Document 4
Asset Category – G&P Transformers
EPN

Asset Stewardship Report 2014

Andrew Stephen

Approved by Richard Wakelen / Barry Hatton

Approved Date 03/03/2014

Document History

Version	Date	Details	Originator	Revision Class	Section Update
1.01	17/01/2014	Added new version control table.	Adrian Searle	Minor	N/A
1.1	19/01/2014	Updated costs in tables/figures. Appendices 8 & 10 added	Andrew Stephen	Minor	1.1, 7.4.2, Appendices 5, 8, 10
1.2	20/01/2014	Appendix 7 amended to identify available scheme papers, Appendix 9 added	Andrew Stephen	Minor	Appendices 7 & 9
1.3	24/02/2014	Preface added	Andrew Stephen	Minor	Preface
1.4	25/02/2014	Update all HI data	Andrew Stephen	Minor	1.3, 4.7, 7.2.1, 7.6.2, Appendix 2
1.5	26/02/2014	Remove risk matrices Update data references	Andrew Stephen	Minor	7.6.2 Appendices
1.6	27/02/2014	HI Tables Updated	Andrew Stephen	Minor	7.2.1
1.7	03/03/2014	Editing grammar	Andrew Stephen	Minor	Preface
1.8	03/03/2014	Reference to Appendix 9 added	Andrew Stephen	Minor	1.3
2.0	04/03/2014	Approved by Barry Hatton	Andrew Stephen	Major	

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 Business Plan Data Table 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 a project in the 'NAMP' are allocated to a wide variety of tables and rows in the RIGS. For example the costs of a typical switchgear replacement project will be allocated to a range of different Ofgem ED1 RIGs tables and rows such as CV3 (Replacement), CV5 (Refurbishment) CV6 (Civil works) and CV105 (Operational IT Technology and Telecoms). However guidance notes of the destination RIGs tables for NAMP expenditure and included in the table in the Section 1.2 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 about the changes made to volumes and costs as a result of reviewing the plans submitted in July 2013. Generally the number of changes made is very small, as we believe the original plan submitted in July 2013 meets the requirements of a well justified plan. However there are areas where we have identified further efficiencies and improvements or recent events have driven us to amend our plans to protect customer safety and service.

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

Contents

1.0 Executive Summary EPN 132kV and EHV Transformers

1.1 Scope

This document details UK Power Networks' non-load related expenditure (NLRE) replacement and refurbishment proposals for 132kV and EHV Transformers for the ED1 period. Indicative proposals for the ED2 period are also included.

There are 255 132kV Transformers in EPN with an estimated MEAV of £403m. The proposed investment including civils is £4.0m per annum, which equates to an average annual 1.0% of the MEAV for this category. There are 895 EHV Transformers in EPN with an estimated MEAV of £548m. The proposed investment including civils is £3.4m per annum, which equates to an average annual 0.63% of the MEAV for this category.

Replacement and refurbishment costs for these assets are held in the following locations in Ofgem and UK Power Networks investment planning documents. Detailed reconciliation of asset removal volumes between RIGs and NAMP can be found in Appendix 8.

Investment type	ED1	NAMP line	RIGs reference
132kV Transformers asset replacement	£23.7m	1.51.01	Additions CV3 Row 101 – 132kV Transformer Removals CV3 Row 229 – 132kV Transformer
132kV Transformers asset refurbishment	£0.8m	1.51.11	CV5 Row 52 – 132kV Transformer
EHV Transformers asset replacement	£19.4m	1.51.03	Additions CV3 Row 83 – 33kV Transformer (GM) Removals CV3 Row 211 – 33kV Transformer (GM)
EHV Transformers asset refurbishment	£3.4m	1.51.11	CV5 Row 32 – 33kV Transformer (GM)

132kV Transformers asset replacement	£2.0m	1.51.01	CV8 multiple rows
EHV Transformers asset replacement	£1.7m	1.51.03	CV8 multiple rows

Table 1 – ED1 investment overview

* Expenditure on this asset type is also included on CV6 Civils, included in the Civil ASR.

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

1.2 Investment Strategy

The ED1 investment strategy for 132kV and EHV Transformers is detailed in UK Power Networks' Engineering Design Procedure EDP 00-0012, *Asset Lifecycle Strategy – Major Substations*. The investment plan has been developed in accordance with this strategy and by making use of the Asset Risk and Prioritisation (ARP) model to assess all asset data available in order to determine asset health, criticality and consequence of failure. This has enabled the construction of a well-justified plan based on detailed knowledge of individual assets rather than age or statistical modelling approaches.

The strategy for selecting the level of investment required has been to maintain a constant number of assets with Health Index scores of 4 or 5 from the start of the ED1 period to the end. Overall network risk will increase due to the deterioration of HI1 and HI2 assets as they become HI2 or HI3.

1.3 ED1 Proposals

Table 2 shows the planned interventions by asset type during the ED1 period.

Figure 1 and Figure 2 show how the numbers of HI4/HI5 132kV and EHV Transformers are projected to vary across the ED1 period, given the planned interventions.

		Intervention volumes								
Asset	**Intervention**	**15/16**	**16/17**	**17/18**	**18/19**	**19/20**	**20/21**	**21/22**	**22/23**	**ED1 total**
132kV Transformers	Replacement	1	3	2	3	3	3	4	3	22
132kV Transformers	Refurbishment	0	3	0	1	0	1	0	0	5
EHV Transformers	Replacement	3	2	7	2	10	9	5	5	43

EHV Transformers	Refurbishment	3	2	2	0	4	3	4	5	23

Table 2 – ED1 intervention volumes summary

Appendix 9 benchmarks our ED1 proposals with reference to other DNOs July 2013 submissions. It shows that for Grid and Primary Transformers we are proposing to replace 5% of our assets while other DNOs were seeking funding to replace 10% of these assets on average. This demonstrates the effectiveness of our asset risk management systems and the value for money of our proposals.

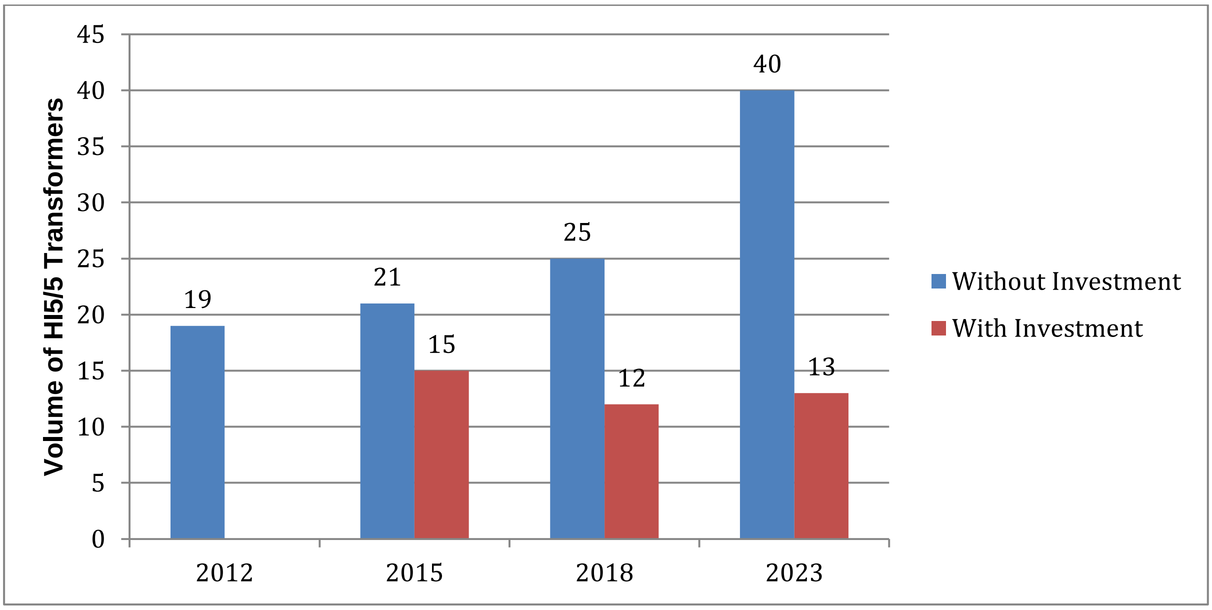


Figure 1 – Projected 132kV Transformer HI4/HI5 profile

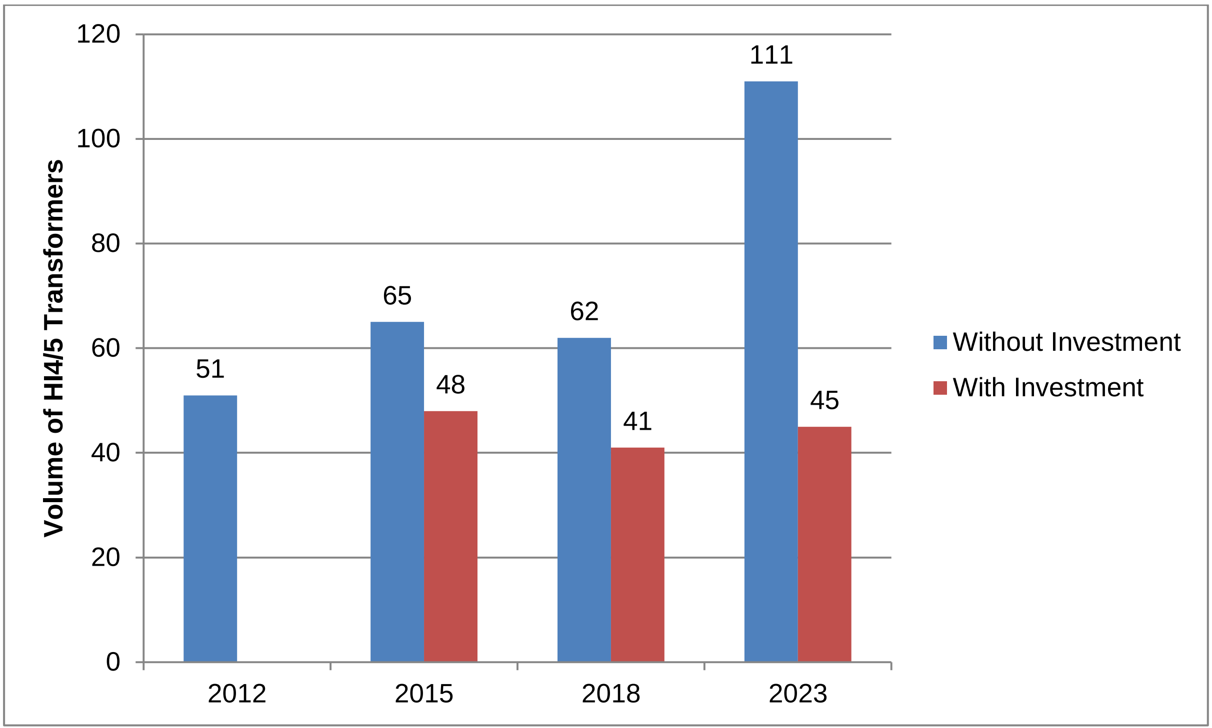


Figure 2 – Projected EHV Transformer HI4/HI5 profile

1.4 Innovation

A number of refurbishment options have been developed, some of which have been tested during DPCR5. These will allow the replacement of assets to be deferred. In the ED1 investment plan, there are 28 refurbishments that will save £19.1m of costs compared with traditional replacement strategies.

Ongoing research will drive continuous improvement in our asset health determinations that will, in turn, ensure the maximum serviceable life of assets while managing network risk effectively.

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 5% more often than planned	(£2.7m)
Risk	Cannot undertake 20% of planned refurbishment	£3.8m
Risk	Cost of refurbishment rises by 20% for 20% of planned refurbishment interventions in ED1 period	£0.2m

Table 3 – Risks and opportunities

2.0 Description of 132kV and EHV Transformer Population

2.1 132kV Transformers

In the EPN licence area, there are 255 transformers with a primary winding voltage of 132kV and ratings ranging from 10MVA to 90MVA. Secondary winding voltages are 33kV, 25kV or 11kV. These assets are located on 106 substation sites; 18 of these transformers are within 5km of the coast, so, as defined by the Galvanizers Association, are subject to higher corrosion ratings.

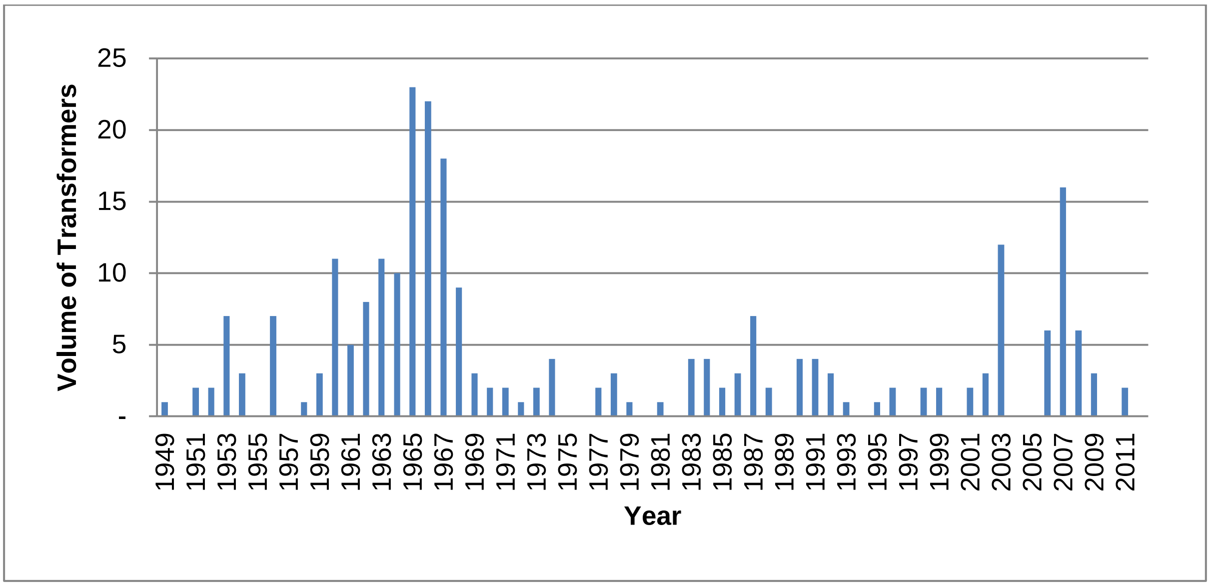


Figure 3 – EPN 132kV Transformer age profile

Source: 2012 RIGs V5

As can be seen from the age profile in Figure 3, significant investment was made in the 1950s/60s; the average age of these assets is 35.4 years. The average age of the oldest 10% of 132kV transformers is 58 years.

NAMP line	Description
1.51.01	132kV Transformer replacement
1.51.11	132kV and EHV Transformer refurbishment

Table 4 – NAMP references

RIGs tab	Line	Asset Category	Activity
CV3	101	132kV Transformer	Additions
CV3	229	132kV Transformer	Removals

CV5	52	132kV Transformer	Refurbishment - Transformer

Table 5 – RIGs reference

2.2 EHV Transformers

In the EPN licence area, there are 895 EHV Transformers with a primary winding voltage of 33kV and ratings ranging from 3MVA to 40MVA. Secondary winding voltages are 11kV, 6.6kV or 3.3kV. These assets are located on 451 substation sites; 86 of these transformers are within 5km of the coast, so, as defined by the Galvanizers Association, are subject to higher corrosion ratings.

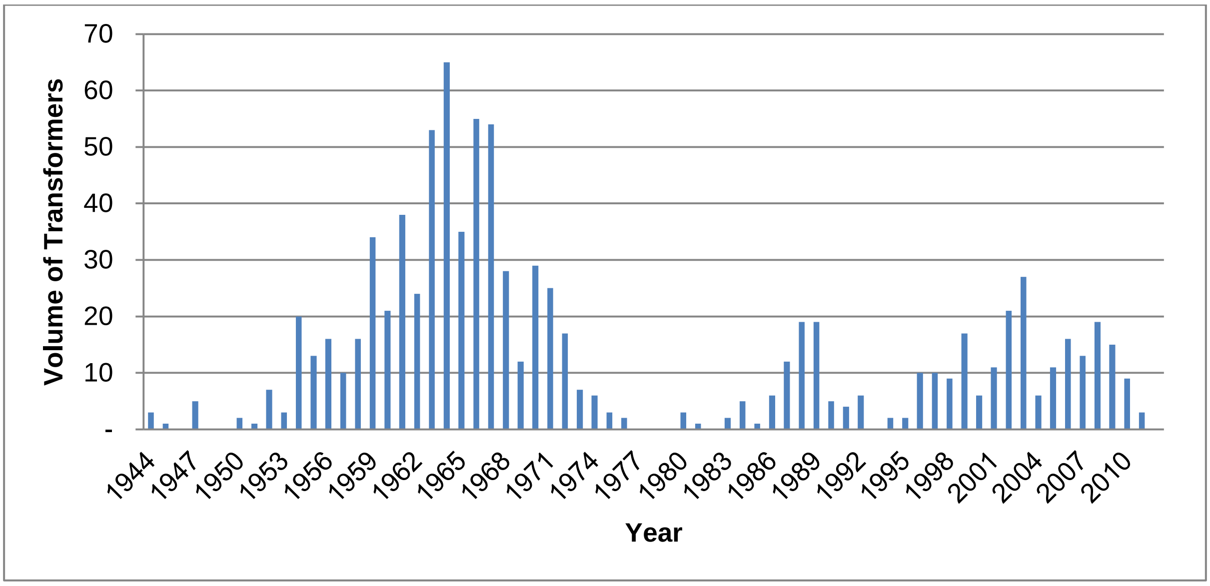


Figure 4 – EPN EHV Transformer age profile

Source: 2012 RIGs V5

As can be seen from the age profile in Figure 4, significant investment was made in the 1960s; the average age of these assets is 36.8 years. The average age of the oldest 10% of EHV Transformers is 58 years.

NAMP line	Description
1.51.03	EHV Transformer replacement
1.51.11	132kV and EHV Transformer refurbishment

Table 6 – NAMP reference

RIGs tab	Line	Asset Category	Activity
CV3	83	33kV Transformer (GM)	Additions
CV3	211	33kV Transformer (GM)	Removals

CV5	32	33kV Transformer (GM)	Refurbishment - Transformer

Table 7 – RIGs reference

3.0 Investment Drivers

3.1 Condition Measures

3.1.1 Transformers

Investment drivers from the transformer can be split into two categories: internal condition and external condition. External condition factors include paint condition and corrosion of any part of the transformer, cooler or conservator, and their pipe work. In addition, old gasket material can become compressed and brittle.

