Document 5
Asset Category – 132kV Switchgear
LPN

Asset Stewardship Report 2014

Richard Gould

Approved by Richard Wakelen / Barry Hatton

Approved Date 06/03/2014

Document History

Version	Date	Details	Originator	Revision Class	Section Update
1.0	17/02/2014	July 2013 Submission	Richard Gould		
1.1	17/02/2014	Expenditure tables and charts updated with 19th February NAMP figures	Richard Gould	Major	Header, 1.1, 1.3, 1.5, 7.4, 7.5, Appendix 5
1.2	20/02/2014	Updated Appendix 7 with list of scheme papers and added Appendices 8-10	Richard Gould	Minor	1.1, Appendix 7, 8, 9, 10
1.3	24/02/2014	Updated HI Profiles and added Preface	Richard Gould	Minor	Preface, 7.2, 7.8, Appendix 2
1.4	26/02/2014	Figure and table numbers added to Appendices. Network risk removed from section 7.8.	Richard Gould	Minor	7.8, Appendix 1-10
1.5	28/02/2014	Updates following C. Jeffrey review	Richard Gould	Minor	Appendix 9, 10
1.6	03/03/2014	Paragraph added to end of section 1.3 and section 7.8	Richard Gould	Minor	1.3, 7.8

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1.7	05/03/2014	HI Profiles updated	Richard Gould	Minor	7.8, Appendix 2
2.0	07/03/2014	Final Version	Richard Gould		

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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) and the replacement volumes contained in the Ofgem RIGS tables. The NAMP is the UKPN ten year rolling asset management investment plan. It is used as the overarching plan to drive both direct and indirect Capex and Opex interventions volumes and costs. The volume and cost data used in this ASR to explain our investment plan is taken from the UK Power Networks NAMP. Appendix 8 explains how the NAMP outputs are translated into the Ofgem RIGS tables. The translation of costs from the NAMP to the ED1 RIGS tables is more complex and it is not possible to explain this in a simple table. This is because the costs of project in the 'NAMP' are allocated to a wide variety of tables and rows in the RIGS. For example the costs of a typical switchgear replacement project will be allocated to a range of different Ofgem ED1 RIGs tables and rows such as CV3 (Replacement), CV5 (Refurbishment) CV6 (Civil works) and CV105 (Operational IT Technology and Telecoms). However guidance notes of the destination RIGs tables for NAMP expenditure and included in the table in the Section 1.2 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

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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.

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Contents

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1.0 Executive Summary LPN 132kV Switchgear

1.1 Scope

This document details UK Power Networks' NLRE investment proposals for 132kV Switchgear for the RIIO-ED1 period. Indicative proposals for the ED2 period are also included.

In total there are 207 items of 132kV Switchgear with an estimated MEAV of £97m. The proposed investment including civils is £1.4m per annum, which equates to an average annual 1.4% of the MEAV for this asset category.

Replacement and refurbishment costs, along with the Network Asset Management Plan (NAMP) lines for these assets during ED1 can be seen in Table 1. Appendix 8 contains a reconciliation between NAMP volumes and RIGs volumes.

Investment type	ED1 total expenditure	NAMP line	RIGs reference
Replacement	£9.1m	1.48	Additions CV3 Row 96 - 132kV CB (Air Insulated Busbar)(ID)(GM) CV3 Row 97 - 132kV CB (Air Insulated Busbar)(OD)(GM) CV3 Row 98 - 132kV CB (Gas Insulated Busbar)(ID)(GM) CV3 Row 99 - 132kV CB (Gas Insulated Busbar)(OD)(GM) CV3 Row 100 – 132kV Switch (other) Removals CV3 Row 224 - 132kV CB (Air Insulated Busbar)(ID)(GM) CV3 Row 225 - 132kV CB (Air Insulated Busbar)(OD)(GM) CV3 Row 226 - 132kV CB (Gas Insulated Busbar)(ID)(GM) CV3 Row 227 - 132kV CB (Gas Insulated Busbar)(OD)(GM)
Refurbishment	£0.5m	1.55	CV5 Row 53 – 132kV CB (GM)

Table 1 – Investment plan

Source: 21st February 2014 ED1 Business Plan Data Tables

*Expenditure on this asset type is also included in CV6 Civils and CV3 Underground Cables.

A full list of abbreviations is included in Section 6.0 of Document 20: Capex Opex overview.

1.2 Investment strategy

The investment plan for ED1 for 132kV Switchgear has been developed using the Asset Risk and Prioritisation (ARP) model. The plan focuses on items of switchgear in poor condition or those that provide poor service and reliability – not items of switchgear that are old. This is shown in Figure 5, where older assets remain on the network because there are no defects recorded against them.

The strategy for selecting the level of investment has been to maintain the same level of risk throughout the period. This has been done by keeping the number of HI4 and HI5s at the start and end of the period at similar levels.

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1.3 ED1 Proposals

The proposal for ED1 includes 26 replacements and eight refurbishments across the eight years. DPCR5, adjusted for an eight-year period, had 10 replacements and no refurbishments.

Appendix 9 benchmarks our ED1 proposals with reference to other DNOs July 2013 submissions. It shows that for EHV Switchgear we are proposing to replace 2% of our assets while other DNOs were seeking funding to replace 13% of these assets on average. This demonstrates the effectiveness of our asset risk management systems and the value for money of our proposals.

1.4 Innovation

As mentioned in section 1.2, the ARP model has been used to develop the investment plan. ARP, which has been created for 132kV Switchgear as well as other asset categories, is industry leading and uses environment, condition and manufacturer/model information to determine a HI for every asset both now and in the future. This has been developed with EA Technology.

The model is able to calculate a criticality index for every asset as well as a risk value in monetary terms, but this part is still in development. The risk for individual assets has not been looked at in this way before.

1.5 Risks and Opportunities

	Description of similarly likely opportunities or risks arising in ED1 period	**Level of (uncertainties)/cost growth (£m)**
Opportunity	Use refurbishment options 20% more often than planned	(0.7)
Risk	Cannot undertake refurbishment options.	2.8
Risk	Cost of refurbishment rises by 20% for planned refurbishment interventions in ED1 period	0.1

Table 2 – Risk and opportunities

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2.0 Description of 132kV Switchgear Population

2.1 132kV Switchgear

There are 207 circuit breakers currently operating at 132kV on the network. These are distributed across 25 substation sites with 168 units installed at indoor locations and 39 outdoor locations. These are split into the four categories of switchgear as shown in Table 3.

Switchgear arc extinction method	Population
Bulk oil	33
SF6	25
GIS	120
Air blast	29

Table 3 – 132kV Switchgear types

Source: ARP Model 27th November 2012

As seen in the age profile in Figure 1, there was a large amount of investment during the 1960s and the 2000s. Of the pre-1970s switchgear remaining on the network, there are 29 air blast circuit breakers and 33 bulk oil breakers. The average age of the switchgear on the network is 22.3 years. The oldest 10% of these assets have an average age of 59 years.

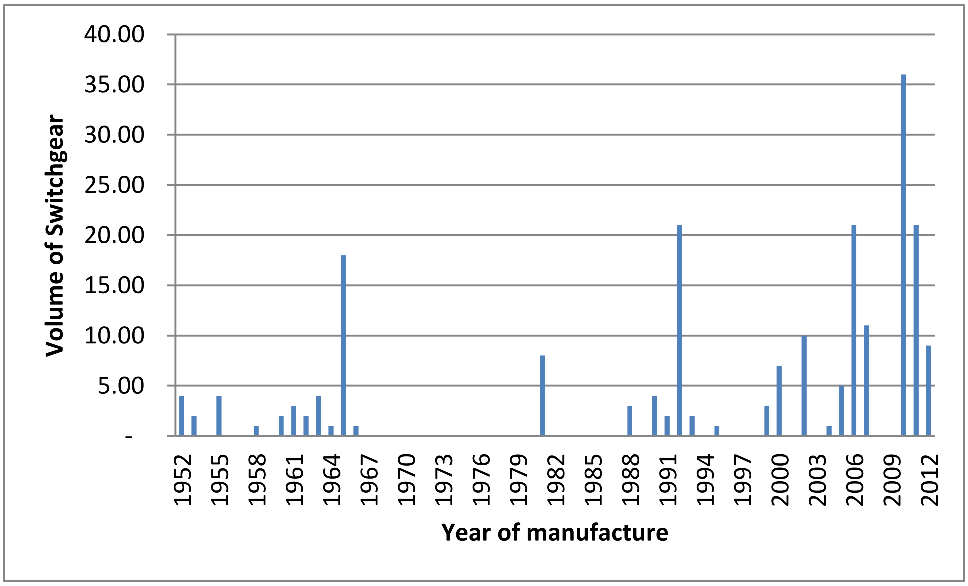

Figure 1 – 132kV Switchgear age profile

Source: 2012 RIGs V5

The NAMP lines used for 132kV Switchgear capital expenditure can be seen in Table 4.

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NAMP line	Description
1.48.01	Replace 132kV/66kV switchgear
1.48.05	Replace with 132kV indoor open terminal CB
1.48.06	Replace with 132kV indoor GIS
1.48.07	Replace with 132kV outdoor open terminal CB
1.48.08	Replace with 132kV outdoor GIS
1.55.02	Misc. EHV asset replacement

Table 4 – 132kV Switchgear NAMP lines

Refer to Table 5 and Table 6 for the mappings for additions and removals in the RIGs tables

Description	Table	Row
132kV CB (Air Insulated Busbar)(ID)(GM)	CV3	96
132kV CB (Air Insulated Busbar)(OD)(GM)	CV3	97
132kV CB (Gas Insulated Busbar)(ID)(GM)	CV3	98
132kV CB (Gas Insulated Busbar)(OD)(GM)	CV3	99
132kV CB (GM)	CV5	53

Table 5 – Additions RIGs mappings

Description	Table	Row
132kV CB (Air Insulated Busbar)(ID)(GM)	CV3	224
132kV CB (Air Insulated Busbar)(OD)(GM)	CV3	225
132kV CB (Gas Insulated Busbar)(ID)(GM)	CV3	226
132kV CB (Gas Insulated Busbar)(OD)(GM)	CV3	227

Table 6 – Removals RIGs mappings

3.0 Investment Drivers

3.1 Investment Drivers

Investment drivers for switchgear can be split into two categories: internal condition and external condition. External condition factors include the condition of the paint and corrosion of any part of the switchgear, such as the bushings or pipework. On outdoor sites the condition of air-insulated busbars and any concrete or steel support structures will also be considered. Internal condition factors include mechanism wear and circuit breaker trip times.

The proposed investment plan for 132kV Switchgear in ED1 includes interventions on three models of switchgear, the Reyrolle OB and OBYR air-blast circuit breakers and the AEI OW410 bulk oil circuit breaker. The specific sites can be found in Appendix 6.

The Reyrolle OB and OBYR air blast circuit breaker can be located indoors or outdoors with air-insulated busbars. The circuit breakers require a constant supply of compressed air, meaning that four compressors are usually required at each site.

