Transmission Network Asset Risk Methodology Licensee Specific Appendix (NARM LSA)

SP Transmission Specific Appendix

ISSUE 1

REVISION 3

Revision Record

Issue	Amendment Details	Updated by:	Date	Revision
NOMS LSA Issue 18	Initial submission to Ofgem	SPT Transmission	July 2018	Revision 1
NARM LSA Issue 1	Update Title consistently with the update of the methodology from NOMS to NARM. This would be the first version of the document under the new methodology title.	SPT	November 2022	Revision 1
NARM LSA Issue 1	Minor changes to document structure and terminology to ensure consistency with NARA document. Sections per each lead asset have been reorganised to follow the same order.	SPT	November 2022	Revision 1
NARM LSA Issue 1	Previous Sections 3, 4 and 5 recombined in a Section titled 'Factors to define the initial EOL modifier'. Some of the information in those previous sections was redundant and already contained in the NARA documents. Sub-section 5.3 Determination of K moved out from this common parameter section to a new section 5 after each individual lead asset section, consistent with the NARA structure.	SPT	November 2022	Revision 1
NARM LSA Issue 1	Subsection for OHL towers changed order after fittings consistent with NARA structure.	SPT	November 2022	Revision 1
NARM LSA Issue 1	Update of the calibration values after CTV, those are currently in use by the Methodology but had not been updated in the previous version of the LSA after CTV.	SPT	November 2022	Revision 1
NARM LSA Issue 1	Appendix 1 added with a step-by-step example of a calculation of EOL and risk values for a transformer using SPT methodology and calibration values.	SPT	November 2022	Revision 1
NARM LSA Issue 1	Formatting and typos correction.	SPT	May 2023	Revision 2
NARM LSA Issue 1	Update table 82 including Total Annual Transmission Demand (MWh) and Total Energy Generated in a Year	SPT	Feb 2026	Revision 3

	(MWh) values. Also included definition of k1 and k3 calculated values. Update example considering definition of k1 and k3.			

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TABLES INDEX

1. Introduction

This SP Transmission (SPT) specific appendix provides further details on the company specific areas of the NARM methodology which have been previously identified within Scottish TO Network Asset Risk Annex (NARA) document and the company specific calibration parameters used to implement the NARM methodology.

2. Factors to derive initial EOL modifier

This section lists the factors used in the methodology to derive the Initial EOL modifier for all lead assets. The initial EOL modifier is calculated using knowledge and experience of the asset performance and expected lifetime, taking account of differentiating factors such as original specification, manufacturer data, operational experience and operating conditions. These factors are calculated for all Lead Assets as specified in this section.

The factors common to all lead assets are:

- Duty
- LSE, Location, Situation and Environment.
- Expected Life

The following subsections provide the details of the derivation of each factor per every lead asset.

2.1 Duty Factor

The Duty Factor reflects the impact of workload on the EOL Indicator of otherwise identical assets. The more an asset is utilised, the faster its deterioration will be. The table below provides the duty factor inputs and calculation for each lead asset types.

Table 1 Duty Factors calculation

<table>
<tr><th>Lead Asset</th><th>Factor 1</th><th>Factor 2</th><th>Factor 3</th></tr>
<tr>
<td>Circuit Breakers</td>
<td><table>
<tr><th>Asset I^2t</th><th>Asset I^2t Factor</th></tr>
<tr><td>>-1 – 25</td><td>1.00</td></tr>
<tr><td>>25 – 50</td><td>1.00</td></tr>
<tr><td>>50 – 60</td><td>1.00</td></tr>
<tr><td>>60 – 75</td><td>1.00</td></tr>
<tr><td>>75 – 100</td><td>1.00</td></tr>
<tr><td>>100-5000</td><td>1.10</td></tr>
</table></td>
<td><table>
<tr><th>Fault Level / Rating (%)</th><th>Fault Level Rating Factor (D_{Fault})</th></tr>
<tr><td>>-1 – 25</td><td>1.00</td></tr>
<tr><td>>25 – 50</td><td>1.00</td></tr>
<tr><td>>50 – 100</td><td>1.00</td></tr>
<tr><td>>100 – 150</td><td>1.50</td></tr>
<tr><td>>150-5000</td><td>1.50</td></tr>
</table></td>
<td><table>
<tr><th>Number of Fault Clearances</th><th>Number of Fault Clearances Factor (D_{Clear})</th></tr>
<tr><td>>-1 – 5</td><td>1.00</td></tr>
<tr><td>>5 – 10</td><td>1.00</td></tr>
<tr><td>>10 – 15</td><td>1.00</td></tr>
<tr><td>>15 - 20</td><td>1.00</td></tr>
<tr><td>>20-5000</td><td>1.00</td></tr>
</table></td>
</tr>
<tr>
<td>Transformers & Reactors</td>
<td><table>
<tr><th>Max Demand / Rating (%)</th><th>Maximum Demand Factor (D_{max})</th></tr>
<tr><td>> -1 – 40</td><td>0.80</td></tr>
<tr><td>>40 – 60</td><td>0.80</td></tr>
<tr><td>>60 – 75</td><td>0.80</td></tr>
<tr><td>>75 – 100</td><td>0.80</td></tr>
<tr><td>>100 – 130</td><td>1.00</td></tr>
<tr><td>>130 – 200</td><td>1.50</td></tr>
</table></td>
<td><table>
<tr><th>Average Demand / Rating</th><th>Average Demand Factor (D_{ave})</th></tr>
<tr><td>> -1 – 40</td><td>0.80</td></tr>
<tr><td>>40 – 60</td><td>0.80</td></tr>
<tr><td>>60 – 75</td><td>0.85</td></tr>
<tr><td>>75 – 85</td><td>1.00</td></tr>
<tr><td>>85 – 100</td><td>1.10</td></tr>
<tr><td>>100 – 200</td><td>1.50</td></tr>
</table></td>
<td><table>
<tr><th colspan="2">Tapchanger</th></tr>
<tr><th>Annual n of operations</th><th>Overall n. of operations factor</th></tr>
<tr><td>> -1 – 1</td><td>1.30</td></tr>
<tr><td>1-500</td><td>1.00</td></tr>
<tr><td>>500–1000</td><td>1.00</td></tr>
<tr><td>>1000 –2000</td><td>1.30</td></tr>
<tr><td>>2000</td><td>1.50</td></tr>
</table></td>
</tr>
</table>

<table>
<tr><th>Lead Asset</th><th>Factor 1</th><th>Factor 2</th><th>Factor 3</th></tr>
<tr><td></td><td></td><td></td><td>High Wear Factor= 1.30, otherwise =1.0</td></tr>
<tr><td>Pressurised Cables (Fluid filled)</td>
<td><table>
<tr><th>Maximum Demand / Rating (%)</th><th>Maximum Demand Factor (D_{max})</th></tr>
<tr><td>0 – 25</td><td>1.0</td></tr>
<tr><td>>25 – 50</td><td>1.0</td></tr>
<tr><td>>50 – 100</td><td>1.0</td></tr>
<tr><td>>100 – 200</td><td>1.50</td></tr>
</table></td>
<td><table>
<tr><th>Average Demand / Rating (%)</th><th>Average Demand Factor (D_{ave})</th></tr>
<tr><td>0 – 25</td><td>1.00</td></tr>
<tr><td>>25 – 50</td><td>1.00</td></tr>
<tr><td>>50 – 100</td><td>1.00</td></tr>
<tr><td>>100 – 200</td><td>1.50</td></tr>
</table></td>
<td><table>
<tr><th>Operating Voltage / Construction Voltage (%)</th><th>Voltage Duty Factor (D_v)</th></tr>
<tr><td>0 – 50</td><td>1.00</td></tr>
<tr><td>>50 – 75</td><td>1.00</td></tr>
<tr><td>>75 – 100</td><td>1.00</td></tr>
<tr><td>>100 – 200</td><td>1.50</td></tr>
</table></td></tr>
<tr><td>Non-pressurised Cables (solid)</td>
<td><table>
<tr><th rowspan="2">Maximum Demand / Cable Rating (%)</th><th colspan="4">Maximum Demand Factor (D_{max})</th></tr>
<tr><th>EPR</th><th>Lapped Paper</th><th>Unknown</th><th>XLPE</th></tr>
<tr><td>0 – 25</td><td>1.00</td><td>1.20</td><td>1.10</td><td>1.00</td></tr>
<tr><td>>25 – 50</td><td>1.00</td><td>1.10</td><td>1.05</td><td>1.00</td></tr>
<tr><td>>50 – 100</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td>>100 – 200</td><td>1.20</td><td>1.20</td><td>1.20</td><td>1.20</td></tr>
</table></td>
<td><table>
<tr><th rowspan="2">Average Demand / Cable Rating (%)</th><th colspan="4">Average Demand Factor (D_{ave})</th></tr>
<tr><th>EPR</th><th>Lapped Paper</th><th>Unknown</th><th>XLPE</th></tr>
<tr><td>0 – 25</td><td>1.00</td><td>1.20</td><td>1.10</td><td>1.00</td></tr>
<tr><td>>25 – 50</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td>>50 – 90</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td>>90 – 200</td><td>1.50</td><td>1.20</td><td>1.20</td><td>1.50</td></tr>
</table></td>
<td><table>
<tr><th rowspan="2">Operating Voltage / Construction Voltage (%)</th><th colspan="4">Voltage Duty Factor (D_v)</th></tr>
<tr><th>EPR</th><th>Lapped Paper</th><th>Unknown</th><th>XLPE</th></tr>
<tr><td>0 – 60</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td>>60 -75</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td>>75 – 100</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td></tr>
<tr><td>>100 – 200</td><td>1.50</td><td>1.50</td><td>1.50</td><td>1.50</td></tr>
</table></td></tr>
<tr><td>Overhead Line (Conductor)</td><td>Not applicable- There is no duty factor for Conductor</td><td></td><td></td></tr>
<tr><td>Overhead Line (Fittings)</td><td>Not applicable- There is no duty factor for Fittings</td><td></td><td></td></tr>
<tr><td>Overhead Line (Towers - Foundations)</td><td>Not applicable- There is no duty factor for Tower foundations.</td><td></td><td></td></tr>
<tr><td>Overhead Line (Towers - Steelwork)</td><td>Not applicable- There is no duty factor for Tower steelwork</td><td></td><td></td></tr>
</table>

2.2 LSE Factor

The life of an asset is affected by the environment in which it is installed. For example, an asset exposed to higher levels of moisture or pollution would be expected to degrade more quickly than a similar type of asset exposed to lower levels of moisture or pollution. The levels of exposure depend on the location of the asset and whether or not it is installed within a building or enclosure that provides protection from the weather.

These effects are recognised using an asset-specific LSE Factor, which is used in the determination of the Expected Life for individual assets. The LSE Factor is influenced by different features depending on the asset class and these are summarised in tables below. LSE Factor is a combination of Location, Situation and Environmental factors.

While an environment factor is provided for Circuit Breakers and Transformers, Reactors and Overhead line conductors at this time there are no specific environmental factors, beyond those otherwise provided for, that have been shown to impact the probability of an asset's failure. As such an environmental rating, corresponding to a factor of 1, is used in the LSE calculation.

Table 2 LSE Factor Calculation for Circuit Breakers, Transformers, Reactors and Underground Cables.

Lead Asset	***Factor 1***		***Factor 2***		***Factor 3***		***Factor 4***		***Factor 5***	
Circuit Breakers	**Distance to Coast (km)**	**Distance from Coast Factor (F_{dist})**	**Altitude (m)**	**Altitude Factor (F_{alt})**	**Corrosion Zone[1]**	**Corrosion Factor (F_{cor})**	**Situation**	**Situation Factor, F_{sit}**	**Environment**	**Environment Factor, F_{env}**
	>-1 -5	1.40	>-1 -50	1.00	1	0.95	Outdoor	1.00	1	1.00
	>5 – 10	1.10	>50 – 100	1.00	2	1.00	Indoor	0.80	2	1.00
	>10 – 15	1.00	>100 – 1000	1.00	3	1.10	Completely Enclosed	0.90	3	1.00
	>15 – 20	1.00	>1000 - 5000	1.10	4	1.20			4	1.00
	>20 – 25	1.00			5	1.25			5	1.40
	>25	1.00			$F_{loc, min}$= 0.8					
Transformers & Reactors	**Distance to Coast (km)**	**Distance from Coast Factor (F_{dist})**	**Altitude (m)**	**Altitude Factor (F_{alt})**	**Corrosion Zone**	**Corrosion Factor (F_{cor})**	**Situation**	**Situation Factor, F_{sit}**	**Environment**	**Environment Factor, F_{env}**
			-1 -50	1.00	1	0.95	Outdoor	1.00	1	1.00
			50 – 100	1.00	2	1.00	Indoor	0.80	2	1.05

[1] Corrosion zone is taken from the Galvanisers' Association map of the UK.

Lead Asset	***Factor 1***	***Factor 2***	***Factor 3***	***Factor 4***	***Factor 5***
	>-1 -5: 1.40 >5 – 10: 1.10 >10 – 15: 1.00 >15 – 20: 1.00 >20 – 25: 1.00 >25: 1.00	100 – 1000: 1.00 1000 - 5000: 1.10	3: 1.10 4: 1.20 5: 1.25 $F_{loc, min}$= 0.8	Noise Enclosure: 1.00 Completely Enclosed: 0.90 Main tank enclosed only: 0.95	3: 1.10 4: 1.15 5: 1.20
Pressurised Cables (Fluid Filled)	F_{mech} set to default value 1.00				
Non-Pressurised Cables (solid)	$F_{shallow}$ set to default value 1.00	F_{plough} set to default value 1.00			

Table 3 Location Factor Calculation for Overhead Line Conductors

	Distance from Coast Factor (F_{dist})			
Distance (km)	ACSR	Al	AAAc	Cu
>-1 -5	1.20	1.20	1.10	1.00
>5 – 10	1.10	1.10	1.05	1.00
>10 – 15	1.00	1.00	1.00	1.00
>15 – 20	1.00	1.00	1.00	1.00
>20 – 25	1.00	1.00	1.00	1.00
>25	1.00	1.00	1.00	1.00

	Altitude Factor (F_{alt})			
Altitude (m)	ACSR	Al	AAAc	Cu
>-1 -50	1.00	1.00	1.00	1.00
>50 – 100	1.00	1.00	1.00	1.00
>100 – 250	1.00	1.00	1.00	1.00
>250 - 350	1.00	1.00	1.00	1.00
>350	1.10	1.10	1.10	1.10

	Corrosion Factor (F_{cor})			
Corrosion Zone	ACSR	Al	AAAc	Cu
1	0.95	0.95	0.95	0.95
2	1.00	1.00	1.00	1.00
3	1.10	1.10	1.10	1.10
4	1.20	1.20	1.20	1.20
5	1.25	1.25	1.25	1.25

Table 4 Location Factor Calculation for Overhead Line Fittings

	Distance from Coast Factor (F_{dist})			
Distance (km)	Glass	Porcelain Brown	Porcelain Grey	Polymeric
>-1 -5	1.40	1.40	1.40	1.20
>5 – 10	1.25	1.25	1.25	1.10
>10 – 15	1.00	1.00	1.00	1.00
>15 – 20	1.00	1.00	1.00	1.00
>20 – 25	1.00	1.00	1.00	1.00
>25	1.00	1.00	1.00	1.00

	Altitude Factor (F_{alt})			
Altitude (m)	Glass	Porcelain Brown	Porcelain Grey	Polymeric
>-1 -50	1.00	1.00	1.00	1.00
>50 – 100	1.00	1.00	1.00	1.00
>100 – 250	1.00	1.00	1.00	1.00
>250 - 350	1.00	1.00	1.00	1.00
>350	1.10	1.10	1.10	1.10

	Corrosion Factor (F_{cor})			
Corrosion Zone	Glass	Porcelain Brown	Porcelain Grey	Polymeric
1	1.00	1.00	1.00	1.00
2	1.00	1.00	1.00	1.00
3	1.00	1.00	1.00	1.00
4	1.10	1.10	1.10	1.10
5	1.20	1.20	1.20	1.20

Table 5 Location Factor Calculation for Overhead Line Tower steelwork

Distance to Coast (km)	Distance from Coast Factor (F_{dist})
>-1 -5	1.20
>5 – 10	1.10
>10 – 15	1.00
>15 – 20	1.00
>20 – 25	1.00
>25	1.00

Altitude (m)	Altitude Factor (F_{alt})
>-1 -50	1.00
>50 – 100	1.00
>100 – 500	1.00
>500 - 5000	1.20

Corrosion Zone	Corrosion Factor (F_{cor})
1	1.00
2	1.00
3	1.05
4	1.10
5	1.20

Table 6 Location Factor- Soil Test Factor Calculation for Overhead Line Tower foundations

Redox Potential (mV)	Rating (R_{pot})
>-500 - 0	6
>0 – 300	5
>300 – 500	3
>500 – 800	1
>800 - 1000	0

Soil pH	Rating (R_{pH})
>-1 – 2	12
>2 – 4	9
>4 – 7	3
>7 – 9	0
>9 -14	0

Soil Resistivity (Ω cm)	Rating (R_{res})
>-1 – 1000	12
>1000- 5000	8
>5000 – 20000	4
>20000 – 80000	1
>80000 - 100000	0

Combined Soil Test Rating	Soil Test Factor
>0 – 2	0.85
>2 – 4	0.95
>4 – 8	1.00
>8 – 12	1.20
>12 - 50	1.35

2.3 Expected Life

Each asset or asset sub-component as required is assigned an Average Life as per the table below.

Table 7 Average Life assigned to different Asset Classes

<table>
<tr><th rowspan="2"></th><th rowspan="2">Component</th><th colspan="2">Average Life</th><th rowspan="2">Average Life (years)</th></tr>
<tr><th>Sub-division 1</th><th>Sub-division 2</th></tr>
<tr><td rowspan="2">Transformer and Reactors</td><td>Transformer</td><td>Manufacturer</td><td>Period of Manufacture</td><td><table><tr><td>Period of Manufacture</td><td>Average Life</td></tr><tr><td>Pre 1980</td><td>60</td></tr><tr><td>Post 1980</td><td>50</td></tr></table></td></tr>
<tr><td>Tap changer</td><td>Manufacturer</td><td>Period of Manufacture</td><td><table><tr><td>Period of Manufacture</td><td>Average Life</td></tr><tr><td>Pre 1980</td><td>60</td></tr><tr><td>Post 1980</td><td>50</td></tr></table></td></tr>
<tr><td>CB</td><td>Circuit Breaker</td><td>Manufacturer</td><td>Model</td><td>50</td></tr>
<tr><td rowspan="2">Cables</td><td>Pressurised cables (fluid filled)</td><td>Metallic Screening Type / Armour Type</td><td>Period of Manufacture</td><td>60</td></tr>
<tr><td>Non-pressurised Cables (solid)</td><td>Armour Type / Insulation Type</td><td>Period of Manufacture</td><td>50</td></tr>
<tr><td rowspan="4">Overhead lines</td><td>Conductors</td><td>Conductor Type</td><td>Cross Sectional Area</td><td><table><tr><td>Conductor Type</td><td>Average Life</td></tr><tr><td>Cu</td><td>65</td></tr><tr><td>Al</td><td>50</td></tr><tr><td>ACSR</td><td>50</td></tr><tr><td>AAAC</td><td>50</td></tr></table></td></tr>
<tr><td>Fittings</td><td>Insulator Material / Insulator Type</td><td>Operating Voltage</td><td>35</td></tr>
<tr><td>Tower</td><td>Steelwork</td><td>Steel Condition at Time of First Painting</td><td><table><tr><td>Tower Coating</td><td>Steel Cond.</td><td>Average Life</td></tr><tr><td>Galvanised</td><td>-</td><td>35</td></tr><tr><td>Painted</td><td>Good</td><td>15</td></tr><tr><td>Painted</td><td>Poor</td><td>12</td></tr><tr><td>Painted</td><td>V. Poor</td><td>9</td></tr></table></td></tr>
<tr><td>Tower</td><td>Foundations</td><td>All types</td><td>100</td></tr>
</table>

3. Factors to derive intermediate and final EOL modifiers

This section lists the factors used in the methodology to derive the intermediate and final EOL modifiers for all lead assets.

