



Document 5
Asset Category – 132kV Switchgear
EPN

Asset Stewardship Report
2014

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Document History

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1.0	19/02/2014	July 2013 Submission	Richard Gould		
1.1	19/02/2014	Expenditure tables and charts updated with 19 th February NAMP figures	Richard Gould	Major	Header, 1.1, 1.3, 1.5, 7.4, 7.5, Appendix 5
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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 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

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 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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1.0 Executive Summary EPN 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 306 items of 132kV Switchgear with an estimated MEAV of £278m. The proposed investment including civils is £6.5m per annum, equating to an average annual 2.4% 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	£29.3m	1.48	<u>Additions</u> 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 – Switchgear other <u>Removals</u> 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)
Replacement	£0.3m	1.48	<u>CV8 multiple lines</u>

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. There is also £8.6m of 132kV expenditure attributed to CV9a High Value Projects

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.

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.

1.3 ED1 Proposals

The proposal for ED1 includes 61 replacements across eight years. This is a similar number of interventions, but an increase in investment, compared to that of DPCR5 which, when adjusted for an eight-year period, had 59 replacements and no refurbishments. The difference in expenditure is caused by the type of switchgear that is being installed (AIS or GIS, explained in section 5) as there is a large variation in cost. Justification for these replacements can be found in section 3.1. This section outlines the increasing number of defects found on older assets, and any safety issues found on certain models of switchgear, such as the Reyrolle OB/OBYR.

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 health index 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	Refurbishment option becomes available instead of replacement on one site.	(7.8)
Risk	Average initial life used in ARP model over optimistic leading to increase of 4.2% in total number of HI4 and HI5s (Section 7) with more interventions required.	11.0
Opportunity	Average initial life used in ARP model under optimistic leading to decrease of 2% in total number of HI4 and HI5s (Section 7) with more interventions required.	(5.2)

Table 2 – Risk and opportunities

2.0 Description of 132kV Switchgear Population

2.1 132kV Switchgear

There are 306 circuit breakers currently operating at 132kV on the network. These are distributed on 48 substation sites with 102 units installed at indoor locations and 204 outdoor locations. These are split into the four categories of switchgear as shown in Table 4.

Switchgear arc extinction method	Population
Bulk oil	9
SF6	125
GIS	77
Air blast	95

Table 3 – 132kV Switchgear types

As seen in the age profile in Figure 1, there was significant investment in the 1960s. This has resulted in an ageing switchgear fleet where the average age is 25.5 years. Of the pre-1970s switchgear, there are 95 air blast circuit breakers and nine bulk oil circuit breakers. The oldest 10% of the assets have an average age of 52 years.

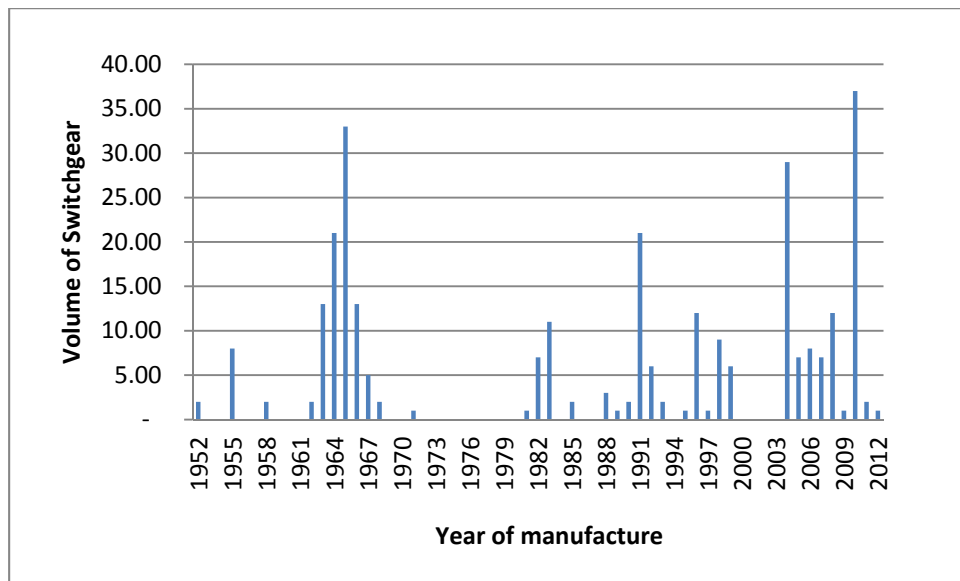


Figure 1 – 132kV Switchgear age profile

Source: 2012 RIGs V5

The NAMP lines used for 132kV Switchgear capital expenditure can be seen in Table 5.

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

Table 4 – 132kV Switchgear NAMP lines

Refer to Table 6 and Table 7 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

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 factors include the condition of the paint and corrosion of any part of the switchgear, such as the bushings. On outdoor sites the condition of air-insulated busbars and any concrete or steel support structures will also be considered.

The proposed investment plan for 132kV Switchgear in ED1 includes interventions on three types of switchgear: the Reyrolle OB and OBYR air blast circuit breaker, the AEI OW410 bulk oil circuit breaker and the GEC OSA bulk oil circuit breaker.

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.



Figure 2 – Reyrolle OBYR circuit breaker

There have been a number of national catastrophic failures of the circuit breaker, with 12 reports in the National Equipment Defect Reporting System (NEDERS). These failures have been due to a number of reasons including the blast tube failing during pressurisation, the isomaker arm not opening fully and, water ingress across the interrupter and stand-off insulator gaskets.

There are a number of switchgear defects which are critical in the ARP model, which is described in section 4 of this document. As defects are found or cleared they are recorded in the Ellipse asset register using the Hand Held Device (HHD). 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 arcing 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 leaks in the air system, this leads to the air compressors running excessively and 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 disruptive failure if the equipment is subject to 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.
- **SF₆ gas pressure.** SF₆ gas is used as an insulating medium. If the pressure falls below the rated value, the equipment could fail disruptively if left in service.

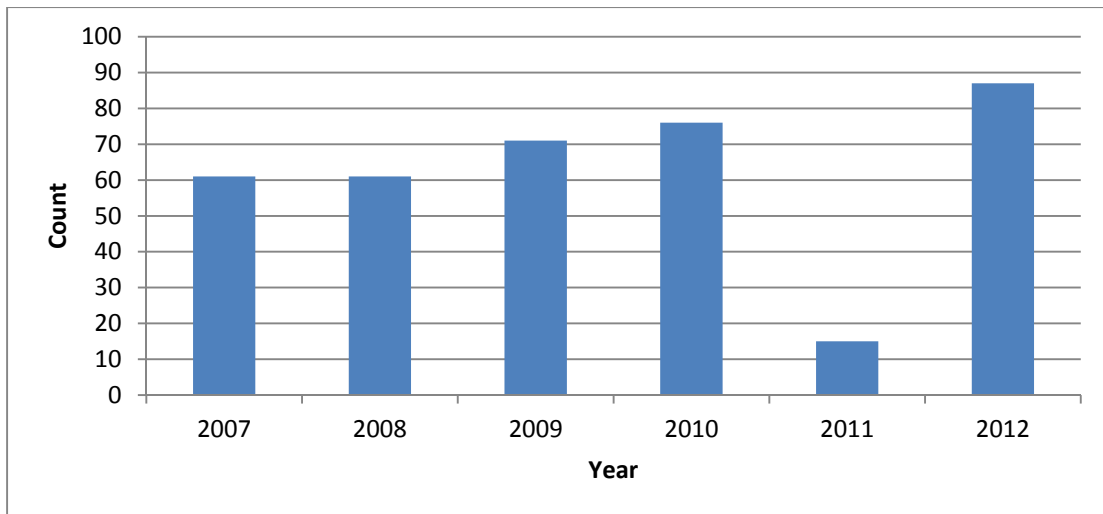


Figure 3 – Reyrolle OB and OBYR defect count

Source: ARP Model 25th July 2012

Figure 3 shows the number of defects that have been recorded in Ellipse each year for the OB and OBYR. This shows that, apart from 2011, there was an increase in the number of defects recorded against the circuit breaker. The drop in 2011 is partly caused by an operational restriction (HSS-406-ORE-25) on Alstom FMJL CTs, which meant that routine inspections could not be carried out on certain sites so defects were not recorded. This was due to the restriction placing a 75m risk management zone around each CT and only essential work could be carried out in this zone. The restriction on the CTs was a national issue that has affected other distribution network operators as well as National Grid. The CTs began to be replaced in 2012, meaning inspections could resume. All Alstom FMJL CTs owned by UK Power Networks have now been replaced, although there are still some present on shared sites with National Grid.

