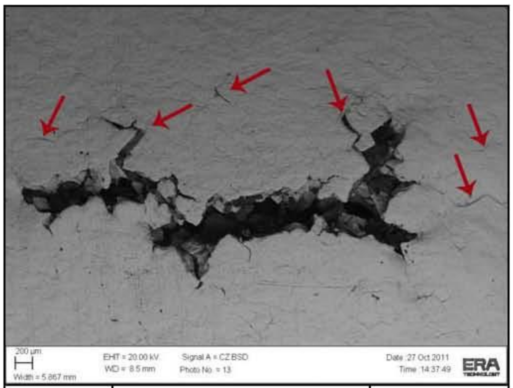


Plate 1	Visible Crack	BS mode

Intergranular cracks on the external surface of the lead sheath. The cracks follow the paths of the grain boundaries as indicated by the arrows.

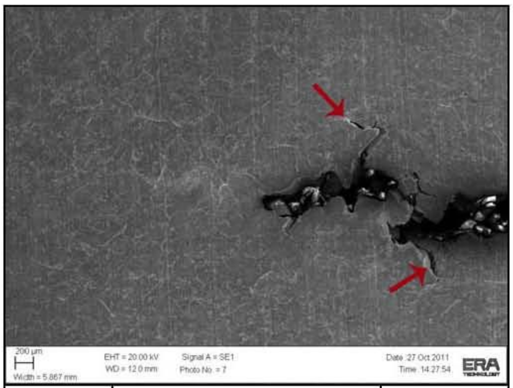


Plate 2	Visible Crack	SE mode

Intergranular cracks on the external surface of the lead sheath. The cracks follow the paths of the grain boundaries as indicated by the arrows.

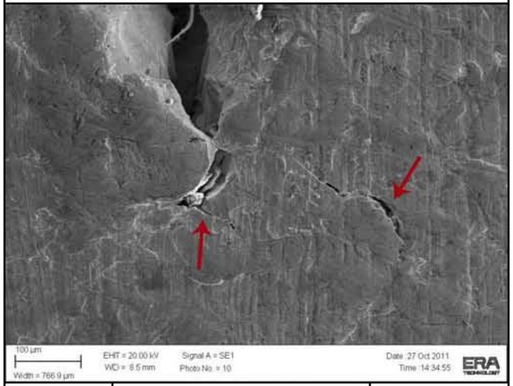


Plate 3	Crack tip	SE mode

Intergranular cracks on the external surface of the lead sheath. The cracks follow the paths of the grain boundaries as indicated by the arrows.

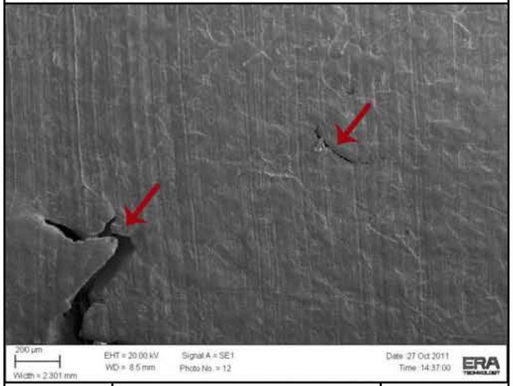


Plate 4	Crack tip	SE mode

Intergranular cracks on the external surface of the lead sheath. The cracks follow the paths of the grain boundaries as indicated by the arrows.

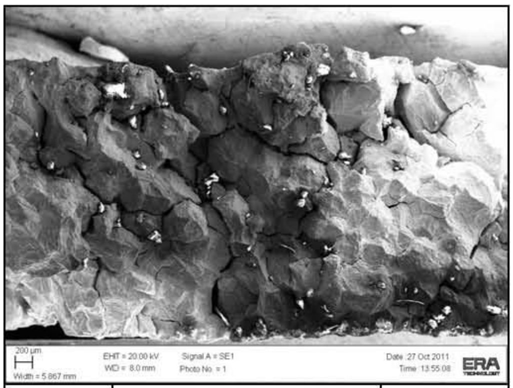


Plate 5 | Fracture surface of crack | SE mode

General appearance of the fracture surface of the crack. The fracture path is mainly intergranular as illustrated by the facetted topography of the crack surface.

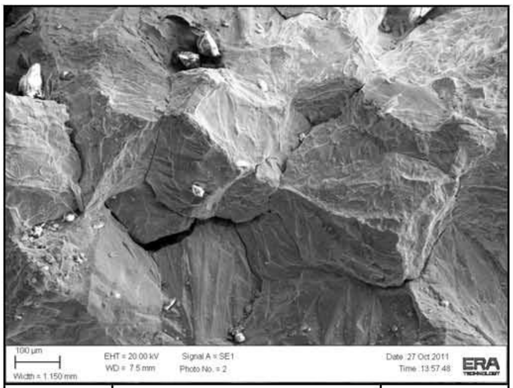


Plate 6 | Fracture surface of crack | SE mode

General appearance of the fracture surface of the crack. The fracture path is mainly intergranular as illustrated by the facetted topography of the crack surface.

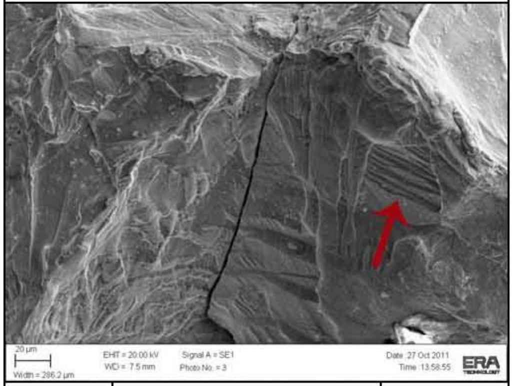


Plate 7 | Fracture surface of crack | SE mode

The fracture path is mainly intergranular but at higher magnifications evidences of fatigue striations could be resolved as indicated by the arrows.

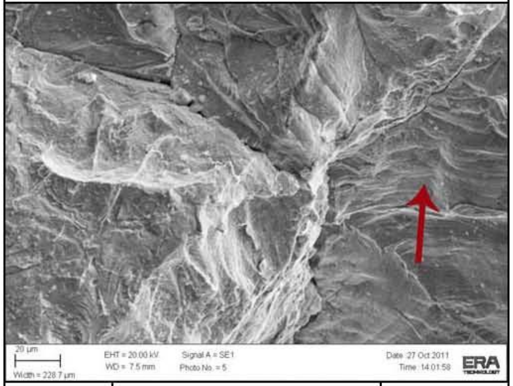
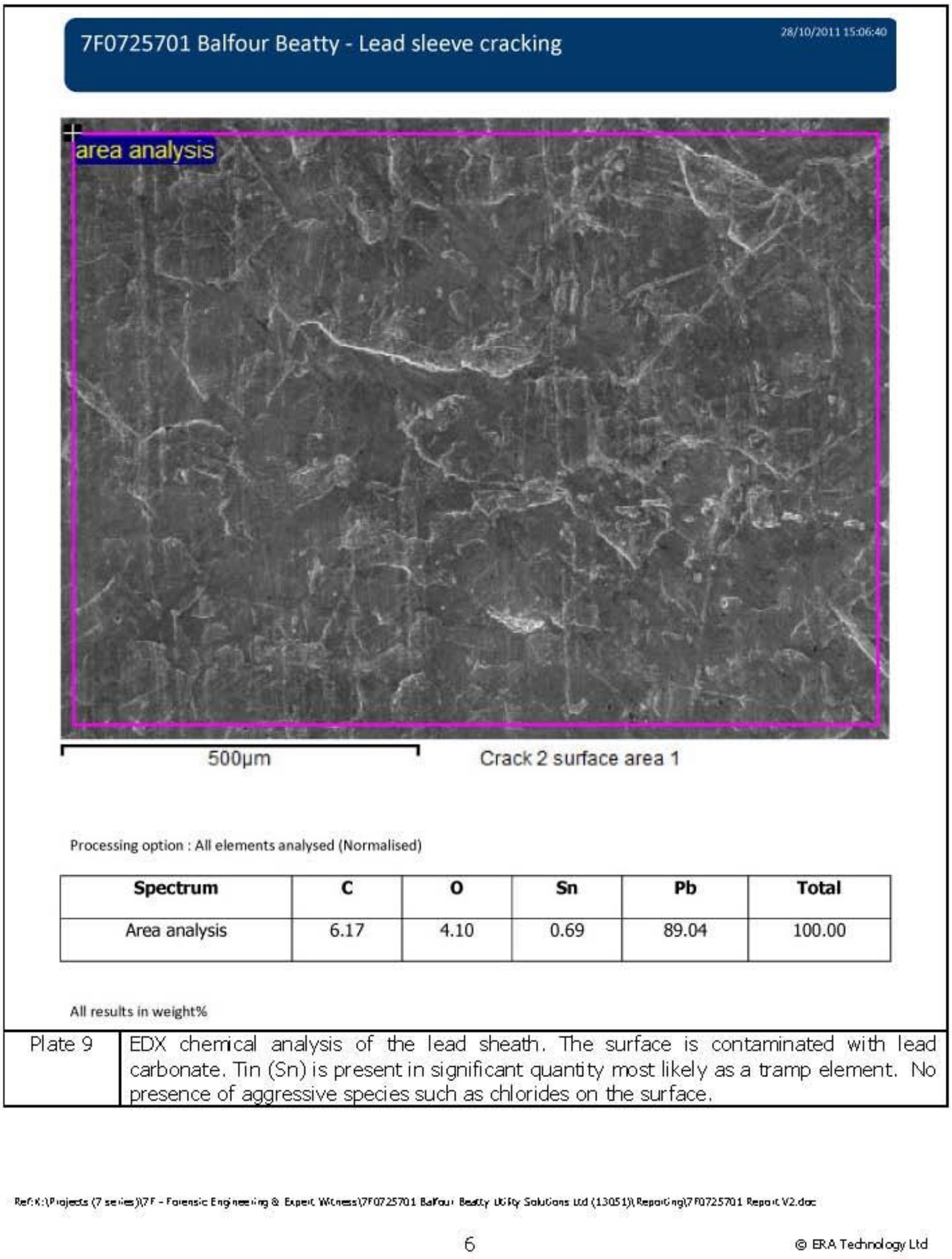


Plate 8 | Fracture surface of crack | SE mode

The fracture path is mainly intergranular but at higher magnifications evidences of fatigue striations could be resolved as indicated by the arrows.



