Document 3
Asset Category – Cables
SPN

Asset Stewardship Report 2014

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Document History

Version	Date	Details	Originator	Revision Class	Section Update
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		All tables amended		Minor	Section 1
		Minor text amended and tables updated		Minor	Section 2
		Minor text amended		Minor	Section 3.1
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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 a 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 the RIIO-ED1 period. Where possible, indicative proposals for the ED2 period are also included.

There are 39,812 kilometres of underground cables of various types in SPN with an estimated MEAV of £5.5 billion. The intervention cost for ED1 is £57.2m across the eight year period.

The proposed investment is £7.15 million per annum and this equates to an average annual 0.1% of the MEAV for this asset category. Replacement cost 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
Fluid-filled cable asset replacement/refurbishment	£5.1m	1.29.01 1.29.02 1.31.01 1.31.04 1.31.08	Additions CV3 Row 63 – 33kV UG Cable (Oil) CV3 Row 93 – 132kV UG Cable (Oil) Removals CV3 Row 191 – 33kV UG Cable (Oil) CV3 Row 221 – 132kV UG Cable (Oil)
Gas cable asset replacement	£0.2m	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 cables asset replacement	£51.9m	1.07.02 1.07.90 1.18.01 1.18.03 1.32.09	Additions CV3 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 62 – 33kV 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 151 – 6.6/11kV OHL (Conventional Conductor) CV3 Row 190 – 33kV 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.

The current fluid-filled cable leakage rates for SPN are around the national average, and the strategy is to maintain this position over the ED1 period.

1.3 ED1 Proposals

Fluid-filled cables (FFC)

Table 2 shows the planned interventions for Fluid-filled cable (FFC) assets in SPN 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 FFC replacement	5	4	0	0	0	3.50	1.70	9	23.20
1.29.02	132kV FFC replacement	0	0	8	0	0	0	0	2.50	10.50
1.31.01	Replace aluminium cable joint plumbs	14	14	14	14	14	14	14	14	112
1.31.04	Install remote pressure-monitoring equipment	7	7	7	7	7	7	7	7	56
1.31.08	Replace pressurised cables ancillary equipment	2	2	2	2	2	2	2	2	16

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 SPN 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	0	0	0	0	0	0	0	7	**7**
1.07.07	132kV gas cable replacement	0	0	0	0	0	0	0.80	10	**10.80**

Table 3 – RIIO-ED1 intervention volumes of gas cables in km

Source: 19th February 2014 NAMP Table O

Solid cables

Table 4 shows the planned interventions for Solid cable assets in SPN through RIIO-ED1.

NAMP line	Description	15/16	16/17	17/18	18/19	19/20	20/21	21/22	22/23	ED1 total
1.07.02	ED1 replace 132kV solid cable provision	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	2.00
1.07.01	ED1 replace 33kV solid cable provision (planned)	1	1	1	1	1	1	1	0.75	7.75
1.18.01	Replace HV cable (planned)	4	4	4	4	4	4	4	4	32
1.18.03	Replace LV cable (planned)	4	4	4	4	4	4	4	4	32
1.32.09	Underground 11kV Overheadline	25	25	25	25	25	25	25	25	200

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

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 these 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 FFC sections to remain in service.	£3.4m
Risk	10 % increase in the proposed ED1 intervention volumes due to sudden degradation of fluid filled cable (FFC) sections..	£2.1m

Table 5 – Risks and opportunities

2.0 Description of Underground Cables

There are 39,812 kilometres of underground cable installed in the SPN area. There are three types of cable construction: solid cable, fluid-filled cable and 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.

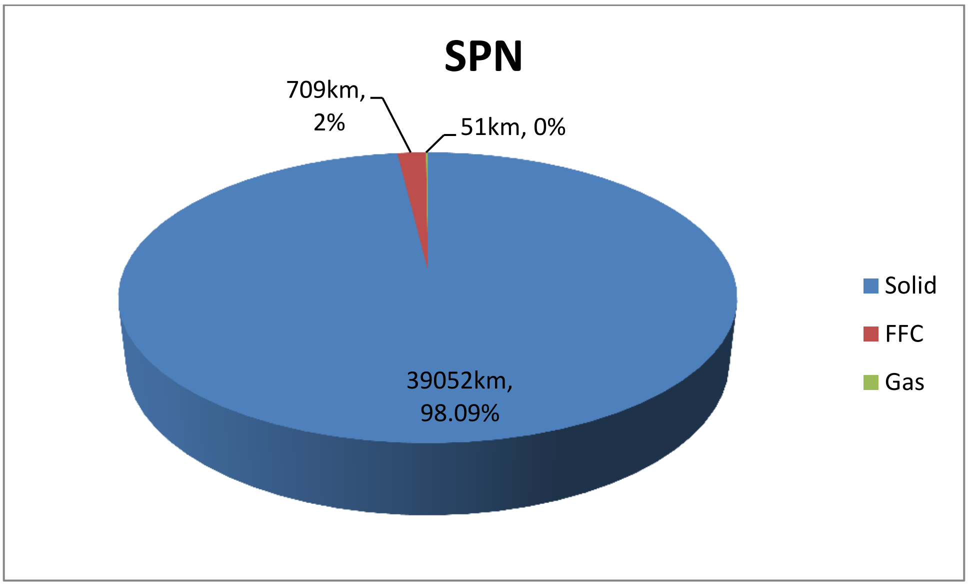

Figure 1 – Population of underground cable by type

Source: RIGs 2012 Table V5

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

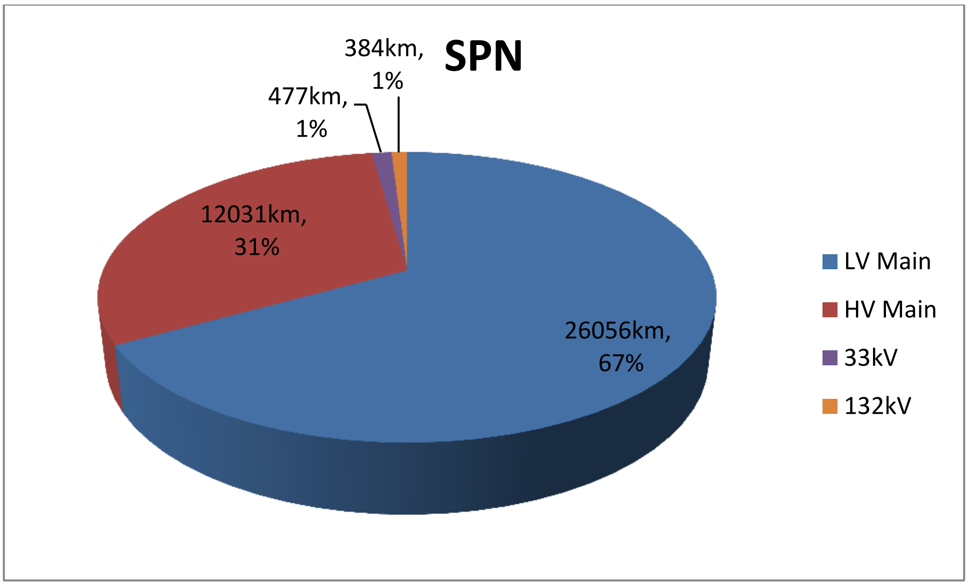

Figure 2 – Population of underground cable by voltage

Source: RIGs 2012 Table V5

The 132kV underground cable network has more fluid cable installed than any other type as can be seen from Figure 3.

Of the 132kV underground cable network, 74% is constructed of either fluid-filled or gas cable.

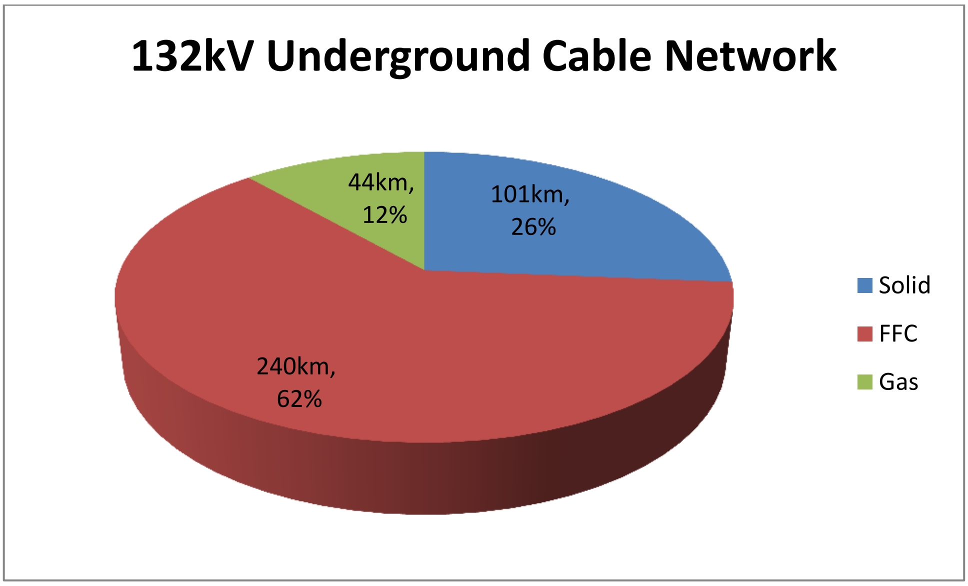

Figure 3 – 132kV underground cable by type

Source: RIGs 2012 Table V5

The EHV underground cable network has more solid cable installed than any other type as can be seen from Figure 4.

Of the EHV underground cable network, 36% is constructed of either fluid-filled or gas cable.

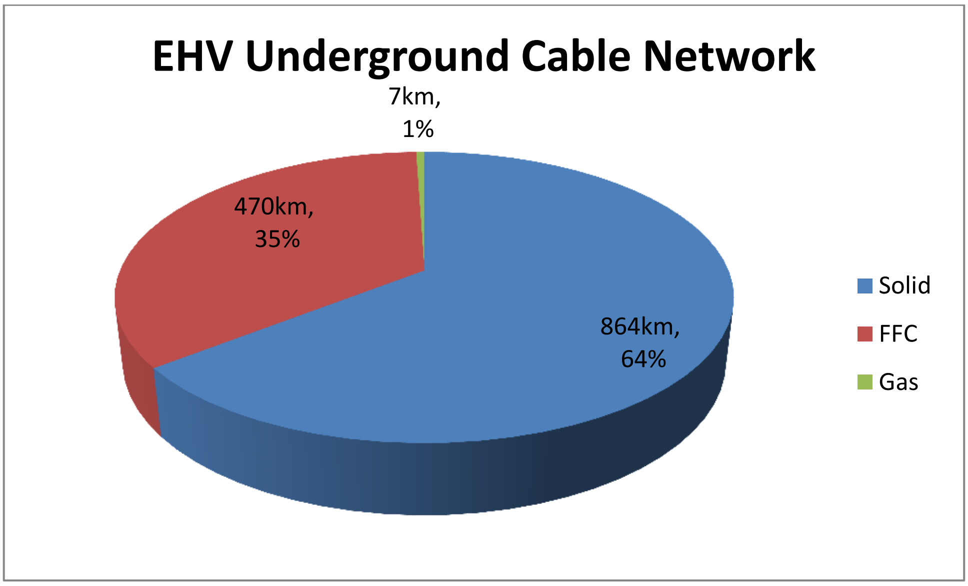

Figure 4 – EHV underground cable by type

Source: RIGs 2012 Table V5

2.1 Fluid-Filled Cables

As mentioned in Section 2.0, there is more fluid-filled cable installed at 132kV or EHV than any other cable type. The 709 kilometres of FFC installed are split between 33kV and 132kV.

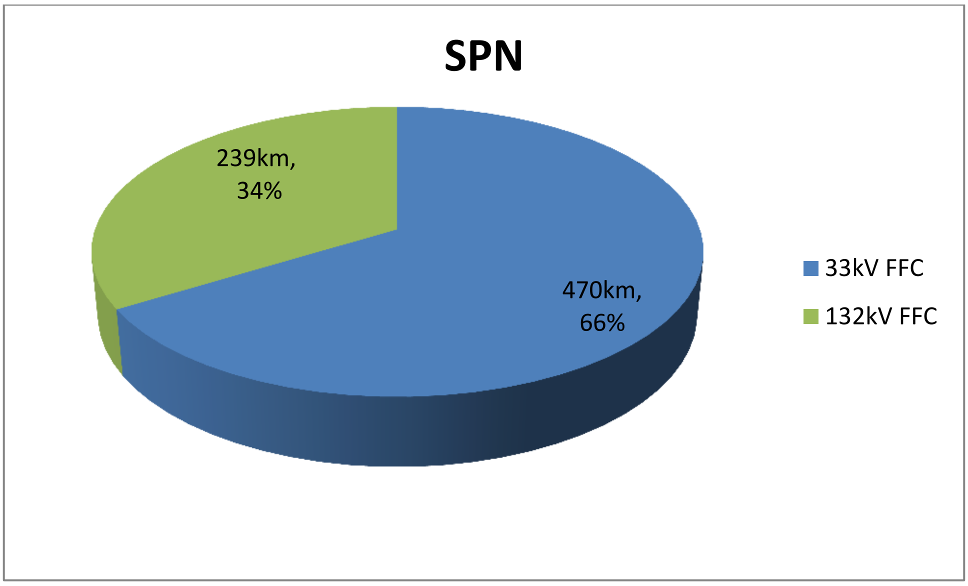

Figure 5 – Population of underground fluid-filled cable (FFC) by voltage

Source: RIGs 2012 Table V5

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

The average age of the fluid-filled cable network is 48 years. The oldest 10% of these assets has an average age of approximately 82 years.

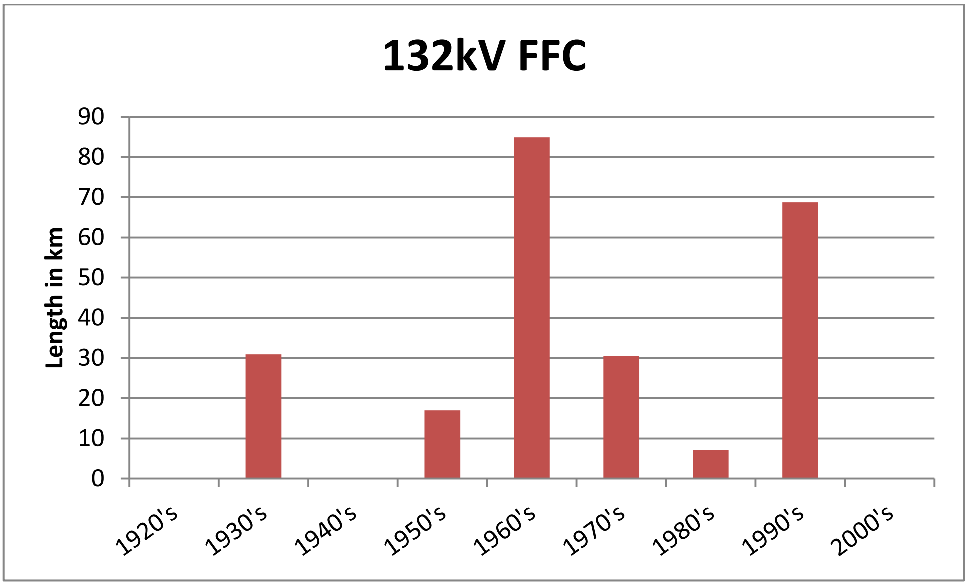

Figure 6 – Age profile of 132kV FFC cable

Source: RIGs 2012 Table V5

The average age of the 132kV fluid-filled cable network is 46 years

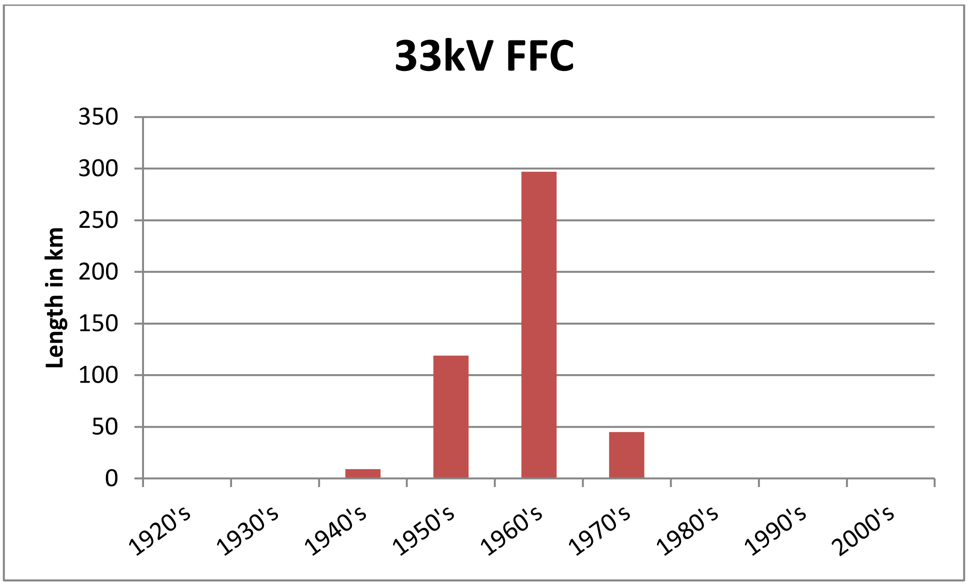

Figure 7 – Age profile of 33kV FFC cable

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 43 kilometres of gas cable installed is at 132kV.

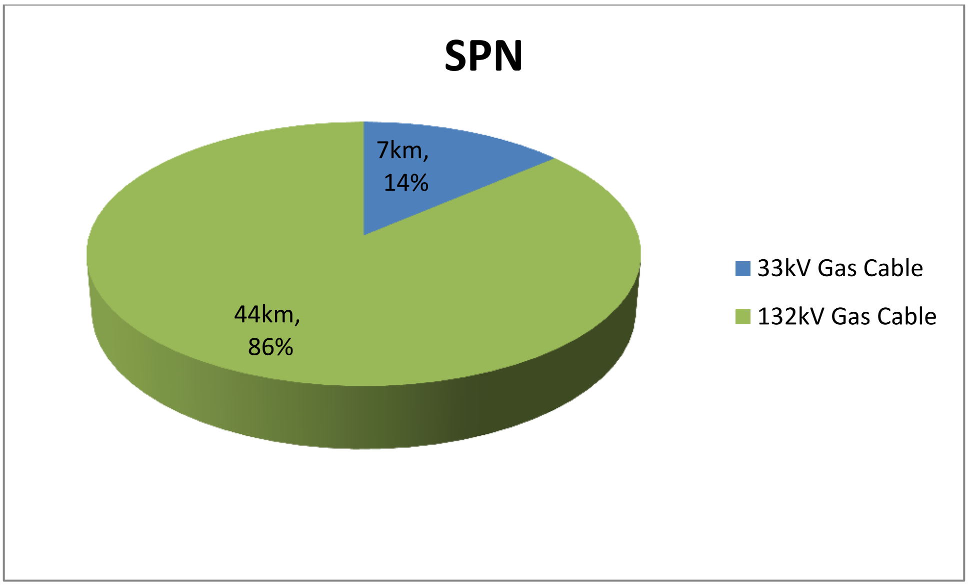

Figure 8 – Population of underground gas cable by voltage

Source: RIGs 2012 Table V5

As can be seen in the age profile graphs below, most of the gas cable at all voltages was installed in the 1960s and 1970s. The average age of the gas cable network is 45 years.

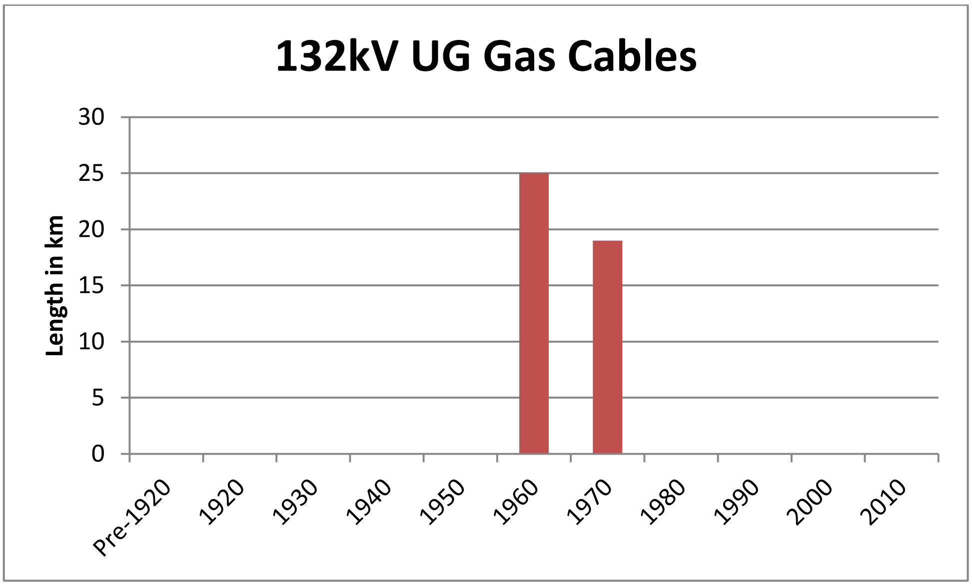

Figure 9 – Age profile of 132kV gas cable

Source: RIGs 2012 Table V5

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

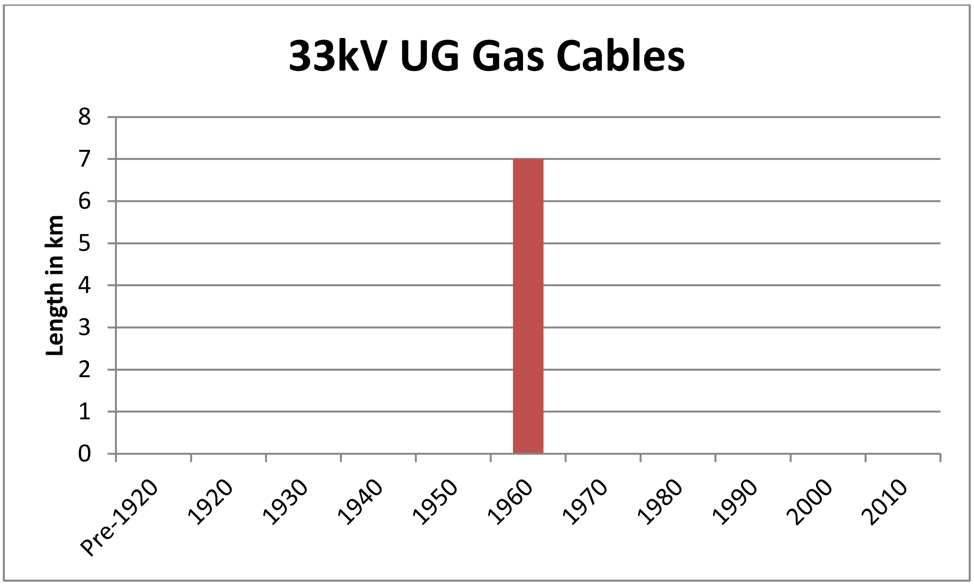

Figure 10 – Age profile of 33kV underground gas cable

Source: RIGs 2012 Table V5

The average age of the 33kV gas cable network is 53 years.

