SP Energy Networks 2015–2023 Business Plan

Updated March 2014

Annex

11kV Substation Plant Strategy

SP Energy Networks

March 2014

SP ENERGY NETWORKS

11kV Substation Plant

March 2014

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17th March 2014	1.0	David Neilson	First Issue

1. Scope

This Annex covers our strategy for the replacement and refurbishment of 11kV substation plant assets through the ED1 period.

2. Table of linkages

This strategy supports our ED1 Business Plan. For ease of navigation, the following table links this strategy to other relevant parts of our plan.

Document	Chapter / Section
SP Energy Networks Business Plan 2015-2023	Chapter C6 – Expenditure
SP Energy Networks Business Plan 2015-2023	Chapter C5 – Outputs
SP Energy Networks Business Plan 2015-2023 Annexes	Annex C5 – Losses Strategy – SPEN
SP Energy Networks Business Plan 2015-2023 Annexes	Annex C6 – Expenditure Supplementary Annex – SPEN
SP Energy Networks Business Plan 2015-2023 Annexes	Annex C6 – Cost Benefit Analysis – SPEN
SP Energy Networks Business Plan 2015-2023 Annexes	Annex C6 – Asset Health and Criticality Strategy – SPEN

3. Executive Summary

Our 11kV asset replacement substation programme is built up using condition information, technical reports, age based modelling and operational adequacy scoring.

Our HV substation infrastructure supplies electricity to domestic, commercial and industrial customers in our SPM and SPD license area. These substations typically contain transformers, ring main units (RMU), circuit breakers (CB) and switches to manage power flow to the local area, and interconnection for security of supply. The majority of these substations were built in the 1950'-s, 1960'-s and 1970'-s, and several are exhibiting a decline in performance and condition as they approach the end of serviceable life.

Switchgear and transformers in substations are important assets and the consequences of failure can be significant in terms of safety, reliability and availability of supply.

Our 11kV asset replacement plan for ED1 ensures the long term stewardship and management of risk through the following deliverables:

Asset	SPM		SPD	
	Volume	£m	Volume	£m
Primary Circuit Breaker replacement	323	10.3	359	11.5
Primary Circuit Breaker refurbishment	366	9.3	540	9.2
Secondary Circuit Breaker replacement	155	3.5	615	5.4
Secondary Ring Main Unit replacement	2301	33.1	1109	11.2
Secondary Ring Main Unit refurbishment	100	0.1	800	1.2
Secondary HV Switch replacement			320	1.7
GM Transformer replacement	218	2.5	230	2.4
GM Transformer refurbishment	1272	6.3	-	-
PM Transformer replacement	1536	4.1	1144	3.0
Total Expenditure	**-**	**69.2**	**-**	**45.6**

Our substation modernisation programme is essential to delivering a number of our primary outputs, particularly public and employee safety, reliable network performance for our customers and reduced environmental impact. The proposed programme allows us to manage the overall health of our assets as measured by Health Index profiles, a key secondary deliverable, and subsequently overall network risk.

4. Introduction

In order to achieve our primary outputs we have a developed a prioritised, fully justified and efficient plan for our substation assets. To ensure we prioritise our investment on the most acute sites, we have used performance data and detailed technical assessments to determine the condition and criticality of our plant.

The top down risk management strategy for our existing 11kV network aims to ensure an optimum level of investment through delivery of a prioritised and targeted bottom-up project specific approach. This is necessary to effectively manage the business risk, ensure cost-efficient investment and continue the long term sustainability of our substation assets.

Our investment plan for RIIO-ED1 involves replacement, retrofitting or refurbishment of assets which are in poor condition and approaching, or at end of life. The investment plan has been developed in accordance with our Asset Management Policy ASSET 01 019. Condition information combined with asset replacement age based modelling, as a proxy for condition where necessary, has determined the intervention volumes. The use of condition and modelling data, combined with site criticality, ensures our plans reflect the key investment priorities. This approach provides prioritised, detailed work programmes at substation site specific level.

Around 50% of the network was built in the 1950’s, 1960’-s and 1970’-s and we plan to invest in approximately 8% through replacement or refurbishment, due to its operational adequacy or condition.

This document details the Non Load Network Investment Strategy for 11kV substation assets. It explains:

- *Our intervention plans*
  - The planned replacement of 11kV secondary transformers
  - The planned replacement, retrofitting and refurbishment of bulk oil HV circuit breakers, HV switches and RMUs
- *the application of age based modelling as a proxy for condition*
- *the cost benefit analysis options considered for the main asset categories*
- *the outputs delivered by the programme*
- *the process for delivering risk based, prioritised asset interventions*
- *the results from the application of these approaches on switchgear and transformer interventions*
  .

5. Network Strategy

The investment strategy for the 11kV network aims to ensure an optimum level of investment by adopting a prioritised and targeted project specific approach. This is necessary to effectively manage the business risk and ensure long term sustainability, utilising appropriate engineering interventions and risk management. Specifically our strategy aims to:

- *Maintain safety, integrity and performance of the network whilst ensuring long term sustainability and support network growth.*
- *To intervene prior to asset failure: When asset performance and reliability fall below acceptable operational limits and cannot be restored without an unacceptable financial risk and / or system risk exposure.*
- *Minimise failures, through interventions targeted on assets at or approaching of critical condition (Health Index 5): Utilising engineering condition or type information, as appropriate.*
- *Target investment based on an assessment of consequences of failure using probability of failure (Asset Health) and criticality: Taking account of factors such as public and staff safety, strategic importance, customer sensitivity to supply disturbances, asset performance and environmental considerations.*

6. Assessment of Condition and Operational Adequacy

The investment plans for 11kV circuit breakers, switches and ring main units utilises our Asset Health Methodology ASSET 01 019 and Assessment of Operational Adequacy detailed in SPEN's policy document **Annex C6 – SWG-02-007 Switchgear Assessment 6kV, 11kV and 33kV – SPEN**. Our Operational Adequacy document provides the scoring assessment that enables us to determine interventions according to asset health.

The investment strategy aims to refurbish Health Index 4 and replace Health Index 5 assets in line with the operational adequacy scoring;

- *The operational adequacy of all plant is assessed on an annual basis by Lead Technical Engineers within Asset Management, utilising standardised templates to score plant components*
- *Site condition inspections are conducted by staff trained in this activity.*
- *The results are augmented to include any reports of plant defects, including a reduction in operational performance and asset condition from operational staff.*
- *The items within the assessment are categorised as Critical, Major, Significant or Minor with scores assigned to each category within the operational adequacy document.*
- *The score of each plant type accumulates to derive the overall asset Health Index table.*
- *The plant incurring the highest score moves towards the top of the table indicating the higher priority for replacement.*

An example of how the scoring relates to HI is shown in the example table below.

Scoring Criteria	Health Index
Total Score is greater than 300 points or any end of life criteria have been met	5
Total Score is greater than 200 and is less than 300	4
Total Score is greater than100 and less than 200	3
Total Score is greater than10 and less than 100	2
Total Score is less than 10	1

Our plant and civil condition assessments consider the detailed condition and technical assessments available for each 11kV primary substation. These sites were assessed using the templates published in our Specification for Primary Substation Audit SUB 03 030 and Civil and Asset Health Methodology detailed in **Annex C6 – Civil Strategy and Plans – SPEN** and informed by foundation document Civil Asset Inspection Specification SUB 03 025.

The prioritised interventions look to exploit advances in new technology, where appropriate, to assess alternative solutions over simply replacing assets on a like for like basis.

In the case of transformers our risk based strategy to ensure staff and public safety from HV Transformers is based on;

- *Ground Mounted (GM) transformers are replaced as determined through condition assessment on reaching HI5 or on failure;*
- *RMU replacement in SPM may require refurbishment of the associated transformer;*
- *Pole Mounted (PM) transformers are only replaced on failure, normally using a recovered unit or during 11kV overhead line replacement work.*

In addition to the ground mounted replacement volumes identified, SP Energy Networks has embarked on the pro-active replacement of high loss pre-1962 transformers. This programme of work is driven and justified by the value of reduced losses and is detailed in **Annex C5 – Losses Strategy – SPEN.**

6.1. Deterioration

An assessment of the length of time it takes for a typical asset to deteriorate is based on experience and engineering knowledge of the increasing probability of failure for each asset health category. This provides the expected rate of deterioration over the assets life. Current Health Indices then form the base to develop forward looking health indices with and without intervention. The difference between with and without intervention HI profiles is indicative of the risk mitigated by the proposed asset specific interventions.

6.2. Criticality Index

SP Energy Networks quantifies asset criticality in accordance with our internal asset management standard, ASSET-01-019 (Asset Health, Criticality & Outputs Methodology). Our criticality measure takes into account the impact on safety, environment, system reliability and cost that would occur as a consequence of the failure of the asset. The asset Criticality Index (CI) is used to prioritise replacement of HI5 assets.

A full description of our approach to the assessment and management of asset health, criticality and network risk is provided in **Annex C6 – Asset Health and Criticality Strategy – SPEN**.

