NARM Methodology SSENT Licensee Specific Appendix (LSA)

ISSUE 1

REVISION 1

1. CONTENTS

2. FACTORS COMMON TO ALL LEAD ASSETS

1.1 LSE FACTOR

LSE Factor is a combination of Location, Situation and Environmental factors. Situation and environmental tend to only include single variables such as if the asset indoors or outdoors and if the weather is poor or not. Location factors are often more complex taking multiple different variables and combining them first before moving to produce an LSE calculation. Each lead asset can calculate its LSE factor differently. The table below describes the processes and input variables to calculate LSE factor for each lead asset.

Table 1 Common LSE Factors

Asset Category	*Location Factor 1*		*Location Factor 2*		*Location Factor 3*		*Location Factor 4*	*Overall LSE Factor*
	Distance to Coast - DC_F - Miles		**Altitude - A_F - Meters**		**Corrosion - C_F**			
	Distance	**Factor, F_D**	**Altitude**	**Factor, F_A**	**Corrosion Factor**	**Factor, F_C**		
Circuit Breakers	**<5**	1.35	**0-50**	1	**1**	0.85		= (((Max [DC_F, A_F, E_F] – Minimum location factor) * Situation factor + Minimum Possible Location factor * Environment factor
	5-10	1.2	**50-100**	1	**2**	1		
	10-15	1.1	**100-250**	1.1	**3**	1.05		
	15-20	1	**250>**	1.2	**4**	1.15		
	20-25	1			**5**	1.35		
	25>	1						
	Distance to Coast - DC_F - Miles		**Altitude - A_F - Meters**		**Corrosion - C_F**			
	Distance	**Factor, F_D**	**Altitude**	**Factor, F_A**	**Corrosion Factor**	**Factor, F_C**		
Transformers & Reactors	**<5**	1.35	**0-50**	1	**1**	0.85		= (((Max [DC_F, A_F, E_F] – Minimum location factor) * Situation factor + Minimum Possible Location factor * Environment factor
	5-10	1.2	**50-100**	1	**2**	1		
	10-15	1.1	**100-250**	1.1	**3**	1.05		
	15-20	1	**250>**	1.2	**4**	1.15		
	20-25	1			**5**	1.35		
	25>	1						

<table>
<tr><th>Asset Category</th><th>Location Factor 1</th><th>Location Factor 2</th><th>Location Factor 3</th><th>Location Factor 4</th><th>Overall LSE Factor</th></tr>
<tr>
<td>Cables (solid)</td>
<td>Shallow Duct - S_F
<table>
<tr><th>Is it shallow? (m)</th><th>Factor, F_D</th></tr>
<tr><td>Yes</td><td>1.0</td></tr>
<tr><td>No</td><td>1.0</td></tr>
</table></td>
<td>Ploughed Installation - P_F
<table>
<tr><th>Ploughed Installation</th><th>Factor, F_C</th></tr>
<tr><td>Yes</td><td>1.0</td></tr>
<tr><td>No</td><td>1.0</td></tr>
</table></td>
<td></td>
<td></td>
<td>= (S_F * P_F) * Situation Factor * Environment Factor</td>
</tr>
<tr>
<td>Cables (fluid filled)</td>
<td>Subject to Mechanical Influence - M_F
<table>
<tr><th>Mechanically influenced?</th><th>Factor, F_M</th></tr>
<tr><td>No</td><td>1</td></tr>
<tr><td>Yes</td><td>1.25</td></tr>
</table></td>
<td></td>
<td></td>
<td></td>
<td>= M_F

OR

= Mechanical influence default factor</td>
</tr>
<tr>
<td>Cables (submarine)</td>
<td>Topography – T_F
<table>
<tr><th>Topography (Detrimental)</th><th>Factor (Sea)</th><th>Factor (land locked)</th></tr>
<tr><td>Low</td><td>1.0</td><td>0.9</td></tr>
<tr><td>Medium</td><td>1.1</td><td>1.0</td></tr>
<tr><td>High</td><td>1.2</td><td>1.1</td></tr>
<tr><td>Very High</td><td>1.4</td><td>1.2</td></tr>
<tr><td>Default</td><td>1.0</td><td>0.9</td></tr>
</table></td>
<td>Situation – S_F
<table>
<tr><th>Situation</th><th>Factor</th></tr>
<tr><td>Laid on bed</td><td>1.0</td></tr>
<tr><td>Covered</td><td>0.9</td></tr>
<tr><td>Buried</td><td>0.8</td></tr>
<tr><td>Default</td><td>1.0</td></tr>
</table></td>
<td>Wind/Wave Factor – W_F
<table>
<tr><th>Rating</th><th>Description</th><th>Factor</th></tr>
<tr><td>1</td><td>Sheltered sea loch, wind<200W/m^2</td><td>1.0</td></tr>
<tr><td>2</td><td>Wave<15kW/m, Wind 200-800W/m^2</td><td>1.2</td></tr>
<tr><td>3</td><td>Wave>15kW/m, Wind >800W/m^2</td><td>1.4</td></tr>
<tr><td></td><td>Default</td><td>1.0</td></tr>
</table></td>
<td>Wave/Current factor - C_F
<table>
<tr><th>Intensity</th><th>Factor (Sea)</th><th>Factor (land locked)</th></tr>
<tr><td>Low</td><td>1.1</td><td>1</td></tr>
<tr><td>Moderate</td><td>1.25</td><td>1.15</td></tr>
<tr><td>High</td><td>1.5</td><td>1.4</td></tr>
<tr><td>Default</td><td>1.1</td><td>1.0</td></tr>
</table></td>
<td>= Max [T_F, SA_F, W_F, C_F]</td>
</tr>
<tr>
<td>Overhead Line (Conductor)</td>
<td>Distance to Coast - DC_F - Miles
<table>
<tr><th>Distance</th><th>AL, F_A</th><th>Cu, F_C</th></tr>
<tr><td><5</td><td>1.5</td><td>1.2</td></tr>
<tr><td>5-10</td><td>1.25</td><td>1.1</td></tr>
<tr><td>10-15</td><td>1.1</td><td>1.05</td></tr>
<tr><td>15-20</td><td>1</td><td>1</td></tr>
<tr><td>20-25</td><td>1</td><td>1</td></tr>
<tr><td>25></td><td>1</td><td>1</td></tr>
</table></td>
<td>Altitude - A_F - Meters
<table>
<tr><th>Alt.</th><th>AL, F_A</th><th>CU, F_C</th></tr>
<tr><td>0-50</td><td>1</td><td>1</td></tr>
<tr><td>50-100</td><td>1</td><td>1</td></tr>
<tr><td>100-250</td><td>1</td><td>1</td></tr>
<tr><td>250-500</td><td>1.35</td><td>1.1</td></tr>
<tr><td>500></td><td>1.35</td><td>1.15</td></tr>
</table></td>
<td>Corrosion - C_F
<table>
<tr><th>Corrosion Factor</th><th>AL, F_A</th><th>CU, F_C</th></tr>
<tr><td>1</td><td>0.85</td><td>0.85</td></tr>
<tr><td>2</td><td>1</td><td>1</td></tr>
<tr><td>3</td><td>1</td><td>1</td></tr>
<tr><td>4</td><td>1</td><td>1</td></tr>
<tr><td>5</td><td>1.5</td><td>1.5</td></tr>
</table></td>
<td></td>
<td>= (((Max [DC_F, A_F, E_F] – Minimum location factor)

* Situation factor + Minimum Possible Location factor

* Environment factor</td>
</tr>
</table>

Asset Category	*Location Factor 1*	*Location Factor 2*	*Location Factor 3*	*Location Factor 4*	*Overall LSE Factor*
Overhead Line (Fittings)	**Distance to Coast - DC_F - Miles** **Distance** – **Factor, F_D** **<5** – 1.5 **5-10** – 1.25 **10-15** – 1.1 **15-20** – 1 **20-25** – 1 **25>** – 1	**Altitude - A_F - Meters** **Altitude** – **Factor, F_A** **0-50** – 1 **50-100** – 1 **100-250** – 1.1 **250>** – 1.25	**Corrosion - C_F** **Corrosion Factor** – **Factor, F_C** **1** – 0.85 **2** – 1 **3** – 1.1 **4** – 1.25 **5** – 1.5	**Severe Weather Zone - S_F** **Weather Factor** – **Factor, F_W** **Normal** – 1 **No** – 1 **Poor** – 1.1 **Bad** – 1.33	= (((Max [DC_F, A_F, E_F] – Minimum location factor) * Situation factor + Minimum Possible Location factor * Environment factor

Overhead Line (Towers - Foundations)	**Soil Resistivity - S_{RS}**
	
	Soil Resistivity – **Rating, S_R**
	<1000 – 12
	<5000 – 8
	<20000 – 4
	<80000 – 1
	80000> – 0
		Soil pH Rating - S_P
		
		Soil pH – **Rating, S_R**
		<2 – 12
		<4 – 9
		<7 – 3
		<9 – 0
		<14 – 0
			Redox Potential - S_{RD}
			
			Potential mV – **Rating, S_R**
			<0 – 6
			<300 – 5
			<500 – 3
			<800 – 1
			<1000 – 0
				Combined Test - F_T
				
				Combined Rating – **Factor**
				<2 – 0.85
				<4 – 0.95
				<8 – 1
				<12 – 1.2
				<50 – 1.35
					IF F_T and/or F_R are available values, then
					
					FLSE = Max (F_T, F_R)
					
					ELSE
					
					IF F_T and or F_R are not available values, then
					
					F_T and/or F_R = Default value and therefore
					
					FLSE = Max (F_T, F_R)
					
					WHERE F_R = SOIL RATING

Overhead Line (Towers - Steelwork)	**Distance to Coast - DC_F - Miles** **Distance** – **Factor, F_D** **<5** – 1.5 **5-10** – 1.25 **10-15** – 1.1 **15-20** – 1 **20-25** – 1 **25>** – 1	**Altitude - A_F - Meters** **Altitude** – **Factor, F_A** **0-50** – 1 **50-100** – 1 **100-250** – 1.1 **250>** – 1.25	**Corrosion - C_F** **Corrosion Factor** – **Factor, F_C** **1** – 0.85 **2** – 1 **3** – 1.1 **4** – 1.25 **5** – 1.5	**Severe Weather Zone - S_F** **Weather Factor** – **Factor, F_W** **Normal** – 1 **No** – 1 **Poor** – 1.1 **Bad** – 1.33	= (((Max [DC_F, A_F, E_F] – Minimum location factor) * Situation factor + Minimum Possible Location factor * Environment factor

1.2 DUTY FACTOR

Duty factor is calculated for all lead assets and is required for calculation of each asset's initial end of life modifier value EoL_1. The duty factor is included in the calculation to give an indication of how much "work" that asset is doing. The more an asset is utilising it will tend to degrade faster than assets utilized less. Below is a table which breaks down the duty factor inputs and calculation for each lead asset types.

Table 2 Common Duty Factors

Asset Category	*Duty Factor 1*	*Duty Factor 2*	*Duty Factor 3*	*Overall Duty Factor*
Circuit Breakers	**Feeder Protection - P_R** **Presence of Feeder Protection** — **Factor, Prot** **No** — 1.0 **Yes** — 1.2	**Auto-Reclose - R_A** **Presence of Auto-Reclose** — **Factor RA** **No** — 1.0 **Yes** — 1.2	**High Duty - D_H** **Duty Level** — **Factor D_H** **Normal** — 1.0 **High** — 1.15 **Very High** — 1.35	***IF*** (D_H = OR (Very High, High) $F_D = D_H$ ***ELSE*** $F_D = R_A * P_R$
Transformers & Reactors	**Maximum Operating Temperature - T_{Max}** **Maximum Operating Temperature** — **Factor, T_{max}** **0 - 80** — 0.75 **80 - 95** — 1.0 **95 - 105** — 1.25 **105 - 150** — 1.5	**Maximum Demand - D_{Max}** **Max Demand/Rating** — **Factor D_{max}** **0.0 – 0.7** — 0.75 **0.7 – 0.9** — 0.9 **0.9 – 1.0** — 1.0 **1.0 – 1.15** — 1.25 **1.15 – 2.0** — 1.5	**Through Faults - T_F** **Severity /Frequency of Through Faults** — **Through Faults Duty Factor (T_F)** **Normal** — 1 **High** — 1 **Very High** — 1	***IF*** (D_{MAX} & T_{MAX} Factor are blank) F_{DY} = Default Demand/Temperature Factor x T_F ***ELSE*** $F_{DY} = Max(D_{MAX}, T_{MAX}) \times T_F$ ***WHERE:*** Default Demand/Temperature Factor = 1.0

<table>
<tr><th>Asset Category</th><th>Duty Factor 1</th><th>Duty Factor 2</th><th>Duty Factor 3</th><th>Overall Duty Factor</th></tr>
<tr><td>Cables (solid)</td><td>Maximum Demand - D_{Max}

Maximum Demand/Rating | Factor, D_{max}
0 - 40 | 1
40 - 60 | 1
60 - 75 | 1
75 - 85 | 1.05
85 - 100 | 1.1
100 + | 1.5</td><td>Reactive Earthing - R_E

Reactive Earth Presence | R_E Factor
No | 1
Yes | 1</td><td></td><td>Overall Duty Factor = Max Demand Factor * Reactive Earth Presence Factor</td></tr>
<tr><td>Cables (fluid filled)</td><td>Maximum Demand - D_{Max}

Maximum Demand/Rating | Factor, D_{max}
0 - 40 | 1
40 - 60 | 1
60 - 75 | 1
75 - 85 | 1.05
85 - 100 | 1.1
100 + | 1.5</td><td>Duty Exception Report - D_E*

Duty Exception Factor | R_E Factor
No | 1
Yes | 1</td><td></td><td>Overall Duty Factor = Maximum demand Factor * Duty Exception Report Factor</td></tr>
<tr><td>Overhead Line (Conductor)</td><td>Default | 1</td><td></td><td></td><td>Default Factor = Overall Duty Factor</td></tr>
<tr><td>Overhead Line (Fittings)</td><td>High Damper Replacement Rate
High Damper Replacement Rate | Factor, D_{max}
No | 1
Yes | 1.2</td><td></td><td></td><td>High Damper Rate = Overall Duty Factor</td></tr>
<tr><td>Overhead Line (Towers - Foundations)</td><td>Default | 1</td><td></td><td></td><td>Default Factor = Overall Duty Factor</td></tr>
<tr><td>Overhead Line (Towers - Steelwork)</td><td>Default | 1</td><td></td><td></td><td>Default Factor = Overall Duty Factor</td></tr>
</table>

3. CIRCUIT BREAKER FACTORS AND EOL CALCULATIONS

The following sections of this document provide an overview of the Circuit Breaker model design.

For each stage in the EoL Value derivation, the overview will identify and name all the component parts of each derivation and provide a high-level explanation of what the component parts represent.