The AEI OW is a bulk oil circuit breaker that can be located either indoors or outdoors. Like the Reyrolle OB and OBYR, the OW has separate air-insulated busbars. There are currently four OWs operating at one site on the 132kV network. The proposed ED1 investment will remove them from the network, making them redundant.

Another circuit breaker model planned for replacement during ED1 is the GEC OSA. There is only one GEC OSA bulk oil circuit breaker on the network, which is at Grendon Grid, a shared site with National Grid and another DNO. The main driver for replacement is from the other occupiers of the site because of the poor condition of their circuit breakers.

Figure 4 shows the age of an asset when a new defect is 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 number of defects increases with the age of an asset. Few defects are recorded on assets less than 20 years old – even with the large proportion of the population in this age range. As

mentioned earlier, defects represent a big risk – not only to the network, but also to operator safety because of the increased likelihood of catastrophic failure.

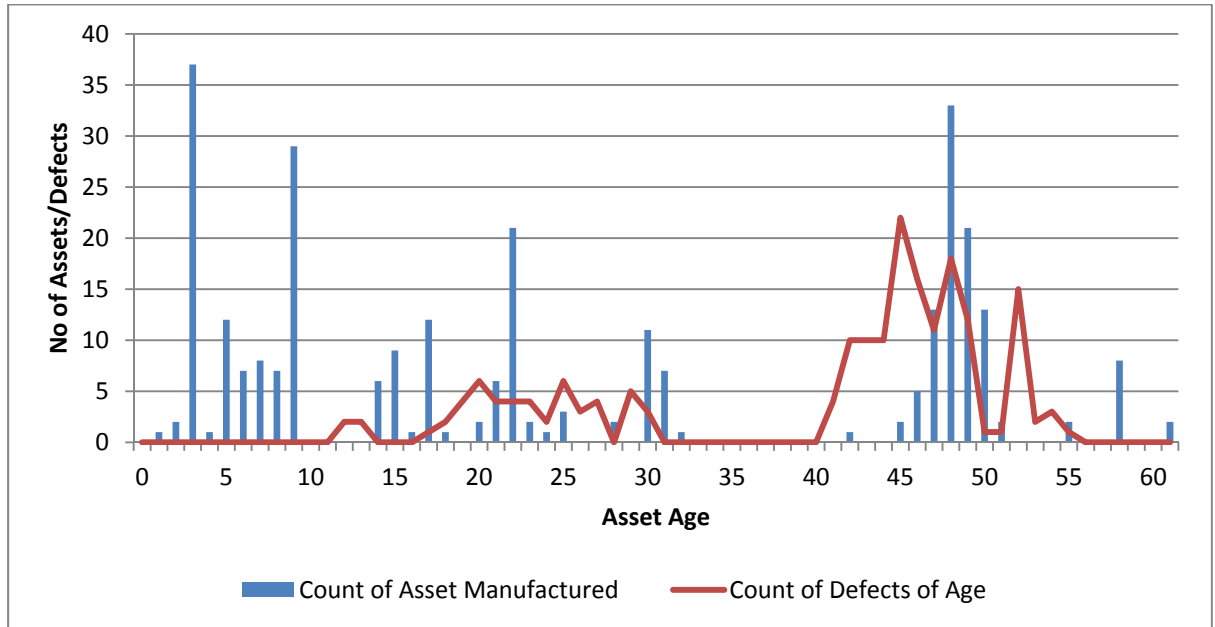


Figure 4 – Defects by asset age

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

Figure 5 shows the fault 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 there is a decreasing amount of faults caused by switchgear.

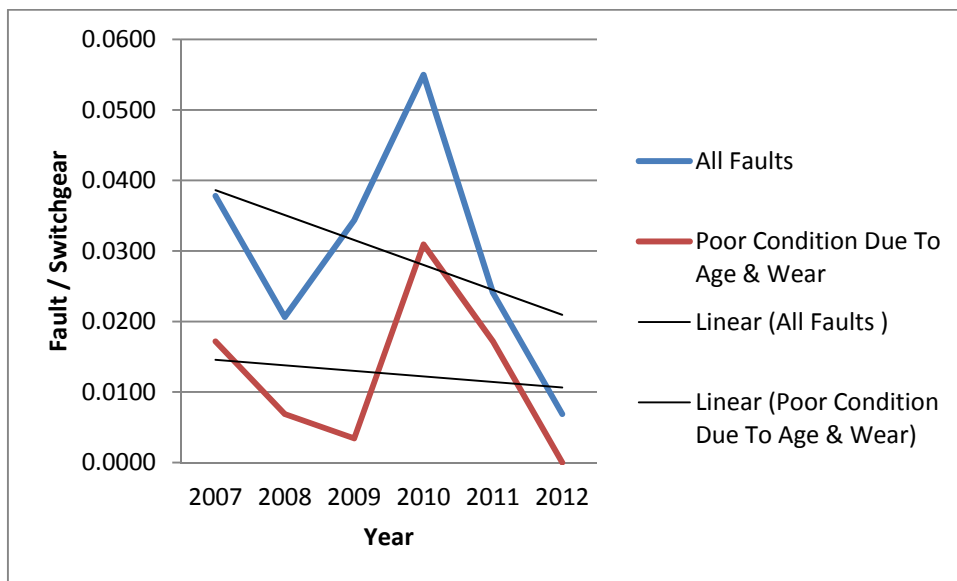


Figure 5 – 132kV Switchgear fault rate

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. The cost of maintaining air blast circuit breakers is significantly more than a modern SF6 circuit breaker. Figure 6 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 more than four times that of a GIS circuit breaker and 20 times that of a SF6 outdoor circuit breaker.