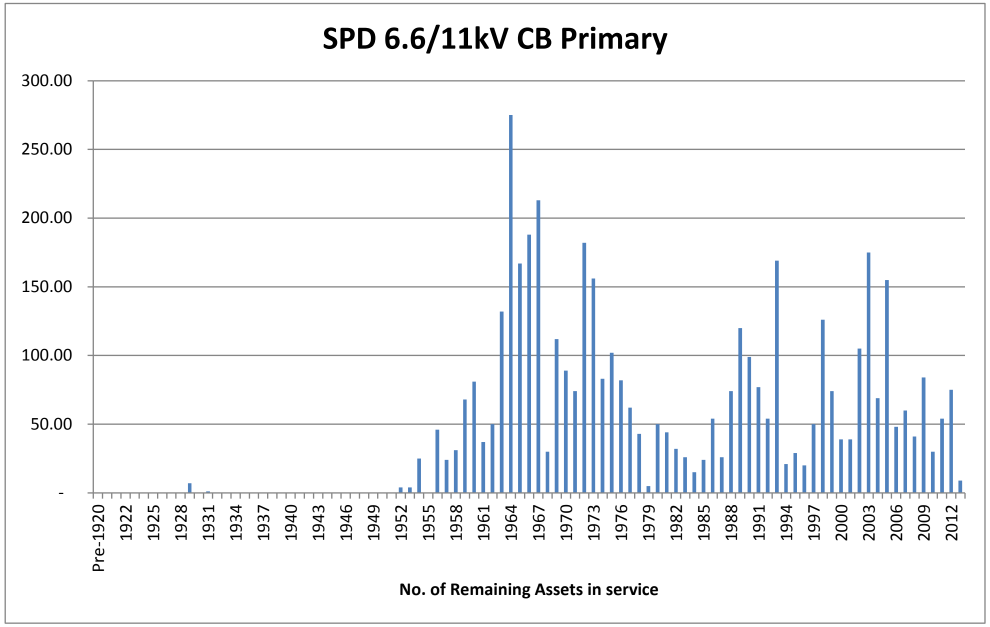
7. Distribution Plant Investment Plan

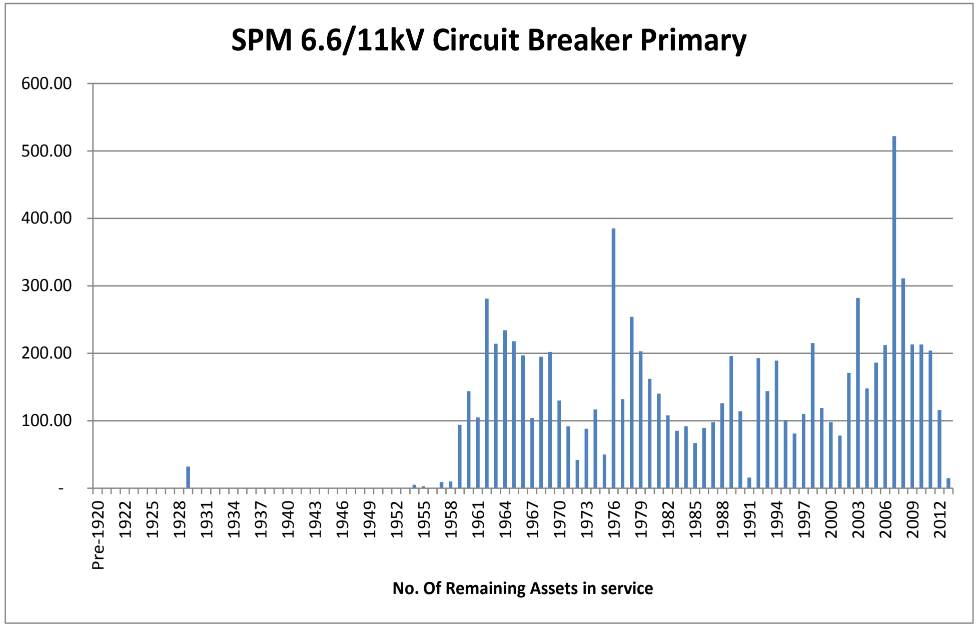
We have a total population of approximately 135,000 main HV distribution assets and we plan to replace and refurbish approximately 8% in RIIO-ED1. We will address this volume of asset interventions based on condition and operational risk factors through the replacement, and refurbishment, of primary CBs, secondary CBs, RMUs, switches and transformers. The key deliverables are indicated in the table below:-

Asset	SPM		SPD	
	Volume	£m	Volume	£m
Primary Circuit Breaker replacement	323	10.3	359	11.5
Primary Circuit Breaker refurbishment	366	9.3	540	9.2
Secondary Circuit Breaker replacement	155	3.5	615	5.4
Secondary Ring Main Unit replacement	2301	33.1	1109	11.2
Secondary Ring Main Unit refurbishment	100	0.1	800	1.2
Secondary HV Switch replacement			320	1.7
GM Transformer replacement	218	2.5	230	2.4
GM Transformer refurbishment	1272	6.3		
PM Transformer replacement	1536	4.1	1144	3.0
Total Expenditure	**-**	**69.2**	**-**	**45.6**

7.1. Primary Circuit Breaker Plan

SP Energy Networks has a total population of around 10,000 11kV circuit breakers and we plan to replace or retrofit approximately 20% during RIIO-ED1. The age profile of 11kV primary circuit breakers is shown below, indicating that the bulk of the population was installed during the 1950s, 60s and 70's.





An age based model is utilised to predict high level, long-term asset replacement volumes for each asset category and provides early identification of potential peaks in future workload. Our approach to determining the contribution to network risk, based on asset heath and criticality indices, from each of the major asset categories forms the basis of the intervention volumes proposed in our business plan.

Our condition assessment programme has identified common investment drivers for primary circuit breakers;

- *Bushing and gasket failures*
- *Solenoid mechanism – closing and*
- *tripping coil failures*
- *Failures of latch mechanism*
- *Slow closing*
- *Internal and external corrosion*
- *Test equipment contact misalignment*
- *Broken or faulty indicators*
- *Phase barrier electrical and mechanical faults*
- *Auxiliary and main contact degradation*
- *Cable end box partial discharge and leaks*
- *Arc control device deterioration*
- *Safety shutters broken or missing*

For more information on the detailed technical defects addressed in our work programme and the intervention options available by circuit breaker type, please reference section 8. Appendix. A detailed type report is also contained within the appendix section of this document to further explain the replacement drivers of each asset type.

The poor condition of some substation buildings housing the switchgear has an impact on equipment condition. We have increased our civil investment in DPCR5 to address this issue and will continue an enhanced civil works programme, particularly in SPM, during ED1. A focussed civil refurbishment programme is detailed in our **Annex C6 – Civil Strategy and Plans – SPEN.**

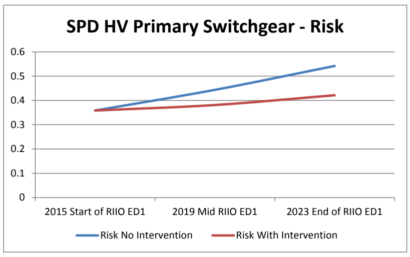
7.1.1. Impact on Health and Criticality Indices

The approach and policy outlined in section 6 provides a mapping of our condition and operational adequacy assessment scores to Health Indices. Combining Criticality Indices with our HI outputs, along with probability and consequence of failure, provides a measure of network risk. Refer to **Annex C6 – Asset Health and Criticality Strategy – SPEN** for a detailed description of our methodology. Our approach to managing overall network risk during ED1 is to maintain a similar level of risk at the end of the ED1 period as experienced at the start. Whilst the overall level of network risk across all asset categories is broadly constant there can be some variation within each asset category. The relative risk measures for each asset category with and without investment are profiled in the graphs below.

A matrix of HI and CI interventions indicating the movement in HI and CI volumes between the start and end of ED1 is also provided.

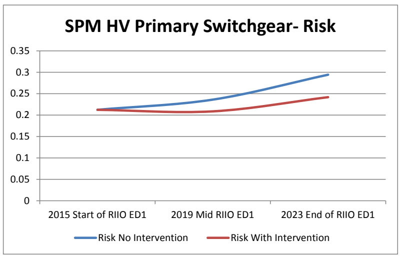
SPD 11kV Primary switchgear interventions – ED1 HI/CI change

SPD	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	165	104	126	-230	-165	0
CI2	111	84	102	-186	-111	0
CI3	58	27	32	-59	-58	0
CI4	25	29	36	-65	-25	0
Total HI	359	244	296	-540	-359	0



SPM 11kV Primary switchgear interventions – ED1 HI/CI change

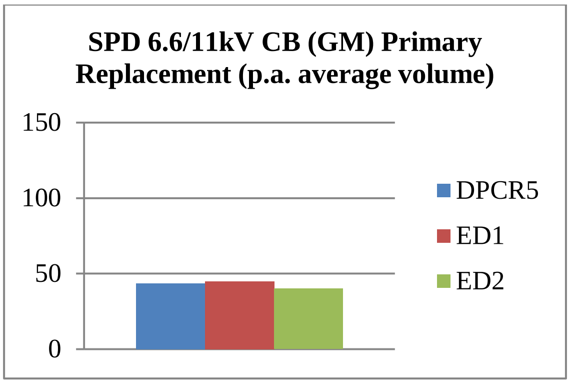
SPM	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	142	73	126	-199	-142	0
CI2	81	33	57	-90	-81	0
CI3	55	17	29	-46	-55	0
CI4	45	11	20	-31	-45	0
Total HI	323	134	232	-366	-323	0