Reference NAMP lines

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

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

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 lines

2.3 Solid Cables

There are a number of different types of solid cables in operation in the SPN 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 below.

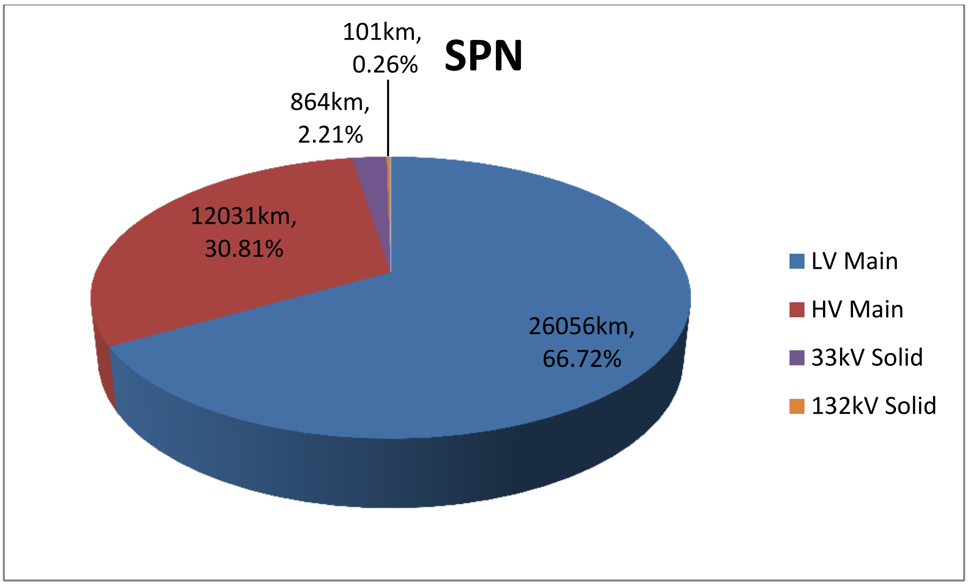

Figure 11 – Population of underground solid cable by voltage

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.

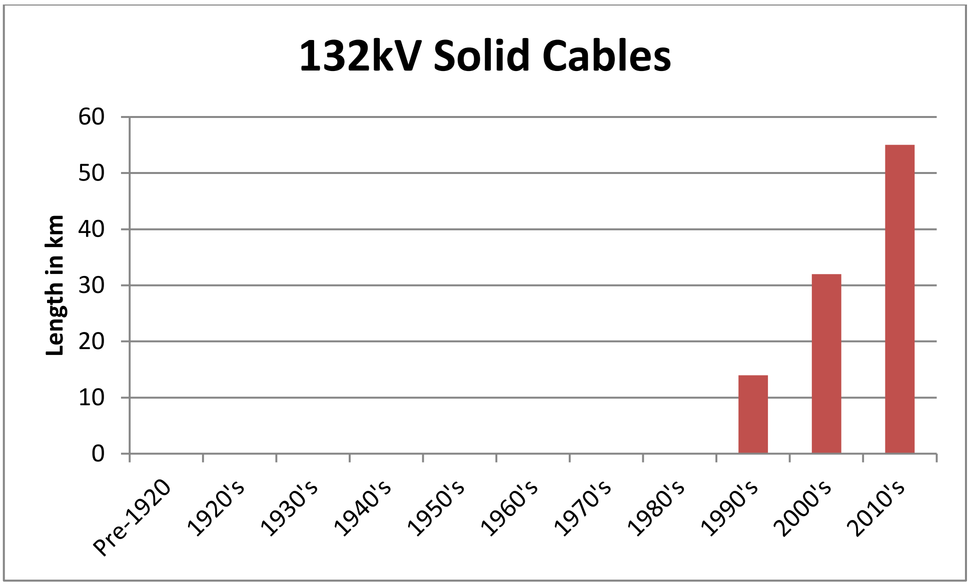

Figure 12 – Age profile of 132kV underground solid cable

Source: RIGs 2012 Table V5

The average age of the 132kV solid cable network is 5 years.

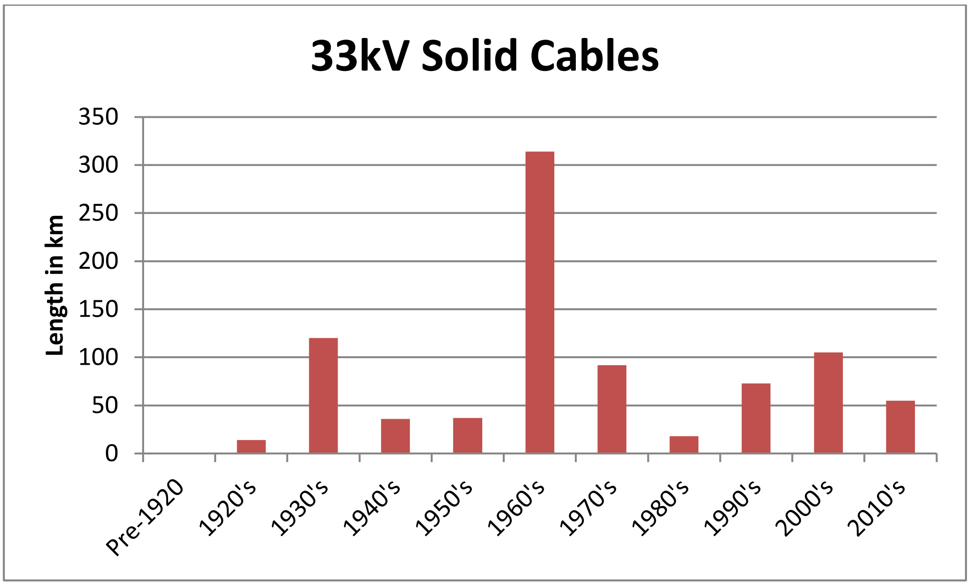

Figure 13 – Age profile of 33kV underground solid cable

Source: RIGs 2012 Table V5

The average age of the 33kV solid cable network is 43 years.

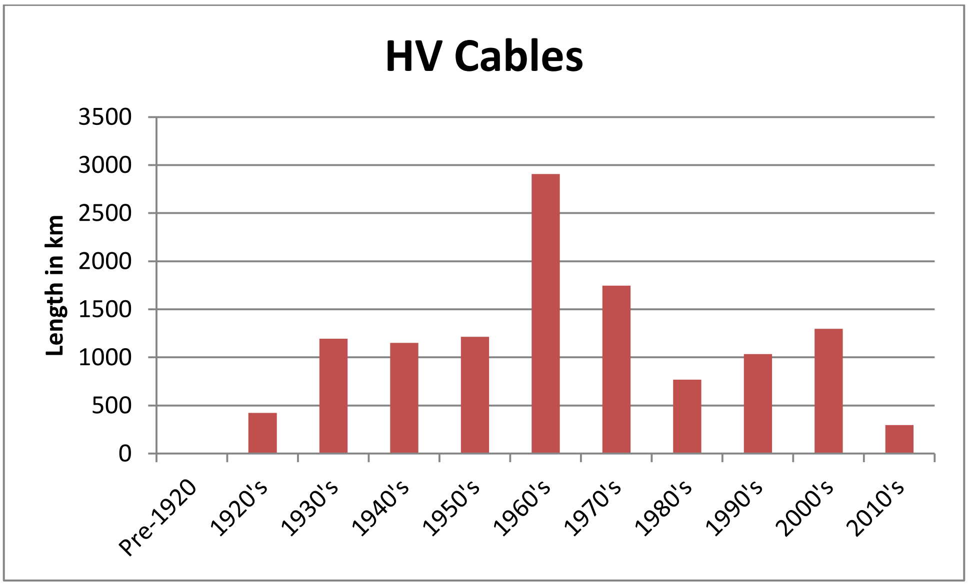

Figure 14 – Age profile of HV underground solid cable

Source: RIGs 2012 Table V5

The average age of the HV solid cable network is 45 years.

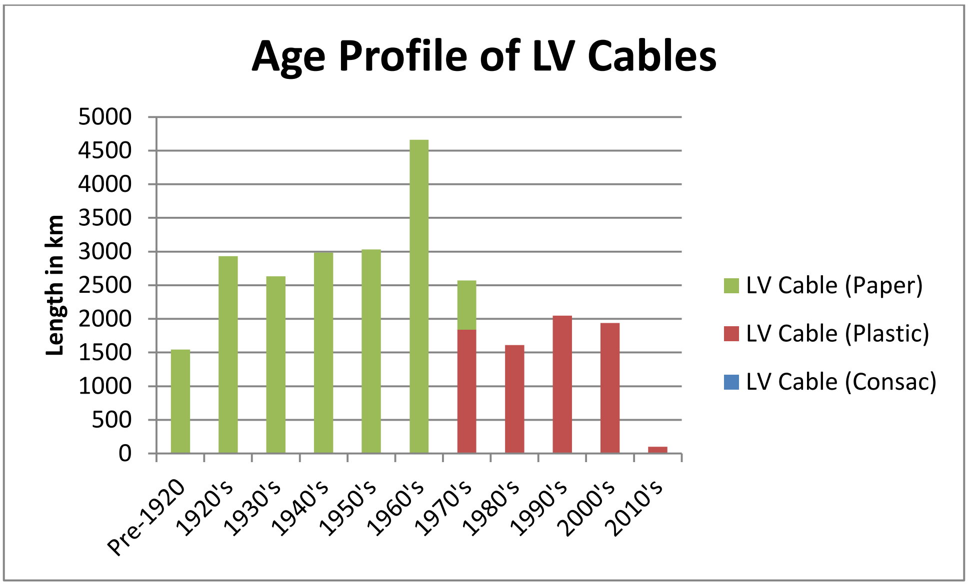

Figure 15 – Age profile of LV underground solid cable

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

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 10 – RIGs lines

3.0 Investment Drivers

The high-level investment drivers for underground cables are detailed in EDP 00-0009 *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 cabled 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 lengths 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 is 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 sections or circuits can still be 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 as 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 16 – Crystallised lead sheath

Figure 17 – 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 SPN contributes 13% of fluid top-ups nationally, which on a per-kilometre basis is around 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 in Figure 18.

This shows that the implementation of the proposed investment plan will maintain leakage rates at roughly the same level throughout the ED1 period. The leakage rate with intervention prediction includes a 2.5% 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 32% over the ED1 period.

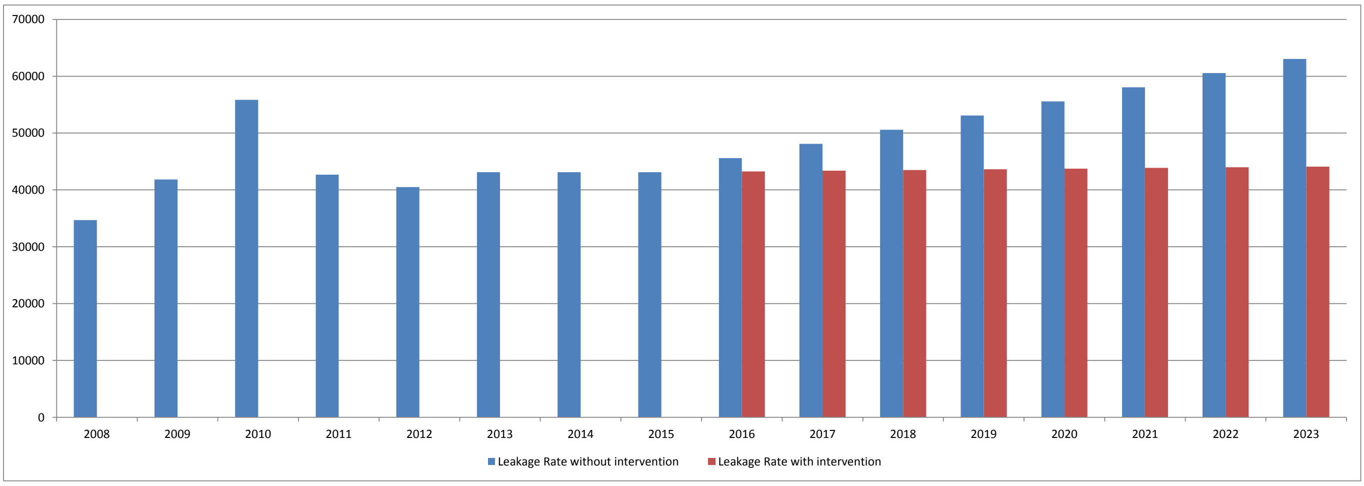

Figure 18 – Fluid-filled cable leakage with and without intervention

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.

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 for 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 licencees “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 per 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 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'[1] report in 1988 highlighted a number of inherent design flaws associated with gas compression pipeline cables, including 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 repressurise the system.

During this time, network security is severely compromised as 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 following 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.

3.4 Cable Fault Rates

The figures show fault rates for cables by voltage level. It is not possible to separate out different cable types from the data. Overall cable fault rates are increasing at all voltages.

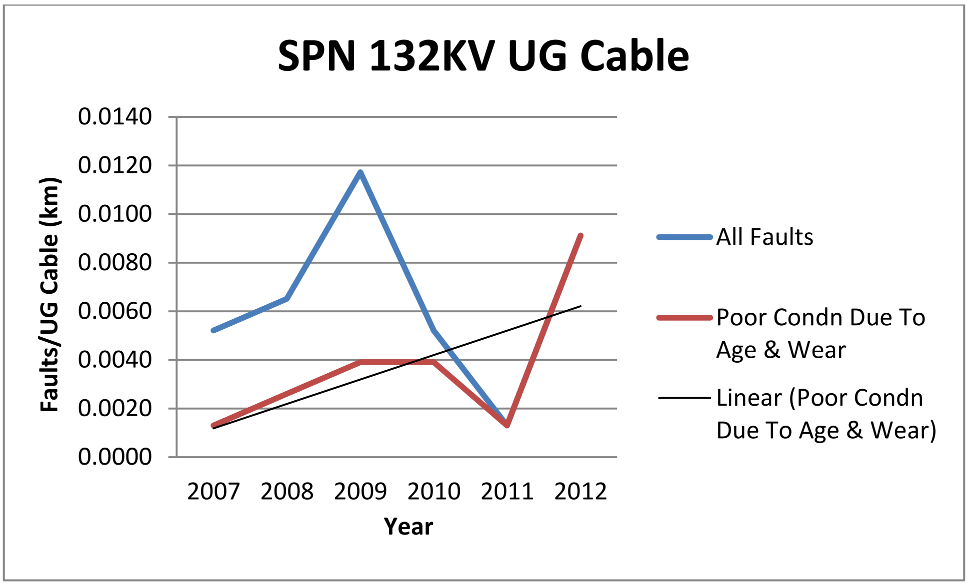

Figure 19 – Fault trends of 132kV underground cable

Source: UKPN Faults Cube

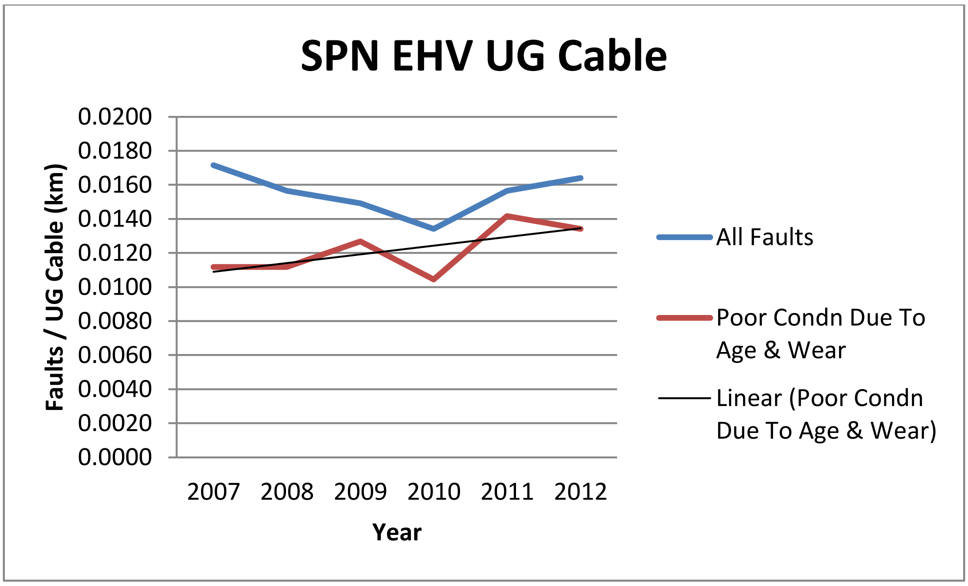

Figure 20 – Fault trends of EHV underground cable

Source: UKPN Faults Cube

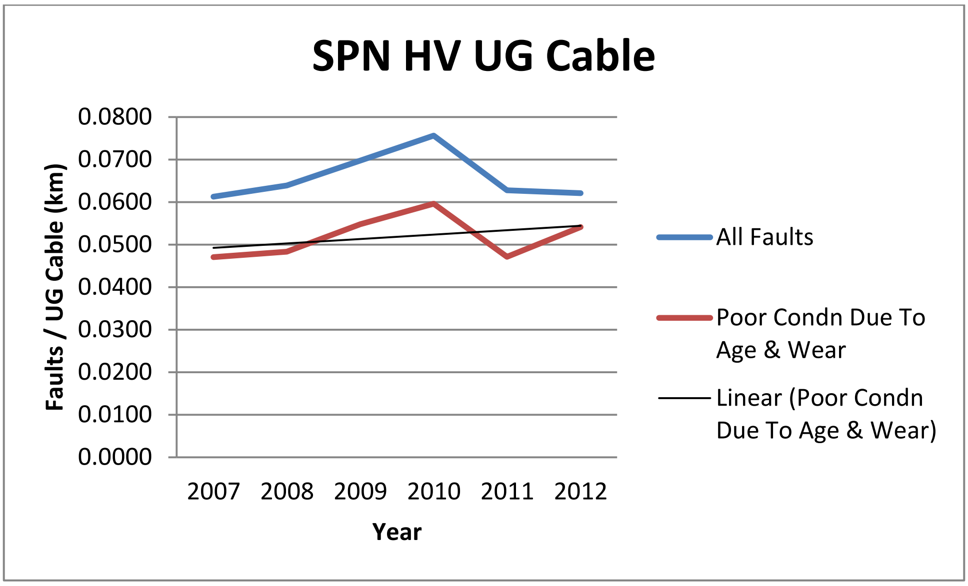

Figure 21 – Fault trends of HV underground cable

Source: UKPN Faults Cube

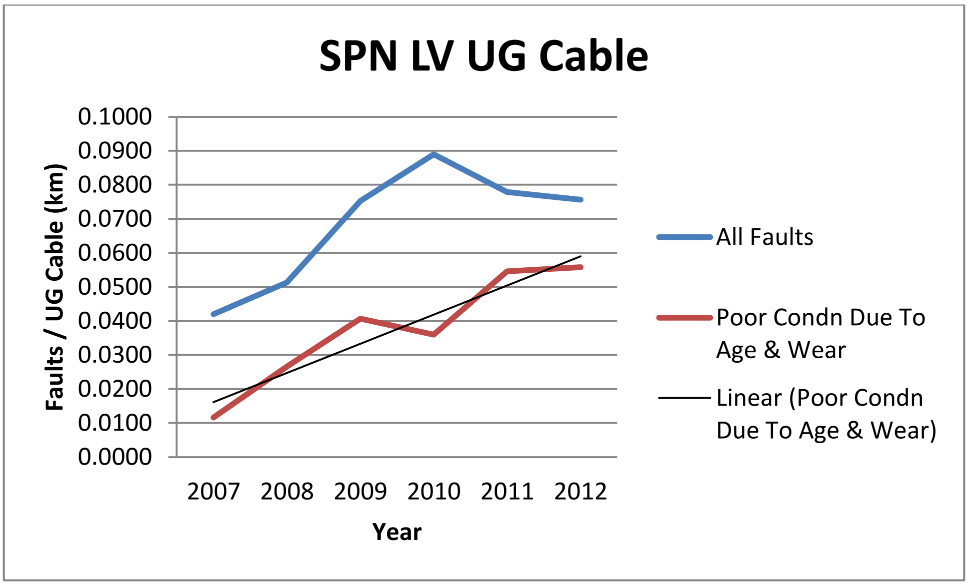

Figure 22 – Fault trends of LV underground cable

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 (as described in Condition information):

- condition
- oil leakage history
- fault history.

An interim final Health Index is calculated for each section. This is the product of the overall factor value and the initial age-related Health Index (see age-related Health Index section).

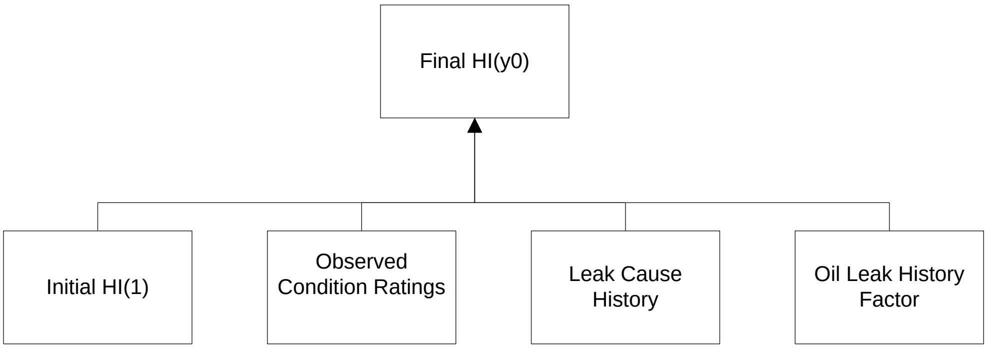

Figure 23 – Flowchart showing calculation of Health Index from ARP model

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 assets; 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 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 allowing continual improvement of data quality.

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	87 %
Accuracy	Not available*
Timeliness	Not available*

Table 11 – 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, 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. 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 24 shows a 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.