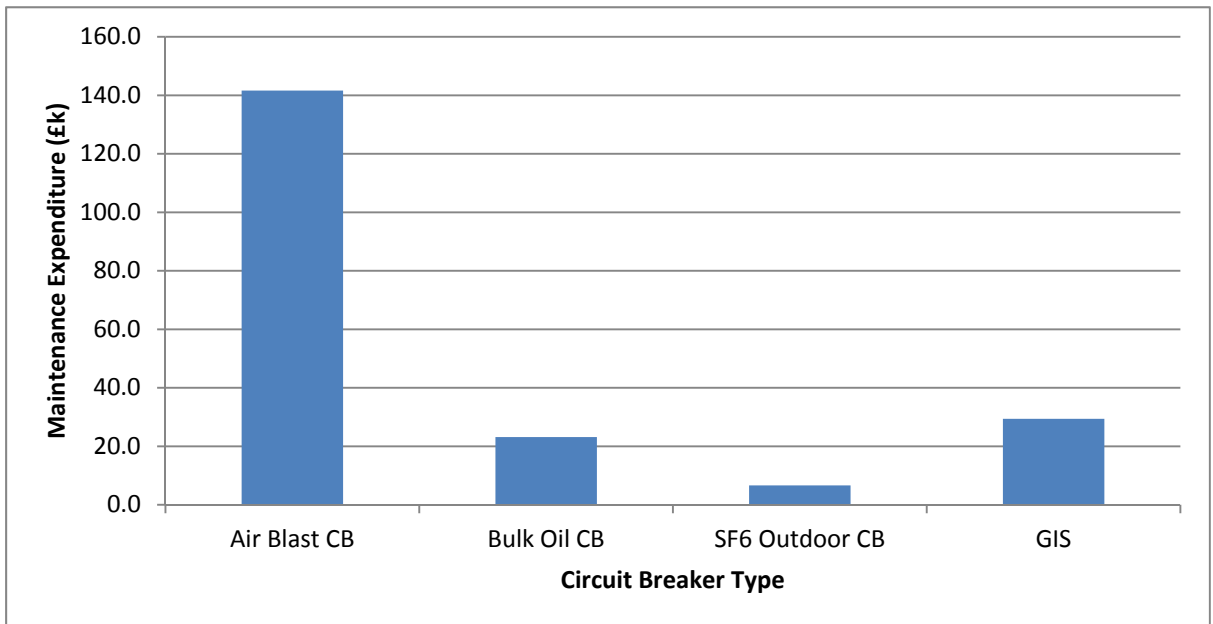


Figure 6 – 132kV Switchgear maintenance costs

Source: EMS 10-0002 Inspection and Maintenance Frequency Schedule

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.



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.

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 HHD technology to record their assessment of internal and external condition of the assets being maintained. 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 SF₆ top-ups. This is 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 switchgear asset, 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 considered when calculating the criticality of an asset: network performance, safety, operational expenditure, capital expenditure and environment. A number of key factors are considered in each of these areas.

- **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.
- **Operation and capital expenditure.** This section considers the criticality between assets in terms of the difference in maintenance costs between makes and models of switchgear, and the difference in capital expenditure for various types of switchgear.
- **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 item of switchgear following one of four failure modes. These are detailed in Table 10.

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

Table 8 – Failure modes

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 10 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 11.

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	76%
Accuracy	89%
Timeliness	94%

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 asset's 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. 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 an 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 arcing 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.

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

There are different options for replacement interventions depending on the equipment installed on the site and its situation. These are outlined in Table 12.

Option	Description	Advantages	Disadvantages
Outdoor AIS solution	This option uses outdoor circuit breakers, for example, the Siemens 3AP1DT circuit breaker in Figure 7. 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 8, showing a Siemens 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



Figure 7 – Siemens 3AP1DT circuit breaker



Figure 8 – Siemens 8DN8 GIS circuit breaker

5.2 Policies: Selecting Preferred Interventions

The process used for selecting interventions can be seen in Figure 9. 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.

If the switchgear is a standalone unit, it can be either be refurbished or replaced as an individual item of switchgear. 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, it can be reused at a different site or as a strategic spare.

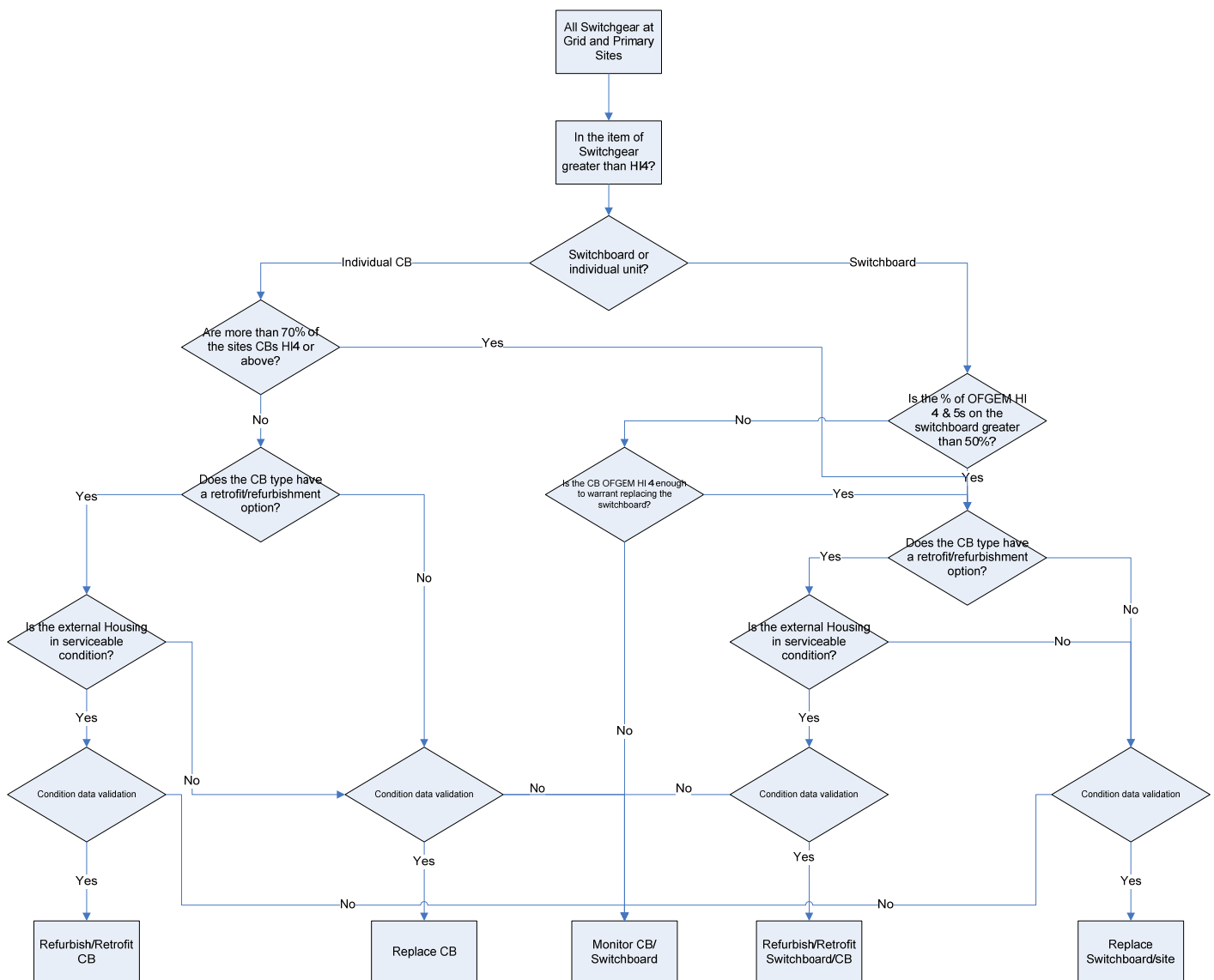


Figure 9 – Intervention strategy process

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.

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 10 shows an overview of the method to construct the RIIO-ED1 NLRE investment plans.