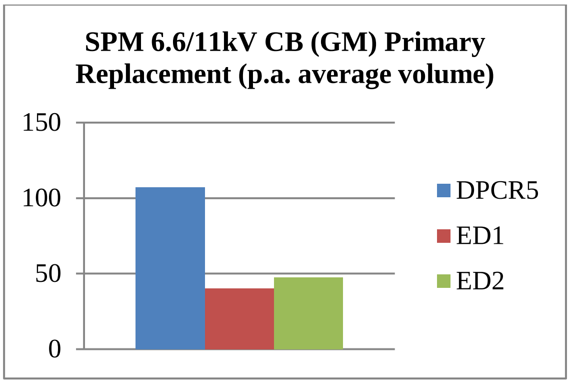


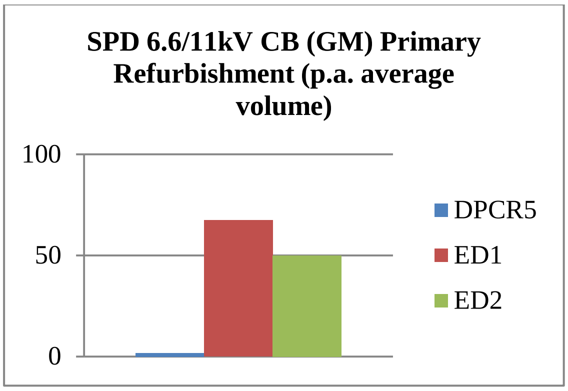
7.1.2. Circuit Breaker Volumes

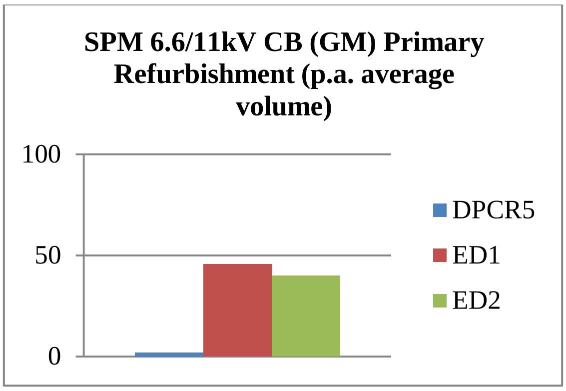
The optimised interventions look to exploit advances in new technology, where appropriate and avoid replacing assets on a like for like basis. We seek to utilise new retrofit technologies and refurbishment strategies where possible.

The proposed asset replacement, retrofit and refurbishment volumes for ED1 are shown in the graphs below. In total there are 1,588 interventions, representing 19.6% of the installed population.









Volumes proposed are aligned to current delivery achievement in DPCR5 and based on our condition and criticality analysis, the following numbers of units are forecast for intervention during ED1.

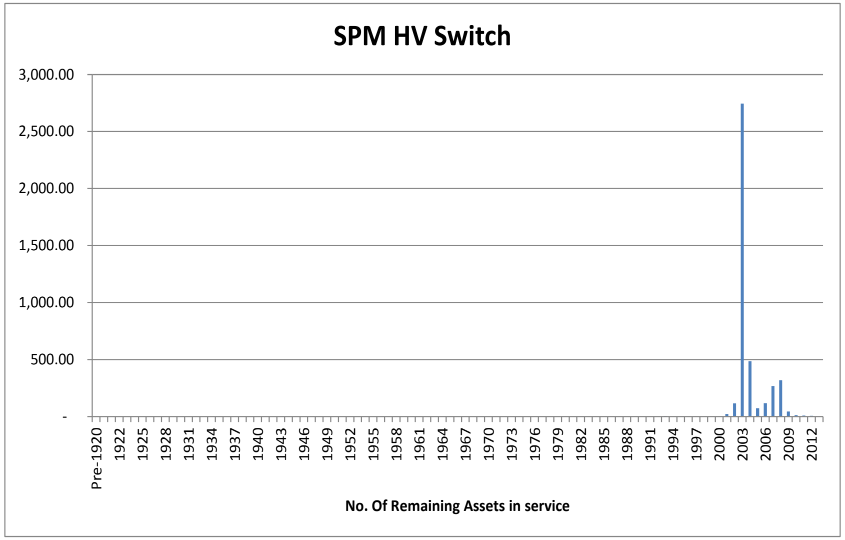
Asset	SPM		SPD	
	Volume	£m	Volume	£m
Primary Circuit Breaker replacement	323	10.3	359	11.5
Primary Circuit Breaker refurbishment / retrofit	366	9.3	540	9.2

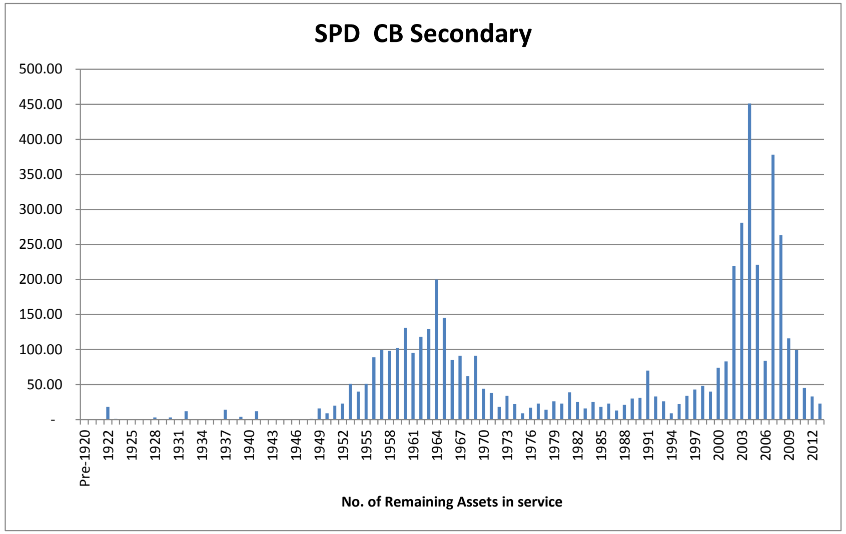
Cost benefit analysis is available for HV refurbishment/retrofit options, and concludes that refurbishment and retrofitting are cost-effective, viable options. The following interventions have been validated in Primary CB CBA 2.

7.2. 11kV Secondary Circuit Breaker Plan

We have a population of approximately 13,000 secondary circuit breakers and switches and we plan to replace 8.4% in SPD and 6% in SPM. Our strategy for 11kV secondary switchgear aims to replace HI5 condition assets deemed to be approaching end of life.

The age profile of 11kV primary circuit breakers is shown below, indicating that the bulk of the population was installed during the 1950s, 60s and 70's


SPM HV Switch
3,000.00
2,500.00
2,000.00
1,500.00
1,000.00
500.00
-
Pre-1920 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012
No. Of Remaining Assets in service


SPD CB Secondary
500.00
450.00
400.00
350.00
300.00
250.00
200.00
150.00
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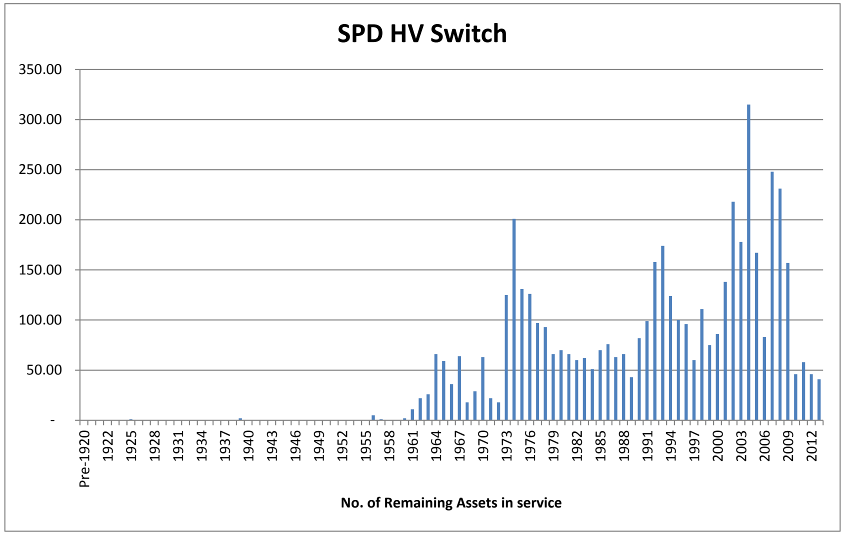
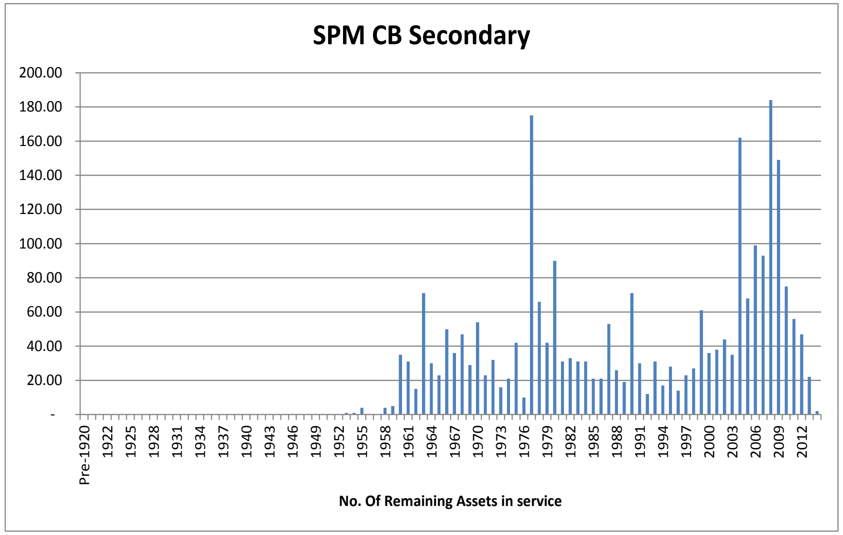
-
Pre-1920 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012
No. of Remaining Assets in service