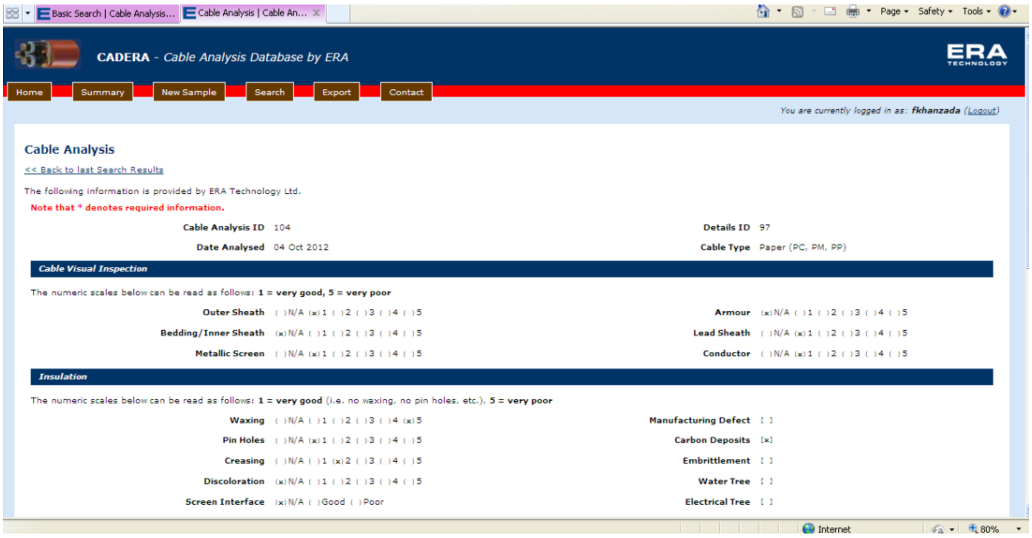

Figure 24 – Snapshot of the cable analysis database

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 taken 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 the 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 being installed during the DPCR5 period and is expected to be complete by end of DPCR5 period.

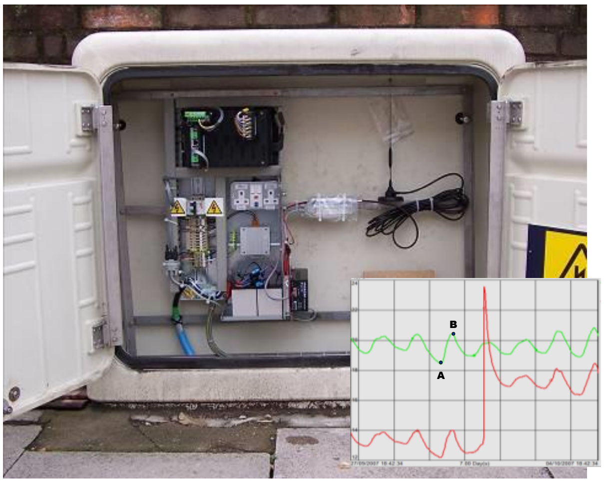

Figure 25 – Online pressure-monitoring system

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 26 – 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 damage to the sheath will selfheal, avoiding oil leakage and a 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. There would potentially be subsequent laboratory and field trial phases, depending on the success of this phase.

6.2 Gas-Filled Cables

UK Power Networks has introduced a novel and innovative design of three core XLPE cable for retrofitting into the existing steel pipe, which used to contain obsolete and poorly performing gas compression cable. It is a low-cost solution with less environmental impact compared to a new open-cut trench. Work also involved the development and type testing of a transition joint to existing gas compression cable.

The technique has already been successfully trialled by UK Power Networks on the Laleham–Twickenham circuits in the SPN licence area.

6.3 Solid Cables

6.3.1 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 through design modification 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.

6.3.2 Innovative design of 33kV and 11kV solid cables

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

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

6.3.3 Partial discharge monitoring system on HV cable network

The use of partial discharge (PD) measurement is a well-known method for 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 27 shows some typical screen shots from the online PD monitoring system, highlighting activity on 11kV cables at Brighton Town 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 27– Partial discharge activity of 11kV cables at Brighton Town substation (SPN)

6.3.4 New cable jointing resin

New greener jointing resin has been introduced, which will reduce the number of joint failures due to its higher viscosity and better penetration into the body of a joint.

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 28. This programme has been produced with the assistance of the Asset Replacement Prioritisation (ARP) tool.

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

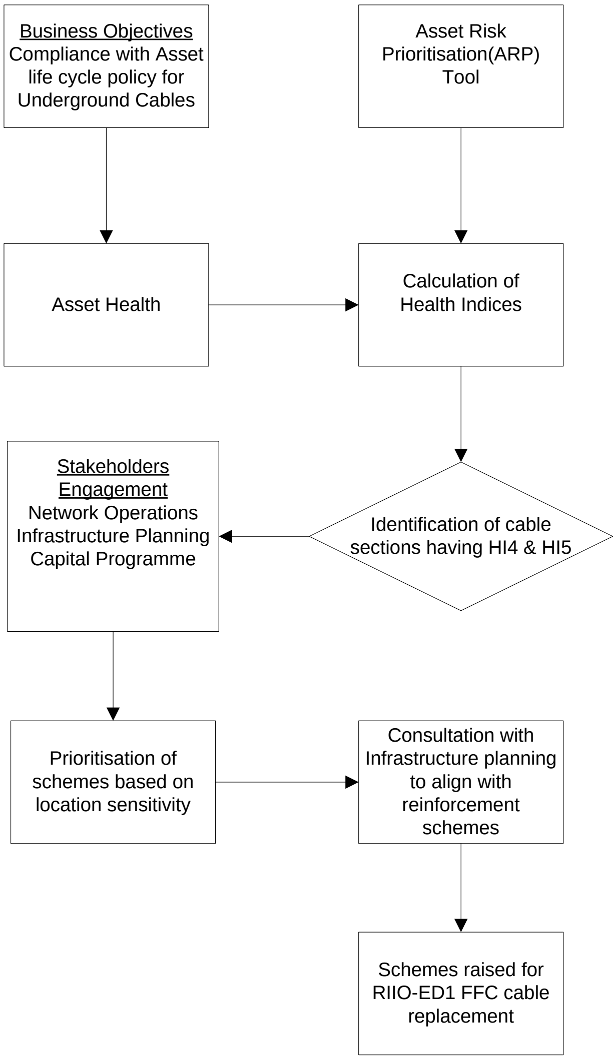

Figure 28 – Construction of NLRE plan for FFC replacement

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 SPN licence area have been included for removal before the end of the ED1 period.

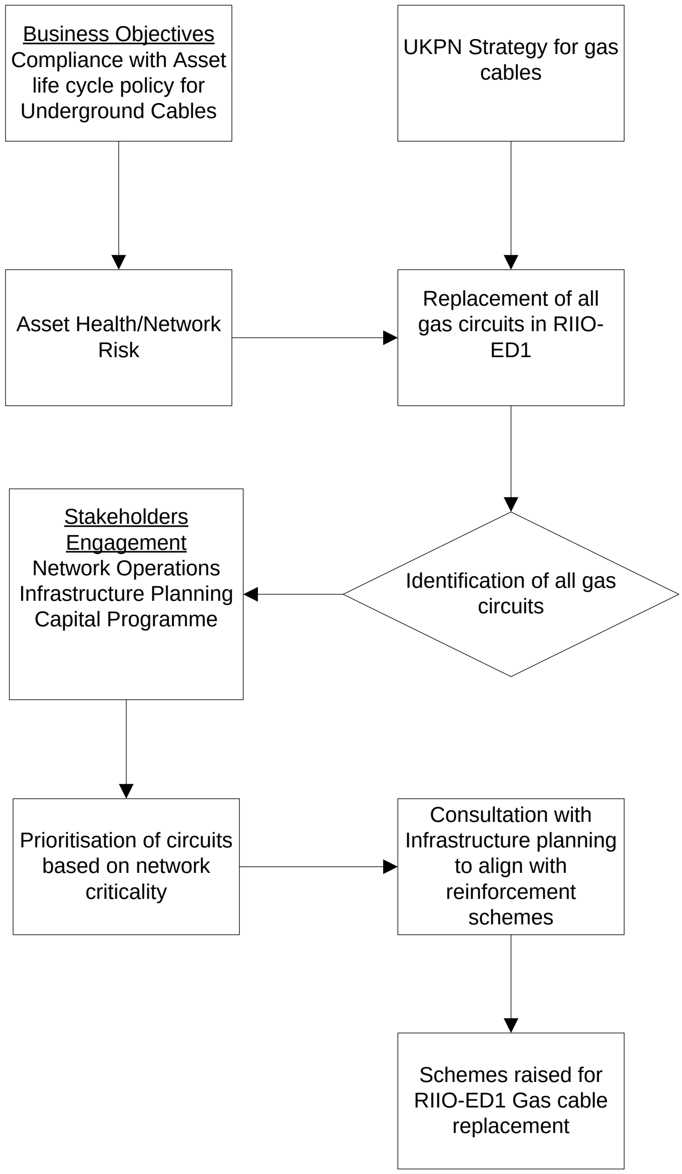

Figure 29 – Construction of NLRE plan for gas cable replacement

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.

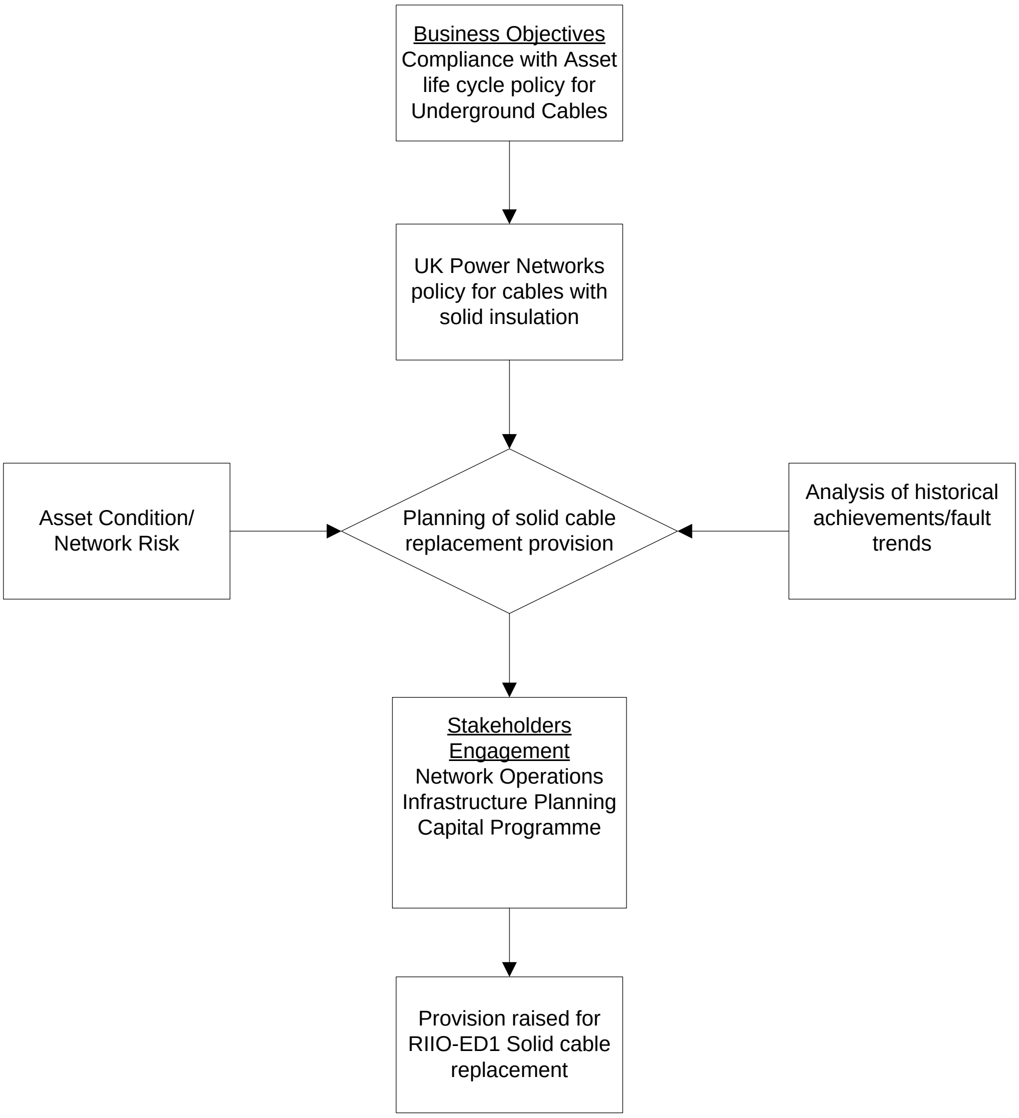

Figure 30 – Construction of NLRE plan for solid cable replacement

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 maintain maintain leakage rates at roughly the same level throughout the ED1 period. To achieve this, the ARP model was used to determine the HI profiles for 132kV 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.

Figure 31 and Figure 32 show how the lengths of HI4 and HI5 fluid-filled cable are projected to change over the remaining period of DPCR5 and ED1 both with and without investment.

HI profiles

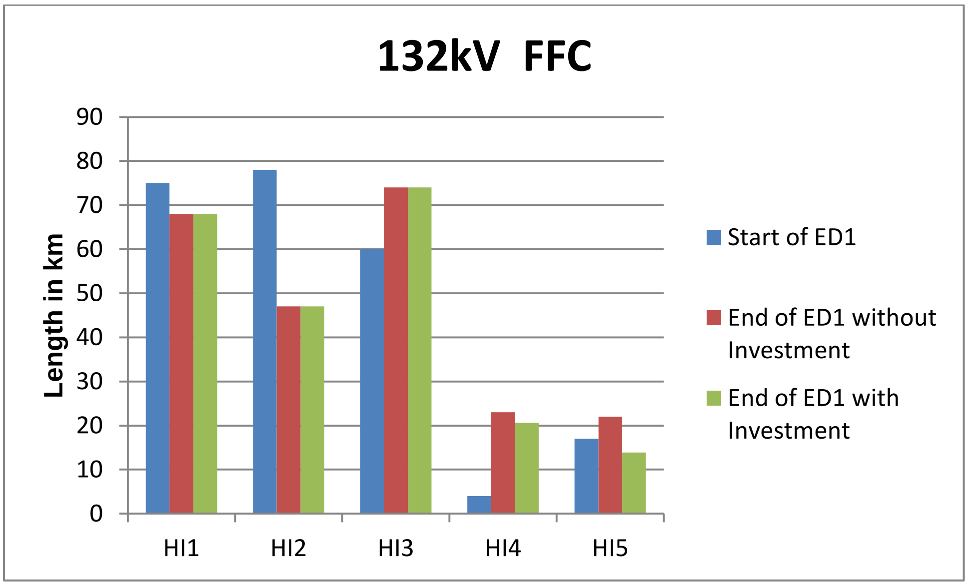

Figure 31– HI profiles of 132kV fluid-filled cables (FFC)

Source: ARP Model W_FFC_25Jul2012_March 2014 submission

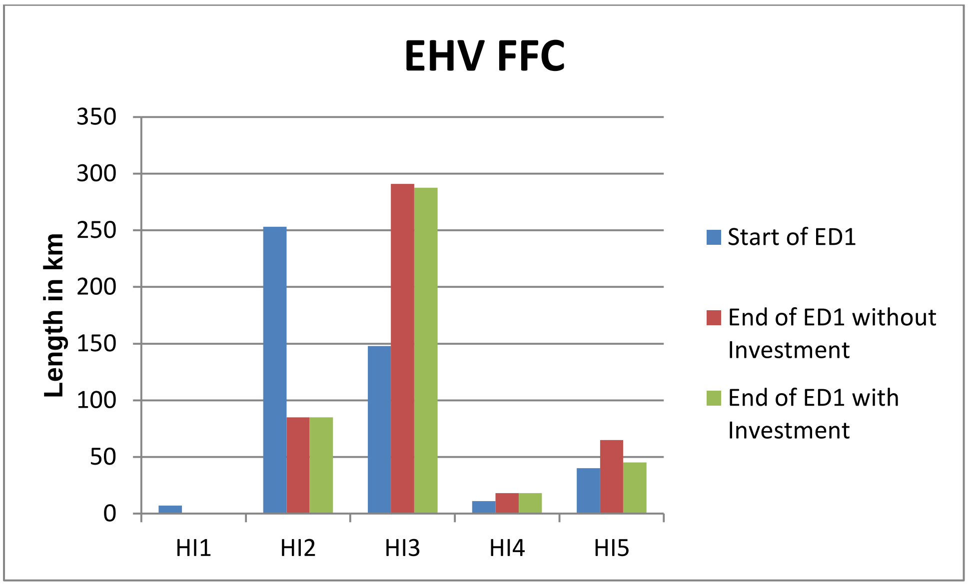

Figure 32 – HI profiles of EHV fluid-filled cables (FFC)

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.

7.2.1 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, Investment Drivers. This is in line with nationally accepted industry best practice in the UK.

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

HIs are not calculated for gas cables and so HI graphs are not available.

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.

7.2.2 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 the ED1 plan.

7.4 Asset Volumes and Expenditure

7.4.1 132kV Fluid-Filled Cables

In total, there are 10.50km of 132kV fluid-filled cables proposed for intervention during ED1. This represents 4.4% of the installed population of 132kV FFC in SPN. The ED2 figures shown in the graph 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.

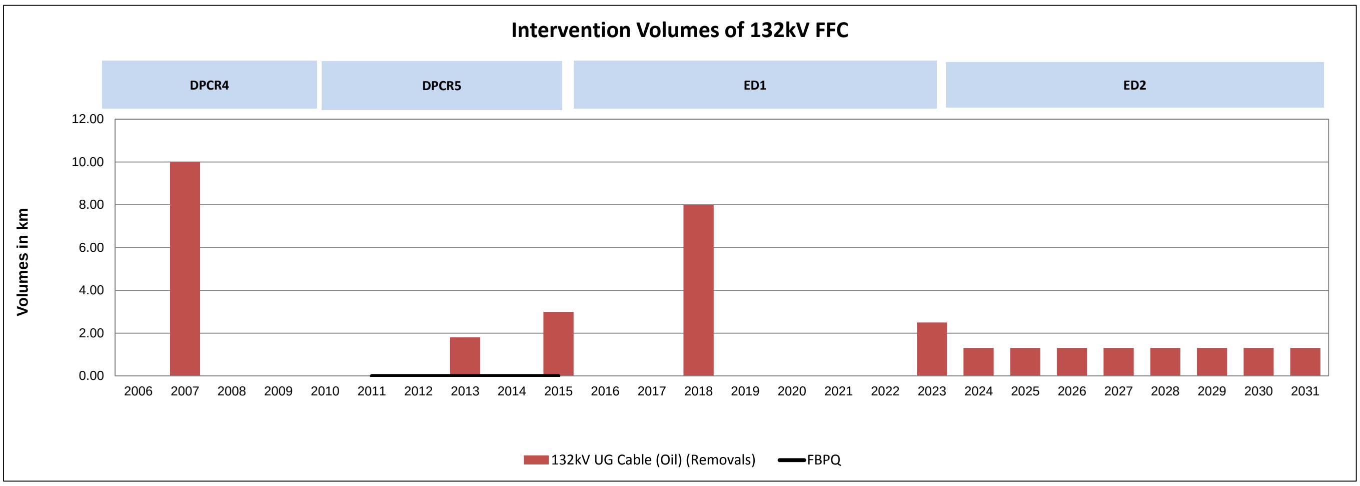

Figure 33 – Intervention volumes of 132kV fluid-filled cables

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 £13.81m.

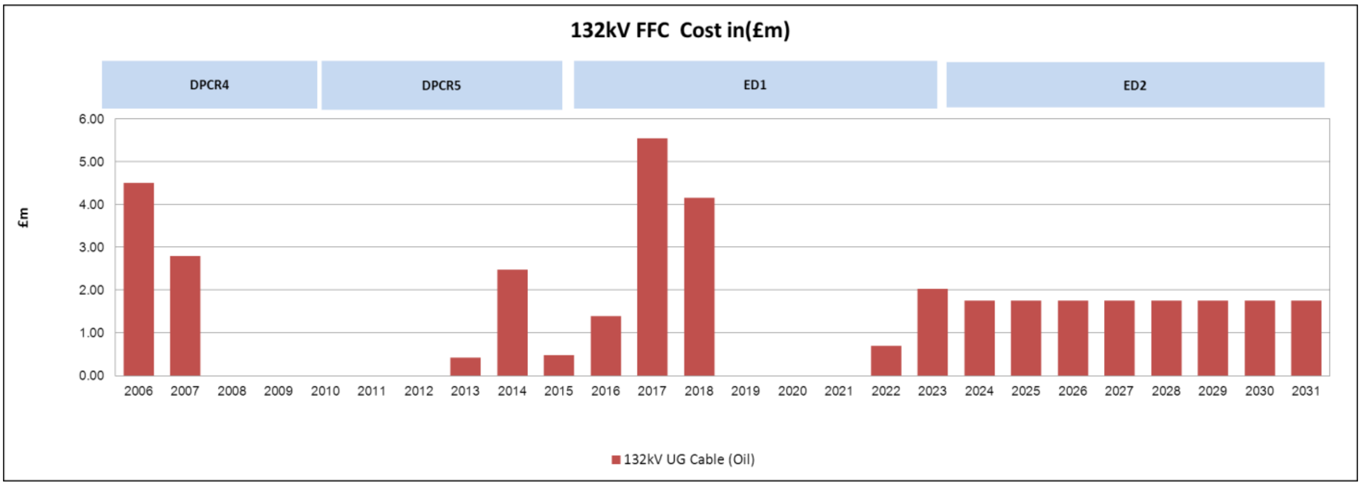

Figure 34 – Intervention cost of 132kV fluid-filled cables

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 23.20km of EHV hydraulic sections proposed for intervention during ED1. This represents 4.9% of the installed population of EHV FFC in SPN. The ED2 figures shown in the graph 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.

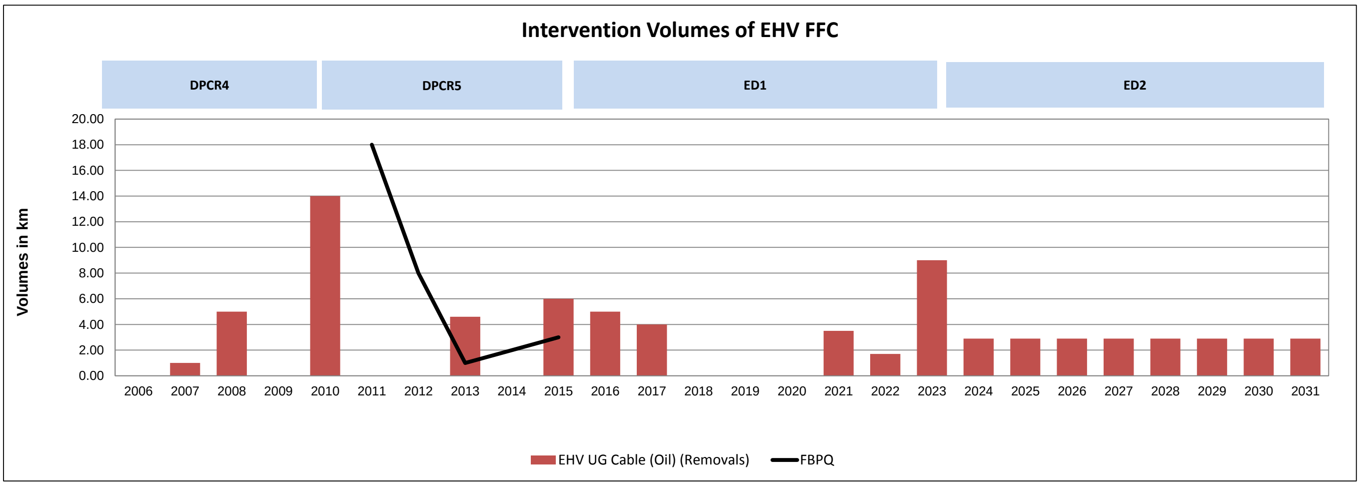

Figure 35 – Intervention volumes of EHV fluid-filled cables

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 £7.51m.