Figure 5 – Severe oil leak from main cover gasket, Kenton Primary T2

These factors pose both an environmental risk, particularly on older transformers without oil bunds, and a network risk, as they can lead to severe oil leaks and unplanned outages. UK Power Networks' Health, Safety and Sustainability Standard HSS 01 021, *Environmental Management of Insulating Oils: Use, Handling, Storage, Recording and Disposal*, requires that transformers with persistent oil leaks are considered for repair or replacement. Internal condition factors are the degradation of solid insulation materials on the windings, and the development of discharge and heating faults. Both of these internal condition factors are detected by non-intrusive oil sample testing.

3.1.2 Tap changers

As tap changers are the only moving part of the transformer, they are the most maintenance-intensive part and so often the most likely to develop defects. Although the assessment of external condition is the same as for the transformer, regular maintenance means that the internal condition can be assessed more easily.

Tap changers regularly have contacts changed, but older models increasingly require additional parts, such as new springs, due to the originals becoming weak over time. With many old tap changers, obsolescence becomes an issue as there is no manufacturer support, which makes it difficult to obtain the necessary parts (an example is the Allenwest LS slow-speed tap changers manufactured from the early 1950s). This increases the operational expenditure as parts are manufactured to order, often without the original designs available, so there is a reliance on recovering parts from decommissioned units. In total there are 60 different tap changer designs commissioned in EPN.

3.2 Defects

Defects are an important way of recording non-conformities that could affect the performance of assets and impact their health. Table 8 shows the defects that affect the health of transformer, tap changer and cooler assets and are reportable within our asset register, Ellipse. Each defect is assigned a priority rating, as defined in Table 9, which sets the target timescale for repair.

Defect description	Defect priority
Compound Leak	P2
Defect Breather	P1
Defect Bushing	P4
Defect Control/Marshalling Cubicle	P3
Defect Cooler Auto Control	P4
Defect Cooler Fail Alarm	P4
Defect Cooler Fan	P4
Defect Cooler Oil Pump	P4
Defect Cooler Water Pump	P4
Defect Drycol Unit	P1
Defect Oil Level Low or High	P5
Defect Tapchanger Operation	P5
Defective Cable Box	P2

Plant Subsidence	P2
Tapchange counter malfunctioning	P2

Table 8 – Transformer, tap changer and cooler defects

Defect criticality	Defect criticality definition
P1	At next maintenance
P2	<4 years
P3	<2 years
P4	<1 year
P5	<3 months

Table 9 – Defect criticality

3.2.1 Compound Leak and Defect Cable Box

Bitumen compound or G38 oil is used as an insulation medium in cable boxes on older transformers. If any of the insulant leaks out, the impulse rating is reduced, increasing the risk of disruptive failure if the equipment is subject to an overvoltage. Defective Cable Box is used to record where thermal imaging surveys identify an abnormal rise in temperature.

3.2.2 Defect Breather/Defect Drycol Unit

These indicate defects with the passive/active breathers on transformers or tap changers. Defective breathers can lead to moist air coming in contact with the oil, increasing the water content of the oil and papers in the transformer.

3.2.3 Defect Bushing

This is used to record damaged bushings or oil filled bushings with severe oil leaks. It is applicable to both HV and LV transformer bushings.

3.2.4 Defect Control/Marshalling Cubicle

This is a means of recording defects in the small wiring, auxiliary fuses and terminal blocks associated with the control of the transformer and tap changer. These defects can prevent the correct operation of the AVC and transformer and tap changer alarms.

3.2.5 Cooler Defects

Defect Cooler Auto Control, Fail Alarm, Fan, Oil Pump and Water Pump all refer to defects with the transformer forced cooling system. Any defects in these systems can affect the rating of the transformer, resulting in overstressing the asset.

3.2.6 Defect Oil Level Low or High

During inspection, the oil sight glasses are checked to ensure the oil level is correct. Low oil level can indicate leaks and is a risk to network security, particularly during cold weather. If the oil level drops too low, it will result in a Buchholz alarm or trip, affecting network security and incurring extra operational expenditure.

3.2.7 Defect Tap changer Operation/Counter Malfunctioning

This is used to record tap changers that are not in an operational state for any number of reasons, such as the AVC scheme malfunctioning or a broken mechanism identified during maintenance. This is classed as a P5 defect due to the impact a non-operational tap changer has on the voltage regulation. A malfunctioning counter can make it harder to identify where abnormal tapping operations are occurring, limiting the ability to identify a potential problem early.

3.2.8 Plant Subsidence

This identifies where subsidence is or will affect the operation of an asset.

3.2.9 Defect analysis

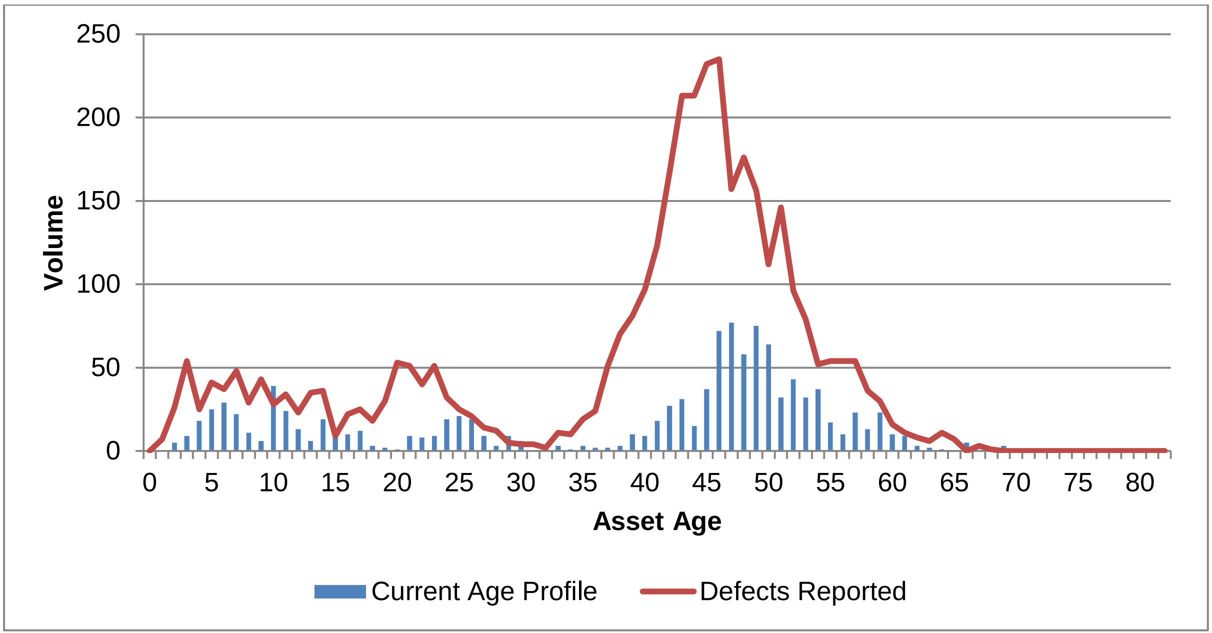


Figure 6 – EPN 132kV and EHV Transformer defect rate

Sources: Ellipse Extract 19/02/2013
2012 RIGs V5

Figure 6 shows the number of defects recorded in Ellipse on transformers, tap changers and coolers versus the age of the asset at the time the defect was reported, superimposed on the current combined age profile of 132kV and EHV Transformers in EPN. The number of defects increases with asset age, with significant numbers of defects reported on transformers in the 40–55-year age bracket. This age bracket corresponds with the Average Asset Life, as used in the HI modelling tool; refer to section 4.1.1 for more information. This rate of defects poses a significant risk to the network and requires continued operational expenditure to remedy. ED1/ED2 capital investment will manage this risk as this age group of transformers moves towards end-of-life.

3.3 Fault Rate

Figure 7 and Figure 8 show that fault rates of both 132kV and EHV Transformers have levelled out following significant peaks in 2008 and 2010 respectively. The replacement and refurbishment programme would address the defects that lead to these faults and stabilise the fault rate going in to ED2.

The fault data has been split into two categories: condition and non-condition faults. Non-condition faults relate to any fault not caused by the asset itself, such as third-party damage, bird strikes or weather. Examples of condition faults are bushing faults, wear and tear of the tap changer mechanism and loss of oil due to severe corrosion.

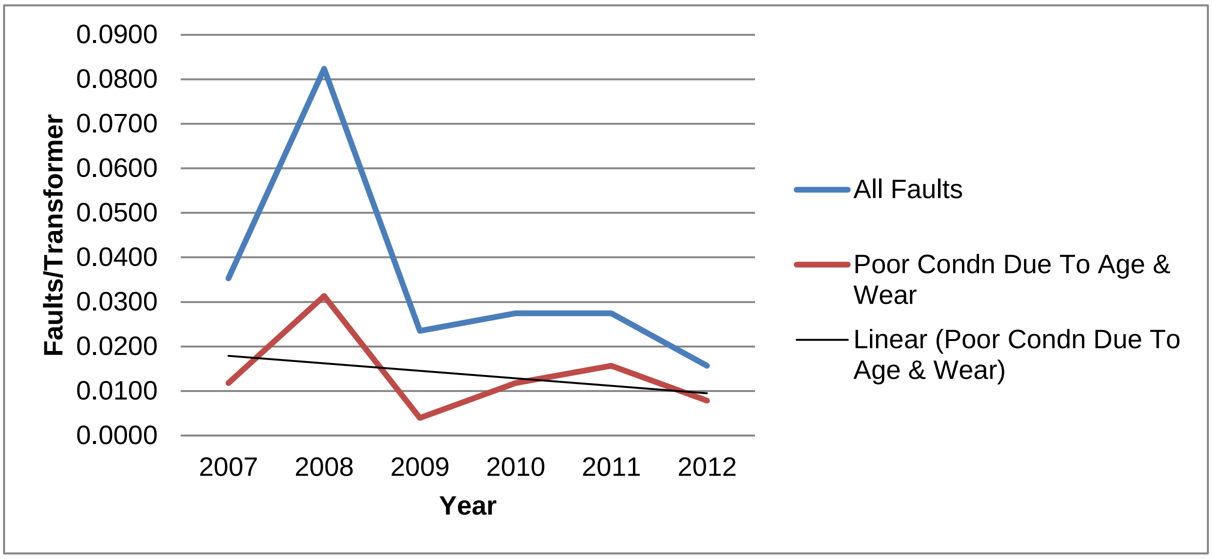


Figure 7 – 132kV Transformer fault rate

Source: UK Power Networks Fault Analysis Cube

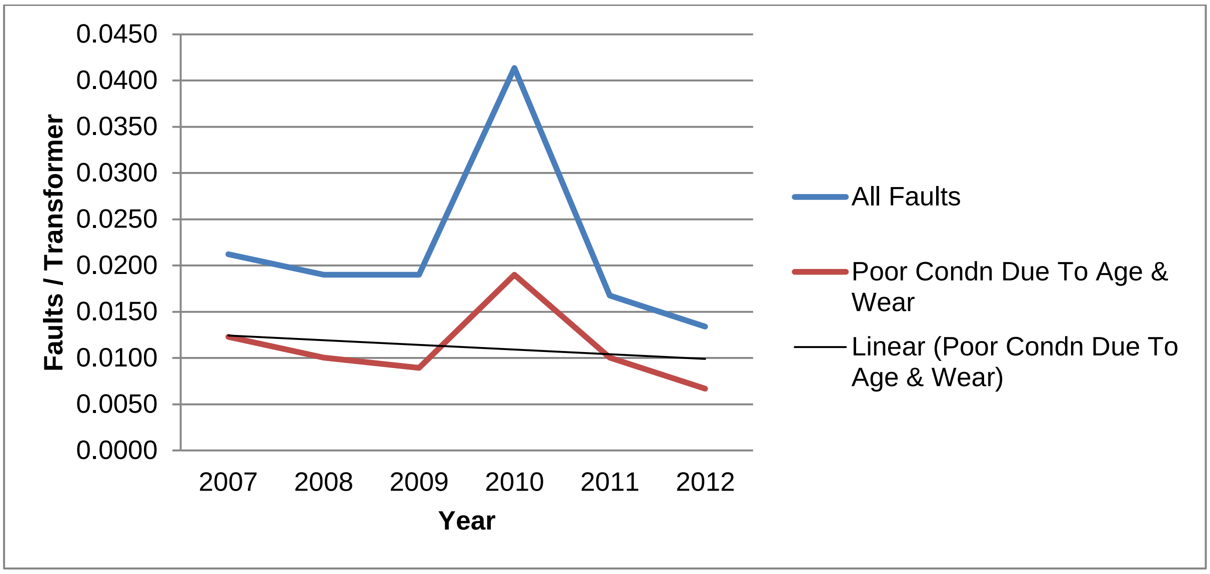


Figure 8 – EHV Transformer fault rate

Source: UK Power Networks Fault Analysis Cube

3.4 Asset Age

Although asset age is not a primary investment driver for the 132kV and EHV Transformer expenditure plans, it does have a cumulative effect on the serviceability of some of these assets. Table 10 shows how the proportion of the population of 132kV and EHV Transformers above the Average Asset Life of 51 years will increase dramatically from 2015 to 2023 without investment.

	Transformer population	Transformers over Average Asset Life in 2015	% Transformers over Average Asset Life in 2015	Transformers over Average Asset Life in 2023	% Transformers over Average Asset Life in 2023
132kV Transformers	255	58	23%	149	58%
EHV Transformers	895	255	28%	567	63%

Table 10 – Asset age vs. Average Asset Life

Source: 2012 RIGs V5
ARP Model LW_TX_25Jul2012

Reliability is linked to asset age and there is a risk to network operation from increasing numbers of defects and faults. As can be seen from Figure 7 and Figure 8, fault rates for these assets are falling slightly on average but are changeable on a year to year basis. The small population of assets and low fault rates make it difficult to forecast fault rates through ED1 and ED2. As the peak of the age profile moves towards an age bracket with a historically higher rate of defects there is a risk this will result in rising fault rates. This is likely to increase customer interruptions and, if not addressed during ED1, would leave a large investment requirement for ED2 that could not be delivered as there is insufficient network capacity to accommodate the number of outages that such a construction project requires.

3.5 Condition Measurements

In order to determine the levels of interventions required in an intelligent way, to provide the best possible value-for-money solution for customers, it is necessary to accurately assess the health of the assets, rather than use an age-based approach. To assess the health, it is essential to have the right data available and to ensure it is of a high quality.

3.5.1 Substation inspection

The main source of asset external condition data is from Substation Inspectors. In order to improve condition data quality, during the first half of DPCR5 a review of the *Substation Inspectors' Handbook* was carried out and a new handbook was issued. All inspectors were required to undertake a two-day training course and pass the theory and practical examinations before being certified as competent inspectors.

Handheld devices (HHD) are increasingly being used on site at the point of inspection in order to ensure good quality and timely data is captured and recorded in the asset register. When an inspection HHD script is run, the user answers a set of questions, specific to each asset type, about the asset's condition; this allows defects to be recorded, reviewed and cleared. This method of inspection, together with in-depth training, ensures that condition and defect assessments are carried out objectively, thereby giving consistent results from inspector to inspector across the business.

Figure 9 – Handheld device used in inspections and maintenance

UK Power Networks' Engineering Maintenance Standard EMS 10-0002, *Inspection and Maintenance Frequency Schedule*, specifies that all 132kV and EHV Transformers be inspected at least every six months.

3.5.2 Maintenance

Maintenance fitters also use the same HHD technology to record their assessment of the internal and external condition of the assets being maintained. This assessment is made twice during each maintenance task, to provide condition data "as found" and "as left".

One key assessment of a transformer's external condition, particularly on older transformers, is the degree of oil leaks. In addition to the substation inspectors' scoring of oil containment, maintenance teams record the volume of oil in litres whenever they top up the oil level. This allows leakage rates to be measured for each transformer.

UK Power Networks' Engineering Maintenance Standard EMS 10-0002, *Inspection and Maintenance Frequency Schedule*, requires that all 132kV and EHV Transformers be maintained every eight years. Tap changers have various maintenance cycles that are dependent upon the make and model. High-speed tap changers are maintained less frequently than older slow-speed tap changers, and some models have known issues or a history of defects that require them to be maintained as often as every two years. An example is the English Electric FDB tap changer, which has a history of hairline cracking on the phase barrier mouldings, which require regular inspection.

3.5.3 Oil analysis

Oil samples are taken regularly from all grid and primary transformers to assess their internal condition. By measuring the furans (FFA) in the oil, the degree of polymerisation of the paper on the windings can be interpolated to give an estimate of the paper's remaining life. Dissolved Gas Analysis (DGA) is also carried out to identify developing faults within the transformer. The dissolved gases are produced in the oil when heating processes such as discharge or arcing are taking place. By assessing the trend of gases, a developing fault can be identified and addressed.

UK Power Networks' Engineering Maintenance Standard EMS 10-0002, *Inspection and Maintenance Frequency Schedule*, specifies that all 132kV and 66kV transformers are sampled annually and all other EHV Transformers are sampled every four years. Samples are sent to one of two external laboratories for independent analysis.

Figure 10 shows the levels of dissolved gases within one transformer, which, until November 2011, was stable with no indications of faults. Following a Buchholz gas alarm, more regular oil sampling revealed a steady increase in gases through to July 2012. Investigations found that the in-tank tap changer was the source of the fault and a UK Power Networks maintenance team from another area with specialist knowledge of this particular tap changer type made temporary repairs. The transformer was returned to service and is scheduled for replacement at the start of ED1.