SPD HV Switch
350.00
300.00
250.00
200.00
150.00
100.00
50.00
-
Pre-1920 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012
No. of Remaining Assets in service


SPM CB Secondary
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
-
Pre-1920 1922 1925 1928 1931 1934 1937 1940 1943 1946 1949 1952 1955 1958 1961 1964 1967 1970 1973 1976 1979 1982 1985 1988 1991 1994 1997 2000 2003 2006 2009 2012
No. Of Remaining Assets in service

An age based model is utilised to predict high level, long-term asset replacement volumes for each asset category and provides early identification of potential peaks in future workload. Our approach to determining the contribution to network risk, based on asset heath and criticality indices, from each of the major asset categories forms the basis of the intervention volumes proposed in our business plan.

Our condition assessment programme has identified common investment drivers for secondary circuit breakers and switches;

- *Bushing and gasket failures*
- *Solenoid mechanism – closing and*
- *tripping coil failures*
- *Failures of latch mechanism*
- *Slow closing*
- *Internal and external corrosion*
- *Test equipment contact misalignment*
- *Broken or faulty indicators*
- *Phase barrier electrical and mechanical*
- *Faults*
- *Auxiliary and main contact degradation*
- *Cable end box partial discharge and leaks*
- *Arc control device deterioration*
- *Safety shutters broken or missing*

Details of technical issues with secondary circuit breakers are contained within section 8 Appendix.

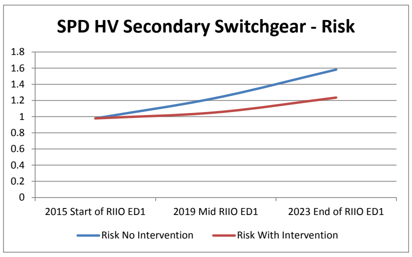
7.2.1. Impact on Health and Criticality Indices

The approach and policy outlined in section 6 provides a mapping of our condition and operational adequacy assessment scores to Health Indices. Combining Criticality Indices with our HI outputs, along with probability and consequence of failure, provides a measure of network risk. Refer to **Annex C6 – Asset Health and Criticality Strategy – SPEN** for a detailed description of our methodology. Our approach to managing overall network risk during ED1 is to maintain a similar level of risk at the end of the ED1 period as experienced at the start. Whilst the overall level of network risk across all asset categories is broadly constant there can be some variation within each asset category. The relative risk measures for each asset category with and without investment are profiled in the graphs below.

A matrix of HI and CI interventions indicating the movement in HI and CI volumes between the start and end of ED1 is also provided.

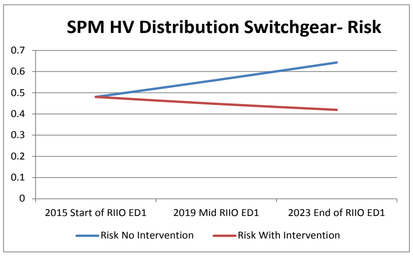
SPD 11kV Secondary switchgear replacement – ED1 HI/CI change

SPD	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	809	0	325	-325	-809	0
CI2	703	0	316	-316	-703	0
CI3	298	0	107	-107	-298	0
CI4	234	0	52	-52	-234	0
Total HI	2044	0	800	-800	-2044	0



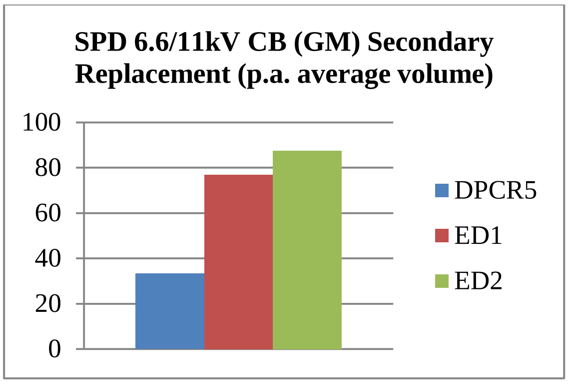
SPM 11kV Secondary switchgear replacement – ED1 HI/CI change

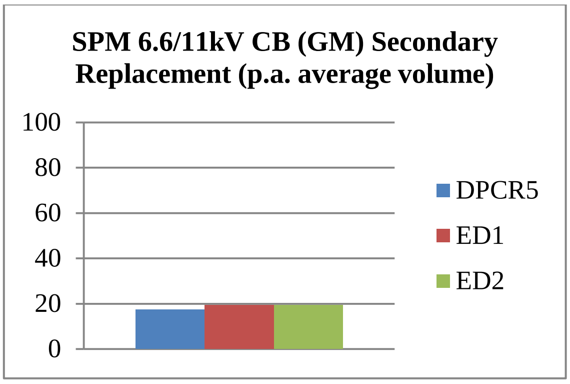
	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	912	0	37	-37	-912	0
CI2	808	0	35	-35	-808	0
CI3	541	0	23	-23	-541	0
CI4	195	0	5	-5	-195	0
Total HI	2456	0	100	-100	-2456	0



7.2.2. Secondary Circuit Breaker and HV Switch Volumes

The proposed asset replacement, retrofit and refurbishment volumes for ED1 are shown in the graphs below. In total there are 1090 replacements, representing 8.4% of the installed population



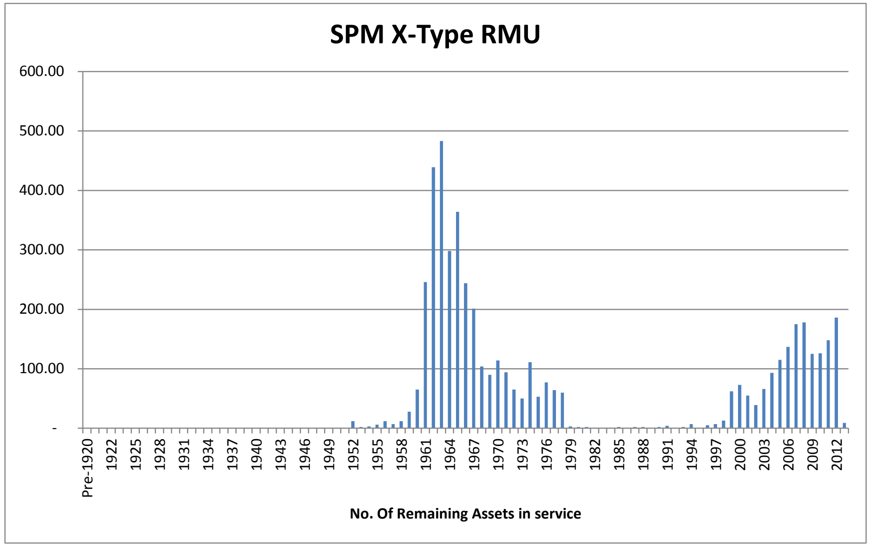


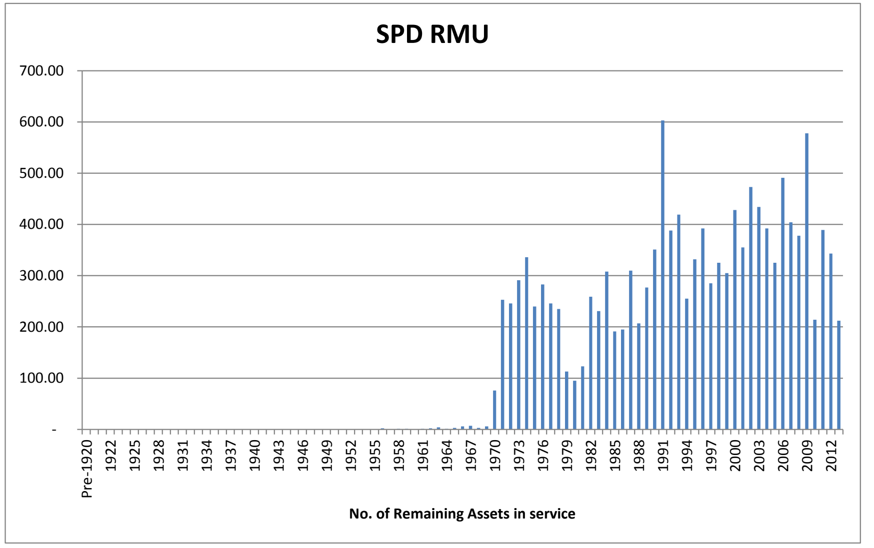
Volumes proposed are aligned to current delivery achievement in DPCR5 and based on our condition and criticality analysis, the following numbers of units are forecast for intervention during ED1.