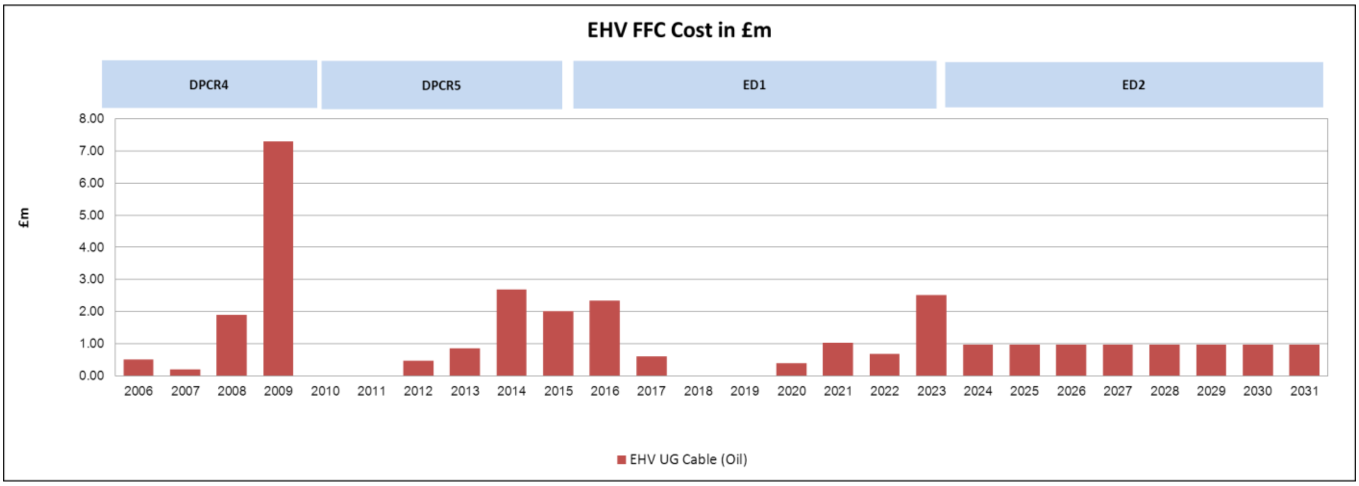

Figure 36 – Intervention cost of EHV fluid-filled cables

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 10.8km of 132kV gas cables proposed for intervention during ED1.

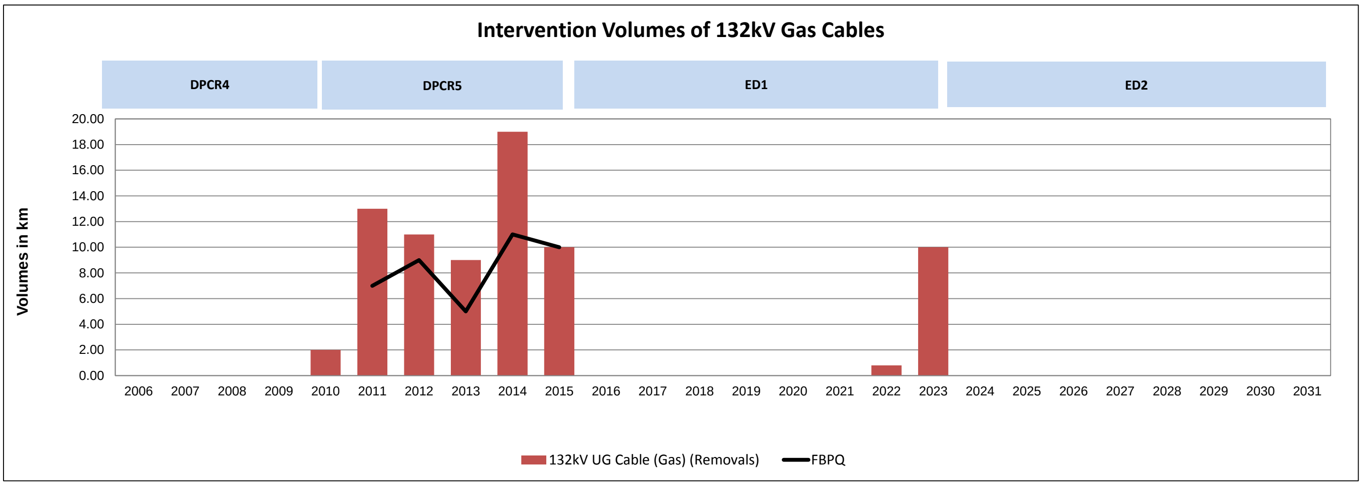

Figure 37 – Intervention volumes of 132kV gas cables

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 £1.17m.

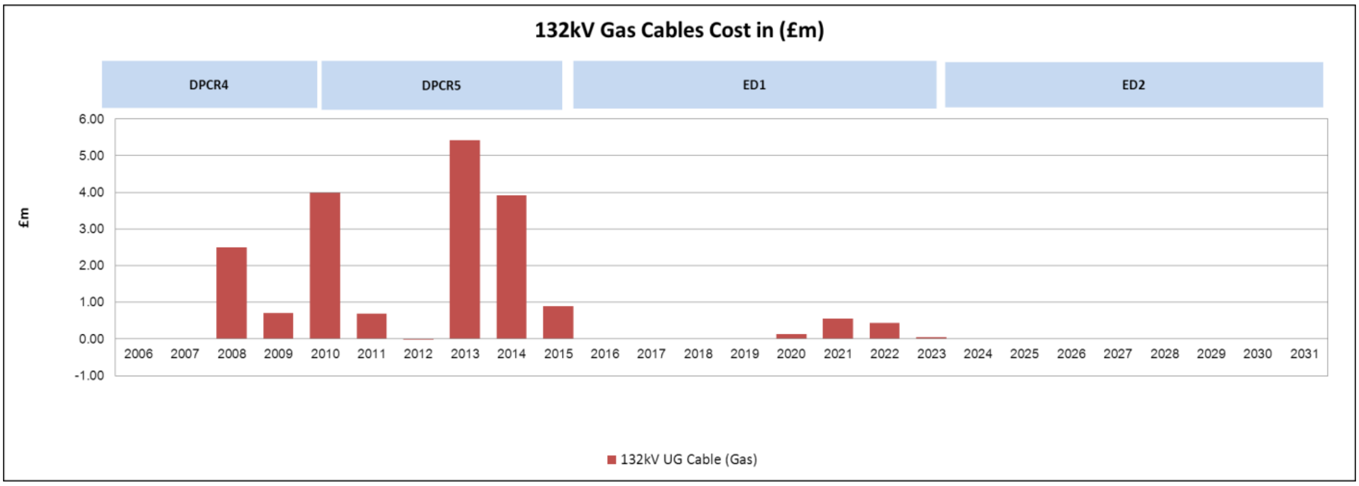

Figure 38 – Intervention cost of 132kV gas cables

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 7km of EHV gas cables are proposed for interventions during ED1.

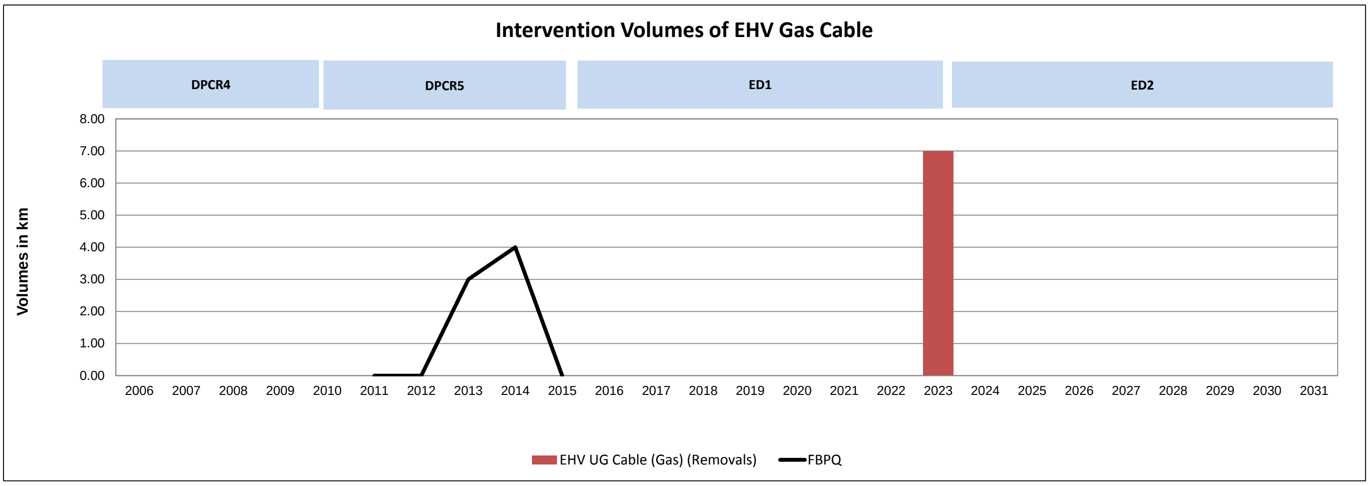

Figure 39 – Intervention volumes of EHV gas cables

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 £2.11m.

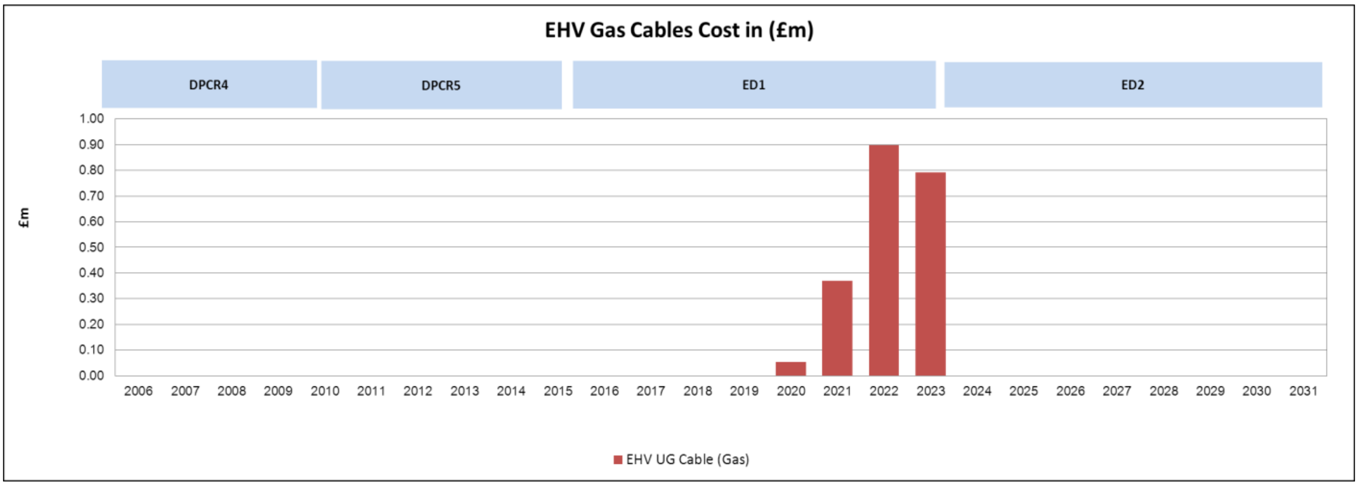

Figure 40 – Intervention cost of EHV gas cables

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 2 kilometres of 132kV solid cable proposed for intervention during ED1. This represents 2% of the installed population in SPN. The ED2 figures shown in the graph below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2.

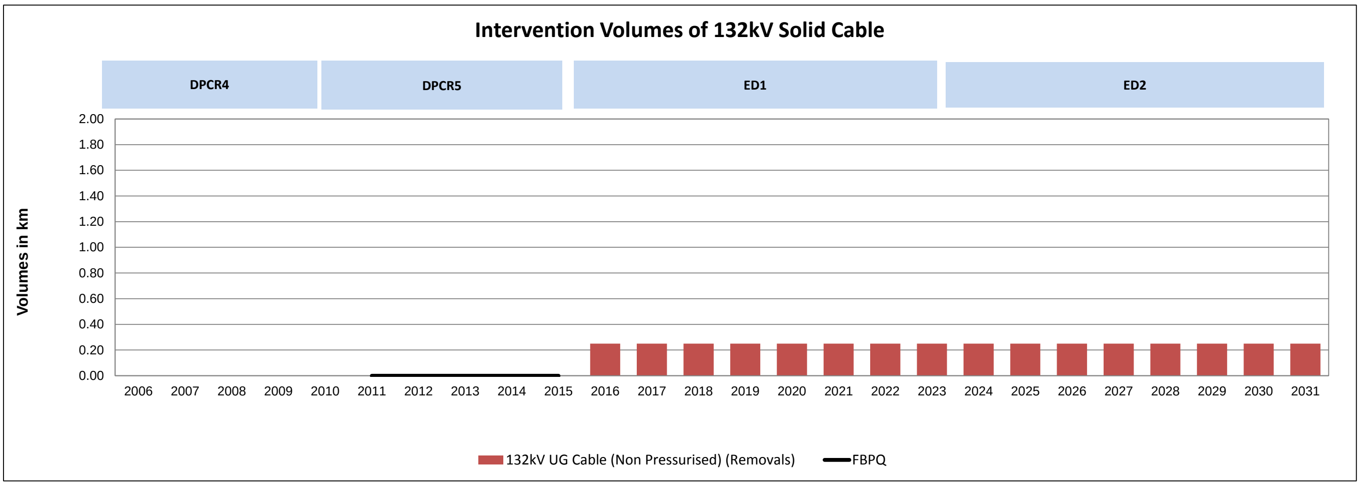

Figure 41 – Intervention volumes of 132kV solid cables

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 £2.44m.

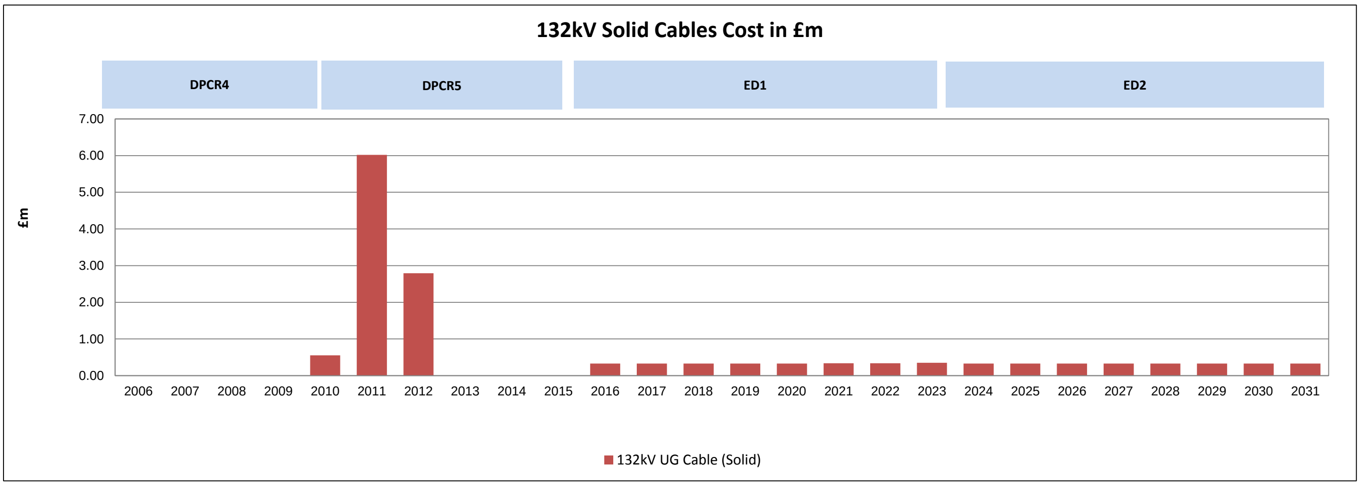

Figure 42 – Intervention cost of 132kV solid cables

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 7.75 kilometres of EHV solid cables proposed for intervention during ED1. This represents 0.9% of the installed population in SPN. The ED2 figures shown in the graph below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2

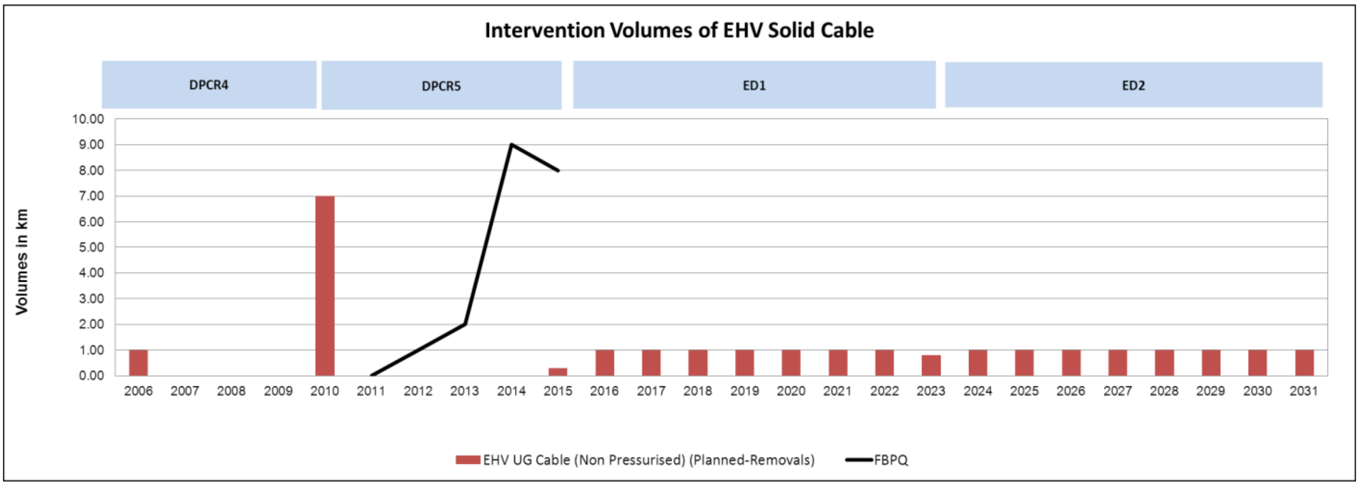

Figure 43 – Intervention volumes of EHV solid cables

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 £2.33m.

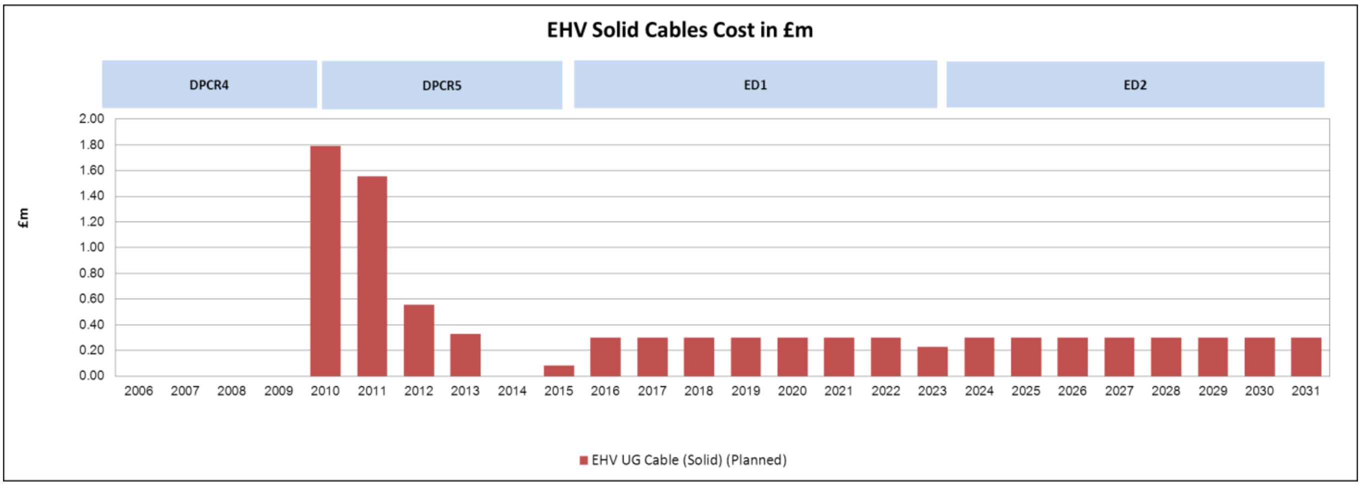

Figure 44 – Intervention cost of EHV solid cables

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 32 kilometres of HV solid cable proposed for intervention during ED1. This represents 0.3% of the installed population in SPN. The ED1 figures in the graph below also include volumes for undergrdounding 11kV overheadline as a result of quality of supply (QOS) driven work.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.

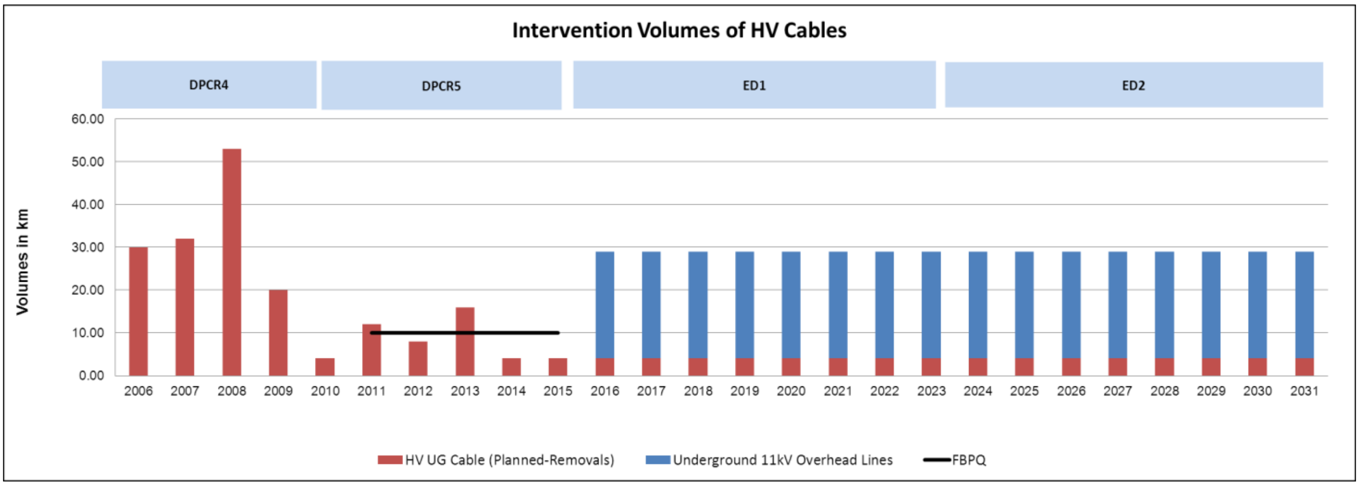

Figure 45 – Intervention volume of HV solid cables

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 £14.64m which includes £2.80m for HV planned cable replacement and £11.84 for undergrounding 11kV overheadline.