There have been a number of national catastrophic failures of the circuit breaker, with 12 reports in NEDERS, the National Equipment Defect Reporting System. These

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failures have been due to a number of reasons including the blast tube failing during pressurisation or the isomaker arm not opening fully and water ingress across the interrupter and stand-off insulator gaskets.

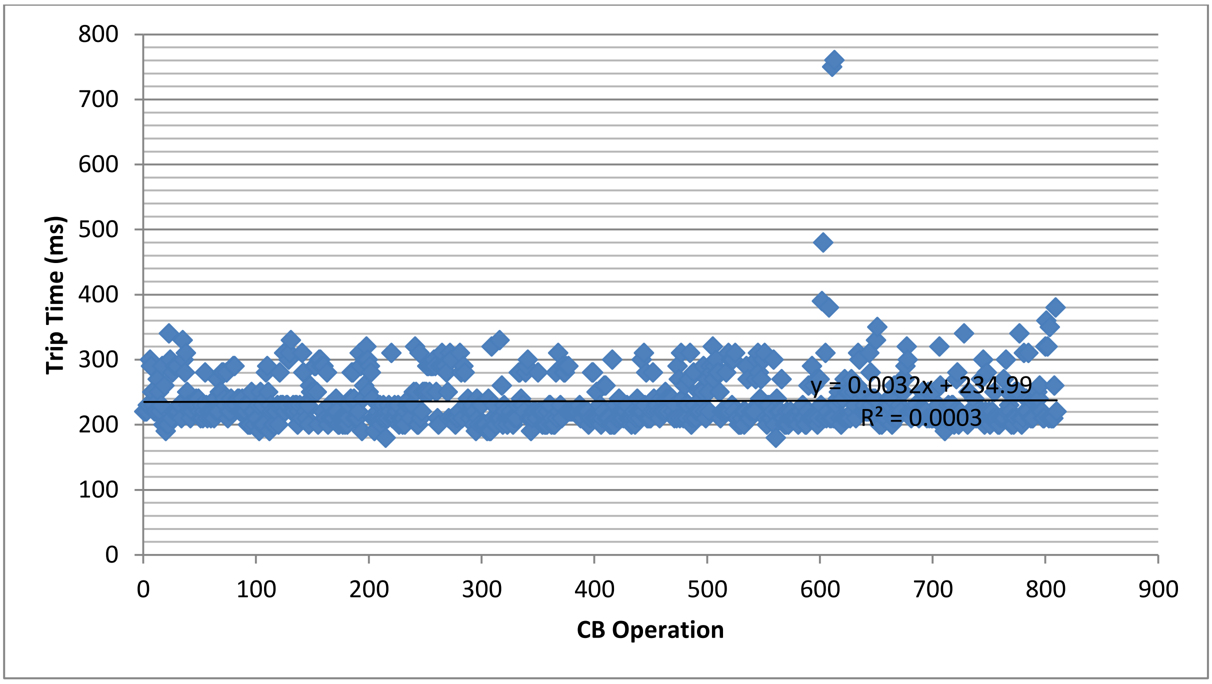

Figure 2 – Reyrolle OB and OBYR CB trip times

Source: ENMAC

Figure 2 shows the circuit trip times for the Reyrolle OB and OBYR taken from the control diagram, ENMAC, between 2007 and 2012. The circuit breaker trip time is the time a circuit breaker takes to open following a fault or an open command from control. The x axis shows the circuit breaker trips sorted by the earliest on the left of the graph and the latest on the right. The figure shows that the trend for trip times has remained reasonably constant during the period. However, the average trip time is 236ms, which is slow compared to a modern equivalent breaker where typical specification would be less than 100ms.

The AEI OW is a bulk oil circuit breaker that can be located either indoor or outdoor. Like the Reyrolle OB and OBYR, the OW has separate air-insulated busbars. There are currently 33 OWs operating on the 132kV network; with the proposed ED1 investment, there will be 18 remaining at the end of the period.

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Figure 3 – AEI OW circuit breaker

There are a number of switchgear defects which are critical in the ARP model, and they are described in section 4 of this document. As defects are found or cleared they are recorded in the Ellipse asset register using a handheld device. Defects can be captured either on an ad-hoc basis or at each inspection and maintenance.

Measure	Inspection	Maintenance
Conditioning air ineffective	If present	If present
Air leaks	No	If present
Compound leak	Yes	Yes
Control cubicle	If present	If present
External connections	If present	If present
Gasket	If present	If present
Oil level	Yes	Yes
Oil sight glass	Yes	Yes
Partial discharge	Yes	Yes
SF_6 gas pressure	Yes	Yes

Table 7 – 132kV defects

In calculating the HI the ARP model counts the total number recorded against individual items of plant, not just those currently outstanding. These defects are described in more detail below.

- **Conditioning air ineffective.** Air-blast circuit breakers require a constant supply of conditioned air to remove any moisture from the air system and circuit breaker. The presence of moisture can lead to catastrophic failure of the circuit breaker.
- **Air leaks.** On air-blast circuit breakers a burst of high-pressure air is used to extinguish any arching at the interrupters when the circuit breaker opens. This is to enable the isomaker arm to operate and for the circuit breaker to become isolated. If there are air leaks in the air system this leads to the air

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compressors running excessively, therefore increased maintenance is required.

- **Compound leak.** To provide an impulse voltage rating, bitumen compound was used as an insulation medium in busbars, current transformer (CT) chambers and cable termination boxes on older metal-clad switchgear. If any compound has leaked the impulse rating is reduced along with the risk of a disruptive failure if the equipment is subject to an overvoltage.
- **Control cubicle.** This is a means of recording defects in the small wiring, auxiliary fuses and terminal blocks associated with control of the circuit breaker. These defects can prevent the circuit breakers from operating correctly with a resultant effect on customer interruptions (CIs) and customer minutes lost (CMLs).
- **External connections.** For 132kV circuit breakers this is used to record defects with the bushings of the switchgear and associated busbar connections. A problem here can result in overheating and eventual disruptive failure.
- **Gasket.** For oil filled switchgear, this is used to record a defective gasket. No action is immediately required, but if it is left unchecked, it can result in a low oil level.
- **Oil level.** For oil filled switchgear, this is used to show that the oil level is low and needs to be topped up. If left unchecked this can result in a disruptive failure.
- **Oil sight glass.** For oil-filled switchgear, this is used to show that the oil sight glass is unreadable, broken or missing. If left unchecked, this can result in a disruptive failure.
- **Partial discharge.** This shows that partial discharge has been recorded. If this is left unchecked this can result in disruptive failure.
- **SF_6 gas pressure.** SF_6 gas is used as an insulating medium. If the pressure falls below the rated value, the equipment could fail disruptively if left in service.

The OW has seen an increasing number of defects reported in the last five years, as shown in Figure 4. The defects include issues with oil levels and gaskets and problems with external connections.

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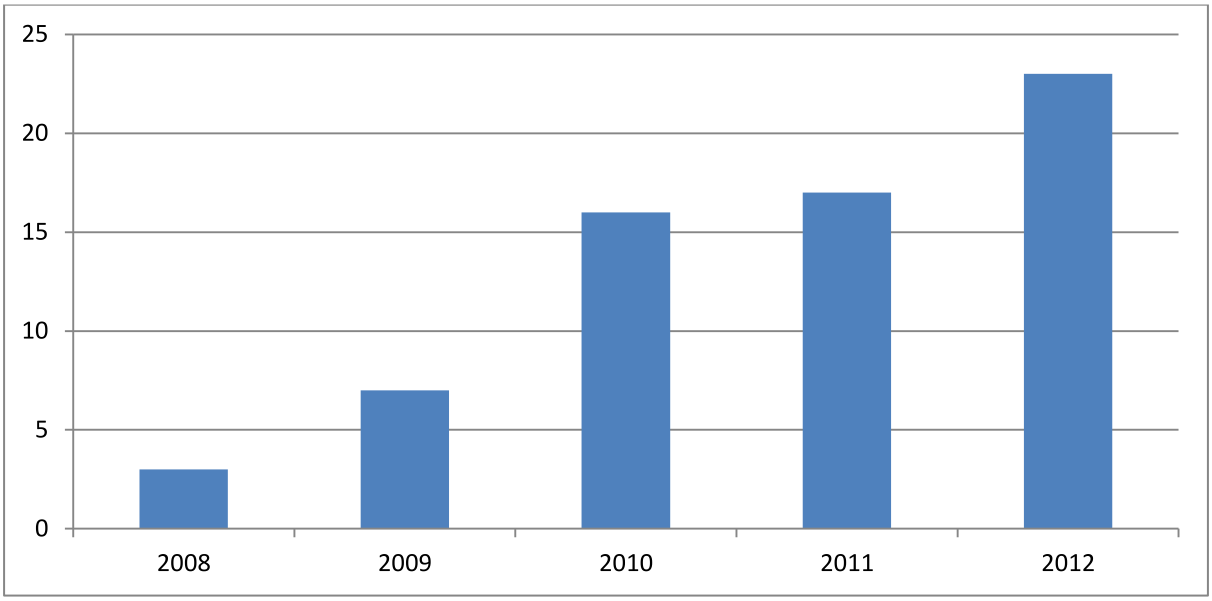

Figure 4 – AEI OW reported defects

Source: ARP Model 25 July 2012

Figure 5 shows the age of an asset when a new defect was reported, plotted against the age of the other assets on the network. There will be defects reported at ages where there are currently no assets, as they will have either aged or been removed from the network since the defect was reported. This shows that the majority of defects occur when an asset is 40-50 years old, with few defects recorded on assets less than 20 years old – even with the large proportion of the population in this age range. As mentioned earlier in this section, defects represent a big risk – not only to the network, but also to operator safety because of the increased likelihood of a catastrophic failure.