The intermediate EOL2 modifier is calculated using specific asset information pertaining to observed condition, inspection surveys, maintenance test results and TO's experience of each asset.

The final EOL modifier is calculated using the EOL2 modifier and it could also use other condition information related to specific degradation process that can indicate end of life conditions with a high degree of confidence (e.g. dissolved gas analysis of transformer oil provides a high confidence indication of the health of the transformer regardless of other information available).

3.1 Circuit Breaker Model

3.1.1 Visual External Condition

The condition points included in the model and the corresponding factors and minimum EoLs are shown in the table below:

Table 8 Circuit Breaker Visual Condition Factors and Minimum EoLs

	Condition Factors					Minimum EoLs				
Condition Point	Condition Score					Condition Score				
	1	2	3	4	5	1	2	3	4	5
Tank/ Container – surface deterioration	0.90	1.00	1.10	1.25	1.40	0.5	0.5	0.5	6.5	8.0
Tank – oil leaks	0.90	1.00	1.05	1.10	1.20	0.5	0.5	0.5	0.5	0.5
Cable End box – general condition	0.85	1.00	1.10	1.25	1.40	0.5	0.5	0.5	0.5	0.5
Fixed Portion – general condition	0.90	1.00	1.05	1.05	1.05	0.5	0.5	0.5	0.5	0.5
Mechanism cabinet – general condition	0.90	1.00	1.05	1.10	1.20	0.5	0.5	0.5	0.5	0.5
Mechanism – general condition	0.90	1.00	1.10	1.25	1.40	0.5	0.5	0.5	6.5	8.0
Air Receivers – general condition	0.90	1.00	1.10	1.25	1.40	0.5	0.5	0.5	6.5	8.0
Pedestal Insulator – general condition	0.90	1.00	1.10	1.25	1.40	0.5	0.5	0.5	6.5	8.0
Contacts – wear	1.00	-	1.00	-	1.00	0.5	-	0.5	-	0.5
Snatch Gap	1.00	-	1.20	-	1.40	0.5	-	0.5	-	8.0
Gas Pressure Test	1.00	-	1.00	-	1.00	0.5	-	0.5	-	0.5
Air System Condition	0.90	1.00	1.10	1.25	1.40	0.5	0.5	0.5	6.5	8.0

The Condition Factor is derived using the 'Maximum and multiple Increment (MMI)' method as described in the NARA with parameters as defined in following table:

Table 9 Circuit Breaker Visual Condition MMI Calculation Parameters

MMI Calculation Term	Value
Condition Max Divider	2
Condition Min Divider	4
Condition Max Boundary	1
Max Number of Combined Factors	6

3.1.2 Defect History

Each of the recorded circuit breaker defects from the past 5 years is assigned a severity score (using a scale of 1-4, where 4 is the most severe) via a calibration table as shown in table below:

Table 10 Calibration of Circuit Breaker Defect Severity Scores

Defect Description	Defect Severity
Air conditioning damaged	4
Air receiver leaking	2
Air receiver rusty	1
Bushing oil level low	2
Bushing damaged	2
Bushing leaking	2
Cable box leaking	1
Cable Box / Band Joint leaking	3
Cable Box / Band Joint / end cap leaking	3
Compound leaks present	3
Earthing damaged	4
Earthing incomplete	4
Gas pressure low	2
Heater(s) damaged	1
Heaters in marshalling kiosk damaged	1
Heaters in marshalling kiosk faulty	1
Hydraulic oil level low	2
Insulators damaged	2
Lubricate OCB mechanism	1
Main tank oil level low	2
Marshalling kiosk requires attention	1
Oil leaks present	2
Painting required	1
Position indicator damaged	2
Protection relays damaged	2
Pump damaged	2
Water ingress present	3
Weather guard damaged	1
CB on local control	1

The severity scores are summed and the total score used to derive the Defect History Factor and minimum EoL via calibration tables as shown below:

Table 11 Calibration of Circuit Breaker Defect History Factor and Minimum EoL

Total Defect Score	Defect History Factor	Minimum EoL
0 – 2	1.00	0.5
>2 – 10	1.05	0.5
>10 – 25	1.10	0.5
>25 – 35	1.15	0.5
>35	1.25	0.5

3.1.3 Generic Reliability

The reliability rating is then linked to a Generic Reliability Factor and a minimum EoL value via calibration tables as shown below:

Table 12 Circuit Breaker Generic Reliability Factor and Minimum EoL

Reliability Rating	Generic Reliability Factor	Minimum EoL
1	1.00	0.5
2	1.10	0.5
3	1.25	6.5
4	1.40	8.0

3.1.4 Tests

The results from a number of tests such as partial discharge (PD) tests, timing tests and Ductor tests can be considered within the model. The calculation steps for each test type are the same and use 3 different measures to calculate each Test Score. The Overall test score for each of the test is calculated as described below:

(1) Test Score 1 is produced via a lookup based on the latest result; the calibration values are shown in table below:

Table 13 Calibration Values for Circuit Breaker Test Score 1

Rating	Latest Result	Test Score 1
1	Pass	0
2	Suspect	4
3	Fail	10

(2) Test Score 2 is based on the number of previous results with rating 1, 2 and 3; the calibration values are shown in table below:

Table 14 Calibration Values for Circuit Breaker Test Score 2

Classification	Test Score 2
All previous test results are rating 1 (pass)	0
One previous test result with rating 2 (suspect) or only one previous test result present (regardless of result)	1
No previous results	2
One previous test result with rating 3 (fail) or more than one with rating 2 (suspect).	4
More than one previous test result with rating 3 (fail)	6

(3) Test Score 3 is derived from the generic rating of the asset which is based on the circuit breaker manufacturer and model. All manufacturer / model combinations have been assigned a score of 1.

(4) The Test Overall Score is then calculated as follows:

$$Test\ Overall\ Score = (Test\ Score\ 1 + Test\ Score\ 2) \cdot Test\ Score\ 3 \qquad \textbf{Equation 1}$$

(5) The Test Factor and minimum EoL are then derived via range lookups in calibration tables as shown in table below:

Table 15 Calibration Values for Circuit Breaker Test Score 3

Test Overall Score	Test Factor	Minimum EoL
>-1 – 0	0.950	0.5
>0 – 2	1.000	0.5
>2 – 4	1.075	0.5
>4 – 5	1.150	0.5
>5 – 8	1.225	6.5
>8+	1.300	8.0

The calibration values in previous tables have been set to be the same for PD tests, timing tests and Ductor tests.

The Overall Combined Test Factor is derived from the PD Test Factor, Timing Test Factor and Ductor Test Factor using the 'Maximum and multiple Increment (MMI)' method as described in the NARA. The Overall Combined Test Minimum EoL is the maximum the minimum EoL values obtained for each test type, namely the PD Test Minimum EoL, Timing Test Minimum EoL and Ductor Test Minimum EoL.

Table 16 Circuit Breaker Combined Test Factor MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	1
Min Divider	0.5
Max Boundary	1
Max Number of Combined Factors	3

3.1.5 Operational Restrictions

Each Operational Restriction (OR)is assigned a severity, which then generates an Operational Restriction Factor and a minimum EoL via calibration tables as shown below:

Table 17 Circuit Breaker Operational Restriction Factor and Minimum EOL

OR Severity	Description	OR Factor	Minimum EoL
0	Temporary / Impact under assessment	1.00	0.5
1	Very minor operational / network impact	1.00	0.5
2	Moderate operational / network impact	1.05	0.5
3	Significant operational / network impact	1.10	0.5
4	Inoperable without intervention	1.40	8.0
5	Inoperable – no cost-effective solution / must be replaced	1.50	10

For assets that have more than one OR assigned to them, it is the largest factor which is used to form the overall OR Factor.

3.1.6 Oil Condition

The oil condition factor considers the latest oil condition tests (moisture, acidity and breakdown strength), each of which is used to create a test score using the standard calibration values shown in below:

Table 18 Circuit Breaker Oil Condition State Threshold and Calibration Values

Relative Humidity (%)	Moisture Score
>0 – 15	0
>15 – 25	2
>25 – 35	4
>35 – 45	8
>45	10

Acidity (mg KOH/g)	Acidity Score
>0 – 0.1	0
>0.1 – 0.15	2
>0.15 - 0.20	4
>0.20 - 0.30	8
>0.30	10

Breakdown Voltage (kV)	Breakdown Strength Score
>0 – 30	10
>30 – 40	4
>40 – 50	2
>50	0

Each of these scores is modified by a multiplier that applies a weighting relative to the importance of the measured condition point. The multiplier values are listed in the following table:

Table 19 Circuit Breaker Oil Condition Multiplier Calibration Values

Condition Point	Multiplier
Relative Humidity (%)	80
Breakdown Voltage (kV)	80
Acidity – mg KOH/g	125
Acidity Adjustment factor	200
Paper Solubility Limit	8
Oil Condition Cut off Years	5
Default Oil Condition Factor	1
Default Oil Condition Minimum HI	0.5

The weighted oil condition test scores are summed to create an Oil Condition Score which is then used to derive an Oil Condition Factor and minimum EoL using the calibration values shown in table below:

Table 20 Circuit Breaker Oil Condition Factor Calibration Values

Oil Condition Score	Oil Condition Factor	Minimum EoL
0 – 50	0.90	0.5
>50 – 200	1.00	0.5
>200 – 500	1.05	0.5
>500 – 1000	1.10	0.5
>1000	1.20	0.5

3.1.7 After Fault Maintenance (AFM)

SPT does not currently use this input value in the model. As such, a factor of 1 and minimum EoL of 0.5 is used for all assets in relation to this condition.

3.1.8 SF_6 Condition

There is currently no robust data available for the gas condition in circuit breakers and hence this module has not yet been calibrated. As we collect data on the tests carried out, we intend to calibrate this module in future revisions of the methodology. As such, a factor of 1 and minimum EoL of 0.5 is used for all assets in relation to this condition.

3.1.9 Gas Leaks

The model includes the facility to use information on gas leaks to generate a factor and minimum EoL. This factor is based on:

(1) the total mass of gas lost during a defined period relative to the design 'weight';

(2) the number of top-ups during a defined period; and

(3) an assessment of the leak history of each asset (e.g. 'normal', 'poor', 'bad').

The ranges and the factors for the three parameters above are calibration values as shown in the following tables:

Table 21 Circuit Breaker Calibration of the Gas Leak Factor

Weighted Lost Gas Factor, $SF_{6\ Lost}$		
Weighted (%)	Factor	Minimum EoL
>-0– 10	1.00	0.5
>10 – 20	1.05	0.5
>20– 50	1.10	0.5
>50 – 80	1.25	6.5
>80-100	1.40	8.0

Number of Leaks Factor, $SF_{6\ NO}$		
Number	Factor	Minimum EoL
0 – 3	1.00	0.5
>3 – 5	1.00	0.5
>5 – 8	1.00	0.5
>8 – 12	1.10	6.5
>12	1.20	8.0

SF_6 Leak History Factor, $SF_{6\ Hist}$		
Description	Factor	Minimum EoL
Normal	1.00	0.5
Poor	1.25	6.5
Bad	1.50	8.0

For each asset, the Gas Leak Factor and the minimum EoL are the maximum of the three factors and the three minimum EoLs in the above tables.

The defined ‘Leak Period’ is set to 5 years.

3.1.10 Overall Factor Value

Table 22 Circuit Breaker Overall Factor Value MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	4
Min Divider	1.5
Max Boundary	1
Max Number of Combined Factors	6

3.2 Transformer and Reactor Model

3.2.1 Visual External Condition Factors

3.2.1.1 Transformer

Table 23 Transformer Visual Condition Factors and Minimum EOLs

Condition Point	Condition Factors					Minimum EoLs				
	Condition Score					Condition Score				
	1	2	3	4	5	1	2	3	4	5
Main tank – surface deterioration	1.0	1.0	1.0	1.1	1.2	0.5	0.5	0.5	0.5	0.5
Main tank – oil leaks	1.0	1.0	1.1	1.3	1.4	0.5	0.5	5.5	6.5	8.0
Radiator fins – surface deterioration	1.0	1.0	1.1	1.3	1.4	0.5	0.5	0.5	0.5	0.5
Radiator fins – oil leaks	1.0	1.0	1.1	1.3	1.4	0.5	0.5	5.5	6.5	8.0
Conservator - surface deterioration	1.0	1.0	1.0	1.1	1.2	0.5	0.5	0.5	0.5	0.5
Conservator – oil leaks	1.0	1.0	1.1	1.3	1.4	0.5	0.5	5.5	6.5	8.0
Cable End box – condition	1.0	1.0	1.1	1.1	1.1	0.5	0.5	0.5	0.5	0.5

The condition factors are combined using the 'Modified Max and Increment' combination method as described in the NARAs to determine the Overall Condition Factor.

The Overall Condition Minimum EoL is the maximum of the individual condition minimum EoLs.

Table 24 Transformer Visual Condition MMI Calculation Parameters

MMI Calculation Term	Value
Condition Max Divider	3
Condition Min Divider	1.5
Condition Max Boundary	1
Max Number of Combined Factors	3

3.2.1.2 Tapchanger

The condition points for the tapchanger that are included in the model and the corresponding factors and minimum EoLs are shown in table below:

Table 25 Tapchanger Visual Condition Factors and Minimum EOLs

Condition Point	Condition Factors					Minimum EoLs				
	Condition Score					Condition Score				
	1	2	3	4	5	1	2	3	4	5
Selector tank – surface deterioration	1.0	1.0	1.0	1.1	1.2	0.5	0.5	0.5	0.5	0.5
Selector – oil leaks	1.0	1.0	1.0	1.3	1.4	0.5	0.5	0.5	6.5	8.0
Tapchanger contacts	1.0	1.0	1.0	1.2	1.4	0.5	0.5	0.5	6.5	8.0
Override Score	1.0	1.0	1.1	1.3	1.4	0.5	0.5	0.5	6.5	8.0

The condition factors are combined using the 'Modified Max and Increment' combination method as described in the NARAs to determine the Overall Condition Factor.

The Overall Condition Minimum EoL is the maximum of the individual condition minimum EoLs.

Table 26 Transfomer tapchanger Visual Condition MMI Calculation Parameters

MMI Calculation Term	Value
Condition Max Divider	3
Condition Min Divider	1.5
Condition Max Boundary	1
Max Number of Combined Factors	3

3.2.2 Defect History

3.2.2.1 Transformer

Each of the recorded transformer defects from the past 5 years are assigned a severity score (using a scale of 1-4, where 4 is the most severe) via a calibration table as shown in table below:

Table 27 Calibration of Transformer Defect Severity Scores

Defect Description	Defect Severity
Heaters in mechanism box faulty	2
Tertiary bushings oil level low	2
Divertor tank oil level low	4
Marshalling kiosk damaged	1
Bushings damaged	3
Oil leaks present	4
Earthing damaged	2
HV bushings oil level low	3
Neutral C.T. bushings oil level low	2
Painting required	2
Conservator oil level low	2
Bushing oil level low	3
Explosion vent damaged	4
Fans/Pumps on manual	1
Gas in buchholz	3
Gas analyser hydran damaged	1
LV bushings oil level low	3
Water ingress present	3
Tapchanger on manual	4

The severity scores are summed and the total score used to derive the Defect History Factor and minimum EoL via calibration tables as shown in table below:

Table 28 Calibration of Transformer Defect History Factor and Minimum EoL

Total Defect Score	Defect History Factor	Minimum EoL
>0 - 2	1.00	0.5
>2 - 10	1.00	0.5
>10 - 20	1.05	0.5
>20 - 35	1.10	0.5
>35	1.20	0.5

3.2.2.2 Tapchanger

Each of the recorded tapchanger defects were also assigned a severity score (scale of 1-4, with 4 being the most severe) in the calibration table shown below:

Table 29 Tapchanger Defect Severity Score Mapping Table

Defect Description	Defect Severity
Diverter tank oil level	4
Heaters in mechanism box faulty	2

The severity scores are summed and the total score used to derive the Defect History Factor and minimum EoL via calibration tables as shown in table below:

Table 30 Calibration of Transformer Tapchanger Defect History Factor and Minimum EoL

Total Defect Score	Defect History Factor	Minimum EoL
0 - 2	1.00	0.5
>2 - 10	1.05	0.5
>10 - 20	1.10	0.5
>20 - 35	1.25	0.5
>35	1.50	0.5

3.2.3 Generic Reliability

3.2.3.1 Transformer

The reliability rating is then linked to a Generic Reliability Factor and a minimum EoL value via calibration tables as shown in table below:

Table 31 Transformer Generic Reliability Factor and Minimum EoL

Reliability Rating	Generic Reliability Factor	Minimum EoL
1	1.00	0.5
2	1.10	0.5
3	1.25	6.5
4	1.40	8.0

3.2.3.2 Tapchanger

The derivation of the Generic Reliability Factor for tap changers is the same as for transformers, using the same calibration values.