1.3 OIL CONDITION

SHE Transmission has no Bulk-Oil Circuit Breakers and no Air Blast Circuit Breakers; therefore, this information is not relevant for SHE Transmission assets.

1.4 AFTER FAULT MAINTENANCE

For assets, which have after fault maintenance (AFM), scores, (i.e. assets whose arc extinguishing medium is either vacuum or SF_6), the AFM Score module considers the rate of change of each assets AFM score to estimate an "extrapolated life". This estimation is used to determine an AFM factor which is used within the "FV_1" derivation.

Table 3 Extrapolated Life Calibration Table

> Extrapolated life Minimum	<= Extrapolated life Maximum	AFM Score Factor
-1	5	1.5
5	20	1.25
20	50	1.1
50	100	1
100	1,000,000.00	1

In the current implementation, AFM is included in the model but is not utilised in the overall calculations. It uses a default score of 1 to neutralise the effects it has on the calculation. In the future, we MAY/MAYNOT include AFM data to produce a more effective FV_1 calculation.

1.5 SF6 CONDITION

SF_6 condition results (e.g. moisture, purity, dew point etc) use a series of defined multipliers to derive separate gas condition scores. The sum of the gas condition scores is then used to determine an overall SF_6 condition factor (SF_{6COND}) (See Table 4) used in the creation of modifying factor "FV_1", and an optional minimum EoL Modifier can be set where poor gas condition is detected, which is set aside for later in the process.

Table 4 SF_6 Condition Calibration Table

Max SF_6 Condition	SF_6 Condition Factor, $SF6_{COND}$
-1 to 50	**1.0**
51 to 200	**1.0**
201 to 500	**1.05**
500 to 1000	**1.1**
1000+	**1.2**

Table 5 Defined Condition PeriodDefined Condition Period (Years)
5

1.6 SF6 LEAKAGE

The leakage history is used to create two different factors as per Table 6:

- $SF6_{NO}$, determined by the number of times an asset has been topped up with SF_6,
- $SF6_{LOST}$ a second factor which considers the percentage of gas replaced relative to the design weight.
- Only leaks that have occurred within a "Defined Leak Period" are considered

Table 6 SF_6 Leakage History Calibration Tables

Number of SF_6 Leaks	SF_6 Volume Factor, $SF6_{NO}$
0	**1.0**
1	**1.1**
2-3	**1.25**
3+	**1.5**

Weighted Lost SF_6	SF_6 Condition Factor, $SF6_{LOST}$
0 to 0.1	**1.0**
0.1 to 0.2	**1.05**
0.2 to 0.5	**1.1**
0.5 to 0.8	**1.25**
0.8 +	**1.4**

Defined Leak Period (years)
5

4. TRANSFORMER AND REACTOR FACTORS AND EOL CALCULATION

1.7 OIL CONDITION

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 factors (See Table 7 Oil Condition Calibration Tables) considers the latest oil condition tests, (moisture, acidity, breakdown strength and tan delta) each of which is used to create a test score (See Table 9 Overall Oil Condition Calibration table) by combination with a Multiplier (See Table 8 Oil Condition Multipliers Calibration Table).

Table 7 Oil Condition Calibration Tables

Relative Humidity (%)	Moisture Score
0 - 15	**0**
15 - 30	**2**
30 - 50	**4**
50 - 65	**8**
65 – 500	**10**

Breakdown Voltage (kV)	Breakdown Strength Score
0 - 30	**10**
30 - 40	**4**
40 - 50	**2**
50 - 10000	**0**

Tan Delta @90°C	Tan Delta Score
0 – 0.02	**0**
0.02 – 0.06	**2**
0.06 – 0.12	**4**
0.12 – 0.2	**8**
0.2 - 1	**10**

Acidity – mg KOH/g	Acidity Score
0 – 0.03	**0**
0.03 – 0.075	**2**
0.075 - 0.15	**4**
0.15 - 0.25	**8**
0.25 - 2	**10**

Each of these scores is given a multiplier which accounts for the significance of the result:

Table 8 Oil Condition Multipliers Calibration Table

Test	Multiplier
Relative Humidity	**80**
Breakdown Voltage (kV)	**80**
Tan Delta @90°C	**80**
Acidity – mg KOH/g	**125**

The summation of the individual oil condition test scores is then used to determine an overall oil condition factor.

Table 9 Overall Oil Condition Calibration table

Oil Condition Score	Factor, F_{OIL}
0 – 200	**1.0**
200 – 500	**1.0**
500 – 950	**1.05**
950 – 1500	**1.1**
1500+	**1.2**

Where the oil test is not considered to be valid it is excluded, and the next available set of results are used. Oil condition is not included if the latest sample is beyond the cut-off date which in the case of SSENT is within the last 7 years.

The EoL_2 module combines the overall condition factor, defect history factor, family reliability factor, overall test result factor, overall OR factor and the overall oil condition score to determine modifying factor 'FV_1'. This is then multiplied by EoL_1 to determine EoL_2. This is further Explained in the Technical Guidance Note and Network Asset Risk Annex.

1.8 DERIVATION OF TX EOLDGA

The parameters used to derive EoL_{DGA} are listed in the tables below:

Table 10 DGA Factors

Hydrogen (H_2) (ppm)	Score
0 – 20	**0**
20 - 40	**2**
40 – 100	**4**
100 – 200	**10**
200+	**16**

Acetylene (C_2H_2) (ppm)	Score
0 – 1	**0**
1 – 5	**2**
5 – 20	**4**
20 – 100	**8**
100+	**10**

Ethylene (C_2H_4) Methane (CH_4) & Ethane (C_2H_6) (Each)(ppm)	Score
0 – 10	**0**
10 – 20	**2**
20 – 50	**4**
50 – 150	**10**
150+	**16**

A specific multiplier is then applied to each score:

Table 11 DGA Multipliers and Parameters

Gas	Multiplier
H_2	**50**
C_2H_2	**120**
C_2H_4	**30**
CH_4	**30**
C_2H_6	**30**

Setting Item	Value
DGA Divider	**220**
DGA HI Max	**10**
DGA HI Min	**0.5**
DGA History Threshold	**4**

>DGA% Change Mininum	<= DGA % Change	DGA Change Description	DGA Factor
-1000	**95**	**Negative**	**0.9**
95	**105**	**Neutral**	**1**
105	**125**	**Small**	**1.05**
125	**200**	**Significant**	**1.15**
200	**1000**	**Large**	**1.2**

1.9 DERIVATION OF TX EOLFFA

The parameters used to derive EoL_{DGA} are listed in the tables below:

Table 4-6 FFA Factors

Factor	Value
FFA HI Maximum	**10**
FFA Multiplier	**0.02125**
FFA Power Value	**0.7056**
DP Multiplier	**-121**
DP Addition	**1294**

5. CABLE FACTORS AND EOL CALCULATION

1.10 LEAK HISTORY

The leak history information for a circuit is used to determine a leak history factor and an associated minimum EoL for each circuit. The leak history is derived from information on the volume of top-ups over a ten-year period.

Leak History Factor

Table 12 Leak History Calibration Table

> Sum of weighted top up volumes/√Length	<= Sum of weighted top up volumes /√Length	Leak History Factor
-1	2	**1.0**
2	5	**1.1**
5	10	**1.2**
10	25	**1.3**
25	50	**1.4**
50	5,000	**1.5**

Leak History Minimum EoL

Table 13 Leak History Min EoL Calibration Table

> Sum of weighted top up volumes	<= Sum of weighted top up volumes	Initial Leak History Minimum EoL
0	5	**0.5**
5	10	**0.5**
10	15	**0.5**
15	20	**6.5**
20	25	**8**
25	1,000	**8**

1.11 FAULT RATE

The fault rate information for a circuit will be used to determine a Fault rate factor and derive a minimum EoL, as shown below.

Fault Rate Factor

Table 14 Fault Rate Calibration Table

Fault rate (Faults/per year/100km)	Fault Rate Factor
-1 - 1	1.0
1 - 2	1.1
2 - 4	1.2
4 - 6	1.3
6 - 50	1.5

Fault Rate Minimum EoL

Table 15 Fault Rate Minimum Calibration Table

Fault rate min	Fault Rate Factor
-1 - 1	0.5
1 - 2	0.5
2 - 4	0.5
4 - 6	5.5
6 - 50	8.0

6. OVERHEAD LINES FACTORS

1.12 CONDUCTORS

1.12.1 CONDUCTOR AGE

The age is based on when the conductor was last replaced.

1.12.1.1 CONDUCTOR AVERAGE LIFE

An average life will be assigned to conductors based on the conductor type and the cross-sectional area. These values will be assigned via a calibration table, as described below.

Table 16 Conductor Average Life Data Capture

Conductor Type	*Conductor Size*	*Average Life (years)*
ACSR	-	50
Araucaria AAAC	-	60
Lynx ACSR	-	50
Tiger ACSR	-	40
ZEBRA ACSR	-	60
Tiger ACSR	125	40
Wolf ACSR	150	50
-	175	50
ACSR	175	50
BEAR	175	50
Bear ACSR	175	50
Lynx	175	50
Lynx ACSR	175	50
Porc	175	50
Wolf ACSR	175	50
Zebra ACSR	175	60
Lynx ACSR	177	-
Lynx ACSR	178	-
Lynx ACSR	179	-
Bear ACSR	250	50
ACSR	300	50
Goat ACSR	300	50
Upas AAAC	300	50
Zebra ACSR	400	60
Cmpctl	520	50
LAMFIL TAAAC	625	50
Araucaris AAAC	700	50
AAAC	821	50

Table 17 Default Age and constants

Setting Item	*Value*
Default Average Age	50
Maximum HI1	5.5
HI at End of Expected Life	5.5

1.12.2 VISUAL CONDITION

The visual condition record will determine a factor per condition point as per below:

Table 18 Conductor Scoring and MinHI Tables

Score	Termination Condition Factor	Conductor Damage Condition Factor	Jumper Condition Factor	Condition at Clamp Condition Factor	Condition Override Factor
1	**1**	**1**	**1**	**1**	**1**
2	**1**	**1.1**	**1**	**1**	**1**
3	**1**	**1.25**	**1.05**	**1.1**	**1.1**
4	**1**	**1.5**	**1.1**	**1.25**	**1.25**

Score	Termination Condition MinHI	Conductor Damage Condition MinHI	Jumper Condition MinHI	Condition at Clamp Condition MinHI	Condition Override MinHI
1	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
2	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
3	**0.5**	**5**	**4**	**0.5**	**5**
4	**0.5**	**8**	**5**	**8**	**8**

1.12.3 DEFECT HISTORY

The number of defects experienced on the span over the previous 5 years (including those that have been repaired are identified. Each defect will then be assigned a severity rating (using a scale of 1 to 4, where 4 is the most severe) via a calibration table.

Table 19 Defect Calibration table

Defect Description	Defect Severity Rating
Minor	**1**
Significant	**2**
Major	**4**

These values are summed together to produce a severity score which is the compared to a severity look up table which in turn produces a Defect factor.

Table 20 Defect Factor Value Calibration Table

Overall defect score minimum	Overall Defect minimum	Defect Factor	Defect MinHI
0	5	**1**	**0.5**
5	10	**1.05**	**0.5**
10	25	**1.1**	**0.5**
25	35	**1.25**	**0.5**
35	50	**1.5**	**0.5**

Override Defect History	Defect History Factor	Defect History MinHI
Normal	**1**	**0.5**
Poor	**1.25**	**0.5**
Bad	1.5	**0.5**

1.12.4 INFRA-RED TESTING

Helicopter inspections of the Overhead Lines are used to identify hot joints on conductors. This information will be used to derive an infra-red test factor and a minimum EoL value via calibration tables as shown below.

Where tests have been undertaken, the results (either pass, or fail) for each test type are used to derive individual test factors (and if desired minimum EoL indices) and are then combined to produce an overall test factor. The overall test factor is included in the formation of modifying factor FV_1, while any defined minimum EoL indices are set aside for use later in the process.

Table 21 Infra-Red Test Factor and Minimum EoL Calculation

Infra-Red Results	Infra-Red Test Factor
Pass	**1.0**

Infra-Red Results	Infra-Red Test Minimum EoL
Pass	**0.5**

Fail	**1.35**

Fail	**6.5**

1.12.5 CORROSION SURVEY TESTING RESULTS

Conductor sampling determines the extent of corrosion a sample of the overhead conductor, which is considered to provide a representative indication of the EoL of the circuit. The results can be used to derive an EoL Modifier independently of any other information on condition or age.
The test results are used to derive a Conductor Sampling EoL Modifier via a calibration table of the form shown below. The tests results are conducted on a span or number of spans and then applied to the whole circuit.

Once an End of Life value has been assigned, it is then used to calculate an overall End of Life for the span by adjusting the Aging rate Reduction factor used in the EoLy0 calculation.

Table 22 Cormon testing Score Conversion table

Cormon EoL Maximum	Aging Rate Reduction Factor
<2	**1**
>2	**1.5**

Table 23 Conductor Sampling Score Conversion Table

Conductor Sampling EoL Maximum	Aging Rate Reduction Factor
<2	**1**
>2	**1.5**

1.13 FITTINGS

To attach, insulate and join conductor spans various fittings and insulators are used. Over the course of the lifetime of these assets an EoL indicator needs to be calculated (on a per circuit and a per tower basis) as summarised in the schematic diagram below.

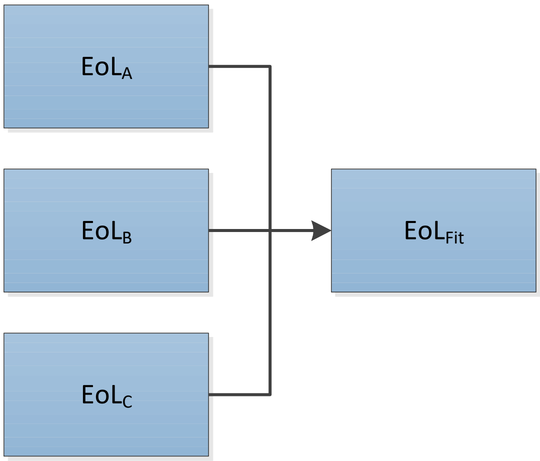

Figure 6-1 Final EoL Indicator for Fittings

EoL_a is the highest of the condition scores divided by a calibration value, whilst EOL_b is the sum of the highest condition scores divided by a second calibration value.

1.13.1 EOLC – ASSET EXPECTED LIFE

Table 24 EoLc Calibration Defaults

EoLc Term	Calibration value
Max HI c	**5.5**
Min Hi	**0.5**
Default Average Life	**35**
HI at End of Expected Life	**5.5**

EoL_C is based on the Initial indicator calculation where LSE factor is multiplied with the average life of that asset class to produce expected life values.