7F0725701 Balfour Beatty - Lead sleeve cracking

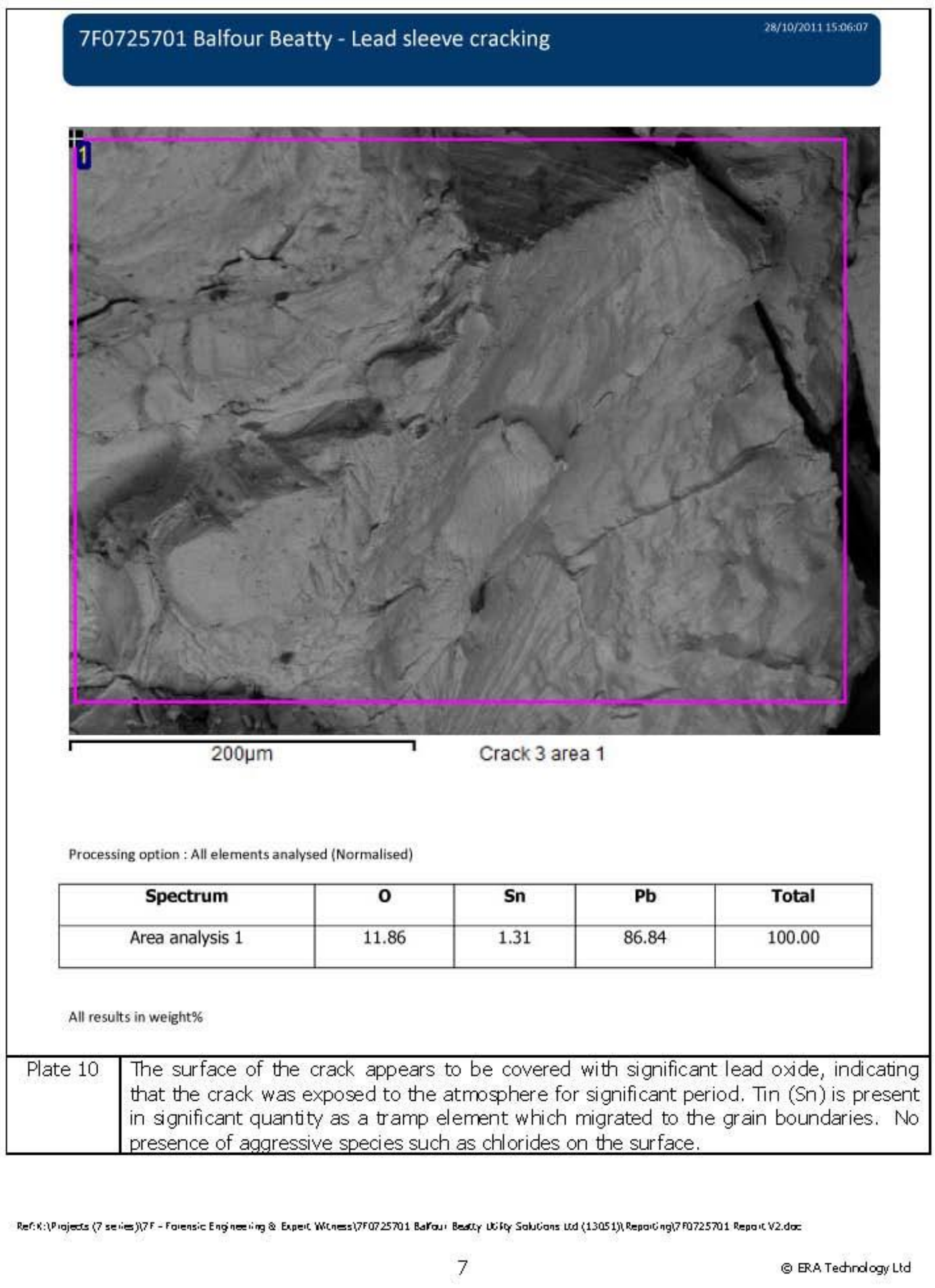
28/10/2011 15:06:40

Processing option : All elements analysed (Normalised)

Spectrum	C	O	Sn	Pb	Total
Area analysis	6.17	4.10	0.69	89.04	100.00

All results in weight%

Plate 9	EDX chemical analysis of the lead sheath. The surface is contaminated with lead carbonate. Tin (Sn) is present in significant quantity most likely as a tramp element. No presence of aggressive species such as chlorides on the surface.



7F0725701 Balfour Beatty - Lead sleeve cracking

28/10/2011 15:06:07

Crack 3 area 1

Processing option : All elements analysed (Normalised)

Spectrum	O	Sn	Pb	Total
Area analysis 1	11.86	1.31	86.84	100.00

All results in weight%

Plate 10	The surface of the crack appears to be covered with significant lead oxide, indicating that the crack was exposed to the atmosphere for significant period. Tin (Sn) is present in significant quantity as a tramp element which migrated to the grain boundaries. No presence of aggressive species such as chlorides on the surface.

Ref: K:\Projects (7 series)\7F - Forensic Engineering & Expert Witness\7F0725701 Balfour Beatty Utility Solutions Ltd (13051)\Reporting\7F0725701 Report V2.doc

7

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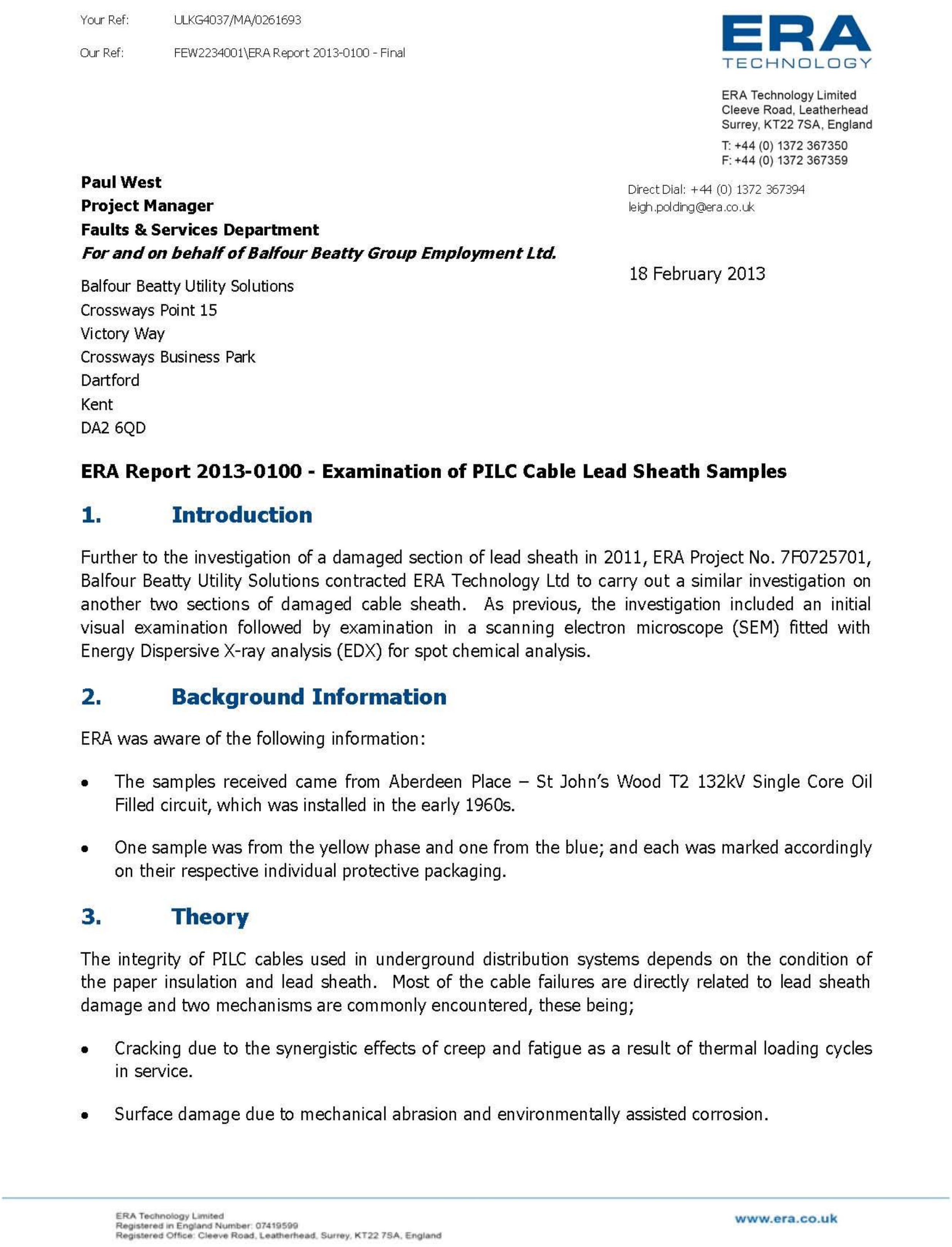
St Johns Wood 132kV- Aberdeen Place:



Your Ref: ULKG4037/MA/0261693

Our Ref: FEW2234001\ERA Report 2013-0100 - Final

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18 February 2013

ERA Report 2013-0100 - Examination of PILC Cable Lead Sheath Samples

1. Introduction

Further to the investigation of a damaged section of lead sheath in 2011, ERA Project No. 7F0725701, Balfour Beatty Utility Solutions contracted ERA Technology Ltd to carry out a similar investigation on another two sections of damaged cable sheath. As previous, the investigation included an initial visual examination followed by examination in a scanning electron microscope (SEM) fitted with Energy Dispersive X-ray analysis (EDX) for spot chemical analysis.