3.2.4 Oil Condition

3.2.4.1 Transformer

Established techniques such as oil analysis provide an effective means of identifying and quantifying degradation of the insulation system (oil and paper) within transformers. Oil results can also be used to identify incipient faults. The Oil Condition Factor considers the latest oil condition tests (moisture, acidity and breakdown strength), each of which is used to create a test score using the standard calibration values shown in table below:

Table 32 Transformer Oil Condition Calibration Values

Relative Humidity (ppm)	Moisture Score, O_M
>-1 – 15	0
>15 – 25	2
>25 – 35	4
>35 – 45	8
>45 - 10000	12

Acidity (mg KOH/g)	Acidity Score, O_A
>-1 – 0.1	0
>0.1 – 0.15	2
>0.15 - 0.20	4
>0.20 - 0.30	8
>0.30 - 10000	12

Breakdown Voltage (kV)	Breakdown Strength Score, O_B
>-1 – 30	12
>30 – 40	6
>40 – 50	2
>50 - 10000	0

Each of these scores is modified by a multiplier that applies a weighting relative to the importance of the measured condition point. The multiplier values are listed in table below:

Table 33 Transformer Oil Condition Multiplier Calibration Values

Condition Point	Multiplier	Value
Relative Humidity (ppm)	O_M	80
Breakdown Voltage (kV)	O_B	80
Acidity – mg KOH/g	O_A	125

The weighted oil condition test scores are summed to create an Oil Condition Score which is then used to derive an Oil Condition Factor and minimum EoL using the calibration values shown in tables below:

Table 34 Transformer Oil Condition Factor Calibration Values

Oil Condition Score	Oil Condition Factor
>-1 – 50	0.90
>50 – 200	1.00
>200 – 500	1.05
>500 – 1000	1.10
>1000 - 10000	1.20

Oil Condition Score	Minimum EoL
>-1 – 50	0.5
>50 – 200	0.5
>200 – 500	0.5
>500 – 1500	0.5
>1500 - 10000	8.0

3.2.4.2 Tapchanger

The calculation of the Oil Condition Factor for the tapchanger is calculated in the same way as for the transformer using the same calibration values.

The Oil Condition Factor and minimum EoL are derived using the calibration values shown in tables below:

Table 35 Tapchanger Oil Condition Factor Calibration Values

Oil Condition Score	Oil Condition Factor, F_{OIL}
>-1 – 50	0.90
>50 – 200	1.00
>200 – 500	1.05
>500 – 1000	1.10
>1000 - 10000	1.20

Oil Condition Score	Minimum EoL_{FOIL}
>-1 – 50	0.5
>50 – 200	0.5
>200 – 500	0.5
>500 – 1000	0.5
>1000 - 10000	8.0

3.2.5 Operational Restrictions

3.2.5.1 Transformer

Each Operational Restriction is assigned a severity, which then generates an Operational Restriction Factor and a minimum EoL via calibration tables as shown below:

Table 36 Operational Restriction Factor and Minimum EOL

OR Severity	Description	OR Factor	Minimum EoL
0	Temporary / Impact under assessment	1.00	0.5
1	Very minor operational / network impact	1.00	0.5
2	Moderate operational / network impact	1.05	0.5
3	Significant operational / network impact	1.10	0.5
4	Inoperable without intervention	1.40	8.0
5	Inoperable – no cost-effective solution / must be replaced	1.50	10.0
SOP Default Minimum EOL		0.5	

For assets that have more than one OR assigned to them, it is the largest factor that is used to form the overall OR Factor.

3.2.5.2 Tapchanger

The derivation of the OR Factor for tap changers is the same as for transformers, using the same calibration values.

3.2.5.3 DGA Factor (Tapchanger Only)

This factor is applied to tap changers only. SPT has currently set this factor as 1 for every tap changer since we do not have data that supports the impact of this input factor. This calibration will be reviewed in future versions of the methodology should this information becomes available.

3.2.6 Overall Factor Value

3.2.6.1 Transformer

Table 37 Transformer Overall Factor Value MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	3
Min Divider	1.5
Max Boundary	1
Max Number of Combined Factors	4

3.2.6.2 Tapchanger

Table 38 Tapchanger Overall Factor Value MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	3
Min Divider	1.5
Max Boundary	1
Max Number of Combined Factors	4

3.2.7 DGA End of Life Indicator (Transformer main tank Only)

The results for each of the five gases are standardised by converting them into scores using the calibration values shown in table below:

Table 39 Transformer DGA Calibration Values

Hydrogen (H_2) (ppm)	Score
>-1 – 20	0
>20 - 40	2
>40 – 100	4
>100 – 200	10
>200 - 5000	16

Acetylene (C_2H_2) (ppm)	Score
>-1 – 1	0
>1 – 5	2
>5 – 20	4
>20 – 100	8
>100 - 5000	10

Ethylene (C_2H_4) Methane (CH_4) & Ethane (C_2H_6) (Each)(ppm)	Score
>-1 – 10	0
>10 – 20	2
>20 – 50	4
>50 – 150	10
>150 - 5000	16

Each condition score is modified by a multiplier that applies a weighting relative to the importance of the quantity of the gas measured. The multiplier values are listed in table below:

Table 40 Transformer DGA Condition Multiplier Calibration Values

Gas		Multiplier
Hydrogen	H_2	50
Acetylene	C_2H_2	120

Ethylene	C_2H_4	30
Methane	CH_4	30
Ethane	C_2H_6	30

EOL_{DGA} is capped to a maximum value of 10. $EOL_{DGA\ Max}$=10

In order to create a standard End of Life Indicator in the range of 0.5 to 10, the DGA Score is divided by a DGA Divider value; this is set at 220 which gives an End of Life Indicator of 7 at the point where DGA levels are indicative of end of life.

The DGA History Factor is then created for each asset by considering the trend with historical results (the principal result compared with the average result). The trend is categorised into one of five categories or bands. This is then used to assign a DGA History Factor using the calibration values in Table 41 no DGA history data is available the default factor is considered to be 1.

Table 41 Transformer DGA History Factor Calibration Values

% Change (Principal/Average Score	Change Category	DGA History Factor
-1000 – 95	Negative	0.95
95 – 105	Neutral	1.00
105 – 125	Small	1.05
125 – 200	Significant	1.10
200 – 1000	Large	1.20

3.2.8 FFA End of Life Indicator (Transformer Main Tank Only)

The FFA End of Life Indicator is derived from the level of 2-furfuraldehyde (FFA) in oil. Furfuraldehyde is one of a family of compounds (furans) produced when the cellulose (paper) within the transformer degrades. As the paper ages, the cellulose chains progressively break, reducing the mechanical strength.

The average length of the cellulose chains is defined by the degree of polymerisation (DP) which is a measure of the length of chains making up the paper fibres. In a new transformer, the DP value is approximately 1000. When this is reduced to approximately 250, the paper has very little remaining strength and is at risk of failure during operation.

There is an approximate relationship between the value of furfuraldehyde in the oil and the DP of the paper, which has been established experimentally by the industry. A value of 5ppm of FFA is indicative of paper with a DP of approximately 250. For this reason, the FFA End of Life Indicator is calibrated to give a value of 7 for a FFA value of 5; this empirical relationship has been mathematically described as shown in the following equation:

$$EoL_{FFA} = FFA_{multiplier}\ x\ FFA_{MAX}{}^{FFAPV}$$

Equation 2

Where:

$FFA_{multiplier} = 2.33$

$FFAPV = 0.68$ (FFA Power Value)

$FFA_{MAX} = Maximum\ level\ of\ FFA\ in\ ppm$

The FFA EOL maximum is set to 10.

3.3 Underground Cable Models

Within this implementation of the methodology, transmission cables are considered as a number of discrete cable lengths which, together, form a distinct circuit.

There are two separate underground cable models reflecting the following types of construction:

- oil;
- non-pressurised

3.3.1 Visual Condition

Table 42 Underground Cable Visual Condition Factors and Minimum EOLs

Condition Point	Condition Factors					Minimum EoLs				
	Condition Score					Condition Score				
	1	2	3	4	5	1	2	3	4	5
Tank Condition	1.0	1.0	1.1	1.3	1.4	0.5	0.5	5.5	6.5	8.0
Earthing and Bonding	1.0	1.0	1.1	1.3	1.4	0.5	0.5	5.5	6.5	8.0

3.3.2 Defect History

At this time there is insufficient evidence to support the correlation of defect data with an increased probability of asset failure. As such a factor of 1 and minimum EoL of 0.5 is used for all assets as part of the subsequent calculation steps.

3.3.3 Generic Reliability

Reliability of specific groups or families of assets is determined by SP-T using its experience of assets in operation. A reliability rating (from 1-4, with 1 being Very Reliable and 4 being Very Unreliable) is assigned on the following basis:

- oil cables - metallic screening type / armour type and period of manufacture;
- non-pressurised cables - armour type / insulation type and period of manufacture; and

The reliability rating is then linked to a Generic Reliability Factor and a minimum EOL value via calibration tables as shown in table below:

Table 43 Underground Cables Generic Reliability Factor and Minimum EoL

Oil Cables		
Reliability Rating	Generic Reliability Factor	Minimum EoL
1	1.00	0.5
2	1.10	0.5
3	1.25	6.5
4	1.40	8.0

Non-Pressurised Cables		
Reliability Rating	Generic Reliability Factor	Minimum EoL
1	1.00	0.5
2	1.10	0.5
3	1.25	0.5
4	1.40	8.0

All oil cables have been assigned a generic reliability rating of 1 (very reliable) and non-pressurised cables have been assigned a generic reliability rating of 2 (normal).

3.3.4 Test Results

The results from a number of tests such as partial discharge (PD) tests, sheath and moisture tests can be considered within the model. The calculation steps for each test type are the same and use 3 different measures to calculate each Test Score. The Overall test score for each of the test is calculated as described below:

(1) Test Score 1 is produced via a lookup based on the latest result; the calibration values are shown in table below:

Table 44 Underground Cables Calibration Values for Test Score 1

Rating	Latest Result	Test Score 1
1	Pass	0
2	Suspect	4
3	Fail	10

(2) Test Score 2 is based on the number of previous results with rating 1, 2 and 3; the calibration values are shown in table below:

Table 45 Underground Cables Calibration Values for Test Score 2

Classification	Test Score 2
All previous test results are rating 1 (pass)	0
One previous test result with rating 2 (suspect) or only one previous test result present (regardless of result)	1
No previous results	2
One previous test result with rating 3 (fail) or more than one with rating 2 (suspect).	4
More than one previous test result with rating 3 (fail)	6

(3) Test Score 3 is derived from the generic rating of the asset which is based on the cable type. All cable types have been assigned a score of 1.

(4) The Test Overall Score is then calculated as follows:

$$Test\ Overall\ Score = (Test\ Score\ 1 + Test\ Score\ 2) \cdot Test\ Score\ 3 \qquad \textbf{Equation 3}$$

(5) The Test Factor and minimum EoL are then derived via range lookups in calibration tables as shown in table below:

Table 46 Underground Cables Calibration Values for Test Score 3

Test Overall Score	Test Factor	Minimum EoL
>-1 – 0	0.95	0.5
>0 – 2	1.00	0.5
>2 – 4	1.075	0.5
>4 – 5	1.15	0.5
>5 – 8	1.225	5.5
>8+	1.30	8.0

The calibration values in the above tables have been set to be the same for PD tests, sheath and moisture tests.

The Overall Combined Test Factor is derived from the partial discharge (PD) tests, Sheath Test and Moisture Tests Factor using the ' Maximum and multiple Increment (MMI)' method as described in the NARA. The Overall Combined Test Minimum EoL is the maximum the minimum EoL values obtained for each test type.

Table 47 Cable Combined Test Factor MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	1
Min Divider	0.5
Max Boundary	1
Max Number of Combined Factors	3

3.3.5 Operational Restrictions

Operational restrictions are not considered by SPT as being indicative of the current asset health for cable system. As such this parameter is not used within the SPT methodology at present. As such this factor is set to 1, with a min EOL of 0.5 for all assets.

3.3.6 Fault History

At present, based on the classification of historic asset performance SPT do not differentiate between cables based on their fault history. As such this factor is set to 1, with a min EOL of 0.5 for all assets. Differentiation of assets is made by measured and observed condition alongside generic reliability.

3.3.7 Leak History (Oil Cables Only)

The leak history information for a particular circuit is used to determine a Leak History Factor and an associated minimum EoL for each cable section based on the oil top-ups over a 10-year period.

A weighted total volume of top-ups is calculated by multiplying the volume of oil added each year by a weighting factor; this ensures that more recent top-ups have a greater effect on the value of the Leak History Factor and the minimum EoL. Weighting factors for each year (where year 1 is the current year) are shown in the following table:

Table 48 Underground Cable Oil Volume Top-ups Weighting Factors

Year	Weighting Factor (F_w)
1	1.00
2	0.95
3	0.90
4	0.85
5	0.80
6	0.75
7	0.70
8	0.65
9	0.60
10	0.55

Each of the ten weighted values are summed and divided by the square root of the hydraulic section length as follows:

$$F_i = \frac{\sum_{j=1}^{10} \left(Vol_{cct,i,j} \cdot F_w \right)}{\sqrt{Length_i}}$$ **Equation 4**

Where:

F_i = Weighted volume of oil top-ups for cable section i

$Vol_{cct,i,j}$ = Volume of oil top-ups for cable section i in year j in litres

$Length_i$ = Hydraulic length of cable section i in metres

The initial leak history factor and minimum EoL are then generated from calibration tables. The number of leaks scaling factor and corresponding minimum EoL are also generated from range look-up tables as shown below:

Table 49 Underground Cables Weighted Leaks Calibration Values

Initial Leak History Factor		
Weighted Volume of Top-up	Initial Leak History Factor (F_{ilh})	Minimum EoL
0 – 2	1.00	0.5
2 – 10	1.10	0.5
10 – 20	1.15	0.5
20 – 40	1.20	6.5
40 – 80	1.25	8.0
80+	1.30	8.0

Number of Leaks Scaling Factor		
Number of Leaks	Scaling Factor (F_{sf})	Minimum EoL
1 – 3	1.0	0.5
3 – 6	1.1	0.5
6 – 10	1.2	6.5
10 - 20	1.3	8.0

The final Leak History Factor, F_{LH}, is the product of the initial leak history factor and the number of leaks scaling factor as follows:

$$F_{LH} = F_{ilh} \cdot F_{sf}$$ **Equation 5**

The final Leak History Minimum EoL is the largest of the initial leak history minimum EoL and the number of leaks minimum EoL.

3.3.8 Overall Factor Value

Table 50 Underground Cable Overall Factor Value MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	2
Min Divider	2
Max Boundary	1
Max Number of Combined Factors	4

3.4 Overhead Lines Model

Within this implementation of the methodology, the overhead lines model is a composite model, whereby health indices, probability of failure and risk are derived separately for the following three lead assets:

- conductors
- fittings
- towers

In combination, the three asset types are representative of an entire overhead line circuit.

The derivation of the End of Life Indicator and criticality factors, including details of the agreed calibration values are provided in the following sections.

3.4.1 Conductors

The model determines the End of Life Indicator of phase conductors on each circuit on the forward span of the tower.

3.4.1.1 Intermediate End of Life Indicator, EoL_2

The EOL2 calculation, introduces more specific asset information pertaining to observed condition, inspection surveys, maintenance test results and operators experience.

The inputs and calibration values used to calculate the Overall Factor, FV1, are described in the following sections.

3.4.1.1.1 Condition

The condition points included in the model and the corresponding factors and minimum EoLs are shown in tables bellow:

Table 51 Overhead Line Conductor Condition Factors and Minimum EoLs

Conductor Condition Factor		
Score	Factor	Minimum EoL
1	1.0	0.5
2	1.0	0.5
3	1.0	0.5
4	1.5	8.0

Spacers' Condition Factor		
Score	Factor	Minimum EoL
1	1.0	0.5
2	1.0	0.5
3	1.0	0.5
4	1.5	8.0

Mid-span Joints Factor		
Description	Factor	Minimum EoL
Yes	1.1	0.5
No	1.0	0.5

The condition factors are combined using the 'Modified Max and Increment' combination method as described in the NARAs to determine the Overall Condition Factor.

The Overall Condition Minimum EoL is the maximum of the individual condition minimum EoLs.

Table 52 Overhead line Conductors Visual Condition MMI Calculation Parameters

MMI Calculation Term	Value
Condition Max Divider	4
Condition Min Divider	3
Condition Max Boundary	1
Max Number of Combined Factors	5

3.4.1.1.2 Tests

SP-T does not currently consider any additional test for conductors other than Cormon and Sample testing, as such this parameter is not used within the SPT methodology at present. As such this factor is set to 1, with a min EOL of 0.5 for all assets.

3.4.1.1.3 Generic Reliability

There are no known reliability issues; the Generic Reliability Factor and Minimum EoL have been set to 1 and 0.5 respectively.

3.4.1.1.4 Defect History

The defect description and corresponding severity points are shown in table below:

Defect Description	Defect Severity
Jumper not uniform	1
Downleads stay earthing damaged	1
Hot spots	1
Fibre optic conduit on down leg damaged	1
Conductor out of regulation	1
Spacers Damaged	1
Dampers damaged/missing	1
Jumper damaged	1
Conductor Damaged	1
Jumper Spacers damaged	1

Each of the recorded conductor defects from the past 5 years is assigned a severity score (using a scale of 1-4, where 4 is the most severe) via a calibration table above.

The severity scores are summed and the total score used to derive the Defect History Factor and minimum EoL via calibration tables as shown in table below:

Table 53 Overhead Line conductor Calibration of Defect History and Minimum EOL

Total Defect Score	Defect History Factor	Minimum EoL
0 – 2	1.00	0.5
2 – 10	1.05	0.5
10 – 20	1.10	0.5
20 – 35	1.25	0.5
>35	1.50	0.5

3.4.1.1.5 Overall Factor Value

The condition factors are combined using the 'Modified Max and Increment' combination method as described in the NARAs to determine the Overall Condition Factor.

The Overall Condition Minimum EoL is the maximum of the individual condition minimum EoLs.

Table 54 Overhead Line Conductor Overall Factor Value MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	2
Min Divider	2
Max Boundary	1
Max Number of Combined Factors	3

3.4.1.2 Cormon End of Life Indicator

The tests results are conducted on a span or number of spans and then applied to the whole circuit. The test results (good, partial, sever and percentage of span in each category) are converted to a 1 to 5 score and this is used to derive a Cormon End of Life Indicator via a calibration table as shown in table below:

Table 55 Calibration of Overhead line conductor Cormon EoL

Cormon Score	Cormon EoL
1	0.5
2	4.0
3	5.5
4	6.5
5	8.0

3.4.1.3 Conductor Sample End of Life Indicator

The tests results are conducted on a span or number of spans and then applied to the whole circuit. The test results are converted to a 1 to 5 score and this is used to derive a Conductor Sampling End of Life Indicator via a calibration table as shown in table below:

Table 56 Calibration of Overhead line Conductor Sample EoL

Conductor Sampling Score	Conductor Sample EoL
1	0.5
2	4.0
3	5.5
4	6.5
5	8.0

3.4.2 Fittings

The Fittings End of Life Indicator is derived from two condition-based health indices, $EoL_{(a)}$ and $EoL_{(b)}$, and an age-based initial End of Life Indicator, $EoL_{(c)}$. The Calibration required for the derivation of these health indices can be found in the following sections.