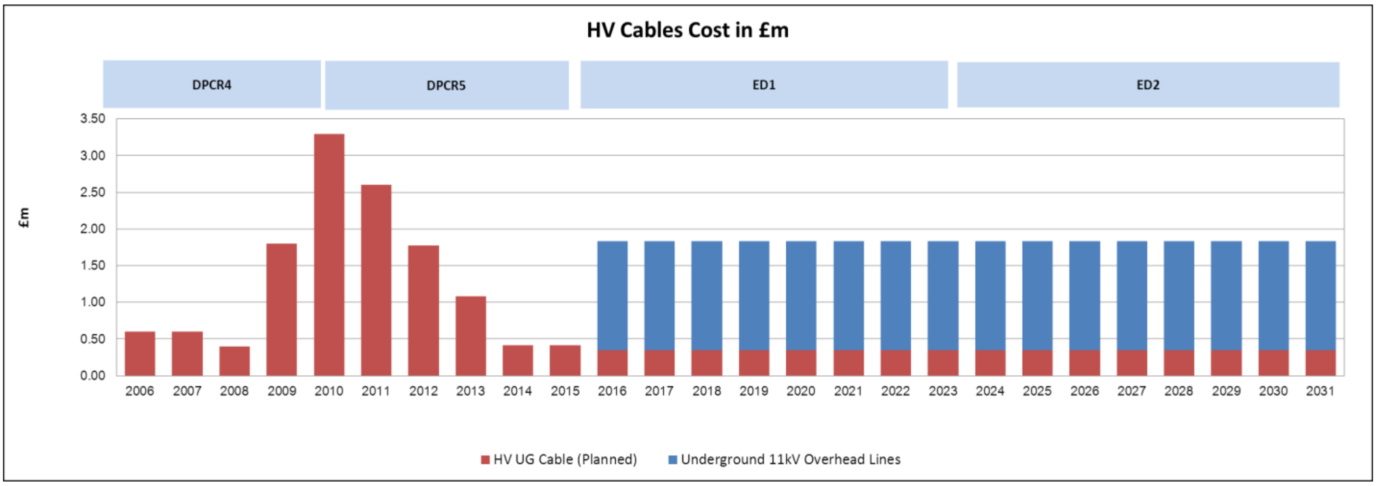

Figure 46 – Intervention cost of HV solid cables

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 32 kilometres of LV solid cable proposed for intervention during ED1. This represents 0.1% of the installed population in SPN. The ED2 figures shown in the graph below have been derived on the basis of assumption that similar rate of ED1 investment will continue in ED2.

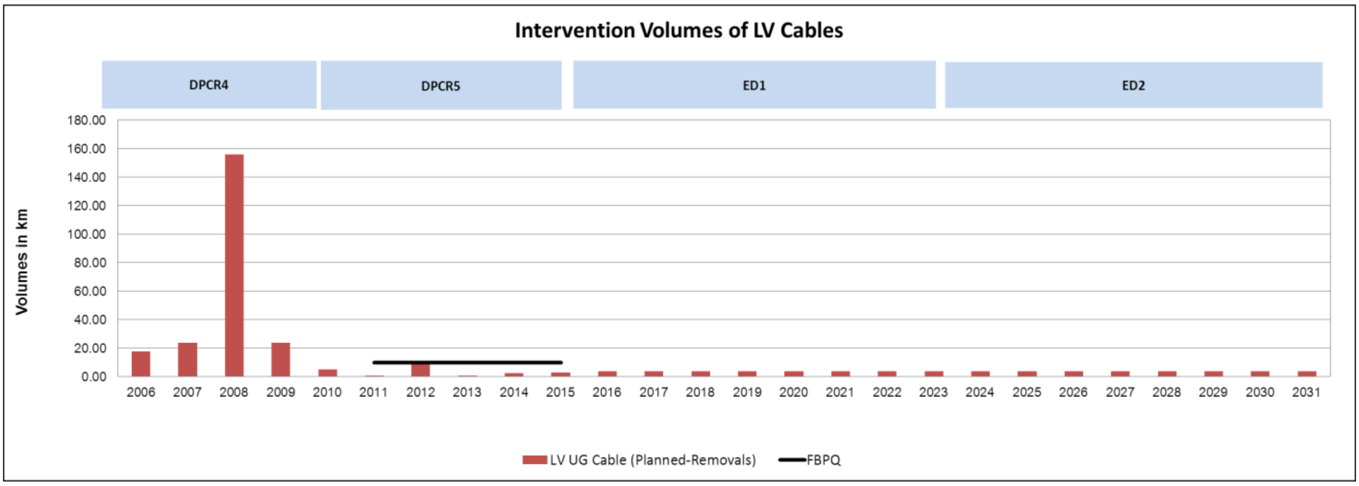

Figure 47 – Intervention volume of LV solid cables

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 £3.36m.

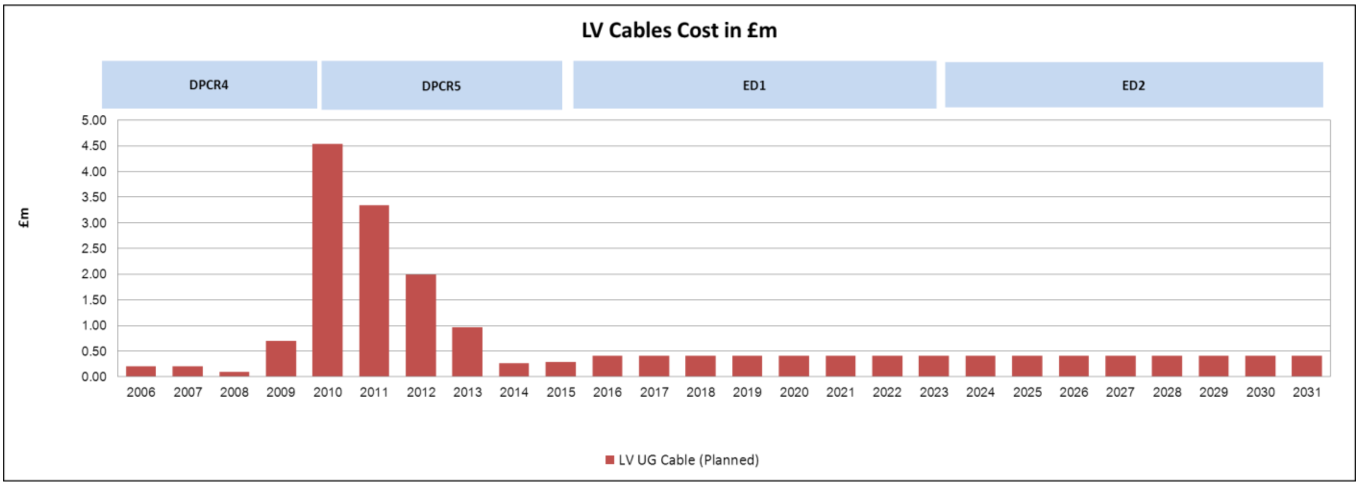

Figure 48 – Intervention cost of LV solid cables

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**	**20/21**	**21/22**	**22/23**
Replace aluminium cable joint plumbs	14	14	14	14	14	14	14	14
Install remote pressure-monitoring equipment	7	7	7	7	7	7	7	7
Replace pressurised cables ancillary equipment (tanks, gauges, etc.)	2	2	2	2	2	2	2	2

Table 12 – Intervention volumes of joints and ancillary equipment

Intervention cost in £m								
Description	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**20/21**	**21/22**	**22/23**
Replace aluminium cable joint plumbs	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Install remote pressure-monitoring equipment	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Replace pressurised cables ancillary equipment (tanks, gauges, etc.)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table 13 – Intervention cost of joints and ancillary equipment in £m

7.5 Commentary

7.5.1 Fluid Filled Cables

As previously discussed in section 3, Investment Drivers, SPN has a leakage rate per kilometre of installed fluid-filled cable that is around the national average.

The hydraulic sections and circuits identified for replacement in ED1 with the assistance of the ARP model represent 5% of the total fluid-filled cable population in SPN and yet are responsible for 24% of the fluid leakage.

The health indices calculated using 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 because of the potential for explosive sealing end failures, gas leaks that 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 a gas cable replacement programme, with National Grid completing a replacement programme in 2001. These issues are discussed fully in 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, and the plan will complete in 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

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	29.9	37.7	28.9	1.8	1.1
-2	29.9	42.6	24.3	1.8	1.1
-1	30.6	42.3	24.3	2.1	0.7
0	30.6	42.3	24.3	2.1	0.7
1	32.4	40.5	24.3	2.1	0.7
2	32.7	42.3	23.6	0.7	0.7
4	33.8	47.2	17.6	1.1	0.0

Average life change	2023 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	29.6	19.0	45.4	2.8	2.8
-2	29.6	25.0	39.8	2.8	2.8
-1	29.6	25.7	38.7	2.8	2.8
0	29.6	26.8	38.0	4.2	1.1
1	29.6	29.6	35.6	4.2	1.1
2	29.6	31.7	34.5	3.2	1.1
4	29.6	35.9	29.9	3.2	1.1

Table 14 – Results of sensitivity analysis of 132kV FFC

Average life change	2015 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	0.0	58.9	33.8	5.6	1.6
-2	0.0	61.5	33.3	4.5	0.9
-1	1.4	61.0	32.4	4.5	0.9
0	1.4	62.7	30.5	4.5	0.9
1	1.4	64.8	29.6	3.5	0.9
2	2.3	66.7	27.5	2.8	0.9
4	2.3	67.6	28.4	0.9	0.7

Average life change	2023 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	0.0	14.6	74.6	1.9	8.7
-2	0.0	30.3	60.1	2.1	7.3
-1	0.0	35.7	54.7	3.5	5.9
0	0.0	36.9	53.5	4.2	5.2
1	0.0	40.6	49.8	5.2	4.2
2	0.0	46.0	44.4	5.9	3.8
4	0.0	49.8	41.5	7.0	1.6

Table 15 – Results of sensitivity analysis of EHV FFC

In Tables 15 and 16, 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.

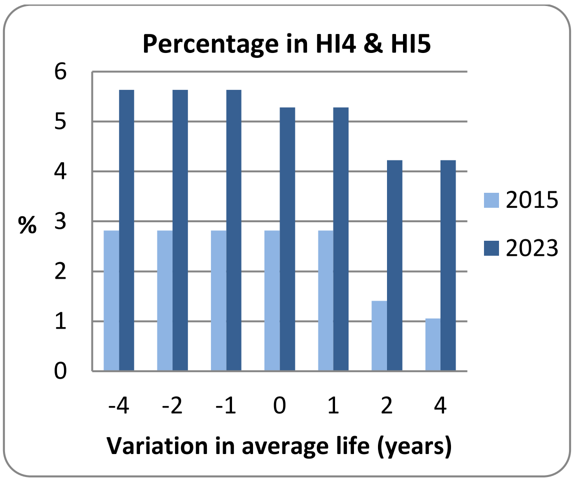

Figure 49 – Effect of average asset life variation on volumes of HI4 and HI5 of 132kV FFC

Figure 49 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 2.8% to 1.1%; but if four years shorter, it will increase to 2.9%. In 2023, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 5.3% to 4.3%; but if four years shorter, it will increase to 5.6%.

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

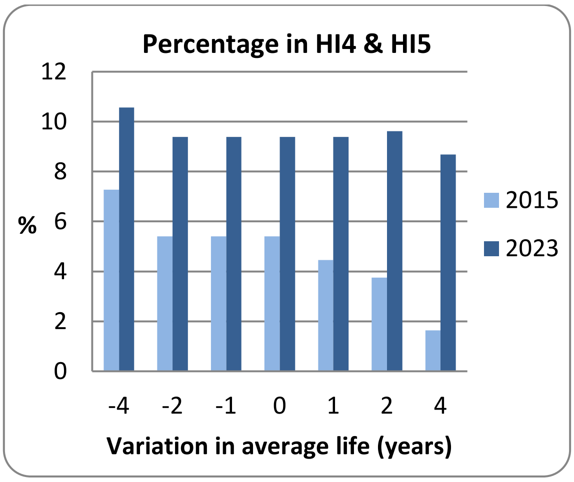

Figure 50 – Effect of average asset life variation on volumes of HI4 and HI5 of EHV FFC

Figure 50 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 5.4% to 1.6%; but if 4our years shorter, it will increase to 7.2%. In 2023, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 9.4% to 8.6%; but if four years shorter, it will increase to 10.6%.

It is concluded from the above observations that the ED1 replacement plan for SPN 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 is 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

Tables 17 to 20 illustrate the estimated asset health and criticality of the assets in SPN 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	11	11	9	1	2	34
	Average	circuit km	9	11	8	0	2	30
	High	circuit km	12	11	9	1	3	36
	Very high	circuit km	43	45	34	2	10	134

Table 16 – 2015 HI and criticality matrix

Asset Category	Criticality	Units	Estimated Asset Health and Criticality Profile 2023					2023
			Asset Health					
			HI1	HI2	HI3	HI4	HI5	
132kV FFC	Low	circuit km	10	7	11	3	3	34
	Average	circuit km	9	5	10	3	3	30
	High	circuit km	10	8	11	4	3	36
	Very high	circuit km	39	27	42	11	5	124

Table 17 – 2023 HI and criticality matrix

Asset Category	Criticality	Units	Estimated Asset Health and Criticality Profile 2015					2015
			Asset Health					
			HI1	HI2	HI3	HI4	HI5	
EHV FFC	Low	circuit km	2	69	41	3	11	126
	Average	circuit km	3	96	56	5	15	175
	High	circuit km	2	80	47	3	13	145
	Very High	circuit km	0	8	4	0	1	13

Table 18 – 2015 HI and criticality matrix

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	23	80	5	18	126
	Average	circuit km	0	34	111	6	16	167
	High	circuit km	0	26	89	6	11	132
	Very High	circuit km	0	2	8	1	0	11

Table 19 – 2023 HI and criticality matrix

Source: 21st February 20144 ED1 Business Plan Data Tables

8.0 Deliverability

The 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 51.

1920's	1930's	1940's	1950's	1960's	1970's	1980's	1990's	2000's
0	31	0	17	85	31	7	69	0

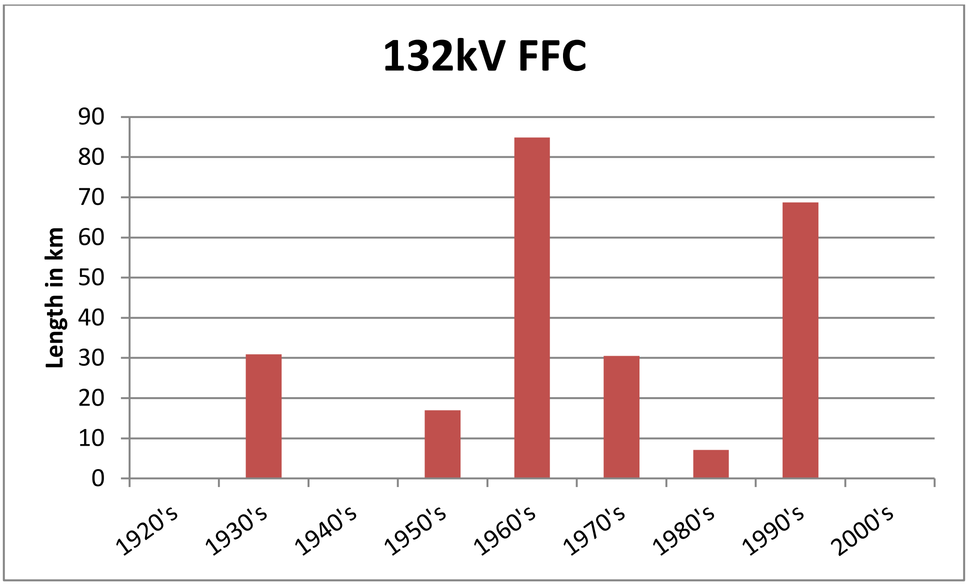


Figure 51– Age profile of 132kV FFC

The age profiles of 33kV FFC cables are shown in Figure 52.

1920's	1930's	1940's	1950's	1960's	1970's	1980's	1990's	2000's
0	0	9	119	297	45	0	0	0

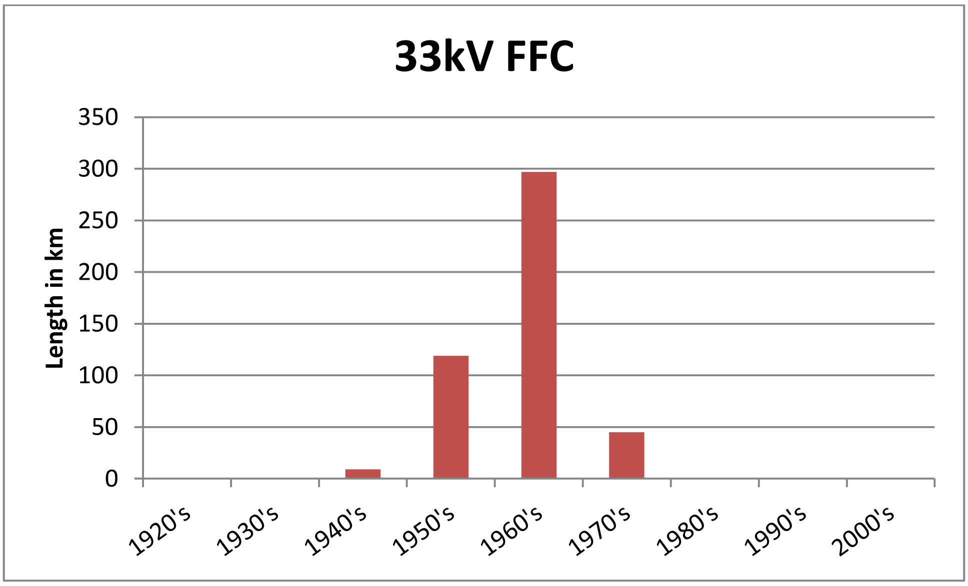


Figure 52 – Age profile of 33kV FFC

Gas cables

The age profile of 132kV gas cable in SPN is shown in Figure 53.

1920's	1930's	1940's	1950's	1960's	1970's	1980's	1990's	2000's
0	0	0	0	25	19	0	0	0

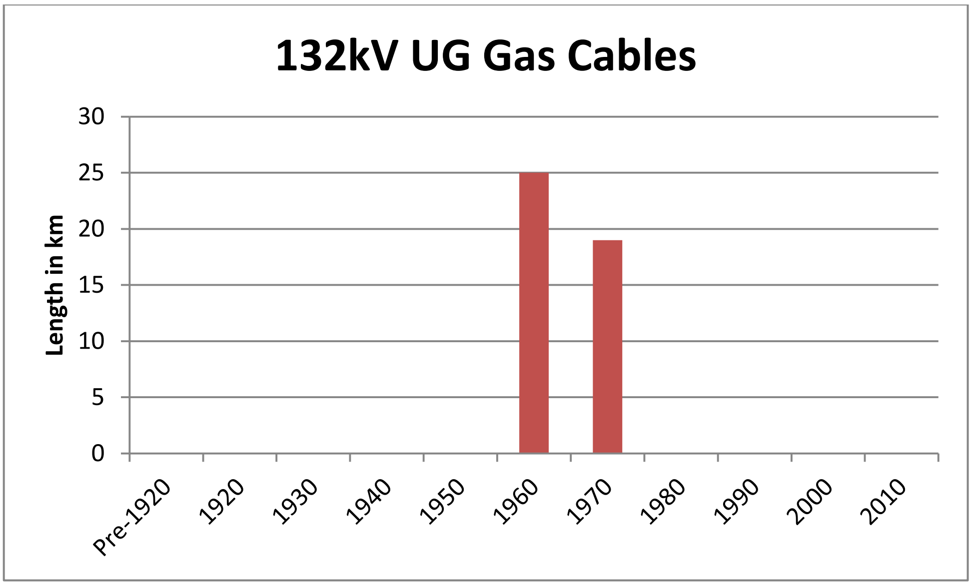


Figure 53 – Age profile of 132kV underground gas cable

The age profile of 33kV gas cables in SPN is shown in Figure 54.

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

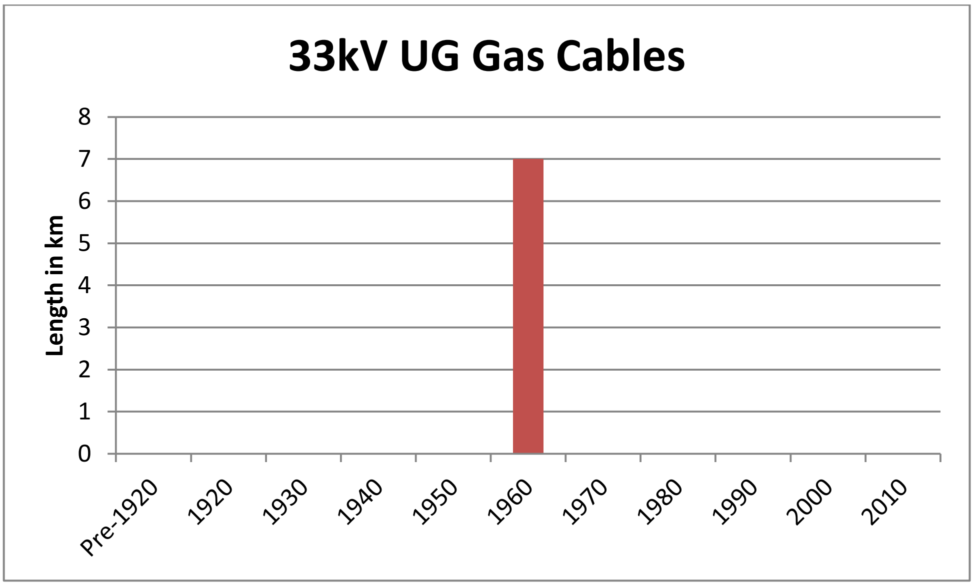


Figure 54 – Age profile of 33kV underground gas cable

Solid cables

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

Pre-1920	1920's	1930's	1940's	1950's	1960's	1970's	1980's	1990's	2000's	2010's
0	0	0	0	0	0	0	0	14	32	55

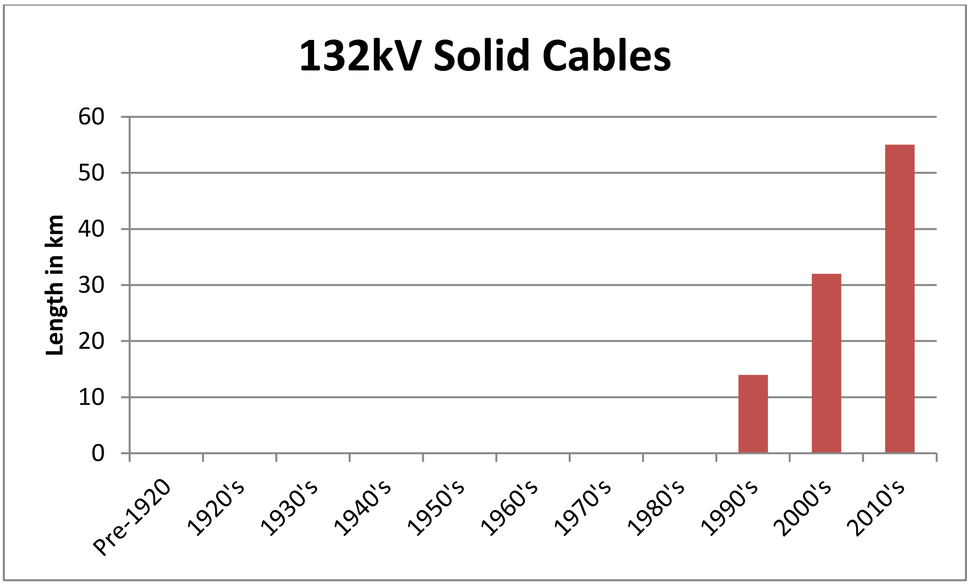


Figure 55 – Age profile of 132kV underground solid cable

The age profiles of 33kV solid cables are shown in Figure 56.