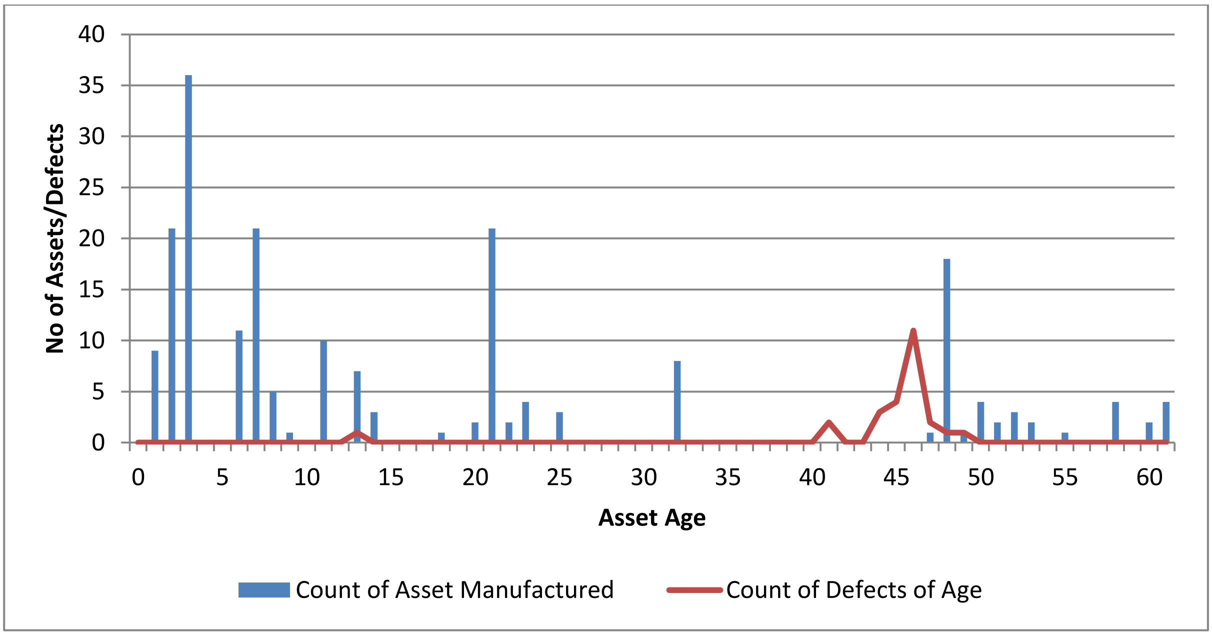

Figure 5 – Defects by asset age

Source: Ellipse Extract 19/02/2013 and 2012 RIGs V5

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Figure 6 shows the rate for all faults relating to switchgear and then split by i) faults caused by the condition of the switchgear and ii) non-condition-related faults. This shows that the number of faults caused by the condition of the switchgear has remained fairly constant over the last six years.

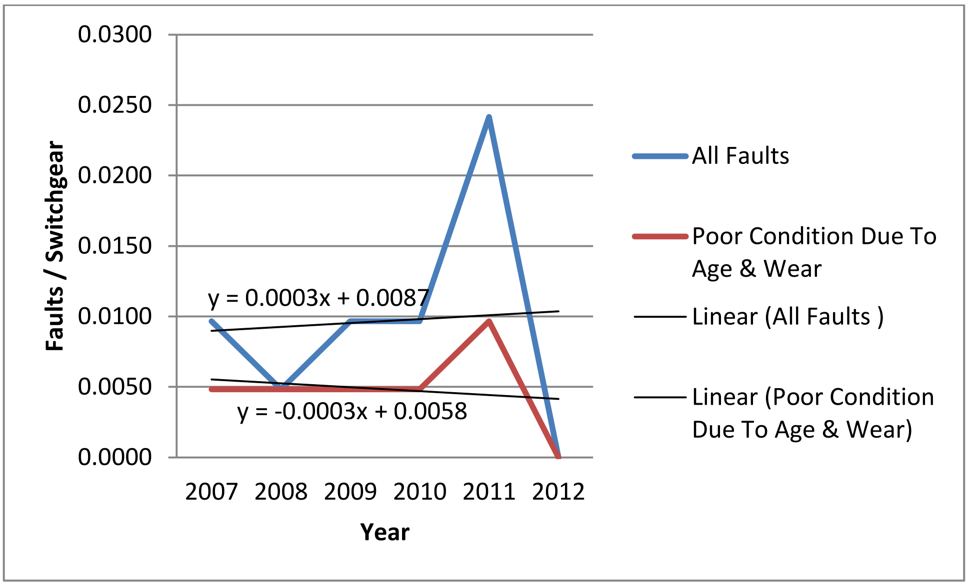

Figure 6 – Fault rate

Source: UK Power Networks Fault Analysis Cube

The maintenance costs of the different types of switchgear is considered, but is not used as a primary driver for investment cases. The cost of maintaining air-blast circuit breakers is significantly more than a modern SF6 circuit breaker. Figure 7 shows the cost of maintenance over a 52-year period, which is the average asset life stated in *Commentary Document 15: Model Overview* section 8. The cost of maintaining an air-blast circuit breaker is five times that of GIS and SF6 outdoor circuit breakers.

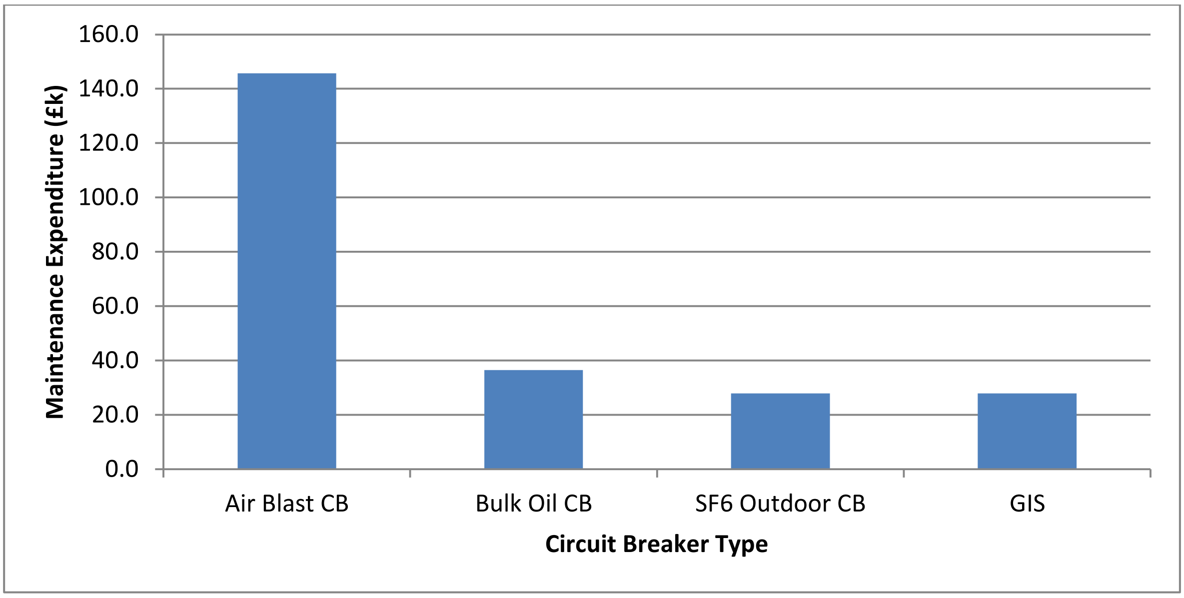

Figure 7 – Whole life maintenance costs

Source: EMS 10-0002 Inspection and Maintenance Frequency Schedule

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3.2 Condition Measurements

3.2.1 Substation inspection

The main source of information about the external condition of assets is substation inspectors. During the first half of DPCR5 a review of the substation inspectors' handbook was carried out and a new handbook issued. All inspectors were required to undertake a two-day training course and pass the theory and practical examinations before being certified as a competent inspector.

Figure 8 – Substation inspector with a handheld device

Data is captured and recorded in the asset register in a timely manner on handheld devices, on site and at the point of inspection, to record it in the correct format within the asset register (Ellipse). When a handheld device script is run, the inspector answers set questions about the condition specific to the asset type, and records any defects as well as reviewing current defects and clear them where required. The inspection scripts have been designed to be as objective as possible, so that there is consistency across the whole network.

Inspections are carried out at a set frequency, which is recorded in *EMS 10-0002 Inspection and Maintenance Frequency Schedule*. For grid and primary substations with wet cell batteries, one major inspection and two minor inspections are carried out annually; for substations with dry cell batteries, one minor inspection and one major inspection are carried out annually. Switchgear is inspected at both minor and major inspections.

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3.2.2 Maintenance

There are two routine maintenance tasks carried out on 132kV Switchgear: mechanism maintenance and full maintenance. The two maintenance tasks are carried out alternatively in six-year intervals, as recorded in *EMS 10-0002 Inspection and Maintenance Frequency Schedule*. A circuit breaker operation is also carried out yearly for bus section and transformer breakers, and every two years for feeder breakers.

Maintenance fitters also use the same technology to record their assessment of the internal and external condition of the assets. This assessment is made twice to provide condition data both 'as found' and 'as left'.

The key condition points recorded at maintenance are the circuit breaker trip time, the overall internal condition, the condition of the operating mechanism and the condition of the isolating contacts. For oil circuit breakers an on-site oil test is also carried out.

4.0 Asset Assessment

4.1 Asset Health

An innovative asset health modelling tool, the ARP model, has been developed for several asset categories including 132kV Switchgear. The methodology behind the modelling is the same for all asset categories, but the switchgear model has been tailored specifically to use the data available against the identified investment drivers for switchgear.

The general methodology for the ARP model can be found in *Commentary Document 15: Model Overview*. The 132kV Switchgear ARP model uses both the age of an asset, its location information and its condition to calculate an HI. An initial HI is calculated based on the year of manufacture, the average initial life, the environment where the asset is installed and the duty of the switchgear during its life.

The environmental factors include the distance from the coast, whether the asset is indoors or outdoors, and the level of pollution. The function of the switchgear, whether it is a feeder, bus section or transformer breaker, is used to account for the duty. An average initial life is assigned per make and model of switchgear, calculated from the date of manufacture to the expected time that the asset will show signs of increased deterioration. It does not show the time from when the asset is commissioned until it is decommissioned. This initial HI is capped at HI3 to ensure assets will never achieve an HI greater than three and therefore be considered for intervention based on age alone.

A factor value is calculated using condition, defects and switchgear reliability data. The condition and defect data that is input into the model is obtained from the asset register, Ellipse. The reliability is based on the make and model of the switchgear. There are a number of condition points that force the HI to a minimum of HI5, including the external condition of the housing and the number of SF_6 top-ups. This is

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due to wanting to flag any assets showing poor condition in these measures regardless of asset age as they will have a higher probability of failure.

This factor value is then combined with the initial HI to produce the current HI of the asset.

4.2 Asset Criticality

The ARP model can also be used to calculate the criticality of a particular item of switchgear, which is in the form of a criticality index from 1 to 4, with 1 being the least critical and 4 the most critical. A detailed methodology for calculating the criticality index can be found in *Commentary Document 15: Model Overview*. The criticality section of the ARP model is under development.

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

- **Network performance.** The key factors are the number of customers the substation feeds and the function of the asset. The function of the switchgear can be either a feeder breaker, bus section or transformer breaker. A bus section breaker is the most critical and a feeder breaker is the least critical.
- **Safety.** The factors considered are the arc extinction method, and whether the switchgear is internally arc rated. The arc extinction method plays a large part in the safety of a particular type of switchgear, with oil switchgear considered the most dangerous method, and therefore the most critical. Items of switchgear that are not internal arc rated are considered more critical that switchgear that is.
- **Operational and capital expenditure.** This section considers the criticality between assets in terms of the difference in maintenance costs between different makes and models of switchgear, and the difference in capital expenditure for various voltage levels.
- **Environmental.** This section considers the type of insulation and the effect it has on the environment. The volume of gas and oil is also considered.