3.4.2.1 Derivation of Fittings EoL(a) and EoL(b)

Each of the ten observed condition ratings is assigned a condition score via a series of calibration lookup tables as shown below:

Table 57 Calibration of Overhead Line Fittings Condition Scores

Insulators Electrical	
Rating	Score
1	0
2	10
3	20
4	40

Insulators Mechanical	
Rating	Score
1	0
2	10
3	20
4	40
5	70

Arcing Horns	
Rating	Score
1	0
2	10
3	20
4	40
5	70

Jumpers	
Rating	Score
1	0
2	10
3	20
4	40

Vibration Dampers	
Rating	Score
1	0
2	10
3	20
4	40
5	70

U-bolts / Tower Attachments	
Rating	Score
1	0
2	10
3	20
4	40
5	70

Shackles or Links	
Rating	Score
1	0
2	10
3	20
4	40
5	70

Suspension Clamps	
Rating	Score
1	0
2	10
3	20
4	40
5	70

Tension Clamps	
Rating	Score
1	0
2	10
3	20
4	40
5	70

Conductor at Clamps	
Rating	Score
1	0
2	10
3	20
4	40
5	70

3.4.2.2 Current End of Life Indicator

Firstly, an interim End of Life Indicator for the fittings (i.e. in the year of inspection) is derived, then the current EOL is then derived by ageing the interim End of Life Indicator as per the NARA.

3.4.3 Towers

3.4.3.1 Steelwork End of Life Indicator

The Steelwork End of Life Indicator is derived from two condition-based health indices, $EoL_{(a)}$ and $EoL_{(b)}$, and an age-based initial End of Life Indicator, $EoL_{(c)}$. The calibration values required for the derivation of these health indices can be found in the following sections.

3.4.3.1.1 Derivation of Steelwork $EOL_{(a)}$ and $EOL_{(b)}$

Each of the ten observed condition ratings is assigned a condition score via a series of calibration lookup tables as shown below:

.

Table 58 Calibration of Tower Steelwork Condition Scores

Tower Legs	
Rating	Score
1	0
2	10
3	20
4	40
5	90

Step Bolts	
Rating	Score
1	0
2	5
3	10
4	15

Bracing	
Rating	Score
1	0
2	7
3	15
4	20
5	60

Cross-arms	
Rating	Score
1	0
2	7
3	15
4	30
5	60

Peak	
Rating	Score
1	0
2	7
3	15
4	30
5	60

Steelwork	
Rating	Score
1	0
2	7
3	15
4	20

3.4.3.1.2 Steelwork Current End of Life Indicator, EoL_{Y0}

The derivation of the Steelwork Current End of Life Indicator is explained in the corresponding section of the NARA.

The Min EOL_{yo} for very good condition is set to 2.

The Steelwork Current End of Life Indicator is then derived by ageing the interim End of Life Indicator.

3.4.3.2 Foundation End of Life Indicator

An End of Life Indicator is calculated for each set of tower foundations for each tower position. The model uses information relating to the type of foundation and the environment in which the foundation is situated, along with more specific foundation test results and inspection information as explained in the NARA. .

3.4.3.2.1 Initial End of Life Indicator, EOL1

The calculation of the Overall Location Factor is explained in the NARA and the calibration values used can be found in section 2.

3.4.3.2.2 Intermediate End of Life Indicator, EoL_2

The second calculation stage, i.e. to find EoL_2, introduces more specific asset information pertaining to observed condition, inspection surveys, maintenance test results and operators experience.

The inputs and calibration values used to calculate the Overall Factor, FV1, can be found in the following sections.

3.4.3.2.2.1 Condition

The condition points included in the model and the corresponding factors and minimum EoLs are shown in tables below:

Table 59 Tower Foundation Condition Factors and Minimum EoLs

Concrete Condition Factor		
Score	Factor	Minimum EoL
1	0.8	0.5
2	0.9	0.5
3	1.0	0.5
4	1.1	0.5

Muff Paint Condition Factor		
Score	Factor	Minimum EoL
1	0.9	0.5
2	1.0	0.5
3	1.1	0.5
4	1.2	0.5

Painted Factor		
Description	Factor	Minimum EoL
Yes	0.9	0.5
No	1.0	0.5

The condition factors are combined using the ‘Modified Max and Increment’ combination method as described in the NARA to determine the Overall Condition Factor. The Overall Condition Minimum EoL is the maximum of the individual condition minimum EoLs.

Table 60 Tower Foundation Condition Factor Value MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	4
Min Divider	3

Max Boundary	1
Max Number of Combined Factors	5

3.4.3.2.2.2 Tests

SPT have recently introduced verticality tests to detect towers that have moved out of vertical. A Test Factor and corresponding minimum EoL are derived based on the measured angle of verticality (on a pass/fail basis).

At present there is no test data in the model and, hence, this element of the model will need to be calibrated when data becomes available.

3.4.3.2.2.3 Generic Reliability

There are no known reliability issues; the Generic Reliability Factor and Minimum EoL have been set to 1 and 0.5 respectively.

3.4.3.2.2.4 Overall Factor Value

Table 61 Tower Foundations Overall Factor Value MMI Calculation Parameters

MMI Calculation Term	Value
Max Divider	4
Min Divider	3
Max Boundary	1
Max Number of Combined Factors	5

3.4.3.2.3 Foundation Current End of Life Indicator, EoL_{Y0}

The derivation of the Current End of Life Indicator can be depicted as shown and is determined as described in the NARA.

4. Forecasting end of life

4.1 Final Ageing Rate

The age threshold for recalculating the ageing rate (Age_{recalc}) and the $\beta_{MAXratio}$ are as per table:

Table 62 Age threshold for recalculating the ageing rate

Asset	Recalculation Age Threshold	Maximum β Recalculation Ratio ($\beta_{MAXratio}$)
Circuit Breaker	10	1.5
Transformers and Reactors	15	1.5
Conductors	10	1.5
Cable (Non-Pressurised)	15	1.5
Cable (oil)	10	1.5
Towers	10	1.5
Fittings	10	1.5

5. Determination of k

The values of k by asset class and failure mode are presented table below. These values were calculated using historical SPT failure data over the period 2009 to 2015 (i.e. over 7 years) where failures have been recorded. Where no failures have occurred over this time period, it is necessary to estimate the "expected" failure rate as described above. Note that these values can change as improved historical data is collected.

Table 63 Calibration values for k per Failure mode

Asset Class	k values per failure mode			
	Defect	Minor	Significant	Major
Circuit Breakers	1.074366E-04	1.161830E-05	9.007446E-06	1.670947E-05
Transformers	1.293121E-03	7.645811E-04	9.569225E-06	6.060509E-06
Reactors	1.293121E-03	7.645811E-04	9.569225E-06	6.060509E-06
Oil Cables	1.110000E-05	2.900000E-07	2.230000E-07	1.500000E-07
Non-Pressurise Cables	N/A	N/A	5.640000E-10	9.740000E-10
OHL (conductors)	N/A	1.118000E-07	2.758700E-08	6.170000E-09
OHL (fittings)	N/A	5.370730E-04	1.537380E-04	6.224200E-05
OHL (towers)	2.609460E-04	2.158480E-05	6.149160E-06	2.057680E-06

6. Consequence Of Failure

6.1 System Consequence

6.1.1 Customer Disconnection Methodology

The customer disconnection consequences of failure are derived by considering the following three elements that contribute to the total disconnection cost:

- the economic value of load not supplied to customers, referred to as the Value of Lost Load (VOLL);
- the cost of compensating generators disconnected from the transmission system; and
- the cost of paying additional generators to replace the power from disconnected generation.

The customer disconnection consequences of failure, $R_{customer}$, is derived using Equation 6 below.

$$R_{customer} = P_{oc} \cdot [G_c + G_R + (k_1 \cdot D \cdot MW_D \cdot VOLL) + V] \cdot M_Z$$ **Equation 6**

The variables used to derive the customer disconnection consequences of failure, $R_{customer}$, are identified below.

Table 64 Customer Disconnection Consequences of Failure

Variable	**Description**	**Variable Type**
P_{oc}	Probability of Disconnection. The probability of customers being disconnected as a result of a failure.	Asset specific variable.
G_c	Generation Disconnection Cost. The compensation payments made to generators that need to be constrained off (£).	Asset specific variable, dependent on the length of time the asset is unavailable.
G_R	Generation Replacement Cost. The payments made to generators that are constrained on to replace generators affected by the failed asset (£).	Asset specific variable, dependent on the length of time the asset is unavailable.
k_1	Total annual transmission demand (MWh) divided by the number of hours in a year and the winter peak demand (MW)	A calculated setting (a single value to be used across all models, with an initial value 0.75).
D	Customer Disconnection Duration. The duration for which customers are disconnected following asset failure (hours).	Asset specific variable, calculated for each failure mode.
MW_D	Volume of Disconnected Demand. Total adjusted winter peak demand connected to the sites at risk (MW).	Asset specific data input.
$VOLL$	Value of Lost Load. The economic value assigned to load not supplied to customers (£/MWh)	Calibration value; a single value to be used by both SPT and SHET across all models.
V	Vital infrastructure site disconnection cost (£).	Asset specific variable.
M_Z	Risk Multiplier. To reflect the risk of customer disconnections due to other combinations of circuit losses.	Asset specific variable.

The asset specific data inputs required for deriving the customer disconnection consequences of failure are listed below.

Table 65 Customer Disconnection Consequences of Failure Asset Specific Data Inputs

Ref	Data Point Reference	Description / Notes
T5	MW_D	Volume of Disconnected Demand (MW). This data point depends on the connectivity of the asset. The value is assumed to be constant for the purposes of deriving future risk.

The calibration table for setting the constants used to derive the generation replacement cost is shown below.

Table 66 Calibration Table for Customer Disconnection Consequences of Failure

Setting Item	Value
$VOLL$	£24,789

6.1.1.1 Probability of Disconnection, P_{oc}

The probability of a generator or consumer being disconnected, P_{oc}, is a function of five probabilities and the number of circuits left supplying a customer connection site after a failure of an asset.

Table 67 Probability of Disconnection Variables

Variable	Description	Variable Type
P_o	The probability of a coincident outage occurring on another circuit	A variable set according to the P_o subgroup that the asset is assigned to, via a calibration table.
P_d	The probability of damage occurring on another circuit	A variable set by the asset failure mode, using a calibration table specific for each model.
P_m	The probability of maloperation on another circuit	A single calibration value, used across all models and for all failure modes.
P_f	The probability of a coincident fault on another circuit	A variable set by the circuit that the asset is associated with, using a calibration table.
P_l	The probability of overloading the remaining circuit	An asset specific input value.
N_o	The probability of no coincident outage occurring on another circuit	Calculated value, $N_o = 1 - P_o$
N_d	The probability of no damage occurring on another circuit	Calculated value, $N_d = 1 - P_d$
N_m	The probability of no maloperation on another circuit	Calculated value, $N_m = 1 - P_m$
N_f	The probability of no coincident fault on another circuit	Calculated value, $N_f = 1 - P_f$
N_l	The probability of no overloading the remaining circuit	Calculated value, $N_l = 1 - P_l$
X_{min}	Constrained maximum value for X	Asset specific variable, derived using Equation 7.

The asset specific data inputs required for deriving the probability of overload are listed below.

Table 68 Probability of Overload Outage Asset Specific Data Inputs

Ref	Data Point Reference	Description / Notes
T15	P_f	Probability of overload occurring, required for deriving P_{oc} where X_{min} = 3

The calibration table for setting the constants used to derive the probability of disconnection is shown in table below:

Table 69 Calibration Table for P_m

Setting Item	Value
P_m	*0.01*

6.1.1.1.1 Probability of a coincident outage

The probability of a coincident outage, P_o, reflects the likelihood that there is a planned outage on the network at the time of the asset failure. The unavailability of the surrounding network will depend upon the maintenance policy of the assets, i.e. the frequency / duration of maintenance activities requiring a planned outage. This value may vary from asset to asset depending upon its network connectivity. Given the way in which outages are coordinated by the System Operator, at this time, all assets have been considered to have a common probability of coincident outage and as such have been allocated to one single group. A lookup is retained here should the coordination of system outages justify any subdivision of this parameter in the future.

Table 70 Probability of Coincident Outage Calibration Table

P_o Subgroup	P_o
Group 1	0.0305

6.1.1.1.2 Probability of damage to another circuit

The probability of damage occurring to an adjoining circuit depends on the failure mode of the asset and is set via the calibration table below.

Table 71 Probability of Damage Calibration Table

Failure Mode	P_d
Defect	0
Minor	0
Significant	0
Major	0.01

6.1.1.1.3 Probability of coincident fault on another circuit

An estimation of the probability of a coincident fault occurring (or having already occurred) on another circuit, at the time of the asset failure being modelled, is expressed through the variable P_f. This could be a weather-related fault or a condition-related fault on another circuit. Using historical network information, the parameter P_f has been assigned a value of 0.066.

6.1.1.1.4 Probability of Overloading Remaining Circuit

Given current network operating parameters the probability of an asset failure causing a subsequent overloading of any remaining circuit has been set to 0.

6.1.1.1.5 Derivation of constrained maximum value of X for an asset, $\boldsymbol{X_{min}}$

X_{min} is the constrained maximum value for X and reflects the fact that once there are four more circuits in parallel supplying a site, the additional circuits do not necessarily decrease the probability of losing customers. This is attributed to the fact that the capacity of the remaining circuits will not be sufficient to meet the import/export of the customers at risk, and there is significant risk of cascade tripping of any remaining circuits due to overloading. For this reason, the Methodology stipulates a maximum value for X_{min}, X_{max} of 3.

Thus, X_{min} can be derived using Equation 7 below.

$$X_{min} = minimum[X_{max}, X]$$ **Equation 7**

The variables used to derive X_{min} for each asset are shown below.

Table 72 Number of Parallel Circuits Variables

Variable	Description	Variable Type
X	Maximum number of circuits supplying customer connection site or group of sites less the circuits tripped as a result of failure.	Asset specific variable set by failure mode.
X_{max}	Maximum value for X.	System Setting.

X is the number of parallel circuits supplying customer site(s) less the number of circuits tripped as a result of the failure mode of the asset.

For the majority of assets, the number of circuits that can potentially be tripped as a result of the failure of the asset is one. The exceptions to this include assets such as towers, bus sections and bus couplers. In addition, the number of circuits tripped will depend on the failure mode of the asset. For example, consider the following failure mode definitions for steel towers:

- Defect: Failure requires a repair, however does not either cause or require an outage.
- Minor: Failure does not cause an unplanned outage but requires a planned outage for repairs to be undertaken.
- Significant: Failure causes an unplanned outage but can be repaired; e.g. failure of a single cross-arm.
- Major: Failure causes an unplanned outage and tower needs to be rebuilt; e.g. a tower collapse.

Therefore, no circuits will be tripped in the case of a defect (no unplanned) outage. For a minor failure, one circuit will require a planned outage. In the case of significant and major failures, there will be an unplanned outage. If the tower supports multiple circuits, there is a possibility that more than one circuit will be affected by the failure.

Therefore, it is proposed that X is derived for each asset and for each failure mode using the following equation.

$$X = [N_{ccts,cust} - minimum\ (N_{trip,max}, N_{ccts,asset}]$$ **Equation 8**

Table 73 X Variables Description

Variable	Description	Variable Type
$N_{ccts,customer}$	The number of parallel circuits supplying customer site(s)	Asset specific data input.
$N_{ccts,asset}$	The number of circuits directly connected to the asset	Asset specific data input
$N_{trip,max}$	The maximum number of circuits tripped in the event of the failure of the asset.	A variable set by the asset failure mode, using a specific calibration table for each model. See below for details.

The maximum number of circuits tripped in the event of the failure of asset $\boldsymbol{N_{trip,max}}$ is given per failure mode in the table below:.

Table 74 Calibration Table for Maximum Number of Circuits Tripped

Failure Mode	Circuit Breaker	Transformer & Reactor	Cable (Non-Pressurised)	Cable (Pressurised)	OHL Conductor	OHL Fittings	OHL Tower
Defect	1	1	0	1	0	0	0
Minor	1	1	0	1	1	1	2
Significant	1	1	1	1	1	1	2
Major	1	1	1	1	1	1	2

6.1.1.2 Customer Disconnection Duration, $\boldsymbol{D}$

The customer disconnection duration, D, is derived from six separate durations

Table 75 Duration of Disconnection Variables

Variable	Description	Variable Type
D_{fm}	Duration of failure mode unavailability (hours)	Calibration value based on asset class (i.e. per model), asset voltage and failure mode.
D_o	Outage restoration time (hours)	A variable set using the subgrouping used to assign a Po value to each asset. See below for details
D_d	Circuit damage restoration time (hours)	A variable set by failure mode. See below for details
D_m	Protection maloperation restoration time (hours)	A single calibration value, used across all models and all failure modes. See below for details.
D_f	Unrelated fault restoration time (hours)	A variable set by the circuit that the asset is associated with. See below for details.
D_l	Circuit overload restoration time (hours)	A single calibration value used across all models and all failure modes. See below for details.
P_o, P_d, P_m, P_f and P_l	Probabilities of coincident outage, damage, maloperation, coincident fault and overloading.	See section 6.1.1.1 for details.
N_o, N_d, N_m, N and N_l	Probabilities of no coincident outage, damage, maloperation, coincident fault and overloading.	
X_{min}	Constrained maximum value for X	Asset specific variable derived using Equation 7.

The asset specific data inputs required for deriving the probability of disconnection are shown below.

Table 76 Duration of Disconnection Asset Specific Data Inputs

Ref	Data Point Reference	Description / Notes
T10	Duration Unavailability Subgroup	Dependent upon asset class
T11	Impacted Circuits	The circuits associated with each asset in the event of a failure. Used to assign the probability of a coincident fault to each asset depending on the circuit associated with the asset.
T9	P_o Subgroup	The subgroup division for deriving P_o. Used to assign the probability of a planned outage being in place at the time of asset failure depending on the unavailability of associated assets.

Table 77 Duration of Unavailability, D_{fm}

		Failure Mode			
Asset Type	Voltage (kV)	Defect	Minor	Significant	Major
Circuit Breaker	132	0	24	240	480
	275	0	24	240	480
	400	0	24	240	480
Transformer & Reactor	132	0	24	240	480
	275	0	24	240	480
	400	0	24	240	480
Cable (Non-Pressurised)	132	0	24	240	480
	275	0	24	240	480
	400	0	24	240	480
Cable (Pressurised)	132	0	24	240	480
	275	0	24	240	480
	400	0	24	240	480
OHL Conductor	132	0	24	240	480
	275	0	24	240	480
	400	0	24	240	480
OHL Fittings	132	0	24	240	480
	275	0	24	240	480
	400	0	24	240	480
OHL Tower	132	0	24	240	480
	275	0	24	240	480
	400	0	24	240	480

The calibration table for setting the remaining constants used to derive the duration of disconnection are shown in the following tables.

Table 78 Restoration Time for Coincident Outage Calibration Table

P_o Subgroup	D_o
Group 1	*24*

Only one group is defined here in line with the categorisation of Coincident Outages, as set out for the P_o term, above.