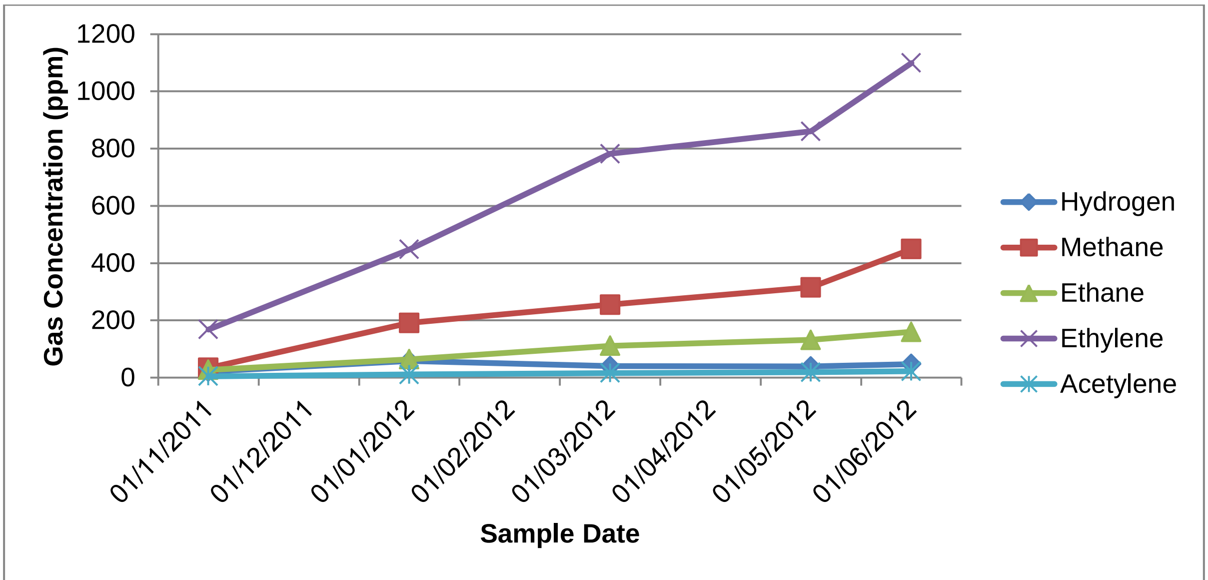


Figure 10 – Dissolved Gas Analysis results, South Chelmsford Primary T1

Source: Ellipse Extract 01/03/2013

One challenge with DGA is identifying spurious results. It is possible for the oil in the main tank of the transformer to be contaminated with gases produced in a common tank tap changer or separate diverter. This contamination can be the result of shared oil, leakage through the barrier board, or shared headspace above the surface of the oil in a transformer/tap changer conservator. Where this problem has been identified, the asset health has been recalculated to ensure the asset is not included in the ED1 plan without further justification; this has been implemented for 22 transformers in EPN and has identified ATL AT tap changers as being particularly prone to contaminating main tank oil. Identifying these spurious results and recalculating the health of the transformer provides savings for our customers, because there is no need to make unnecessary allowances.

4.0 Asset Assessment

4.1 Asset Health

An innovative asset-health modelling tool has been developed for several asset categories, including grid and primary transformers. The methodology behind the modelling is the same for all asset categories, but the transformer model has been tailored specifically to use the data collected to assess against the identified investment drivers for transformers.

Further information is available in *Commentary Document 15: Model Overview*, which details the methodology and asset data required to calculate an initial Health Index (HI) for each asset. Figure 11 shows the process from inputting data through to calculating the current and future health indices for 132kV and EHV Transformers.

Condition scores recorded during inspection and maintenance as well as oil top-up history are used to calculate a weighting factor that is applied to the initial HI. A similar process is also used to calculate a weighted HI for the tap changer. Separate HI scores are calculated for DGA, FFA and oil quality using oil sample results, excluding any data more than 10 years old. The highest score from these contributing HIs is identified as the main HI driver and is used as the overall HI score for each transformer.

Transformer oil leaks can have significant environmental, network and business consequences, so it is our policy, as stated in UK Power Networks' Health, Safety and Sustainability Standard HSS 01-021, *Environmental Management of Insulating Oils: Use, Handling, Storage, Recording and Disposal*, to ensure all topping up of oil is recorded in the asset register. This ensures that leaking transformers can be identified and the appropriate course of action is planned in a timely manner. Where the Oil Containment condition measure is recorded as a 4 (on a 1–4 scale), the overall HI of the transformer cannot be less than 4.

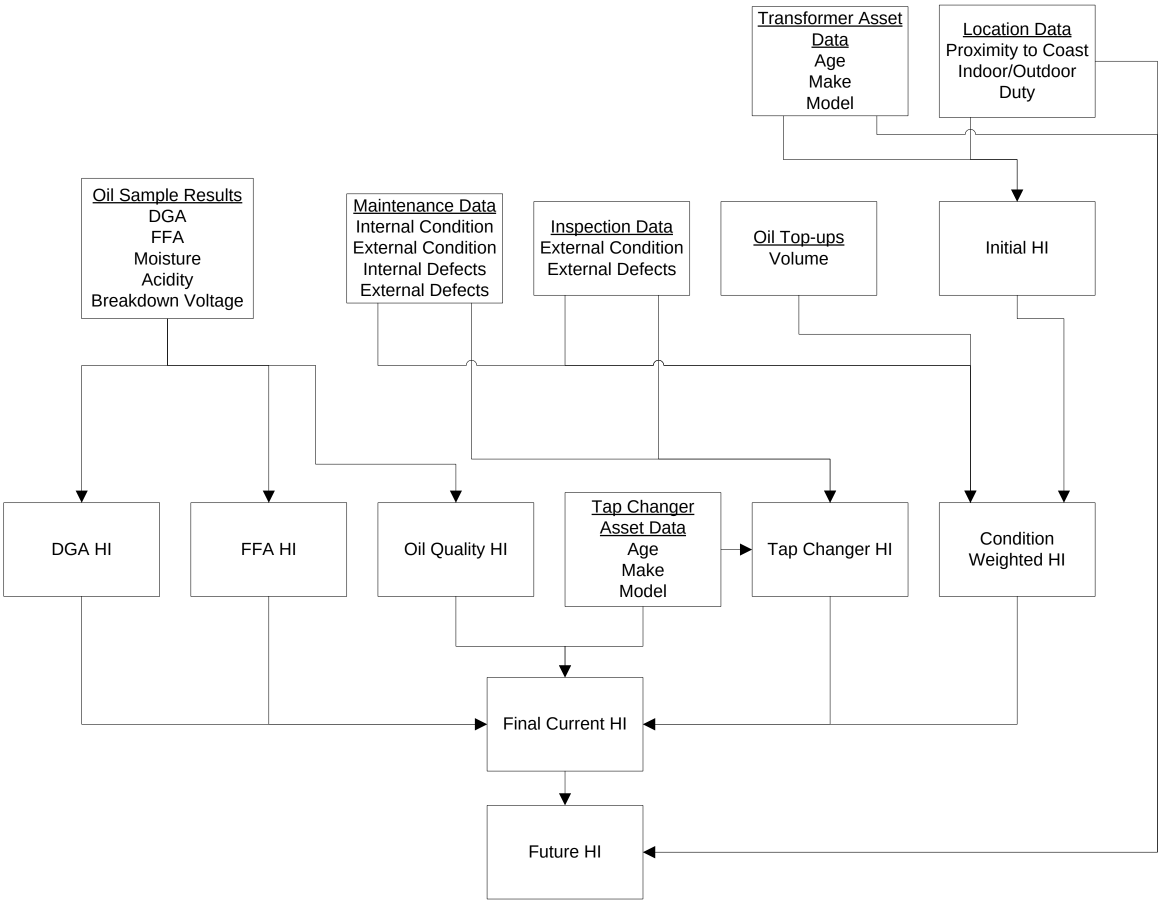


Figure 11 – Transformer HI modelling methodology

4.1.1 Average Asset Life

In order to calculate asset health degradation, each asset is assigned an Average Asset Life in the ARP model. This is defined in the model calibration and is specific to the manufacturer and model of the asset. This approach takes into account the changes in transformer design and manufacturing processes over time. In this context, within the ARP model, the Average Asset Life is considered to be the point in the life of the asset when significant increases in defects start to appear and it is found to be in poorer condition.

Note: The majority of transformers will remain in service significantly beyond their assigned Average Asset Life in the ARP model. For further details and examples of Average Asset Lives for these assets, refer to *Commentary Document 15: Model Overview*.

4.2 Asset Criticality

Another feature of the ARP model still under development can be used to calculate the criticality of a particular transformer asset. This is then defined in the form of a Criticality Index with a scale of 1 to 4, with 1 being the least critical and 4 being the most critical. A detailed methodology for calculating the Criticality Index can be found in *Commentary Document 15: Model Overview*.

Five main areas are considered when calculating the criticality of assets: network performance, safety, operational expenditure, capital expenditure and the environment. A number of factors generic to all ARP models are used in these areas, in addition to some specific to transformers.

For network performance, the key factors for the transformer model are the number of customers that the substation feeds and the maximum substation demand.

The safety criticality is assessed based on the ESQC risk rating for the site and the situation of the transformer (indoors, outdoors or basement).

The operational and capital expenditure criticalities consider the assets in terms of the ease of carrying out works due to the equipment situation and site type and also the transformer rating.

Finally, the environment section considers whether the site is in an environmentally sensitive location and if the transformer is housed in a bunded area.

4.3 Network Risk

ARP provides for an innovative new approach to calculating network risk for a given asset category. UK Power Networks believes this is one of the first comprehensive applications of such quantified risk modelling for electricity distribution networks worldwide. The network risk is determined by the probability of failure, directly proportional to the HI, and the criticality of each asset. The consequence of failure is the average cost to repair or replace a transformer following one of three failure modes. This section of the ARP model is still in the early stages of development.

Failure mode	Description
Minor	Can be repaired by maintenance teams

Significant	Can be repaired using external resources/expertise
Major	Cannot be repaired on site; offsite repair or replacement is required

Table 11 – Failure mode definitions

Section 7.6.2 details the method of this risk analysis and the results obtained.

4.4 Data Validation

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

One measure used in the ARP model, Moisture Corrected to 20°C, has a valid range of 0 to 100ppm, with any data outside this range being excluded from the model and leading to the creation of an exception report. In addition, oil sample data more than 10 years old is excluded from the model.

4.5 Data Completeness

As the asset condition data, particularly oil sample results, is such a vital part of determining the health of a transformer, the data was tested for completeness. In order for a particular set of oil sample results to be considered complete, certain measures had to be identified as 'essential': moisture, acidity, FFA, hydrogen, methane, ethane, ethylene and acetylene. To establish trends while ensuring data is not obsolete, oil sample results older than 10 years old are excluded from the ARP model.

Table 12 shows the numbers of oil sample result sets, distinct transformers with at least one set of oil sample results and distinct transformers with at least one set of oil sample results with all 'essential' measures, also expressed as a percentage of the asset population.

	132kV Transformers	EHV Transformers
Total number of oil sample records	1,135	1,866
Number of records with essential measures populated	1,063	1,632
% records with essential measures populated	94%	87%
Number of distinct transformers with oil sample records	250	857

% distinct transformers with oil sample records	97%	96%
Number of distinct transformers with essential measures populated	250	822
% distinct transformers with essential measures populated	97%	92%

Table 12 – EPN oil sample data completeness

Source: Ellipse Extract 28/01/2013

The completeness, accuracy and timeliness of all the data used in the ARP model, including oil sample results, are routinely checked. The latest results are shown in Table 13.

Area	Result
Completeness	89%
Accuracy	89%
Timeliness	99%

Table 13 – ARP EPN data CAT scores

Source: Ellipse Extract 27/11/2012

These results provide confidence in our key condition data, which has allowed us to better manage risk and build a well-justified plan for ED1.

4.6 Model Testing

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

1.3.1 Algorithm testing

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

1.3.2 Software testing

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

1.3.3 Data flow testing

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

1.3.4 User and methodology testing

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

4.7 HI Profile

Figure 12 and Figure 13 show the projected HI profile at the end of DPCR5, including the impact of planned investments in years 4 and 5 of DPCR5.

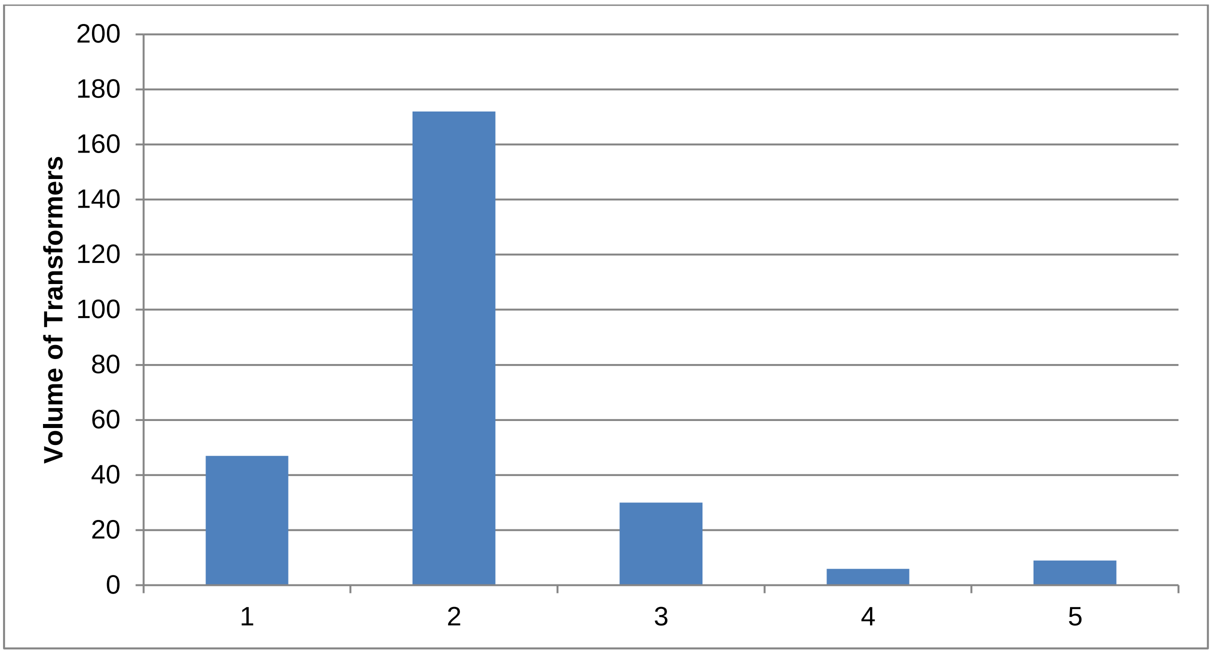


Figure 12 – Projected 2015 132kV Transformer HI profile

Source: ARP Model LW_TX_Jul2012

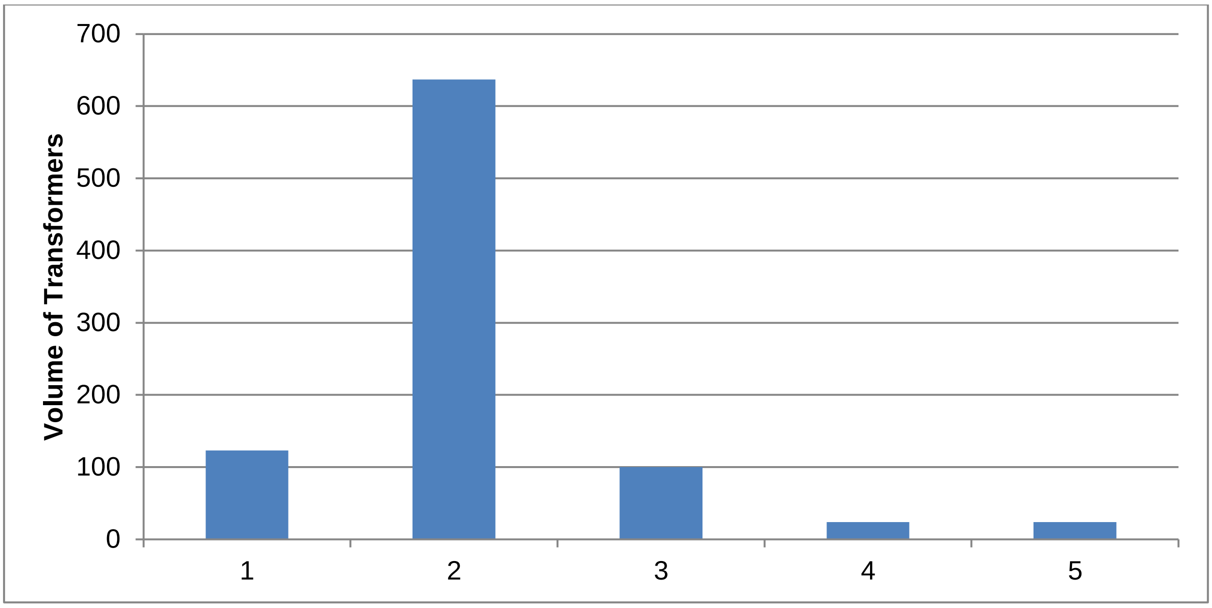


Figure 13 – Projected 2015 EHV Transformer HI profile

Source: ARP Model LW_TX_Jul2012

5.0 Intervention Policies

5.1 Interventions: Description of Intervention Options

In order to maximise value in ED1 and contain network risk at the lowest cost, a significant and innovative programme of transformer refurbishments is proposed in ED1, in addition to the replacement programme. Refurbishment can be broken down into a range of options that will be driven specifically by the individual transformer's requirements as defined in UK Power Networks' Engineering Design Standard EDS 04-0006 *132kV and EHV Transformer Non-Load Related Refurbishment and Replacement*.

Transformer refurbishment	
Intervention	**Description**
Gasket replacement	Replacement of old gasket material to cure oil leaks
Transformer bushing replacement	Replacement of damaged bushings or to cure severe oil leaks
Tap changer refurbishment	Replacement of tap changer mechanism
Oil treatment	Treatment to reduce moisture and acidity to extend the life of windings
Tap changer replacement	Replacement of obsolete tap changers, or where a type defect has been identified
Cooler replacement	Replacement of radiator, with consideration for fans, pumps and cooler control systems
Conservator replacement	Replacement due to corrosion
AVC replacement	New AVC scheme
Full factory refurbishment	May include replacement of core and windings

Table 14 – Transformer refurbishment options

The chosen refurbishment options, which align to the Ofgem scope of transformer refurbishment work, will target specific problems with each transformer, while returning the transformer to HI2 to achieve a life extension of at least 15 years.

5.2 Policies: Preferred Interventions

5.2.1 Selecting interventions

The ARP model is used to identify the preferred intervention for each asset using the method shown in Figure 14. The key drivers behind the HI score of 4 or 5 are identified, allowing the most appropriate interventions to be selected on an engineering and cost-benefit basis.