2. Background Information

ERA was aware of the following information:

- The samples received came from Aberdeen Place – St John's Wood T2 132kV Single Core Oil Filled circuit, which was installed in the early 1960s.
- One sample was from the yellow phase and one from the blue; and each was marked accordingly on their respective individual protective packaging.

3. Theory

The integrity of PILC cables used in underground distribution systems depends on the condition of the paper insulation and lead sheath. Most of the cable failures are directly related to lead sheath damage and two mechanisms are commonly encountered, these being;

- Cracking due to the synergistic effects of creep and fatigue as a result of thermal loading cycles in service.
- Surface damage due to mechanical abrasion and environmentally assisted corrosion.

4. Examinations Performed and Findings

4.1 Visual Examination

The internal and external surfaces of the lead sheaths were examined in the as-received condition visually by eye and with the aid of a microscope at magnifications up to x16. Representative photographs are included in Attachment A.

Blue Phase Sample

- The thickness of the lead sheath appeared to be uniform and there were no signs of significant mechanical damage in the bulk of the sample away from the cut edges.

- The inner surface was found to be bright indicating no significant lead oxide and lead carbonate formation, while the external surface was clearly dulled.

- When examined by eye, three distinct circumferentially orientated cracks measuring 3-4 mm in length were clearly evident on the inner surface of the sheath at the central axis of the sample; each crack separated by 5-8 cm. Examination by microscope revealed some further fine cracks away from the central axis of the sample, also predominantly circumferential in orientation, but less than 2 mm in length.

- The external surface initially appeared clear when examined by eye, but examination by microscope clearly revealed that the three main cracks observed on the inner surface penetrated fully through the thickness. Some further fine cracks were also noted on the external surface. In addition, a multi-axial nature to some of the external surface cracking was noted.

- When observed under the microscope the large grain size typical of this material was apparent and the cracking appeared to be intergranular in nature.

Yellow

- The thickness of the lead sheath appeared to be uniform. A small straight sided impression, ~2mm square, was evident on the outer surface; otherwise there were no signs of significant mechanical damage in the bulk of the sample away from the cut edges.

- The inner surface was found to be bright indicating no significant lead oxide and lead carbonate formation, while the external surface was clearly dulled.

- Large through wall cracks, predominantly circumferential in orientation, were clearly visible by eye. Subsequent examination by microscope of the external surface revealed fine multi-axial cracks were associated with the main cracks. Furthermore the external surface was found to be covered in numerous fine cracks with a strong circumferential element, but also with associated multi-axial cracks.

- When observed under the microscope the large grain size typical of this material was apparent and the cracking appeared to be intergranular in nature.

4.2 SEM Examination and EDX Analysis

A representative cracked region from each of the two sheath samples was removed and the surface examined in the SEM (external of the yellow sample and internal of the blue). This included chemical analysis of the area surrounding the cracks by EDX. The cracks from each sample were opened to enable examination of the fracture surface by SEM and EDX. Representative photographs and results of the EDX analysis are provided in Attachment B.

Blue

- SEM examination of the blue sample inside surface at the selected crack provided further evidence of the predominantly intergranular nature of the cracking. This was further confirmed through examination of the fracture surface, which revealed a faceted topography. Distinct regularly spaced lines reminiscent of fatigue striations were noted at high magnifications in some regions of the fracture surface.

- EDX analysis revealed the bulk material is high purity lead, with a small trace of cadmium (Cd) at grain boundaries noted on the fracture surface. However, no aggressive species such as chlorides were present. Oxygen (O) and carbon (C) concentrations detected indicated that the internal surface was covered with a relatively low level of lead oxide and carbonate; while the fracture surface of the through wall crack examined exhibited elevated levels.

Yellow

- SEM examination of the yellow sample outside surface at the selected crack provided further evidence of the predominantly intergranular nature of the cracking. This was further confirmed through examination of the fracture surface, which revealed a faceted topography. Distinct regularly spaced lines reminiscent of fatigue striations were noted at high magnifications in some regions of the fracture surface.

- EDX analysis revealed the bulk material is high purity lead, with traces of tin (Sn) and cadmium (Cd) at grain boundaries noted on the fracture surface. However, no aggressive species such as chlorides were present. Oxygen (O) and carbon (C) concentrations detected indicated that the external surface was covered with a relatively high level of lead oxide and carbonate; the fracture surface of the through wall crack examined exhibited a similar level.

5. Discussion

- The examination findings for both samples are consistent with cracking due to the synergistic effects of creep and fatigue as a result of thermal loading cycles in service. There is no evidence of aggressive species that would contribute to environmentally assisted corrosion.

- The yellow phase sample was in a poorer condition than the blue sample with significantly larger and more widespread cracking present. This may be due to the much higher levels of tramp elements discovered in the yellow sample compared with the blue, resulting in lower rupture and fatigue strengths.

- The level of lead oxide and carbonate present on the fracture surfaces of both the yellow and blue samples, as indicated by the oxygen and carbon concentrations, suggests that the cracks have been present (exposed to the atmosphere) for a significant length of time.

6. Conclusions

- It may be concluded from the findings of the examinations performed that normal ageing processes were ultimately responsible for the observed failure.

Report Written by

Mr L Polding
Principal Engineer

Report Checked by:

M.W. Coates

Mr M Coates
Cable Engineering Consultant

Approved by:

Dr A Friday
Head of Engineering Design and Performance

Attachment A

Blue Sample - Plates and Figures

BLUE PHASE SAMPLE

Plate A.1 Inner Surface

Blue phase sample in the as-received condition.

Plate A.2 Outer Surface

Blue phase sample in the as-received condition.

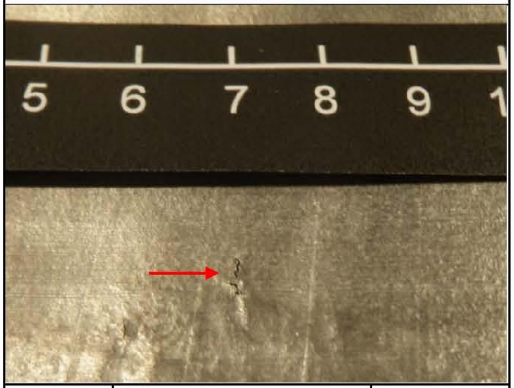


Plate A.3 Inner Surface

One of three cracks easily distinguishable by eye.

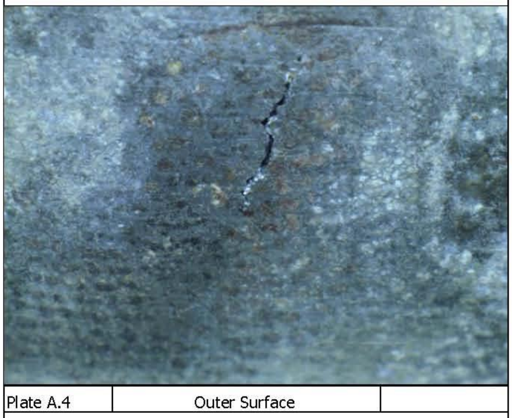


Plate A.4 Outer Surface

Through wall penetration noted when examined by macroscope.

Plate A.5 Inner Surface

One of three cracks easily distinguishable by eye.

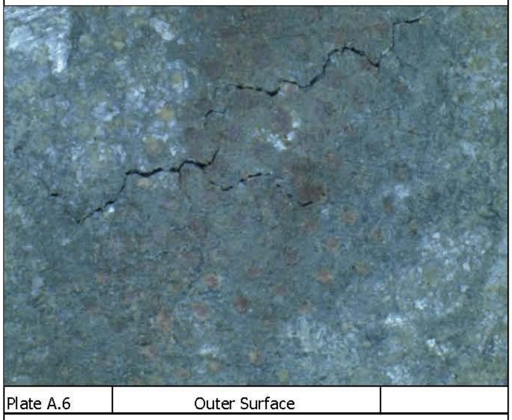


Plate A.6 Outer Surface

Multi-axial cracking noted when examined by macroscope.

Note: All plates orientated in the axial direction.

BLUE PHASE SAMPLE

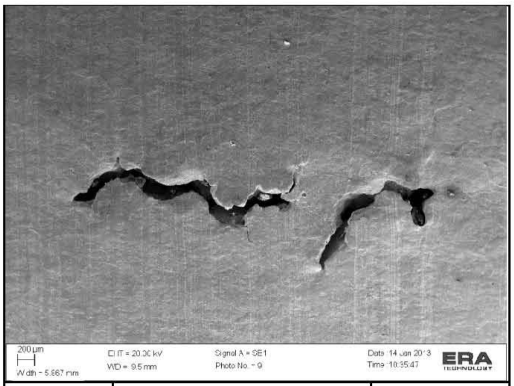


Plate A.7 | Inner Surface | SE Mode

Intergranular cracks on the internal surface of the lead sheath.