Table 79 Calibration Table for Duration of Disconnection

Setting Item	Value (hours)
D_d	168
D_m	2
D_f	84
D_l	2

Table 80 Circuit Damage Restoration Time Calibration Table

Failure Mode	Circuit Damage Restoration Time (Hours)
Defect	*168*
Minor	*168*
Significant	*168*
Major	*168*

6.1.1.3 Generation Disconnection Cost, G_c

The calibration table for setting the constants used to derive the generation disconnection cost is shown below.

Table 81 Calibration Table for Generation Disconnection Cost

Setting Item	Value
Annual TNUoS charge for all generators (£)	*842m*
Total TEC of all generation on the system (MW)	*72,443*
C_{SMP}	*181.73*
C_{SBP}	*183.92*

6.1.1.4 Generation Replacement Cost, G_R

The calibration table for setting the constants used to derive the generation replacement cost is shown below.

Table 82 Calibration Table for Generation Replacement Cost

Setting Item	Value
C_{SMP}	*181.73*
Total Annual Transmission Demand (MWh)	*320,700,000*
Total Energy Generated in a Year (MWh)	*240,564,175*

Winter peak demand 48600(MW) (50Hours per year)

k1 and k3 are calculated values and are defined as per below:

k1 = Total annual transmission demand (MWh) divided by the number of hours in a year and the winter peak demand (MW)

k3 = Total energy generated in a year (MWh) divided by the number of hours in a year and the total TEC of all generation on the system (MW)

6.1.1.5 Vital Infrastructure Cost, V

The calibration table for setting the constants used to derive the Vital Infrastructure Site Disconnection Cost is shown in below.

Table 83 Calibration Table for Vital Infrastructure Site Disconnection Cost

Setting Item	Value
V_T	£1.86 m / hour
V_E	1.44 m / hour
V_C	16.97 m / event

6.1.2 Boundary Transfer Methodology

The calibration table for setting the constants used to derive the boundary constraint cost for any given number of circuits rendered unavailable following the fault is shown below.

Table 84 Calibration Table for Annual Constraint Costs-example

Annual Intact Cost (£m)	**456**		
	Boundary Value		
Setting Item	[redacted]	[redacted]	[redacted]
Annual N-1 cost (£m)	[redacted]	[redacted]	[redacted]
Annual N-2 cost (£m)	[redacted]	[redacted]	[redacted]

Table 85 Calibration Table for Probabilities of Boundary Depletion - example

Boundary	P_{Y+1}
B6	*0.113*
B5	*0.113*
B4	*0.113*

6.1.3 Reactive Compensation Methodology

Table 86 Calibration table for C_{MVArh}

Requirement	Setting Item
Annual sum of all costs to absorb MVArs (£)	392
Sum of MVArhs absorbed over the year	100

6.2 Safety Consequence

The approach for deriving the safety consequences of failure (CoF)[2] is set out in Section 3.2 of the Transmission NOMs Methodology. The safety consequences of failure are derived for each failure mode using Equation 9.

$$R_{Safety,i} = Exposure.\sum_{j}\left(P_{injury,j,i}.C_{injury,j}\right)$$

Equation 9

The variables used in Equation 9 are described in table below.

Table 87 Safety Consequences of Failure Variables

Variable	Description	Variable Type
j	Injury type	System settings, aligned to requirements of the Methodology, i.e. minor injury, lost time injury, major injury and fatality.
i	Failure mode	The failure modes specified in the relevant asset model, e.g. minor, significant, major.
$P_{injury,j,i}$	Probability of injury j occurring for failure mode i	Calibration values set by failure mode for each asset class. See section 6.2.1 for details.
$C_{injury,j}$	The cost associated with injury j (£)	Standard industry wide calibration figures. See Section 6.2.2 for further information.
$Exposure$	Exposure modifier to reflect the number of people who are exposed to the effects of an asset failure.	Asset specific variable derived from proximity of the asset to public and staff and the characteristics of the asset. Further information is provided in Section 6.2.3.

[2] Referred to as the Safety Cost in the Methodology.

6.2.1 Probability of Injury

The safety consequences of failure are quantified by considering the impact associated with the following categories of injuries:

- Fatality;
- Permanently incapacitating injury;
- Serious injury; and
- Slight injury.

The probability of injury represents the likelihood that an individual is injured when exposed to the effects of asset failure. The probabilities are assigned to each injury type for each failure mode via a calibration table of the form shown in table below. The values in the table will be set by each TO, based on experience of the effects of different failures.

Table 88 Calibration Table for Probability of Injury, P_{injury}

		Failure Mode			
Asset Type	Failure Mode	Slight Injury	Serious Injury	Permanent Incapacitation	Fatality
Circuit Breaker	Defect	4.164E-05	1.065E-04	1.065E-04	1.065E-04
	Minor	8.329E-05	2.130E-04	2.130E-04	2.130E-04
	Significant	2.082E-03	5.324E-03	5.324E-03	5.324E-03
	Major	4.164E-03	1.065E-02	1.065E-02	1.065E-02
Transformer & Reactor	Defect	4.164E-05	1.065E-04	1.065E-04	1.065E-04
	Minor	8.329E-05	2.130E-04	2.130E-04	2.130E-04
	Significant	2.082E-03	5.324E-03	5.324E-03	5.324E-03
	Major	4.164E-03	1.065E-02	1.065E-02	1.065E-02
Cable (Non-Pressurised)	Defect	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Minor	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Significant	2.082E-03	5.324E-03	5.324E-03	5.324E-03
	Major	4.164E-03	1.065E-02	1.065E-02	1.065E-02
Cable (Pressurised)	Defect	4.164E-05	1.065E-04	1.065E-04	1.065E-04
	Minor	8.329E-05	2.130E-04	2.130E-04	2.130E-04
	Significant	2.082E-03	5.324E-03	5.324E-03	5.324E-03
	Major	4.164E-03	1.065E-02	1.065E-02	1.065E-02
OHL Conductor	Defect	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Minor	8.00E-04	1.00E-04	5.00E-05	1.50E-05
	Significant	9.00E-04	1.50E-04	7.50E-05	2.50E-05
	Major	1.00E-03	2.50E-04	1.00E-04	5.00E-05
OHL Fittings	Defect	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Minor	8.00E-04	1.00E-04	5.00E-05	1.50E-05
	Significant	9.00E-04	1.50E-04	7.50E-05	2.50E-05
	Major	1.00E-03	2.50E-04	1.00E-04	5.00E-05
OHL Tower	Defect	8.00E-04	1.00E-04	5.00E-05	1.50E-05
	Minor	9.00E-04	1.50E-04	7.50E-05	2.50E-05
	Significant	1.00E-03	2.50E-04	1.00E-04	5.00E-05
	Major	1.25E-03	3.00E-04	1.50E-04	8.00E-05

6.2.2 Cost of Injury

The cost associated with each injury type is derived using Equation 10. The variables are described in table below:

$$C_{injury,j} = DF.\left(C1_j + C2_j\right) \quad \textbf{Equation 10}$$

Table 89 Cost of Injury Variables

Variable	Description	Variable Type
$C1_j$	Financial cost associated with injury j (£)	Calibration value, representing the total financial cost of injury, to include the productivity cost and the cost of employer liability compulsory insurance.
$C2_j$	Non-financial human cost associated with injury j (£)	Calibration value. A monetary estimate of the loss of quality of life, and loss of life in the case of fatal injuries.
DF	Disproportion factor	Calibration value. recognising the high-risk nature of the Transmission Industry is applied. Such disproportion factors are described by the HSE guidance when identifying reasonably practicable costs of mitigation.

The costs associated each of the categories identified above are set via calibration tables shown below.

Table 90 Calibration Table for Cost of Injury, C_{injury}

	Cost of Injury Sub-division			
Setting value	**Slight Injury**	**Serious Injury**	**Permanent Incapacitation**	**Fatality**
Financial cost	*£0*	*£0*	*£0*	*£0*
Non-financial human cost	*£568*	*£38,789*	*£3,920,503*	*£2,529,405*

Table 91 Calibration Table for Disproportion Factor

Setting value	Value
Disproportion Factor (DF)	10.0

6.2.3 Exposure

The Exposure modifier reflects the number of people who are exposed to the effects of the asset failure. An exposure modifier is assigned to each asset from the following components:

- Activity Level. This represents the number of people (both the public and staff) who could be in the vicinity in the event of asset failure. The derivation of the Activity Level Rating is described in Section 6.2.3.1.
- Type. This represents the characteristics of the asset, including any mitigation measures, and its physical location (based on an evaluation of the surrounding land use). See 6.2.3.2 for further details on the derivation of the Type Safety Rating.

The Exposure Modifier is derived from the Activity Level Rating and Type Rating via a calibration table as shown in table below.

Table 92 Calibration Table for Derivation of Exposure Modifier

		Type Rating		
		Low	**Medium**	**High**
Activity Level	Low	1	2.5	5
	Medium	2.5	6.25	12.5
	High	5	12.5	25

The variables used to derive the Exposure Modifier are listed in Table 93 below.

Table 93 Exposure Modifier Variables

Variable		Description	Variable Type
F_1	Activity level	Factor to reflect the number of people who are potentially exposed to different types of injury and the likelihood they will be present when the failure effect occurs. This reflects the proximity of the asset to the general public and the level of staff activity at the site.	Asset specific variable.
F_2	Type safety rating	A factor to reflect the characteristics of the asset in terms of the likely severity of injury caused by asset failure (i.e. indoor/outdoor, signage, blast walls etc).	Asset specific variable.

6.2.3.1 Activity Level

The activity level rating reflects the number of people who are potentially exposed to different types of injury and the likelihood they will be present when the failure effect occurs. This reflects the proximity of the asset to the general public and the level of staff activity at the site. It is derived using Equation 11 as follows:

$$F_1 = maximum\ (F_{ESQCR}, F_{staff}) \qquad \textbf{Equation 11}$$

Where maximum indicates the 'worst case', or highest risk rating.

The variables used to derive F_1 are listed in Table 94 below.

Table 94 Activity Level Variables

Variable		Description	Variable Type
F_{ESQCR}	ESQCR factor	A factor to reflect the exposure to the public due to the nature and location of the asset.	Asset specific variable derived from the ESQCR rating, using a calibration table of the form shown in table below.
F_{Staff}	Staff activity level factor	A factor to reflect the level of staff exposure to the asset, for example does the site have an office.	Asset specific variable derived from a staff activity level rating, using a calibration table of the form shown in table below.

Table 95 ESQCR Factor Calibration Table

ESQCR Rating	Value
Lower than Normal	*1*
Normal	*2*
Higher than Normal	*3*
High	*3*

Table 96 Staff Activity Level Factor Calibration Table

Staff Activity Level	Value
Low	*1*
Normal	*2*
High	*3*

Table 97 Activity Level Rating Data Inputs

Ref	Data Point Reference	Description / Notes
Existing (*)	ESQCR rating	ESQCR rating, which reflects nature and situation of surrounding land, and hence the risk of danger from interference to the equipment.
T16	Staff Activity Level	Staff activity level, to reflect the exposure levels to employees due to activity levels in proximity to the asset location.

(*) ESQCR is an existing data point. The data point reference varies by TNO and asset type.

Table 98 Overall Activity Level

F_1	Overall Activity Level
1	*Low*
2	*Medium*
3	*High*

6.2.3.2 Type Safety Rating

The type safety rating reflects the characteristics of the asset in terms of the likely severity of injury caused by asset failure. It reflects the nature of the asset (e.g. in the case of switchgear, this would include the interruption medium), and the presence of any mitigation measures such as fire suppression. The type safety rating will depend upon the asset type but will derived from factor F_2 using Equation 12 below.

$$F_2 = (F_a . F_b . F_c) \qquad \textbf{Equation 12}$$

Where $F_a . F_b$ *and* F_c are asset specific type factors, derived from the inputs identified in table below. Up to three inputs, they will be converted into a Factor using calibration tables of the form shown in tables below using a Transformer example.

Table 99 Type safety rating factors- example

Asset Type	F_a		F_b		F_c	
Circuit Breaker	Internally Arc Tested	Factor	Insulating Medium	Factor	n/a	
	Yes	1	SF6	1		
	No	1	Oil	1		
			Air	1		
			Vacuum	1		
Transformer & Reactor	Situation	Factor	Insulating Medium	Factor	Fire Suppression	Factor
	Outdoor	1	Gas	0.8	Yes	1
	Indoor	1	Oil	1	No	1
	Noise Enclosure	1				
	Completely Enclosed	1				
	Main Tank Enclosed	1				
Cable (Non-Pressurised)	Route Nature	Factor	Termination Type	Factor	SF6 Termination	Factor
	Alongside Railway	0.75	Type 1	0.5	Yes	0.75
	Cable Bridge	1	Type 2	0.75	No	1
	Cable Tunnel	1.2	Type 3	1		
	Standard	1	Type 4	1.25		
			Type 5	1.5		
Cable (Pressurised)	Route Nature	Factor	Termination Type	Factor	SF6 Termination	Factor

<table>
<tr>
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<td><table><tr><td>Alongside Railway</td><td>0.75</td></tr><tr><td>Cable Bridge</td><td>1</td></tr><tr><td>Cable Tunnel</td><td>1.2</td></tr><tr><td>Standard</td><td>1</td></tr></table></td>
<td><table><tr><td>Type 1</td><td>0.5</td></tr><tr><td>Type 2</td><td>0.75</td></tr><tr><td>Type 3</td><td>1</td></tr><tr><td>Type 4</td><td>1.25</td></tr><tr><td>Type 5</td><td>1.5</td></tr></table></td>
<td><table><tr><td>Yes</td><td>0.75</td></tr><tr><td>No</td><td>1</td></tr></table></td>
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<tr>
<td>OHL Conductor</td>
<td><table><tr><td>Major Crossing</td><td>Factor</td></tr><tr><td>Yes</td><td>1.1</td></tr><tr><td>No</td><td>1</td></tr></table></td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>OHL Fittings</td>
<td><table><tr><td>Major Crossing</td><td>Factor</td></tr><tr><td>Yes</td><td>1</td></tr><tr><td>No</td><td>1</td></tr></table></td>
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<td>n/a</td>
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<tr>
<td>OHL Towers</td>
<td><table><tr><td>Major Crossing</td><td>Factor</td></tr><tr><td>Yes</td><td>1.2</td></tr><tr><td>No</td><td>1</td></tr></table></td>
<td>n/a</td>
<td>n/a</td>
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</table>

The Type Safety Rating is then derived from factor F_2 using a calibration table of the form shown below.

Table 100 Calibration Table for Type Safety Rating

F_2	**Type Safety Rating**
=<0.75	*Low*
>0.75 and =<1.3	*Medium*
>=1.3	*High*

6.3 Environmental Consequence

The approach for deriving the environmental consequences of failure (CoF)[3] is set out in Section 3.3 of the Transmission NOMs Methodology. The environmental consequences of failure are derived for each failure mode using Equation 13.

$$R_{Environ,i} = Exposure.\sum_{j}(P_{impact,j,i}.C_{impact,j})$$ **Equation 13**

The variables used in Equation 9 are described in table below.

Table 101 Environmental Consequences of Failure Variables

Variable	Description	Variable Type
j	Environmental impact type	System settings, aligned to impact types used, i.e. loss of oil, loss of SF6, probability of fire and waste.
i	Failure mode	The failure modes specified in the relevant asset model, e.g. minor, significant, major.
$P_{impact,j,i}$	Environmental impact j associated with failure mode i	Calibration values set by failure mode for each asset class. See Section 6.3.1 for details.
$C_{impact,j}$	The cost associated with environmental impact j (£)	Calibration values. See Section 6.3.2 for further information.
$Exposure$	Exposure modifier to reflect the type / location of an asset and how this will influence the magnitude of the environmental consequence.	Asset specific variable. Further information is provided in Section 6.3.3.

[3] Referred to as the Environmental Cost in the Methodology.

6.3.1 Environmental Impact

The environmental consequences of failure are quantified by considering the severity of different environmental impacts as follows:

- Volume of oil lost (litres);
- Amount of SF6 lost (kg);
- Probability that the failure results in a fire; and
- Quantity of waste produced (tonnes).

The environmental impact represents the environmental damage that occurs when an asset fails. Values are assigned to each impact type based on the failure mode via a calibration table of the form shown in table below. The values in the table will be set by each TNO, based on experience of the environmental impacts of different failures.

The setting values will be defined by asset class as follows:

- For Transformers, Steel Tower OHLs and Cables, the secondary reporting category will be used to define the asset category.
- For Circuit breakers, the following asset categories will be defined from the secondary reporting category, the insulating medium and whether the asset is AIS or GIS.