1.13.2 ASSET AVERAGE LIFE

An average life will be assigned to the fittings based on the type of insulators (i.e. glass, polymeric or porcelain), whether they are tension/suspension fittings and the operating voltage, and its operating voltage as highlighted below.

Table 25 Fitting Material and Average Life Look-Up Table

Fitting Type	Voltage	Average Life (years)
Glass - Suspension	132	35
Porcelain - Suspension	132	35
Polymeric – Suspension	132	35
Glass – Tension	132	35
Porcelain – Tension	132	35
Polymeric – Tension	132	35
Glass - Suspension	275	35
Porcelain - Suspension	275	35
Polymeric – Suspension	275	35
Porcelain - Tension	275	35
Glass - Suspension	400	35
Porcelain - Suspension	400	35
Polymeric – Suspension	400	35
Glass – Tension	400	35
Porcelain – Tension	400	35
Polymeric – Tension	400	35

1.13.3 CONDITION SCORING

Table 26 Fittings Condition Point Weighting table

	Component Score							
Component Condition Point	UBolts/attachments	Shackles & Links	Suspension Clamps	Tension Clamps	Conductors at Clamps	Jumpers	Dampers	Insulators Electrical
1	0	0	0	0	0	0	0	0
2	8	8	8	8	0	0	8	8
3	22	22	22	22	0	0	22	22
4	40	40	40	40	0	0	40	40
5	40	40	40	40	0	0	40	40
Component Condition Point	Insulators Mechanical	Flashover Marks	Arcing Horns	Downlead Insulators (top)	Downlead Insulators (Bottom)	Cable Sealing Ends		
1	0	0*	0	0	0	0		
2	8	16*	8	8	8	8		
3	22	-	22	22	22	22		
4	40	-	40	40	40	40		
5	40	-	40	40	40	40		

**Flashover marks are only present or not present (Y/N), as such these are not graded like the other data points*

Table 27 Condition Divider Calibration

Condition Score Summation	Calibrated Divider
EoL_A	4
EoL_B	15
No of Max Scores Required	4

1.14 TOWERS

1.14.1 STEELWORK EOL VALUE

1.14.1.1 DERIVATION OF STEELWORK EOL_C

Table 28 Steelwork Constants Calibration

Setting Item	Value
Max EoLc	5.5
Minimum HI	0.5
Default Average Age	80
HI at End of Expected Life	5.5

1.14.1.2 DERIVATION OF STEELWORK EOL_A AND EOL_B

Table 29 Steelwork Condition Point Weighting table

	Component Score					
Component Condition Point	Tower Legs	Step Bolt	Bracings	Cross-arms	Peak	Paint
1	0	0	0	0	0	0
2	8	8	8	8	8	8
3	22	22	22	22	22	22
4	40	40	40	40	40	40

5	40	40	40	40	40	40

Table 30 Condition Divider Calibration

Condition Score Summation	Calibrated Divider
EoL_A	4
EoL_B	15
No. of Max Scores Required	4

1.14.1.3 DERIVATION OF STEELWORK EOL_{Y0}

Table 31 Steelwork Max and Min HIs

Setting Item	Value
MinHI for Very Good Condition	1.5
MaxHI for No Condition Data	4
MinHI	0.5
Max Y0 EoL	10

>HIY0 Minimum	<=HIY0 Maximum	HIY0 Weighting
0	2.5	1
2.5	5.5	2
5.5	15	3

1.14.2 FOUNDATION EOL VALUE

1.14.2.1 FOUNDATION OF THE INITIAL EOL INDICATOR

Table 32 Soil Resistivity Rating

>Soil Resistivity Minimum	<= Soil Resistivity Maximum	Soil Resistivity Rating

-1	1000	**12**
1000	5000	**8**
5000	20000	**4**
20000	80000	**1**
80000	100000	**0**

Table 33 Soil Chemistry Rating

>Soil Chemistry (pH) Minimum	<= Soil Chemistry (pH) Maximum	Soil Chemistry Rating
-1	2	**12**
2	4	**9**
4	7	**3**
7	9	**0**
9	14	**0**

Table 34 Redox Potential Rating

>Redox Potential (mV) Minimum	<= Redox Potential (mV) Maximum	Redox Potential Rating
-500	2	**6**
0	300	**5**
300	500	**3**
500	800	**1**
800	1000	**0**

Table 35 Combined Soil Test Factor

>Combined Soil Test Rating Minimum	<= Combined Soil Test Rating Maximum	Combined Soil Test Factor
0	2	**0.85**

2	4	**0.95**
4	8	**1**
8	12	**1.2**
12	50	**1.35**

Table 36 Overall Soil Rating Factor

Overall Soil Rating	Overall Soil Rating Factor
1	0.85
2	1
3	1.2
4	1.35

Table 37 Constants and Defaults

Setting Item	Value
Location Factor Default	1

Setting Item	Value
HI at End of Expected Life	5.5
Maximum HI1	5.5
Default Average Age	80

1.14.2.2 FOUNDATION OF THE INTERMEDIATE EOL INDICATOR

The results from polarisation resistance tests provide an indication of the probability of future corrosion of the tower foundation taking place, while TDR/TECO measurements can detect cracks and abnormalities in the foundation concrete. The results from either test are converted into factors via calibration lookup tables before combination into an overall modifying factor value used to adjust foundation EoL_1 to create an interim foundation EoL in the year the tests were carried out.

Table 38 Constants and Defaults

Setting Item	TDR/TECO Factor
Ecorr Default	**0**
Kcorr Deault	**2**
TDR/TECO Factor Default	**1**
TDR/TECO Min HI Default	**0.5**

Table 39 Ecorr Rating

>Ecorr Value (mVs) Minimum	<=Ecorr Value (mVs) Maximum	ECorr Rating
-10000	-850	**1**
-850	-250	**0**
-250	0	**0**

Table 40 Kcorr Rating

>Kcorr Value (mA) Minimum	<=Kcorr Value (mA) Maximum	KCorr Rating
-5	50	**1**
50	150	**2**
150	300	**3**
300	1000	**4**

Table 41 Polarisation Resistance Factor & Min HI

Ecorr Rating	Kcorr Rating	Polarisation Resistance Factor
1	1	**1**
1	2	**1**
1	3	**1**
1	4	**1**
0	1	**1**

0	2	**1**
0	3	**1.2**
0	4	**1.35**

Ecorr Rating	Kcorr Rating	Polarisation Resistance Facot
1	1	**0.5**
1	2	**0.5**
1	3	**0.5**
1	4	**0.5**
0	1	**0.5**
0	2	**0.5**
0	3	**0.5**
0	4	**0.5**

Table 42 Test Results Factors Calibration Table

TDR/TECT Result	TDR/TECO Factor
1	**1**
2	**1**
3	**1.15**
4	**1.35**

ECorr Rating	ICorr Rating	Polarisation Resistance Factor
0	1	**1**
0	2	**1**
0	3	**1.2**
0	4	**1.35**
1	Any	**1**

Table 43 Constants and Defaults

Setting Item	Value
As New HI Default	**0.5**
Max Y0 HI	**10**
Repair HI (@ repair date)	**0.5**
Default Min HI	**0.5**

Default Max HI	**10**

Table 44 Excavation Condition Rating Min and Max HI

Excavation Foundation Condition Rating	Excavation Foundation Condition MinHI
1	**0.5**
2	**0.5**
3	**6.5**
4	**8**
5	**8**

Excavation Foundation Condition Rating	Excavation Foundation Condition MaxHI
1	**3.5**
2	**5.5**
3	**8**
4	**10**
5	**10**

Table 45 Unstable Condition Min HI

Foundation Unstable Rating	Foundation Unstable MinHI
No	**0.5**
Yes	**8**

1.14.2.3 FOUNDATION OF THE FINAL EOL INDICATOR

Table 46 Foundation Weighting

>HIY0 Minimum	<=HIY0 Maximum	HIY0 Weighting
0	5.5	1
5.5	7.5	1.5
7.5	15	3

7. VALUES OF K

The values of k by asset class and failure mode are presented in the Table below. These values are calculated using historical 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 in the NARA. Note that these factors are subject to change as a result of the "Calibration, Testing and Validation" Exercise.

Table 47 Calibration for Values of K per Failure Mode

Asset Class	Failure Mode			
	Defect	Minor	Significant	Major
Circuit Breakers	0.00359	0.00139	0.000455	0.0006601
Transformers	0.00576	0.000810	0.000326	0.000130
Reactors	0.00576	0.000810	0.000326	0.000130
Cables **(Solid)**	N/A	N/A	7.193e-10	9.114e-9[1]
Cables **(Fluid Filled)**	2.183e-6	1.092e-6	3.191e-9	2.019e-9
Overhead Lines **(Conductors)**	N/A	7.898e-8	1.949e-8	4.163e-9
Overhead Lines **(Fittings)**	N/A	0.000396	0.000114	0.0000429
Overhead Lines **(Towers)**	0.000573	0.0000474	0.0000135	0.00000575

[1] The k-value is calculated based on a combination of failure rate and our asset base, so the age and condition of our solid cables indicates we are more likely to have a major failure than a significant failure.

8. SYSTEM CONSEQUENCE

Section 9 of the NARA outlines the manner in which the system consequence of asset failures is calculated. Three distinct consequence costs are calculated using separate methodologies, the cost of customer disconnection, a boundary transfer constraint cost and finally a reactive compensation unavailability cost. These are included in National Grid's risk model by separately calculating the three costs for each failure mode of every lead asset. The three costs for a specific failure mode are summed to give the monetised System Consequence of that failure mode for a specific lead asset. These costs are then fed into the model to be combined with the safety, environmental and financial costs of the failure mode.

1.15 CUSTOMER DISCONNECTION

Table 10-1 shows the values of M_z for commonly expected values of Z, calculated using Equation 57 in the System Consequence section of the NARA.

Z	M_z
1	1
2	1.5
3	2
4	2.5
5	3

Table 48 Values of M_z for Z=1 to Z=5

Table 10-2 outlines values used by SSENT for the different probabilities of events leading to losses of circuits other than those lost by the original asset Failure being assessed.

Probability	Symbol	Definition of Value	Value Used
Coincident outage	P_o	Average planned unavailability across SSENT ownership area	$0.047X_{min}$
Damage to another circuit	P_d	TO historical experience of proportion of explosive/incendiary failures that result in the loss of a parallel circuit and engineering judgement of asset specific experts	For defect, minor and significant failure modes 0. For major failure mode, 0.01.
Maloperation of another circuit	P_m	TO statistics on number of protections maloperations against number of faults on the system	$0.01X_{min}$
Coincident fault to another circuit	P_f	Average circuit unplanned unavailability	$0.017X_{min}$
Overloading of remaining circuit(s)	P_l	See below	Circuit supplies 132 kV or below = 0.19

			Circuit supplies 275 kV with MW_D > 1200 MW = 0.09 Otherwise = 0

Table 49

The probability of overloading remaining circuits after the loss of at least three circuits (including from the original lead asset failure mode) is dependent upon two things:

1. The capacity of the remaining circuits against the load they supply
2. The demand-time curve of the supplied load

Point 1 is primarily dictated by the SQSS and the rating of available and used asset types. The lower the voltage of the circuits the lower the capacity margin above the load supplied. This is because capacity become more expensive per MVA at lower voltages, so circuits are less likely to be designed with spare capacity. For this reason, three different values of P_l are defined in table 2 dependent upon the lowest voltage found on the circuits in question.

<u>Derivation of 132 kV circuit value</u>

The largest transformer units used to supply 132 kV in common deployment are 240 MVA. It is highly unusual for a demand group to have more transformers than required. Assuming a uniform spread of demand values across a population of demand groups with the same number of transformers the average spare capacity will be 120 MVA. For sites in the GB Transmission area with at least 3 transformers the average number of transformers will be 5. Given transformers are designed for N-2 during access period this means the average site has 720 MVA of post fault capacity. If our average spare capacity is 120 MVA then the access period peak of pour average is 600 MVA. Across the network the average ration of access period to peak demand is 0.9. Our average site therefore has a peak demand of 667 MVA.

In order for Pl to be relevant to a calculation it is assumed at least 3 circuits have been lost so in our average case the remaining capacity is 480 MVA. Therefore, if demand exceeds 72% of peak demand at the time of our asset failure then cascade tripping will occur. Looking at a year of demand data this is true for 19% or the year therefore a value of 0.19 is assigned to P_l for circuits that supply 132 kV.

<u>Derivation of 275 kV circuit value</u>

The nature of much of the 275 kV network is more similar to the 132 kV network than the 400 kV network. Flows are dominated by that which is necessary to supply local demand rather than bulk power transfer across the country as for 400 kV circuits. The rating of 275 kV circuits vary form 800 MVA in the case of cable circuits to 1600 MVA for highly rated overhead lines. Taking a mid-point gives us an indicative rating of 1200 MVA which is also around the rating of 400/275 interbus circuits. Therefore P_l will be zero if MW_D < 1200 MW. Demand groups supplied by 4 or 5 circuits in excess of 1500 MW are very rare given the security requirement for no demand loss for an N-D event even during the access period when outages occur. If 1500 MW is a reasonable maximum then customers will be lost when demand is in excess of 1200/1500 = 80 % of peak demand. This is true for 9% or the year therefore a value of 0.09 is assigned to P_l for circuits that supply 275 kV with MW_D > 1200 MW.

<u>Derivation of 400 kV circuit value</u>

400 kV circuits, especially those which connect customers with 4 or more circuits (the cases for which P_l is relevant) are rated to facilitate wider network flows and as such are more than adequate rated for local demand. Only very rarely is a 400 kV circuit rated below 2000 MVA so the risk of circuits being

inadequately rated even with three other circuits lost is negligible. Therefore, for circuits entirely at 400 kV $P_l = 0$.

1.16 CUSTOMER DISCONNECTION - DURATION

Table 50 outlines values used by SSENT for the different durations of events leading to losses of circuits other than those lost by the original asset Failure being assessed.

Duration	Symbol	Definition of Value	Value Used
Duration of failure mode unavailability	D_{fm}	TO experience of failure durations	Defect failure mode: 0 Minor failure mode: 24 Significant failure mode: 240 Major failure mode: 480
Outage restoration time	D_o	TO statistics on planned unavailability of circuits	48
Circuit damage restoration time	D_d	TO historical experience of explosive/incendiary failures of failure mode	168
Protection mal-operation restoration time	D_m	TO statistics on protection maloperation	3
Unrelated fault restoration time	D_f	TO fault statistics	72
Circuit overload restoration time	D_l	TO historical experience of overload trips	3

Table 50

1.17 CUSTOMER DISCONNECTION – SIZE AND UNIT COST

The value of φ to be used is 0.01. This is because the expected reliability of a single circuit is on average around 100 times lower than that of a double circuit connection. The risk of disconnection of a customer choice connection (usually single circuit) is therefore given 1% of the weighting of a double circuit connection.