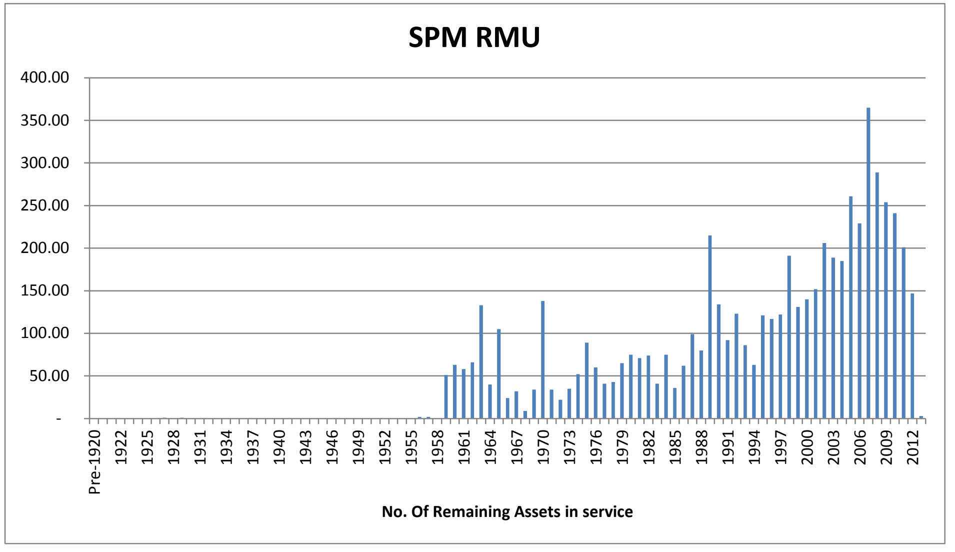
Asset	SPM		SPD	
	Volume	£m	Volume	£m
Secondary Circuit Breaker replacement	155	3.5	615	5.4
Secondary HV Switch replacement	-	-	320	1.7

7.3. 11kV Ring Main Units Investment Plan

SP Energy Networks has a population of approximately 25,000 ring main units and we plan to replace or refurbish 17.4% during ED1. These high volume units are now showing sign of deterioration and are becoming operationally inadequate.


SPM X-Type RMU
No. Of Remaining Assets in service


SPD RMU
No. of Remaining Assets in service


SPM RMU
No. Of Remaining Assets in service

An age based model is utilised to predict high level, long-term asset replacement volumes for each asset category and provides early identification of potential peaks in future workload. Our approach to determining the contribution to network risk, based on asset heath and criticality indices, from each of the major asset categories forms the basis of the intervention volumes proposed in our business plan.

We will replace critical condition (HI5) 11kV Ring Main Units with the most economic, low maintenance, modern equivalent switchgear which is future proofed for automation, and in addition refurbish poor condition (HI4) RMU assets to achieve cost-effective life extension.

SP Energy Networks has developed an efficient refurbishment option for Ring Main Units. The RMU end boxes are normally insulated using compound which can leak, or in some cases create air voids. We plan to refurbish these chambers and replace the insulating material with an improved modern equivalent as required.

The RMU will have all gaskets replaced, the sight glasses replaced and new earth fault indicator fitted where required. The RMU will be extensively refurbished internally with all barrier boards checked for defects and moisture, and all contacts checked for damage or arc pitting. Further to this we will check and make good any mechanical springs or linkages and replace any damaged fuses.

RMUs will be painted and where necessary we will erect a GRP to protect selected units exposed to more adverse environmental conditions.

For more information on the detailed technical defects addressed in our work programme please reference 8.3 in the Appendix.

Our condition assessment programme has identified common investment drivers for RMUs;

- *Bushing and gasket failures*
-
- *HV fuse failure resulting in serious internal condition*
- *Failures of fuse trip mechanism*
- *Water ingress through cracked sight glasses*
- *Internal and external corrosion*
- *Test equipment contact misalignment*
- *Phase barrier electrical and mechanical faults*
- *Auxiliary and main contact degradation*
- *Cable end* box partial discharge and leaks

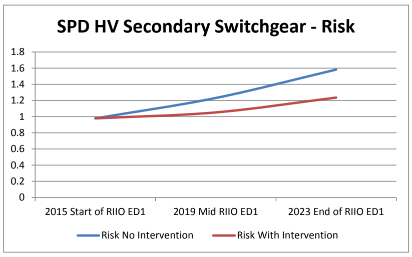
7.3.1. Impact on Health and Criticality Indices

The approach and policy outlined in section 6 provides a mapping of our condition and operational adequacy assessment scores to Health Indices. Combining Criticality Indices with our HI outputs, along with probability and consequence of failure, provides a measure of network risk. Refer to **Annex C6 – Asset Health and Criticality Strategy – SPEN** for a detailed description of our methodology. Our approach to managing overall network risk during ED1 is to maintain a similar level of risk at the end of the ED1 period as experienced at the start. Whilst the overall level of network risk across all asset categories is broadly constant there can be some variation within each asset category. The relative risk measures for each asset category with and without investment are profiled in the graphs below.

A matrix of HI and CI interventions indicating the movement in HI and CI volumes between the start and end of ED1 is also provided.

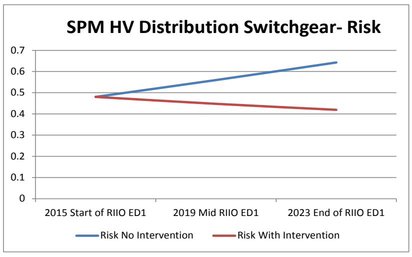
SPD 11kV Secondary switchgear interventions – ED1 HI/CI change

SPD	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	809	0	325	-325	-809	0
CI2	703	0	316	-316	-703	0
CI3	298	0	107	-107	-298	0
CI4	234	0	52	-52	-234	0
Total HI	2044	0	800	-800	-2044	0



SPM 11kV Secondary switchgear interventions – ED1 HI/CI change

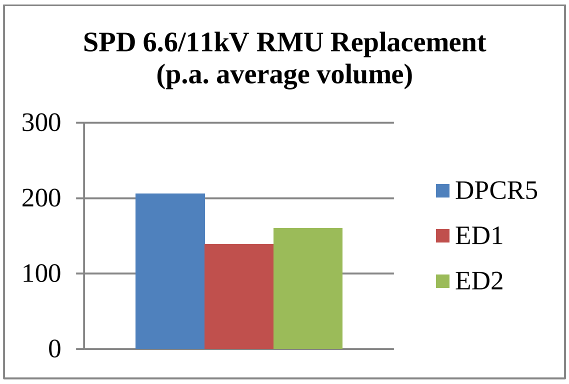
	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	912	0	37	-37	-912	0
CI2	808	0	35	-35	-808	0
CI3	541	0	23	-23	-541	0
CI4	195	0	5	-5	-195	0
Total HI	2456	0	100	-100	-2456	0

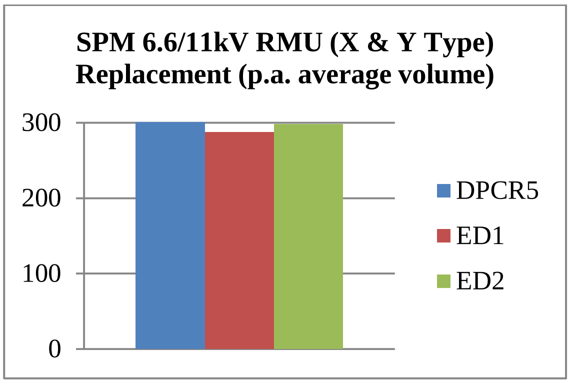


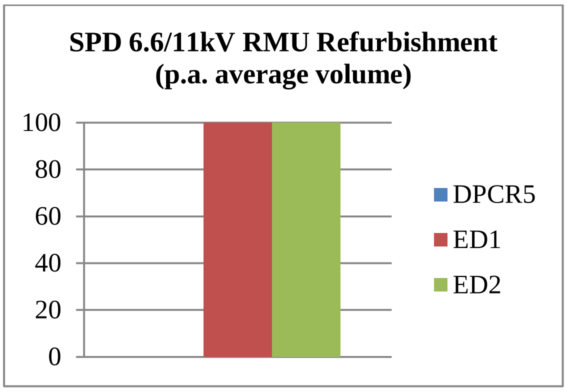
7.3.2. Secondary RMU Volumes

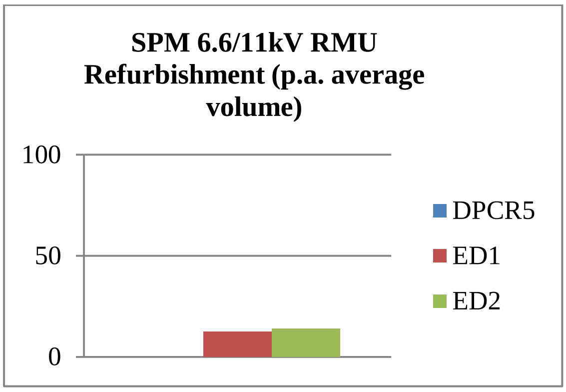
The optimised interventions look to exploit advances in new technology, where appropriate and avoid replacing assets on a like for like basis. We seek to utilise new refurbishment strategies where possible.