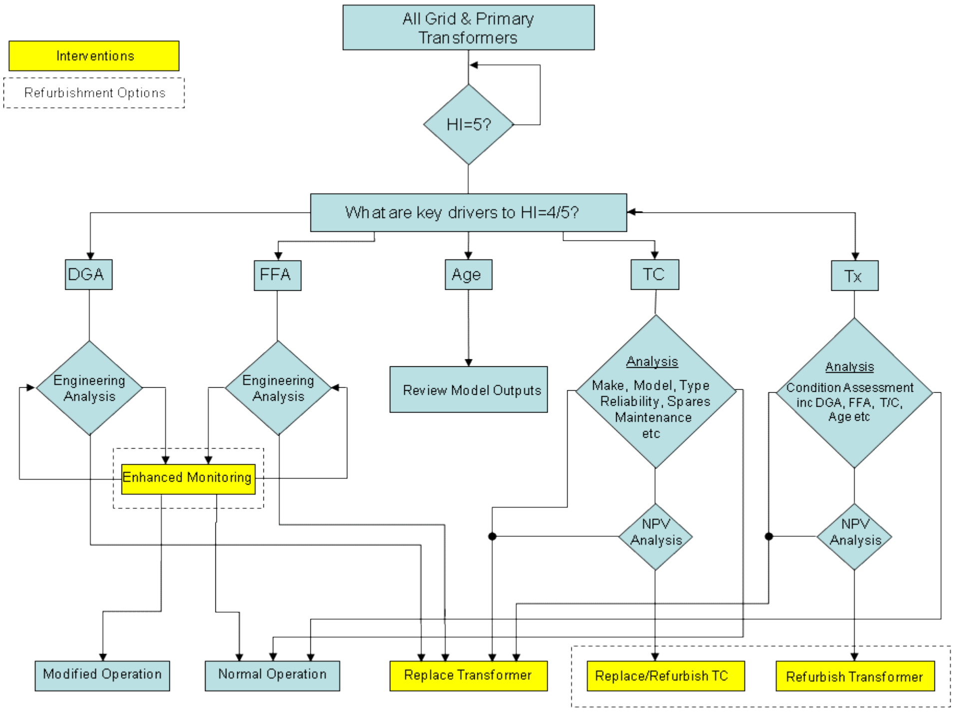


Figure 14 – Intervention strategy process

5.2.2 Benefits of refurbishment

By implementing this programme of transformer refurbishments, we will be able to manage the deterioration of the transformers, addressing failure modes that would, if left untreated, result in asset replacement. This will extend the lives of these transformers, reduce whole-life costs and improve reliability and network risk, while minimising short-term expenditure and improving our service to customers. An example *Whole-Life Costs* case study comparing replacement and refurbishment options can be found in Appendix 4.

5.2.3 Operational expenditure

This capital expenditure programme, in terms of both replacement and refurbishment interventions, will provide significant benefits to our operational expenditure. Slow-speed tap changers have increased maintenance frequency and are likely to be less reliable and require more defect repairs. By replacing the transformer or the tap changer, as part of a refurbishment, the number of maintenance requirements will reduce.

Also, refurbishing a transformer with severe oil leaks will eliminate the need for both regular oil top-ups and for environmental clean-up operations as a result of the leaks.

6.0 Innovation

UK Power Networks is actively involved in a number of innovative ways to manage the 132kV and EHV Transformer fleet in addition to the industry-leading health and criticality modelling currently in use. A trial is under way using a failed EHV transformer from Gorringe Park Primary in LPN to assess the benefits of a 're-manufacture' of transformers: the removal of the asset back to the manufacturer for complete refurbishment, including the replacement of the core, windings and tap changer. This option can minimise project costs by limiting the cabling and civil works associated with a full transformer replacement. This could be beneficial, particularly where we have a high number of transformers of the same design, because the initial design cost and time would be limited to the first order.

Another trial to begin shortly is on the use of advanced transformer cooler control. This system can initiate forced cooling systems based on transformer load, anticipating and limiting a rise in temperature that could increase the rate of ageing of the transformer. It will also monitor the forced cooling system, sending alarms if any failure occurs, enabling Control Engineers to take proactive action to prevent damage to the transformer caused by overloading.

UK Power Networks is also involved in research into areas such as the ageing of transformer insulation, partial discharge diagnostic of transformer insulating fluids, DGA measurement/data interpretation and thermal analysis of transformer insulation systems. More information can be found in the *Innovation Strategy* document.

7.0 ED1 Expenditure Requirements for 132kV/EHV Transformers

7.1 Method

Figure 15 shows an overview of the method used to construct the ED1 NLRE investment plans.

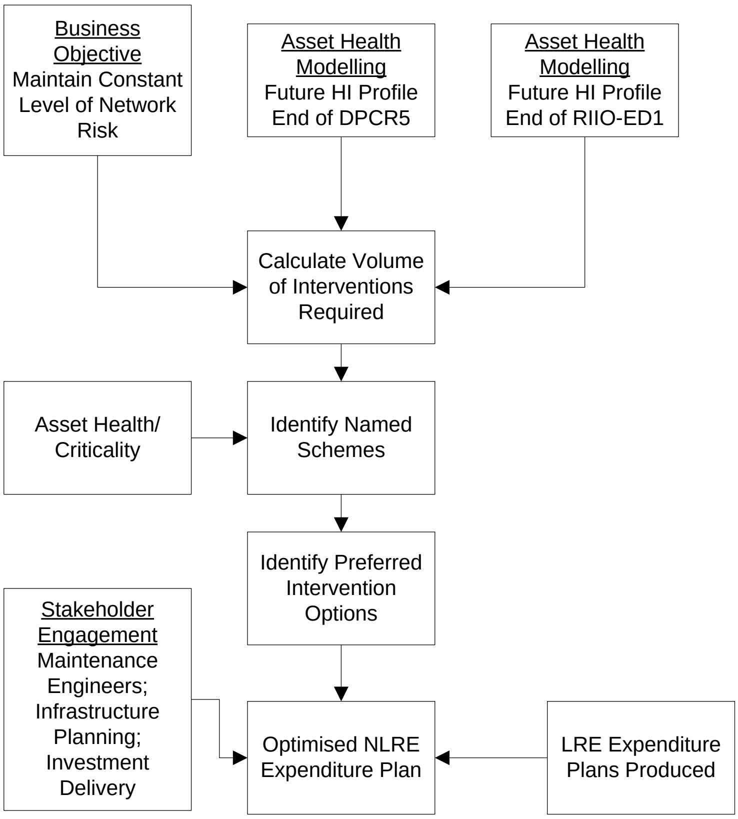


Figure 15 – Constructing the ED1 NLRE Plan

7.2 Constructing the Plan

7.2.1 Intervention volumes

The business objective throughout the planning process for ED1 NLRE was to prevent any increase in the number of HI4/HI5 assets. To achieve this, the ARP model was used to determine the HI profiles for 132kV and EHV Transformers at the end of DPCR5 and at the end of ED1 to project how the number of HI4s and HI5s would increase without investment. This provided the basis for the volume of interventions required during ED1, with priority given to the assets with the highest HI/Criticality. Figure 16 and Figure 17 show how the numbers of HI4 and HI5 transformers are projected to change over the remainder of DPCR5 and ED1 both with and without the proposed investment. The HI profiles indicated are derived from condition related investment only and exclude the contribution from load related expenditure.

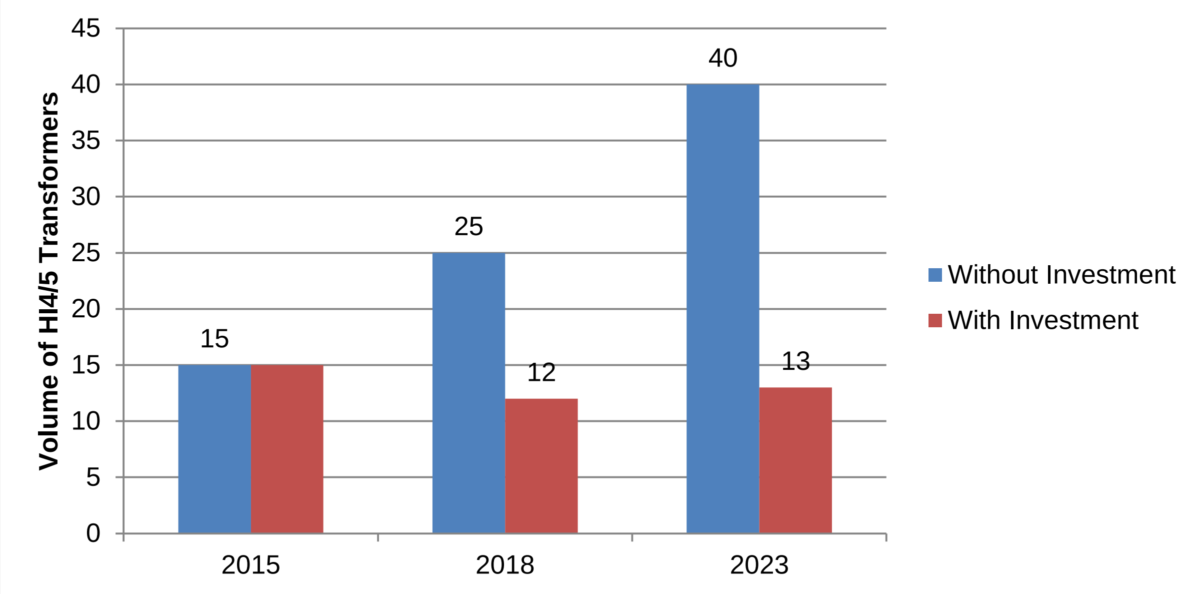


Figure 16 – 132kV Transformer projected HI4 and HI5 volumes

Source: ARP Model LW_TX_Jul2012

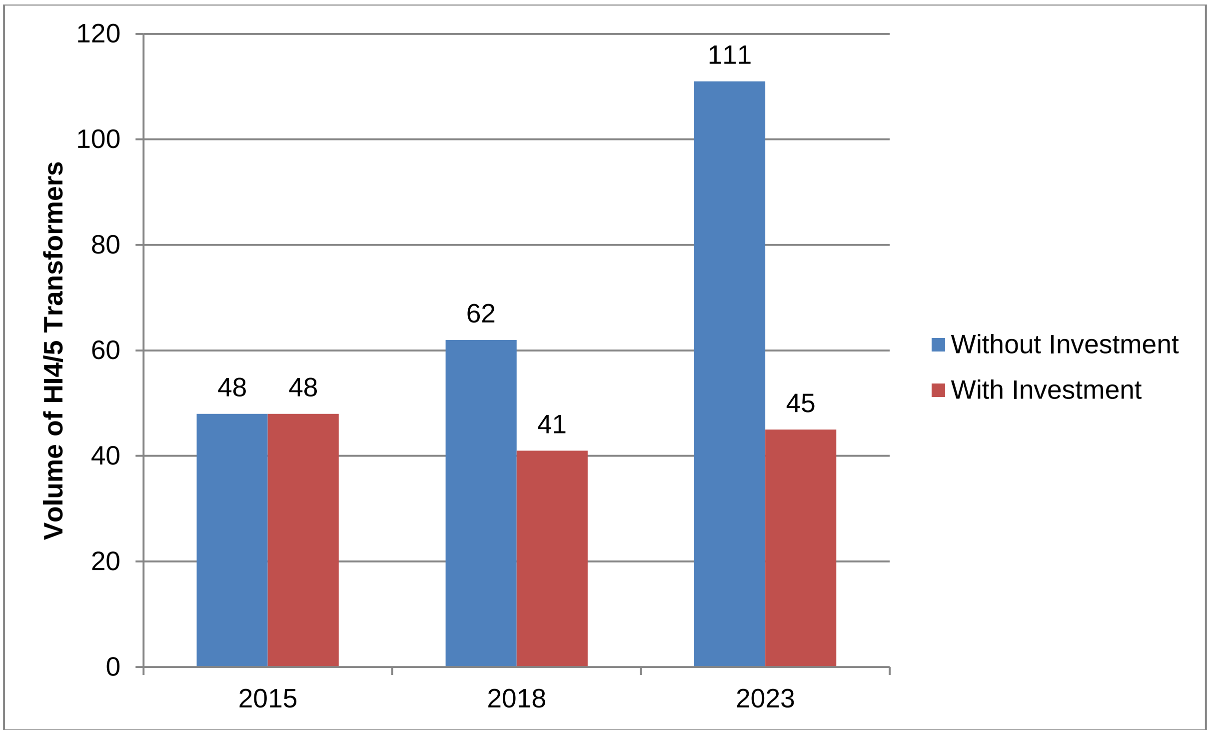


Figure 17 – EHV Transformer projected HI4 and HI5 volumes

Source: ARP Model LW_TX_Jul2012

7.2.2 Intervention types

The five contributory HIs calculated by the ARP model (DGA, FFA, Oil Condition, Tap Changer and Condition Weighted Transformer) were used to determine the main driver for a transformer being HI4 or HI5. Those transformers with a DGA or FFA driver, indicating internal degradation, were selected for replacement, with the remaining transformers considered for refurbishment based on whole life cost analysis; an example is given in Appendix 4.

7.2.3 Optimising the plan

Stakeholder engagement was an important part of the process to finalise the ED1 plan. Maintenance engineers were consulted, because they are the most familiar with the assets. They provided additional reassurance that the data used in the ARP model reflected their own assessment of each asset's condition. There was also detailed consultation with those involved in constructing the ED1 LRE expenditure plans to ensure the optimal investment for maximum achievement.

Consideration was also given to NLRE plans for other equipment classes to allow significant cost savings to be made by consolidating projects. An example is the co-ordination of the replacement of GT1B and the 15 33kV CBs at Crowlands Grid.

7.3 Additional Considerations

Consideration was also given to the efficiency of the programme. Where multiple transformer interventions were planned on one site but an additional identical transformer on the site was projected to be an HI4 early in ED2, then it was also included in the ED1 plan. It was deemed more efficient to adopt this approach due to the high project costs associated with a major intervention on transformers.

7.4 Asset Volumes and Expenditure

7.4.1 Intervention volumes

Figure 18 and Figure 19 show the DPCR4/5 investment volumes followed by the required investment volumes for ED1 and ED2. Investment volumes can be found in more detail in Appendix 7.

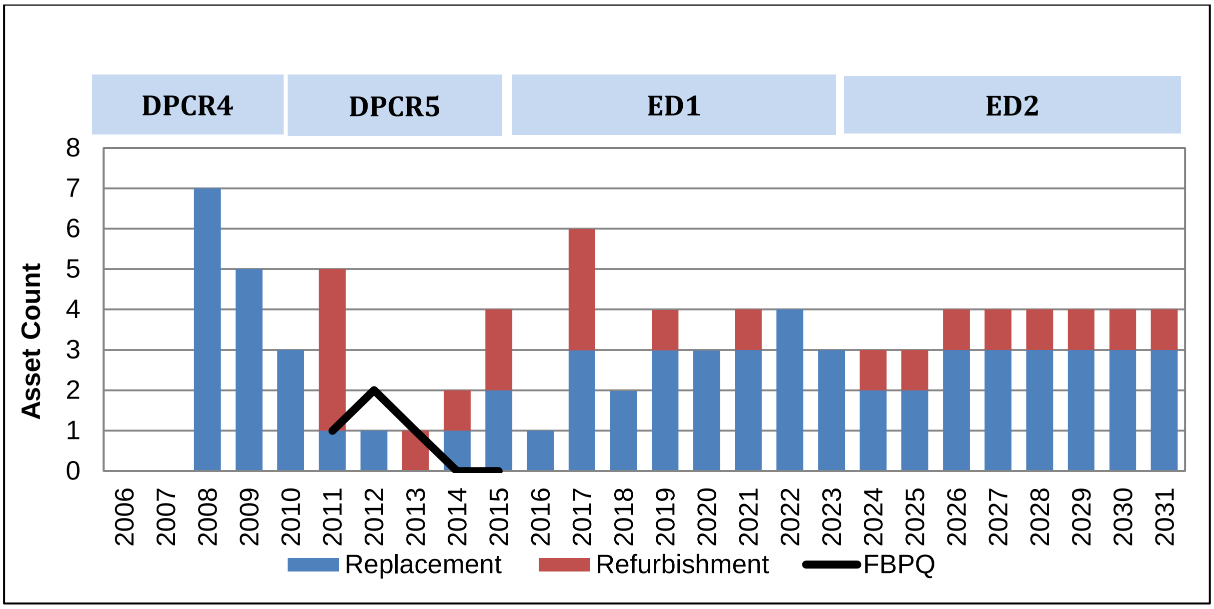


Figure 18 – EPN 132kV Transformer intervention volumes, DPCR4–ED2

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs
DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model

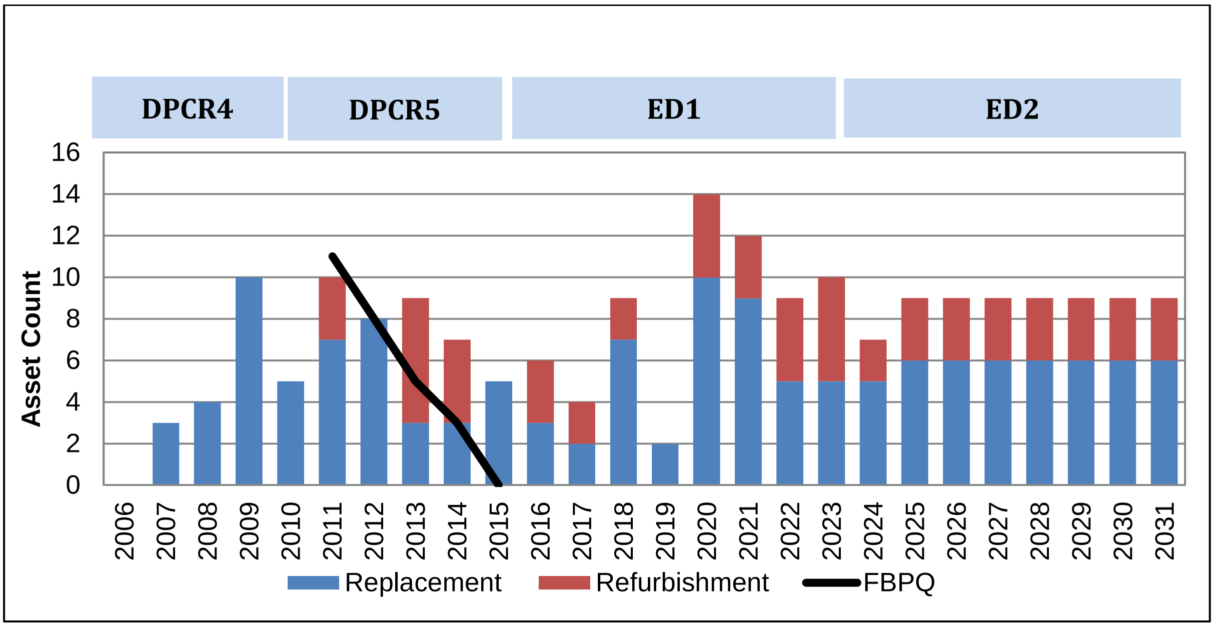


Figure 19 – EPN EHV Transformer intervention volumes DPCR5–ED1

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs
DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model

7.4.2 Intervention expenditure

Figure 20 and Figure 21 show the DPCR5 investment expenditure followed by the required investment expenditure for ED1.