As described in the NARA document the cost per site per hour/event are based on historical data from disconnection events and are converted to pounds and today's money. The values to be used are shown below in Table 51

	Symbol and Cost

Vital Infrastructure Category	Number of Sites	Cost per site per hour (£/hr)	Cost per site per disconnection event (£)
Transport Hubs	S_T	V_T =	-
Economic Key Point	S_E	V_E =	-
Particularly sensitive COMAH sites	S_C	-	V_C =

Table 51

Setting Item	Value
$VOLL$	
Total annual transmission demand (MWh)	
Hours per year	
Winter peak demand (MW)	

Table 52

1.18 BOUNDARY TRANSFER

The only variable to be TO define in this part of the methodology is P_{Y+1}, the proportion of time that another circuit on the boundary is unavailable in addition to a failure of the lead asset. Given the probability of another circuit being unavailable is dominated by the probability of planned unavailability then assuming the lead asset failure could occur at any time during the outage then the average time between failure and restoration on recommissioning will be half the planned unavailability of circuits which is equal to 0.18.

1.19 REACTIVE COMPENSATION

R_f is defined as one for reactors and 0 for all other assets.

9. SAFETY CONSEQUENCE

1.20 INJURY AND PROBABILITY OF INJURY

Individuals can sustain varying degrees of injury because of an asset failure. The TOs propose to categorise the severity of injury into the following types, the values below are the financial costs associated with a death or injury relating to any part of the system:

Table 53 Cost breakdown of different types of injuries

Type of Injury		Values (2003 Q3) [1]	Values (RPI to 2017)
FATALITY		**£1,336,800**	**£2,005,200**
INJURY			
Permanently incapacitating injury	Moderate to severe pain for 1-4 weeks. Thereafter some pain gradually reducing but may recur when taking part in some activities. Some permanent restrictions to leisure and possibly some work activities.	**£2,072,000**	**£3,108,000**
Serious	Slight to moderate pain for 2-7 days. Thereafter some pain/discomfort for several weeks. Some restrictions to work and/or leisure activities for several weeks/months. After 3-4 months return to normal health with no permanent disability.	**£20,500**	**£30,750**
Slight	Injury involving minor cuts and bruises with a quick and complete recovery.	**£300**	**£450**

The prices will be brought to 16/17 prices as per the Office of National Statistics RPI.

From 2003 to 2017 the RPI is 1.5

The prices are then multiplied by a Disproportion Factor which is currently set at **10**.

1.21 EXPOSURE

Under the Electricity Safety Quality and Continuity Regulations 2002 (ESQCR), risk assessments must be carried out on substation sites and overhead lines to assess the risk of interference, vandalism or unauthorised access to the asset by the public.

The overall exposure value is built from an assigned matrix which adjusts the exposure based on the Staff activity level and the Type.

	Low type	Medium Type	High Type
Low Activity	1	3.5	7.5
Medium Activity	7.5	12.5	20

High Activity	15	24.5	49

1.21.1 ACTIVITY RATING

For staff activity; scores were provided as data points and then these were converted into an Activity "Low/Medium/High" setting for use in the exposure calibration table.

Table 54 Activity Score Calibration Table

Activity Risk Rating	
Low	1
Medium	2
High	3

1.21.2 TYPE RATING

For type risk, the data was inputted in as a low medium high value and this provided a type risk factor.

Table 55 Type factor Calibration Table

Type Risk Rating	
Low	0.8
Medium	1
High	1.2

This type risk factor was then combined with an arc interuption medium factor through multiplication.

Arc Interruption Medium Factor	
Air	1
Oil	1
SF6	1
Vacuum	1

Table 56 Arc Interruption Medium Factor

Overall type factor	
< 0.8	Low
0.8 – 1.19	Medium
1.19 >	High

A final Type “Low/Medium/High” setting was estbalished based on this product value.

10. ENVIRONMENTAL CONSEQUENCE

1.22 ENVIRONMENTAL IMPACT TYPE

Costs will be assigned to the different environmental impact types as per below:

Impact Type	Environmental Impact Measure
Oil	Average volume of oil lost per failure (litres)
SF_6	Average volume of SF_6 lost per failure (kg)
Fire	Average probability that failure results in a fire
Waste	Average quantity of waste per failure (t)

Environmental Impact Costs:

- **Environmental cost per litre oil** = £35/litre
- **Environmental cost per kg of SF_6 lost** = £275/kg
  Which is derived from:
  - Traded carbon price = £12.05/tonne
  - Cost of SF_6 loss c/w cost of carbon = 22,800 (CO2)/kg
- **Environmental cost of fire** = £5,000
- **Environmental cost per tonne waste** = £150/tonne

Table 57 Source Table for the Above Costs

Fixed value	Source
Environmental cost per litre oil (£/litre)	The value used in the DNO CNAIM, page 81: https://www.ofgem.gov.uk/system/files/docs/2017/05/dno_common_network_asset_indices_methodology_v1.1.pdf and in Ofgem's RIIO-ED1 Cost Benefit Analysis template (used for the RIIO-ED1 submissions)
Traded carbon price (£/t)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/671194/Updated_short-term_traded_carbon_values_for_appraisal_purposes.pdf Table 1, central value estimated as at 2021
Conversion factor for cost of SF_6 loss c/w cost of carbon (kg CO_2e/kg)	https://www.gov.uk/guidance/calculate-the-carbon-dioxide-equivalent-quantity-of-an-f-gas
Environmental Cost of Fire	The value used in the DNO CNAIM, page 81: https://www.ofgem.gov.uk/system/files/docs/2017/05/dno_common_network_asset_indices_methodology_v1.1.pdf
Environmental Cost per Tonne Waste	The value used in the DNO CNAIM, page 81: https://www.ofgem.gov.uk/system/files/docs/2017/05/dno_common_network_asset_indices_methodology_v1.1.pdf

1.23 PER ASSET APPLIED ENVIRONMENTAL COSTS

1.23.1 ENVIRONMENTAL COST OF OIL LEAKAGE

CIRCUITBREAKERS				
Setting Item	**132kV Circuit Breaker, Oil**	**132kV Circuit Breaker, Other Types**	**132kV Circuit Breaker, SF6, AIS**	**132kV Circuit Breaker, SF6, GIS**
Average Volume of Oil Lost (litres) - Defect (Condition)	3068.5	0	0	0
Average Volume of Oil Lost (litres) - Minor (Condition)	4909.6	0	0	0
Average Volume of Oil Lost (litres) - Significant (Condition)	6137	0	0	0
Average Volume of Oil Lost (litres) - Major (Condition)	12274	0	0	0
Setting Item	**275kV Circuit Breaker, Oil**	**275kV Circuit Breaker, Other Types**	**275kV Circuit Breaker, SF6, AIS**	**275kV Circuit Breaker, SF6, GIS**
Average Volume of Oil Lost (litres) - Defect (Condition)	9625	0	0	0
Average Volume of Oil Lost (litres) - Minor (Condition)	15400	0	0	0
Average Volume of Oil Lost (litres) - Significant (Condition)	19250	0	0	0
Average Volume of Oil Lost (litres) - Major (Condition)	38500	0	0	0
Setting Item	**400kV Circuit Breaker, Oil**	**400kV Circuit Breaker, Other Types**	**400kV Circuit Breaker, SF6, AIS**	**400kV Circuit Breaker, SF6, GIS**
Average Volume of Oil Lost (litres) - Defect (Condition)	0	0	0	0
Average Volume of Oil Lost (litres) - Minor (Condition)	0	0	0	0

Average Volume of Oil Lost (litres) - Significant (Condition)	0	0	0	0
Average Volume of Oil Lost (litres) - Major (Condition)	0	0	0	0
TRANSFORMERS				
Setting Item	**132kV Reactor**	**132kV Transformer**		
Average Volume of Oil Lost (litres) - Defect (Condition)	432	471.9		
Average Volume of Oil Lost (litres) - Minor (Condition)	718	707.8		
Average Volume of Oil Lost (litres) - Significant (Condition)	2157.5	2359.3		
Average Volume of Oil Lost (litres) - Major (Condition)	21575	23593		
Setting Item	**275kV Reactor**	**275kV Transformer**		
Average Volume of Oil Lost (litres) - Defect (Condition)	432	1282.6		
Average Volume of Oil Lost (litres) - Minor (Condition)	718	1923.9		
Average Volume of Oil Lost (litres) - Significant (Condition)	2157.5	6412.9		
Average Volume of Oil Lost (litres) - Major (Condition)	21575	64129		
Setting Item	**400kV Reactor**	**400kV Transformer**		
Average Volume of Oil Lost (litres) - Defect (Condition)	432	1955		
Average Volume of Oil Lost (litres) - Minor (Condition)	718	2933		
Average Volume of Oil Lost (litres) - Significant (Condition)	2157.5	9775		
Average Volume of Oil Lost (litres) - Major (Condition)	21575	97752		

<u>SOLID CABLES</u>				
Setting Item	**132kV Solid Cable**	**275kV Solid Cable**	**400kV Solid Cable**	
Average Volume of Oil Lost (litres) - Significant (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Major (Condition)	0	0	0	
<u>FLUID CABLES</u>				
Setting Item	**132kV Fluid Cable**	**275kV Fluid Cable**	**400kV Fluid Cable**	
Average Volume of Oil Lost (litres) - Defect (Condition)	175.84	158.23	404.77	
Average Volume of Oil Lost (litres) - Minor (Condition)	281.34	253.17	647.64	
Average Volume of Oil Lost (litres) - Significant (Condition)	351.68	316.46	809.55	
Average Volume of Oil Lost (litres) - Major (Condition)	703.36	632.92	1619.1	
<u>TOWER</u>				
Setting Item	**132kV Tower**	**275kV Tower**	**400kV Tower**	
Average Volume of Oil Lost (litres) - Defect (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Minor (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Significant (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Major (Condition)	0	0	0	
<u>CONDUCTOR</u>				
Setting Item	**132kV Conductor**	**275kV Conductor**	**400kV Conductor**	

Average Volume of Oil Lost (litres) - Minor (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Significant (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Major (Condition)	0	0	0	
FITTINGS				
Setting Item	**132kV Fittings**	**275kV Fittings**	**400kV Fittings**	
Average Volume of Oil Lost (litres) - Minor (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Significant (Condition)	0	0	0	
Average Volume of Oil Lost (litres) - Major (Condition)	0	0	0	

1.23.2 ENVIRONMENTAL COST OF SF6 LEAKAGE

CIRCUITBREAKERS				
Setting Item	**132kV Circuit Breaker, Oil**	**132kV Circuit Breaker, Other Types**	**132kV Circuit Breaker, SF6, AIS**	**132kV Circuit Breaker, SF6, GIS**
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	1.91	1.91	21.75
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	3.06	3.06	34.8
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	3.83	3.83	43.5
Average Volume of SF6 Lost (kg) - Major (Condition)	0	23	23	87
Setting Item	**275kV Circuit Breaker, Oil**	**275kV Circuit Breaker, Other Types**	**275kV Circuit Breaker, SF6, AIS**	**275kV Circuit Breaker, SF6, GIS**
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	5.33	5.33	22.83

Average Volume of SF6 Lost (kg) - Minor (Condition)	0	8.53	8.53	36.53
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	10.66	10.66	45.6
Average Volume of SF6 Lost (kg) - Major (Condition)	0	64	64	274
Setting Item	**400kV Circuit Breaker, Oil**	**400kV Circuit Breaker, Other Types**	**400kV Circuit Breaker, SF6, AIS**	**400kV Circuit Breaker, SF6, GIS**
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	21.6	21.6	64.58
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	34.6	34.6	103.33
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	43.33	43.33	129.16
Average Volume of SF6 Lost (kg) - Major (Condition)	0	260	260	775
TRANSFORMERS				
Setting Item	**132kV Reactor**	**132kV Transformer**		
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0		
Setting Item	**275kV Reactor**	**275kV Transformer**		
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	0		

Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0		
Setting Item	**400kV Reactor**	**400kV Transformer**		
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0		
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0		
SOLID CABLES				
Setting Item	**132kV Solid Cable**	**275kV Solid Cable**	**400kV Solid Cable**	
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0	0	
FLUID CABLES				
Setting Item	**132kV Fluid Cable**	**275kV Fluid Cable**	**400kV Fluid Cable**	
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0	0	

TOWER				
Setting Item	**132kV Tower**	**275kV Tower**	**400kV Tower**	
Average Volume of SF6 Lost (kg) - Defect (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0	0	
CONDUCTOR				
Setting Item	**132kV Conductor**	**275kV Conductor**	**400kV Conductor**	
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0	0	
FITTINGS				
Setting Item	**132kV Fittings**	**275kV Fittings**	**400kV Fittings**	
Average Volume of SF6 Lost (kg) - Minor (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Significant (Condition)	0	0	0	
Average Volume of SF6 Lost (kg) - Major (Condition)	0	0	0	

1.23.3 ENVIRONMENTAL COST OF FIRE

CIRCUITBREAKERS				

Setting Item	132kV Circuit Breaker, Oil	132kV Circuit Breaker, Other Types	132kV Circuit Breaker, SF6, AIS	132kV Circuit Breaker, SF6, GIS
Average Likelihood of Fire - Defect (Condition)	0.001	0.001	0.001	0.001
Average Likelihood of Fire - Minor (Condition)	0.001	0.001	0.001	0.001
Average Likelihood of Fire - Significant (Condition)	0.05	0.05	0.05	0.05
Average Likelihood of Fire - Major (Condition)	0.1	0.1	0.1	0.1
Setting Item	**275kV Circuit Breaker, Oil**	**275kV Circuit Breaker, Other Types**	**275kV Circuit Breaker, SF6, AIS**	**275kV Circuit Breaker, SF6, GIS**
Average Likelihood of Fire - Defect (Condition)	0.001	0.001	0.001	0.001
Average Likelihood of Fire - Minor (Condition)	0.001	0.001	0.001	0.001
Average Likelihood of Fire - Significant (Condition)	0.05	0.05	0.05	0.05
Average Likelihood of Fire - Major (Condition)	0.1	0.1	0.1	0.1
Setting Item	**400kV Circuit Breaker, Oil**	**400kV Circuit Breaker, Other Types**	**400kV Circuit Breaker, SF6, AIS**	**400kV Circuit Breaker, SF6, GIS**
Average Likelihood of Fire - Defect (Condition)	0.001	0.001	0.001	0.001
Average Likelihood of Fire - Minor (Condition)	0.001	0.001	0.001	0.001
Average Likelihood of Fire - Significant (Condition)	0.05	0.05	0.05	0.05
Average Likelihood of Fire - Major (Condition)	0.1	0.1	0.1	0.1
TRANSFORMERS				
Setting Item	**132kV Reactor**	**132kV Transformer**		
Average Likelihood of Fire - Defect (Condition)	0.001	0.001		