4.3 Network Risk

The network risk in monetary terms can also be calculated in the ARP model using the probability of failure, the criticality and the consequence of failure, although it is still under development. The probability of failure is calculated using the current HI of the item of switchgear, 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 switchgear following one of four failure modes. These are detailed in Table 8.

Failure mode	Description
Minor	Can be repaired in house
Significant	Can be repaired using external resource
Major	Beyond repair – disruptive failure ***or*** sent away for repair
Failure to trip	No repair needed

Table 8 - Failure modes

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For the failure to trip mode, although no repair is needed, post-fault maintenance will be carried out to investigate the cause of the stuck circuit breaker. Stuck or slow operating breakers have a huge effect on customers as they result in increased CIs and CMLs. This is because if a feeder circuit breaker fails to trip or is slow to trip during a fault, the circuit breaker upstream will operate. The circuit breaker upstream will usually be the transformer breaker that feeds the bus section, meaning the bus section will be lost. This loss will result in an increased number of customers affected than if just the original feeder was lost.

4.4 Data Validation

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

An example is the circuit breaker trip times used in the model. These values have to be between 10ms and 1,000ms, otherwise they will be discarded. There is also an age limit on the condition data, so no data recorded more than five years ago is used. This is to ensure that the outputs describe the current asset rather than in the past.

4.5 Data Quality

The completeness, accuracy and timeliness of the data used in the ARP model is routinely checked and a CAT score produced. For the latest results of the data used in the 132kV Switchgear model, refer to Table 9.

The score is colour coded as follows.

- Green – score of 85% or greater
- Amber – score of 65% or greater
- Red – score of less than 65%.

Area	Score
Completeness	68%
Accuracy	89%
Timeliness	98%

Table 9 – CAT score

Source: Ellipse Extract 27/11/2012

The completeness score is a combination of switchgear nameplate data and condition data. Information used on the nameplate includes the year of manufacture, the operating voltage, circuit breaker function, and any other information that will remain constant during an assets life. Condition data is recorded by substation inspectors, as described in section 3.4, and will change with time.

Investment in a project during DPCR5 has attempted to improve the completeness of the condition data, and this has led to some new condition points being created.

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Because of this, in some cases, the condition point may not be populated until the next maintenance.

The accuracy score is a measure of how reliable and correct the condition data stored in Ellipse is. This is done by making a comparison between the condition measure recorded by UK Power Networks and the same measure recorded by a independent third party, SKM.

The timeliness score shows the percentage of assets that have condition data recorded within the expected time period, as stated in *EMS 10-0002 Inspection and Maintenance Frequency Schedule*.

5.0 Intervention policies

5.1 Interventions: Description of Intervention Options

Two options were considered during planning for ED1: replacement and refurbishment. There are a number of refurbishment options available for 132kV Switchgear. For air-blast circuit breakers, a full refurbishment would include the following:

- Supply a full set of seals, O-rings and grease
- Refurbish the circuit breaker operating mechanism
- Dismantle the blast valve and sequence-switch motor, and clean the pistons
- Sand the cylinder walls
- Replace all rubber components and gaskets
- Replace valve seats and buffers
- Examine all linkages for signs of wear
- Lower the tank of the oil dashpot and clean and replace oil
- Examine the circuit breaker and series break arm contacts nozzles and arching electrodes
- Examine both fixed and moving contacts and carry out ductor tests
- Check all electrical connections are secure
- Carry out speed curve tests
- Carry out timing tests.

Where only some of these activities are completed the Ofgem definition of refurbishment is checked to assess whether the activity should be classified as refurbishment or not.

For refurbishments of SF6 circuit breakers would involve replacing the entire operating mechanism due to the ‘sealed for life’ design. In these cases a new mechanism can be installed in the circuit breaker and the old mechanism can be returned to the manufacturer to be refurbished and used elsewhere.

For replacement interventions there different options available depending on the equipment currently installed on the site, and the site situation. These are outlined in Table 10.

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Option	Description	Advantages	Disadvantages
Outdoor AIS solution	This option uses outdoor circuit breakers, for example, the Siemens 3AP1DT circuit breaker shown in Figure 9. If there are existing outdoor busbars these can be reused depending on condition.	Cheaper than an indoor solution. Can reuse existing busbar. Replacement of individual circuit breakers possible.	Requires a lot of space. Can't always reuse busbar due to poor condition support structures. Prone to deterioration as outdoors. Trespass risk resulting in security/safety issues.
Indoor AIS solution	This option would only be considered if there were already indoor AIS circuit breakers at the site. It uses the same type of circuit breaks as the outdoor solution.	Can reuse existing busbar and building. Replacement of individual breakers possible. Slower deterioration due to being indoors.	Requires a lot of space. Can't always reuse busbar and building.
GIS solution	Indoor switchboard-type switchgear. Gas-insulated busbars located indoors. An example of GIS is in Figure 10, showing a Siemens 8DN8 GIS circuit breaker.	Small footprint. Slower deterioration due to being indoors.	Expensive compared to AIS solutions. May have to replace whole board for future extensions.

Table 10 – Replacement options

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Figure 9 – Siemens 3AP1DT circuit breaker

Figure 10 – Siemens 8DN8 GIS circuit breaker

5.2 Policies: Selecting Preferred Interventions

The process used for selecting interventions can be seen in Figure 11. The process is different depending on whether the switchgear asset is part of a switchboard or a standalone unit.

If the switchgear asset is part of a switchboard, replacement will require the whole board to be replaced, whereas refurbishment can be carried out on individual unit. However, in most cases, the switchboard will contain circuit breakers of the same model, year of manufacture, environmental conditions and maintenance engineers, so they should be in similar health.

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If the switchgear is a standalone unit, it can be either be refurbished or replaced. If there are multiple items of switchgear on the site, the condition and health of the other assets has to be considered to see if efficiencies can be made by replacing them at the same time. If modern switchgear is replaced as part of one of these projects, this can be reused at a different site or as a strategic spare.

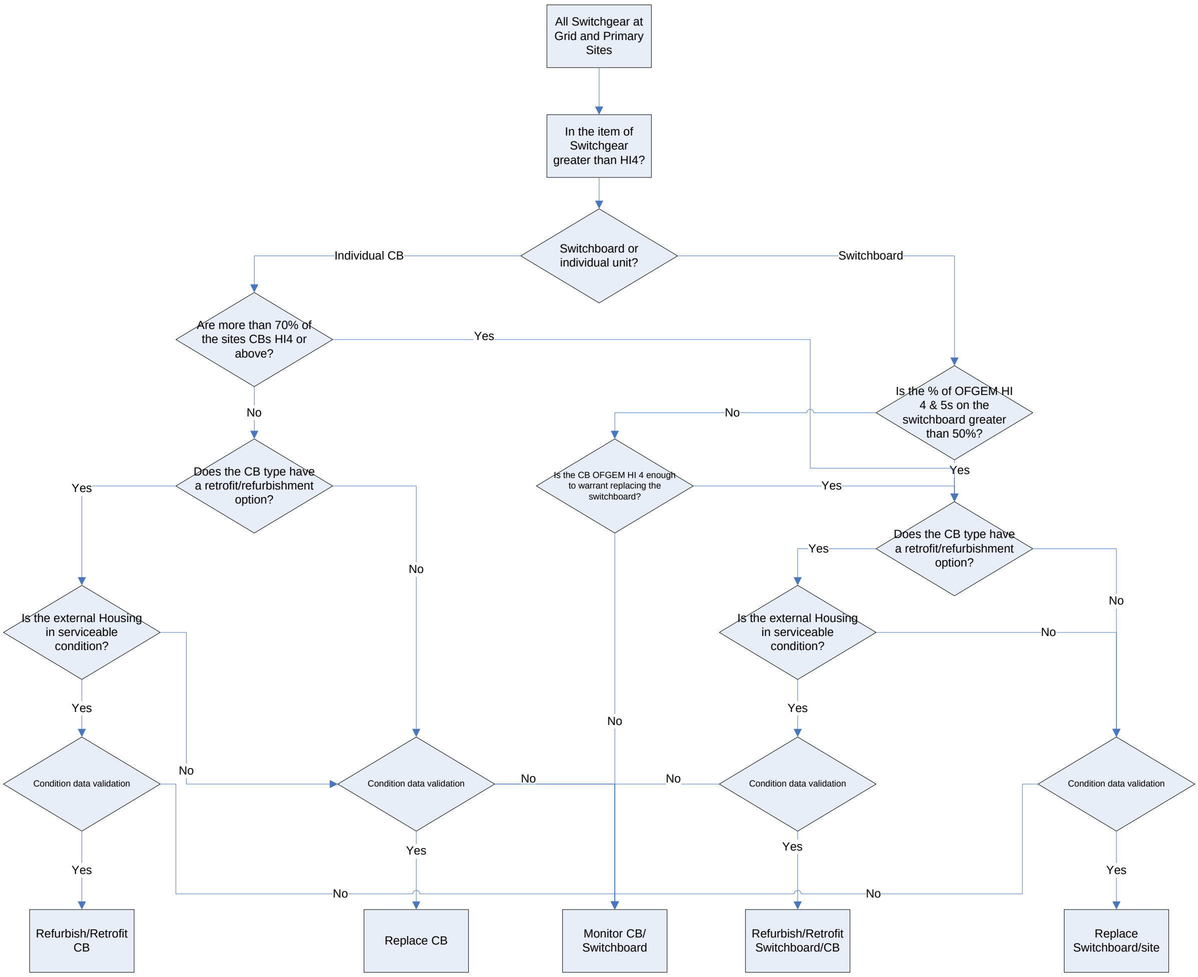

Figure 11 – Intervention strategy process

The capital expenditure plan for 132kV Switchgear can lead to cost savings in operational expenditure. This is because the maintenance costs for air blast and oil switchgear are higher than modern equivalent SF6 switchgear, so replacement of these assets will see operational expenditure savings. Whole life costs will be considered on a site-by-site basis as part of an internal investment approval process.

6.0 Innovation

As mentioned in section 4, an innovative new model has been used: the ARP model. This has been developed for 132kV Switchgear as well as other asset categories. The model is industry leading and uses environment, condition and manufacturer/model information to determine an HI for every asset, both now and in the future. It has been developed with EA Technology.

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The model can calculate a criticality index for every asset as well as a risk value in monetary terms, though this is still in development. The risk for individual assets has not been looked at in this way before.

7.0 ED1 Expenditure Requirements for 132kV Switchgear

7.1 Method

Figure 12 shows an overview of the method to construct the ED1 NLRE investment plans.