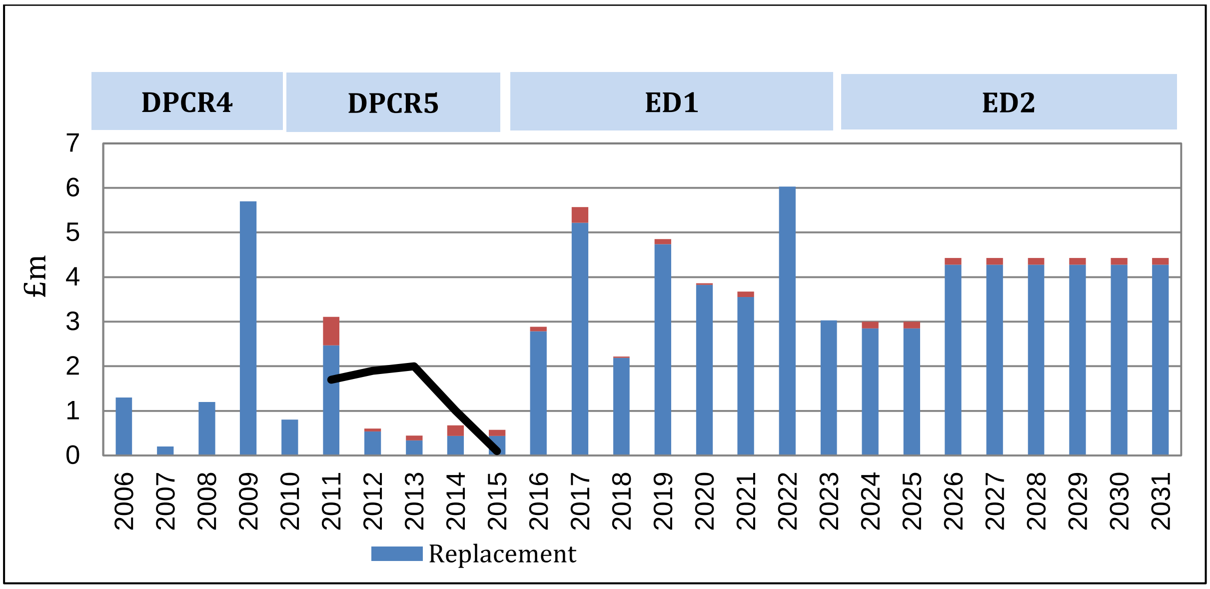


Figure 20 – 132kV Transformer expenditure

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs
DPCR5 costs: Last two years – 14th June 2013 NAMP
DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8
ED1 costs: 19th February 2014 NAMP
ED2 costs: Average from ED1 costs

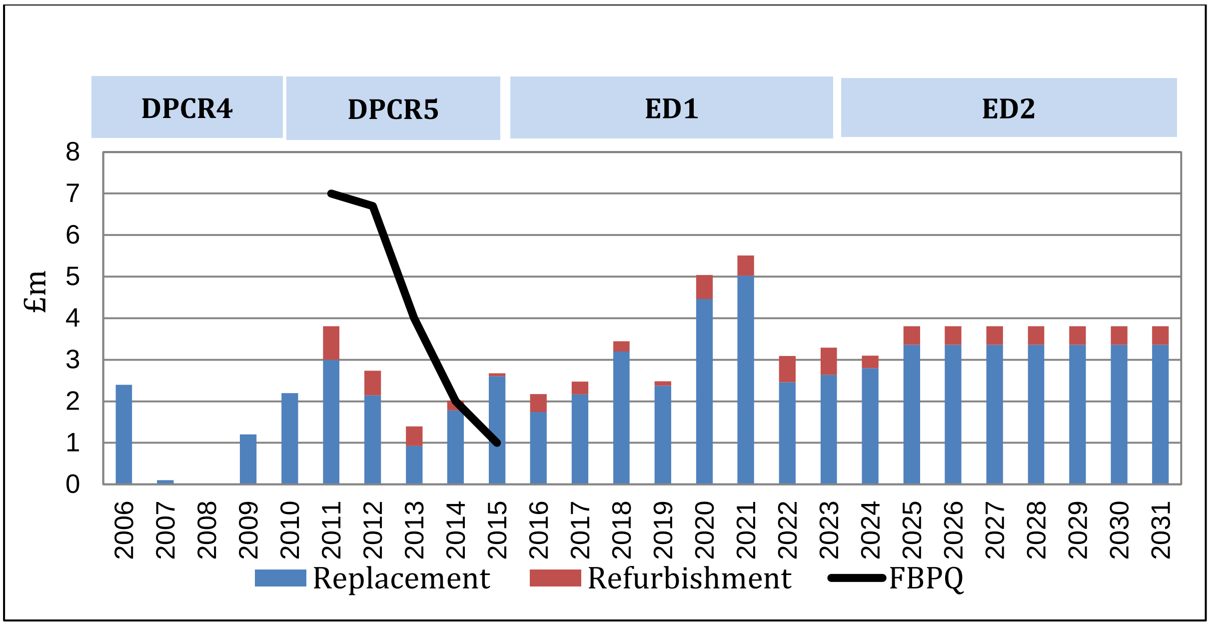


Figure 21 – EHV Transformer expenditure

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs

DPCR5 costs: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8
ED1 costs: 19th February 2014 NAMP
ED2 costs: Average from ED1 costs

Note: Due to efficiency savings, careful risk management and the introduction of the refurbishment programme in the latter part of DPCR5, the volumes of interventions in the FBPQ were exceeded, while the costs were below the FPBQ level.

7.5 Commentary

7.5.1 132kV Transformers

The rate of 132kV Transformer NLRE replacement proposed for ED1 has increased from the DPCR5 programme, from 1 per year to 2.75 per year as is to be expected for an ageing population. This increase in the rate of replacement has been limited by the creation of the refurbishment programme. This improves asset health and risk while minimising short-term expenditure by extending the life of assets that would, in the past, have been considered for replacement. The improved data and better interpretation of the data allow the risks to be managed effectively.

The proposed plan will ensure that maximum asset life is achieved while optimising cost efficiency by co-ordinating projects on a given site and co-ordinating resources shared with LRE projects, although the phasing of planned achievement is not constant across ED1 as a result.

As seen in section 3.4, with no interventions the average age of the transformer population would increase significantly during the course of ED1. Extending this analysis to include planned interventions in ED1, Table 15 shows that the investment plan mitigates some of the increasing risk from the age profile of the assets. Our modern approach to asset data, heath and criticality will allow us to manage this risk effectively.

				Without investment		With NLRE investment	
	Transformer population	Transformers over Average Asset Life in 2015	% Transformers over Average Asset Life in 2015	Transformers over Average Asset Life in 2023	% Transformers over Average Asset Life in 2023	Transformers over Average Asset Life in 2023	% Transformers over Average Asset Life in 2023
132kV Transformers	255	58	23%	149	58%	128	50%

Table 15 – Asset age vs. Average Asset Life with ED1 investment (132kV Transformers)

Sources: 2012 RIGs V5
ARP Model LW_TX_25Jul2012

Further work will be required and further development of health, criticality and risk modelling techniques to further refine the ED2 projections during ED1.

7.5.2 EHV Transformers

The rate of EHV Transformer NLRE replacement proposed for ED1 has increased from the DPCR5 programme, from 5.2 to 5.4 per year as is to be expected for an ageing population. This increase in the rate of replacement has been limited by the creation of the refurbishment programme. This improves asset health and risk while minimising short-term expenditure by extending the life of assets that would, in the past, have been considered for replacement. The improved data and better interpretation of the data allow the risks to be managed effectively.

The proposed plan will ensure that maximum asset life is achieved while optimising cost efficiency by co-ordinating projects on a given site and co-ordinating resources shared with LRE projects, although the phasing of planned achievement is not constant across ED1 as a result.

As seen in section 3.4, with no interventions the average age of the transformer population would increase significantly during the course of ED1. Extending this analysis to include planned interventions in ED1, Table 16 shows that the investment plan mitigates some of the increasing risk from the age profile of the assets. Our modern approach to asset data, heath and criticality will allow us to manage this risk effectively.

				Without investment		With NLRE investment	
	Transformer population	Transformers over Average Asset Life in 2015	% Transformers over Average Asset Life in 2015	Transformers over Average Asset Life in 2023	% Transformers over Average Asset Life in 2023	Transformers over Average Asset Life in 2023	% Transformers over Average Asset Life in 2023
EHV Transformers	895	258	29%	567	63%	518	58%

Table 16 – Asset age vs. Average Asset Life with ED1 investment

Source: 2012 RIGs V5
ARP Model LW_TX_25Jul2012

Further work will be required and further development of health, criticality and risk modelling techniques to further refine the ED2 projections during ED1.

7.6 Sensitivity Analysis and Plan Validation

7.6.1 Average Asset Life sensitivity

As discussed in section 4.1.1, the Average Asset Life of each transformer is used in the ARP model to calculate the initial HI and also affects the degradation of the asset health over time. Analysis was carried out of the sensitivity of the ARP model due to the Average Asset Life. Setting the correct Average Asset Life is an important part of using the ARP model, but is particularly difficult for transformer designs that are not yet approaching the end of their serviceable lives.

In Table 17 and Table 18, each Average Asset Life change of years +/- 1, 2 and 4 is represented as a percentage of the current population. With each change in Average Asset Life, there is a subsequent movement in the percentage of population in each Health Index. An Average Asset Life at 0 represents the current population split within each Health Index with intervention strategies applied. The two tables range from the start of ED1 (2015) and the end of ED1 (2023). These tables show the percentage population movements over the eight-year period and the impact any change in Average Asset Life will have on the asset group's HI profile.

Average Asset Life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	15.8	67.2	11.1	1.6	4.3
-2	16.2	66.4	11.5	2.4	3.6
-1	17.4	65.2	11.5	2.4	3.6
0	18.2	64.0	11.9	2.4	3.6
1	18.6	64.0	11.5	2.4	3.6
2	18.6	64.0	11.5	2.4	3.6
4	18.6	64.0	11.5	2.4	3.6

Average Asset Life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	13.8	41.5	39.9	3.6	1.2
-2	14.2	41.5	39.1	4.0	1.2
-1	14.6	41.9	38.3	4.4	0.8
0	15.0	41.5	38.3	4.7	0.4
1	15.0	41.1	38.7	4.7	0.4
2	15.8	40.3	38.7	4.7	0.4
4	15.8	39.9	39.1	4.7	0.4

Table 17 – 132kV Transformer sensitivity analysis results

Source: DecisionLab Ltd Analysis February 2013

Average Asset Life change	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	13.4	70.6	11.7	2.2	2.1
-2	13.6	70.7	11.4	2.3	2.0
-1	13.6	71.0	11.0	2.3	2.0
0	13.6	71.3	10.8	2.2	2.0
1	13.6	71.1	11.1	2.1	2.0

Average Asset Life change	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	13.8	37.5	43.9	2.8	2.0
-2	13.8	39.5	42.1	3.3	1.2
-1	13.8	39.5	42.5	3.2	1.0
0	13.9	39.7	42.6	3.2	0.6
1	13.9	39.7	43.0	3.0	0.3

2	13.6	71.1	10.8	2.2	2.0
4	13.7	71.1	11.0	2.1	2.0

2	13.9	39.7	43.0	3.0	0.3
4	13.9	40.8	42.1	2.9	0.2

Table 18 – EHV Transformer sensitivity analysis results

Source: DecisionLab Ltd Analysis February 2013

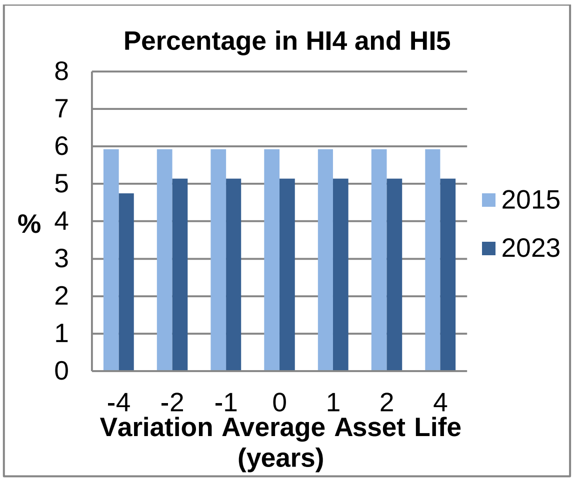


Figure 22 – % variation in HI4 and HI5 132kV Transformers

Source: DecisionLab Ltd Analysis February 2013

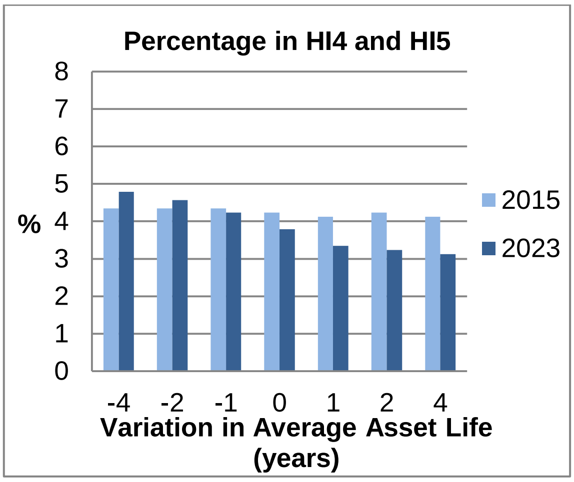


Figure 23 – % variation in HI4 and HI5 EHV Transformers

Source: DecisionLab Ltd Analysis February 2013

Figure 22 and Figure 23 represent summed HI4s and HI5s as a percentage of the population, showing the change at each Average Asset Life iteration and comparing 2015 and 2023.

The analysis shows that changing the Average Asset Life of 132kV Transformers by ± four years has limited effect on the proportion of HI4/HI5 assets in 2015 or 2023. For EHV Transformers, the variation in 2015 is also limited. In 2023 the proportion of HI4/HI5 assets ranges from 3.1% to 4.8%.

This shows that the ED1 investment plan is robust to variations in Average Asset Life. The consultant's full report can be found in Appendix 6.

7.6.2 Network risk

As mentioned in section 4 of this document, the ARP model is able to produce a criticality index (C1 to C4) for each individual asset, although this is a new concept and still being developed. The criticality index can be combined with the Health Index to give an indication of the level of risk on the network. Table 19 and Table 20 show the HI and criticality matrix for 2015 and 2023 with investment during ED1.

	Criticality	Units	Estimated asset health and criticality profile 2015					Asset register
			Asset Health Index					2015
			HI1	HI2	HI3	HI4	HI5	
EHV Transformer	Low	No. TX	58	263	49	15	12	397
	Average	No. TX	46	344	46	9	11	456
	High	No. TX	13	11	3	0	1	28
	Very high	No. TX	6	20	2	0	0	28
132kV Transformer	Low	No. TX	21	61	2	1	1	86
	Average	No. TX	23	101	23	5	4	156
	High	No. TX	3	10	5	0	4	22
	Very high	No. TX	0	0	0	0	0	0

Table 19 – Projected 2015 HI-CI matrix

Sources: ARP Model LW_TX_25Jul2012
ARP Model LW_TX_27Nov2012

	Criticality	Units	Estimated asset health and criticality profile 2023					Asset register
			Asset Health Index					2023
			HI1	HI2	HI3	HI4	HI5	
EHV Transformer	Low	No. TX	39	199	137	12	9	396
	Average	No. TX	29	205	198	18	6	456
	High	No. TX	9	16	3	0	0	28
	Very high	No. TX	0	19	9	0	0	28
132kV Transformer	Low	No. TX	11	42	32	1	0	86
	Average	No. TX	26	68	54	6	1	155
	High	No. TX	1	9	7	1	4	22
	Very high	No. TX	0	0	0	0	0	0

Table 20 – Projected 2023 HI-CI matrix with investment

Source: ARP Model LW_TX_25Jul2012
ARP Model LW_TX_27Nov2012

8.0 Deliverability

The EPN Capital Programme Investment Delivery Team, key stakeholders in the development of the plan, will carry out all infrastructure asset intervention projects, both LRE and NLRE. They have confirmed that the proposed transformer intervention plan is achievable in co-ordination with other planned investments. The programme of transformer interventions will be coordinated with that of other asset groups to ensure efficient delivery.