The proposed asset replacement and refurbishment volumes for ED1 are shown in the graphs below. In total there are 4300 interventions, representing 17.4% of the installed population.









Volumes proposed are aligned to current delivery achievement in DPCR5 and based on our condition and criticality analysis, the following numbers of units are forecast for intervention during ED1.

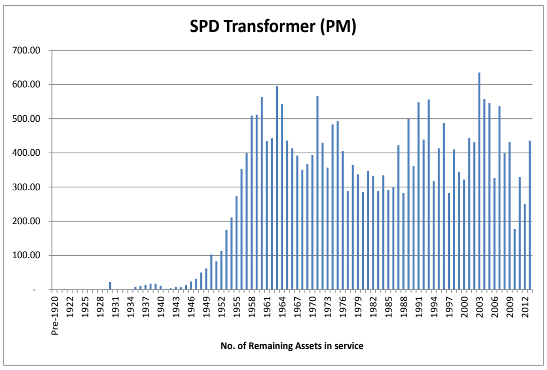
Asset	SPM		SPD	
	Volume	£m	Volume	£m
Secondary Ring Main Unit replacement	2301	33.1	1109	11.2
Secondary Ring Main Unit refurbishment	100	0.1	800	1.2

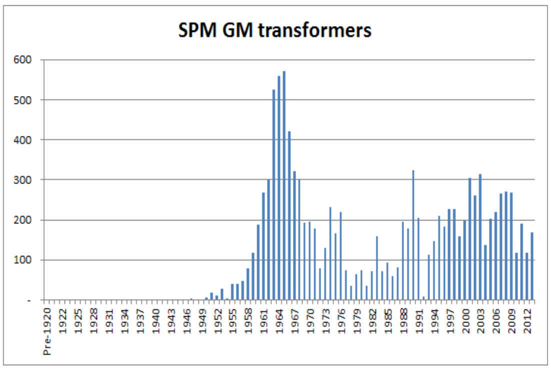
Cost benefit analysis is available for RMU refurbishment options, indicating that refurbishment is a viable, cost-effective option. The selected intervention has been validated in **Annex C6 – Cost Benefit Analysis – SPEN** for RMU, CBA 58.

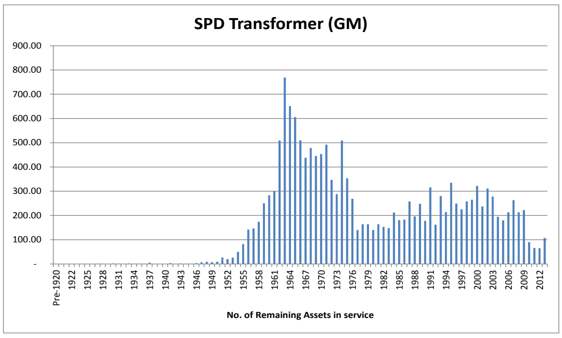
7.4. Transformer Investment Plan

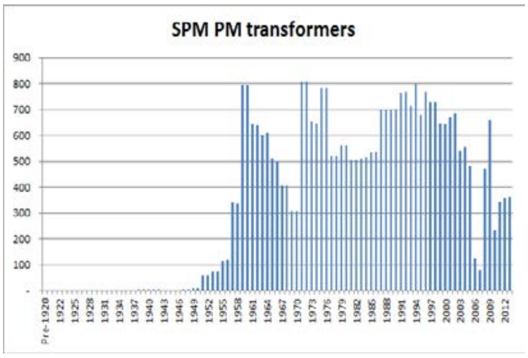
We have approximately 87,000 ground mounted and pole mounted transformers and we plan to replace or refurbish 5%. Our risk based strategy to ensure staff and public safety from HV Transformers is based on;

- *Ground Mounted (GM) transformers are replaced as determined through condition assessment on reaching HI5 or on failure;*
- *RMU replacement in SPM may require refurbishment of the associated transformer;*
- *Pole Mounted (PM) transformers are only replaced on failure, normally using a recovered unit or during 11kV overhead line replacement work.*









An age based model is utilised to predict high level, long-term asset replacement volumes for each asset category and provides early identification of potential peaks in future workload. Our approach to determining the contribution to network risk, based on asset heath and criticality indices, from each of the major asset categories forms the basis of the intervention volumes proposed in our business plan.

In addition to the ground mounted replacement volumes identified, SP Energy Networks has embarked on the pro-active replacement of high loss pre-1962 transformers. This programme of work is driven and justified by the value of reduced losses and is detailed in our Losses Strategy in **Annex C5 – Losses Strategy – SPEN.**

Our preferred intervention option for pole mounted transformers is to utilise reconditioned PM units where practicable. This approach is cost-effective and minimises the number of units that would previously have been scrapped.

The current design of RMU to replace the legacy units in SPM requires the coupling of the associated transformer to be modified.

Currently, new RMUs are fitted with cable termination boxes that are designed to accommodate 3 x single core XLPE cable. The original transformer cable box and CT chamber is designed to accept a single 3c PILC cable only. Therefore, it is necessary to install a modified, purpose built cable termination box and CT chamber suitable for the termination of single core XLPE cables. This transformer modification increases the cost of RMU replacement and is unique to the legacy interconnected network configuration employed in SPM.

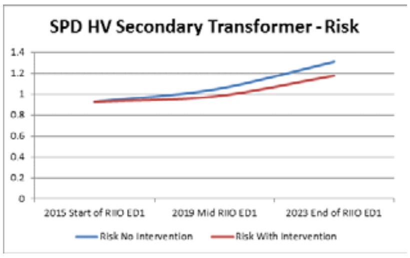
Due to the challenges of oil handling and heavy lifting on site, a traveller transformer is delivered to site with the appropriate modified cable box design and the original transformer disconnected and transported to SP Energy Networks workshop facilities to be adapted as a traveller for future projects. If assessed to be in suitable condition, the disconnected transformer will also be refurbished in accordance with our refurbishment scope of work outlined in section 8.6 in the Appendix.

7.4.1. Impact on Health and Criticality Indices

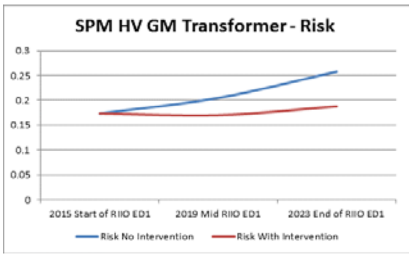
The approach and policy outlined in section 6 provides a mapping of our condition and operational adequacy assessment scores to Health Indices. Combining Criticality Indices with our HI outputs, along with probability and consequence of failure, provides a measure of network risk. Refer to **Annex C6 – Asset Health and Criticality Strategy – SPEN** for a detailed description of our methodology. Our approach to managing overall network risk during ED1 is to maintain a similar level of risk at the end of the ED1 period as experienced at the start. Whilst the overall level of network risk across all asset categories is broadly constant there can be some variation within each asset category. The relative risk measures for each asset category with and without investment are profiled in the graphs below.

A matrix of HI and CI interventions indicating the movement in HI and CI volumes between the start and end of ED1 is also provided.

SPD	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	264	0	0	0	-264	0
CI2	241	0	0	0	-241	0
CI3	139	0	0	0	-139	0
CI4	70	0	0	0	-70	0
Total HI	714	0	0	0	-714	0

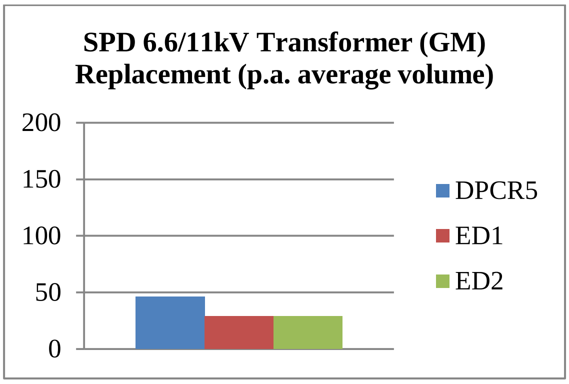


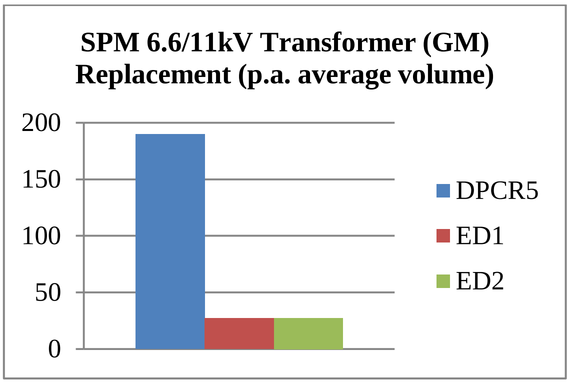
SPM	HI1	HI2	HI3	HI4	HI5	Total CI
CI1	424	319	319	-638	-424	0
CI2	233	175	175	-351	-233	0
CI3	133	100	100	-200	-133	0
CI4	55	41	41	-83	-55	0
Total HI	845	636	636	-1272	-845	0

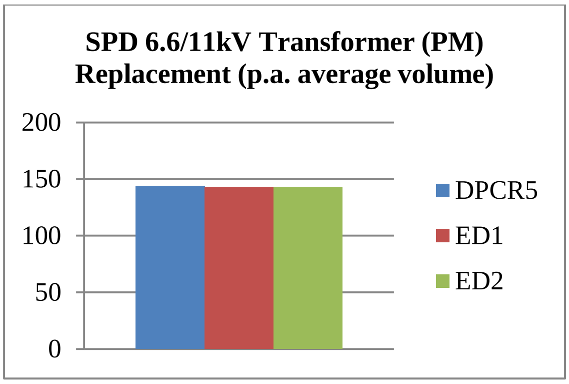


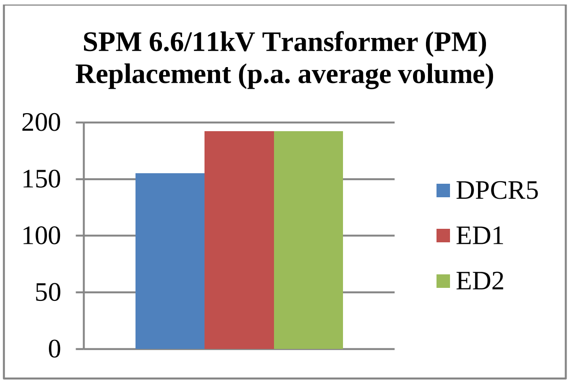
7.4.2. Transformer Volumes

The proposed asset replacement and refurbishment volumes for ED1 are shown in the graphs below. In total there are 4,400 interventions, representing 5% of the installed population.