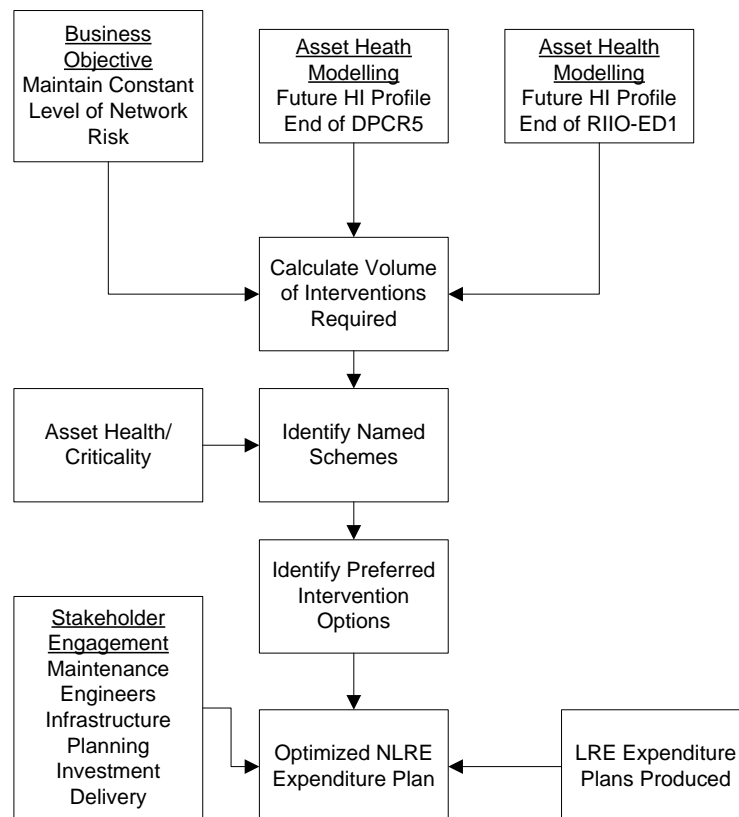


Figure 10 – Programme development methodology

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 11 for the HI profiles at the beginning and end of ED1, with and without investment.

The percentage of HI4 and HI5s at the beginning of ED1 is 11% of the total population, and at the end of the period the number is 12%. The HI profiles indicated are derived from condition related investment only and exclude the contribution from load related expenditure and High Value Projects, even if they are condition driven.

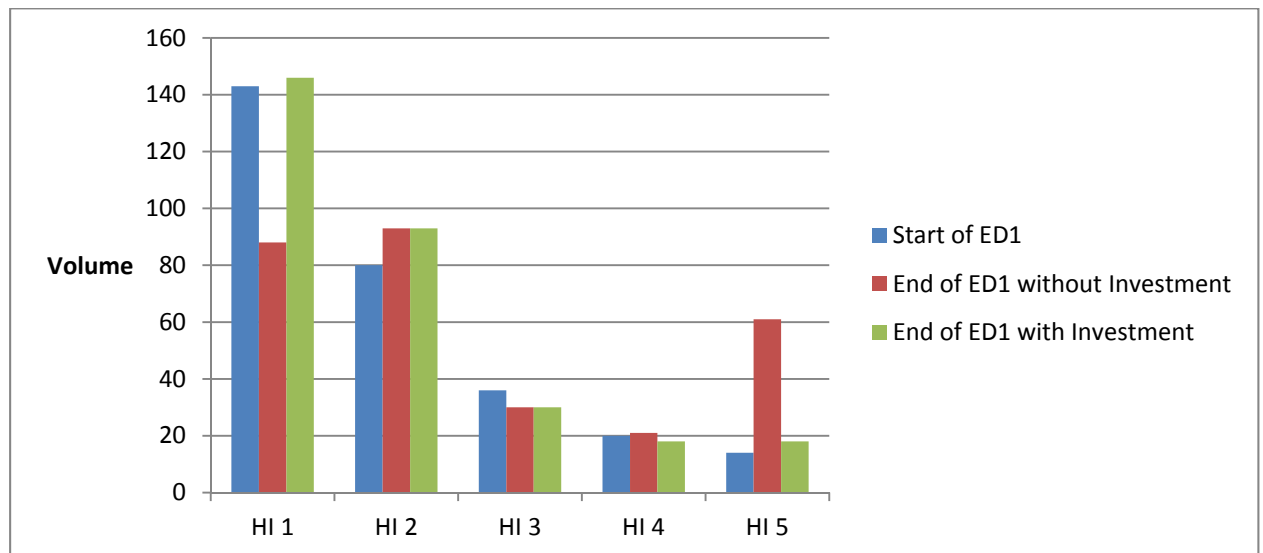


Figure 11 – ED1 HI profiles

Source: ARP Model 25th July 2012

Figure 12 shows the number of HI4 and HI5s with and without investment, at the beginning, middle and end of ED1.

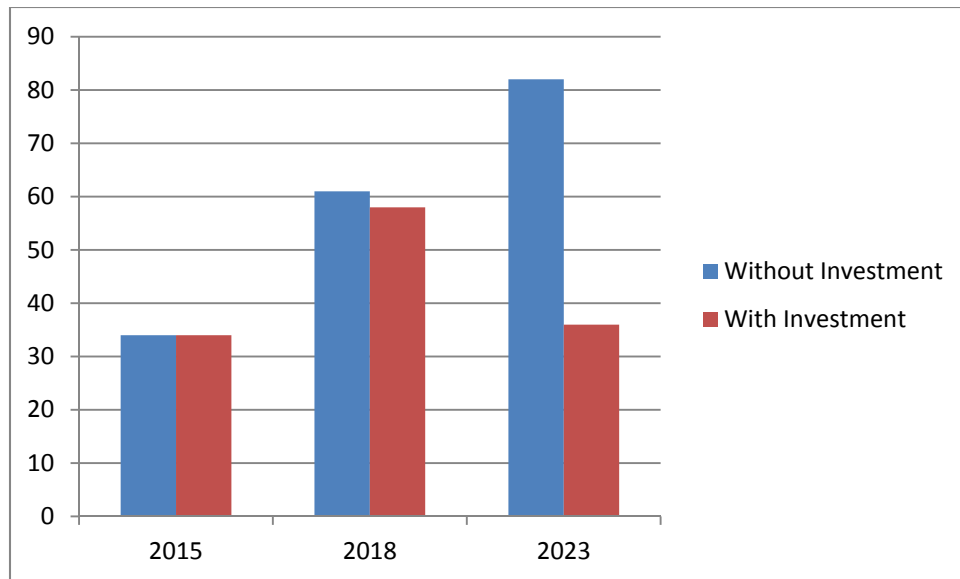


Figure 12 – Total number of HI4 and HI5s

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 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.

At 132kV, many of the substation's 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 13 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.

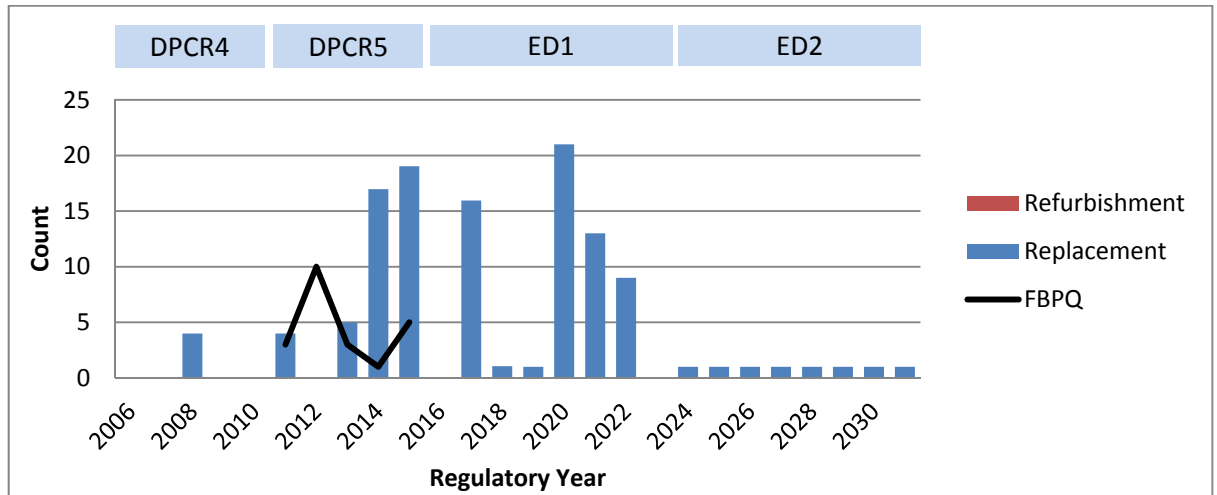


Figure 13 – 132kV Switchgear yearly interventions

Source: DPCR5 FBPQ, 2013 RIGS, 19th February 2014 NAMP, and SARM Statistical Model

Refer to Figure 14 for 132kV Switchgear expenditure from the start of DPCR4 to the end of ED2.