Appendices

Appendix 1 – Age Profiles

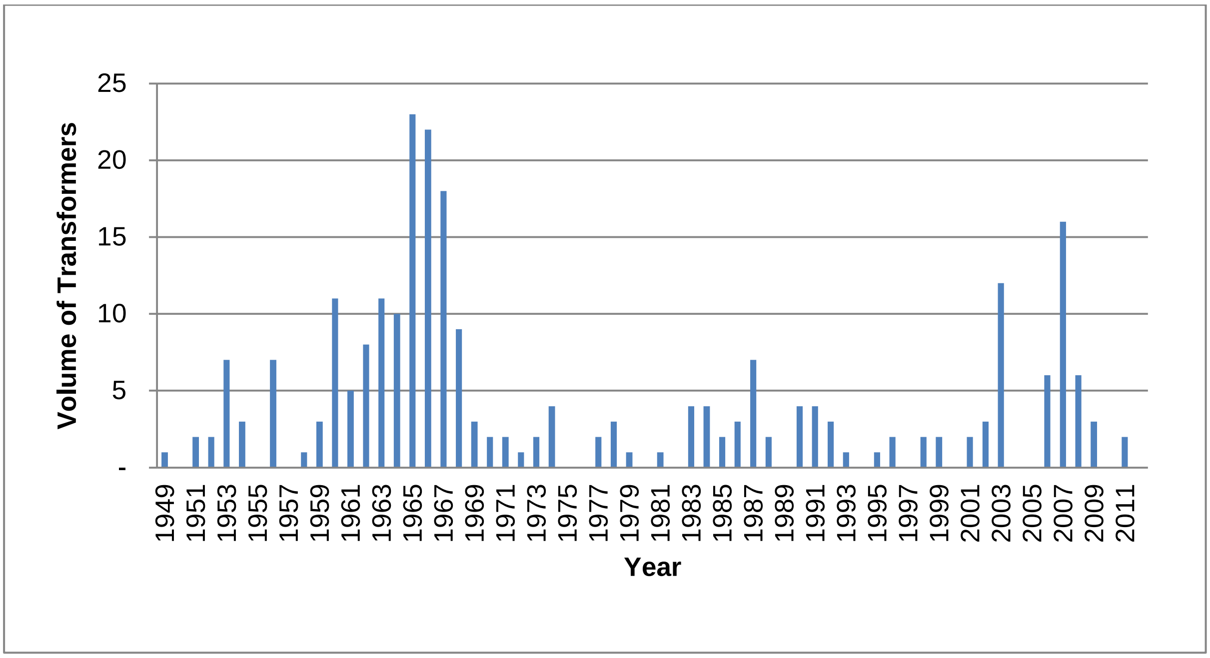


Figure *24: EPN 132kV Transformer age profile*

Source: 2012 RIGs V5

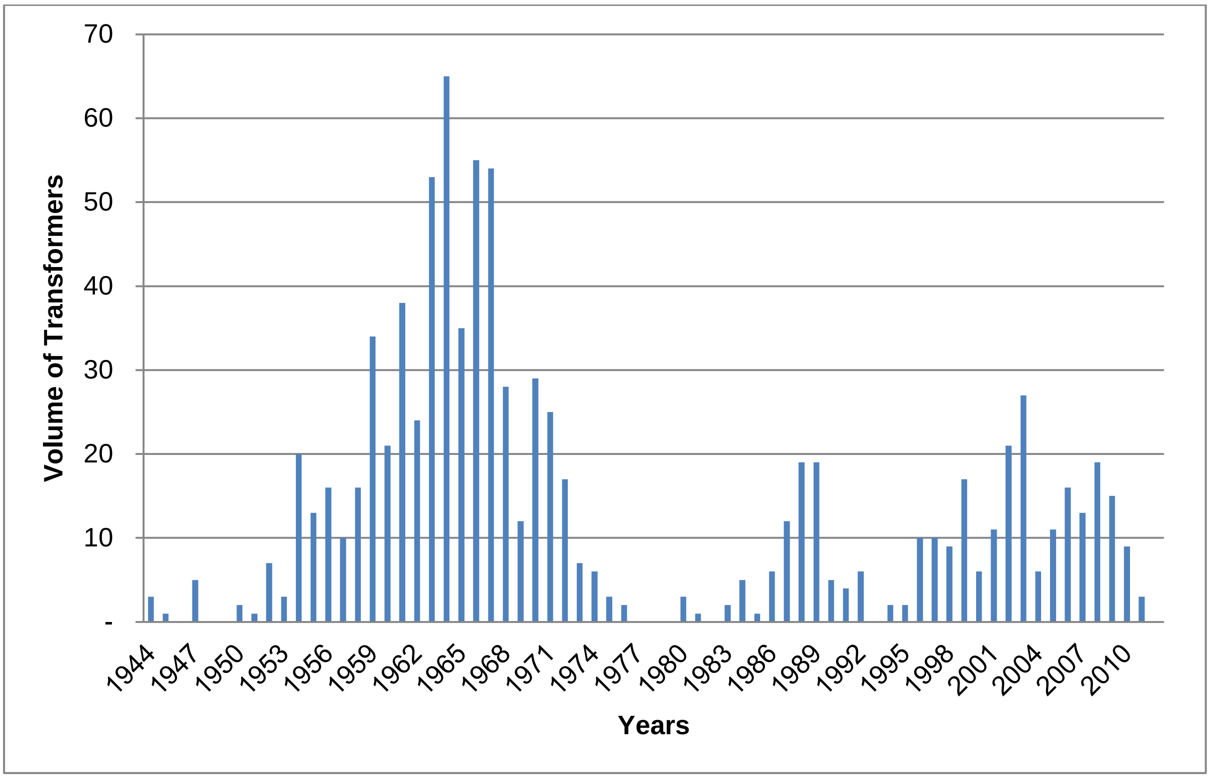


Figure *25: EPN EHV Transformer age profile*

Source: 2012 RIGs V5

Appendix 2 – HI and Criticality Profiles

	Criticality	Units	Estimated asset health and criticality profile 2015					Asset register
			Asset Health Index					2015
			HI1	HI2	HI3	HI4	HI5	
EHV Transformer	Low	No. TX	58	263	49	15	12	397
	Average	No. TX	46	344	46	9	11	456
	High	No. TX	13	11	3	0	1	28
	Very high	No. TX	6	20	2	0	0	28
132kV Transformer	Low	No. TX	21	61	2	1	1	86
	Average	No. TX	23	101	23	5	4	156
	High	No. TX	3	10	5	0	4	22
	Very high	No. TX	0	0	0	0	0	0

Table *21: Projected 2015 HI-CI matrix*

Source: ARP Model LW_TX_25Jul2012
ARP Model LW_TX_27Nov2012

	Criticality	Units	Estimated asset health and criticality profile 2023					Asset register
			Asset Health Index					2023
			HI1	HI2	HI3	HI4	HI5	
EHV Transformer	Low	No. TX	39	199	137	12	9	396
	Average	No. TX	29	205	198	18	6	456
	High	No. TX	9	16	3	0	0	28
	Very high	No. TX	0	19	9	0	0	28
132kV Transformer	Low	No. TX	11	42	32	1	0	86
	Average	No. TX	26	68	54	6	1	155
	High	No. TX	1	9	7	1	4	22
	Very high	No. TX	0	0	0	0	0	0

Table *22: Projected 2023 HI-CI matrix with investment*

Source: ARP Model LW_TX_25Jul2012
ARP Model LW_TX_27Nov2012

		HI1	HI2	HI3	HI4	HI5
132kV Transformers	Start of ED1	47	172	30	6	9
	End of ED1 without investment	17	114	93	26	14
	End of ED1 with investment	38	119	93	8	5
EHV Transformers	Start of ED1	123	638	100	24	24
	End of ED1 without investment	35	416	347	63	48
	End of ED1 with investment	77	439	347	30	15

Table 23: Project HI deterioration summary (Source - ARP Model LW_TX_25Jul2012)

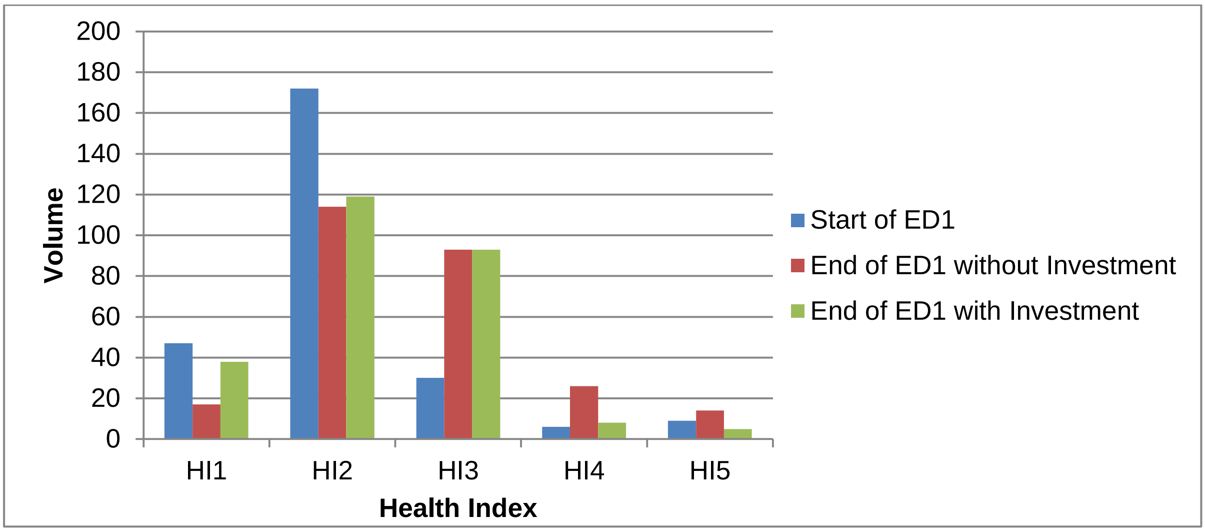


Figure 26: 132kV Transformer HI Profiles

Source: ARP Model LW_TX_Jul2012

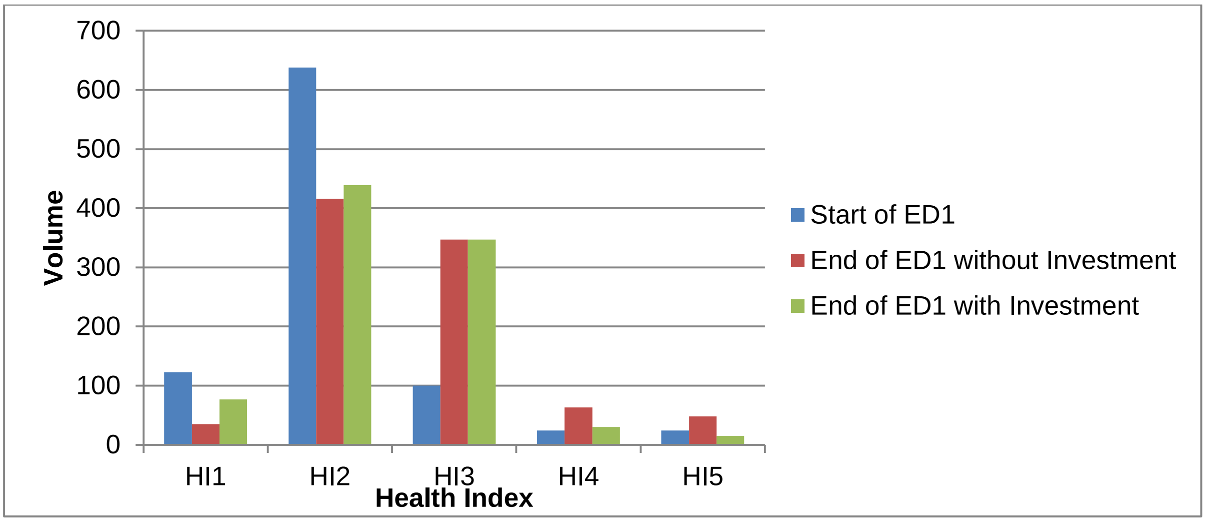


Figure 27: EHV Transformer HI Profiles

Source: ARP Model LW_TX_Jul2012

Appendix 3 – Fault Data

EPN 132kV Transformers						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
All faults	**9**	**21**	**6**	**7**	**7**	**4**

Deterioration due to ageing or wear (excluding corrosion)	**3**	**8**	**1**	**3**	**4**	**2**
Deterioration due to ageing or wear (including corrosion)	**3**	**8**	**1**	**3**	**4**	**2**
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
All faults	0.0353	0.0824	0.0235	0.0275	0.0275	0.0157
Poor condition due to age and wear	0.0118	0.0314	0.0039	0.0118	0.0157	0.0078

Table 24: 132kV Transformer historic fault data

Source: UK Power Networks Fault Analysis Cube

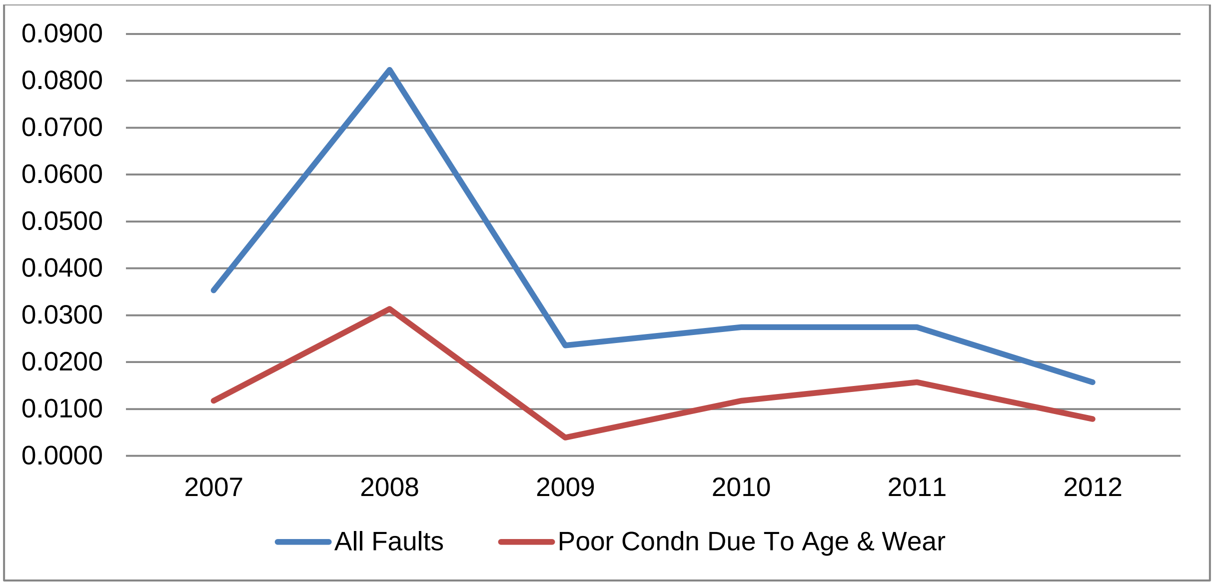


Figure 28: 132kV Transformer historic fault rates (Source - UK Power Networks Fault Analysis Cube)

	2007	2008	2009	2010	2011	2012
All faults	19	17	17	37	15	12
Deterioration due to ageing or wear (excluding corrosion)	11	9	8	17	9	6
Deterioration due to ageing or wear (including corrosion)	11	9	8	17	9	6
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
All faults	0.0212	0.0190	0.0190	0.0413	0.0168	0.0134
Poor condition due to age and wear	0.0123	0.0101	0.0089	0.0190	0.0101	0.0067

Table 25: EHV Transformer historic fault data

Source: UK Power Networks Fault Analysis Cube

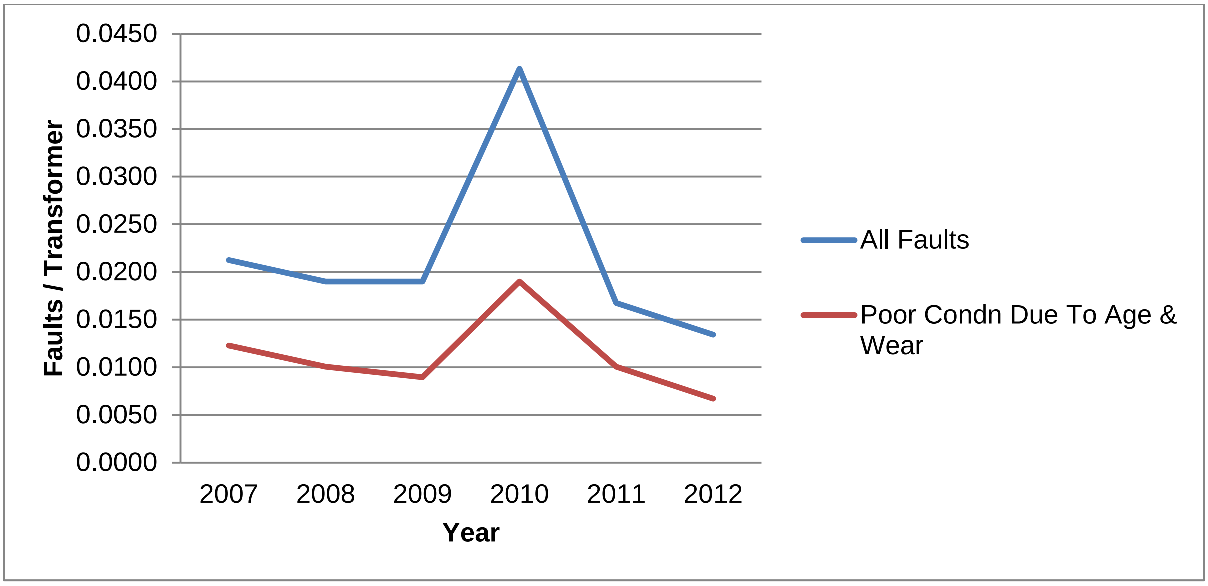


Figure 29: EHV Transformer historic fault rates (Source: UK Power Networks Fault Analysis Cube)

Appendix 4 – WLC Case Study

Whole life cost description	132 kV Transformer: replacement v refurbishment analysis.
Starting assumption (same for all scenarios)	It is assumed the transformer is 40 years old at the beginning of the scenario, that it has a current new purchase cost of £450k and has an average useful operating life of 60 years.

Scenario 1	
Assumptions specific to this scenario	40 year old Tx with slow speed tap changer requiring main tank and selector DGA annually, diverter maintenance every 4 years and selector maintenance every 16 years. Inspection carried out evry 6 months. Replaced after 10 years with a new transformer with modern tap changer requiring mainteance every 8 years.

Description of costs/(income) items	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Totals
Notional purchase cost of a 50 year old transformer (i.e.: 19 years remaining service life)	330																														330
Annual inspection & maintenance costs of initial transformer	1	1	1	4	1	1	1	4	1	1																					16
Purchase of replacement transformer in year 10										1,200																					1,200
Annual inspection & maintenance costs of replacement transformer										1	1	1	1	7	1	1	1	1	1	1	1	7	1	1	1	1	1	1	1	7	39
Residual value of replacement transformer at end of scenario (i.e.: 49 years remaining life)																														-852	-852
Net cash flow	331	1	1	4	1	1	1	4	1	1202	1	1	1	7	1	1	1	1	1	1	1	7	1	1	1	1	1	1	1	-845	733

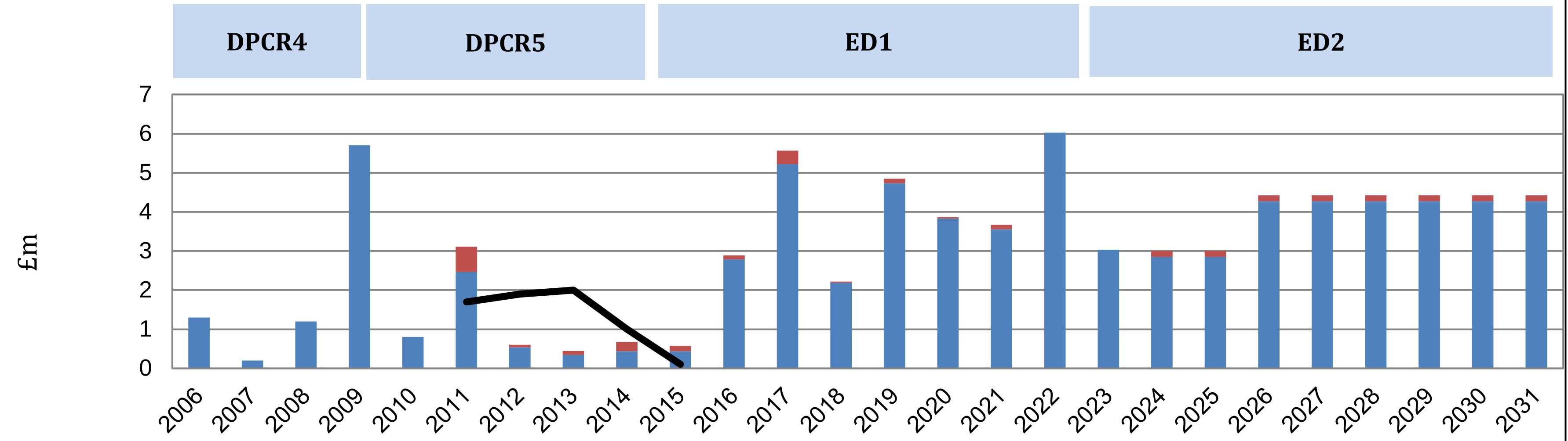
Discount rate: Select 6.85%	6.85%
Discounted whole life cost	833

Scenario 2	
Assumptions specific to this scenario	40 year old Tx with slow speed tap changer requiring main tank and selector DGA annually, diverter maintenance every 4 years and selector maintenance every 16 years. Inspection carried out evry 6 months. Refurbished after 10 years, providing 15 years further servicable life after which it is replaced with a new transformer with modern tap changer requiring mainteance every 8 years.