Volumes proposed are aligned to current delivery achievement in DPCR5 and based on our condition and criticality analysis, the following numbers of units are forecast for intervention during ED1.

Asset	SPM		SPD	
	Volume	£m	Volume	£m
GM Transformer replacement	218	2.5	230	2.4
GM Transformer refurbishment	1272	6.3	-	-
PM Transformer replacement	1536	4.1	1144	3.0

Cost benefit analysis is available for transformer refurbishment options, indicating that refurbishment is a cost-effective, viable option. The selected interventions have been validated in **Annex C6 – Cost Benefit Analysis – SPEN** CBA 1.1, 1.2 and 7.

8. Appendix

8.1. Circuit Breaker Intervention Type

Our replacement, retrofit and refurbishment programme comprises various types of circuit breaker including:

Type	Replacement	Retrofit	Refurbishment
J&P PDP	Y		
J&P FG16	Y		
J&P JPBF	Y		
Reyrolle L22/23	Y	Y	
Brush VSIR4	Y		
JPBF	Y		
Brush VBA/VBC	Y		
MetVic V2r	Y		
Reyrolle C	Y	Y	Y
SWS C4	Y	Y	Y
GEC VMX	Y	Y	
S&C AE4	Y		

8.2. Circuit Breaker Type Issues

VMX circuit breakers

One recent developing issue has been the early failures of GEC VMX switchgear which are vacuum circuit breakers installed in the 1980'-s and 1990'-s, mainly in SPM (population of over 1000). A number of these are on critical primary switchboards that are part of demand groups supplying more than 10,000 customers. These switchboards are very susceptible to the environment they are kept in. Failures of these units have been where the unit is in a damp environment. Our strategy is to replace a percentage of our VMX population that reduces the risk to an acceptable level and also allows us to manage the population going forward. We will start with the worst condition first. These will be VMX in the substation buildings that have, or had, the highest humidity/poorest heating, or a known history of discharging breakers that we have nursed back to serviceability. Most of these will be the early versions which cannot be refurbished so the entire switchboard will need to be replaced. However later versions can be refurbished and these will be sent back to works and will provide spares for others reported as audibly discharging. By the end of ED1 we will have replaced 13% of the VMX population in the ED1 period, and will also have generated enough refurbished spare circuit breakers to keep the remaining VMX switchboard population serviceable. We will deal with the remaining VMX in ED2, by which time we may need to further accelerate the replacement rate.



Reyrolle LMT

Reyrolle LMT circuit breakers have suffered: performance failure to trip issues failure to trip - due to a cam within the mechanism failing to operate properly, auxiliary contacts deterioration with the result that the circuit breaker fails to close when required and greater than normal deterioration of busbar chambers due to condensation or moisture. Reyrolle LMT is has an economic retrofit option which we have included in our plans.

South Wales C4X

South Wales circuit breakers have suffered: performance failure to trip issues failure to trip due to oil within the tripping coil hindering the magnetic tripping bar arrangement, the mechanism failing to operate properly when spring charging, fixed portion busbar and end box failures due to the deterioration of G38 insulating material.

Reyroll C

Reyrolle c circuit breakers are generally good units but have suffered performance failure to trip issues: failure to trip due to a cam within the mechanism failing to operate properly, auxiliary contacts on the right hand side of the mechanism and fixed portion suffer a degree of deterioration with the result that the circuit breaker fails to close when required and greater than normal deterioration of busbar chambers due to condensation and moisture.

8.3. RMU Type Issues

J&P 'NX' with JPBF RMU

Early 1950's indoor ocb RMU originally fitted with direct manual mechanism un-potted 150MVA type TDB ocb. All ocbs rebuilt to revised 250MVA design by Baldwin and Francis between 1976 and 1985 (hence JPBF). Rebuilt OCB uses original ocb top plate tank, bushings and drive crank. All new mechanism and contact system/turbulators (pots). The internal of the top plate suffers from crystalline rusting due to condensation in an identical manner to the latter manufactured PDB ocbs replaced under DPRC5.

Its onset was delayed by attempted internal re-painting during the rebuild. These ocbs are unique in having ferrous top plates (other makes/types use non-ferrous (and hence nonmagnetic castings). RMU oil switches identical to later NX RMU and are fully rated. Design is very vulnerable to failure if rainwater from roof leak falls on unit – no protection for oil switch tank breather under test access lids. No manufacturer support from either J&P or Baldwin and Francis. No spare parts available other than 'pattern-part' ocb contacts. OCB uses extension earthing kit (new kits purchased from B&F in early 1980's) earth kits beginning to wear out and tested replacements unavailable.

Lucy FRMU RMU

Oil filled switchfuse RMU purchased by Manweb from early 1970's to mid 1980's. Units installed outdoors suffer from inadequate original paint finish and many (especially costal location units) have terminal corrosion, despite maintenance painting. Outdoor units suffered rainwater ingress due to inadequate design of test access lids. Several attempts to rectify and finally use of GRP 'hood'. The latter unfortunately promotes corrosion by trapping condensation. Multiple internal defects - late 1980s a major modification programme to resolve 17 serious type defects. Some defects will re-occur due to aging.

SWS RMN4 RMU

Mid 1950's indoor ocb RMU originally early types fitted with direct manual mechanism un-potted 150MVA type 'C4' ocb with 'H04' mechanism. All C4 ocbs replaced between 1976 and 1985 with SWS D4XDM type adapted to fit the original ocb carriage. Later RMN4 RMUs had original 250MVA C4X ocb with porcelain bushings, many of which have developed bitumen compound leaks into the ocb oil tank and externally due to natural deterioration of rubber/cork gaskets. OCB can be refurbished by Hawker Siddeley but price similar to all new non-oil RMU. No manufacturer support and no parts available for oil switches, RMU housings or ocb mechanisms. Manufacturers and others can supply only pattern-part contacts. OCB uses extension earthing kits supplied in mid to late 1950's. Many now becoming unserviceable and replacements are unavailable.

L&C RMU

Oil filled switchfuse RMU purchased by Manweb (and SSEB) from early 1970's to mid1980's. Generally a reliable RMU although there have been a number of nationally reported type defects, most of which were resolved over a decade ago. Our maintenance strategy evolved into a testing regime 'live tank oil sampling' (LTOS) regime complemented with intrusive maintenance.

During RIIO ED 1 plan to replace RMU based on condition. We will be able to use our testing data and condition information to generate a prioritised plan. Units installed outdoors have suffered some deterioration due to corrosion dependant on location. In addition perishing gaskets, sight glasses, barrier boards, damaged fuses, damaged contacts and internal corrosion have informed our investment assumptions for such assets.

Reyrolle ROKSS RMU

Oil filled switchfuse RMU purchased by SSEB from mid 1970's. An asset failure and fatality generated an SOP 1998/0198/00 which banned live operation due to test bushing spacer dislocation in to HV oil tank. SOP2001/0374 banned live operation on all units manufactured before 1982 due to failure of low tensile contact fixing bolts which were irreparable, and the installation of new barrier boards.

Our maintenance strategy evolved into a testing regime 'live tank oil sampling' (LTOS) regime complemented with intrusive maintenance as per our Long and Crawford fleet.

During RIIO ED 1 plan to replace RMU based on condition. We will be able to use our testing data and condition information to generate a prioritised plan. Units installed outdoors have suffered some deterioration due to corrosion dependant on location. In addition perishing gaskets, sight glasses, faulted barrier boards, damaged fuses, damaged contacts and internal corrosion have informed our investment assumptions for such assets.