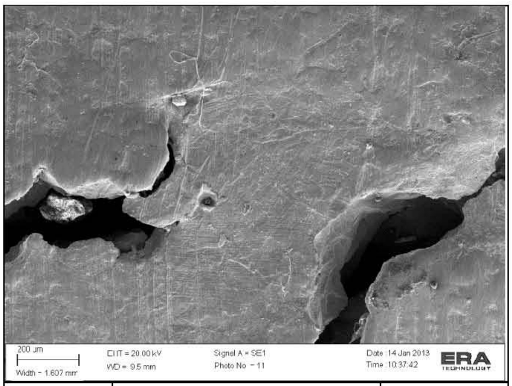


Plate A.8 | Inner Surface | SE Mode

Intergranular cracks on the internal surface of the lead sheath.

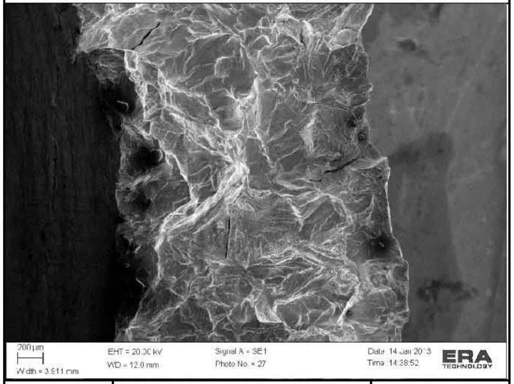


Plate A.9 | Fracture Surface | SE Mode

General appearance of the fracture surface of the crack. The fracture path is mainly intergranular as illustrated by the facetted topography of the crack surface.

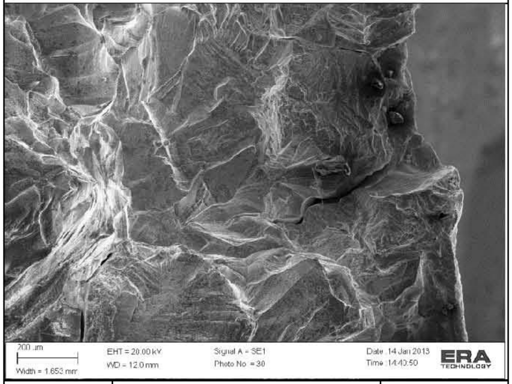
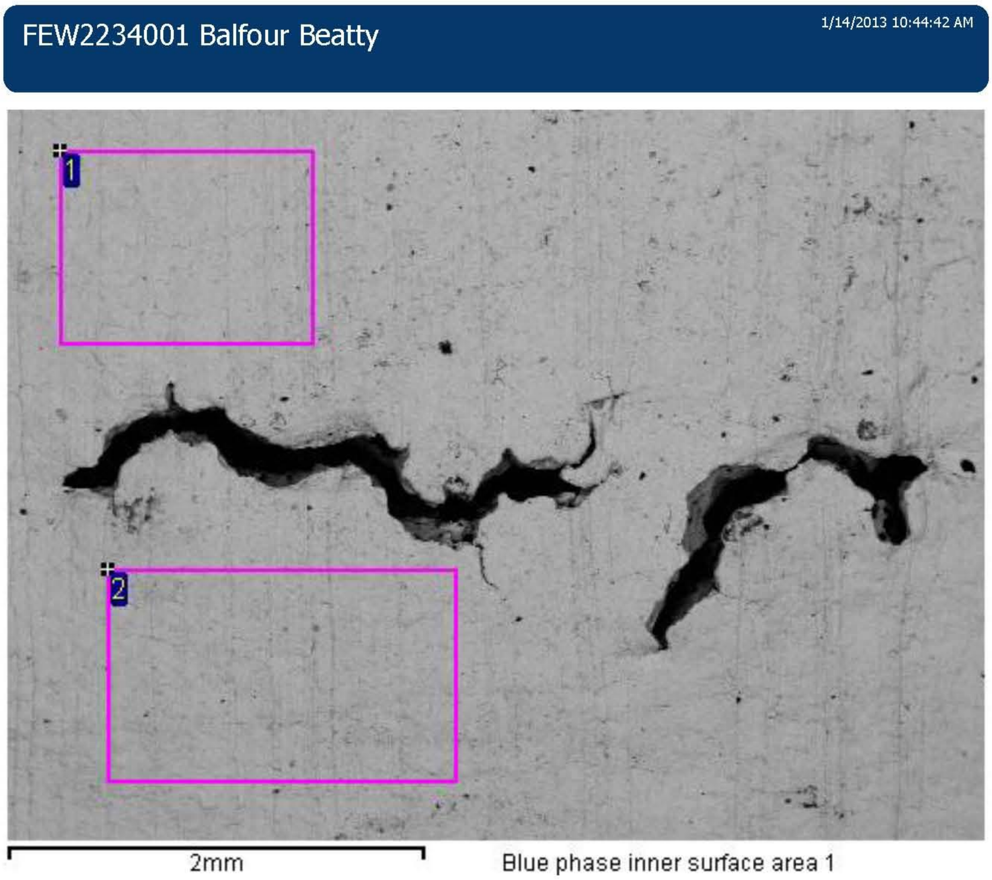


Plate A.10 | Fracture Surface | SE Mode

General appearance of the fracture surface of the crack. The fracture path is mainly intergranular as illustrated by the facetted topography of the crack surface.

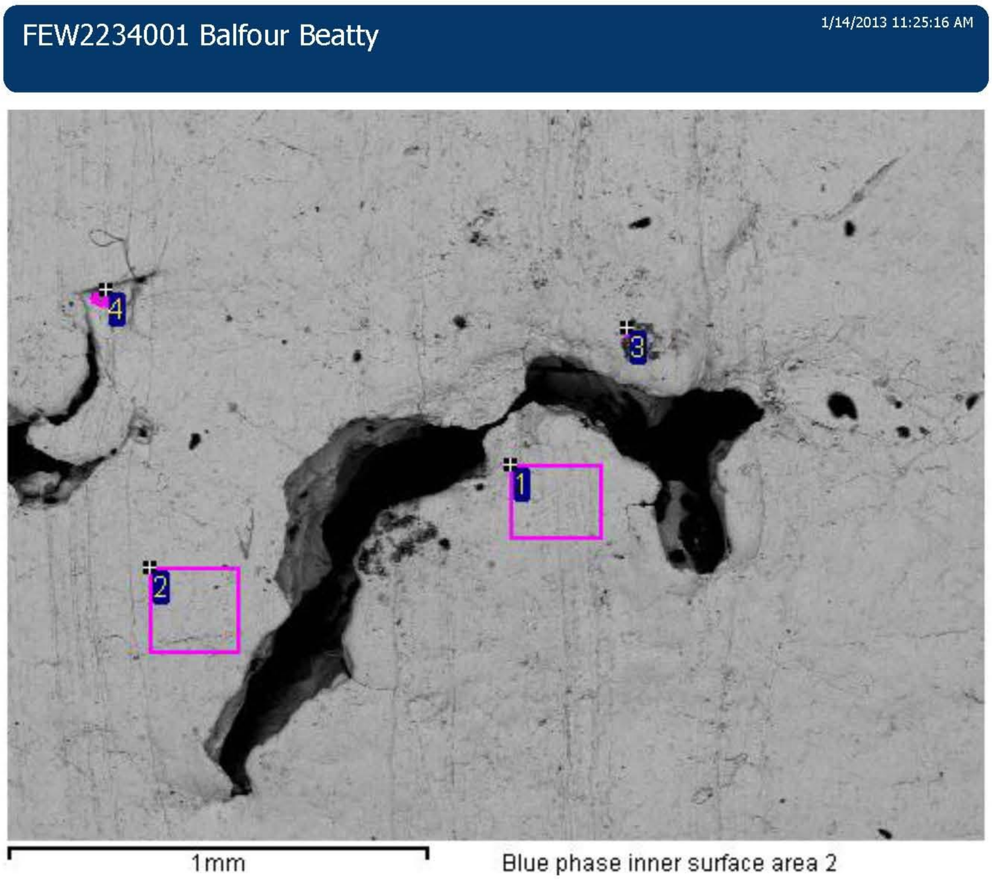


Processing option: All elements analysed (Normalised)

Spectrum	C	O	Pb	Total
1	7.6	3.6	88.8	100.0
2	9.0	3.1	87.8	100.0

All results in weight%

Figure A.1: EDX chemical analysis of the inner surface of the lead sheath in the vicinity of one of the cracks. The surface is contaminated with Lead Carbonate. No aggressive species such as chlorides present.



Processing option: All elements analysed (Normalised)

Spectrum	C	O	Pb	Total
1	8.8	3.5	87.6	100
2	7.6	3.9	88.5	100
3	46.4	7.9	45.6	100
4	19.3	14.8	66.0	100

All results in weight%

Figure A.2: EDX chemical analysis of the inner surface of the lead sheath in the vicinity of one of the cracks. The surface is contaminated with Lead Carbonate, peaking to high levels in some areas. No aggressive species such as chlorides present.