Table 102 Calibration Table for Environmental Impact, P_{impact}

			Environmental Impact Category			
Asset Type	Sub Category	Failure Mode	Volume of Oil (litres)	Mass of SF6 (kg)	Probability of Fire	Mass of Waste (tonnes)
Circuit Breaker	132kV Oil	Defect	3068.5	0	0.001	
		Minor	4909.6	0	0.001	
		Significant	6137	0	0.05	
		Major	12274	0	0.1	
	132kV AIS SF6	Defect	0	6.488	0.001	
		Minor	0	10.38	0.001	
		Significant	0	12.975	0.05	
		Major	0	25.95	0.1	
	132kV GIS SF6	Defect	0	9.288	0.001	
		Minor	0	15.48	0.001	
		Significant	0	19.35	0.05	
		Major	0	38.7	0.1	
	132kV Other	Defect	3068.5	8.081	0.001	
		Minor	4909.6	12.93	0.001	
		Significant	6137	16.163	0.05	
		Major	12274	32.325	0.1	
	275kV Oil	Defect	9625	0	0.001	
		Minor	15400	0	0.001	
		Significant	19250	0	0.05	
		Major	38500	0	0.1	
	275kV AIS SF6	Defect	0	11.608	0.001	
		Minor	0	18.572	0.001	
		Significant	0	23.215	0.05	
		Major	0	46.43	0.1	
	275kV GIS SF6	Defect	0	12.525	0.001	
		Minor	0	20.04	0.001	
		Significant	0	25.05	0.05	
		Major	0	50.1	0.1	
	275kV Other	Defect	9625	12.066	0.001	
		Minor	15400	19.306	0.001	

		Significant	19250	24.133	0.05	
		Major	38500	48.265	0.1	
	400kV Oil	Defect	0	0	0.001	
		Minor	0	0	0.001	
		Significant	0	0	0.05	
		Major	0	0	0.1	
	400kV AIS SF6	Defect	0	18.118	0.001	
		Minor	0	28.988	0.001	
		Significant	0	36.235	0.05	
		Major	0	72.47	0.1	
	400kV GIS SF6	Defect	0	55	0.001	
		Minor	0	88	0.001	
		Significant	0	110	0.05	
		Major	0	220	0.1	
	400kV Other	Defect	0	0	0.001	
		Minor	0	0	0.001	
		Significant	0	0	0.05	
		Major	0	0	0.1	
Transformer & Reactor	132kV Transformer	Defect	640	0	0.001	
		Minor	960	0	0.001	
		Significant	3200	0	0.05	
		Major	32000	0	0.1	
	275kV Transformer	Defect	1566.867	25	0.001	0.6135
		Minor	2611.445	250	0.001	6.135
		Significant	7834.335	1000	0.05	24.54
		Major	78343.35	5000	0.1	122.7
	400kV Transformer	Defect	1900.38	16.075	0.001	0.985
		Minor	3167.3	160.75	0.001	9.85
		Significant	9501.9	643	0.05	39.4
		Major	95019	3215	0.1	197
	132kV Reactor	Defect	640	0	0.001	0.016
		Minor	960	0	0.001	0.16
		Significant	3200	0	0.05	0.64
		Major	32000	0	0.1	3.2
	275kV Reactor	Defect	338.712	0	0.001	0.006
		Minor	564.52	0	0.001	0.055
		Significant	1693.56	0	0.05	0.218
		Major	16935.6	0	0.1	1.089
	400kV Reactor	Defect	564.52	0	0.001	0.009
		Minor	940.867	0	0.001	0.091
		Significant	2822.6	0	0.05	0.363
		Major	28226	0	0.1	1.816
Cable (Non-Pressurised)	132kV	Defect	0	0	0	0
		Minor	0	0	0	0
		Significant	0	0	0.001	0.179
		Major	0	0	0.001	0.894
	275kV	Defect	0	0	0	0
		Minor	0	0	0	0
		Significant	0	0	0.001	0.241
		Major	0	0	0.001	1.205
	400kV	Defect	0	0	0	0
		Minor	0	0	0	0
		Significant	0	0	0.001	0.339
		Major	0	0	0.001	1.695
Cable (Pressurised)	132kV	Defect	175.839	0	0.001	0
		Minor	281.343	0	0.001	0.063
		Significant	351.678	0	0.05	0.629
		Major	703.356	0	0.1	3.149
	275kV	Defect	158.22	0	0.001	0
		Minor	253.166	0	0.001	0.057
		Significant	316.458	0	0.05	0.567
		Major	632.016	0	0.1	2.834
	400kV	Defect	404.774	0	0.001	0
		Minor	647.639	0	0.001	0.145

		Significant	809.548	0	0.05	1.450
		Major	1619.096	0	0.1	7.251
OHL Conductor	132kV	Defect	0	0	0	0
		Minor	0	0	0.00001	0.1
		Significant	0	0	0.0005	0.2
		Major	0	0	0.00075	1
	275kV	Defect	0	0	0	0
		Minor	0	0	0.00001	0.2
		Significant	0	0	0.0005	0.4
		Major	0	0	0.00075	2.5
	400kV	Defect	0	0	0	0
		Minor	0	0	0.00001	0.3
		Significant	0	0	0.0005	0.6
		Major	0	0	0.00075	4
OHL Fittings	132kV	Defect	0	0	0	0
		Minor	0	0	0.00001	0.1
		Significant	0	0	0.0005	0.2
		Major	0	0	0.00075	1
	275kV	Defect	0	0	0	0
		Minor	0	0	0.00001	0
		Significant	0	0	0.0005	0.2
		Major	0	0	0.00075	0.4
	400kV	Defect	0	0	0	0
		Minor	0	0	0.00001	0.3
		Significant	0	0	0.0005	0.6
		Major	0	0	0.00075	4
OHL Tower	132kV	Defect	0	0	0.0001	0.1
		Minor	0	0	0.0005	0.2
		Significant	0	0	0.00075	1
		Major	0	0	0.001	2
	275kV	Defect	0	0	0.0001	0.2
		Minor	0	0	0.0005	0.4
		Significant	0	0	0.00075	2.5
		Major	0	0	0.001	4
	400kV	Defect	0	0	0.0001	0.3
		Minor	0	0	0.0005	0.6
		Significant	0	0	0.00075	4
		Major	0	0	0.001	6

6.3.2 Cost of Environmental Impact

The cost associated with each environmental impact is derived via a calibration table of the form shown below.

Table 103 Calibration Table for Cost of Environmental Impact, C_{impact}

Setting value	Cost
Environmental cost per litre of oil (£/litre)	*50.31*
Environmental cost per kg of SF6 (£/kg)	*3555.67*
Environmental cost of fire (£)	*7186.11*
Environmental cost of waste (£/tonne)	*215.58*

6.3.3 Exposure

The exposure modifier reflects the potential level of risk that an asset poses to the environment. An exposure modifier is assigned to each asset based on its proximity to environmentally sensitive sites. The overall exposure modifier is derived using Equation 14 for transformers, switchgear and cables.

$$Exposure = F_{location}.F_{type}$$ **Equation 14**

For OHLs, the Exposure Modifier is set to 1 as this is a linear asset and as such the locational aspect of proximity is considered to be constant.

The variables used to derive the Exposure Modifier are summarised in Table 104.

Table 104 Environmental Exposure Variables

Variable	Description	Variable Type
$F_{location}$	A factor to reflect the impact of asset location on the environment	Asset specific variable.
F_{type}	A factor to reflect the impact of asset type on the environment	Asset specific variable.

6.3.3.1 *Location Environmental Factor*

Table 105 Calibration Tables for Proximity to Water and Environmentally Sensitive Site – Oil Filled Transformers, Oil Circuit Breakers and Fluid Filled Cables

> Distance to Water (m)	<= Distance to Water (m)	Proximity to Water Factor
-1	40	*2.5*
40	80	*1.5*
80	120	*1*
120	1,000	*0.8*

Environmentally Sensitive Site (**)	Factor
SSSI	1.5
National Park	1

6.3.3.2 *Type Environmental Factor*

The type environmental factor considers the impact of asset type on the environmental consequences of failure. It is only used for transformers to capture the impact of transformer insulating medium as the asset categories used to define the environmental impact does not fully capture asset type issues. This allows the environmental impact of gas filled transformers to be differentiated from those of oil filled transformers. It is understood that SHE-T do not have any gas filled transformers, and thus a default environmental factor will be set assuming that all transformers are oil filled.

The type environmental factor for SPT transformers is set via a calibration table of the form shown in table below. For all other assets, the type environmental factor is set to 1.

Table 106 Calibration Table for Type Environment Factor

Transformer Insulating Medium	F_{type}
Oil	*1.2*
Midel	*1*
Gas	*1*

6.4 Financial Consequence

The approach for deriving the financial consequences of failure ($R_{Financial,i}$) is set out in Section 3.4 of the Transmission NOMs Methodology and can be described for each failure mode using Equation 15 as follows:

$$R_{Financial,i} = F_{location}.Cost_{Rep}.p_i \qquad \textbf{Equation 15}$$

The variables used in Equation 15 are described in table below.

Table 107 Financial Consequences of Failure Variables

Variable	Description	Variable Type
i	Failure mode	Determined failure modes identified in the relevant asset model.
n	Number of failure modes	Determined number of failure modes identified in the relevant asset model.
$F_{location}.$	Location financial factor, to reflect the impact of asset location on repair/replacement cost.	Asset specific variable.
F_{size}	Size financial factor, to reflect the impact of asset size on repair/replacement cost.	Asset specific variable.
$Cost_{Rep}$	The replacement cost associated with the asset	Calibration values set by asset class. See below.
p_i	The proportion of the replacement cost associated with failure mode i	Calibration values set by asset class. See below.

The replacement cost and the proportion of replacement cost by failure mode is to be set by asset category via a calibration table of the form shown in table below.

Table 108 Replacement cost per failure mode Calibration Table

			Percentage of Replacement Cost Per Failure Mode (%)			
Asset Model	Voltage / Asset Category	Replacement Cost (£)	Defect	Minor	Significant	Major
Circuit Breaker	132 kV	400,000	10	25	50	100
	275 kV	500,000	10	25	50	100
	400 kV	600,000	10	25	50	100
Transformer & Reactor	132 Transformer	2,000,000	10	25	50	100
	275 Transformer	6,000,000	10	25	50	100
	400 Transformer	8,000,000	10	25	50	100
	132 Reactor	4,500,000	10	25	50	100
	275 Reactor	6,000,000	10	25	50	100
	400 Reactor	6,000,000	10	25	50	100
Cable (Non-Pressurised)	132 kV	1,000,000	0	0	35	100
	275 kV	2,000,000	0	0	35	100
	400 kV	3,000,000	0	0	35	100
Cable (Pressurised)	132 kV	1,000,000	10	25	50	100
	275 kV	2,000,000	10	25	50	100
	400 kV	3,000,000	10	25	50	100
OHL Conductor	132 kV	100,000	0	10	50	100
	275 kV	300,000	0	10	50	100
	400 kV	400,000	0	10	50	100
OHL Fittings	132 kV	40,000	0	10	50	100
	275 kV	50,000	0	10	50	100
	400 kV	60,000	0	10	50	100
OHL Tower	132 kV	60,000	0	10	50	100
	275 kV	100,000	0	10	50	100
	400 kV	150,000	0	10	50	100

6.4.1 Location Financial Factor

The location financial factor considers the impact of asset location on the financial consequences of failure, e.g. assets located in sites associated with high replacement costs. It is derived from a calibration table of the form indicated in table below.

Table 109 Location Financial Factor Calibration Table

Location Financial Rating	Location Factor
Standard	*1.0*
Non-Standard	*1.5*

7. Appendix 1- Transformer Worked Example

Initial End of Life Modifier (EoL1) – Main Tank TX

1.1 Duty

The Transformer has a rating 90 MVA that is turned into factors using LSA Table 1.

The maximum demand is 22.05 MVA and the average demand is 8.325 MVA.

Term	Value	Factor
Maximum Demand	Maximum demand is 24.5% of rated value	D_{max} = 0.8
Average Demand	Average load is 9.25% of rated value	D_{ave} = 0.8

Duty Factor for transformers SPT is calculated using NARA Equation 29:

$$F_{DY} = max(D_{max}, D_{ave}) = \max(0.8,0.8) = 0.8$$

1.2 Location, Situation, Environment

The Transformer data is turned into factors using LSA Table 2.

Term	Value	Factor
Distance to Coast	Asset is 2 km from the coast	F_{dis} = 1.4
Altitude	Asset is 83 m above sea level	F_{alt} = 0.9
Corrosion	Asset is in corrosion zone 3	F_{cor}= 1
Situation	Asset is completely enclosed	F_{sit} = 1
Environment	Asset is in a good environment	F_{env} = 1

The location factor (F_{loc}) is calculated using NARA equation 31:

$$F_{loc} = max(F_{dis}, F_{alt}, F_{cor}) = max(1.4,1,1.1) = 1.4$$

The LSE Factor (FLSE) is calculated using NARA equation 30:

$$F_{LSE} = \left(\left(\left(F_{loc} - F_{loc,min}\right).F_{sit} + F_{loc,min}\right)F_{env}\right)$$

$$F_{LSE} = \left(\left((1.4 - 0.8) \times 0.9 + 0.8\right) \times 1\right) = 1.34$$

$F_{loc,min}$ is the minimum possible location factor and is set to 0.8 according with LSA Table 2.

1.3 Expected Life

The average life can be found using Look up LSA Table 7.

Term	Value	Years
Average Life	Asset is of make Bruce Peebles Pre 1980	60

Expected Life is calculated using NARA equation 32:

$$\mathrm{L_E} = \frac{\mathrm{L_A}}{\mathrm{F_{LSE}} \times \mathrm{F_{DY}}} = \frac{60}{1.34 \times 0.8} = 55.97\ years$$

1.4 Initial Ageing Rate

Initial Ageing Rate is calculated using NARA equation 7:

$$B_i = \ln\left(\frac{EoL_{MAL}}{EoL_{New}}\right) \cdot \frac{1}{L_E} = \ln\left(\frac{5.5}{0.5}\right) \cdot \frac{1}{55.97} = 0.04284$$

Where:

EoL_{MAL} is the EoL Modifier of the asset when it reaches its Modified Anticipated Life (set to 5.5)
EoL_{New} is the EoL Modifier of a new asset (normally set to 0.5)

1.5 EoL_1

Transformer age from date of manufacture is 50 years

The EoL_1 is calculated using NARA equation 33:

$$\mathrm{EoL_1} = \min\left((\mathrm{EoL_{New}} \cdot \exp\{\beta_1 \cdot \mathrm{Age}\}), EoL_{1,max}\right)$$

$$\mathrm{EoL_1} = \min\left((0.5 \cdot \exp\{0.04284 \cdot 50\}), 5.5\right)$$

$$\mathrm{EoL_1} = 4.26$$

The maximum value of the $EoL_{1,max}$ is capped to 5.5 according with NARA section 4.1.1.4.

Intermediate End of life Modifier (EoL_2) – Main Tank TX

1.6 Visual Condition Factor

The condition rating taken from the last inspection is used to look up a factor and a minimum EoL values in LSA Table 23.

Component	Value	Factor	Min EoL
Main Tank - Surface Deterioration	2	$F_{main,surf}$ = 1	0.5
Main Tank - Oil Leaks	4	$F_{main,oil}$ = 1.3	6.5
Radiator Fins - Surface Deterioration	2	$F_{rad,surf}$ = 1	0.5
Radiator Fins - Oil Leaks	3	$F_{rad,oil}$ = 1.1	5.5
Conservator - Surface Deterioration	2	$F_{cons,surf}$ = 1	0.5
Conservator Tank - Oil Leaks	1	$F_{cons,oil}$ = 1	0.5

Cable End Box - Condition	1	$F_{CEB} = 1$	0.5

The transformers condition constants from LSA Table 24 are:

Condition Maximum Boundary $C_{max,boundary} = 1$

Maximum Number of Combined Factors $N_{max} = 3$

Condition Maximum Divider $C_{max,divider} = 3$

A method of maximum and multiple increment (MMI) is used to combine these factors.

One or more factors is > $C_{max,boundary}$ therefore the overall condition factor (F_{OC}) is calculated using NARA equation 9 (page 22):

$$F_{OC} = \text{largest factor} + \frac{\sum_{i=1}^{n}((n+1)th\ largest\ factor - 1)}{Condition\ Max\ Divider}\ where\ (n+1)th\ largest\ factor > Condition\ Max\ Boundary$$

$$F_{OC} = 1.3 + \frac{1.1 - 1}{3}$$

$$F_{OC} = 1.33$$

1.7 Defect Factor

This transformer has 7 defects recorded with severity scores as follows: 2,2,2,3,3,4,4. All are marked as current so an overall asset defect score of 20 is obtained by summating the severity scores.

The Defect factor and minimum EoI can be found in LSA Table 28:

$F_{defecthistory} = 1.05$

Minimum $EoL_{Fdefect} = 0.5$

1.8 Reliability Factor

The generic reliability score associated with this asset is 1, relating to a Generic Reliability Factor (F_{GR}) of 1 and minimum EoL of 0.5, as per LSA Table 31.

$F_{GR} = 1$

Minimum $EoL_{FGR} = 0.5$

1.9 Operational Restriction (OR)Factor

The Operational Restriction Factor is taken to be the factor related to the Maximum OR severity in place for the asset.

As this asset does not have any OR applied it receives the value of 1 as per LSA Table 36.

$F_{OR} = 1$

Minimum EoL_{FOR} = 0.5

1.10 Oil Condition Factor

Scores and multipliers for Moisture, breakdown Voltage and acidity are found in the Table 32 and Table 33, respectively.

Term	Value	Score	Multiplier
Oil Moisture	Relative humidity is 16 (ppm)	O_M = 2	O_{M_M} = 80
Oil Breakdown Voltage	Breakdown strength from latest test is 55 (kV)	O_B = 0	O_{B_M} = 80
Oil Acidity	Acidity content from latest test is 0.05 (mg KOH/g)	O_A = 0	O_{A_M} = 125

Oil Condition Score is calculated using NARA equation 35:

$$O_{TOTAL} = sum\left(\left(O_M \times O_{M\_M}\right) + \left(O_B \times O_{B\_M}\right) + \left(O_A \times O_{A\_M}\right)\right)$$

$$O_{TOTAL} = sum\left((2 \times 80) + (0 \times 80) + (0 \times 125)\right) = 160$$

From LSA Table 34, the oil factor (F_{OIL}) and minimum EoL for the oil factor, relating to the oil condition score of 160 are:

F_{OIL} = 1

Minimum EoL_{FOIL} = 0.5

1.11 Overall Factor Value

Again, the MMI method is used to generate the Overall Factor Value.

A summary table is presented below:

Term	Factor
Oil Condition Factor	F_{OIL} = 1
Operational Restrictions Factor	F_{OR} = 1
Generic Reliability Factor	F_{GR} = 1
Defect History Factor	$F_{defect,history}$ = 1.05
Overall Condition Factor	F_{OC} = 1.33

The transformers Intermediate EoL constants from LSA Table 37 are:

Factor Maximum Boundary Value $F_{max,boundary}$ = 1

Maximum Number of Combined Factors N_{max} = 4

Overall Factor Maximum Divider $F_{max,divider}$ = 3

One or more factors is > $F_{max,boundary}$ therefore the overall factor value (FV_1) is calculated using NARA equation 9:

$$FV_1 = \text{largest factor} + \frac{\sum_{i=1}^{n}((n+1)th\ largest\ factor - 1)}{Factor\ Max\ Divider}\ where\ (n+1)th\ largest\ factor > Factor\ Max\ Boundary$$

$$FV_1 = 1.33 + \frac{1.05 - 1}{3}$$

$$FV_1 = 1.35$$

1.12 EoL_2

Considering the EoL_1 and the FV_1 previously calculated:

Initial Stage End of Life Modifier	$EoL_1 = 4.26$
Overall Factor Value	$FV_1 = 1.35$

The EOL_2 is calculated using NARA equation 36:

$$EoL_2 = EoL_1 \times FV_1 = 4.26 \times 1.35 = 5.75$$

Final End of Life Modifier (EoLY0) - Main Tank TX

1.13 DGA – Part 1 – Calculate EOL_{DGAi}

The following table presents 10 different Oil Sample results. The results have been converted into scores using the LSA Table 39.

Each condition score is then modified by a multiplier according with LSA Table 40 to obtain the The DGA Score and the EoL_{DGAi} for each sample result.