Pre-1920	1920's	1930's	1940's	1950's	1960's	1970's	1980's	1990's	2000's	2010's
0	14	120	36	37	314	92	18	73	105	55

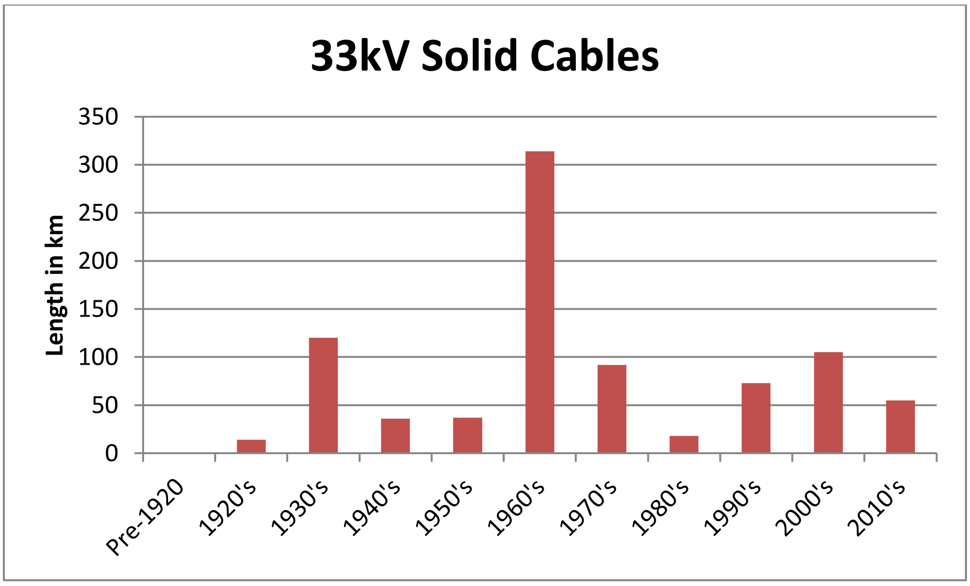


Figure 56 – Age profile of 33kV underground solid cable

The age profiles of HV solid cables are shown in Figure 57.

Pre-1920	1920's	1930's	1940's	1950's	1960's	1970's	1980's	1990's	2000's	2010's
0	422	1195	1150	1215	2908	1746	768	1034	1296	297

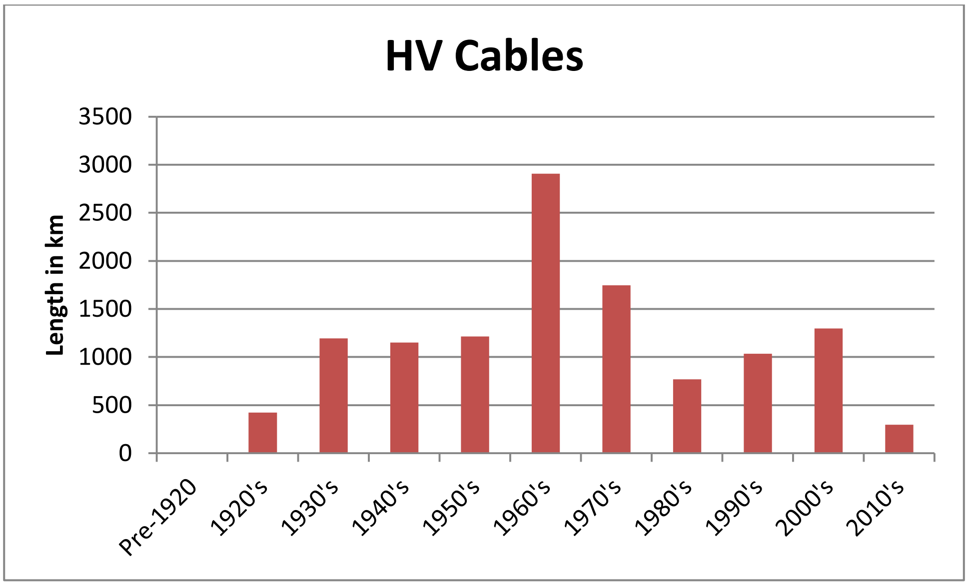


Figure 57 – Age profile of HV underground solid cable

The age profiles of LV solid cables are shown in Figure 58.

Pre-1920	1920's	1930's	1940's	1950's	1960's	1970's	1980's	1990's	2000's	2010's
1546	2932	2632	2982	3034	4660	2570	1611	2050	1940	99

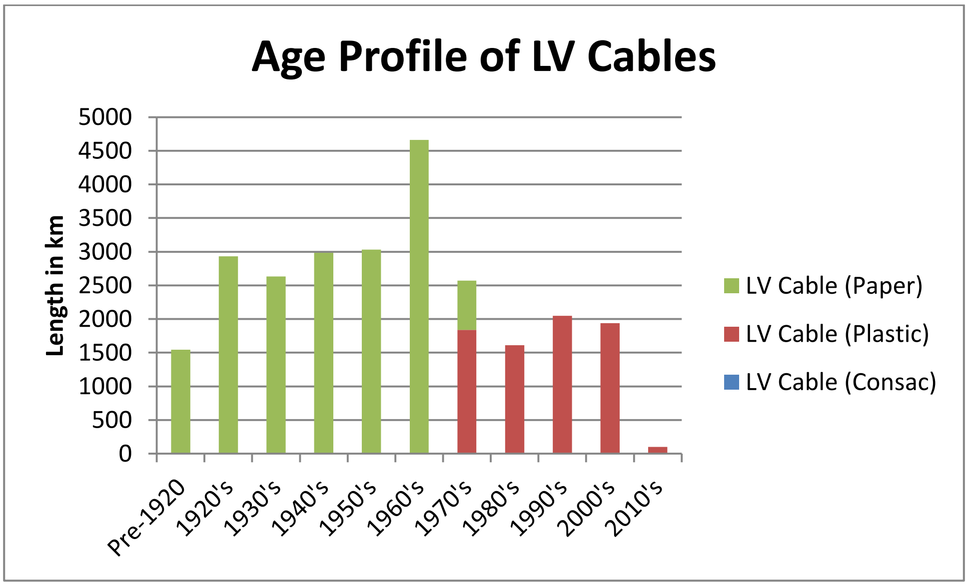


Figure 58 – Age profile of LV underground solid cable

Appendix 2 – HI Profiles

Fluid-filled cables (FFC)

132kV	HI1	HI2	HI3	HI4	HI5
Start of ED1	75	78	60	4	17
End of ED1 without Investment	68	47	74	23	22
End of ED1 with Investment	68	47	74	21	14

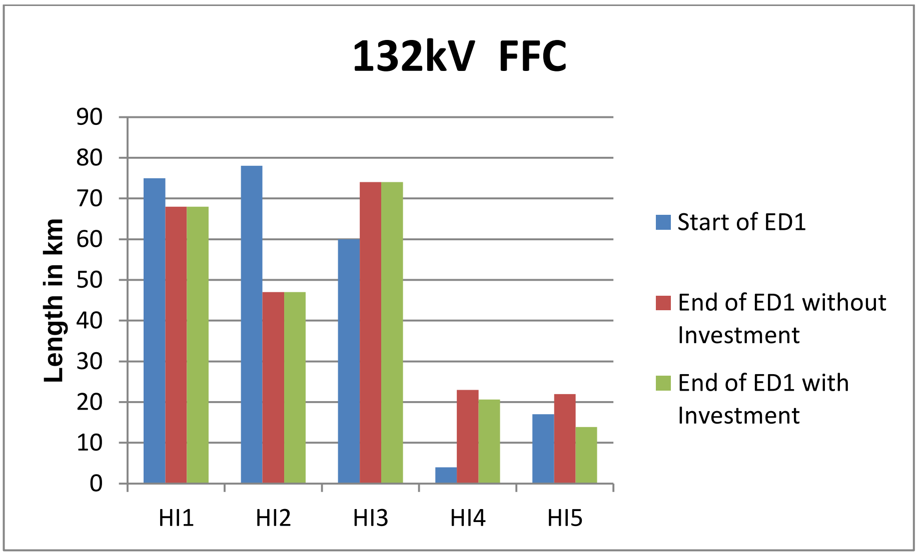


Figure 59 – HI profiles of 132kV fluid-filled cables (FFC)

Source: ARP Model W_FFC_25Jul2012_March 2014 submission

EHV	HI1	HI2	HI3	HI4	HI5
Start of ED1	7	253	148	11	40
End of ED1 without Investment	0	85	291	18	65
End of ED1 with Investment	0	85	288	18	45

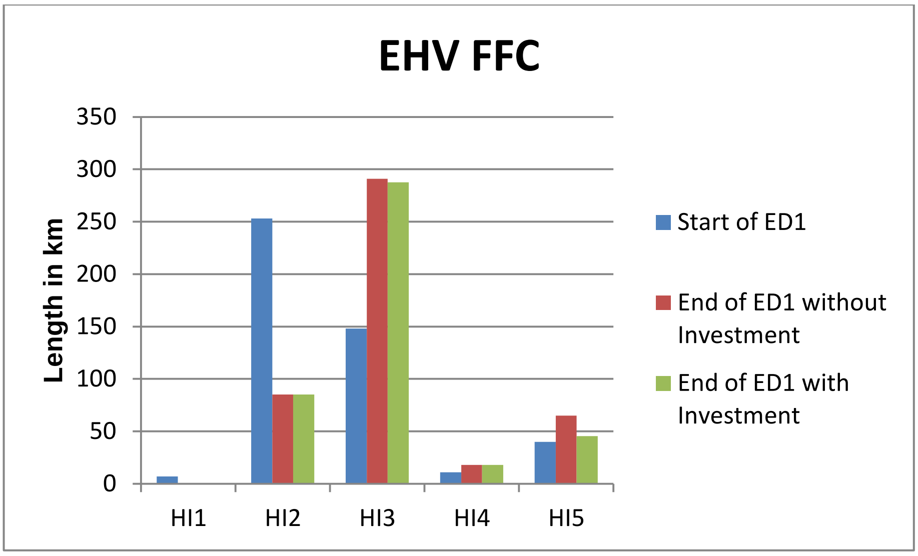


Figure 60 – HI profiles of EHV fluid-filled cables (FFC)

Source: ARP Model W_FFC_25Jul2012_March 2014 submission

Appendix 3 – Fault Data

132KV UG Cable	2007	2008	2009	2010	2011	2012
All Faults	0.0052	0.0065	0.0117	0.0052	0.0013	0.0091
Poor Condn Due To Age & Wear	0.0013	0.0026	0.0039	0.0039	0.0013	0.0091

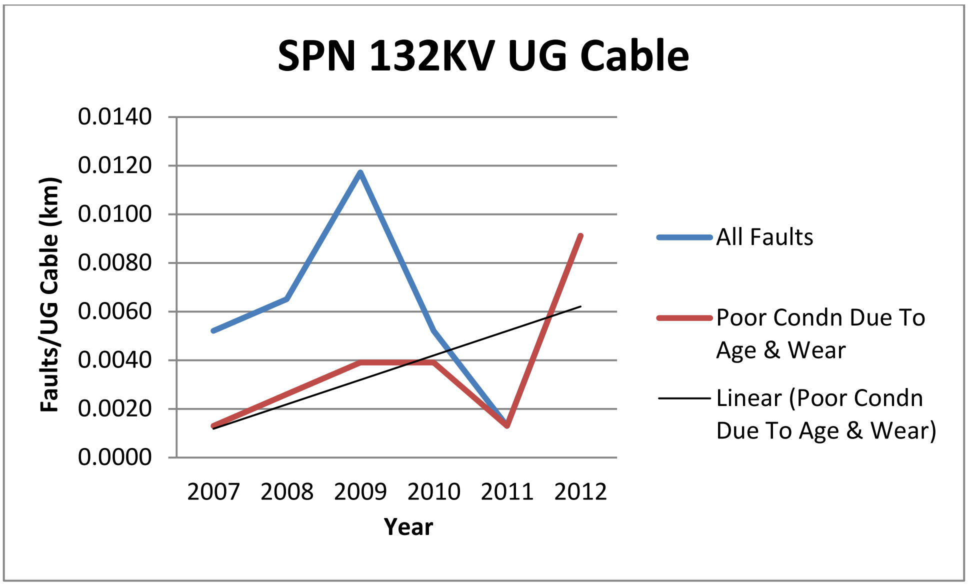


Figure 61 – Fault trends of 132kV underground cable

EHV UG Cable	2007	2008	2009	2010	2011	2012
All Faults	0.0172	0.0157	0.0149	0.0134	0.0157	0.0164
Poor Condn Due To Age & Wear	0.0112	0.0112	0.0127	0.0104	0.0142	0.0134

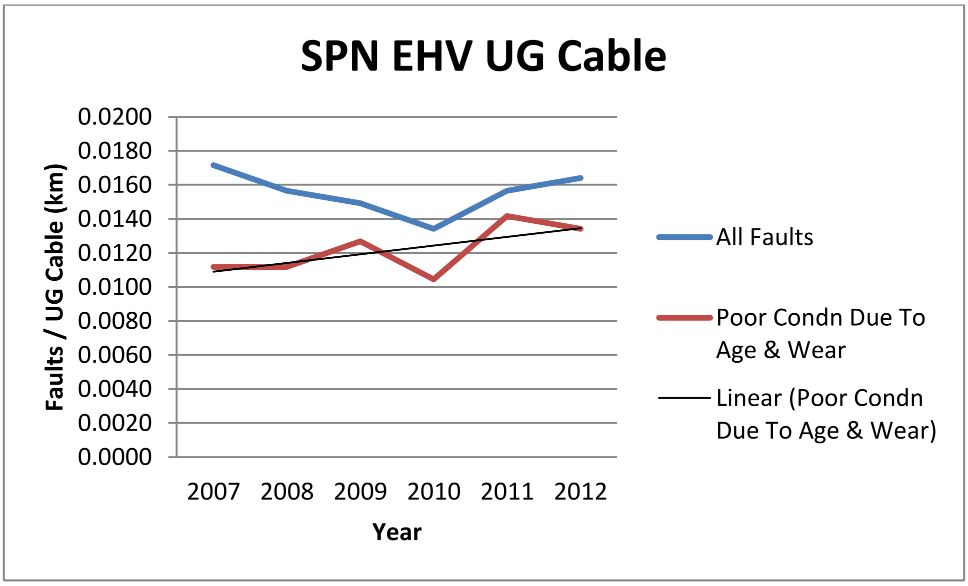


Figure 62 – Fault trends of EHV underground cable

HV UG Cable	2007	2008	2009	2010	2011	2012
All Faults	0.0613	0.0639	0.0697	0.0756	0.0628	0.0621
Poor Condn Due To Age & Wear	0.0470	0.0483	0.0548	0.0596	0.0471	0.0541

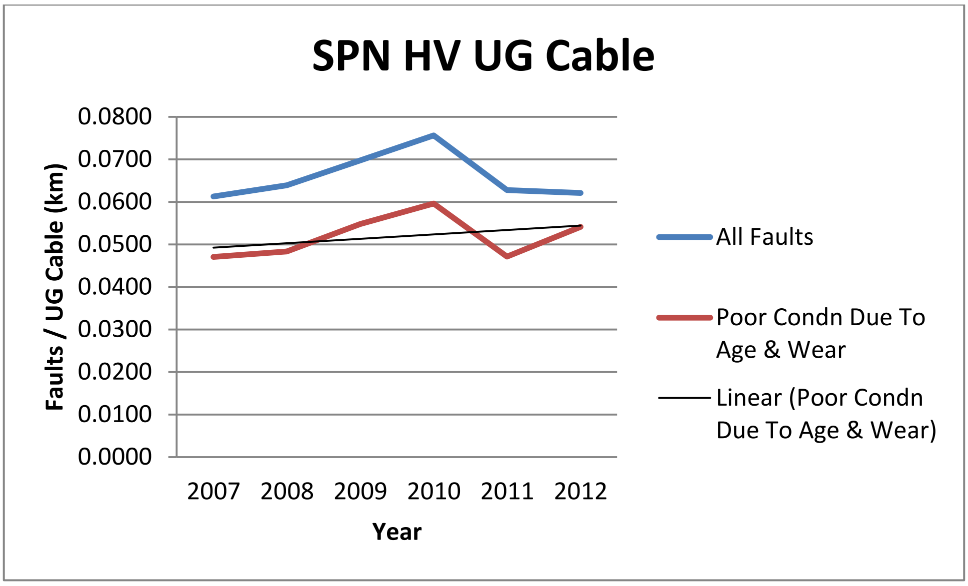


Figure 63 – Fault trends of HV underground cable

LV UG Cable	2007	2008	2009	2010	2011	2012
All Faults	0.0420	0.0513	0.0753	0.0890	0.0778	0.0756
Poor Condn Due To Age & Wear	0.0116	0.0265	0.0407	0.0360	0.0545	0.0558

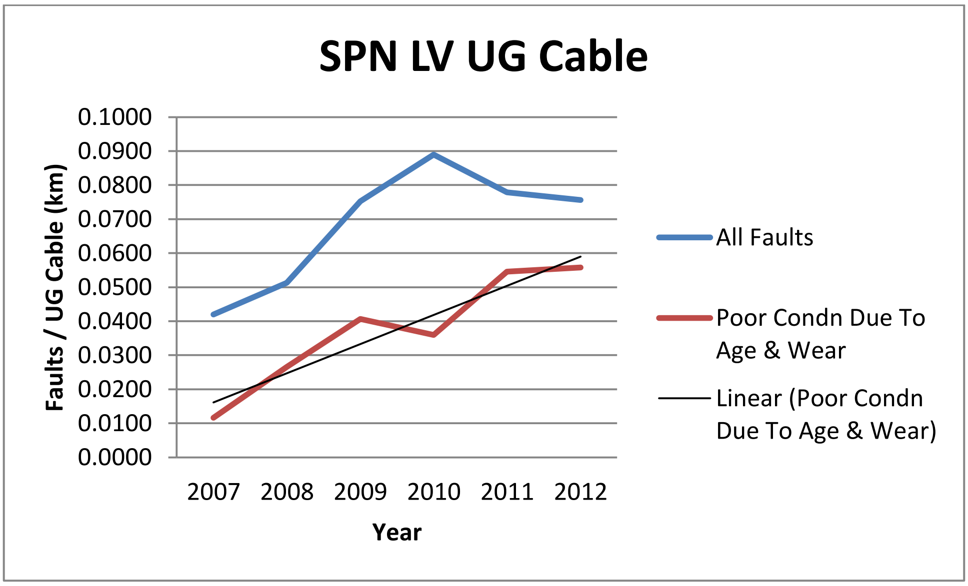


Figure 64 – Fault trends of LV underground cable

Source: UKPN Faults Cube Feb 2013

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

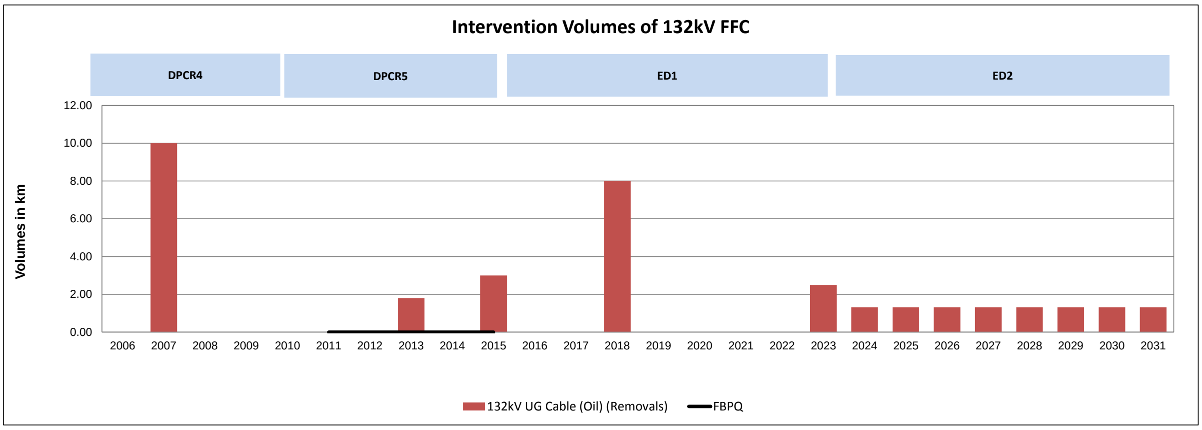
Discount rate: Select 6.85%	6.85%
Discounted whole life cost	468

Appendix 5 – NLRE Expenditure Plan

132kV fluid-filled cable 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)						0.00	0.00	0.00	0.00	0.00
132kV UG Cable (Oil) (Removals)	0.00	10.00	0.00	0.00	0.00	0.00	0.00	1.80	0.00	3.00

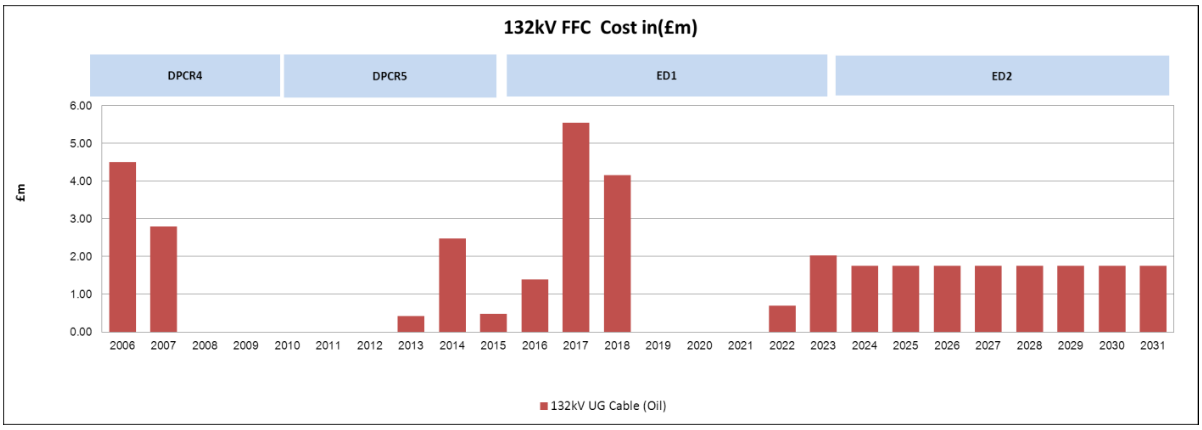
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Oil) FBPQ (Removals only)																
132kV UG Cable (Oil) (Removals)	0.00	0.00	8.00	0.00	0.00	0.00	0.00	2.50	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31