Average Likelihood of Fire - Minor (Condition)	0.001	0.001		
Average Likelihood of Fire - Significant (Condition)	0.05	0.05		
Average Likelihood of Fire - Major (Condition)	0.1	0.1		
Setting Item	**275kV Reactor**	**275kV Transformer**		
Average Likelihood of Fire - Defect (Condition)	0.001	0.001		
Average Likelihood of Fire - Minor (Condition)	0.001	0.001		
Average Likelihood of Fire - Significant (Condition)	0.05	0.05		
Average Likelihood of Fire - Major (Condition)	0.1	0.1		
Setting Item	**400kV Reactor**	**400kV Transformer**		
Average Likelihood of Fire - Defect (Condition)	0.001	0.001		
Average Likelihood of Fire - Minor (Condition)	0.001	0.001		
Average Likelihood of Fire - Significant (Condition)	0.05	0.05		
Average Likelihood of Fire - Major (Condition)	0.1	0.1		
SOLID CABLES				
Setting Item	**132kV Solid Cable**	**275kV Solid Cable**	**400kV Solid Cable**	
Average Likelihood of Fire - Significant (Condition)	0.001	0.001	0.001	
Average Likelihood of Fire - Major (Condition)	0.001	0.001	0.001	
FLUID CABLES				
Setting Item	**132kV Fluid Cable**	**275kV Fluid Cable**	**400kV Fluid Cable**	
Average Likelihood of Fire - Defect (Condition)	0.001	0.001	0.001	

Average Likelihood of Fire - Minor (Condition)	0.001	0.001	0.001	
Average Likelihood of Fire - Significant (Condition)	0.001	0.001	0.001	
Average Likelihood of Fire - Major (Condition)	0.001	0.001	0.001	
TOWER				
Setting Item	**132kV Tower**	**275kV Tower**	**400kV Tower**	
Average Likelihood of Fire - Defect (Condition)	0.001	0.001	0.001	
Average Likelihood of Fire - Minor (Condition)	0.001	0.001	0.001	
Average Likelihood of Fire - Significant (Condition)	0.001	0.001	0.001	
Average Likelihood of Fire - Major (Condition)	0.001	0.001	0.001	
CONDUCTOR				
Setting Item	**132kV Conductor**	**275kV Conductor**	**400kV Conductor**	
Average Likelihood of Fire - Minor (Condition)	0	0	0	
Average Likelihood of Fire - Significant (Condition)	0	0	0	
Average Likelihood of Fire - Major (Condition)	0.001	0.001	0.001	

1.23.4 ENVIRONMENTAL COST OF WASTAGE

CIRCUITBREAKERS				
Setting Item	**132kV Circuit Breaker, Oil**	**132kV Circuit Breaker, Other Types**	**132kV Circuit Breaker, SF6, AIS**	**132kV Circuit Breaker, SF6, GIS**
Average Volume of Waste (tonnes) - Defect (Condition)	0.1	0.1	0.1	0.1
Average Volume of Waste (tonnes) - Minor (Condition)	0.4	0.4	0.4	0.3

Average Volume of Waste (tonnes) - Significant (Condition)	0.7	0.7	0.7	0.5
Average Volume of Waste (tonnes) - Major (Condition)	3.3	3.3	3.3	2.66
Setting Item	**275kV Circuit Breaker, Oil**	**275kV Circuit Breaker, Other Types**	**275kV Circuit Breaker, SF6, AIS**	**275kV Circuit Breaker, SF6, GIS**
Average Volume of Waste (tonnes) - Defect (Condition)	0.2	0.2	0.2	0.1
Average Volume of Waste (tonnes) - Minor (Condition)	0.7	0.7	0.7	0.5
Average Volume of Waste (tonnes) - Significant (Condition)	1.2	1.2	1.2	1
Average Volume of Waste (tonnes) - Major (Condition)	6	6	6	4.99
Setting Item	**400kV Circuit Breaker, Oil**	**400kV Circuit Breaker, Other Types**	**400kV Circuit Breaker, SF6, AIS**	**400kV Circuit Breaker, SF6, GIS**
Average Volume of Waste (tonnes) - Defect (Condition)	0.3	0.3	0.3	0.3
Average Volume of Waste (tonnes) - Minor (Condition)	1.2	1.2	1.2	1.2
Average Volume of Waste (tonnes) - Significant (Condition)	2.2	2.2	2.2	2.2
Average Volume of Waste (tonnes) - Major (Condition)	10.8	10.8	10.8	10.8
TRANSFORMERS				
Setting Item	**132kV Reactor**	**132kV Transformer**		
Average Volume of Waste (tonnes) - Defect (Condition)	0.3	0.3		
Average Volume of Waste (tonnes) - Minor (Condition)	2.8	3.5		

Average Volume of Waste (tonnes) - Significant (Condition)	11.2	14		
Average Volume of Waste (tonnes) - Major (Condition)	56.17	69.94		
Setting Item	**275kV Reactor**	**275kV Transformer**		
Average Volume of Waste (tonnes) - Defect (Condition)	0.3	0.7		
Average Volume of Waste (tonnes) - Minor (Condition)	2.8	7		
Average Volume of Waste (tonnes) - Significant (Condition)	11.2	28		
Average Volume of Waste (tonnes) - Major (Condition)	56.17	140.05		
Setting Item	**400kV Reactor**	**400kV Transformer**		
Average Volume of Waste (tonnes) - Defect (Condition)	0.65	1.336		
Average Volume of Waste (tonnes) - Minor (Condition)	6.5	13.361		
Average Volume of Waste (tonnes) - Significant (Condition)	26	53.445		
Average Volume of Waste (tonnes) - Major (Condition)	130	267.223		
SOLID CABLES				
Setting Item	**132kV Solid Cable**	**275kV Solid Cable**	**400kV Solid Cable**	
Average Volume of Waste (tonnes) - Significant (Condition)	3.959	3.686	3.686	
Average Volume of Waste (tonnes) - Major (Condition)	19.795	18.43	18.43	
FLUID CABLES				

Setting Item	132kV Fluid Cable	275kV Fluid Cable	400kV Fluid Cable	
Average Volume of Waste (tonnes) - Defect (Condition)	0.256	0.652	0.652	
Average Volume of Waste (tonnes) - Minor (Condition)	1.295	3.26	3.26	
Average Volume of Waste (tonnes) - Significant (Condition)	12.95	32.6	32.6	
Average Volume of Waste (tonnes) - Major (Condition)	12.95	32.6	32.6	
TOWER				
Setting Item	**132kV Tower**	**275kV Tower**	**400kV Tower**	
Average Likelihood of Fire - Defect (Condition)	0	0	0	
Average Likelihood of Fire - Minor (Condition)	0.3	1	3	
Average Likelihood of Fire - Significant (Condition)	1.6	5	19.5	
Average Likelihood of Fire - Major (Condition)	5	16	65	
CONDUCTOR				
Setting Item	**132kV Conductor**	**275kV Conductor**	**400kV Conductor**	
Average Volume of Waste (tonnes) - Minor (Condition)	0.03	0.1	0.1	
Average Volume of Waste (tonnes) - Significant (Condition)	0.08	0.3	0.4	
Average Volume of Waste (tonnes) - Major (Condition)	0.3	1	1.4	
FITTINGS				
Setting Item	**132kV Fittings**	**275kV Fittings**	**400kV Fittings**	
Average Volume of Waste (tonnes) - Minor (Condition)	0.01	0.03	0.04	

Average Volume of Waste (tonnes) - Significant (Condition)	0.04	0.1	0.1	
Average Volume of Waste (tonnes) - Major (Condition)	0.1	0.3	0.4	

1.24 PROXIMITY TO WATER COURSE FACTOR

Table 58 Water Course Factor Calibration Table

Asset Register Category (All Voltages)	Proximity to Water Course Factor			
	Not Close to Water Course (>120m) or No Oil	Moderately Close to Water Course (between 80m and 120m)	Close to Water Course (between 40m and 80m)	Very Close to Water Course (<40m)
Transformer	0.8	1	1.5	2.5
Circuit Breaker	0.8	1	1.5	2.5
Reactor	0.8	1	1.5	2.5
Cable	0.8	1	1.5	2.5

1.25 ASSET LOCATED WITHIN SSSI

This section is used to indicate whether an asset is located within a Site of Special Scientific Interest and will apply a multiplying factor accordingly. This is due to the recognition that any environmental impact within an SSSI is likely to have a more devastating effect.

Table 59 Site of Special Scientific Interest Calibration Table

Asset Located within SSSI	Multiplying Factor
Yes	1.5
No	1

The resulting Financial Cost of Failure value can then be modified for individual assets within a Lead Asset Category based on the application of a Location Factor to result in a Financial CoF that reflects the characteristics of an individual assets location.

Table 60 Location Factor of SSSI Calibration Table

Location Factor	Multiplying Factor
Standard (Default)	1
Non - Standard	1.5

1.26 ENVIRONMENTAL RISK TABLE – WORKED EXAMPLE

	Impact Type																					
Asset Category	Average volume of oil lost per failure (litres)				Average volume of SF6 lost per failure (kg)				Average probability that failure results in a fire				Average quantity of waste per failure (t)				Probability of Failure Mode Effect				Exposure	Reference Environmental Consequence
	Defect	Minor	Significant	Major	Defect	Minor	Significant	Major	Defect	Minor	Significant	Major	Defect	Minor	Significant	Major	Defect	Minor	Significant	Major		
132kV Transformer	100	200	500	5000	0	0	0	0	0.0002	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1	£3,281
275kV Transformer	100	200	500	5000	0	0	0	0	0.0002	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1.5	£4,259
400kV Transformer	100	200	500	5000	0	0	0	0	0.0002	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1	£3,281
132kV Reactor	100	200	500	5000	0	0	0	0	0.0002	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1.5	£4,259
275kV Reactor	100	200	500	5000	0	0	0	0	0.0002	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1	£3,281
400kV Reactor	100	200	500	5000	0	0	0	0	0.0002	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1.5	£4,259
132kV Circuit Breaker	0	0	0	0	0	5	20	50	0	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1	£611
275kV Circuit Breaker	0	0	0	0	0	10	60	170	0	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1.5	£1,406
400kV Circuit Breaker	0	0	0	0	0	20	30	75	0	0.002	0.01	0.02	0.5	10	50	100	15%	3%	2%	1%	1	£827
132kV Tower	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1.5	£378
275kV Tower	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1	£302
400kV Tower	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1.5	£378
132kV Conductor	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1	£302
275kV Conductor	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1.5	£378
400kV Conductor	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1	£302
132kV Fittings	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1.5	£378
275kV Fittings	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1	£302
400kV Fittings	0	0	0	0	0	0	0	0	0	0	0.01	0.02	0	0	50	100	25%	10%	2%	1%	1.5	£378
132kV Cable	100	200	500	5000	0	0	0	0	0	0	0.01	0.02	0	0	50	100	0%	10%	7%	2%	1	£6,423
275kV Cable	100	200	500	5000	0	0	0	0	0	0	0.01	0.02	0	0	50	100	0%	10%	7%	2%	1.5	£8,378
400kV Cable	100	200	500	5000	0	0	0	0	0	0	0.01	0.02	0	0	50	100	0%	10%	7%	2%	1	£6,423

The worked example uses the “Environmental Impact Costs” stated in section 10.1 above.

11. FINANCIAL CONSEQUENCE

1.27 LOCATION FACTOR

The resulting Financial Cost of Failure value can then be modified for individual assets within a Lead Asset Category based on the application of a Location Factor to result in a Financial CoF that reflects the characteristics of an individual assets location.

Table 61 Location Factor for Financial Consequence Calibration Table

Location Factor	Multiplying Factor
Standard (Default)	1
Non - Standard	1.5

1.28 PER ASSET FINANCIAL COST

	132kV	275kV	400kV
Circuit Breakers			
Transformers			
Reactors			
Solid Cable			
Fluid Cable			
Tower			
Fittings			
Conductor			

1.29 PERCENTAGE OF REPLACEMENT

	Defect	Minor	Significant	Major
Circuit Breakers	5	15	40	100
Transformers	5	15	40	100
Reactors	5	15	40	100
Solid Cable	-	-	40	100
Fluid Cable	5	15	40	100
Tower	5	15	40	100
Fittings	-	15	40	100
Conductor	-	15	40	100

1.30 EXAMPLE FINANCIAL RISK CALCULATION

Financial Risk = Sum (PoF of a Failure Mode X * Financial Concequence of a Failure X) * Location Factor.

12. APPENDIX II – TRANSFORMER ASSET EXAMPLE CALCULATION

12.1. INTRODUCTION

This document is to be used to give a breakdown of each equation used in the methodology to calculate End of Life and Probability of Failure.
There are multiple examples each showing a unique aspect of how the change in factors affect the overall Probability of Failure.
The first example includes;

- An overview of the asset
- The main tank EoL calculation
- The tap changers EoL calculation
- The End of Life Value outputted by the system
- The nominal years to end of life
- The final Probability of Failure value of the system

The four examples cover:

- A control asset calculation where no failures or interventions having taken place in that assets life cycle. (Transformer)
- An asset which has failed due to Dissolved Gas presence and then a follow up showing a refurbishment Intervention
- A 3rd to cover the methodology on a different type of asset (Circuit Breaker)

This should provide readers with extensive understanding of the main process and how the methodology operates.

12.2. LOOKUP TABLES

The following section compiles an entire extensive list of the look up tables that are involved with calculating the End of life modifier for the main tanks, tap changers and circuit breakers.
When the look up table is referred to in the calculation its Section and page number will be included so that it is easy to follow where the data is provided from.
When the look up table is referred to in the calculation, its section number will be included so that it is easy to follow where the data is provided from. These tables are indicative to help with the current example.