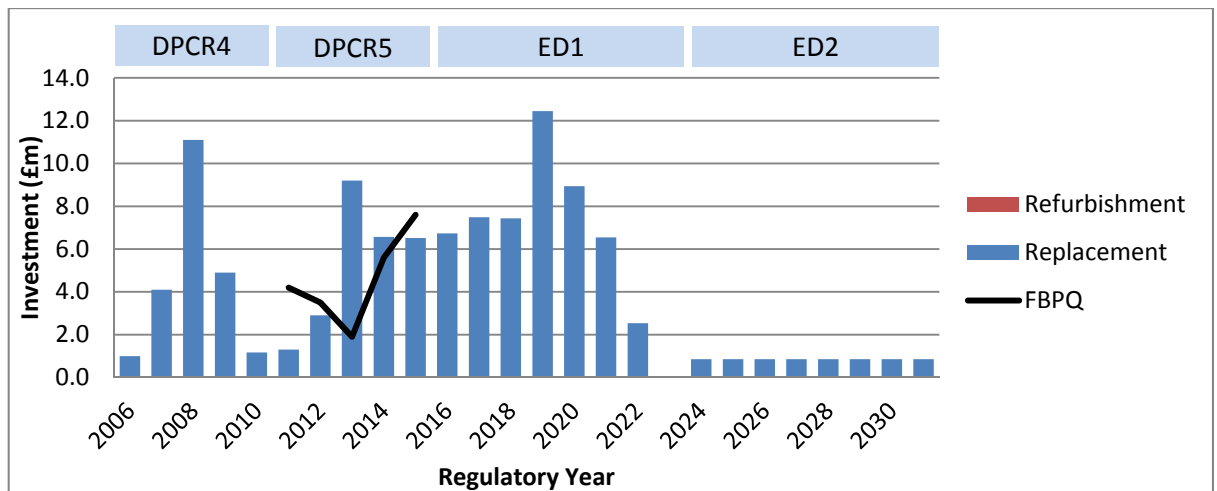


Figure 14 – 132kV Switchgear yearly expenditure

Source: DPCR5 FBPQ, 2013 RIGS, 19th February 2014 NAMP, and SARM Statistical Model

Full page versions of Figure 13 and Figure 14 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 for DPCR4 is 0.8 items of switchgear. The

forecast yearly average for DPCR5 is 9 items of switchgear, and the proposed yearly average for ED1 is 8. The proposed volume of replacements in ED1 is 61 and no refurbishments.

In the FBPQ there were 22 planned circuit breaker replacements, compared to an expected value of 45. The reason for this increase is a reassessment of the circuit breakers at Elstree Grid that required their replacement being brought forward to DPCR5 due to poorer than anticipated condition.

The number of interventions planned for ED1 is a similar level as DPCR5, but more than DPCR4. The increase in DPCR5 and ED1 is caused by an increasing number of defects being found on the older switchgear assets, as shown in Figure 4.

The average yearly expenditure for DPCR4 and DPCR5 is £4.5m and £5.1m. This increases slightly in ED1 to £6.5m. This is due to a greater proportion of projects using a GIS solution, which has a higher unit cost.

The ED2 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. The reduction in ED2 is due to the majority of the older switchgear being replaced in ED1 as it is showing high levels of defects.

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 their average initial life does not turn out as predicted

Average life change	2015 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	44.6	28.5	14.4	5.9	6.6
-2	45.6	28.2	14.4	5.9	5.9
-1	46.9	28.9	12.8	6.6	4.9
0	46.9	30.2	11.8	6.6	4.6
1	46.9	30.2	12.5	5.9	4.6
2	47.2	29.8	13.4	4.9	4.6
4	47.2	31.1	12.5	4.6	4.6

Table 11 – 2015 sensitivity analysis

Average life change	2023 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	48.5	31.2	11.5	1.6	7.2
-2	48.9	36.1	7.9	3.6	3.6
-1	49.5	35.4	8.2	3.6	3.3
0	50.8	35.1	9.5	1.3	3.3
1	50.8	35.4	10.5	1.0	2.3
2	50.8	36.7	9.2	1.0	2.3
4	50.8	38.3	8.2	0.3	2.3

Table 12 – 2023 sensitivity analysis

Source: Decision Lab Analysis February 2013

In Table 13 and Table 14 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.

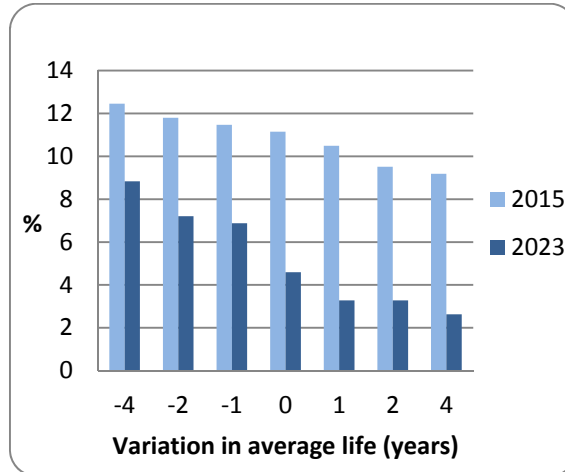


Figure 15 – Total HI4 and HI5s sensitivity analysis

Source: Decision Lab Analysis February 2013

Figure 15 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 3.3% 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 6.2%. This shows that changes in the average initial life have more of an impact on future HIs.

If the average initial lives turn out to be less than assumed in the ARP models, the number of interventions required in ED1 will rise by 4.2%. Conversely, if average initial lives in ED1 transpire to be slightly longer than assumed, the required number of interventions to maintain the same number of HI4 and HI5s in ED1 will drop by 2%. Accordingly, the company is carrying more of the risk than customers for uncertainty in the average initial life of these assets in the ED1 regulatory period.

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.

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.

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 on the network. Table 15 and Table 16 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 HI					2015
			H1	H2	H3	H4	H5	

132kV Switchgear	Low	No. CB	70	62	25	18	13	188
	Average	No. CB	26	13	9	2	1	51
	High	No. CB	47	5	2	0	0	54
	Very high	No. CB	0	0	0	0	0	0

Table 13 – 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 HI					2023
			HI1	HI2	HI3	HI4	HI5	
132kV Switchgear	Low	No. CB	89	58	26	9	18	200
	Average	No. CB	33	8	3	7	0	51
	High	No. CB	24	27	1	2	0	54
	Very high	No. CB	0	0	0	0	0	0

Table 14 – 2023 HI and criticality matrix

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

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.