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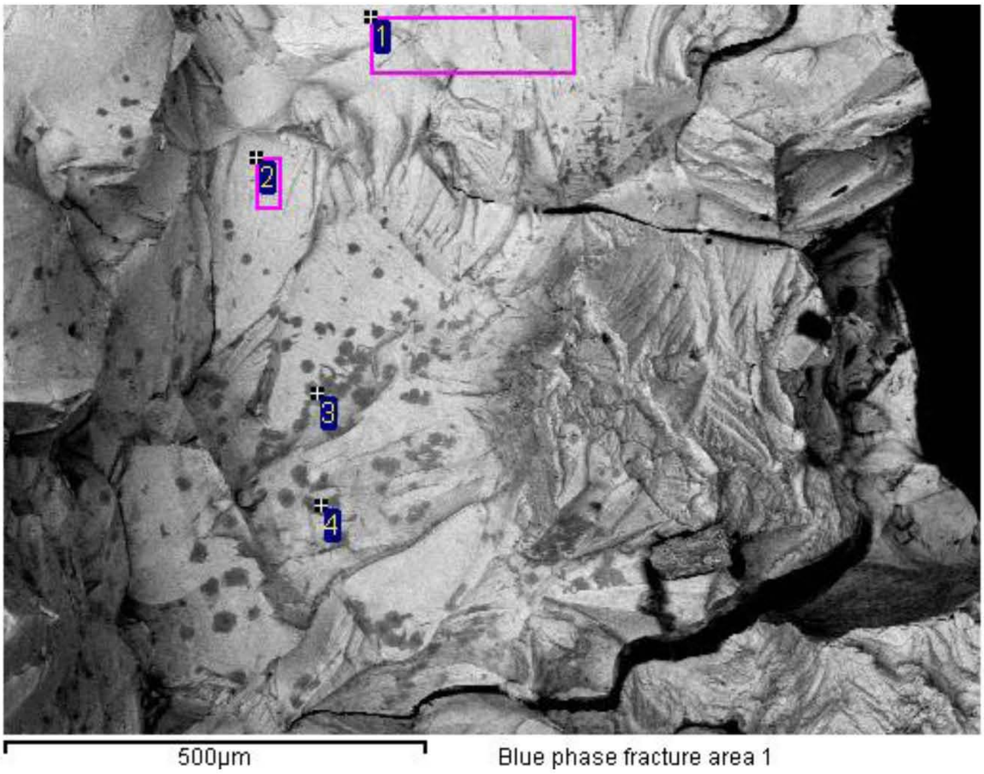
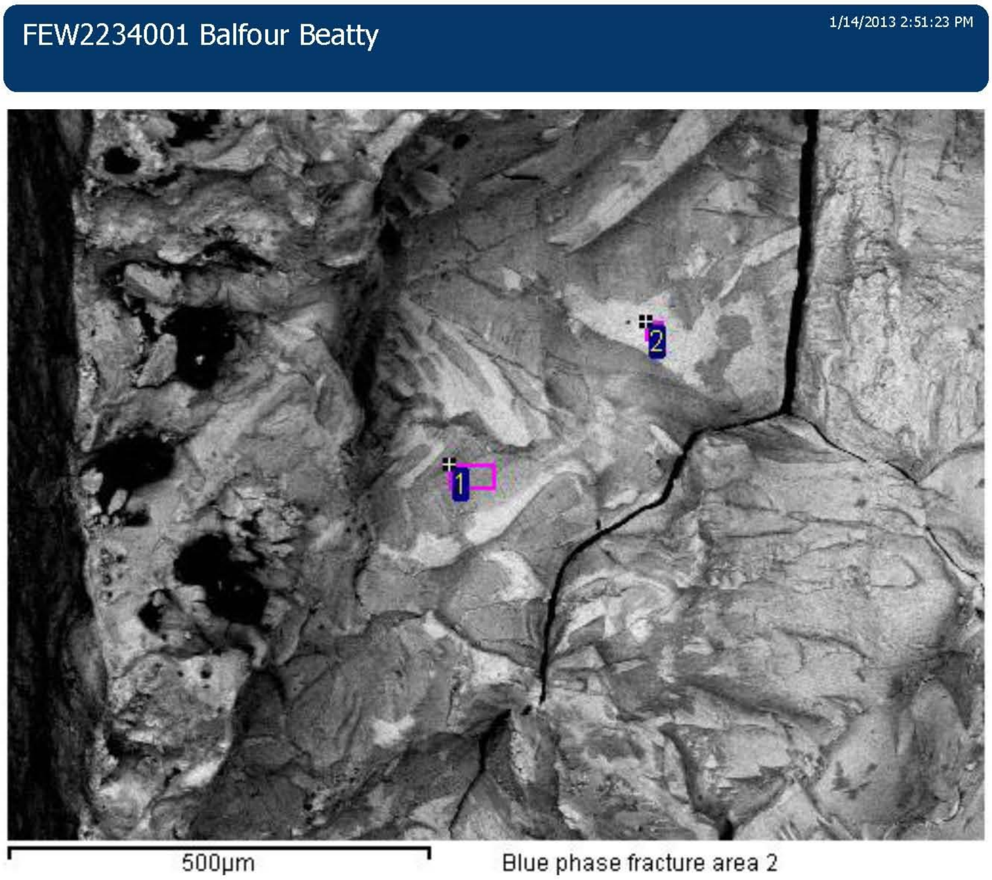


Processing option: All elements analysed (Normalised)

Spectrum	C	O	Cd	Pb	Total
1	13.5	4.4	0.0	82.0	100.0
2	14.1	8.6	0.0	77.3	100.0
3	5.2	17.4	34.4	43.0	100.0
4	2.3	22.9	34.4	40.3	100.0

All results in weight%

Figure A.3: EDX chemical analysis of the fracture surface of the lead sheath. The surface is contaminated with Lead Carbonate. Cadmium was found to be present (dark spots) as a grain boundary tramp element. No aggressive species such as chlorides present.



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Processing option: All elements analysed (Normalised)

Spectrum	C	O	Pb	Total
1	27.7	14.3	57.9	100.0
2	13.5	6.9	79.7	100.0

All results in weight%

Figure A.4: EDX chemical analysis of the fracture surface of the lead sheath. The surface is contaminated with a significant quantity of Lead Carbonate. No aggressive species such as chlorides present.

Attachment B

Yellow Sample - Plates and Figures

YELLOW PHASE SAMPLE

Plate B.1	Outer Surface	
Yellow phase sample in the as-received condition.		

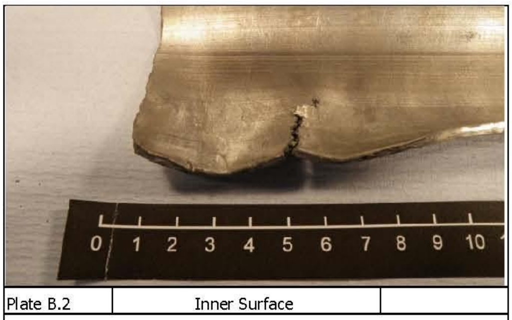

Plate B.2	Inner Surface	
Yellow phase sample in the as-received condition.		

Plate B.3	Outer Surface	
Small straight sided impression – mechanical indentation.		

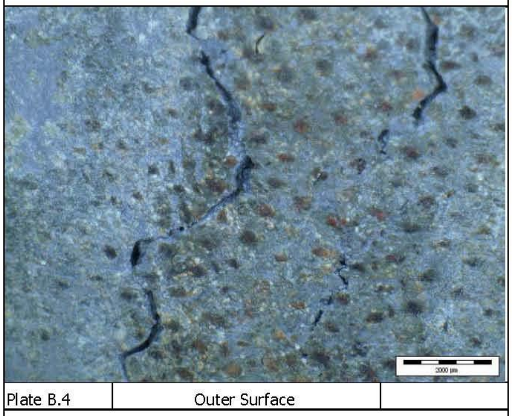

Plate B.4	Outer Surface	
Cracking at the external surface. Cracking has appearance of being intergranular in nature.		

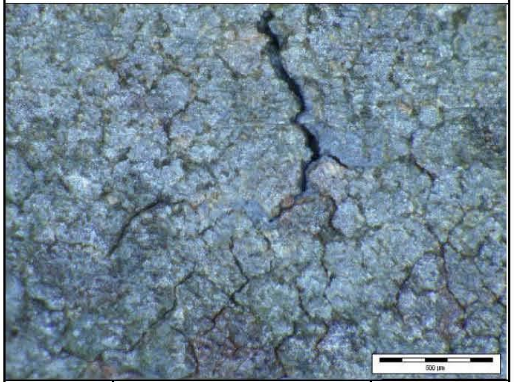

Plate B.5	Inner Surface	
Cracking at the external surface. Main crack predominantly circumferential with associated fine multi-axial cracking. Cracking has appearance of being intergranular in nature.		

Note: All plates orientated in the axial direction.

YELLOW PHASE SAMPLE

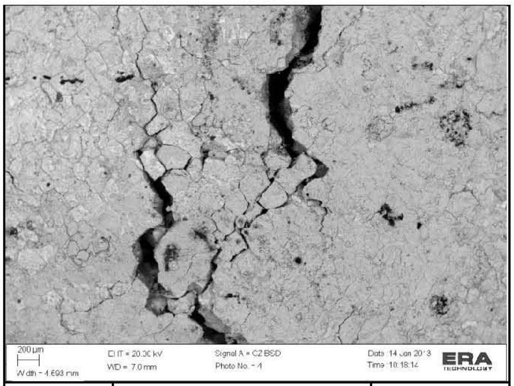

Plate B.7	Outer Surface	BS Mode

Intergranular cracks on the external surface of the lead sheath.