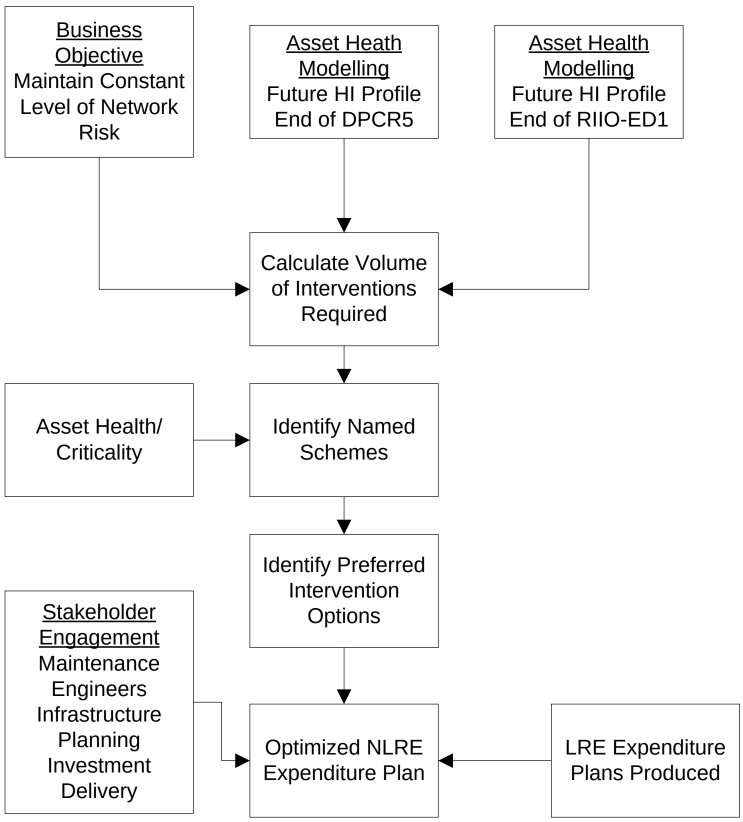

Figure 12 – Programme development methodology

7.2 Constructing the plan

The overall strategy for non-load related expenditure on 132kV Switchgear during ED1 has been to maintain the same level of risk at the end of the period as there is at the start. This is achieved by keeping the number of HI4 and HI5s at the beginning and end of the period the same. The HI profiles are outputs from the ARP model. Refer to Figure 13 for the HI profiles at the beginning and end of ED1.

At the start of ED1 the number of HI4 and HI5s is 1% of the total population. At the end of the period this increased to 10%. This figure does not take into account the reduction in HI4 and HI5s driven by reinforcement. In particular, a sizable scheme to replace the switchgear at Wimbledon for reinforcement reasons will reduce the HI4/HI5 percentage to 5%

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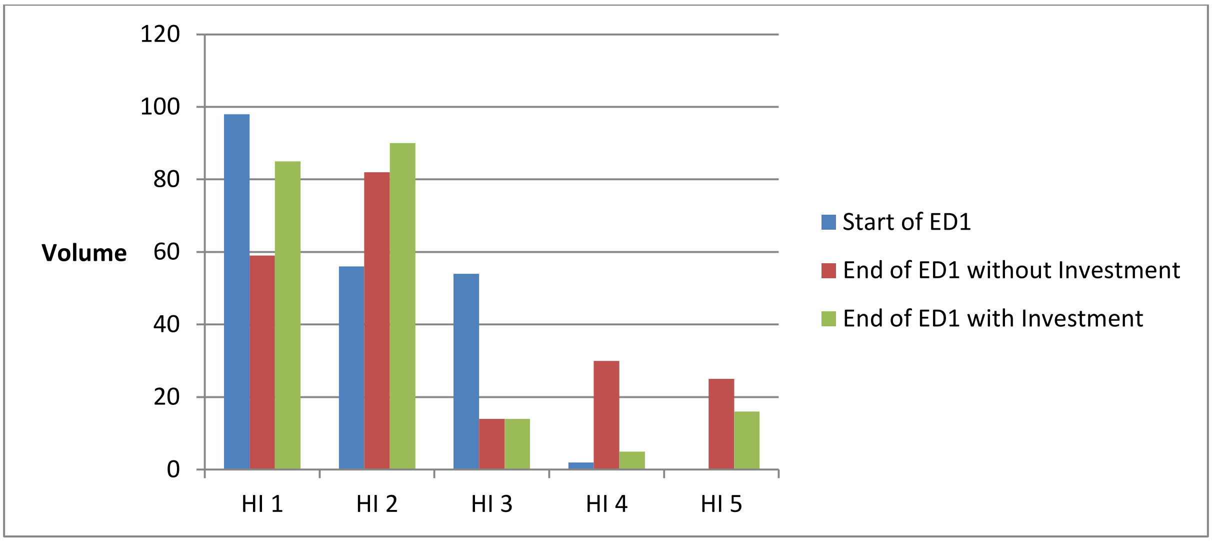

Figure 13 – ED1 HI profiles

Source: ARP Model 25th July 2012

Figure 14 shows the number of HI4 and HI5s with and without investment, and the beginning, middle and end of ED1.

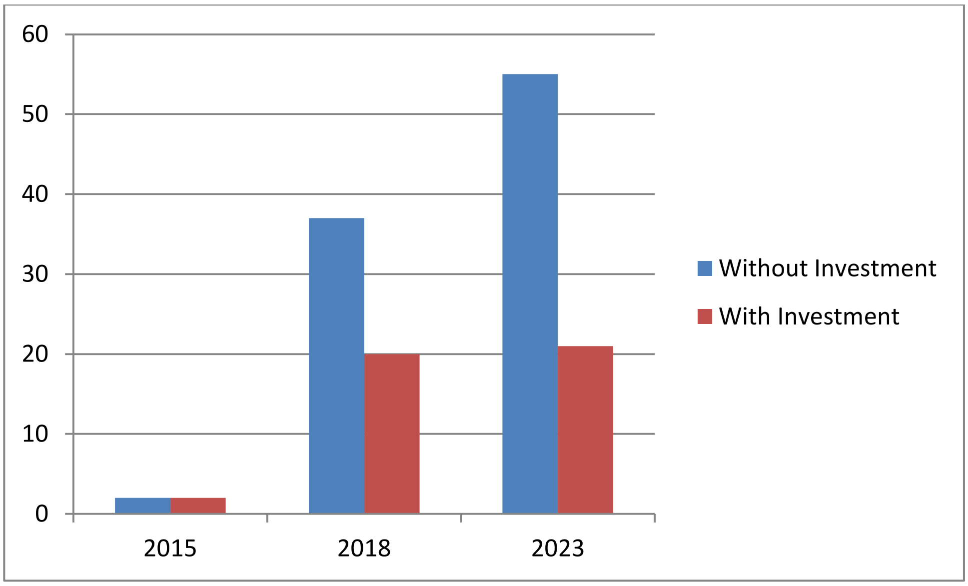

Figure 14 – Total number of HI4 and HI5s

Source: ARP Model 25th July 2012

7.3 Additional Considerations

There are a number of additional requirements that need to be considered when constructing the plan. The three major factors are other NLRE investment, LRE investment required at the site during ED1 and any National Grid work at the site or on the surrounding network.

The main NLRE schemes that will affect 132kV Switchgear projects is work on switchgear of other voltages on the same site and transformer interventions at the

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site. If these schemes are set to happen within five years of the 132kV Switchgear scheme, consideration has been given as to whether cost efficiencies are possible by combining the schemes. This can mean that site establishment (CDM) costs are reduced, project administration can be combined, and there is the possibility of combining network outages.

Any LRE requirements at the site may mean that a project needs to be re-phased. Where a project has both NLRE and LRE drivers, NLRE is used as the primary driver where appropriate. In some cases LRE has been used as the primary driver following a project specific review.

At 132kV, many of the substations sites are shared between National Grid and UK Power Networks and, in some cases, switchgear from both companies can be connected to the same busbar. In these cases, National Grid normally owns the incoming circuit breakers and the busbar, and UK Power Networks owns the outgoing circuit breakers. Due to this, consultation with National Grid has taken place to discuss investment plans and align them. Following the consultation, the plans align.

7.4 Asset Volumes and Expenditure

Figure 15 shows the number of interventions on 132kV Switchgear from the start of DPCR4 to the end of ED2. For a list of named schemes, refer to Appendix 7.

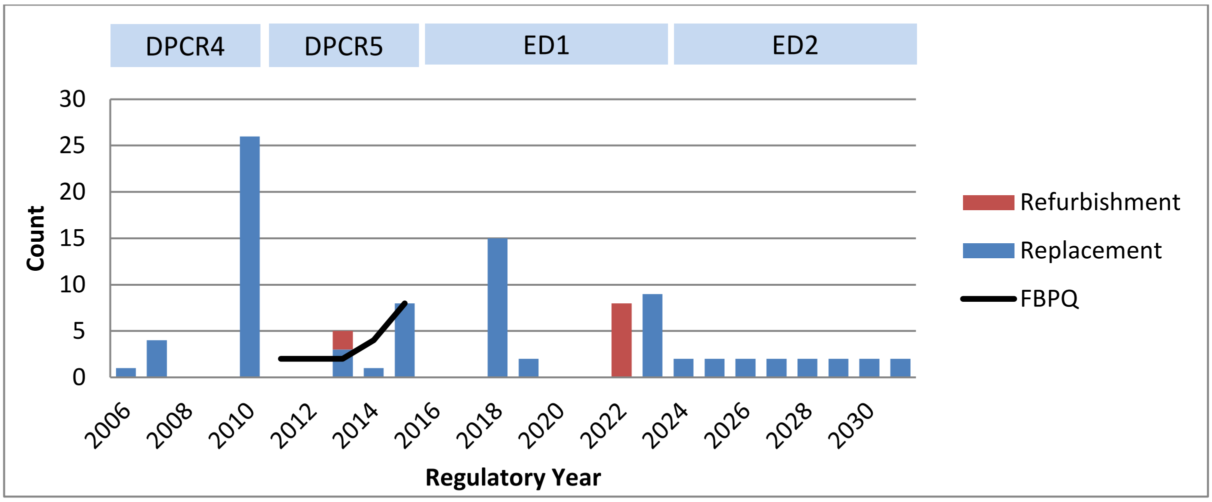

Figure 15 – 132kV Switchgear yearly interventions

Source: DPCR5 FBPQ, 2013 RIGS, 19th February 2014 NAMP, and Age-Based Model

Refer to Figure 16 for 132kV Switchgear expenditure from the start of DPCR4 to the end of ED2.