Description of costs/(income) items	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Totals
Notional purchase cost of a 50 year old transformer (i.e.: 19 years remaining service life)	330																														330
Annual inspection costs of initial transformer	1	1	1	4	1	1	1	4	1	1																					16
Transformer Refurbishment in Year 10										110																					110
Annual inspection costs of refurbished transformer										1	1	4	1	1	1	4	1	1	1	4	1	1	1	7	1						31
Purchase of replacement transformer in year 25																									1,200						1,200
Annual inspection costs of replacementtransformer																									1	1	1	1	7	1	12
Residual value of replacement transformer at end of scenario (i.e.: 64 years remaining life)																														-939	-939
Net cash flow	331	1	1	4	1	1	1	4	1	112	1	4	1	1	1	4	1	1	1	4	1	1	1	7	1202	1	1	1	7	-938	760

Discount rate: Select 6.85%	6.85%
Discounted whole life cost	489

Appendix 5 NLRE Expenditure Plan

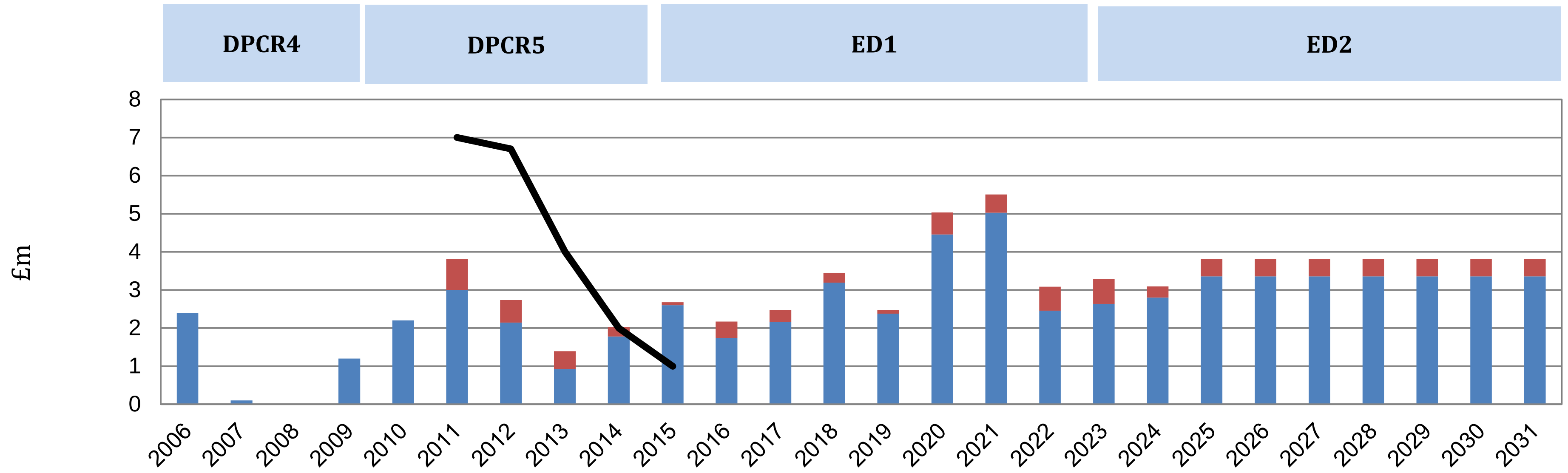


	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Refurbishment	0	0	0	0	0	0.64	0.07	0.11	0.23	0.13	0.1	0.35	0.03	0.12	0.03	0.12	0	0	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Replacement	1.3	0.2	1.2	5.7	0.8	2.47	0.54	0.34	0.44	0.44	2.79	5.22	2.19	4.73	3.83	3.56	6.03	3.03	2.85	2.85	4.28	4.28	4.28	4.28	4.28	4.28
FBPQ						1.7	1.9	2	1	0																

Figure 30: 132kV NLRE investment expenditure

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs
DPCR5 costs: Last two years – 14 June 2013 NAMP

DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8
ED1 costs: 19th February 2014 NAMP
ED2 costs: Average from ED1 costs

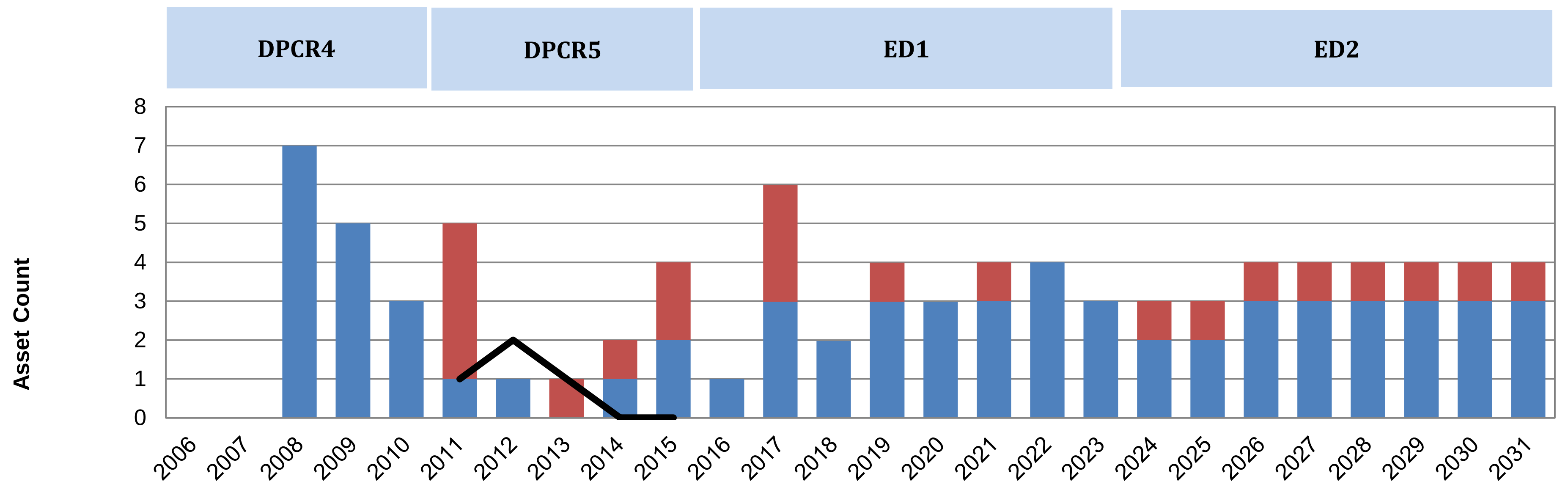


	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Refurbishment						0.81	0.59	0.47	0.24	0.08	0.43	0.3	0.25	0.1	0.58	0.48	0.63	0.65	0.3	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Replacement	2.4	0.1	0	1.2	2.2	3	2.14	0.92	1.78	2.6	1.74	2.17	3.2	2.38	4.46	5.03	2.46	2.64	2.8	3.36	3.36	3.36	3.36	3.36	3.36	3.36
FBPQ						7	6.7	4	2	1																

Replacement Refurbishment FBPQ

Figure 31: EHV NLRE investment expenditure

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs
DPCR5 costs: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8
ED1 costs: 19th February 2014 NAMP
ED2 costs: Average from ED1 costs

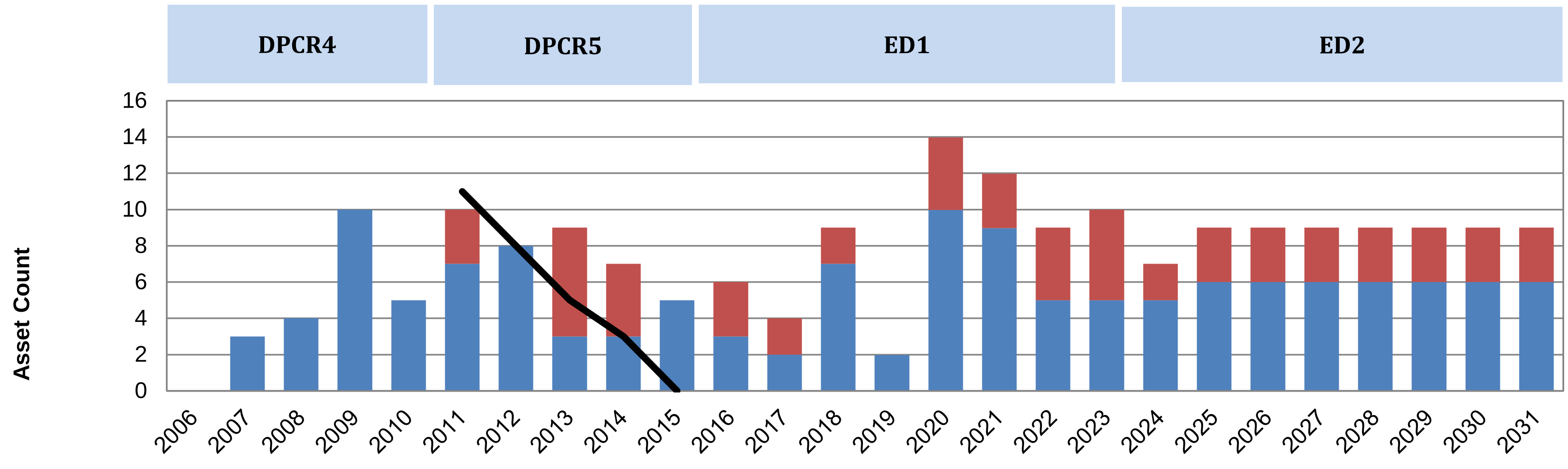


	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Refurbishment						4	0	1	1	2	0	3	0	1	0	1	0	0	1	1	1	1	1	1	1	1
Replacement	0	0	7	5	3	1	1	0	1	2	1	3	2	3	3	3	4	3	2	2	3	3	3	3	3	3
FBPQ						1	2	1	0	0																

Figure 32: 132kV NLRE investment volumes

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs

DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model



	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						3	0	6	4	0	3	2	2	0	4	3	4	5	2	3	3	3	3	3	3	3
Replacement	0	3	4	10	5	7	8	3	3	5	3	2	7	2	10	9	5	5	5	6	6	6	6	6	6	6
FBPQ						11	8	5	3	0																

Regulatory Year Ending

Replacement Refurbishment FBPQ

Figure 33: EHV NLRE investment volumes

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs
DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model

Appendix 6 Sensitivity Analysis

Sensitivity Analysis:

Asset Risk and Prioritisation Model for EPN Transformers
(written by Decision Lab)

Introduction

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

The objective is to understand how the Health Index profile of assets may change if the Average Asset Life of assets does not turn out as predicted.

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

The Asset Risk and Prioritisation Model

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

Sensitivity Analysis

Variation in Average Asset Life can occur, but this is significantly less than the variation in individual asset lives.

Standard Average Asset Lives are used in the ARP model. For transformers, these are specified for each manufacturer. The values are 55, 40 and 35 years. In 2012, about 74% of the EPN transformers have a current Average Asset Life of 55 years and about 26% have an Average Asset Life of 40 years. This study covered the full population of 132kV and EHV Transformers.

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

All results are shown below as the percentages of either the 132kV transformer or EHV Transformer asset population.

132kV TX

Average Asset Life	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	15.8	67.2	11.1	1.6	4.3
-2	16.2	66.4	11.5	2.4	3.6
-1	17.4	65.2	11.5	2.4	3.6
0	18.2	64.0	11.9	2.4	3.6
1	18.6	64.0	11.5	2.4	3.6
2	18.6	64.0	11.5	2.4	3.6
4	18.6	64.0	11.5	2.4	3.6

EHV TX

Average Asset Life	**2015** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	13.4	70.6	11.7	2.2	2.1
-2	13.6	70.7	11.4	2.3	2.0
-1	13.6	71.0	11.0	2.3	2.0
0	13.6	71.3	10.8	2.2	2.0
1	13.6	71.1	11.1	2.1	2.0
2	13.6	71.3	10.8	2.2	2.0
4	13.7	71.1	11.0	2.1	2.0

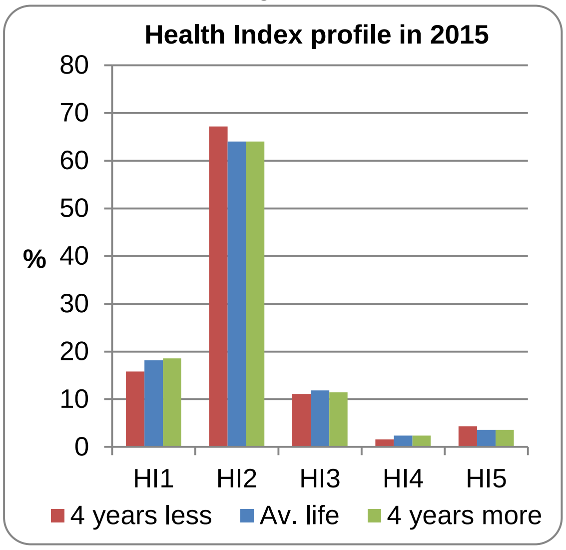
Average Asset Life	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	13.8	41.5	39.9	3.6	1.2
-2	14.2	41.5	39.1	4.0	1.2
-1	14.6	41.9	38.3	4.4	0.8
0	15.0	41.5	38.3	4.7	0.4
1	15.0	41.1	38.7	4.7	0.4
2	15.8	40.3	38.7	4.7	0.4
4	15.8	39.9	39.1	4.7	0.4

Average Asset Life	**2023** percentage HI profile				
	HI1	HI2	HI3	HI4	HI5
-4	13.8	37.5	43.9	2.8	2.0
-2	13.8	39.5	42.1	3.3	1.2
-1	13.8	39.5	42.5	3.2	1.0
0	13.9	39.7	42.6	3.2	0.6
1	13.9	39.7	43.0	3.0	0.3
2	13.9	40.1	42.7	2.9	0.3
4	13.9	40.8	42.1	2.9	0.2

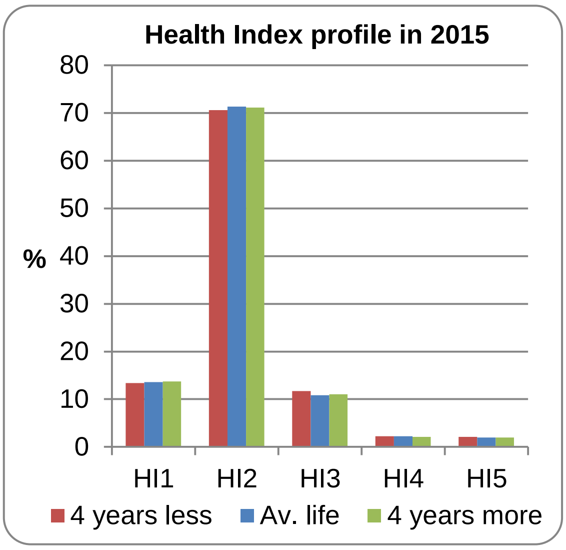
As the percentages above are rounded, the sum of a row may be 0.2% above or below 100%.

The upper, lower and current Average Asset Life cases are charted below.

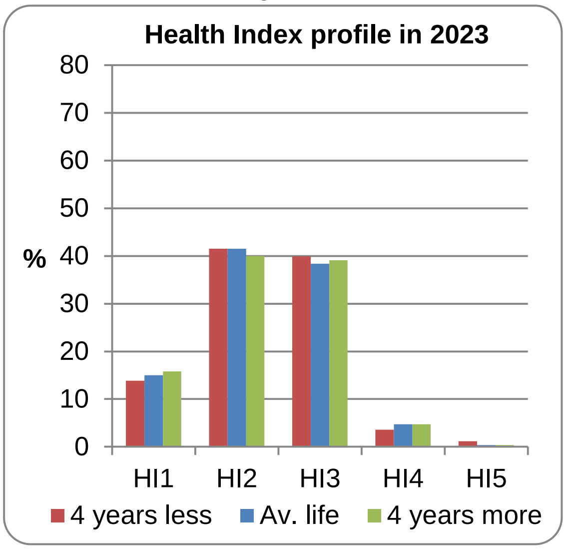
132kV TX



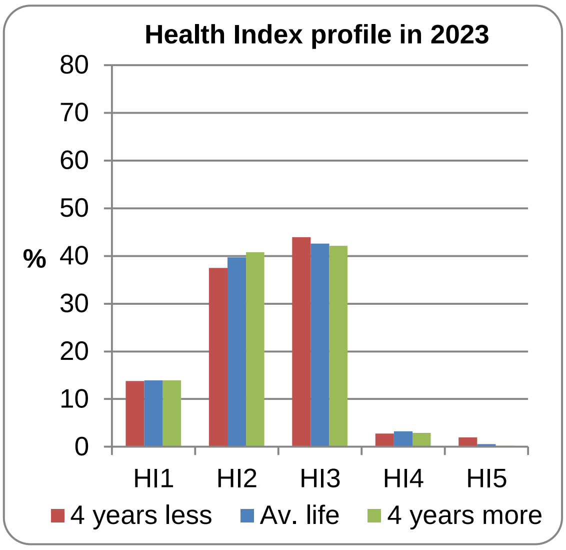
EHV TX



132kV TX

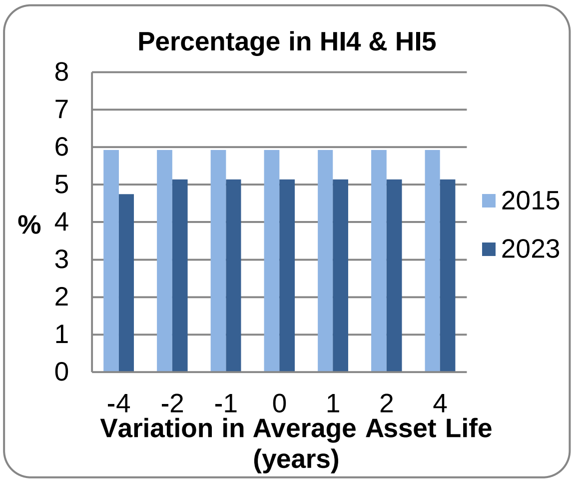


EHV TX

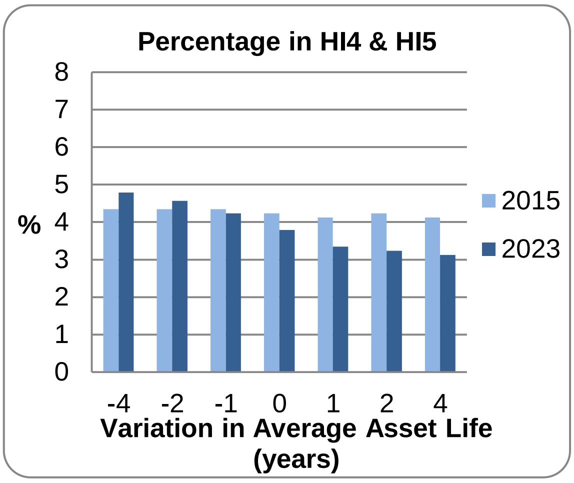


For all cases modelled, the sum of assets in Health Indices HI4 and HI5 is plotted below.