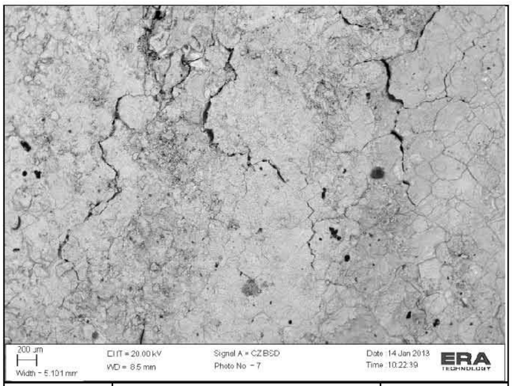

Plate B.8	Inner Surface	BS Mode

Intergranular cracks on the external surface of the lead sheath.

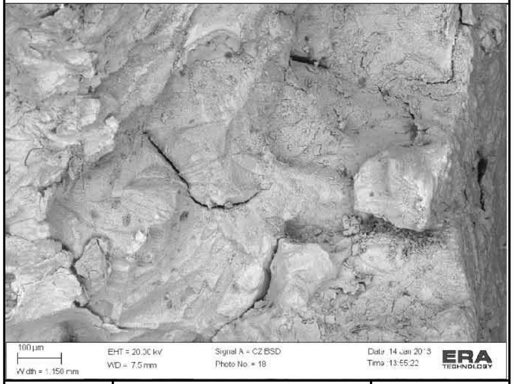

Plate B.9	Fracture Surface	BS Mode

General appearance of the fracture surface of the crack. The fracture path is mainly intergranular as illustrated by the facetted topography of the crack surface.

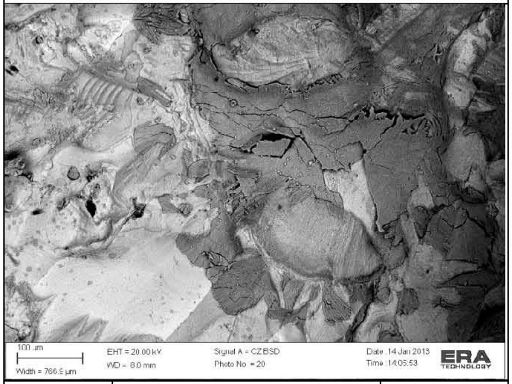

Plate B.10	Fracture Surface	SE Mode

General appearance of the fracture surface of the crack. The fracture path is mainly intergranular as illustrated by the facetted topography of the crack surface.

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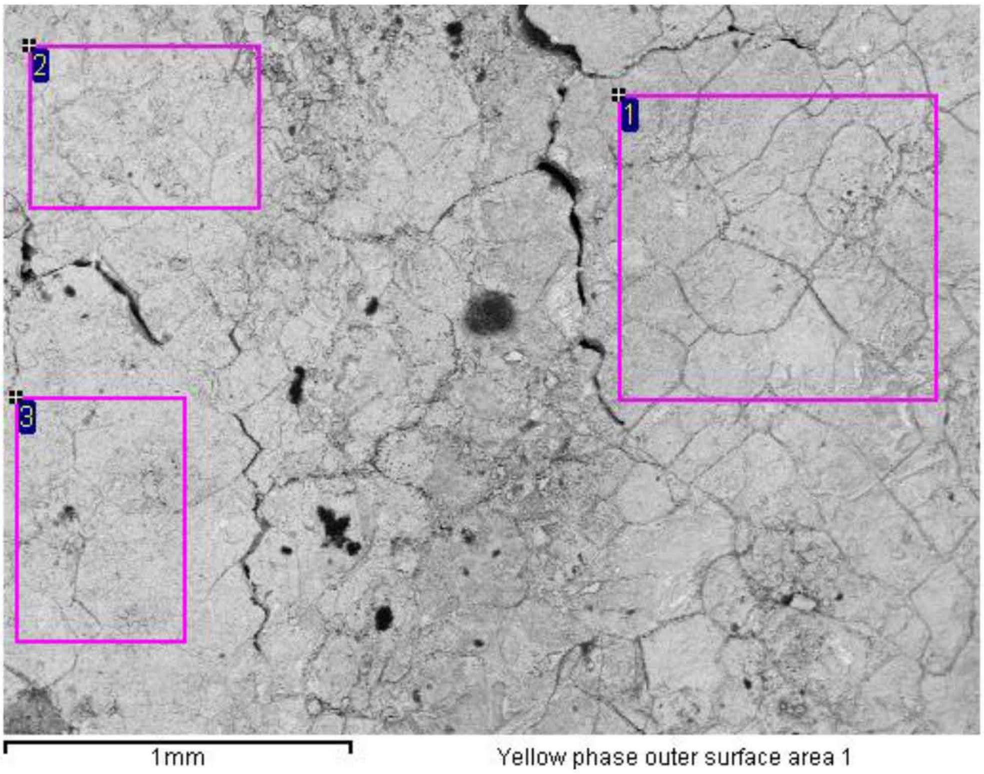

Processing option: All elements analysed (Normalised)

Spectrum	C	O	Cu	Pb	Total
1	23.1	15.9	0.8	60.2	100.0
2	21.4	15.4	0.3	62.9	100.0
3	20.6	15.8	0.0	63.6	100.0

All results in weight%

Figure B.1: EDX chemical analysis of the outer surface of the lead sheath in the vicinity of the cracking. The surface is contaminated with significant levels of Lead Carbonate. Minor traces of copper were present, but no aggressive species such as chlorides.

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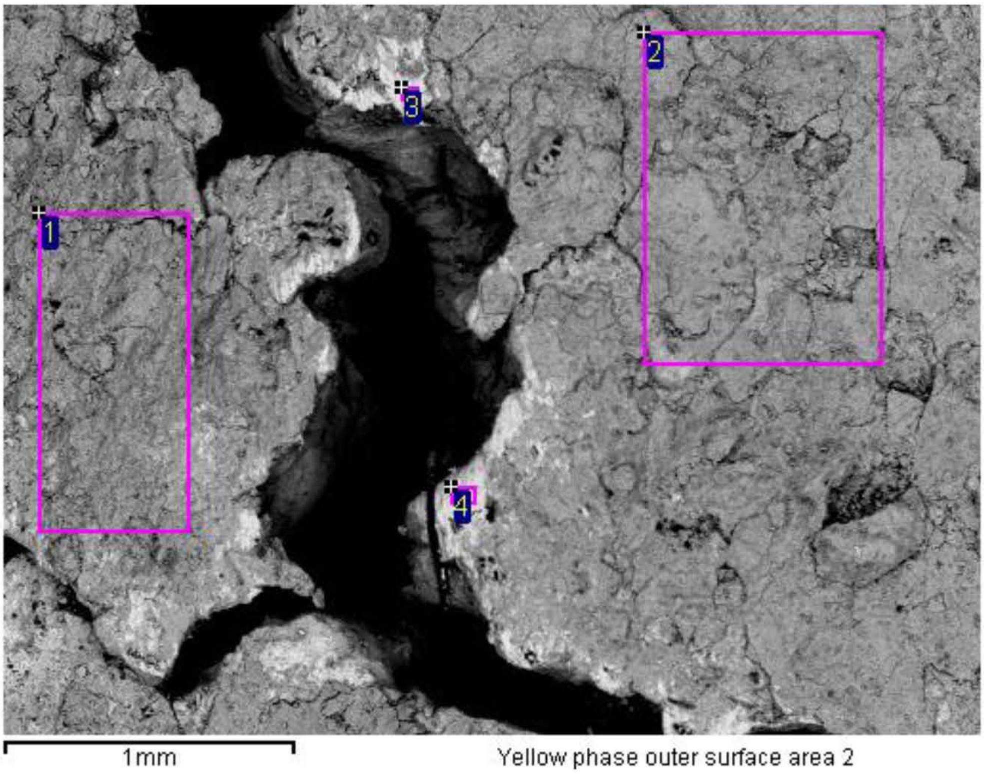
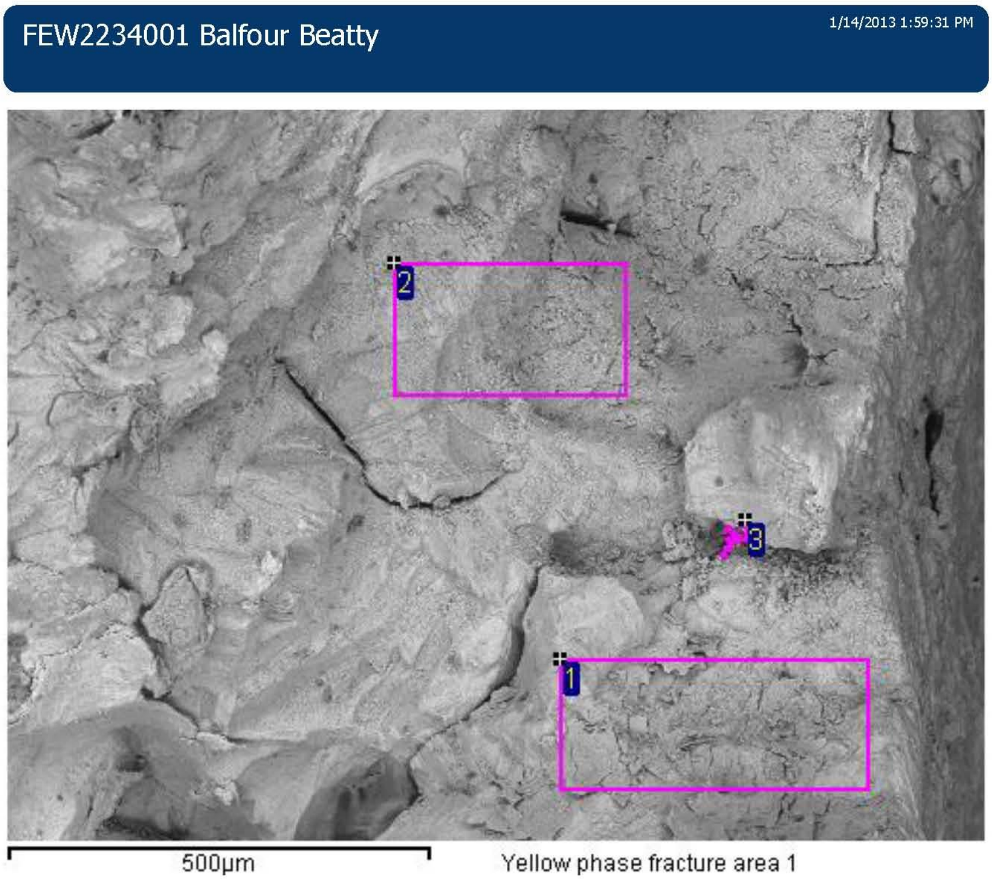