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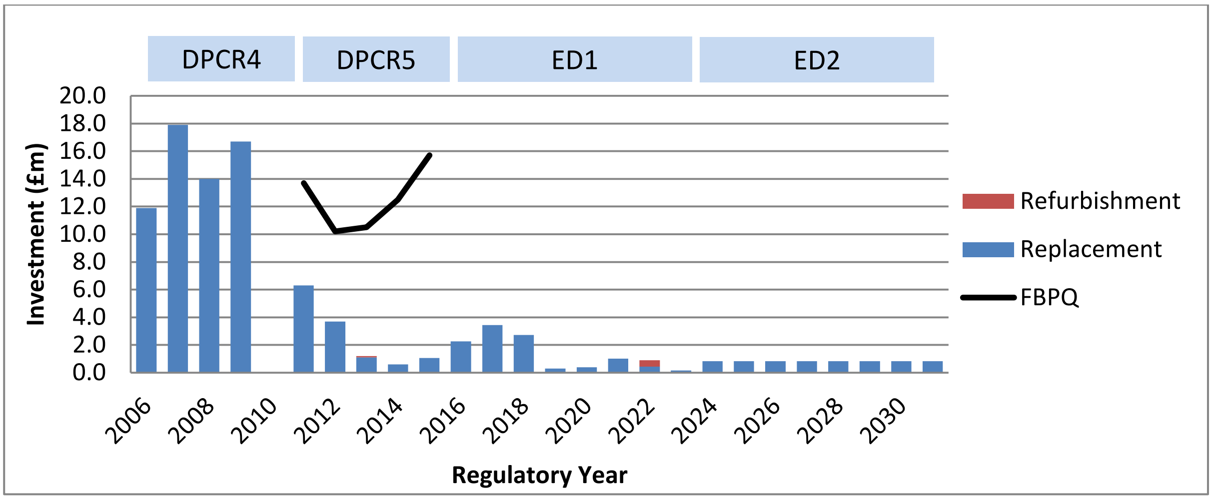

Figure 16 – 132kV Switchgear yearly expenditure

Source: DPCR5 FBPQ, 2013 RIGS, 19th February 2014 NAMP, and Age-Based Model

The actual and forecast level of investment in DPCR5 is below the level submitted in the FBPQ submission. This is largely the result of improved risk management during this period, which has allowed the deferral of some expenditure.

Full page versions of Figure 15 and Figure 16 can be found at the end of Appendix 7.

7.5 Commentary

To compare the number of interventions in each period, the average number each year will be used. The yearly average number of interventions for DPCR4 is six items of switchgear, with a number of large projects finishing in the final year. The forecast yearly average for DPCR5 is three item of switchgear, and the proposed yearly average for ED1 is four. The proposed volume of replacements in ED1 is 26 and the volume of refurbishments is eight. The refurbishments intervention being carried out on eight circuit breakers in ED1 is only available on these breakers.

The averages show that the number of interventions planned for ED1 is more than DPCR5 – however, it is less than was achieved in DPCR4. This increase is due to a rising number of known defects on certain types of switchgear that pose safety issues, as mentioned in section 3.1.

The average yearly expenditure for DPCR4 and DPCR5 is £12.1m and £2.6m; for ED1 it is £1.4m. This shows that although the number of interventions is increasing in ED1, the cost is reducing due to refurbishments having a lower UCI and AIS solutions being used rather than GIS, which also have a lower UCI.

There is a large amount of expenditure in DPCR4 with no volumes being seen until the final year of the period. This is due to work being required on the sites prior to the assets being decommissioned.

The actual and forecast level of investment in DPCR5 is below the level submitted in the FBPQ submission. This is largely the result of improved risk management during this period, which has allowed the deferral of some expenditure.

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The ED2 intervention and investment figures shown in the chart have been derived from age-based modelling. Asset condition and health will be used closer to ED2 to reassess the volume of interventions required.

7.6 Sensitivity Analysis and Plan Validation

An independent report has been carried out by Decision Lab to understand how the HI profile of assets may change if the average initial life of assets does not turn out as predicted.

Average life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	46.1	25.2	22.3	6.3	0.0
-2	46.6	25.2	24.8	3.4	0.0
-1	46.6	26.2	25.7	1.5	0.0
0	47.6	25.2	26.2	1.0	0.0
1	47.6	26.2	25.2	1.0	0.0
2	47.6	26.7	24.8	1.0	0.0
4	47.6	28.1	23.3	1.0	0.0

Table 11 – 2015 sensitivity analysis

Average life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	35.5	48.0	4.9	0.0	12.1
-2	42.7	41.7	5.3	0.5	9.7
-1	42.7	42.2	5.3	2.4	7.3
0	42.7	42.2	6.3	1.5	7.3
1	42.7	44.2	4.4	3.4	5.3
2	42.7	44.2	4.9	4.8	3.4
4	42.7	44.2	8.2	1.5	3.4

Table 12 – 2023 sensitivity analysis

Source: Decision Lab Analysis February 2013

In Table 11 and Table 12 each average initial life change of years +/- 1, 2 and 4 are represented in percentage of the current population. With each change in average initial life there is a subsequent movement in the percentage of population in each HI. An average initial life at '0' represents the current population split within each HI 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 effect any change in average initial life will have on the HI profile.

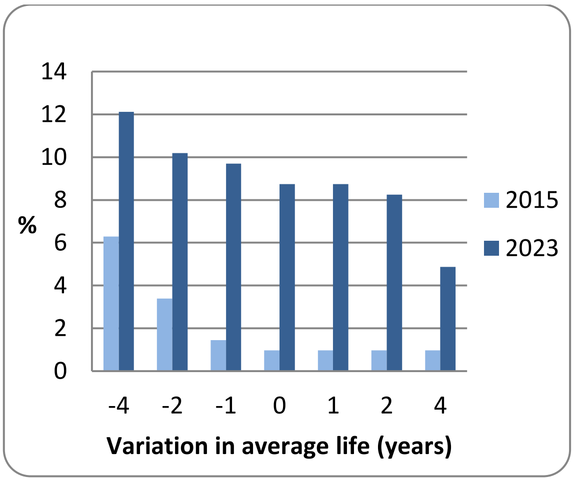

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Figure 17 – Total HI4 and HI5s sensitivity analysis

Source: Decision Lab Analysis February 2013

Figure 17 represents the number of HI4 and HI5s as a percentage of the population showing the change at each average initial life iteration comparing 2015 and 2023.

The analysis shows that the model is mildly sensitive with a difference of 5.3% in the number of HI4 and HI5s in 2015 for a change of eight years in the average initial life. The difference in 2023 for a change of eight years in average life is 7.2%. This shows that changes in the average initial life have very similar effects on current and future HIs, with future HIs slightly more sensitive.

7.7 Model Testing

The ARP model has 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 and 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. Each algorithm is mimicked by the tester in a spreadsheet with the results compared to 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. To pass the test, all results from the ARP algorithm are required to match the spreadsheet calculation.

7.7.2 Software testing

A number of new software functions are used in the model which required testing to ensure correct performance. A test script was created to identify the functional requirement, the method to carry out the function and the expected outcome. To pass the test the achieved outcome had to match the expected outcome.

7.7.3 Data flow testing

To ensure data presented in the ARP upload files passes into the model correctly data flow testing has been carried out. The test carries out data counts to check that the number of records put into the model is the same as the number shown in the final model.

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7.7.4 User and methodology testing

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

7.8 Network Risk

As mentioned in section 4, the ARP model produces a criticality index (C1 to C4) for each individual asset, although this is a very new concept and it is still being developed. The criticality index can be used with the HI to give an indication of the level of risk seen on the network. Table 13 and Table 14 show the HI and criticality matrix for 2015 and 2023 with investment during ED1.

Asset categories	Criticality	Units	Estimated asset health and criticality profile 2015					Asset register
			Asset health index					2015
			-+	HI2	HI3	HI4	HI5	
132kV Switchgear	Low	No. CB	4	1	9	0	0	14
	Average	No. CB	20	32	20	1	0	73
	High	No. CB	51	15	21	0	0	87
	Very high	No. CB	23	22	4	1	0	50

Table 13 – 2015 HI and criticality matrix

Source: ARP Model (HI: 25 July 2012, Criticality: 27th November 2012)

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Asset categories	Criticality	Units	Estimated Asset Health and Criticality Profile 2023					Asset register
			Asset health index					2023
			HI1	HI2	HI3	HI4	HI5	
132kV Switchgear	Low	No. CB	10	2	1	1	0	14
	Average	No. CB	27	35	4	3	4	73
	High	No. CB	29	46	2	1	9	87
	Very high	No. CB	19	21	7	0	3	50

Table 14 – 2023 HI and criticality matrix

Source: ARP Model (HI: 25 July 2012, Criticality: 27th November 2012)

The increase in the number of HI4 and HI5 circuit breakers is because a large scheme to replace the switchgear at Wimbledon is being done as a load driven project, however some of these circuit breakers have high HIs. This is described in section 7.2

8.0 Deliverability

The number of interventions taking place during ED1 is in line with those delivered during DPCR5, so resources are available and consideration of network outage issues has taken place during project phasing.

All projects will be created in the NAMP and this will be used to manage the project portfolio internally.

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Appendices

Appendix 1 – Age Profiles

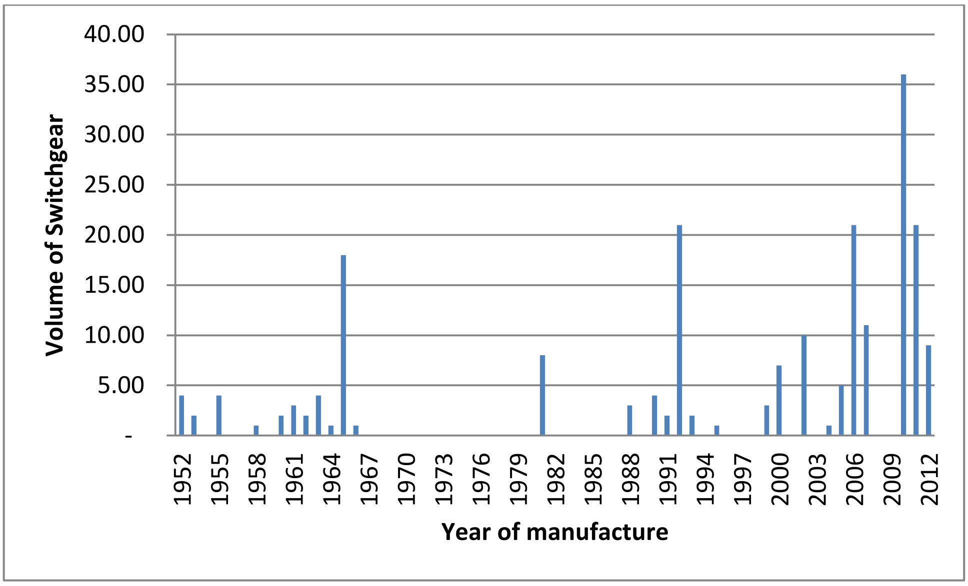

Figure 18 – 132kV Switchgear age profile

Source: 2012 RIGs V5

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Appendix 2 – HI Profiles

Asset categories	Criticality	Units	Estimated asset health and criticality profile 2015					Asset Register
			Asset health index					2015
			HI1	HI2	HI3	HI4	HI5	
132kV Switchgear	Low	No. CB	4	1	9	0	0	**14**
	Average	No. CB	20	32	20	1	0	**73**
	High	No. CB	51	15	21	0	0	**87**
	Very high	No. CB	23	22	4	1	0	**50**

Table 15 – 2015 HI and criticality matrix

Source: ARP Model (HI: 25th July 2012, Criticality: 27th November 2012)

Asset categories	Criticality	Units	Estimated asset health and criticality profile 2023					Asset Register
			Asset health index					2023
			HI1	HI2	HI3	HI4	HI5	
132kV Switchgear	Low	No. CB	10	2	1	1	0	**14**
	Average	No. CB	27	35	4	3	4	**73**
	High	No. CB	29	46	2	1	9	**87**
	Very high	No. CB	19	21	7	0	3	**50**