132kV fluid-filled cable 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)	4.50	2.80	0.00	0.00	0.00	0.00	0.00	0.43	2.47	0.48

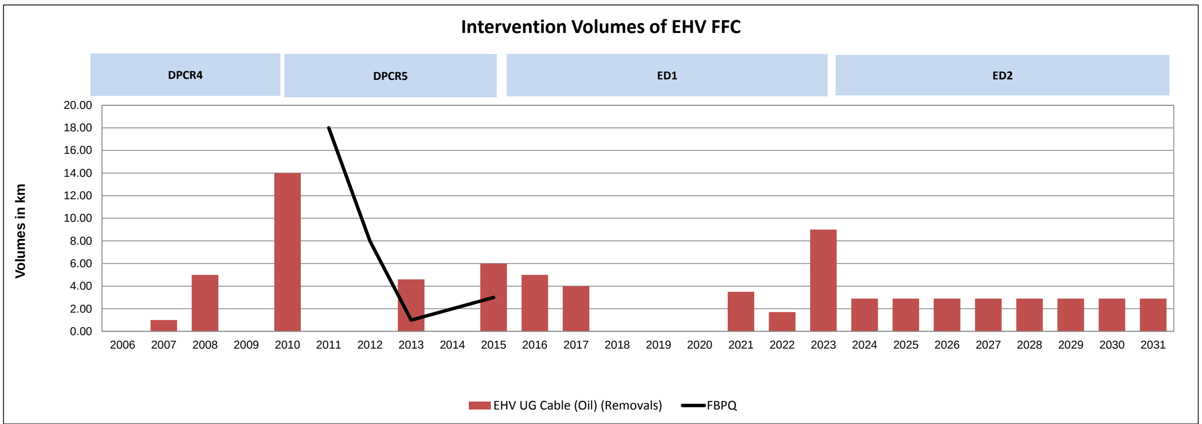
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Oil)	1.39	5.55	4.16	0.00	0.00	0.00	0.69	2.02	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75



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)						18.00	8.00	1.00	2.00	3.00
EHV UG Cable (Oil) (Removals)	0.00	1.00	5.00	0.00	14.00	0.00	0.00	4.60	0.00	6.00

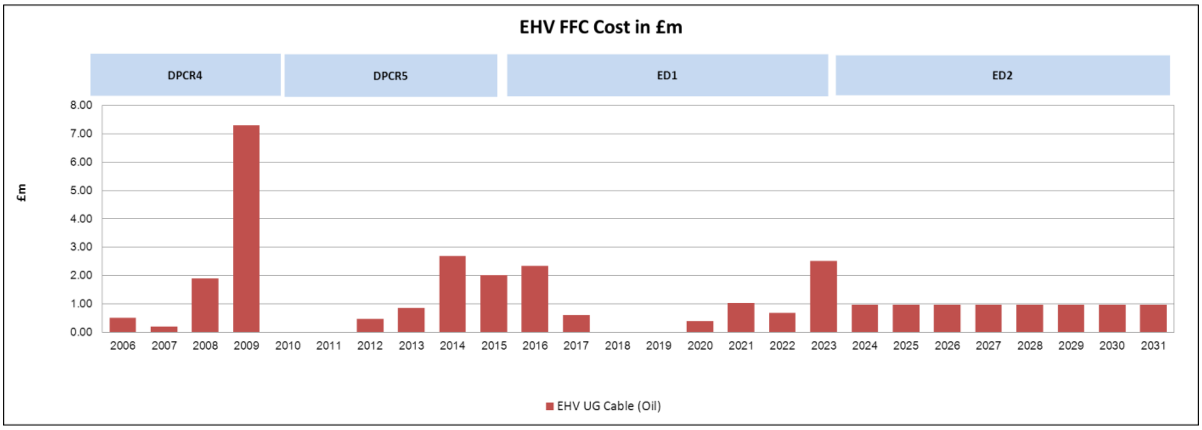
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Oil) FBPQ (Removals only)																
EHV UG Cable (Oil) (Removals)	5.00	4.00	0.00	0.00	0.00	3.50	1.70	9.00	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90



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
EHV UG Cable (Oil)	0.50	0.20	1.90	7.30	0.00	0.00	0.45	0.85	2.68	2.01

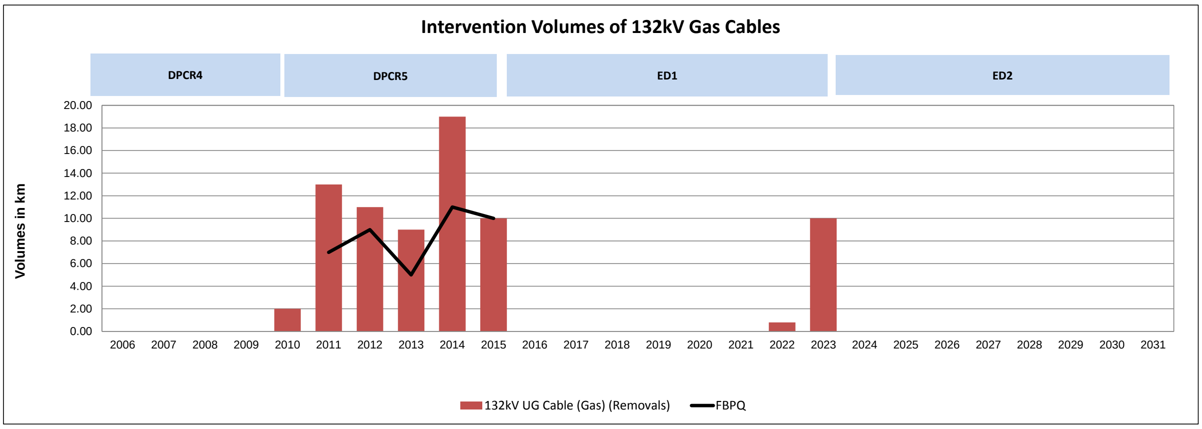
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Oil)	2.33	0.60	0.00	0.00	0.38	1.01	0.68	2.51	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96



132kV gas cables volume:

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)						7.00	9.00	5.00	11.00	10.00
132kV UG Cable (Gas) (Removals)	0.00	0.00	0.00	0.00	2.00	13.00	11.00	9.00	19.00	10.00

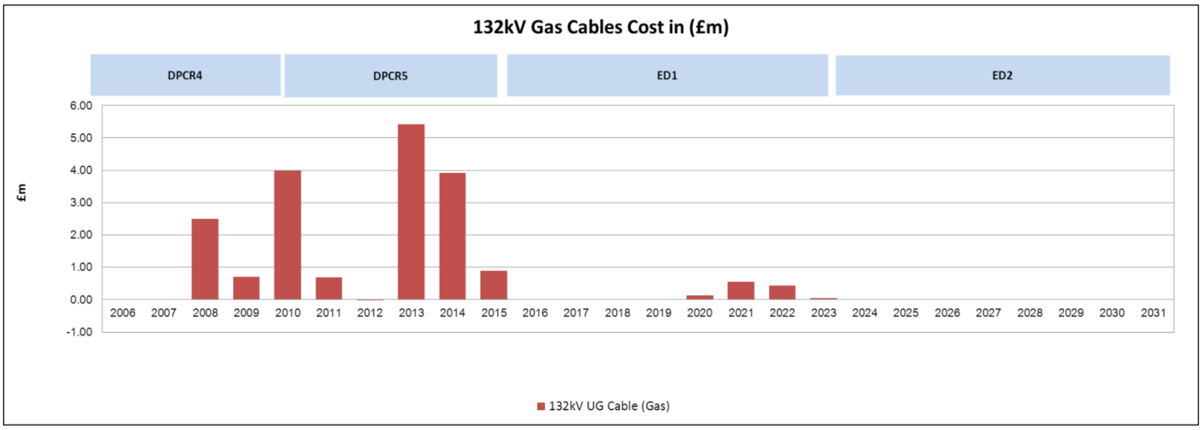
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Gas) FBPQ (Removals only)																
132kV UG Cable (Gas) (Removals)	0.00	0.00	0.00	0.00	0.00	0.00	0.80	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



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)	0.00	0.00	2.50	0.70	3.98	0.68	0.00	5.42	3.91	0.89

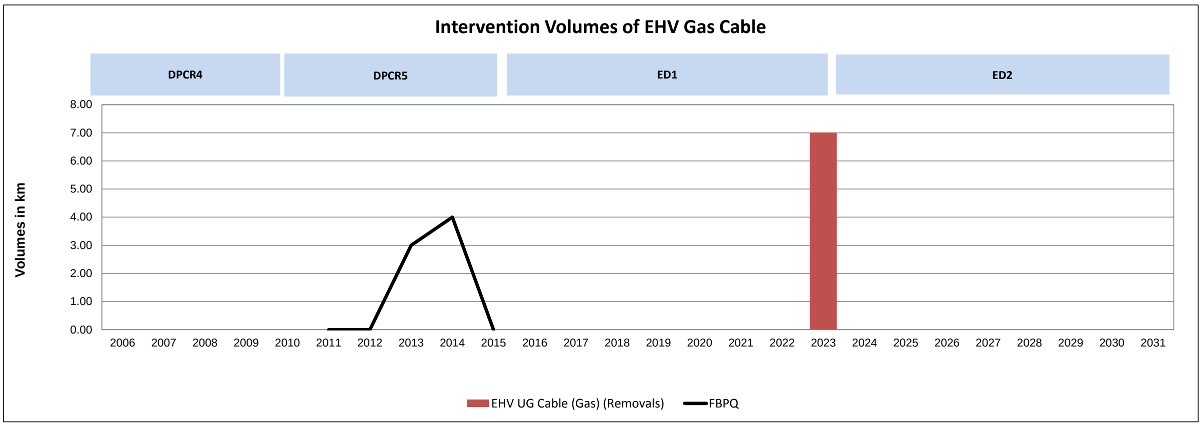
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Gas)	0.00	0.00	0.00	0.00	0.14	0.55	0.43	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



EHV gas cable volume:

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)						0.00	0.00	3.00	4.00	0.00
EHV UG Cable (Gas) (Removals)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

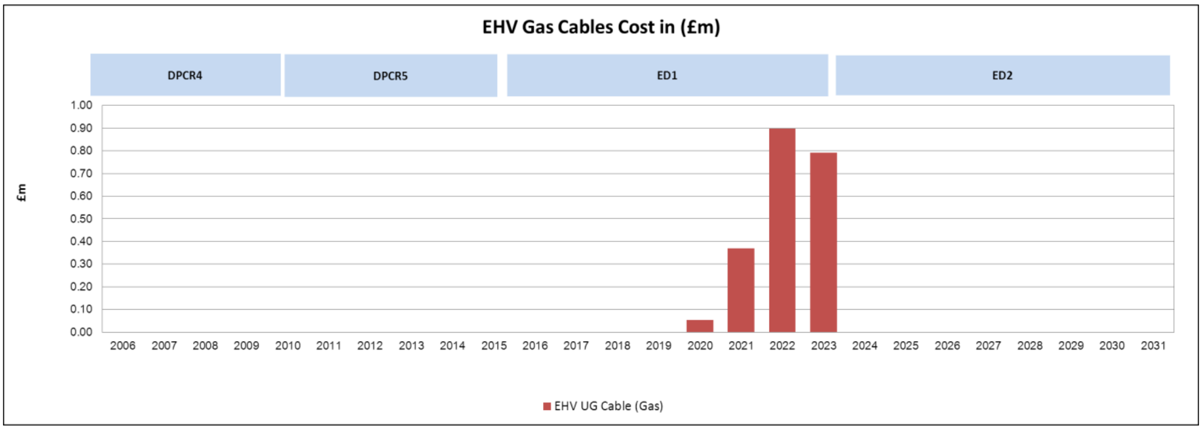
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Gas) FBPQ (Removals only)																
EHV UG Cable (Gas) (Removals)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



EHV gas cable 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	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
EHV UG Cable (Gas)	0.00	0.00	0.00	0.00	0.05	0.37	0.90	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

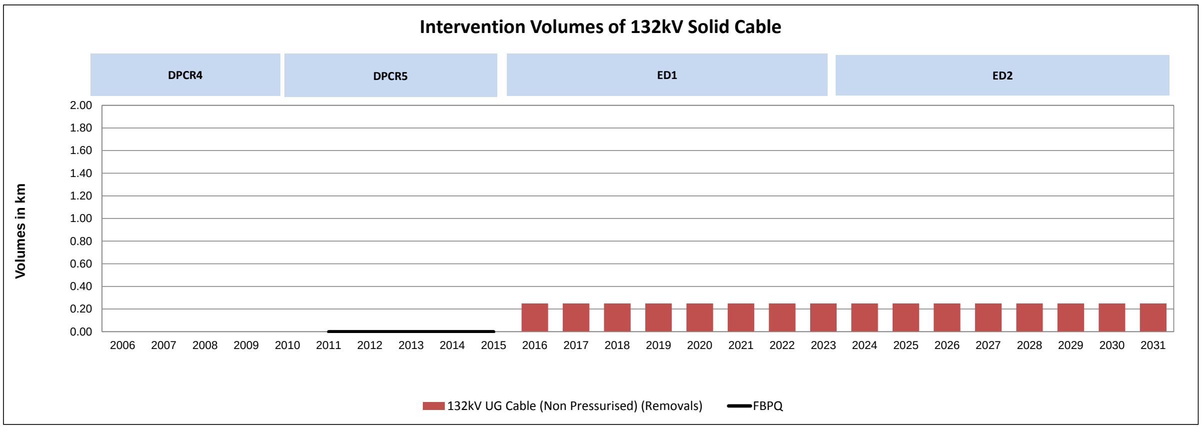


All of the cost numbers displayed in this document are before the application of on-going efficiencies and real price effects.

132kV solid cables volume:

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) (Removals)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

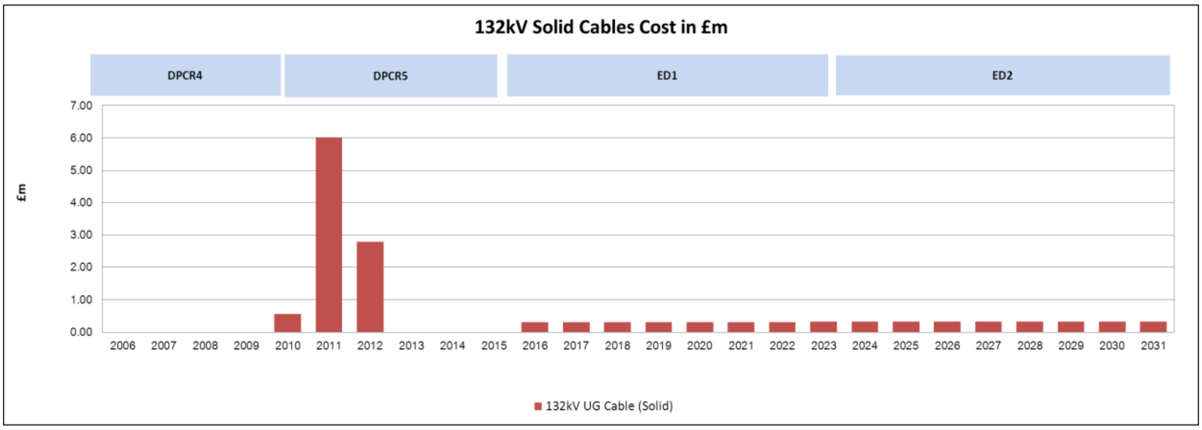
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Non Pressurised) FBPQ (Removals only)																
132kV UG Cable (Non Pressurised) (Removals)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25



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	0.55	6.02	2.79	0.00	0.00	0.00

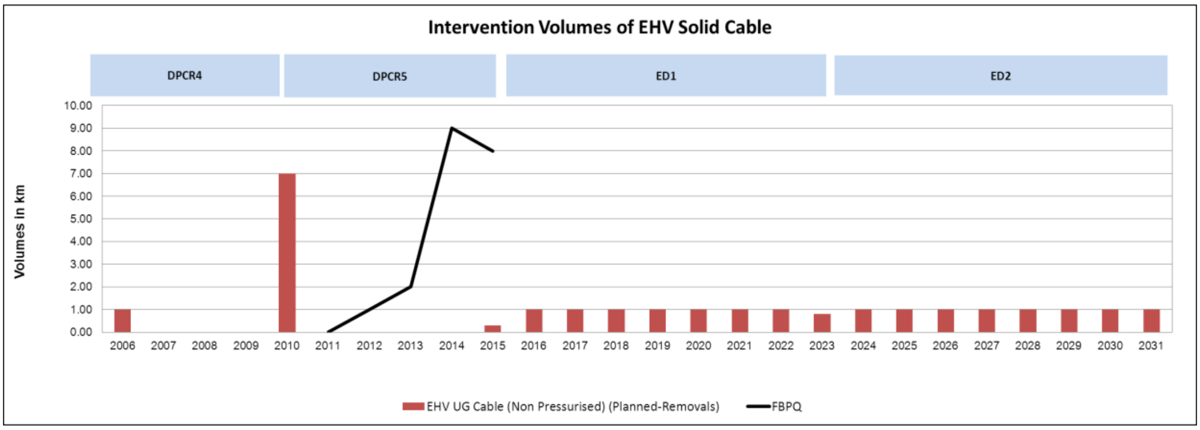
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
132kV UG Cable (Solid)	0.30	0.30	0.30	0.30	0.30	0.31	0.31	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32



EHV solid cables volume:

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)						0.00	1.00	2.00	9.00	8.00
EHV UG Cable (Non Pressurised) (Planned-Removals)	1.00	0.00	0.00	0.00	7.00	0.00	0.00	0.00	0.00	0.30

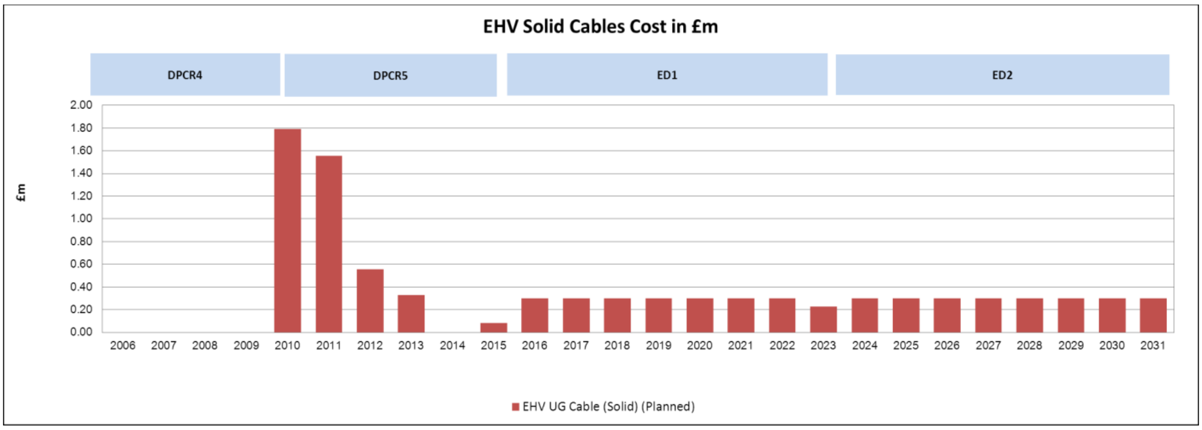
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Non Pressurised) FBPQ (Removals only)																
EHV UG Cable (Non Pressurised) (Planned-Removals)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00



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	0.00	0.00	0.00	1.79	1.55	0.56	0.33	0.00	0.08

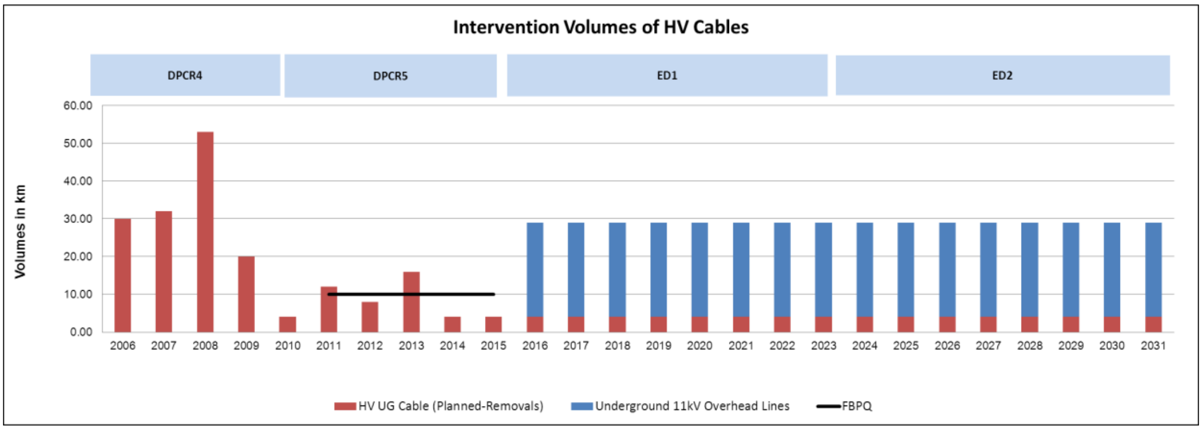
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
EHV UG Cable (Solid) (Planned)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.23	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30



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 (Removals only)						10.00	10.00	10.00	10.00	10.00
HV UG Cable (Planned-Removals)	30.00	32.00	53.00	20.00	4.00	12.00	8.00	16.00	4.00	4.00
Underground 11kV Overhead Lines										