Appendices

Appendix 1 – Age Profiles

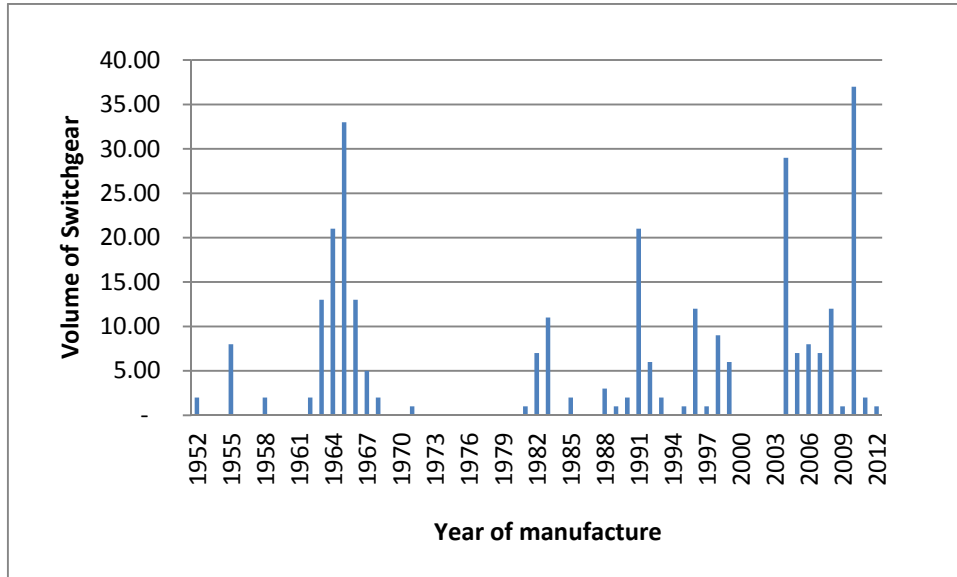


Figure 16 – 132kV Switchgear age profile

Source: 2012 RIGs V5

Appendix 2 – HI Profiles

Asset categories	Criticality	Units	Estimated asset health and criticality profile (2015)					Asset register
			Asset HI					2015
			HI1	HI2	HI3	HI4	HI5	
132kV Switchgear	Low	No. CB	70	62	25	18	13	188
	Average	No. CB	26	13	9	2	1	51
	High	No. CB	47	5	2	0	0	54
	Very high	No. CB	0	0	0	0	0	0

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 HI					2023
			HI1	HI2	HI3	HI4	HI5	
132kV Switchgear	Low	No. CB	89	58	26	9	18	200
	Average	No. CB	33	8	3	7	0	51
	High	No. CB	24	27	1	2	0	54
	Very high	No. CB	0	0	0	0	0	0

Table 16 – 2023 HI and criticality matrix

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

Appendix 3 – Fault Data

	2007	2008	2009	2010	2011	2012
All faults	11	6	10	16	7	2
Corrosion	0	0	0	0	0	0
Deterioration due to ageing or wear (excluding corrosion)	5	2	1	9	5	0
Deterioration due to ageing or wear (including corrosion)	5	2	1	9	5	0

	2007	2008	2009	2010	2011	2012
All faults	0.0378	0.0206	0.0344	0.0550	0.0241	0.0069
Poor condition due to age and wear	0.0172	0.0069	0.0034	0.0309	0.0172	0.0000

Table 17 – 132kV Switchgear Faults data

Source: UKPN Faults cube

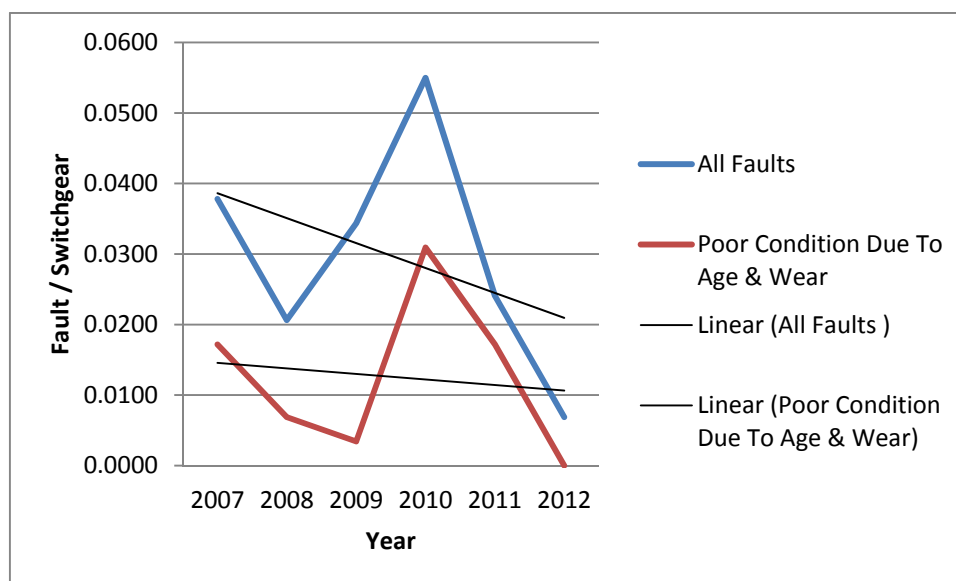


Figure 17 – Fault Rate 132kV Switchgear in EPN

Source: UKPN Faults Cube

Appendix 4 – WLC Case Studies

Section not applicable.