12.3. MAIN TANK - LOOK-UP TABLES

12.3.1. LSE TABLES

12.3.1.1. LOCATION

> Distance to Coast Minimum	< Distance to coast Maximum	Distance to Coast Factor
0	5	**1.35**
5	10	**1.2**
10	15	**1.1**
15	20	**1.0**
20	25	**0.9**
25	5000	**0.85**
> Altitude Minimum	< Altitude Maximum	Altitude Factor
0	50	**0.9**
50	100	**1.0**
100	250	**1.1**
250	5000	**1.2**

Corrosion Zone	Corrosion Zone Factor
1	**0.85**
2	**1.00**
0	**1.00**
3	**1.05**
4	**1.15**
5	**1.35**

12.3.1.2. ENVIRONMENT

Environment	Environment Factor
Normal	**1.00**
Poor	**1.06**
Bad	**1.11**

12.3.1.3. SITUATION

Situation	Situation Factor
Indoor	**0.5**
Outdoor	**1.0**

12.3.1.4. CONSTANTS

Minimum Possible Location Factor
0.8

12.3.2. DUTY FACTOR TABLES

12.3.2.1. MAXIMUM DEMAND DUTY FACTOR

> Max. Demand / Rating Minimum	< Max. Demand / Rating Maximum	Maximum Demand Factor
0	0.70	**0.75**
0.70	0.90	**0.90**
0.90	1.00	**1.00**
1.00	1.15	**1.25**
1.15	2.00	**1.50**

12.3.2.2. MAXIMUM OPERATING TEMPERATURE DUTY FACTOR

> Max. Demand / Rating Minimum	< Max. Demand / Rating Maximum	Operating Temp. Factor
0	80	**0.75**
80	95	**1.00**
95	105	**1.25**
105	150	**1.50**

12.3.2.3. THROUGH FAULTS DUTY FACTOR

Severity / Frequency Through Faults	Through Faults Duty Factor
Normal	**1.00 (Default)**
High	**1.15**
Very High	**1.50**

12.3.2.4. CONSTANTS

Demand / Temperature Default Factor
1

12.3.3. OIL CONDITION FACTOR

12.3.3.1. MOISTURE SCORE

> Relative Humidity Minimum	< Relative Humidity Maximum	Moisture Factor
-1	15	**0**
15	30	**2**
30	50	**4**
50	65	**8**
65	500	**20**

Moisture Condition Index Multiplier
80

12.3.3.2. BREAKDOWN STRENGTH SCORE

> Breakdown kV Minimum	< Breakdown kV Maximum	Breakdown Factor
-1	30	**20**
30	40	**6**
40	50	**2**
50	10000	**0**

Breakdown Condition Index Multiplier
80

12.3.3.3. ACIDITY SCORE

> Acidity – mg KOH/g Minimum	< Acidity – mg KOH/g Maximum	Acidity Factor
-1	0.03	**0**
0.03	0.075	**2**
0.075	0.15	**4**
0.15	0.25	**8**
0.25	2.00	**20**

Acidity Condition Index Multiplier
125

12.3.3.4. TAN DELTA SCORE

> Tan Delta @ 90°c Minimum	< Tan Delta @ 90°c Maximum	Tan Delta Factor
-1	0.02	**0**
0.02	0.06	**2**
0.06	0.12	**4**
0.12	0.2	**8**
0.2	1	**20**

Tan Delta Condition Index Multiplier
80

12.3.3.5. OIL CONDITION FACTOR

> Combined Score Minimum	< Combined Score Maximum	Oil Condition Factor
-1	200	**0.75**
200	500	**1.00**
500	950	**1.10**
950	1500	**1.25**
1500	100000	**1.50**

12.3.4. DEFECT HISTORY FACTOR

12.3.4.1. DEFECT CONSTANTS

Max Age of Defects	**10**
Max Overall Asset Score	**50**
Default Initial Defect His. Fac.	**1.0**
Default Initial Min EoL	**0.5**

12.3.4.2. DEFECT TYPES

Defect Description	Defect Score
Motor Drive	**1-5**
Cooling System	**1-5**
HV Connections	**1-5**
LV Connections	**1-5**
Ancillary	**1-5**

12.3.4.3. DEFECT HISTORY FACTOR

> Asset Defect Score Minimum	< Asset Defect Maximum	Defect Factor
0	**5**	**1.00**
5	**10**	**1.05**
10	**20**	**1.1**
20	**35**	**1.25**
35	**50**	**1.5**

12.3.5. ACTIVE SOP FACTOR

12.3.5.1. MAXIMUM ACTIVE SOP

Max Active SOP Severity	Active SOP Factor
1	**1.00**
2	**1.10**
3	**1.20**
4	**1.35**

12.3.6. STANDARD TEST RESULTS FACTOR

12.3.6.1. PD TEST FACTOR

Latest Test Result	Latest Test Result Factor
1	**0**
2	**4**
3	**10**
Classification	**Classification Score**
1	**0**
2	**1**
3	**2**
4	**4**
5	**6**
Generic Rating	**Rating Score**
1	**0**
2	**1**
3	**2**
4	**4**

Overall Score Min.	Overall Score Max.	PD Test Factor
-1	0	0.950
0	2	1.000
2	4	1.075
4	5	1.150
5	8	1.225
8	100	1.300

12.3.6.2. DUCTOR TEST FACTOR

Latest Test Result	Latest Test Result Factor
1	**0**
2	**4**
3	**10**
Classification	**Classification Score**
1	**0**
2	**1**
3	**2**
4	**4**
5	**6**
Generic Rating	**Rating Score**
1	**0**
2	**1**
3	**2**
4	**4**

Overall Score Min.	Overall Score Max.	PD Test Factor
-1	0	0.950
0	2	1.000
2	4	1.075
4	5	1.150
5	8	1.225
8	100	1.300

12.3.6.3. IR TEST FACTOR

Latest Test Result	Latest Test Result Factor
1	**0**
2	**4**
3	**10**

Classification	Classification Score
1	**0**
2	**1**
3	**2**
4	**4**
5	**6**

Generic Rating	Rating Score
1	**0**
2	**1**
3	**2**
4	**4**

Overall Score Min.	Overall Score Max.	PD Test Factor
-1	0	0.950
0	2	1.000
2	4	1.075
4	5	1.150
5	8	1.225
8	100	1.300

12.3.7. GENERIC RELIABILITY

12.3.7.1. GENERIC RELIABILITY

Reliability Score	Reliability Factor
1	**0.85**
2	**1.00**
3	**1.15**
4	**1.35**

12.3.8. VISUAL ASSESSMENT

12.3.8.1. MAIN TANK, GASKETS AND SEALS CONDITION FACTOR

Condition	Condition Factor
1	**0.75**
2	**1**
3	**1.1**
4	**1.25**
5	**1.5**

12.3.8.2. HV CONNECTIONS CONDITION FACTOR

Condition	Condition Factor
1	**0.85**
2	**1**
3	**1.05**
4	**1.15**
5	**1.35**

12.3.8.3. LV CONNECTIONS CONDITION FACTOR

Condition	Condition Factor
1	**0.85**
2	**1**
3	**1.05**
4	**1.15**
5	**1.35**

12.3.8.4. ANCILLARY CONDITION FACTOR

Condition	Condition Factor
1	**0.85**
2	**1**
3	**1.05**
4	**1.15**
5	**1.35**

12.3.8.5. COOLING SYSTEM CONDITION FACTOR

Condition	Condition Factor
1	**0.75**
2	**1**
3	**1.1**
4	**1.25**

5	**1.5**

12.3.9. DISSOLVED GAS ANALYSIS

12.3.9.1. HYDROGEN (H_2) CONDITION STATE

Hydrogen (H_2) ppm	Condition Factor
0 – 20	**0**
20 – 40	**2**
40 – 100	**4**
100 – 200	**10**
200 +	**16**

12.3.9.2. ACETYLENE (C_2H_2) CONDITION FACTOR

Acetylene (C_2H_2) ppm	Condition Factor
0 – 1	**0**
1 – 5	**2**
5 – 20	**4**
20 – 100	**8**
100+	**10**

12.3.9.3. OTHER HYDROCARBONS CONDITION FACTOR

Hydrocarbon ppm	Condition Factor
0 – 10	**0**
10 – 20	**2**
20 – 50	**4**
50 – 150	**10**
150+	**16**

12.3.9.4. GAS MULTIPLIER SCORE

Gas	Gas Multiplier
H2	**50**
C2H2	**120**
C2H4	**30**
CH4	**30**
C2H6	**30**

12.3.9.5. CONSTANTS

Condition	Value
DGA Divider	**220**
EoL_{DGA} Max	**10**

12.3.9.6. GAS MULTIPLIER SCORE

> Δ DGA% Min.	< Δ DGA% Max.	Δ Description
-1000000	**80**	**Negative**
80	**120**	**Neutral**
120	**150**	**Small**
150	**200**	**Significant**
200	**1000000**	**Large**

12.3.9.7. GAS MULTIPLIER SCORE

Δ Description	DGA History Factor
Negative	**0.75**
Neutral	**0.90**
Small	**1.00**
Significant	**1.10**
Large	**1.25**

12.3.10. FURFURALDEHYDE ANALYSIS

12.3.10.1. CONSTANTS

Constant	Value
EoLFFA Max	10
FFA Multiplier	0.02125
FFA Power Value	0.7056
DP Multiplier	-121
DP Addition	1294

12.4. TAP CHANGERS – LOOK-UP TABLES

12.4.1. LSE TABLES

12.4.1.1. LOCATION

> Distance to Coast Minimum	< Distance to coast Maximum	Distance to Coast Factor
0	5	**1.35**
5	10	**1.15**
10	15	**1.05**
15	20	**1.0 (Default)**
20	25	**0.9**
25	5000	**0.85**
> Altitude Minimum	< Altitude Maximum	Altitude Factor
0	50	**0.9**
50	100	**1.0 (Default)**
100	250	**1.1**
250	5000	**1.2**

Corrosion Zone	Corrosion Zone Factor
1	**0.85**
2	**1.00**
0	**1.00 (Default)**
3	**1.05**
4	**1.15**
5	**1.35**

12.4.1.2. ENVIRONMENT

Environment	Environment Factor
Normal	**1.00 (Default)**
Poor	**1.06**
Bad	**1.11**

12.4.1.3. SITUATION

Situation	Situation Factor
Indoor	**0.5**
Outdoor	**1.0 (Default**

12.4.1.4. CONSTANTS

Minimum Possible Location Factor
0.8

12.4.2. DUTY FACTOR TABLES

12.4.2.1. TAP COUNT DUTY FACTOR

> Mod. Annual Tap-count Min.	< Mod. Annual Tap-count Max.	Tap Count Factor
-1	1000	**0.85**
1000	2000	**0.95**
2000	3500	**1.00**
35000	10000	**1.15**
100000	10000000	**1.35**

12.4.2.2. COUNT SCALING DUTY FACTOR

Tap-Changer Type	Through Faults Duty Factor
Vacutap	**0.25**
OCTC/OLTC Slow	**2.00**
Other	**1.00**

12.4.2.3. HIGH WEAR RATE DUTY FACTOR

Exception Report	High Wear Rate Factor
Very High	**1.35**
High	**1.00**
Normal	**1.00**

12.4.2.4. CONSTANTS

Count Scaling / Tap-count / High Wear Rate Default Factor
1

12.4.3. OIL CONDITION FACTOR

12.4.3.1. MOISTURE SCORE

> Relative Humidity Minimum	< Relative Humidity Maximum	Moisture Factor
-1	15	**0**
15	30	**2**
30	50	**4**
50	65	**8**
65	500	**20**
Moisture Condition Index Multiplier		
80		

12.4.3.2. BREAKDOWN STRENGTH SCORE

> Breakdown kV Minimum	< Breakdown kV Maximum	Breakdown Factor
-1	30	**20**
30	40	**6**
40	50	**2**
50	10000	**0**
Breakdown Condition Index Multiplier		
80		

12.4.3.3. ACIDITY SCORE

> Acidity – mg KOH/g Minimum	< Acidity – mg KOH/g Maximum	Acidity Factor
-1	0.03	**0**
0.03	0.075	**2**
0.075	0.15	**4**
0.15	0.25	**8**
0.25	2.00	**20**
Acidity Condition Index Multiplier		
125		

12.4.3.4. TAN DELTA SCORE

> Tan Delta @ 90°c Minimum	< Tan Delta @ 90°c Maximum	Tan Delta Factor
-1	0.02	**0**
0.02	0.06	**2**
0.06	0.12	**4**
0.12	0.2	**10**
0.2	1	**20**
Tan Delta Condition Index Multiplier		
80		

12.4.3.5. OIL CONDITION FACTOR

> Combined Score Minimum	< Combined Score Maximum	Oil Condition Factor
-1	200	**0.9**
200	500	**0.95**
500	950	**1.00**
950	1500	**1.05**
1500	100000	**1.20**

12.4.4. DEFECT HISTORY FACTOR

12.4.4.1. DEFECT CONSTANTS

Max Age of Defects	**5**
Max Overall Asset Score	**50**
Default Initial Defect His. Fac.	**1.0**
Default Initial Min EoL	**0.5**

12.4.4.2. DEFECT TYPES

Defect Description	Defect Score
Gas in Buchholz	**1-5**
Faulty Heaters (Mechanism)	**1-5**
HV Bushings Oil Level Low	**1-5**
Tertiary Bush. Oil level Low	**1-5**
Explosion Vent Damaged	**1-5**

Bushings Damaged	**1-5**

12.4.4.3. DEFECT HISTORY FACTOR

Range	Defect Factor
0 - 5	**1.00**
5 - 10	**1.00**
10 - 25	**1.10**
25 – 35	**1.25**
35 - 50	**1.50**

12.4.5. ACTIVE SOP FACTOR

12.4.5.1. MAXIMUM ACTIVE SOP

Max Active SOP Severity	Active SOP Factor
1	**1.00**
2	**1.05**
3	**1.15**
4	**1.35**

12.4.6. STANDARD TEST RESULTS FACTOR

12.4.6.1. PD TEST FACTOR

Latest Test Result	Latest Test Result Factor
1	**0**
2	**4**
3	**10**
Classification	Classification Score
1	**0**
2	**1**
3	**2**
4	**4**
5	**6**
Generic Rating	Rating Score
1	**0**
2	**1**
3	**2**
4	**4**

Overall Score Min.	Overall Score Max.	PD Test Factor
-1	0	0.950
0	2	1.000
2	4	1.075
4	5	1.150
5	8	1.225
8	100	1.300

12.4.6.2. DUCTOR TEST FACTOR

Latest Test Result	Latest Test Result Factor
1	**0**
2	**4**
3	**10**
Classification	Classification Score
1	**0**
2	**1**
3	**2**
4	**4**
5	**6**
Generic Rating	Rating Score
1	**0**
2	**1**
3	**2**
4	**4**

Overall Score Min.	Overall Score Max.	PD Test Factor
-1	0	0.950
0	2	1.000
2	4	1.075
4	5	1.150
5	8	1.225
8	100	1.300

12.4.6.3. IR TEST FACTOR

Latest Test Result	Latest Test Result Factor
1	**0**
2	**4**
3	**10**

Classification	Classification Score	
1	**0**	
2	**1**	
3	**2**	
4	**4**	
5	**6**	
Generic Rating	Rating Score	
1	**0**	
2	**1**	
3	**2**	
4	**4**	
Overall Score Min.	Overall Score Max.	PD Test Factor
-1	0	0.950
0	2	1.000
2	4	1.075
4	5	1.150
5	8	1.225
8	100	1.300