Oil Sample Date	Hydrogen - ppm	Acetylene - ppm	Ethylene - ppm	Methane - ppm	Ethane - ppm	Carbon Dioxide - ppm	Carbon Monoxide - ppm	Hydrogen Score	Acetylene Score	Ethylene Score	Methane Score	Ethane Score	Hydrogen Condition Index	Acetylene Condition Index	Ethylene Condition Index	Methane Condition Index	Ethane Condition Index	DGA Score	EoL_{DGAi}
Jun 15 2009 12:00 AM	9	2	7	8	5	4,186	523	0	2	0	0	0	0	240	0	0	0	240	1.09
Jun 18 2010 12:00 AM	7	1	16	9	6	4,268	454	0	0	2	0	0	0	0	60	0	0	60	0.27
May 25 2011 12:00 AM	4	0	17	11	9	7,829	547	0	0	2	2	0	0	0	60	60	0	120	0.55
May 18 2012 12:00 AM	11	0	13	14	10	10,473	768	0	0	2	2	2	0	0	60	60	60	180	0.82

May 20 2013 12:00 AM	12	1	10	11	8	8,006	623	0	0	2	2	0	0	0	60	60	0	120	0.55
Jul 1 2014 12:00 AM	17	1	9	11	7	7,745	615	0	0	0	2	0	0	0	0	60	0	60	0.27
Jan 26 2015 12:00 AM	22	1	7	13	8	8,131	811	2	0	0	2	0	100	0	0	60	0	160	0.73
Jul 31 2015 12:00 AM	10	1	8	9	7	7,895	539	0	0	0	0	0	0	0	0	0	0	0	0
Aug 11 2015 12:00 AM	14	1	8	9	8	7,755	695	0	0	0	0	0	0	0	0	0	0	0	0
Jun 30 2016 12:00 AM	6	0	7	9	8	5,286	474	0	0	0	0	0	0	0	0	0	0	0	0

Taking the oil sample on Jun 15 2009, as an example, the DGA score is calculated using NARA equation 39:

$$DGA\ Score\ = \sum 50 \times Hydrogen\ Score + 30 \times Methane\ Score\ +\ 30 \times Ethylene\ Score + 30 \times Ethane\ Score + 120 \times Acetylene\ Scores$$

$$DGA\ Score\ = 240$$

According with LSA Section 4.2.7, the DGA Divider is set to 220 and the $EoL_{DGA,max}$ is capped to 10

The EoL_{DGAi} is calculated using NARA equation 40:

$$EoL_{DGAi} = \min\left(\frac{DGA\ Score_i}{DGA\ Divider}, EoL_{DGA,max}\right) = \ \min\left(\frac{240}{220}, 10\right) = 1.09$$

1.14 DGA – Part 2 – Calculate DGA % Change

The principal result is taken to be the maximum EoL_{DGA} value in the principle result period. The principal result period is set at 90 days prior to the last result.

The % DGA Change is calculated using NARA equation 41:

$$DGA\ \%\ Change = \left(\frac{max(EoL_{DGAi})}{average(EoL_{DGA})}\right) \times\ 100$$

$$DGA\ \%\ Change = \left(\frac{1.09}{0.428}\right) \times\ 100 = 254.67$$

From a lookup of the DGA % Change this gives a change description of “Large” which results as found in LSA Table 41 in a value of:

$DGA_{HistoryFactor}$ = 1.2

1.15 EoL_{DGA}

EoL_{DGA} is calculated using NARA equation 42:

$$EoL_{DGA} = max(min(IF(Principle\ Result > DGA\ History\ Threshold, Principle\ Result\ \times DGA\ History\ Factor, Principle\ Result), 10), 0.5)$$

The DGA History threshold is a constant set to 4 according with NARA document.

$$EoL_{DGA} = max(min(1.09, 10), 0.5) = 1.09$$

$Principal\ Result\ = max(EoL_{DGAi})$ in the calibrated time period before the last sample

For this example the principal result is 1.09

1.16 EoL_{FFA}

Test result data for this asset gives the following FFA results.

Oil Sample Date	Furans - ppm
Jun 15 2009 12:00 AM	3
Jun 18 2010 12:00 AM	3
May 25 2011 12:00 AM	5
May 18 2012 12:00 AM	5
May 20 2013 12:00 AM	5
Jul 1 2014 12:00 AM	5
Jan 26 2015 12:00 AM	5
Jul 31 2015 12:00 AM	5
Aug 11 2015 12:00 AM	5
Jun 30 2016 12:00 AM	5

From all the results the FFA_{MAX} = 5 ppm

EoL_{FFA} is calculated using NARA equation 43:

$$EoL_{FFA} = \min\left(\left(FFA_{multiplier} \times FFA_{MAX}{}^{FFAPV}\right), EoL_{FFA,max}\right)$$

$$EoL_{FFA} = \min\left((2.33 \times 5^{0.68}), 10\right) = \min(6.96,10) = 6.96$$

From LSA Equation 2:

FFA Multiplier $FFA_{multiplier}$ = 2.33

FFA Power value FFAPV = 0.68

FFA EoL Max $EoL_{FFA,max}$ = 10

1.17 Maximum of Minimum EOL (EOL_{max_min})

EoL Component	Minimum Value

Condition EoL	= 6.5
Defect History EoL	= 0.5
Reliability EoL	= 0.5
Operational Restrictions	= 0.5
Oil Condition	= 0.5

Maximum of Minimum values is taken to be the maximum value in the table above. EoL_{maxmin} = 6.5.

1.18Main Tank EoLY0

A summary of the EoL calculated for the main tank can be found in the table below:

EoL	Value
EoL_{DGA}	1.09
EoL_{FFA}	6.96
EoL_2	5.75
$EoL_{max,min}$	6.5

As $EoL_{FFA} > EoL_2$, the $TxEoL_{y0}$ is calculated using NARA equation 38:

$$TxEoL_{y0} = Max(EoL_{DGA}, EoL_{FFA}, Maximum\ of\ the\ Minimums)$$

$$TxEoL_{y0} = Max(1.09, 6.96, 6.5) = 6.96$$

Final Ageing Rate Factor – Main Tank TX

Asset Age = 50 years

The Initial Ageing Rate is β_i = 0.04284

The EoL modifier, Y0 is EoL_{y0} = 6.96

From NARA Equation 6, the End of life value of a new asset is EoL_{new} = 0.5

Asset Age threshold value, as per LSATable 62 Age_{recalc} = 15

Maximum EoL Modifier for using the Initial Ageing Rate EoL_{recalc} = 2

The $\beta_{MAXratio}$ is set as per Table 62 The $\beta_{MAXratio}$ = 1.5

As $Age_{asset} > Age_{recalc}$ so a final ageing rate must be used

1.19Final Ageing Rate

Using NARA equation 14:

$$\beta_{\mathrm{final,i}} = \min\left[\frac{\ln\left(\frac{\mathrm{EoL_{Y0}}}{\mathrm{EoL_{New}}}\right)}{\mathrm{Age_{asset}}}, \mathrm{B_i} \times \beta_{\mathrm{ratio}}\right]$$

$$= \min[0.05267, 0.04284 \times 1.5] = \min[0.05267, 0.06426] = 0.05267$$

With EoL_{y0} = 6.96 this is translated to an ageing rate reduction factor (F_{age}) of 1.5 as it is explained in NARA section 2.3.2.

1.20 End of Life Forecasting

The End of life modifier, Y0 is	EoL_{Y0} = 6.96
The Final Ageing Rate is	β_{final} = 0.05267
the Age Reduction Factor is	F_{age} = 1.5
Number of years over which the asset moves from EoL_{Y0} to EoL_{Yn} (t_{YN} - t_{Y0})	set to 8 in this example

NARA equation 12:

$$\mathrm{EoL_{Yn,1}} = \mathrm{minimum}\left(\mathrm{EoL_{Y0,i}} \cdot \exp\left\{\frac{\beta_{\mathrm{final,i}} \cdot (\mathrm{t_{YN}} - \mathrm{t_{Y0}})}{\mathrm{F_{age,i}}}\right\}, EOL_{\mathrm{YN,max}}\right)$$

$$\mathrm{EoL_{Yn}} = \mathrm{minimum}\left(6.96 \times \exp\left\{\frac{0.05267 \times 8}{1.5}\right\}, 15\right)$$

$$\mathrm{EoL_{Yn}} = \mathrm{minimum}(9.21, 15) = 9.21$$

Initial End of Life Modifier (EoL_1) – Tapchanger TX

1.21 Duty

Term	Value
Number of Annual Operations	345
Tapchanger high wear rate	No

The Tapcount factor (TF) and high wear rate factor (H_F), using LSA Table 1 are:

T_F=1

H_F = 1

The Duty Factor is calculated using the NARA equation 44:

$$F_{DY} = max(T_F, H_F)$$

$$F_{DY} = \max(1,1) = 1$$

1.22 Location, Situation, Environment

The Transformer data is turned into factors using the look up LSA Table 2.

Term	Value	Factor
Distance to Coast	Asset is 2 km from the coast	F_{dis} = 1.4
Altitude	Asset is 83 m above sea level	F_{alt} = 0.9
Corrosion	Asset is in corrosion zone 3	F_{cor}= 1
Situation	Asset is completely enclosed	F_{sit} = 1
Environment	Asset is in a good environment	F_{env} = 1

The location factor (F_{loc}) is calculated using NARA equation 31 (same for Main tank):

$$F_{loc} = max(F_{dis}, F_{alt}, F_{cor}) = max(1.4,1,1.1) = 1.4$$

The LSE Factor (FLSE) is calculated using NARA equation 45:

$$F_{LSE} = \left(\left(\left(F_{loc} - F_{loc,min}\right). F_{sit} + F_{loc,min}\right) F_{env}\right)$$

$$F_{LSE} = \left(\left((1.4 - 0.8) \times 0.9 + 0.8\right) \times 1\right) = 1.34$$

$F_{loc,min}$ is the minimum possible location factor and is set to 0.8 according with LSA Table 2 (using same for main tank).

1.23 Expected Life

The average life can be found using Look up LSA Table 7.

Term	Value	Years
Average Life	Asset is of make Bruce Peebles Pre 1980	60

Expected life is calculated using formula for main tank:

$$L_E = \frac{L_A}{F_{LSE} \times F_{DY}} = \frac{60}{1.34 \times 1} = 44.78\ years$$

1.24 Initial Ageing Rate

Initial Ageing Rate is calculated using the NARA equation 7:

$$B_i = \ln\left(\frac{EoL_{MAL}}{EoL_{New}}\right)\cdot\frac{1}{L_E} = \ln\left(\frac{5.5}{0.5}\right)\cdot\frac{1}{44.78} = 0.05355$$

Where:

EoL_{MAL} is the EoL Modifier of the asset when it reaches its Modified Anticipated Life (set to 5.5)
EoL_{New} is the EoL Modifier of a new asset (normally set to 0.5)

1.25 EoL_1

Transformer age from date of manufacturer is 50 years

The EoL_1 is calculated using NARA equation 46:

The maximum value of the $EoL_{1,max}$ is 5.5

$$\mathrm{EoL}_1 = \min\left((\mathrm{EoL}_{\mathrm{New}}\cdot \exp\{\beta_1\cdot \mathrm{Age}\}), EoL_{1,max}\right)$$

$$\mathrm{EoL}_1 = \min\left((0.5\cdot \exp\{0.05355\cdot 50\}), 5.5\right)$$

$$\mathrm{EoL}_1 = \min(7.27, 5.5) = 5.5$$

Intermediate End of Life Modifier (EoL_2) – Tapchanger TX

1.26 Oil Condition Factor

No oil test data for this tapchanger is available so a condition factor of 1 is applied.

1.27 Operation Restrictions (OR) Factor

The Operation Restriction Factor is taken to be the factor related to the Maximum OR Category in place for the asset.

As this asset does not have any SOPs applied it receives the value of 1, in accordance with LSA Table 36.

Tap Changer Minimum EoL_{FSOP} = 0.5

1.28 Reliability Factor

The generic reliability score associated with this asset is 1, relating to a Generic Reliability Factor (F_{GR}) of 1 in accordance with LSA Table 31.

Tap Changer Minimum EoL_{FGR} = 0.5

1.29 Visual Condition Factor

The condition rating taken from the last inspection is used to look up a factor value according with LSA Table 25:

Component	Condition Rating	Factor	Min EoL
Selector Tank - Surface Deterioration	2	$F_{select,surf}$ = 1	0.5
Selector Tank - Oil Leaks	No value	$F_{select,oil}$ = No value	No value
Tapchanger Contacts – Condition	No value	$F_{tap,con}$ = No value	No value

The transformers condition constants from LSA Table 26 are:

Condition Maximum Boundary $C_{max,boundary}$ = 1

Maximum Number of Combined Factors N_{max} = 3

Condition Maximum Divider $C_{max,divider}$ = 3

A method of maximum and multiple increment (MMI) is used to combine these factors.

One or more factors is > $C_{max,boundary}$ therefore the overall condition factor (F_{OC}) is calculated using NARA equation 9

$$F_{OC} = \text{largest factor} + \frac{\sum_{i=1}^{n}((n+1)th\ largest\ factor - 1)}{Condition\ Max\ Divider}\ where\ (n+1)th\ largest\ factor > Condition\ Max\ Boundary$$

$$F_{OC} = 1 + \frac{0-1}{3}$$

$$F_{OC} = 1$$

1.30 Defect Factor

There are no defects against this item of plant so it receives a defect factor of 1.

1.31DGA Factor

A DGA score of 60 was recorded as the principal result, calculated in the same as was for transformers, resulting in a DGA factor of 1 being applied, according with LSA Section 3.2.5.3.

1.32Overall Factor Value

Again the MMI method is used to generate the Overall Factor Value.

A summary table is presented below:

Term	Factor
Oil Condition Factor	F_{OIL} = 1
Operational Restrictions Factor	F_{OR} = 1
Generic Reliability Factor	F_{GR} = 1
Defect History Factor	$F_{defect,history}$ = 1

Overall Condition Factor	$F_{OC} = 1$
DGA Factor	$F_{DGA} = 1$

The transformers Intermediate EoL constants from LSA Table 38 are:

Factor Value Boundary Value $F_{value,boundary} = 1$

Maximum Number of Combined Factors $N_{max} = 4$

Overall Factor Maximum Divider $F_{max,divider} = 3$

Overall Factor Minimum Divider $F_{min,divider} = 1.5$

One or more factors is > $F_{max,boundary}$ therefore the overall factor value (FV_1) is calculated using NARA equation 9:

$$FV_1 = \text{largest factor} + \frac{\sum_{i=1}^{n}((n+1)th\ largest\ factor - 1)}{Factor\ Max\ Divider}\ where\ (n+1)th\ largest\ factor > Factor\ Max\ Boundary$$

$$FV_1 = 1.33 + \frac{1.05 - 1}{3}$$

$$FV_1 = 1.35$$

No factor is > $F_{value,boundary}$ therefore, using NARA equation 10:

$$FV_1 = Smallest\ Factor + \frac{Second\ Smallest\ Factor - 1}{Condition\ Min\ Divider}$$

$$FV_1 = 1 + \frac{1-1}{1.5} = 1 + 0 = 1$$

1.33EoL2 Calculation

Considering the EoL_1 and the FV_1 previously calculated:

Initial Stage End of Life Modifier $EoL_1 = 5.5$

Overall Factor Value $FV_1 = 1$

EoL2 is calculated using NARA equation 48

$$EoL_2 = EoL_1 \times FV_1 = 5.5 \times 1 = 5.5$$

Final End of Life Modifier (EoL_{Y0}) – Tapchanger TX

A summary table is presented below:

EoL	Value
EoL_2	5.5
$EoL_{max,min}$	0.5

EoL_{YO} is calculated using NARA equation 49:

$$TcEoL_{y0} = Max(EoL_2, EoL_{max,min})$$

$$TcEoL_{y0} = Max\ (5.5, 0.5) = 5.5$$

1.34 Final Ageing Rate Factor – Tapchanger TX

Asset Age = 50 years

The Initial Ageing Rate is $\beta_i = 0.05355$

The EoL modifier, Y0 is $EoL_{y0} = 5.5$

From Nara Equation 6, the End of life value of a new asset is $EoL_{new} = 0.5$

Asset age threshold value, as per LSA Table 62 $Age_{recalc} = 15$

Maximum EoL Modifier for using the Initial Ageing Rate $EoL_{recalc} = 2$

The $\beta_{MAXratio}$ is set a s per Table 62 $\beta_{MAXratio} = 1.5$

$Age_{asset} > Age_{recalc}$ so a final ageing rate must be used

1.35 Final Ageing Rate

Using NARA equation 14:

$$\beta_{final,i} = \min\left[\frac{\ln\left(\frac{EoL_{Y0}}{EoL_{New}}\right)}{Age_{asset}}, B_i \times \beta_{MAXratio}\right]$$

$$= \min[0.04796, 0.5355 \times 1.5] = \min[0.04796, 0.080325] = 0.04796$$

With $EoL_{y0} = 5.5$ this is translated to an ageing rate reduction factor (F_{age}) of 1.5 using Figure 6 in NARA.

1.36 End of Life Forecasting

The End of life modifier, Y0 is $EoL_{Y0} = 5.5$

The Final Ageing Rate is $\beta_{final} = 0.04796$

the Age Reduction Factor is $F_{age} = 1.5$

Number of years over which the asset moves from EoL_{Y0} to EoL_{Yn} $(t_{YN} - t_{Y0})$ set to 8 in this example

NARA equation 12:

$$\mathrm{EoL}_{\mathrm{Yn}} = \min\left(\mathrm{EoL}_{\mathrm{Y0}} \times \exp\left\{\frac{\beta_{\mathrm{final}} \times (t_{\mathrm{YN}} - t_{\mathrm{Y0}})}{F_{\mathrm{age}}}\right\}, EOL_{\mathrm{YN,max}}\right)$$

$$= \min(7.1, 15) = 7.1$$

Transformer System EoLYo

EoL	Value
$TxEoL_{Y0}$	6.96
$TcEoL_{Y0}$	5.5

The transformer system EoL is calculated using NARA equation 27:

$$TxSystemEoL_{(y0)} = max\left(TxEoL_{(y0)}, TcEoL_{(y0)}\right)$$

$$= max(6.96, 5.5) \quad = 6.96$$

Transformer System Probability of Failure

1.37 Probability of Failure Mode (Defect failure)

$TxSystemEoL_{Y0} = 6.96$

For this example $EoL_{lim} = 4$

From NARA Section 7.2 Consequence Constant C=1.086

From LSA Table 63, Failure Mode K(Minor Condition Failure) = 0.001293121

As $TxSystemEoL_{Y0} > EoL_{lim}$ therefore the NARA equation 105 applies:

$$\mathrm{PoF}_{minor} = \mathrm{k} \cdot \left(1 + (\mathrm{EoL} \cdot \mathrm{c}) + \frac{(\mathrm{EoL} \cdot \mathrm{c})^2}{2!} + \frac{(\mathrm{EoL} \cdot \mathrm{c})^3}{3!}\right)$$

$$= 0.001293121 \cdot \left(1 + (6.96 \cdot 1.086) + \frac{(6.96 \cdot 1.086)^2}{2!} + \frac{(6.96 \cdot 1.086)^3}{3!}\right)$$

$$= 0.001293121 \cdot (1 + (7.565) + 28.619 + 72.171) = 0.1414$$

1.38 Probability of Failure Mode (Minor failure)

$TxSystemEoL_{Y0}$ = 6.96

For this example EoL_{lim} = 4

From NARA Section 7.2 Consequence Constant C=1.086

From LSA Table 63, Failure Mode K(Minor Condition Failure) = 0. 000764

As $TxSystemEoL_{Y0} > EoL_{lim}$ therefore the NARA equation 105 applies:

$$\mathrm{PoF}_{minor} = \mathrm{k} \cdot \left(1 + (\mathrm{EoL} \cdot \mathrm{c}) + \frac{(\mathrm{EoL} \cdot \mathrm{c})^2}{2!} + \frac{(\mathrm{EoL} \cdot \mathrm{c})^3}{3!}\right)$$

$$= 0.000764 \cdot \left(1 + (6.96 \cdot 1.086) + \frac{(6.96 \cdot 1.086)^2}{2!} + \frac{(6.96 \cdot 1.086)^3}{3!}\right)$$

$$= 0.000764 \cdot (1 + (7.565) + 28.619 + 72.171) = 0.082$$

1.39 Probability of Failure Mode (Significant failure)

$TxSystemEoL_{Y0}$ = 6.96

For this example EoL_{lim} = 4

From NARA Section 7.2 Consequence Constant C=1.086

From LSA Table 63, Failure Mode K(Significant Condition Failure) = $9.59x10^{-6}$