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

Appendix 5 – NLRE Expenditure Plan

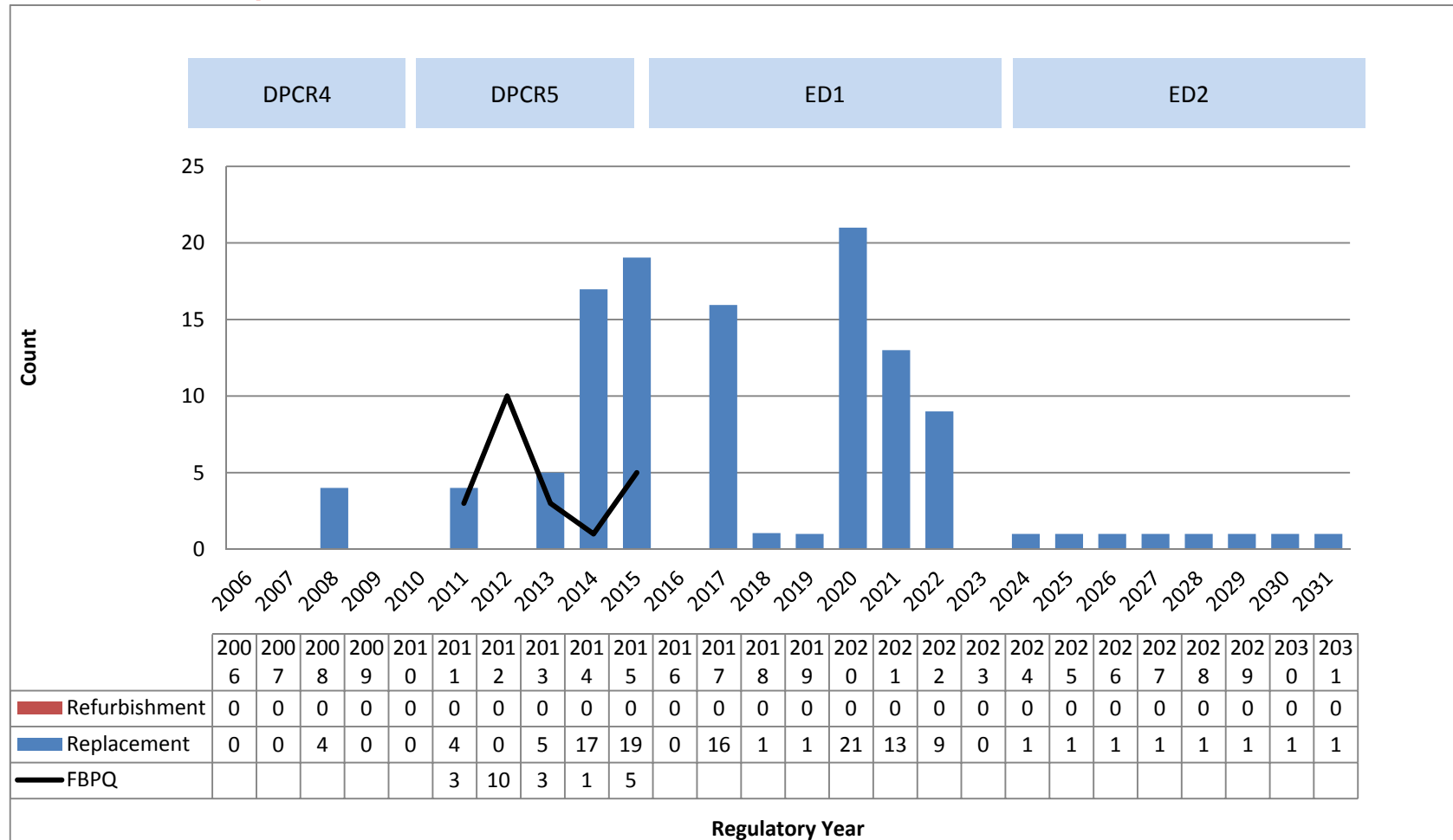


Figure 18 – 132kV Switchgear yearly interventions



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

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

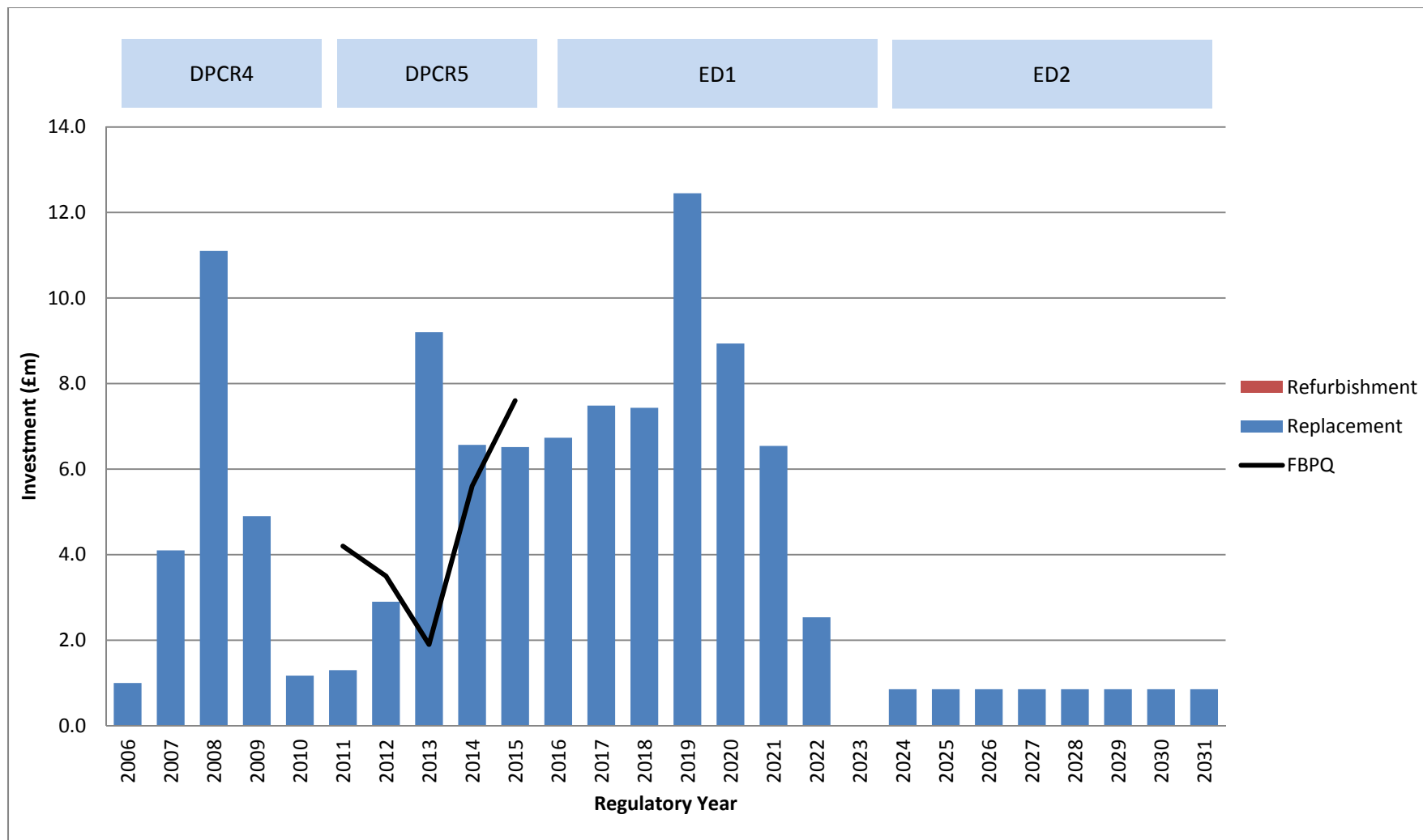


Figure 19 – 132kV Switchgear yearly expenditure

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

Appendix 6 – Sensitivity Analysis

Sensitivity Analysis:

Asset Risk and Prioritisation Model for EPN 132kV Switchgear (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 EPN 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 44.9 years. This study covered the full population of EPN 132kV Switchgear.

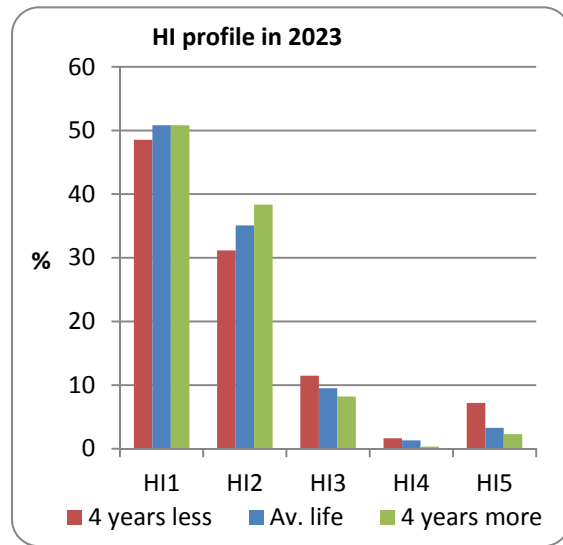
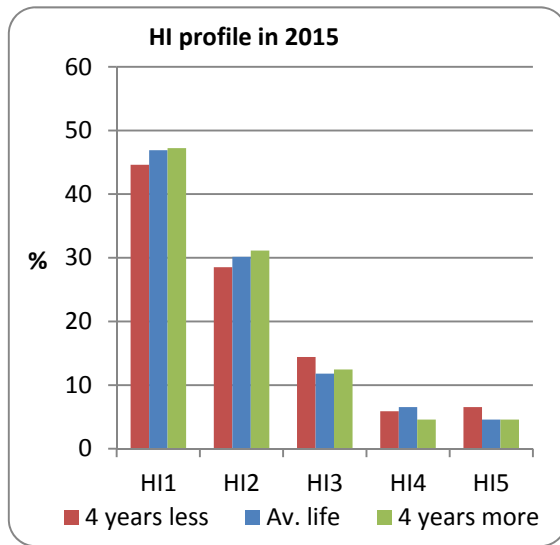
Using 2012 asset data and the replacement plans up to 2023, the ARP model was used to predict the HI of each asset at the beginning and end of ED1. This was then repeated varying each current average asset life by ± 1 , 2 and 4 years.