12.4.7. GENERIC RELIABILITY

12.4.7.1. GENERIC RELIABILITY

Reliability Score	Reliability Factor
1	**0.85**
2	**1.00**
3	**1.15**
4	**1.35**

12.4.8. VISUAL ASSESSMENT

12.4.8.1. MOTOR DRIVE CONDITION FACTOR

Condition	Condition Factor
1	**0.75**
2	**1**
3	**1.1**
4	**1.25**
5	**1.5**

12.4.8.2. HV CONNECTIONS CONDITION FACTOR

Condition	Condition Factor
1	**0.85**
2	**1**
3	**1.05**
4	**1.15**
5	**1.35**

12.4.8.3. LV CONNECTIONS CONDITION FACTOR

Condition	Condition Factor
1	**0.85**
2	**1**
3	**1.05**
4	**1.15**
5	**1.35**

12.4.8.4. ANCILLARY CONDITION FACTOR

Condition	Condition Factor
1	**0.85**
2	**1**
3	**1.05**
4	**1.15**
5	**1.35**

12.4.8.5. COOLING SYSTEM CONDITION FACTOR

Condition	Condition Factor
1	**0.75**
2	**1**
3	**1.1**
4	**1.25**
5	**1.5**

12.4.9. DISSOLVED GAS ANALYSIS

12.4.9.1. HYDROGEN (H_2) CONDITION STATE

Hydrogen (H_2) ppm	Condition Factor
0 – 20	**0**
20 – 40	**2**
40 – 100	**4**
100 – 200	**10**
200 +	**16**

12.4.9.2. ACETYLENE (C_2H_2) CONDITION FACTOR

Acetylene (C_2H_2) ppm	Condition Factor
0 – 1	**0**
1 – 5	**2**
5 – 20	**4**
20 – 100	**8**
100+	**10**

12.4.9.3. OTHER HYDROCARBONS CONDITION FACTOR

Hydrocarbon ppm	Condition Factor
0 – 10	**0**
10 – 20	**2**
20 – 50	**4**
50 – 150	**10**
150+	**16**

12.4.9.4. GAS MULTIPLIER SCORE

Gas	Gas Multiplier
H2	**50**
C2H2	**120**
C2H4	**30**
CH4	**30**
C2H6	**30**

12.4.9.5. CONSTANTS

Condition	Value
DGA Divider	**220**
EoLDGA Max	**10**

12.4.9.6. GAS MULTIPLIER SCORE

> Δ DGA% Min.	< Δ DGA% Max.	DGA Cond. Factor
-1	250	**1.00**
250	500	**1.05**
500	1000	**1.10**
1000	1500	**1.15**
1500	1000000	**1.20**

12.5. EXAMPLE 1 – FULL ASSET AUTOPSY

12.5.1. ASSET INFORMATION:

Distance to Coast:	23 Miles	
Altitude:	22m	
Corrosion Zone:	2	
Environment:	Normal	
Installation Year:	1982	
Asset Age:	36	
Average Life:	50	
Sub-Assets:	1x	Transformer
	1x	Tap-changer

Last Gas Test: January 15 2018

Chemical	TxQuantity - ppm	TcQuantity - ppm
Hydrogen (H2)	5	27
Acetylene (C2H2)	1	17
Ethylene (C2H4)	3	34
Methane (CH4)	8	36
Ethane (C2H6)	2	8
Furfuraldehyde	240	-

Last Oil Test: January 15 2018

Tests	Tx Result	Tc Result
Moisture - ppm	3	14
Acidity – mg KOH/g	0.01	0.01
Breakdown kVoltage	80	65
Tan Delta @ 90°C	0.009	0.023

Last Visual Condition Test: December 29 2015

TxCondition	Score	TcCondition	Score
Main tank	2	1	2
Cooling	2	2	2
HV Connec.	1	3	1
LV Connec.	1	4	1
Ancillary	1	5	1

No Standard Test Factor Values.
No Active SOP Factor Values.
No Defect Factor Values.
No Generic Reliability Factor Values.

12.5.2. EXPECTED RESULTS:

	Y0	B_{final}	Yn	$Years_{fail}$
TxEoL	1.56	0.03597	1.74	41.70
TcEoL	3.09	0.04378	3.53	18.67

Failure Mode	Condition	Non-Condition
Defect	0.03833	0.001
Minor	0.00374	0.0015
Significant	0.00144	0.0007
Major	0.00057	0.0002
Totals	0.04409	0.00340
Asset PoF	0.04749	

12.6. MAIN TANK

12.6.1. INITIAL END OF LIFE MODIFIER - EOL_1

DC_F	**23 miles from the coast**	**= 0.9**
A_F	**22 m above sea level**	**= 0.9**
C_F	**In corrosion zone 2**	**= 1**
E_F	**Environment – Normal**	**= 1**
S_F	**Located - Outside**	**= 1**
O_F	**Operating Temperature Factor**	**= 1**
D_F	**Maximum Demand Factor**	**= 1**
T_F	**Through Faults Factor**	**= 1**
L_{FMin}	**Minimum location factor**	**= 0.8**
L_A	**Average life of the Main Tank**	**= 50**
EoL_{END}	**End of Life value of an aging asset**	**= 5.5**
EoL_{NEW}	**End of Life value of a new asset**	**= 0.5**
Age	**Age of asset**	**= 36**
DEFAULT	**Default Factor Value**	**= 1**

12.6.1.1. FIND LSE – (F_{LSE}) – [TABLE 12.3.1]

L_F = Max (DC_F, A_F, C_F)
= Max (0.9, 0.9, 1.0)
= 1.0

E_F **= 1.0**

S_F **= 1.0**

F_{LSE} = ((L_F – L_{FMin}) * S_F) + (L_{FMin} * E_F)
= ((1 - 0.8) * 1) + (0.8 * 1.0)
= 1.0

12.6.1.2. FIND DUTY – (F_D) – [TABLE 12.3.2]

The Duty data is turned into factors using a look up table.

F_D = Max (O_F, D_F) * T_F
= Max (1, 1) * Normal
= 1 * 1
= 1

12.6.1.3. FIND EXPECTED LIFE – (L_E)

L_E = L_A / (F_{LSE} * F_D)
= 50 / (1 * 1)
= 50 Years

12.6.1.4. FIND INITIAL AGING RATE – (B_I)

B_i = ln (EoL_{END} / EoL_{NEW}) / L_E
= ln (5.5 / 0.5) / 50
= 0.04795

12.6.1.5. FIND INITIAL END OF LIFE MODIFIER – (EOL_1)

EoL_1 = EoL_{NEW} * Exp (B_i * Age)
= 0.5 * e^ (0.04795 * 36)
= 2.80

EoL_1 = 2.8

Initial EoL Modifier is always capped at 5.5 even if $EoL_1 > 5.5$.

12.6.2. INTERMEDIATE END OF LIFE MODIFIER – EOL_2

EoL_1	**Initial End of Life Modifier**	**= 2.8**
F_O	**Oil Condition Factor**	**= 0.75**
F_S	**Standard Testing Factor**	**= 1.00**
F_A	**Active SOP Factor**	**= 1.00**
F_G	**Generic Reliability Factor**	**= 1.00**
F_D	**Defect Factor**	**= 1.00**
F_V	**Visual Condition Factor**	**= 1.00**
FV_1	**Factor Value**	**= 0.75**
$FMAX_{Div}$	**Max Divider for MaxMI Calculation**	**= 3.0**
$FMIN_{Div}$	**Min Divider for MinMI Calculation**	**= 1.5**

12.6.2.1. FIND OIL CONDITION FACTOR – (F_O) – [TABLE 12.3.3]

TAKING THE RESULTS FROM EACH OIL CONDITION TEST A SCORE CAN BE ASSIGNED TO EACH RESULT BASED ON A LOOK-UP TABLE AND AN INDEXING VALUE.

S_M Moisture Final Score = Score * Index
= 0 * 80
= 0

S_B Breakdown Final Score = 0 * 80
= 0

S_T Tan Delta Final Score = 0 * 80
= 0

S_A Acidity Final Score = 0 * 125
= 0

F_O Oil Condition Factor = Sum (S_M, S_B, S_T, S_A)
= 0

<u>On a look-up table this score equates to a factor value of 0.75</u>

12.6.2.2. FIND STANDARD TEST FACTOR – (F_S) – [TABLE 12.3.6]

1.1.1.1.1. PD TEST FACTOR – [TABLE 12.3.6.1]

Check for the PD highest result in the last 5 Years. If the results are the same over that period of 5 years use the absolute latest result.
SPDR – That result (between 1 and 3) will be converted into a score, Using a look up table. In this case, SPDR = **1**
S_{PDC} – That result should also have a numerical classification (between 1-5) which can also be converted into its own score using a look up table. **In this case, S_{PDC} = 0**
S_{PDG} – The result should finally have a generic rating based on Manufacture data and the transformers Voltage Ratio between 1 and 4, which then can be converted into a 3rd and final score. In this case, **S_{PDG} = 1**
The individual factor for PD can then be found as:

PD_S PD Test Score = Sum (S_{PDR}, S_{PDC}, S_{PDG})
= 1 + 0 + 1
= 2

Which equates to a Factor of 1 on the look up table.

1.1.1.1.2. IR TEST FACTOR – [TABLE 12.3.6.2]

Check for the IR highest result in the last 5 Years. If the results are the same over that period of 5 years use the absolute latest result.
S_{IRR} – That result (between 1 and 3) will be converted into a score, Using a look up table. **In this case, S_{IRR} = 1**
S_{IRC} – That result should also have a numerical classification (between 1-5) which can also be converted into its own score using a look up table. **In this case, S_{IRC} = 0**
S_{IRG} – The result should finally have a generic rating based on Manufacture data and the transformers Voltage Ratio between 1 and 4, which then can be converted into a 3rd and final score. **In this case, S_{PDG} = 1**
The individual factor for IR can then be found as:

IR_S IR Test Score = Sum (S_{IRR}, S_{IRC}, S_{IRG})
= 1 + 0 +1
= 2

Which equates to a Factor of 1 on the look up table.

1.1.1.1.3. DUCTOR TEST FACTOR – [TABLE 12.3.6.3]

Check for the PD highest result in the last 5 Years. If the results are the same over that period of 5 years use the absolute latest result.
S_{DR} – That result (between 1 and 3) will be converted into a score, Using a look up table. **In this case, S_{DR} = 1**
S_{DC} – That result should also have a numerical classification (between 1-5) which can also be converted into its own score using a look up table. **In this case, S_{DC} = 0**
S_{DG} – The result should finally have a generic rating based on Manufacture data and the transformers Voltage Ratio between 1 and 4, which then can be converted into a 3rd and final score. **In this case, S_{DG} = 1**

The individual factor for Ductor can then be found as:

D_S Ductor Test Score= Sum (S_{DR}, S_{DC}, S_{DG})

= 1 + 0 + 1

= 2

Which equates to a Factor of 1 on the look up table

1.1.1.1.4. Overall Standard Test Factor – Maximum Multiple Increment Method.

IF Any Factors ≤ 1, THEN MinMI Cals, ELSE MaxMI Calcs

Factors ($PD_F = 1$, $IR_F = 1$, $D_F = 1$) $FMin_{DIV} = 1.5$

V_1 (Minimum) = 1

V_2 (2nd Minimum) = 1

V_3 = $(V_2 – 1) / FMin_{DIV}$

= (1 – 1) / 1.5

= 0

F_S = $V_3 + V_1$

= 0 + 1

= 1

12.6.2.3. FIND ACTIVE SOP FACTOR – (F_A) – [TABLE 12.3.5]

Each Active SOP an asset has is given a severity rating (between 1 and 4), the factor is determined by a look-up table based on this rating.

SEVERITY SCORE = RANGE BASED FACTOR ON LOOK-UP TABLE

E.G.

3 (Do not operate live) = Active SOP factor of 1.2

If there are multiple SOP's, then the Maximum factor is taken.

We do not have Active SOP data for any asset and therefore the default is set to 1.

12.6.2.4. FIND GENERIC RELIABILITY FACTOR – (F_G) – [TABLE 12.3.7]

This factor is determined by a look-up table based on Manufacture data and the voltage ratio of the transformer.

Manufacturer data & Voltage Ratio = Generic Reliability Score

Generic Reliability Score = 2

Which equates to a Factor of 1 ON THE LOOK UP TABLE.

12.6.2.5. FIND DEFECT FACTOR – (F_D) – [TABLE 12.3.4]

Looking only at defect scores from the last 5 years. Each defect is assigned a severity rating between 1 and 4. Each component can have multiple defects.

E.G.

$DS_1 = 1$, $DS_2 = 3$, $DS_3 = 4$, …

The defect factor is determined by a look-up table and then summing the individual scores which is then confirmed on another look up table.

F_D	Defect Factor	= Sum (DS_1, DS_2, $DS_{3, \ldots}$)
		= 1 + 3 + 4 + …
		= 8 + …

On a Look-Up table this would equate to a Defect factor of 1.05

We do not have defect data for any asset and therefore the default is set to 1.

12.6.2.6. FIND VISUAL CONDITION FACTOR – (F_V) – [TABLE 12.3.8]

Using a look up table you can change the visual condition results in to individual factor values which are then combined in a Maximum Multiple Increment function to determine in an overall factor value

IF Any Factors ≤ 1, THEN MinMI Calcs, ELSE MaxMI Calcs

Factors		(1, 1, 1, 1, 1)	$FMin_{DIV} = 1.5$
V_1	(Minimum)	= 1	
V_2	(2nd Minimum)	= 1	
V_3		= (V_2 – 1) / $FMin_{DIV}$	
		= (1 – 1) / 1.5	
		= 0	
F_V		= $V_3 + V_1$	
		= 0 + 1	
		= 1	

12.6.2.7. FIND OVERALL FACTOR VALUE – (FV_1)

With all the previous factor values, another MMI function can determine an overall factor value.

IF Any Factors ≤ 1, THEN MinMI Calcs, ELSE MaxMI Calcs

Factors		(0.75, 1, 1, 1, 1, 1)	$FMin_{DIV} = 3$
V_1	(Minimum)	= 1	
V_2	(2nd Minimum)	= 1	
V_3		$= (V_2 – 1) / FMin_{DIV}$	
		= (1 – 1) / 1.5	
		= 0	
FV_1		$= V_3 + V_1$	
		= 0 + 0.75	
		= 0.75	

12.6.2.8. FIND INTERMEDIATE END OF LIFE MODIFIER – (EOL_2)

Multiply the Overall Factor Value with the Initial End of Life modifier to generate the Intermediate End of Life modifier.