132kV TX



EHV TX



For 132kV transformers in EPN, the results show:

- An Average Asset Life variation of four years has almost no effect on the proportion of HI4 and HI5 assets in 2015. It is expected to be between 5.9% and 6.0%.
- An Average Asset Life variation of four years has almost no effect on the proportion of HI4 and HI5 assets in 2023. It is expected to be between 4.8% and 5.1%.

For EHV Transformers in EPN, the results show:

- An Average Asset Life variation of four years has no effect on the proportion of HI4 and HI5 assets in 2015. It is expected to be between 4.1% and 4.3%.
- In 2023, the proportion of HI4 and HI5 assets is expected to be 3.8%. An increase of four years in Average Asset Life would change this to 3.1% and a decrease in Average Asset Life of four years would change it to 4.8%.

Conclusion

The ED1 replacement plan for EPN transformers is robust and fairly insensitive to a variation in Average Asset Life of up to four years.

Appendix 7 Named Schemes

The following tables show the planned replacement/refurbishment projects for ED1 with their predicted HI in 2023 and their main driver(s) for intervention.

<table>
<tr><th colspan="4">132kV Transformer replacements</th></tr>
<tr><th>Site</th><th>Asset</th><th>Replacement driver</th><th>Scheme Paper</th></tr>
<tr><td rowspan="3">BURWELL LOCAL GRID</td><td>GRID TRANSFORMER GRID T2</td><td>FFA / tap changer</td><td rowspan="3">Yes</td></tr>
<tr><td>GRID TRANSFORMER GRID T1</td><td>FFA / tap changer</td></tr>
<tr><td>GRID TRANSFORMER GRID T3</td><td>FFA</td></tr>
<tr><td>CROWLANDS GRID</td><td>GRID TRANSFORMER GRID T1B</td><td>FFA</td><td>No</td></tr>
<tr><td>EDISON RD GRID</td><td>GRID TRANSFORMER GRID T2</td><td>FFA</td><td>No</td></tr>
<tr><td rowspan="2">HORNSEY GRID</td><td>GRID TRANSFORMER GT1A</td><td>FFA / tap changer</td><td rowspan="2">No</td></tr>
<tr><td>GRID TRANSFORMER GT2A</td><td>External condition / tap changer</td></tr>
<tr><td>MILTON 132</td><td>GRID TRANSFORMER GRID T1</td><td>FFA</td><td>No</td></tr>
<tr><td>PETERBOROUGH CENTRAL 132</td><td>GRID TRANSFORMER GRID T3</td><td>FFA / oil condition</td><td>No</td></tr>
<tr><td rowspan="2">PURFLEET GRID</td><td>GRID TRANSFORMER GRID T2</td><td>FFA / external condition</td><td rowspan="2">No</td></tr>
<tr><td>GRID TRANSFORMER GRID T1</td><td>FFA / external condition</td></tr>
<tr><td rowspan="4">RYE HOUSE 132</td><td>GRID TRANSFORMER GRID T1B</td><td>FFA / external condition</td><td rowspan="4">No</td></tr>
<tr><td>GRID TRANSFORMER GRID T2A</td><td>FFA / external condition</td></tr>
<tr><td>GRID TRANSFORMER GRID T4B</td><td>FFA / external condition</td></tr>
<tr><td>GRID TRANSFORMER GRID T3A</td><td>FFA / DGA / external condition</td></tr>
<tr><td rowspan="2">SOUTHEND GRID 33KV</td><td>GTX 259140 GT1B</td><td>External condition / tap changer / External condition / tap changer</td><td rowspan="2">No</td></tr>
<tr><td>GTX 259140 GT2B</td><td>External condition / tap changer</td></tr>
<tr><td rowspan="3">SUNDON GIS 132KV</td><td>GRID TRANSFORMER GRID T3</td><td>External condition / Oil leaks</td><td rowspan="3">No</td></tr>
<tr><td>GRID TRANSFORMER GRID T1</td><td>FFA / tap changer</td></tr>
<tr><td>GRID TRANSFORMER GRID T2</td><td>FFA / tap changer</td></tr>
<tr><td rowspan="2">TILBURY LOCAL GRID</td><td>GRID TRANSFORMER GRID T5</td><td>Tap changer / external condition</td><td rowspan="2">No</td></tr>
<tr><td>GRID TRANSFORMER GRID T7</td><td>Tap changer / external condition</td></tr>
</table>

132kV Transformer refurbishments			
Site	Asset	Driver	Scheme Paper
CLIFF QUAY GRID	GRID TRANSFORMER GRID T3	External condition / oil containment	No
	GRID TRANSFORMER GRID T2	External condition / oil containment	
	GRID TRANSFORMER GRID T4	External condition / oil containment	
CORYTON GRID	GRID TRANSFORMER GRID T2	External condition / oil containment	No
THORPE GRID	GRID TRANSFORMER GRID T2B	Oil condition	No

EHV Transformer replacements			
Site	Asset	Replacement driver	Scheme Paper
BARROW PRIMARY	PRIMARY TRANSFORMER T2	Tap changer / external condition / Oil condition	No
	PRIMARY TRANSFORMER T1	Tap changer / external condition / Oil condition	
BRAISWICK PRIMARY	PRIMARY TRANSFORMER T2	Tap changer / external condition	No
	PRIMARY TRANSFORMER T1	Tap changer / external condition	
CENTRAL WELWYN PRIMARY	PRIMARY TRANSFORMER T3	Tap changer / external condition	No
	PRIMARY TRANSFORMER T1	Tap changer / external condition	
CHAUL END PRIMARY	PRIMARY TRANSFORMER T1	FFA	No
CHEQUERS PRIMARY	PRIMARY TRANSFORMER T2	Tap changer / external condition / oil condition	No
CHISBON HEATH PRIMARY	PRIMARY TRANSFORMER T2	FFA / tap changer	No
	PRIMARY TRANSFORMER T1	FFA / tap changer	
CLAYDON CEMENT PRIMARY	PRIMARY TRANSFORMER T1	Tap changer / external condition	No
	PRIMARY TRANSFORMER T2	Tap changer / external condition	
DURHAM RD PRIMARY	PRIMARY TRANSFORMER T1	Tap changer	No
	PRIMARY TRANSFORMER T2	Tap changer	

Site	Asset	Replacement driver	Scheme Paper
EYE PRIMARY	PRIMARY TRANSFORMER T2	FFA / DGA	No
	PRIMARY TRANSFORMER T1	Tap changer / external condition	
HARDINGHAM PRIMARY	PRIMARY TRANSFORMER T1; 468210	DGA / tap changer	No
HAVERHILL PRIMARY	PRIMARY TRANSFORMER T1	DGA	No
	PRIMARY TRANSFORMER T2	External Condition	
HIGH ST PRIMARY	PRIMARY TRANSFORMER T2	FFA	No
HORNCHURCH LOCAL PRIMARY	PRIMARY TRANSFORMER T1	FFA / external condition	No
ILMER PRIMARY	PRIMARY TRANSFORMER T1	FFA / external condition	No
	PRIMARY TRANSFORMER T2	External condition / oil containment	
KENSWORTH PRIMARY	PRIMARY TRANSFORMER T2	Tap changer / external condition / FFA	No
	PRIMARY TRANSFORMER T1	Tap changer / external condition / FFA	
KIMBOLTON PRIMARY	PRIMARY TRANSFORMER T1	DGA	No
LEISTON PRIMARY	PRIMARY TRANSFORMER T1	DGA / Tap changer	No
	PRIMARY TRANSFORMER T2	External condition / oil condition / tap changer	
NORTH DR PRIMARY	PRIMARY TRANSFORMER T4	Tap changer	No
REED PRIMARY	PRIMARY TRANSFORMER T1	DGA / tap changer	No
ROMFORD PRIMARY	PRIMARY TRANSFORMER T1	FFA / oil condition / external condition	No
	PRIMARY TRANSFORMER T8	FFA / oil condition / external condition	
	PRIMARY TRANSFORMER T9	FFA / oil condition / external condition	
SELINAS LN PRIMARY	PRIMARY TRANSFORMER T2	DGA / FFA / oil condition	No
	PRIMARY TRANSFORMER T1	DGA / FFA / oil condition	
SELWYN RD PRIMARY	PRIMARY TRANSFORMER T1	DGA / tap changer	No

Site	Asset	Replacement driver	Scheme Paper
SWAFFHAM GRID	PRIMARY TRANSFORMER T2	DGA / external condition	No
	PRIMARY TRANSFORMER T1	Tap changer / external condition	
	PRIMARY TRANSFORMER T3	DGA / external condition	
THUNDERSLEY PRIMARY	PRIMARY TRANSFORMER T2	DGA	No
	PRIMARY TRANSFORMER T1	External condition / tap changer	
WHITE RODING PRIMARY	PRIMARY TRANSFORMER T2	FFA / Tap changer / external condition	No
WRATTING PRIMARY	PRIMARY TRANSFORMER T1	DGA / external condition	No

EHV Transformer refurbishments			
Site	Asset	Driver	Scheme Paper
BURY ST PRIMARY	PRIMARY TRANSFORMER T1	External condition / tap changer	No
	PRIMARY TRANSFORMER T2	External condition / tap changer	
CORNARD PRIMARY	PRIMARY TRANSFORMER T2	External condition	No
	PRIMARY TRANSFORMER T1	External condition	
DOVERCOURT PRIMARY	PRIMARY TRANSFORMER T1	Tap changer	No
	PRIMARY TRANSFORMER T2	Tap changer	
DUNSTABLE PRIMARY	PRIMARY TRANSFORMER T1	External condition	No
	PRIMARY TRANSFORMER T2	Oil Quality	
ELMSWELL PRIMARY	PRIMARY TRANSFORMER T1	Oil Quality / External Condition	No
GUSFORD HALL PRIMARY	PRIMARY TRANSFORMER T1	External condition / tap changer	No
HONINGTON PRIMARY	PRIMARY TRANSFORMER T1	External condition	No
	PRIMARY TRANSFORMER T2	External condition	
MARSHFOOT ROAD PRIMARY	PRIMARY TRANSFORMER T2	External condition / tap changer	No
ONGAR PRIMARY	PRIMARY TRANSFORMER T1	External condition / tap changer	No
PARK ST PRIMARY	PRIMARY TRANSFORMER T2	External condition / tap changer	No
	PRIMARY TRANSFORMER T1	Tap changer / oil condition / external condition	
SOUTHEND WEST PRIMARY	PRIMARY TRANSFORMER T2	Tap changer	No
	PRIMARY TRANSFORMER T1	Tap changer	

Site	Asset	Driver	Scheme Paper
STOPSLEY PRIMARY	PTX 148323 T3 PHASE SHIFT TX	External condition	Yes
WALTHAM ABBEY PRIMARY	PRIMARY TRANSFORMER T3	Oil condition / external condition / oil containment	No
WELWYN PRIMARY	PRIMARY TRANSFORMER T4	External condition / tap changer	No
WIXOE WPS PRIMARY	PRIMARY TRANSFORMER T2	External condition	No
WRATTING PRIMARY	PRIMARY TRANSFORMER T2	External condition	No

Source: 19th February 2014 NAMP

Appendix 8 Output NAMP/ED1 Business Plan Data Table Reconciliation

Outputs		Asset Stewardship reports									RIG Table										
Investment description	NAMP Line	2015/6	2016/7	2017/8	2018/9	2019/20	2020/21	2021/22	2022/23	Total	RIG Table	RIG Row	2015/6	2016/7	2017/8	2018/9	2019/20	2020/21	2021/22	2022/23	Total
132kV Transformer Replacement	1.51.01	1	3	2	3	3	3	4	3	22	CV3	229	1	3	2	3	3	3	4	3	**22**
EHV Transformer Repalcement	1.51.03	3	2	7	2	10	9	5	5	43	CV3	211	3	2	7	2	10	9	5	5	**43**
											CV3	212	0	0	0	0	0	0	0	0	**0**
132kV Transformer Refubishmen	1.51.11	0	3	0	1	0	1	0	0	5	CV5	52	0	3	0	1	0	1	0	0	**5**
EHV Transformer Refurbishment	1.51.11	3	2	2	0	4	3	4	5	23	CV5	32	3	2	2	0	4	3	4	5	**23**
											CV5	42	0	0	0	0	0	0	0	0	**0**
Total		**7**	**10**	**11**	**6**	**17**	**16**	**13**	**13**	**93**			**7**	**10**	**11**	**6**	**17**	**16**	**13**	**13**	**93**

Table 26: NAMP to ED1 Business Plan Data Table Reconciliation

[Source: 19th February 2014 Namp Table O / 21st February 2014 ED1 Business Plan Data Tables]

Appendix 9 Efficiency benchmarking with other DNOs

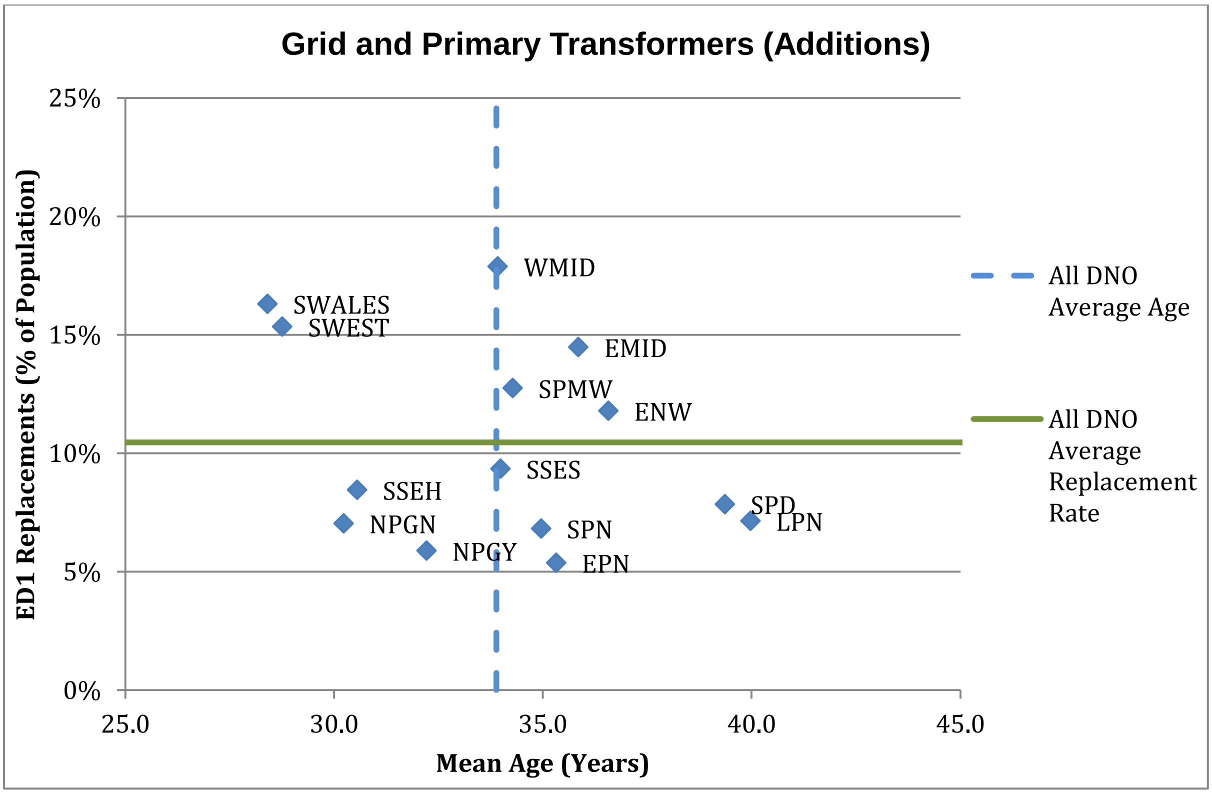


Figure 34: All DNO asset replacement rate vs. mean asset age [Source: DNO Datashare_2013]

The above graph shows that EPN has the lowest replacement rate of any DNO as a proportion of the asset population despite having an older than average population age. This shows that the planned investment has not been made using a solely age-based approach but by identifying the individual assets that require interventions based on their health.

Appendix 10 Material Changes Since 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 Transformers	Replace	Volume (Additions)	22	21	(1)	
		Volume (Disposals)	22	22	-	
		Investment (£m)	23.73	23.73	-	
		UCI (£k)	1081.8	1133.5	51.7	
EHV Transformers	Replace	Volume (Additions)	43	42	(1)	
		Volume (Disposals)	43	43	-	
		Investment (£m)	19.38	19.36	(0.02)	
		UCI (£k)	450.9	460.8	9.9	

Table 27: Material Changes to July 2013 ED1 Submission (CV3)

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

132kV/33kV Transformers

The reductions in additions to 132kV and 33kV Transformers is the result of correction of data errors in the CV3 table. No change has been made to the submitted programme of transformer replacements.