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

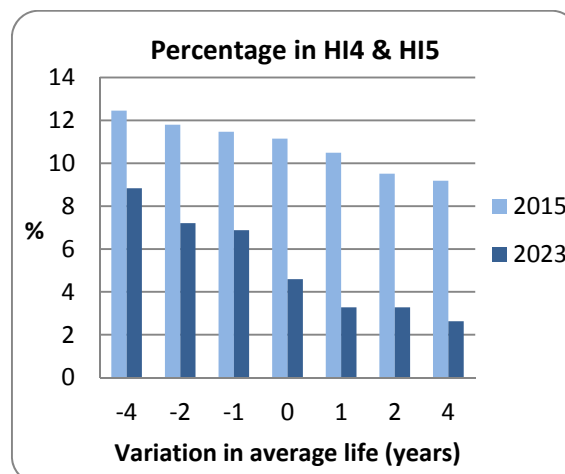
Average life change	2015 percentage HI profile					Average life change	2023 percentage HI profile				
	HI1	HI2	HI3	HI4	HI5		HI1	HI2	HI3	HI4	HI5
-4	44.6	28.5	14.4	5.9	6.6	-4	48.5	31.2	11.5	1.6	7.2
-2	45.6	28.2	14.4	5.9	5.9	-2	48.9	36.1	7.9	3.6	3.6
-1	46.9	28.9	12.8	6.6	4.9	-1	49.5	35.4	8.2	3.6	3.3
0	46.9	30.2	11.8	6.6	4.6	0	50.8	35.1	9.5	1.3	3.3
1	46.9	30.2	12.5	5.9	4.6	1	50.8	35.4	10.5	1.0	2.3
2	47.2	29.8	13.4	4.9	4.6	2	50.8	36.7	9.2	1.0	2.3
4	47.2	31.1	12.5	4.6	4.6	4	50.8	38.3	8.2	0.3	2.3

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.



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 reduce from 11.2% to 9.2%, but if it is four years shorter, it will increase to 12.5%.
- In 2023, if average life is four years longer, the proportion of HI4 and HI5 will reduce from 4.6% to 2.6%, but if it is four years shorter, it will increase to 8.8%.

Conclusion

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

Appendix 7 – Named Schemes

GWP	Ref	Project ID	DNO	Description	Switchgear manufacturer and model	Volume	Scheme Paper
1.48	1.48.01.2061	2061	EPN	Barking 132kV grid supply point – replace 132kV switchgear EPN (NG)	Reyrolle OB	2	No
1.48	1.48.01.2152	2152	EPN	Pelham 132kV grid supply point – replace 132kV switchgear	Reyrolle OBYR	7	Yes
1.48	1.48.01.2307	2307	EPN	Mill Hill 132kV grid supply point – replace 132kV switchgear (NG)	AEI OW	4	No
1.48	1.48.01.3404	3404	EPN	Tottenham 132kV grid supply point – replace 132kV switchgear (NG *)	Reyrolle OBYR	13	No
1.48	1.48.01.3940	3940	EPN	Warley 132kV grid supply point – replace 132kV switchgear	Reyrolle OBYR	9	No
1.48	1.48.01.7600	7600	EPN	Grendon 132kV grid supply point – replace 132kV switchgear (NG)	GEC OSA	1	No
1.48	1.48.01.7601	7601	EPN	Watford South 132kV grid supply point – replace 132kV switchgear	Reyrolle OBYR	10	No
1.48	1.48.08.5593	5593	EPN	Little Barford 132kV grid substation – replace switchboard	Reyrolle OBYR	15	Yes (HVP scheme)

Table 18 – 132kV Switchgear Named Schemes

Source: 19th February NAMP 2014 Table J Less Indirect

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

Outputs	Asset Stewardship Report										Business Plan Data Table											
	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											CV3	224	0	2	0	0	10	13	0	0	25
	1.48.05											CV3	225	0	0	0	1	11	0	9	0	36
	1.48.06	0	16	1	1	21	13	9	0	61		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											CV9a		0	14	1	0	0	0	0	0	15
132kV Switchgear Refurbishment	1.55.02	0	0	0	0	0	0	0	0	0		CV5	53	0	0	0	0	0	0	0	0	0
Total		0	16	1	1	21	13	9	0	61				0	16	1	1	21	13	9	0	61

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

Appendix 9 – Efficiency Benchmarking with other DNOs

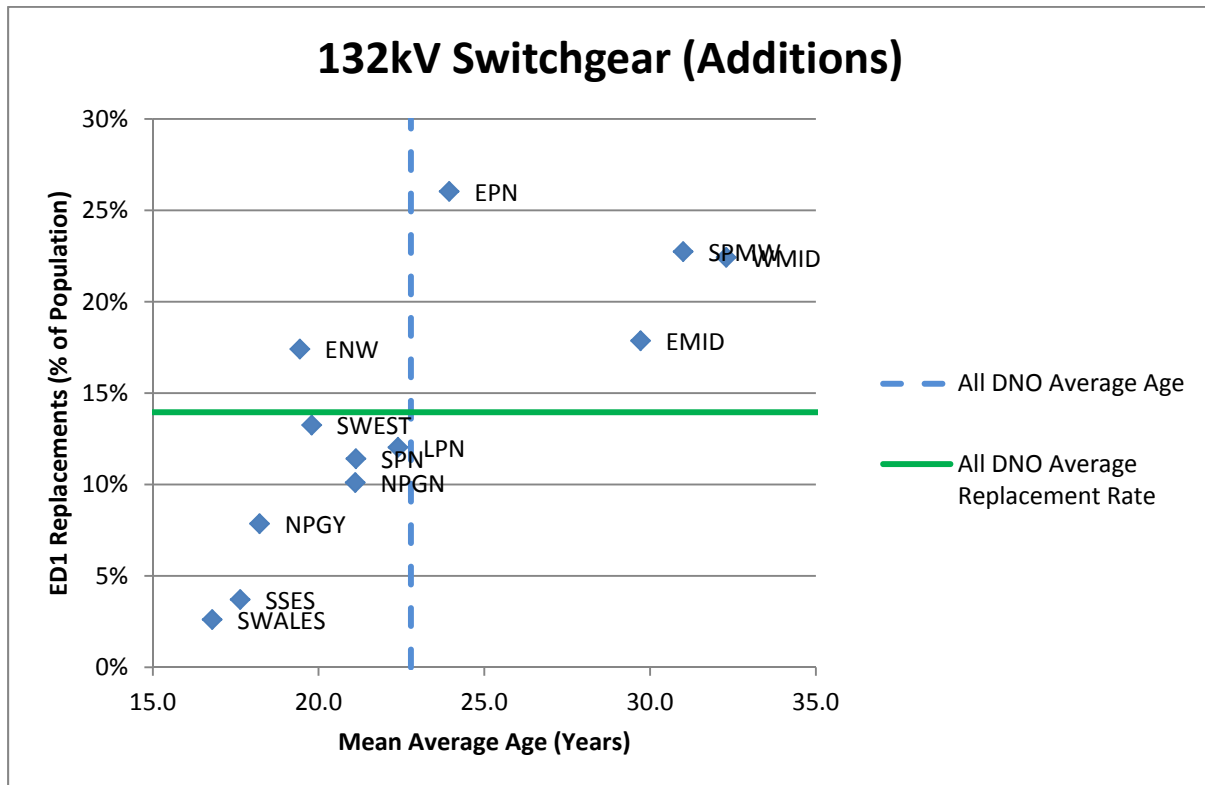


Figure 20 - Efficiency Benchmarking

Source: DNO Datashare_2013

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

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)(ID) (GM)	Replace	Volumes (Additions)	75	58	(17)	Volumes relating HVP removed
		Volumes (Removals)	0	0	0	
		Investment (£m)	27.47	27.47	0	
		UCI (£k)	366.2	473.6	107.4	
132kV CB (Air Insulated Busbars)(OD) (GM)	Replace	Volumes (Additions)	0	0	0	Volumes relating HVP removed
		Volumes (Removals)	36	21	(15)	
		Investment (£m)	0.74	0.74	0	
		UCI (£k)	-	-	-	

Table 20 - 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)(ID) (GM) & 132kV CB (Air Insulated Busbars)(OD) (GM)

In the July 2013 submission volumes from the High Value Project (HVP) at Little Barford were included in both CV9a and CV3. In the March 2014 submission these volumes have been removed from CV3. Costs relating to the HVP were not included in CV3 in the July 13 submission.

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

- Ph1-14
- Ph1-148

Neither question resulted in a changed to the submission values.