Processing option: All elements analysed (Normalised)

Spectrum	C	O	Pb	Total
1	23.1	12.9	63.9	100.0
2	21.4	14.2	64.4	100.0
3	7.0	3.0	90.0	100.0
4	10.3	4.3	85.4	100.0

All results in weight%

Figure B.2: EDX chemical analysis of the outer surface of the lead sheath in the vicinity of the cracking. The surface is contaminated with significant levels of Lead Carbonate. No aggressive species such as chlorides were present.



Processing option: All elements analysed (Normalised)

Spectrum	C	O	Cd	Sn	Pb	Total
1	18.2	16.2	1.0	1.3	63.3	100.0
2	22.9	19.5	1.3	3.3	53.1	100.0
3	24.1	16.9	0.0	1.0	58.0	100.0

All results in weight%

Figure B.3: EDX chemical analysis of the fracture surface of the lead sheath. The surface is contaminated with significant levels of Lead Carbonate. Cadmium and tin were found to be present as a grain boundary tramp element. No aggressive species such as chlorides present.

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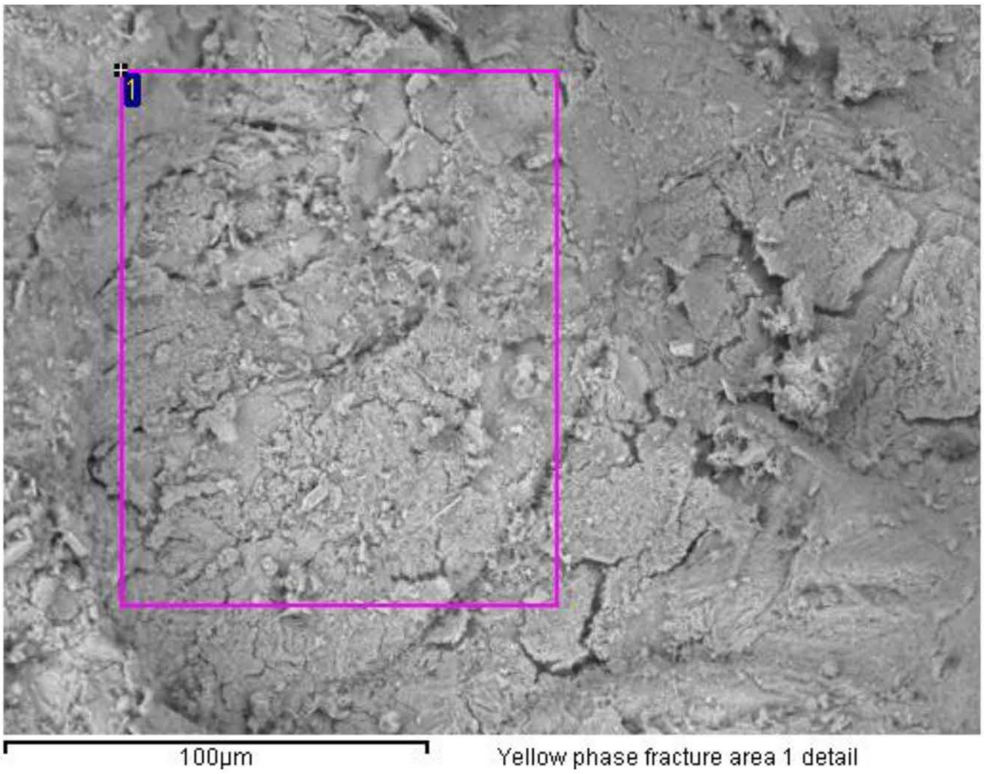

Processing option: All elements analysed (Normalised)

Spectrum	C	O	Cd	Sn	Pb	Total
1	21.5	18.5	1.2	3.3	55.5	100.0

All results in weight%

Figure B.4: EDX chemical analysis of the fracture surface of the lead sheath. The surface is contaminated with significant levels of Lead Carbonate. Cadmium and tin were found to be present as a grain boundary tramp element. No aggressive species such as chlorides present.

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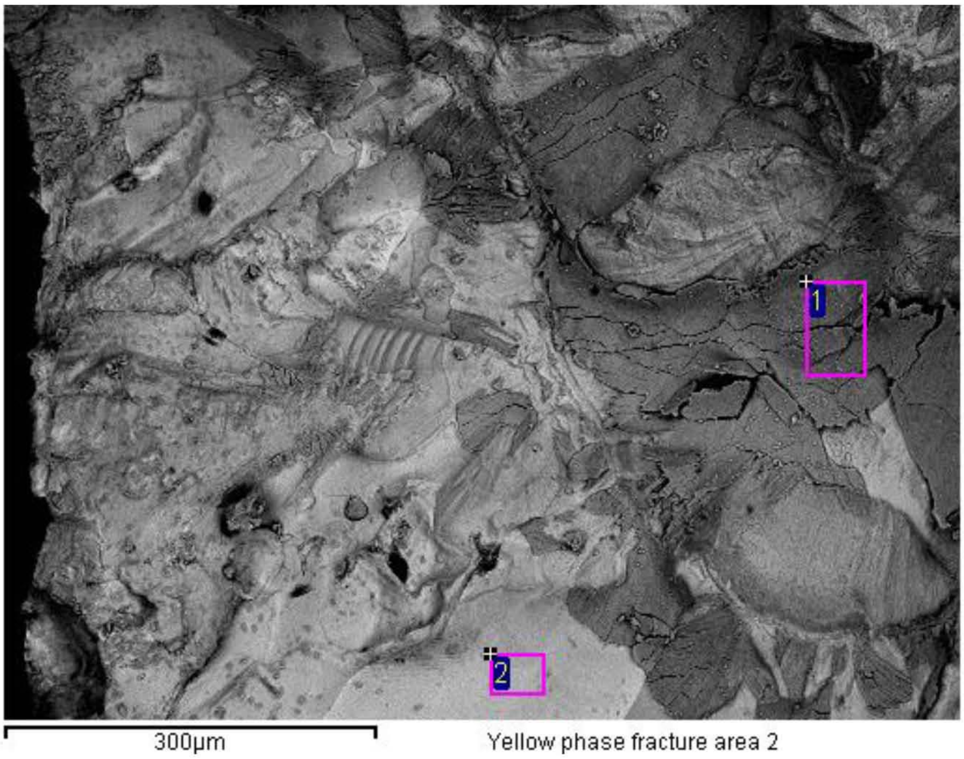


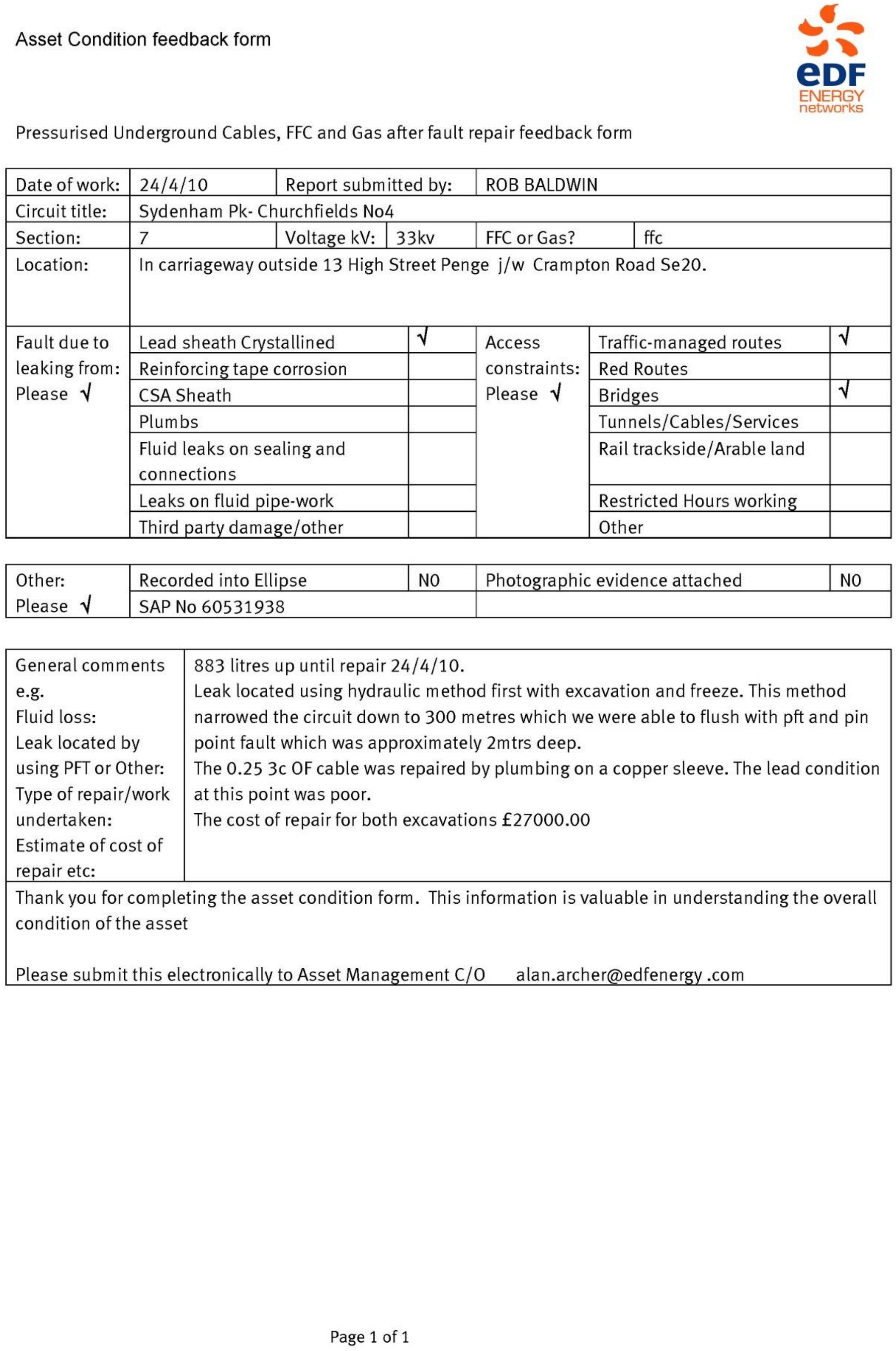
Processing option: All elements analysed (Normalised)