As $TxSystemEoL_{Y0} > EoL_{lim}$ therefore the NARA equation 105 applies:

$$\mathrm{PoF}_{significant} = \mathrm{k} \cdot \left(1 + (\mathrm{EoL} \cdot \mathrm{c}) + \frac{(\mathrm{EoL} \cdot \mathrm{c})^2}{2!} + \frac{(\mathrm{EoL} \cdot \mathrm{c})^3}{3!}\right)$$

$$= 9.59\mathrm{x}10^{-6} \cdot \left(1 + (6.96 \cdot 1.086) + \frac{(6.96 \cdot 1.086)^2}{2!} + \frac{(6.96 \cdot 1.086)^3}{3!}\right) = 0.00103$$

1.40 Probability of Failure Mode (Major failure)

$TxSystemEoL_{Y0}$ = 6.96

For this example $EoL_{lim} = 4$

From NARA Section 7.2 Consequence Constant C=1.086

From LSA Table 63, Failure Mode K(Major Condition Failure) = $6.06x10^{-6}$

As $TxSystemEoL_{Y0} > EoL_{lim}$ therefore the NARA equation 105 applies:

$$\mathrm{PoF}_{major} = \mathrm{k} \cdot \left(1 + (\mathrm{EoL} \cdot \mathrm{c}) + \frac{(\mathrm{EoL} \cdot \mathrm{c})^2}{2!} + \frac{(\mathrm{EoL} \cdot \mathrm{c})^3}{3!}\right)$$

$$= 6.06\mathrm{x}10^{-6} \cdot \left(1 + (6.96 \cdot 1.086) + \frac{(6.96 \cdot 1.086)^2}{2!} + \frac{(6.96 \cdot 1.086)^3}{3!}\right) = 0.0006$$

1.41Total Probability of Failure

$$\mathrm{PoF}_{total} = \mathrm{PoF}_{minor} + \mathrm{PoF}_{significant} + \mathrm{PoF}_{major}$$

$$\mathrm{PoF}_{total} = 0.082 + 0.00103 + 0.0006 = 0.083$$

Probability of Failure Yn

$PoF_{YN,total}$ is calculated in the same way as above using $TXSystemEoL_{Yn}$ in place of $TXSystemEoL_{Y0}$.

Transformer Consequence of Failure

1.42 System Consequence

1.42.1 Probability of Disconnection (P_{OC})

P_{OC} is a function of five probabilities.

I. **Probability of a coincident outage (P_O)**
Asset is P_O subgroup 1 that corresponds a value of 0.0305 according with LSA Table 70.

II. **Probability of damage to another circuit (P_d)**
According with LSA Table 71, P_d values for each of the failure mode of the transformers are as follow:

Failure mode defect:	P_d=0
Failure mode minor:	P_d=0
Failure mode significant:	P_d=0
Failure mode major:	P_d=0.01

III. **Probability of maloperation on another circuit (P_m)**
P_m is a constant for all assets and is set to 0.01 according with LSA Table 69

IV. **Probability of coincident fault on another circuit (P_f)**
Aaccording with LSA Table 70 6.1.1.1.3, the value is P_f=0.066

V. **Probability of overloading on the remaining circuit (P_l)**
P_l is an asset specific input value. In this case P_l=0.19

The probabilities of no outage, no damage, no maloperation, no coincident faults and no overloading are also required and are calculated as follow:

i. **Probability of no coincident outage occurring on another circuit (N_O)**
$N_O = 1 - P_O = 1 – 0.0305 = 0.9695$

ii. **Probability of no damage occurring on another network (N_d)**

Failure mode defect: $N_d = 1 – 0 = 1$
Failure mode minor: $N_d = 1 – 0 = 1$
Failure mode significant: $N_d = 1 – 0 = 1$
Failure mode major: $N_d = 1 – 0.01 = 0.99$

iii. **Probability of no maloperation on another circuit (N_m)**
$N_m = 1 – P_m = 1 – 0.01 = 0.99$

iv. **Probability of no coincident fault on another circuit (N_f)**
$N_f = 1 – P_f = 1 – 0.01 = 0.9340$

v. **Probability of no overloading on the remaining circuit (N_l))**
$N_l = 1 – P_l = 1 – 0.19 = 0.81$

For this example, have been considered X_{min} = 1 and the probability of disconnection P_{OC} is calculated using NARA equation 114:

$$P_{OC} = P_d + (N_d \times P_O) + (N_O \times N_d \times P_m) + \left(N_O \times N_d \times N_m \times P_f\right)$$

For defect, minor and significant condition:

$$P_{OC} = 0 + (1 \times 0.0305) + (0.9695 \times 1 \times 0.01) + (0.9695 \times 1 \times 0.99 \times 0.066) = 0.10354$$

For major condition:

$$P_{OC} = 0.01 + (0.99 \times 0.0305) + (0.9695 \times 0.99 \times 0.01) + (0.9695 \times 0.99 \times 0.99 \times 0.066) = 0.11251$$

1.42.2 Customer Disconnection Duration (D)

The customer disconnection duration, D, is derived from six separate durations:

I. **Duration of failure mode unavailability (hours) (D_{fm})**
According with LSA Table 77, D_{fm} values for each of the failure mode of the transformers are as follow:

Failure mode defect: $D_{fm} = 0$
Failure mode minor: $D_{fm} = 24$
Failure mode significant: $D_{fm} = 240$
Failure mode major: $D_{fm} = 480$

II. **Outage restoration time (hours) (D_o)**

The outage restoration time for subgroup 1 is 24 hours for all the Subgroups according with LSA Table 78.

III. Circuit damage restoration time (hours) (D_d)

According with LSA Table 80, D_d values for each of the failure mode of the transformers are as follow:

Failure mode defect:	$D_d = 168$
Failure mode minor:	$D_d = 168$
Failure mode significant:	$D_d = 168$
Failure mode major:	$D_d = 168$

IV. Protection maloperation restoration time (hours) (D_m)

According with LSA Table 79, D_m is a constant set to 2.

V. Unrelated fault restoration time (hours) (D_f)

According with LSA Table 79, D_f have been set to 84.

VI. Circuit overload restoration time (hours) (D_l)

According with LSA Table 79, D_l is a constant set to 2.

For this example, have been considered $X_{min} = 1$

Using NARA equation 118:

$$D = \frac{min(D_{fm}, D_d) \times P_d + min(D_{fm}, D_O) \times N_d \times P_O + min(D_{fm}, D_m) \times N_O \times N_d \times P_m + min(D_{fm}, D_f) \times N_O \times N_d \times N_m \times P_f}{P_{OC}}$$

$$= \frac{min(24{,}168) \times 0 + min(24{,}24) \times 1 \times 0.0305 + min(24{,}2) \times 0.9695 \times 1 \times 0.01 + min(24{,}84) \times 0.9695 \times 1 \times 0.99 \times 0.066}{0.10354}$$

$$= \frac{0 + (24 \times 0.0305) + (2 \times 0.9695 \times 0.01) + (24 \times 0.9695 \times 0.99 \times 0.066)}{0.10354} = 21.94007$$

For minor condition	D = 21.94007
For significant condition	D = 58.64810
For major condition	D = 68.36769

1.42.3 Generation Disconnection Cost

The cost of disconnection of generation is in two parts

1.42.3.1 Part 1: Generation compensation cost (GC)

For this example, the weighted quantity of generation disconnected $MW_W = 0$

The constants used to derive the generation disconnection cost are dummy values:

- Annual average System Buy Price $C_{SBP} = 10$
- Annual average System Marginal Price $C_{SMP} = 20$
- Average Transmission Network Use of System $C_{TNUoS} = 1$

Equation changes depend of the value of the Customer Disconnection Duration (D)

For minor condition D = 21.94007

NARA equation 123:

$$G_c = MW_W(1.5C_{SBP} + \{D - 1.5\}C_{SMP}) = 0$$

For significant condition D = 58.64810

NARA equation 124:

$$G_C = G_c = MW_W(1.5C_{SBP} + 22.5C_{SMP} + \{D - 24\}C_{TNUoS}) = 0$$

For major condition D = 68.36769

NARA equation 124:

$$G_C = G_c = MW_W(1.5C_{SBP} + 22.5C_{SMP} + \{D - 24\}C_{TNUoS}) = 0$$

1.42.3.2 Part 2: Generation replacement cost (GR)

For this example, the peak adjusted demand MW_D = 94.67

For all 3 conditions, minor, significant and major, using NARA equation 125:

For $D > 2$

$$G_R = 2C_{SMP}(k3.MW_W - k1.MW_D)$$

k1 and k3 are defined in section 6.1.1.4 and the values are:

k3=0.38

k1=0.75

$$G_R = 2 \times 20 \times (0.38 \times 0 - 0.75 \times 94.67)$$

$$G_R = 40\ x\ (0 - 71.0025)$$

$$G_R = -2840$$

According with NARA equation 127:

For $G_R < 0$, $G_{R*} = 0$

1.42.3.3 Vital Infrastructure Cost

The input used to calculate the vital infrastructure cost are:

- Number of Transport Hubs supplied by sites at risk $S_T = 0$
- Number of Economic Key Points supplied by sites at risk $S_E = 0$
- Number particularly sensitive COMAH sites supplied by sites at risk $S_C = 0$
- Number of Black Start sites supplied by sites at risk $S_B = 0$

The constants used to derive the generation replacement cost are dummy values:

- Hourly disconnection cost for Transport Hubs $V_T = 1$
- Hourly disconnection cost for Economic Key Points $V_E = 1$
- Disconnection cost per site per disconnection event for COMAH sites $V_C = 1$

- Disconnection cost per site per disconnection event for Black Start sites V_B = 1

Using NARA equation 129:

$$V = D \times (V_T S_T + V_E S_E) + V_C S_C = 21.95 \times (0 + 0) + 0 = 0$$

1.42.3.4 Risk Multiplier

The No. customer sites with X=X_{min} for this example is z=1

$$M_Z = \frac{z + \sum_{i=1}^{Z}(z - i)}{z} = \frac{1 + 0}{1} = 1$$

1.42.3.5 Costumer Disconnection Risk Cost (Rcustomer)

The constant used to derive the costumer disconnection risk cost are dummy values:

- Value of lost load (£/MWh) $VOLL = 100$

For this example, the peak adjusted demand MW_D = 94.67

V=0

M_Z=1

Using NARA equation 130:

$$R_{customer} = P_{OC} \times (G_C + G_R + (k1 \times D \times MW_D \times VOLL) + V) \times M_Z$$

For minor condition:

$$R_{customer} = P_{OC} \times (G_C + G_R + (k1 \times D \times MW_D \times VOLL) + V) \times M_Z$$
$$= 0.10354 \times (0 + 0 + (0.75 \times 21.94007 \times 94.67 \times 100) + 0) \times 1 = 16{,}129.459$$

For significant condition:

$R_{customer} = P_{OC} \times (G_C + G_R + (k1 \times D \times MW_D \times VOLL) + V) \times M_Z = 0.10354 \times (0 + 0 + (0.75 \times 58.64810 \times 94.67 \times 100) + 0) \times 1$ =43,115.730

For major condition

$$R_{customer} = P_{OC} \times (G_C + G_R + (k_1 \times D \times MW_D \times VOLL) + V) \times M_Z$$
$$= 0.11251 \times (0 + 0 + (0.75 \times 68.36769 \times 94.67 \times 100) + 0) \times 1 = 54{,}615.469$$

1.42.3.6 Reactive Compensation (RC)

For this example:

- Capacity of the asset in MVar Q = 0

- R_F is the requirement factor and is set to 0 in this example.

The constants used:

- Duration of failure mode unavailability (hours) (D_{fm})
  According with LSA Table 77, D_{fm} values for each of the failure mode of the transformers are as follow:
  Failure mode defect: $D_{fm} = 0$
  Failure mode minor: $D_{fm} = 24$
  Failure mode significant: $D_{fm} = 240$
  Failure mode major: $D_{fm} = 480$
- MVAr Procurement Cost
  According with LSA Table 7.42, $C_{MVArh} = 3.92$

For all conditions, using NARA equation 135

$$R_{RC} = R_F \times D_{fm} \times Q \times C_{MVArh} = 0$$

1.43 Safety Consequence

For this example, Rating type: Medium & Activity type: Medium - Therefore exposure modifier = 6.25 using LSA Table 92.

The constants used to derive the safety consequence cost are according to the following table:

Term	Variable	Severity	Condition	Value	Reference
Probability of Injury, j, occurring for failure mode i	$P_{injury,j,i}$	Slight	Defect Condition	0.00004164	LSA Table 88
			Minor Condition	0.00008329	
			Significant Condition	0.00208219	
			Major Condition	0.00416438	
		Serious & Perm Inca & Fatal	Defect Condition	0.00010648	
			Minor Condition	0.00021297	
			Significant Condition	0.00532414	
			Major Condition	0.01064829	
Cost associated with injury, j	$C_{injury,j}$	Slight		= 4500	LSA Table 90
		Serious		= 307500	
		Perm Inc		= 31080000	
		Fatal		= 20052000	
Disproportion factor	DF	NA	NA	= 10	LSA Table 91

NARA equation 137:

$$Safety\ Cost_i = Probability\ of\ Injury_{j,i} \times Cost\ of\ Injury_j \times Exposure_i$$

For defect:

$$Safety\ Cost_i = Probability\ of\ Injury_{j,i} \times Cost\ of\ Injury_j \times Exposure_i$$
$$= 6.25\big((0.00004164 \times 4500) + (0.00010648 \times 307500) + (0.00010648 \times 31080000) + (0.00010648 \times 20052000)\big) = 34{,}234.16$$

For minor = 68,471.53

For significant = 1,711,752.93

For major = 3,423,509.08

1.44 Environmental Consequence

1.44.1 Exposure

For this example, the Proximity to water course is 90 and asset is located in National Park. According with LSA Table 105, the factors are:

$F_{proximity,water} = 0.8$

$F_{env\ sensitive\ site} = 1$

The exposure is calculated using NARA equation 144:

$$Exposure = F_{proximity,water} \times F_{env\ sensitive\ site} = 0.8x1 = 0.8$$

1.44.1.1 Environmental Impact Volume

The environmental consequences of failure are quantified by considering the severity of different environmental. Considering a 132 kV transformer for this example, the values can be found in the LSA Table 102:

Term	**Variable**	**Condition**	**Value**
Amount of SF6 Lost	V_{SF6}	Defect Condition	0
		Minor Condition	0
		Significant Condition	0
		Major Condition	0
Avg. Volume Litres Lost	V_{Oil}	Defect Condition	640
		Minor Condition	960
		Significant Condition	3200
		Major Condition	32000
Likelihood of Fire	V_{Fire}	Defect Condition	0.001
		Minor Condition	0.001
		Significant Condition	0.05
		Major Condition	0.1
Amount of Waste	V_{Waste}	Defect Condition	0.016
		Minor Condition	0.16
		Significant Condition	0.64

		Major Condition	3.2

The cost of environmental impact is according with LSA Table 103:

Environment cost of	Value
SF6 (per kg)	C_{SF6} = 308.99
Oil (per litre)	C_{Oil} = 39.33
Fire	C_{Fire} = 5618.00
Waste (per tonne)	C_{Waste} = 168.54

Consequence of environmental impact (CEI) is calculated using NARA equation 143:

$$Consequence\ of\ Environmental\ Impact_i = \sum_i (Environmental\ Impact\ Costs \times Impact\ Volume \times Exposure)_{jk}$$

$$\begin{aligned} CEI_{defect} &= Exposure \times (V_{SF6} \times C_{SF6} + V_{Oil} \times C_{Oil} + V_{Fire} \times C_{Fire} + V_{Waste} \times C_{Waste}) \\ &= 0.8 \times \big((0 \times 308.99) + (640 \times 39.33) + (0.001 \times 4618) + (0.016 \times 168.54)\big) \\ &= 20{,}143.61 \end{aligned}$$

$$CEI_{minor} = 30{,}231.51$$

$$CEI_{significant} = 100955.81$$

$$CEI_{major} = 1007728.90$$

1.45 Financial Consequence

The Financial Location Rating is Standard which associates, according with LSA Table 109 to a factor:

$$F_{location} = 1$$

Replacement cost ($Cost_{Rep}$)of a 132 kV Transformer is a dummy value of 1000.

The proportion of replacement cost (p_i) by failure mode, are dummy values as follow:

Condition	Percentage of Replacement Cost
Defect Condition	10%
Minor Condition	25%
Significant Condition	50%
Major Condition	100%

The financial consequence of failure mode effect is calculated using NARA equation 146:

$$Financial\ Consequence\ of\ Failure\ Mode\ Effect = \sum_i (Financial\ Consequence\ of\ Failure\ (£)_i \times Location\ Factor_i)$$

$$Financial\ Consequence\ of\ Failure\ Mode\ Effect_{defect} = 1 \times 1000 \times 10\% = £100$$

$$Financial\ Consequence\ of\ Failure\ Mode\ Effect_{minor} = 1 \times 1000 \times 25\% = £250$$

$$Financial\ Consequence\ of\ Failure\ Mode\ Effect_{significant} = 1 \times 1000 \times 50\% = £500$$

$$Financial\ Consequence\ of\ Failure\ Mode\ Effect_{major} = 1 \times 1000 \times 100\% = £1000$$

Total Monetised Risk

Nara equation 2:

$$\begin{aligned} Total\ Risk\ _{defect} &= PoF_{defect} \\ &\times \left(R_{customer,defect} + Safety\ Cost_{defect} + CEI_{defect}\right. \\ &\left.+ Financial\ Consequence\ of\ Failure\ Mode\ Effect_{defect}\right) \\ &= 0.1414 \times (0 + 34234.16 + 20143.61 + 100) = £7{,}703.05 \end{aligned}$$

$$Total\ Risk\ _{minor} = 0.082 \times (13333.686 + 68471.53 + 30231.51 + 250) = £9{,}207.51$$

$$Total\ Risk\ _{significant} = 0.00103 \times (35642.337 + 1711752.93 + 100955.81 + 500) = £1{,}904.31$$

$$Total\ Risk\ _{major} = 0.0006 \times (45148.788 + 3423509.08 + 1007728.90 + 1000) = £2{,}686.43$$

$$Monetised\ Risk_{total} = £21{,}501.31$$