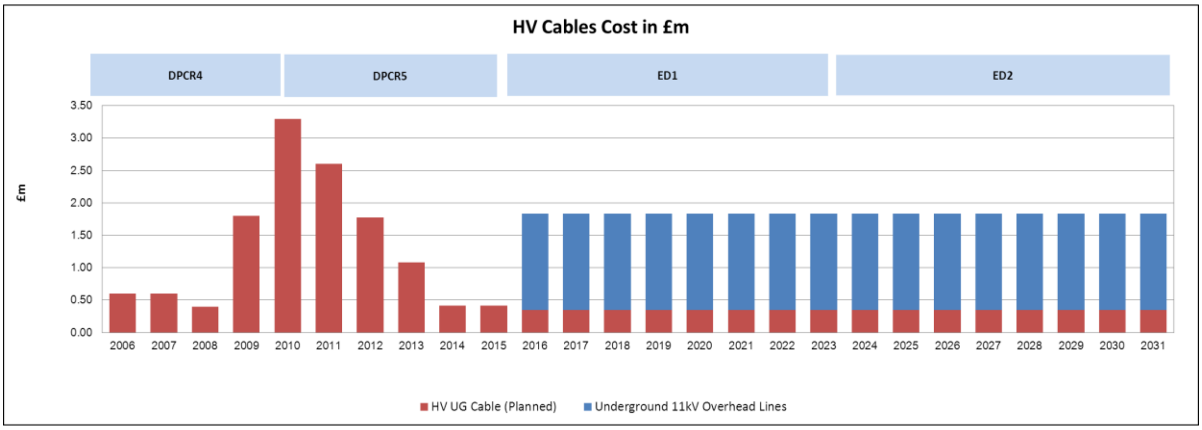
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
HV UG Cable FBPQ (Removals only)																
HV UG Cable (Planned-Removals)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Underground 11kV Overhead Lines	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00



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)	0.60	0.60	0.40	1.80	3.30	2.60	1.77	1.09	0.41	0.41
Underground 11kV Overhead Lines										

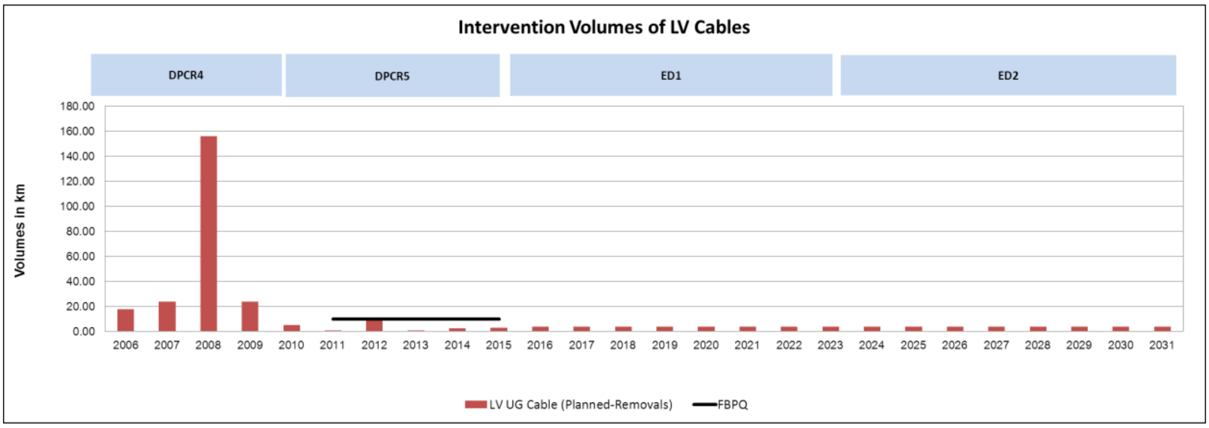
Investment £'m	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
HV UG Cable (Planned)	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Underground 11kV Overhead	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48



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)						10.00	10.00	10.00	10.00	10.00
LV UG Cable (Planned-Removals)	18.00	24.00	156.00	24.00	5.00	1.00	9.00	1.00	2.66	2.99

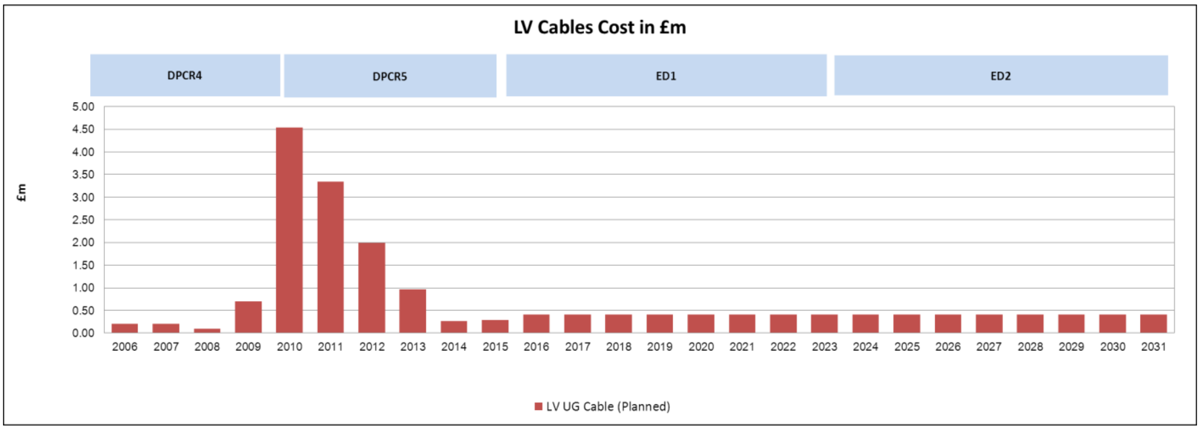
Volumes	ED1 Plan								ED2 Plan							
Year end	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
LV UG Cable FBPQ (Removals only)																
LV UG Cable (Planned-Removals)	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00



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)	0.20	0.20	0.10	0.70	4.54	3.34	2.00	0.97	0.26	0.29

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)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42



FFC joints and ancillary equipment

Intervention volumes								
Description	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Replace aluminium cable joint plumbs	14	14	14	14	14	14	14	14
Install remote pressure-monitoring equipment	7	7	7	7	7	7	7	7
Replace pressurised cables ancillary equipment (tanks, gauges, etc.)	2	2	2	2	2	2	2	2

Intervention cost in £m								
Description	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Replace aluminium cable joint plumbs	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Install remote pressure-monitoring equipment	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Replace pressurised cables ancillary equipment (tanks, gauges, etc.)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Appendix 6 – Sensitivity Analysis

Sensitivity Analysis:

Asset Risk and Prioritisation Model for SPN 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 SPN 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 46% had a current average asset life of 80 years, and about 42% of 70 years. This study covered the full population of SPN 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.

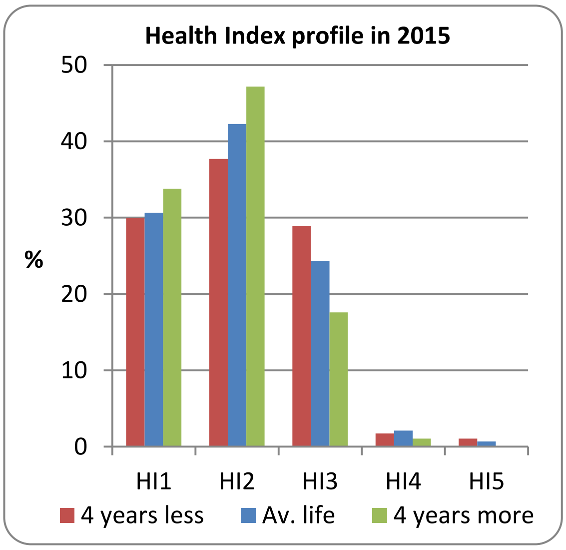
All results are shown below as the percentages of the population.

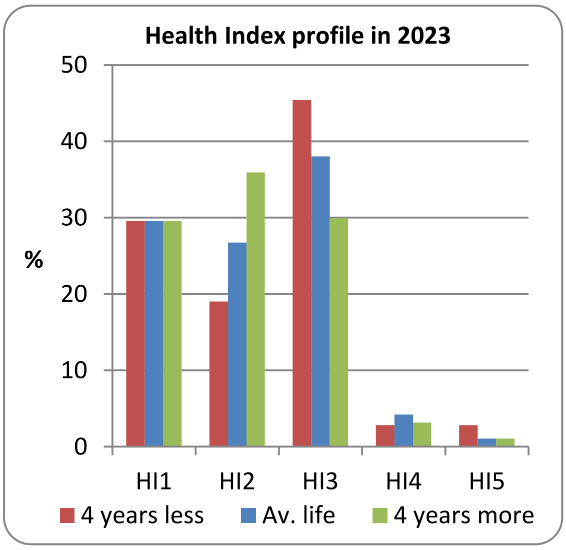
Average life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	29.9	37.7	28.9	1.8	1.1
-2	29.9	42.6	24.3	1.8	1.1
-1	30.6	42.3	24.3	2.1	0.7
0	30.6	42.3	24.3	2.1	0.7
1	32.4	40.5	24.3	2.1	0.7
2	32.7	42.3	23.6	0.7	0.7
4	33.8	47.2	17.6	1.1	0.0

Average life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	29.6	19.0	45.4	2.8	2.8
-2	29.6	25.0	39.8	2.8	2.8
-1	29.6	25.7	38.7	2.8	2.8
0	29.6	26.8	38.0	4.2	1.1
1	29.6	29.6	35.6	4.2	1.1
2	29.6	31.7	34.5	3.2	1.1
4	29.6	35.9	29.9	3.2	1.1

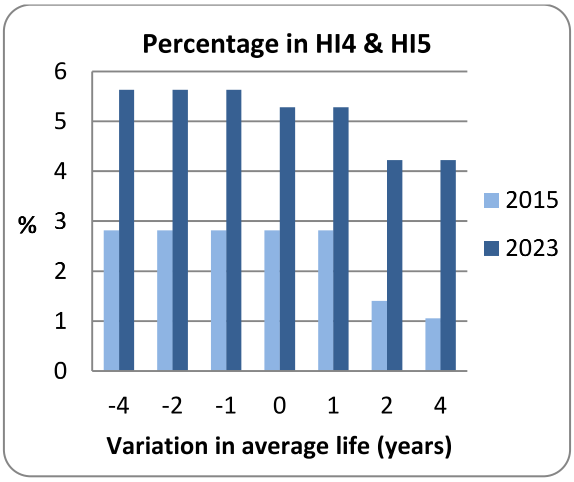
As the percentages above are rounded, the sum of a row may be 0.2% above or below 100%.

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 2.8% to 1.1%; but if four years shorter, it will increase to 2.9%.
- In 2023, if average asset life is four years longer, the proportion of HI4 and HI5 assets will reduce from 5.3% to 4.3%; but if four years shorter, it will increase to 5.6%.

Conclusion

The ED1 replacement plan for SPN 132kV UG Cable (Oil) is slightly sensitive to a variation in average asset life of up to 4 years.

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Sensitivity Analysis:

Asset Risk and Prioritisation Model for SPN 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 SPN 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 91% had a current average asset life of 80 years and about 4% of 70 years. This study covered the full population of SPN 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.

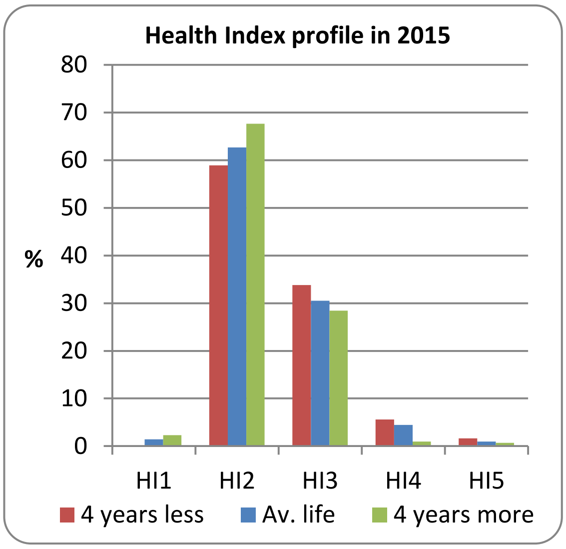
All results are shown below as the percentages of the population.

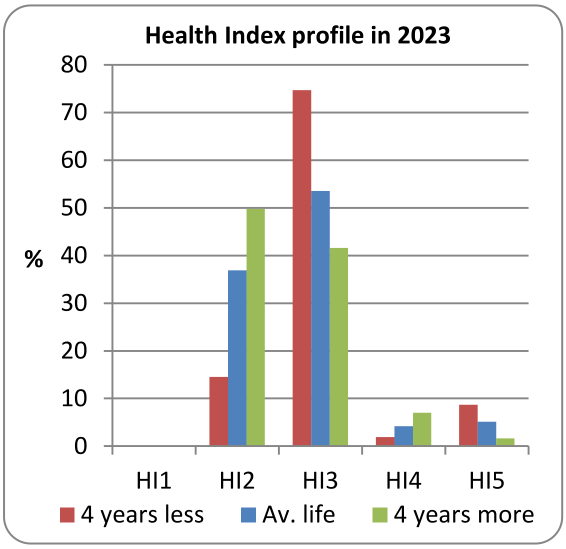
Average life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	0.0	58.9	33.8	5.6	1.6
-2	0.0	61.5	33.3	4.5	0.9
-1	1.4	61.0	32.4	4.5	0.9
0	1.4	62.7	30.5	4.5	0.9
1	1.4	64.8	29.6	3.5	0.9
2	2.3	66.7	27.5	2.8	0.9
4	2.3	67.6	28.4	0.9	0.7

Average life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	0.0	14.6	74.6	1.9	8.7
-2	0.0	30.3	60.1	2.1	7.3
-1	0.0	35.7	54.7	3.5	5.9
0	0.0	36.9	53.5	4.2	5.2
1	0.0	40.6	49.8	5.2	4.2
2	0.0	46.0	44.4	5.9	3.8
4	0.0	49.8	41.5	7.0	1.6

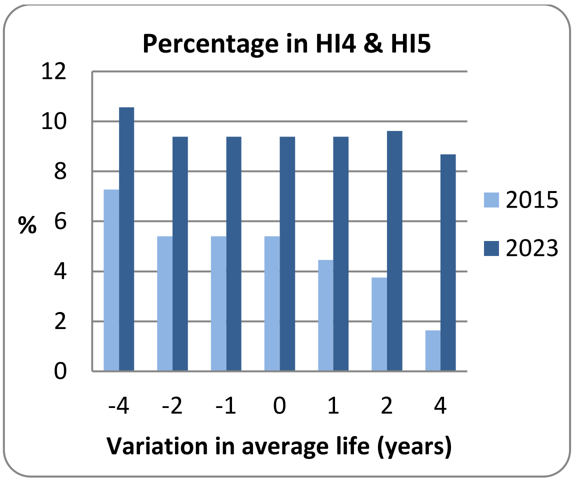
As the percentages above are rounded, the sum of a row may be 0.2% above or below 100%.

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 5.4% to 1.6% but if four years shorter it will increase to 7.2%.
- In 2023 if average asset life is four years longer, the proportion of HI4 & HI5 assets will reduce from 9.4% to 8.6% but if four years shorter it will increase to 10.6%.

Conclusion

The ED1 replacement plan for SPN 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	7965	SPN	Purley Grid-West Croydon 33/11 (Circuit 2-A-C & 2-C-F) - 33kV FFC replacement	2.8	0.97
1.29.01	7966	SPN	Northfleet East Grid to Gravesend Town (Circuit 1-F-G, Circuit 1-H1-I1, Circuit 1-J-J1, Circuit1-C-D & Circuit 2-C-D) - 33kV FFC replacement	1.7	0.59
1.29.01	7967	SPN	Fishersgate-Withdean 33kV (Circuit 1-2) - 33kV FFC replacement	1.7	0.59
1.29.01	7968	SPN	Fishergate Grid-Brighton Local (Circuit 2-2) - 33kV FFC replacement	1.7	0.62
1.29.01	7969	SPN	Bromley Grid to Orpington (Circuit 2-1,Circuit 2-2,Circuit 2-3) - 33kV FFC replacement	4.0	1.21
1.29.01	7970	SPN	Beddington Local 33kV-Sutton Grid 33kV (Circuit 1-E-J & Circuit 2-E-J) - 33kV FFC replacement	5.0	1.73
1.29.01	8653	SPN	Chessington Grid-Ewell 33kV FFC Replacement (Circuit 1-2,Circuit3-1)	6.2	1.82
1.29.02	7971	SPN	Sittingbourne Grid T3-3 - 132kV Fluid filled cable replacement	0.10	0.14
1.29.02	7972	SPN	Beddington-Addington Grid (Circuit 1-A-B-P3,Circuit 1-D-E-P2,Circuit 1-E-F-P1, Circuit 2-DE1-P3,Circuit 1-B-D-P3,Circuit 1-B-D-P2) - 132kV Fluid filled cable replacement	8.0	11.10
1.29.02	8652	SPN	Kingsnorth Grid-Strood 132kV FFC Replacement (Circuit 2-3)	2.4	2.58

Gas Cables:

Ref	Project ID	DNO	Description	Volume (km)	Cost £m
1.07.90	4087	SPN	Leigh – Reigate 33kV IP Gas Cable Replacement	7.0	2.21
1.07.07	8399	SPN	Southern Cross to Lewes 132kV: Replace 132kV Gas cable section between Southern Cross-Mile Oak	0.8	1.11
1.07.07	8643	SPN	Decomissioning of Steyning-Worthing Gas cable circuit	10	0.07

Solid Cables:

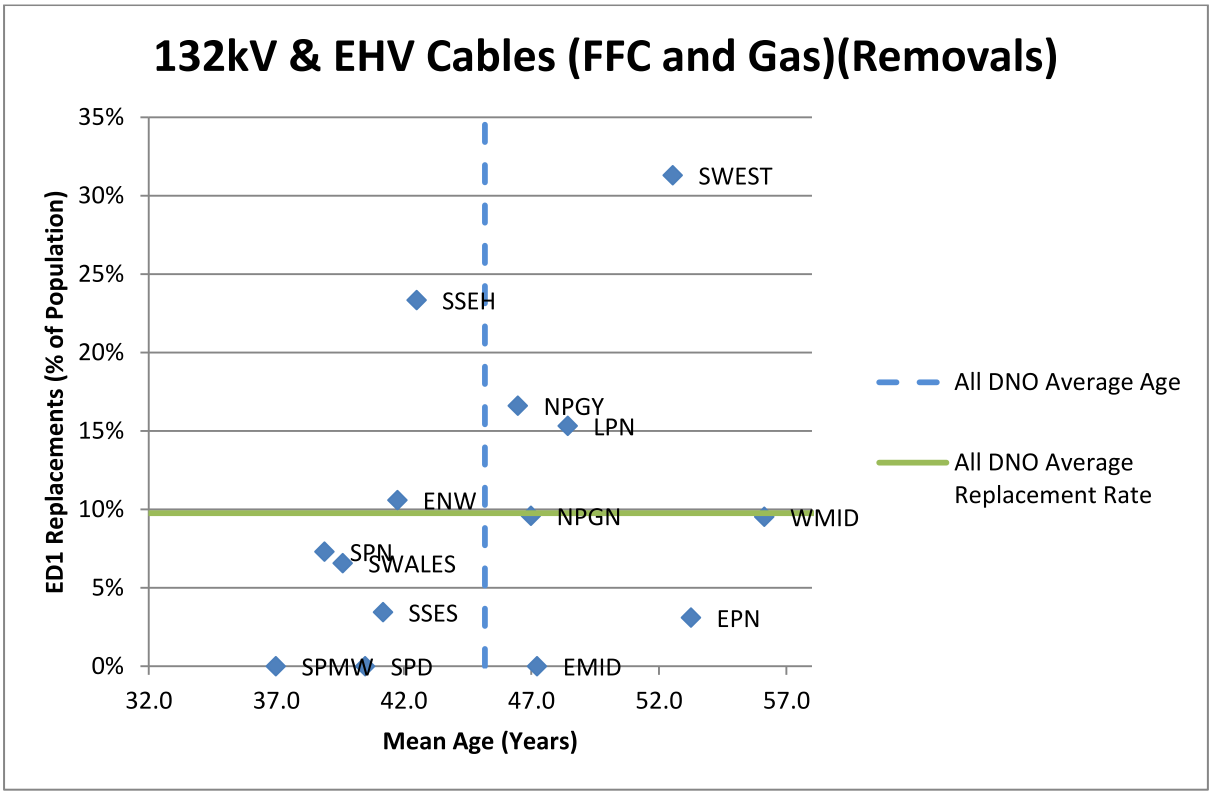
Ref	Project ID	DNO	Description	Volume (km)	Cost £m
1.07.02	8404	SPN	ED1 132kV solid cable replacement provision	2	2.44
1.07.01	3118	SPN	ED1 33kV solid cable replacement provision	7.75	2.33
1.18.01	6651	SPN	Replace HV Cable (Planned)	32	2.80
1.18.03	6533	SPN	Replace LV Cable (Planned)	32	3.12
1.32.09	8920	SPN	Underground 11kV Overhead Lines	200	1.48

Appendix 8 – Output NAMP/ED1 Business Plan Data Tables

Outputs	Asset Stewardship reports										RIG Table										
Investment destription	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	0.00	8.00	0.00	0.00	0.00	0.00	2.50	10.50	CV3	221	-	-	8.00	-	-	-	-	2.50	**10.50**
EHV FFC replacement	1.29.01	5.00	4.00	0.00	0.00	0.00	3.50	1.70	9.00	23.20	CV3	191	5.00	4.00	-	-	-	3.50	1.70	9.00	**23.20**
											CV3	194	-	-	-	-	-	-	-	-	
132kV Gas replacement	1.07.07	0.00	0.00	0.00	0.00	0.00	0.00	0.80	10.00	10.80	CV3	222	-	-	-	-	-	-	0.80	10.00	**10.80**
EHV Gas replacement	1.07.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.00	7.00	CV3	192	-	-	-	-	-	-	-	7.00	**7.00**
											CV3	195	-	-	-	-	-	-	-	-	
Replace 132kV solid cable	1.07.02	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	2.00	CV3	220	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.26	**2.00**
Replace EHV solid cable (planned)	1.07.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75	7.75	CV3	190	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75	**7.75**
											CV3	193	-	-	-	-	-	-	-	-	
Replace HV cable (planned)	1.18.01	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	32.00	CV3	157	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	**32.00**
Underground 11kV Overhead Lines	1.32.09	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	200.00	CV3	151	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	**200.00**
Replace LV cable (planned)	1.18.03	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	32.00	CV3	137	-	-	-	-	-	-	-	-	**0.00**
											CV3	138	2.89	2.89	2.89	2.89	2.89	2.89	2.89	2.89	**23.12**
											CV3	139	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	**8.87**
Total		**39.25**	**38.25**	**42.25**	**34.25**	**34.25**	**37.75**	**36.75**	**62.50**	**325.25**			**39.25**	**38.25**	**42.25**	**34.25**	**34.25**	**37.75**	**36.75**	**62.51**	**325.23**

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 SPN have below average level of investment. The business objective throughout the planning process for ED1 was to invest at a level that will maintain leakage rates at roughly the same level throughout the ED1 period

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 maintain leakage rates at roughly the same level throughout the ED1 period.

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)	32	232	200	-
		Volume (Removals)	120	32	(88 no. of services)	-
		Investment (£m)	8.1	20.2	12.1	-
		UCI (£k)	254	87.2	(168.8)	-

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

The increase in 6.6/11kV solid cable addition volumes is due to the movement of activity from CV2 for the undergrounding of 11kV overhead lines as a result of Quality of Supply (QOS) driven work.

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.