S&C RA4/RAE4

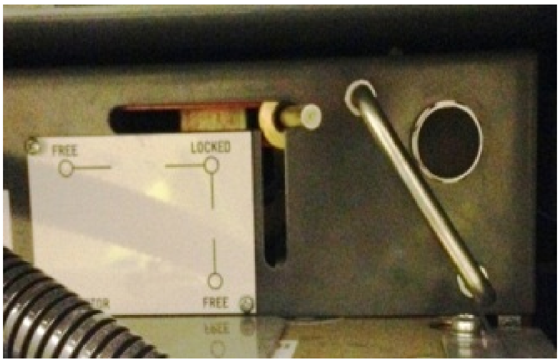
Oil filled indoor ocb RMU manufactured from approx 1958 onward. RA4 units manufactured by S&C in Manchester. Later RAE4 units manufactured at EE works in Liverpool following takeover of S&C. All have 250MVA oil switches and ocb from new. OCBs suffer from deterioration of ocb paper bushings which are poorly varnish sealed and absorb oil at the lower end and air moisture at the upper end. Reducing loss angle (tan delta) tests, few catastrophic failures to date, but deterioration progressive. Oil switches suffer tired contact pressure springs – operational restriction requiring monitoring of temperature within oil switch tank. No failure in Manweb but multiple failures of similar units in London area due to higher current loading. A few ocbs beginning to exhibit failure to close problems due to trip roller wear – suspect soft surface finish of component. RAE4 units have integral ocb earthing, earlier RA4 units use extension earthing. The original RA4 extension earthing kit had brittle cast resin body and few, if any, are serviceable.
Tested replacements made in the early 1980s by Baldwin and Francis but many of these are becoming worn, and further tested replacements are unavailable.

8.4. Circuit Breaker Retrofitting

We have already started to install 11kV CB moving portion retrofit solutions during DPCR5, and we plan to further develop this technology during ED1. All solutions will be ENA assessed. One type is the Siemens LMT retrofit which utilises a Sion vacuum device. This requires minimal maintenance, increasing switching durability and has no oil or SF6 gas. A successful condition assessment was carried out at Abronhill Primary SS, Lanarkshire, which included an inspection of the fixed portion, civils and heating. Six moving portions have now been installed. It should be noted that one Reyrolle Pacific CB moving portion retrofit (earlier model) remains in place within this switchboard. The Reyrolle LMT Retrofit brochure and Inspection, Operating and Maintenance manual contains more detailed information and can be found on the SPEN Intranet under Manufacturers Manuals.

Key features include: -

- *The CB status can be locked using the slide mechanism which covers the manual ‘I’ & ‘O’ buttons.*
- *To enhance reliability the secondary contacts now utilise an umbilical with connections via a Harting plug/socket connection. When connected this enables protection functionality and CB operation via remote facilities.*
- *The selector lever can only be moved when the black solenoid release push button is pressed. This action releases a solenoid connected to the lever mechanism. Should supplies be ‘lost’ the solenoid interlock can be defeated by inserting a small screwdriver into a hole which is located underneath the ‘locked/free’ label.*
- *The CB trip function is only operative when the racking switch plunger is engaged when the circuit breaker is in the raised service position. The functionality must be proven following disconnection/reconnection. For example: Following works and when the Harting plug/sock is reconnected - Rack in, close, trip test and tele close. The CB cannot be tripped electrically when the CB is in the circuit earth position or bus-bar earth position.*



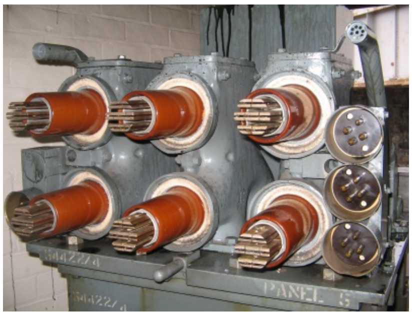
8.5. Circuit Breaker Refurbishment

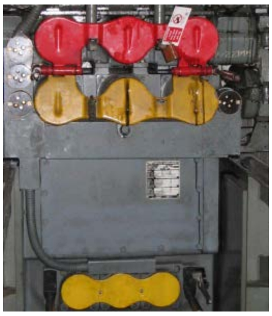
The scope for circuit breaker refurbishment includes both the fixed and moving portions.

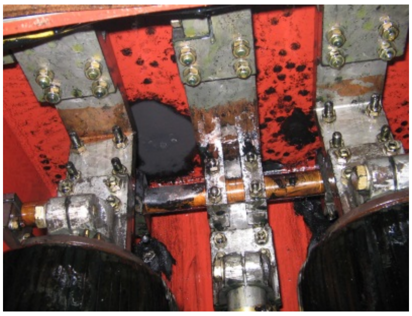
The fixed portions consist of busbar and cable end box chambers. They are normally insulated using a bitumen compound or G38 oil based material which can leak, or in some cases create air voids. Where appropriate we will refurbish these chambers and replace the insulating material with new Guroflex type technologies. Further to this the fixed portion shutters, HV and auxiliary contacts will be refurbished or replaced depending on the extent of arc pitting or mechanical damage.

The moving portion intervention will include the refurbishment or replacement of the operating mechanism. Worn mechanisms can diminish the circuit breakers ability to trip, or charge, during normal operations. The moving portion shutter mechanism drives, external HV and auxiliary electrical contacts will be fully refurbished or replaced, making good any mechanical or electrical defects.

The moving portion main tank interior will be cleaned and repainted where required. The arc control device and main contacts will be fully restored and in addition the baffle boards will be tested for moisture and replaced if necessary. The circuit breaker will have the protection tested, with timing test checked for the r unit, and prior to service, fully pressure tested.







8.6. Transformer Refurbishment Scope

This current procedure has been identified as best practice by SP Energy Networks for switchgear and transformer replacement programmes, due to being efficient, flexible and cost effective. It is the purpose of this document to establish the criteria for making a decision on the suitability and reuse of the transformer, as well the works required to adapt it.

The above procedure will be only applicable to Ground mounted 11 kV secondary transformers, installed in SPEN.

Initial checks

After being disconnected, the transformer will be transported to SPEN workshop facilities in where the following initial checks are made.

- *Transformer age. If manufactured before 1962, the transformer will be scrapped, due to old manufacturing techniques which produce high losses, size and / or weight limitations.*
- *LV connections. If LV connections are higher than 1525mm, which is the height specified in TRAN-03-021, the transformer will not be suitable to be installed at the current sites therefore scrapped.*

External condition. In case the transformer presents significant and non-repairable rust and/or oil leaks, it will be scrapped.

Oil Tests

If the unit is compliant with all checks detailed above, it will be transported indoors for a second round of tests:

- *The lid will be removed and the tank half drained.*
- *An oil sample will be extracted and the following tests performed:*

	Oil condition		
Test	GOOD	FAIR	POOR
Colour	Clear and without visible contamination		Dark and or Turbid
Breakdown Voltage (kV)	>40	30 to 40	<30
Water content (mgkg at 20C)	<10	10 to 25	>25
Acidity (mgKOH/g)	<0.15	0.15 to 0.30	>0.30
Sediment & Sludge	No sediment or perceptible sludge. Results below 0.02% by Mass may be neglected		

The following criteria will be used to determine the next steps.

A. *If any of the values above shows poor condition, the transformer will be scrapped as not only the oil but the paper insulation may be affected.*

B. *If all the values above show good condition, the transformer will be assessed as suitable for refurbishment without oil replacement.*

C. *If all the values above show either good or fair condition, the transformer will be assessed as suitable for adaption including replacing the oil.*

Electrical Tests

If the unit is compliant with all checks detailed above, the following electrical tests shall be carried out, and windings not under test shall be earthed:

- *HV side windings. Insulation resistance test, with a 5 kV Megger for 1 minute. Expected values shall be 0.5 GΩ, any value lower than that shall be reviewed and the transformer scrapped if required.*
- *LV side windings. Insulation resistance test, with a 1 kV Megger for 1 minute. Expected values shall be 0.5 GΩ, any value lower than that shall be reviewed and the transformer scrapped if required.*

Transformer oil

If oil needs to be replaced as per the criteria before, new oil supplied for the main tank shall be unused naphthenic based and comply with the requirements of IEC 60296 and any additional requirements detailed in SPEN document SUB-03-009. The oil shall be of a type approved by SP Energy Networks.

When main tank needs to be either fully or partially drain of oil, it shall be stored in a clean oil tanker and in a way that ensures no contamination for it. This shall apply as well to the oil filling of the transformer once works have finished.

Transformer tank

The adaption work shall include for cleaning of the outer surfaces of the transformer but surface treatment and re-painting shall not generally be undertaken, only if required.

Main gasket on the lid will be replaced in all cases. LV connections gasket replaced only in case of poor condition or oil leaks present.

The existing bitumen compound filled HV cable box/CT chamber will be removed and scrapped, as well as the three core connection. A new cable box including protection CT's will be fitted and connected to the winding connections. Two three phase sets of current transformers complying with the detail requirements of SPEN specification TRAN-03-021, clause 10.2.1 shall be installed in the replacement cable box and wired to the secondary terminal compartment of the cable box/CT chamber in strict accordance with figure 17 of TRAN-03-021

LV bushings and gaskets shall be inspected, and any deteriorated or damaged components replaced. Internal flexible connection to the LV winding shall be inspected. The cause of any deterioration to these laminations for the winding connections shall be investigated. If damage is limited to laminated connections these may be replaced In case of doubt over the serviceability of the winding connections, the transformer shall be scrapped. All valves shall be inspected and checked for oil leaks and correct operation.

Post Refurbishment Testing

All adapted transformers shall be stored and CT's tested including: Type, polarity, ratio and insulation resistance.