Table 16 – 2023 HI and criticality matrix

Source: ARP Model (HI: 25th July 2012, Criticality: 27th November 2012)

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Appendix 3 – Fault Data

	2007	2008	2009	2010	2011	2012
All faults	2	1	2	2	5	0
Corrosion	0	0	0	0	0	0
Deterioration due to ageing or wear (excluding corrosion)	1	1	1	1	2	0
Deterioration due to ageing or wear (including corrosion)	1	1	1	1	2	0

	2007	2008	2009	2010	2011	2012
All faults	0.0097	0.0048	0.0097	0.0097	0.0242	0.0000
Poor condition due to age and wear	0.0048	0.0048	0.0048	0.0048	0.0097	0.0000

Table 17 – 132kV Switchgear Faults data

Source: UKPN Faults cube

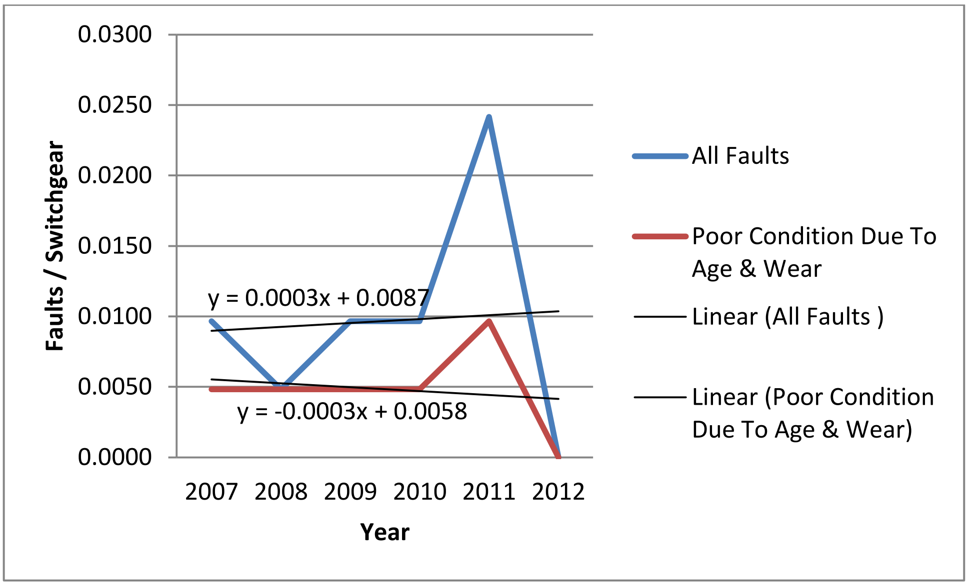

Figure 19 – Fault Rate 132kV Switchgear in LPN

Source: UKPN Faults Cube

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Appendix 4 – WLC Case Studies

Section not applicable.

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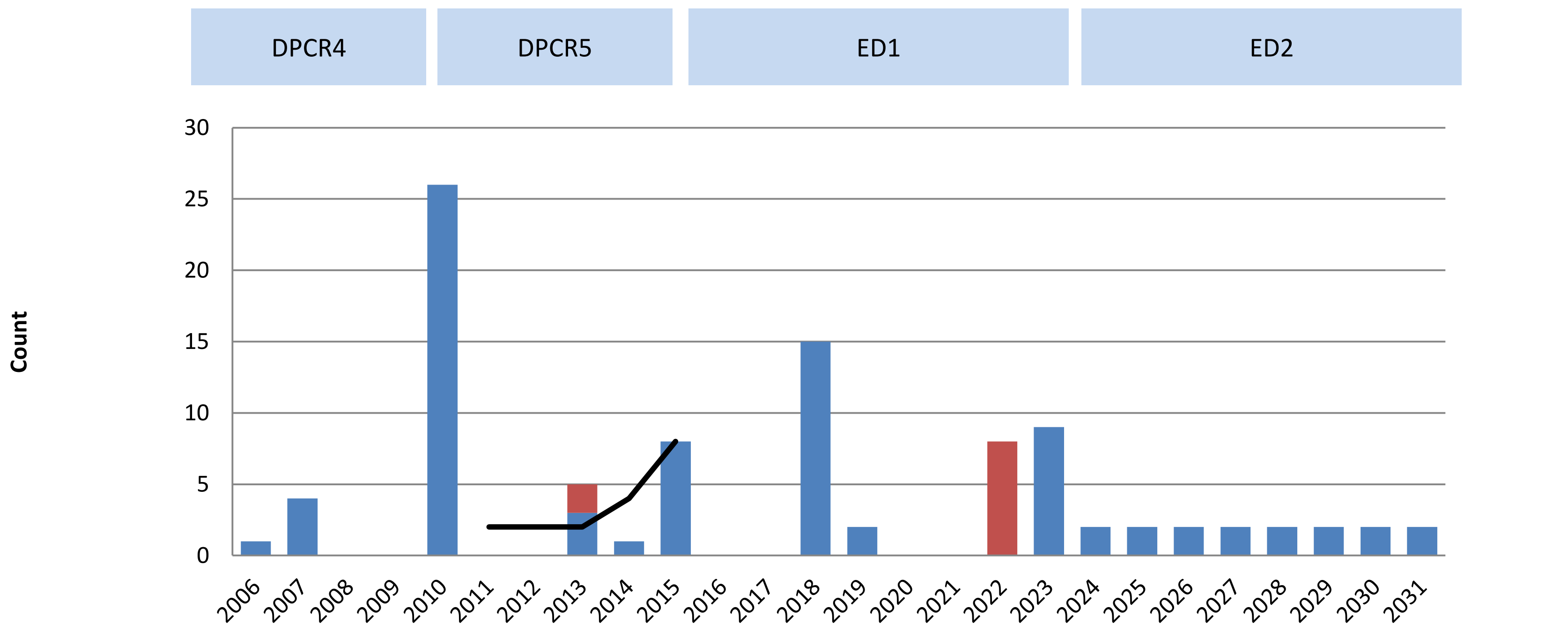
Appendix 5 – NLRE Expenditure Plan



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Refurbishment	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0
Replacement	1	4	0	0	26	0	0	3	1	8	0	0	15	2	0	0	0	9	2	2	2	2	2	2	2	2
FBPQ						2	2	2	4	8																

Regulatory Year

Figure 20 – 132kV Switchgear yearly interventions

Source: DPCR5 FBPQ, 2013 RIGs, 19th February 2014 NAMP, and Age Based Model

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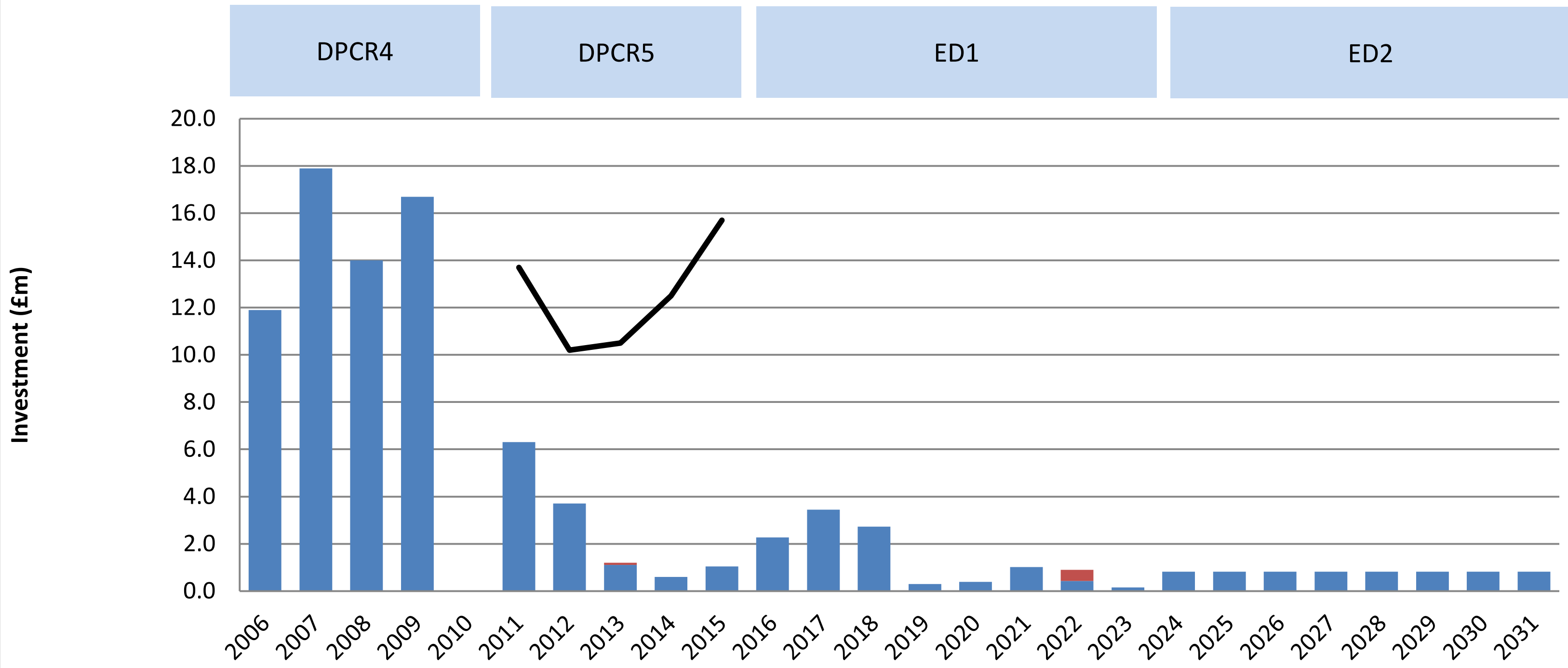

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Refurbishment	0	0	0	0	0	0	0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0	0	0	0	0	0	0	0
Replacement	11.9	17.9	14.0	16.7	0.0	6.3	3.7	1.1	0.6	1.0	2.3	3.4	2.7	0.3	0.4	1.0	0.4	0.2	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
FBPQ						13.7	10.2	10.5	12.5	15.7																

Regulatory Year

Figure 21 – 132kV Switchgear yearly expenditure

Source: DPCR5 FBPQ, 2013 RIGs, 19th February 2014 NAMP, and Age Based Model

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Appendix 6 – Sensitivity Analysis

Sensitivity Analysis:
Asset Risk and Prioritisation Model for LPN 132kV Switchgear (written by Decision Lab)

Introduction

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

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

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

The ARP model

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

Sensitivity analysis

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

Standard average asset lives are used in the ARP model. These are 40, 45, 50 and 55 years. In 2012 the current average life values of the population had a mean of 49.0 years. This study covered the full population of LPN 132kV Switchgear.

Using 2012 asset data and the replacement plans up to 2023, the ARP model was used to predict the HI 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.