Spectrum	C	O	Pb	Total
1	24.6	17.3	58.1	100.0
2	14.0	9.1	76.9	100.0

All results in weight%

Figure B.5: EDX chemical analysis of the fracture surface of the lead sheath. The surface is contaminated with significant levels of Lead Carbonate. No aggressive species such as chlorides present.

Sydenham Park 33kV-Churchfield:



Asset Condition feedback form

Pressurised Underground Cables, FFC and Gas after fault repair feedback form

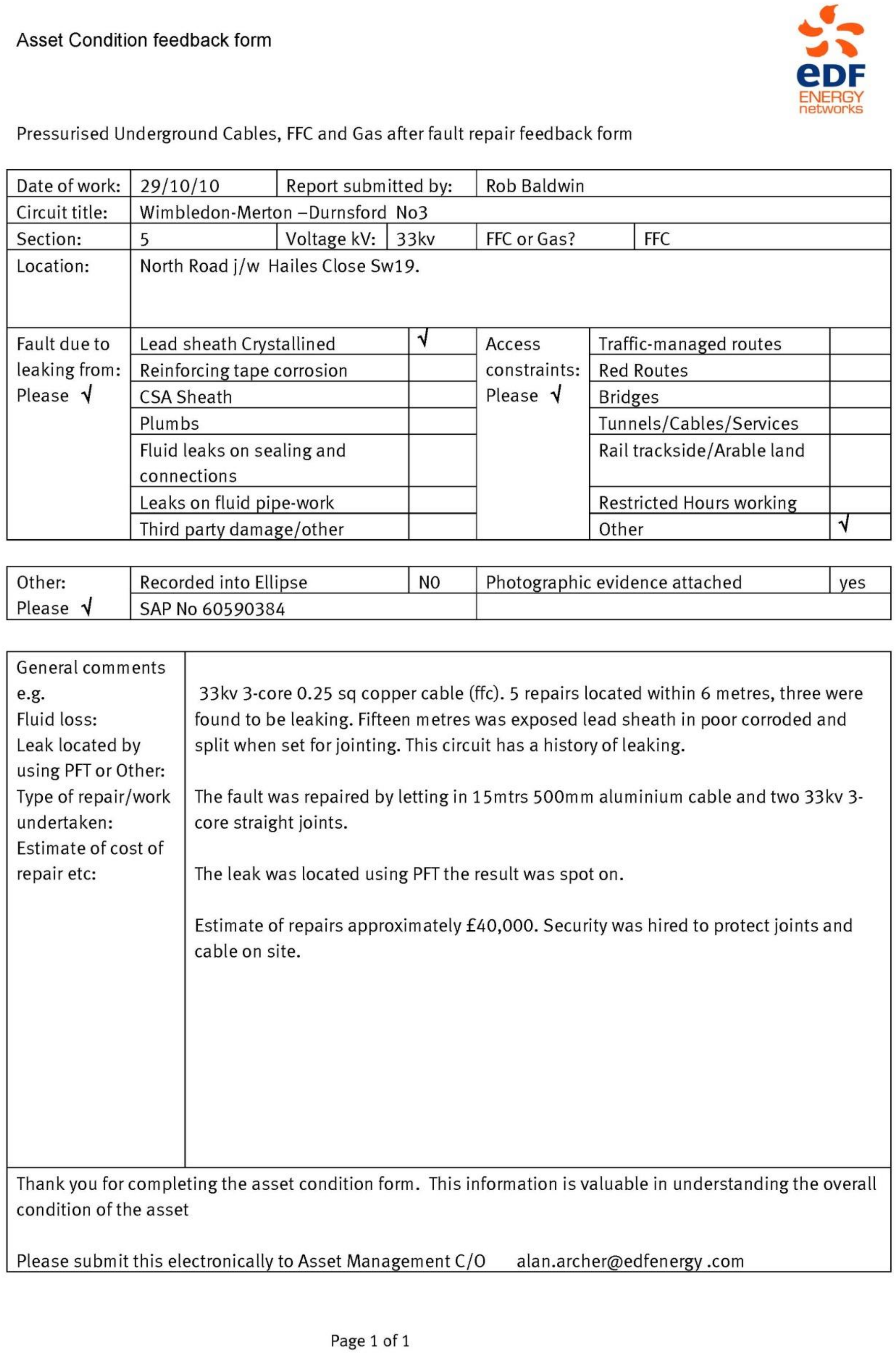
Date of work:	24/4/10	Report submitted by:	ROB BALDWIN		
Circuit title:	Sydenham Pk- Churchfields No4				
Section:	7	Voltage kV:	33kv	FFC or Gas?	ffc
Location:	In carriageway outside 13 High Street Penge j/w Crampton Road Se20.				
Fault due to leaking from: Please √	Lead sheath Crystallined	√	Access constraints: Please √	Traffic-managed routes	√
	Reinforcing tape corrosion			Red Routes	
	CSA Sheath			Bridges	√
	Plumbs			Tunnels/Cables/Services	
	Fluid leaks on sealing and connections			Rail trackside/Arable land	
	Leaks on fluid pipe-work			Restricted Hours working	
	Third party damage/other			Other	

Other: Please √	Recorded into Ellipse	N0	Photographic evidence attached	N0
	SAP No 60531938			

General comments e.g. Fluid loss: Leak located by using PFT or Other: Type of repair/work undertaken: Estimate of cost of repair etc:	883 litres up until repair 24/4/10. Leak located using hydraulic method first with excavation and freeze. This method narrowed the circuit down to 300 metres which we were able to flush with pft and pin point fault which was approximately 2mtrs deep. The 0.25 3c OF cable was repaired by plumbing on a copper sleeve. The lead condition at this point was poor. The cost of repair for both excavations £27000.00
Thank you for completing the asset condition form. This information is valuable in understanding the overall condition of the asset Please submit this electronically to Asset Management C/O alan.archer@edfenergy .com	

Page 1 of 1

Wimbledon-Merton 33kV:



Asset Condition feedback form

Pressurised Underground Cables, FFC and Gas after fault repair feedback form

Date of work:	29/10/10	Report submitted by:	Rob Baldwin		
Circuit title:	Wimbledon-Merton –Durnsford No3				
Section:	5	Voltage kV:	33kv	FFC or Gas?	FFC
Location:	North Road j/w Hailes Close Sw19.				

Fault due to leaking from: Please ✓	Lead sheath Crystallined	✓	Access constraints: Please ✓	Traffic-managed routes	
	Reinforcing tape corrosion			Red Routes	
	CSA Sheath			Bridges	
	Plumbs			Tunnels/Cables/Services	
	Fluid leaks on sealing and connections			Rail trackside/Arable land	
	Leaks on fluid pipe-work			Restricted Hours working	
	Third party damage/other			Other	✓

Other: Please ✓	Recorded into Ellipse	NO	Photographic evidence attached	yes
	SAP No 60590384			

General comments e.g. Fluid loss: Leak located by using PFT or Other: Type of repair/work undertaken: Estimate of cost of repair etc:	33kv 3-core 0.25 sq copper cable (ffc). 5 repairs located within 6 metres, three were found to be leaking. Fifteen metres was exposed lead sheath in poor corroded and split when set for jointing. This circuit has a history of leaking. The fault was repaired by letting in 15mtrs 500mm aluminium cable and two 33kv 3-core straight joints. The leak was located using PFT the result was spot on. Estimate of repairs approximately £40,000. Security was hired to protect joints and cable on site.

Thank you for completing the asset condition form. This information is valuable in understanding the overall condition of the asset

Please submit this electronically to Asset Management C/O alan.archer@edfenergy .com

Page 1 of 1