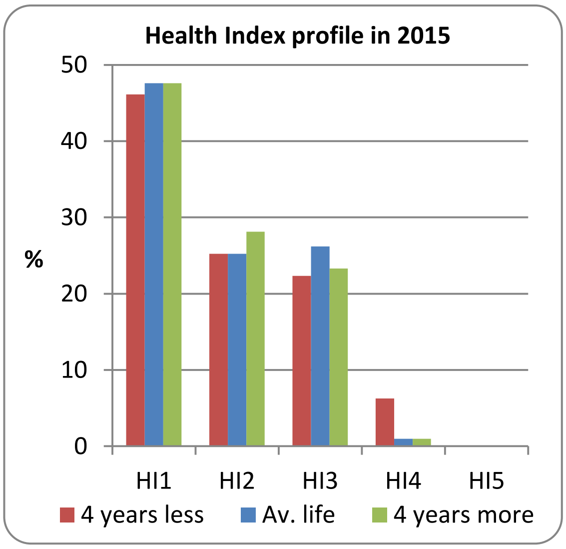
 ©DecisionLab Ltd

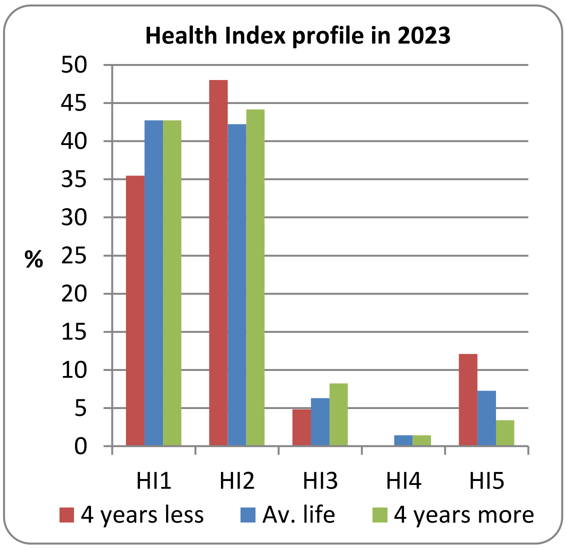
Average life change	2015 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	46.1	25.2	22.3	6.3	0.0
-2	46.6	25.2	24.8	3.4	0.0
-1	46.6	26.2	25.7	1.5	0.0
0	47.6	25.2	26.2	1.0	0.0
1	47.6	26.2	25.2	1.0	0.0
2	47.6	26.7	24.8	1.0	0.0
4	47.6	28.1	23.3	1.0	0.0

Average life change	2023 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	35.5	48.0	4.9	0.0	12.1
-2	42.7	41.7	5.3	0.5	9.7
-1	42.7	42.2	5.3	2.4	7.3
0	42.7	42.2	6.3	1.5	7.3
1	42.7	44.2	4.4	3.4	5.3
2	42.7	44.2	4.9	4.8	3.4
4	42.7	44.2	8.2	1.5	3.4

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 life cases are charted below.





For all cases modelled, the sum of assets in HI4 and HI5 is plotted below.

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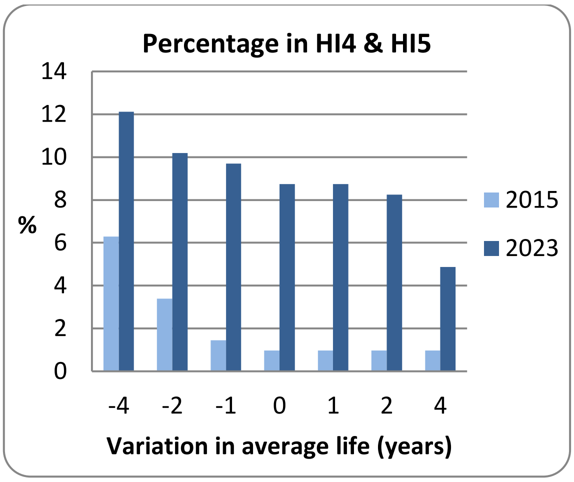

The results show

- A variation in asset life will affect the proportion of HI4 and HI5 assets in 2023 and possibly also in 2015.
- In 2015 if average life is four years longer, the proportion of HI4 and HI5 will remain at 1.0%, but if it is four years shorter, it will increase to 6.3%.
- In 2023 if average life is four years longer, the proportion of HI4 and HI5 will reduce from 8.8% to 4.9%, but if it is four years shorter, it will increase to 12.1%.

Conclusion

The ED1 replacement plan for LPN 132kV Switchgear is mildly sensitive to a variation in average asset life of up to four years.

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Appendix 7 – Named Schemes

Ref	Project ID	DNO	Description	Switchgear type	Volume	Scheme Paper
1.48.01.7778	7778	LPN	Back Hill 132kV – replace 132kV switchgear	Reyrolle OB	3	No
1.48.01.7779	7779	LPN	Eltham grid– replace 132kV switchgear	AEI OW	9	No
1.48.06.7780	7780	LPN	Deptford grid – replace 132kV switchgear	AEI OW	2	No
1.48.08.2545	2545	LPN	Barking 132kV GSP – 132kV switchgear replacement LPN	Reyrolle OB	12	No
1.55.02.7777	7777	LPN	Willesden grid 132kV – refurb 132kV switchgear	Reyrolle OBYR	8	No

Table 18 – 132kV Switchgear Named Schemes

Source: 19th February NAMP 2014 Table J Less Indirect

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Appendix 8 – Output NAMP/ED1 Business Plan Data Table reconciliation

Outputs	Asset Stewardship Report										RIGs Table										
Investment description	NAMP Line	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	**Total**	RIG Table	RIG Row	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	**Total**
132kV Switchgear Removals	1.48.01	0	0	15	2	0	0	0	9	26	CV3	224	0	0	12	0	0	0	0	0	**12**
	1.48.05										CV3	225	0	0	3	2	0	0	0	9	**14**
	1.48.06										CV3	226	0	0	0	0	0	0	0	0	**0**
	1.48.07										CV3	227	0	0	0	0	0	0	0	0	**0**
	1.48.08																				
132kV Switchgear Refurbishment	1.55.02	0	0	0	0	0	0	8	0	8	CV5	53	0	0	0	0	0	0	8	0	8
Total		**0**	**0**	**15**	**2**	**0**	**0**	**8**	**9**	**34**			**0**	**0**	**15**	**2**	**0**	**0**	**8**	**9**	**34**

Table 19 - NAMP to ED1 Business Plan Data Table Reconciliation

Source: 19th February 2014 NAMP Table J less indirects and 21st February 2014 ED1 Business Plan Data Tables

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Appendix 9 – Efficiency Benchmarking with other DNOs

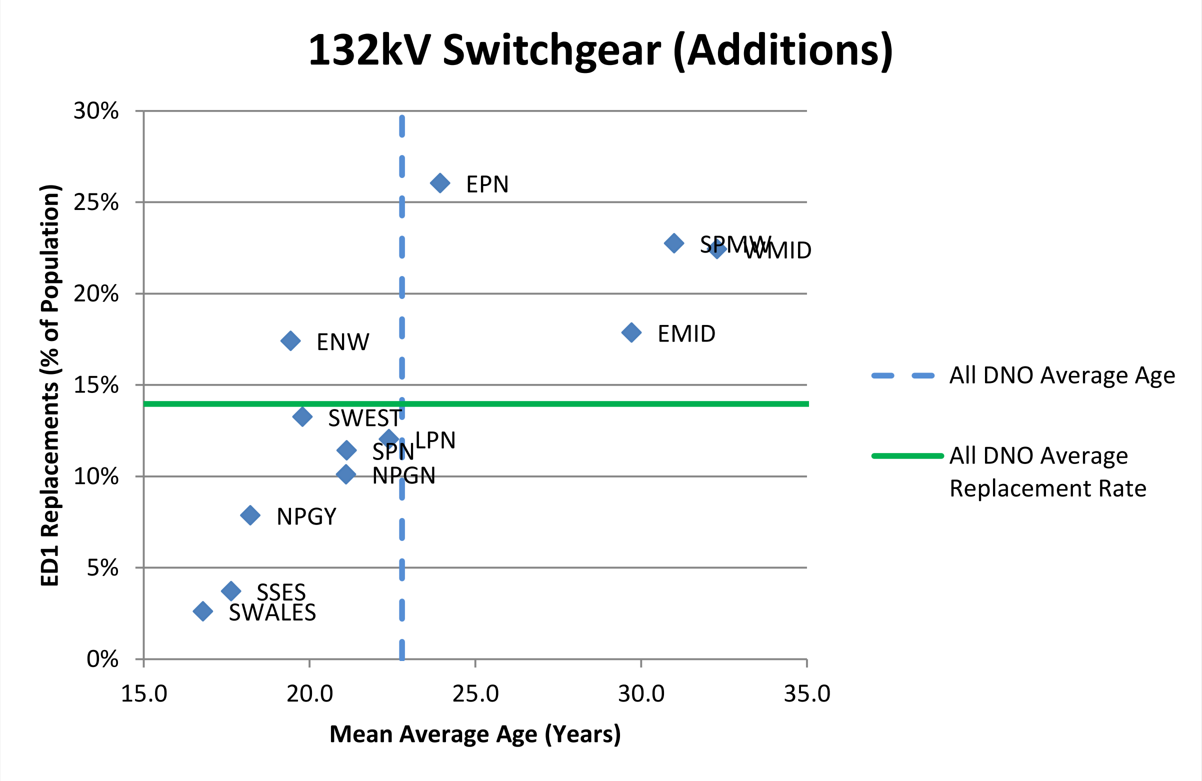

Figure 22 - Efficiency Benchmarking

Source: DNO Datashare_2013

The graph above shows that although LPN has a lower replacement rate than the industry average per percentage of population and it also has a slightly lower average age. As mentioned within this document the plan for ED1 has been based on the condition of the assets rather than age.

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Appendix 10 – Material changes since the July 2013 ED1 submission

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

Asset type	Action	Change type	2013 Submission	2014 Submission	Difference (Reduction)	Comment
132kV CB (Gas Insulated Busbars)(OD) (GM)	Replace	Volumes (Additions)	0	0	0	Costs moved from 132kV CB line to 66kV CB line
		Volumes (Removals)	0	0	0	
		Investment (£m)	0.12	0	(0.12)	
		UCI (£k)	-	-	-	

Table 2 - Material Changes to July 2013 ED1 Submission (CV3)

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

132kV CB (Gas Insulated Busbars)(OD) (GM)

This expenditure decrease are costs mapped incorrectly to the 132kV CB (Air Insulated Busbars)(OD) (GM) line in the July 13 submission moving to the 66kV CB (Air Insulated Busbars)(OD) (GM) line. The costs relate to the 66kV switchgear replacement at Hackney and were moved following Ofgem question Ph1-14.

The following Ofgem questions were answered relating to 132kV Switchgear:

- Ph1-14
- Ph1-146

As mentioned above, only Ph1-14 resulted in a changed to CV3.

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