EoL_2	$= EoL_1 * FV_1$
	= 2.8 * 0.75
	= 2.11

$EoL_2 = 2.11$

12.6.3. END OF LIFE VALUE FINAL – $TXEOL_{Y0}$

DGA_{DIV}	**DGA Analysis Divider Constant**	**= 220**
DGA_{HIS}	**DGA Analysis History Constant**	**= 0.75**
EoL_{DGAMAX}	**Maximum Allowable EoL for DGA**	**= 10**
DP_M	**DP Multiplier**	**= -121**
DP_A	**DP Addition**	**= 1294**
Eol_{FFAMAX}	**Maximum allowable EoL_{FFA}**	**= 10**
FFA_{Multi}	**FFA Multiplier**	**= 0.02125**
FFA_{PV}	**FFA Power Value**	**= 0.7056**
FFA_{MAX}	**Maximum FFA History Presence**	**= 240**

12.6.3.1. FIND DGA OVERALL SCORE – (S_{DGA}) – [TABLE 12.3.9]

S_{DGA} = SUM (Chemical PPM * Calibrated Multiplier)
= (0*50) + (0*120) + (0*30) + (0*30) + (0*30)
= 0

12.6.3.2. FIND END OF LIFE MODIFIER DUE TO DGA – (EOL_{DGA})

EoL_{DGA} = Min ((S_{DGA} / DGA_{DIV}), EoL_{DGAMAX})
= Min (0 / 220), 10)
= Min (0, 10)
= 0

Take and average EoL_{DGA} for all data that you have on that asset. (= 2.58) and divide it against your principal EoL_{DGA} Result (Worst case result)

0.0 / 2.58 = 0.0

This is considered as a NEGATIVE percentage change and therefore on the Look-up table this equates to a DGA History factor of 0.75

12.6.3.3. MULTIPLY BY THE HISTORY CONSTANT OF 0.75

= 0 * DGA_{HIS}
= 0 * 0.75
= 0

EoL_{DGA} = 0

12.6.3.4. FIND END OF LIFE MODIFIER DUE TO FFA – (EOL_{FFA}) -[TABLE 12.3.10]

Find the Maximum FFA, ppm across history - 240ppm (2018)

Est DP = DP_M * ln (FFA_{MAX}) + DP_A

= -121 * 240 + 1294

= 630.84

EoL_{FFA} = Min [FFA_{Multi} * (FFA_{MAX} ^ FFA_{PV}), Eol_{FFAMAX}]

EoL_{FFA} = Min [(0.02125 * (240^0.7056)), 10

= Min [(0.02125 * 47.80), 10]

= Min [1.01, 10]

EoL_{FFA} = 1.01

12.6.3.5. FIND END OF LIFE VALUE – (EOL_{Y0})

If either chemical modifier is larger than our previous EoL_2 calculated value, then the largest one becomes the final EoL_{y0}

In this case however,

EoL_2	>	Max (EoL_{DGA}, EoL_{FFA})
2.11	>	Max (0, 1.01)

Because EoL_2 modifier is greater than both the modifiers for DGA and FFA, then we can determine a EoL_{y0} as below

$TxEoL_{y0}$ = EoL_2 – ((EoL_2 – Max [EoL_{DGA}, EoL_{FFA}]) / 2)

= 2.11 – ((2.11- Max [0,1.01]) / 2

= 2.11 – ((2.11-1.01) / 2)

= 2.11 – (1.1 / 2)

= 2.11 – 0.55

= 1.56

$TxEoL_{y0}$ = 1.56

12.6.4. FORECASTING FUTURE EOL - $TXEOL_{YN}$

EoL_{y0}	**Current EoL Value of Main Tank**	**= 1.56**
EoL_{New}	**EoL value of a new asset**	**= 0.5**
EoL_{Max}	**EoL value of an asset at end of life**	**= 7**
L_E	**Expected Life**	**= 50**
Age	**Age of an asset**	**= 36**
AgeThres	**Threshold age of a new asset**	**= 10**
Bi	**Initial aging rate**	**= 0.04796**
By0Cap	**Recalculation Cap**	**= 1.5**
By0Col	**Recalculation Collar**	**= 0.75**
$F_{age,lo}$	**Lower increasing age threshold**	**= 1.0**
$F_{age,up}$	**Highest increasing age threshold**	**= 1.5**
EoL_{lo}	**Lower value where age increases**	**= 2.0**
EoL_{up}	**Upper value where age increases**	**= 5.5**
Δt	**Years to age (Future Year – Present)**	**= 3**

12.6.4.1. CHECK TO SEE IF AGE LIES BELOW THRESHOLD AGE

If asset age is less than the threshold age of a new asset, then find Initial aging rate. Else recalculate a new aging rate. Then jump to Step 6.

If	Age <	Age_{Thres}	**Then**	$B_{final} = B_i$
			Else	$B_{final} = B_{y0}$
	36 <≠ 10		∴	$B_{final} = B_{y0}$

12.6.4.2. FIND INITIAL AGING RATE – (B_I)

B_i $= \ln (EoL_{END}/EoL_{NEW}) / L_E$

$= \ln (5.5 / 0.5) / 50$

$\underline{= 0.04796}$

Jump immediately to Step 6.

12.6.4.3. FIND RECALCULATED AGING RATE – (B_{Y0})

B_{y0} = ln (EoL_{y0} / EoL_{NEW}) / Age
= ln (1.56 / 0.5) / 36
= 0.0316

12.6.4.4. FIND THE AGING RATIO – (B_{RATIO})

B_{ratio} = B_{y0} / B_i
= 0.0316 / 0.04796
= 0.6590

Check if (B_{ratio}) is near to Cap (B_{y0Cap}) or Collar (B_{y0Col})

If	$B_{ratio} > B_{y0Cap}$	***Then***	$B_{final} = B_i * B_{y0Cap}$
Else	$B_{ratio} < B_{y0Col}$	***Then***	$B_{final} = B_i * B_{y0Col}$
Else	$B_{y0Col} < B_{ratio} < B_{y0Cap}$	***Then***	$B_{y0} = B_{Final}$

0.66 < 0.75 < 1.5 ∴ B_{final} = B_i * B_{y0Col}
= 0.04796 * 0.75
= 0.03597

12.6.4.5. FIND AGING REDUCTION FACTOR – (F_{AGE})

F_{age} = $F_{AGE, LO}$ + ((EoL_{y0} - EoL_{lo})/ (EoL_{up} - EoL_{lo})) * ($F_{age,up}$ - $F_{age,up}$)
= 1.0 + ((1.56 – 2.0) / (5.5 – 2.0)) * (1.5 - 1)
= 0.937
= 1 (as Fage = 1 is the lower limit)

12.6.4.6. FIND AGEING CONSTANT FOR FUTURE YEARS – (B_{YN})

B_{yn} = B_{final} / F_{age}

= 0.03597 / 1

= 0.03597

12.6.4.7. FIND END OF LIFE VALUE FOR YEAR N – (EOL_{Y3})

TxEoLy3 = EoLy0 * EXP (Byn * 3)

= 1.56 * e ^ (0.03597 * 3)

= 1.737

TxEoLy3 = 1.74

12.6.4.8. CALCULATE YEARS TO REACH NOMINAL END OF LIFE.

Years to EoL = ln (EoLMax / EoLy0) / Byn

= ln (7 / 1.56) / 0.03597

= 41.94 years

Years to nominal End of Life = 41.94 Years

12.7. TAP CHANGER

12.7.1. INITIAL END OF LIFE MODIFIER - EOL_1

DC_F	**23 miles from the coast**	**= 0.9**
A_F	**22 m above sea level**	**= 0.9**
C_F	**In corrosion zone 2**	**= 1.00**
E_F	**Environment – Normal**	**= 1.00**
S_F	**Located - Outside**	**= 1.00**
O_F	**Operating Temperature Factor**	**= 1**
D_F	**Maximum Demand Factor**	**= 1**
T_F	**Through Faults Factor**	**= 1**
L_{FMin}	**Minimum location factor**	**= 0.8**
L_A	**Average life of the Tap Changer**	**= 50**
EoL_{END}	**End of Life value of an aging asset**	**= 5.5**
EoL_{NEW}	**End of Life value of a new asset**	**= 0.5**
Age	**Age of asset**	**= 36**
DEFAULT	**Default Factor Value**	**= 1**

12.7.1.1. FIND LSE – (FLSE) – [TABLE 12.4.1]

L_F = Max (DC_F, A_F, C_F)
= Max (0.9,0.9,1.0)
= 1.0

E_F **= 1.0**

S_F **= 1.0**

F_{LSE} = ((L_F – L_{FMin}) * S_F) + (L_{FMin} * E_F)
= ((1 - 0.8) * 1) + (0.8 * 1.0)
= 1.0

12.7.1.2. FIND DUTY – (F_D) – [TABLE 12.4.2]

The Duty data is turned into factors using a look up table.

F_D = Max (O_F, D_F) * T_F
= Max (1, 1) * 1
= 1 * 1
= 1

12.7.1.3. FIND EXPECTED LIFE – (L_E)

L_E = L_A / (F_{LSE} * F_D)
= 50 / (1 * 1)
= 50 Years

12.7.1.4. FIND INITIAL AGING RATE – (B_I)

B_i = ln (EoL_{END} / EoL_{NEW}) / L_E
= ln (5.5 / 0.5) / 50
= 0.04795

12.7.1.5. FIND INITIAL END OF LIFE MODIFIER – (EOL_1)

EoL_1 = EoL_{NEW} * Exp (B_i * Age)
= 0.5 * e^ (0.04795 * 36)
= 2.80

EoL_1 = 2.8

Initial EoL Modifier is always capped at 5.5 even if $EoL_1 > 5.5$.

12.7.2. INTERMEDIATE END OF LIFE MODIFIER – EOL_2

EoL_1	**Initial End of Life Modifier**	**= 2.8**
F_O	**Oil Condition Factor**	**= 0.9**
F_S	**Standard Testing Factor**	**= 1.00**
F_A	**Active SOP Factor**	**= 1.00**
F_G	**Generic Reliability Factor**	**= 1.00**
F_D	**Defect Factor**	**= 1.00**
F_V	**Visual Condition Factor**	**= 1.00**
FV_1	**Factor Value**	**= 0.75**
$FMAX_{Div}$	**Max Divider for MaxMI Calculation**	**= 3.0**
$FMIN_{Div}$	**Min Divider for MinMI Calculation**	**= 1.5**

1.1.1.1.5. FIND OIL CONDITION FACTOR – (F_O) – [TABLE 12.4.3]

TAKING THE RESULTS FROM EACH OIL CONDITION TEST A SCORE CAN BE ASSIGNED TO EACH RESULT BASED ON A LOOK-UP TABLE AND AN INDEXING VALUE.

S_M	Moisture Final Score	= Score * Index = 0 * 80 = 0
S_B	Breakdown Final Score	= 0 * 80 = 0
S_T	Tan Delta Final Score	= 2 * 80 = 160
S_A	Acidity Final Score	= 0 * 125 = 0
F_O	Oil Condition Factor	= Sum (S_M, S_B, S_T, S_A) = 160

Which equates to a factor value of 0.9 on the look up table.

1.1.1.1.6. FIND STANDARD TEST FACTOR – (F_S) – [TABLE 12.4.6]

PD TEST FACTOR – [TABLE 12.4.6.1]

Check for the PD highest result in the last 5 Years. If the results are the same over that period of 5 years use the absolute latest result.

S_{PDR} – That result (between 1 and 3) will be converted into a score, Using a look up table. **In this case, $S_{PDR} = 1$**

S_{PDC} – That result should also have a numerical classification (between 1-5) which can also be converted into its own score using a look up table. **In this case, $S_{PDC} = 0$**

S_{PDG} – The result should finally have a generic rating based on Manufacture data and the transformers Voltage Ratio between 1 and 4, which then can be converted into a 3rd and final score. In this case, **$S_{PDG} = 1$**

The individual factor for PD can then be found as:

PD Test Score = Sum (S_{PDR}, S_{PDC}, S_{PDG})

= 1 + 0 + 1

= 2

<u>Which equates to a Factor of 1 on the look up table.</u>

IR TEST FACTOR – [TABLE 12.4.6.2]

Check for the IR highest result in the last 5 Years. If the results are the same over that period of 5 years use the absolute latest result.

S_{IRR} – That result (between 1 and 3) will be converted into a score, Using a look up table. **In this case, $S_{IRR} = 1$**

S_{IRC} – That result should also have a numerical classification (between 1-5) which can also be converted into its own score using a look up table. **In this case, $S_{IRC} = 0$**

S_{IRG} – The result should finally have a generic rating based on Manufacture data and the transformers Voltage Ratio between 1 and 4, which then can be converted into a 3rd and final score. **In this case, $S_{IRG} = 1$**

The individual factor for PD can then be found as:

IR_S IR Test Factor = Sum (S_{IRR}, S_{IRC}, S_{IRG})

= 1 + 0 +1

= 2

<u>Which equates to a Factor of 1 on the look up table.</u>

DUCTOR TEST FACTOR – [TABLE 12.4.6.3]

Check for the Ductor highest result in the last 5 Years. If the results are the same over that period of 5 years use the absolute latest result.

S_{DR} – That result (between 1 and 3) will be converted into a score, Using a look up table. **In this case, $S_{DR} = 1$**

S_{DC} – That result should also have a numerical classification (between 1-5) which can also be converted into its own score using a look up table. **In this case, $S_{DC} = 0$**

S_{DG} – The result should finally have a generic rating based on Manufacture data and the transformers Voltage Ratio between 1 and 4, which then can be converted into a 3rd and final score. **In this case, $S_{DG} = 1$**

The individual factor for PD can then be found as:

D_S Ductor Test Score= Sum (S_{DR}, S_{DC}, S_{DG})

$= 1 + 0 + 1$

$= \mathbf{2}$

Which equates to a Factor of 1 on the look up table

OVERALL STANDARD TEST FACTOR – MAXIMUM MULTIPLE INCREMENT METHOD.

IF Any Factors ≤ 1, THEN MinMICals, ELSE MaxMI Calcs

Factors ($PD_F = 1$, $IR_F = 1$, $D_F = 1$) $FMin_{DIV} = 1.5$

V_1 (Minimum) $= 1$

V_2 (2nd Minimum) $= 1$

V_3 $= (V_2 - 1) / FMin_{DIV}$

$= (1 - 1) / 1.5$

$= 0$

F_S $= V_3 + V_1$

$= 0 + 1$

$= 1$

1.1.1.1.7. FIND ACTIVE SOP FACTOR – (F_A) – [TABLE 12.4.5]

Each Active SOP an asset has is given a severity rating (between 1 and 4), the factor is determined by a look-up table based on this rating.

SEVERITY SCORE = RANGE BASED FACTOR ON LOOK-UP TABLE

E.G.

3 (Do not operate live) = Active SOP factor of 1.2

We do not have Active SOP data for any asset and therefore the default is set to 1.

1.1.1.1.8. FIND GENERIC RELIABILITY FACTOR – (F_G) – [TABLE 2.7]

This factor is determined by a look-up table based on Manufacture data and the voltage ratio of the transformer.

Manufacterer and Voltage Ratio = Generic reliability

Generic Reliability Score: 2

Which when converted on the Look up table equates to a Factor of 1.

1.1.1.1.9. FIND DEFECT FACTOR – (F_D) – [TABLE 12.4.4]

Looking only at defect scores from the last 5 years. Each defect is assigned a severity rating between 1 and 4. Each component can have multiple defects.

E.G.

$DS_1 = 1$, $DS_2 = 3$, $DS_3 = 4$, …

The defect factor is determined by a look-up table and then summing the individual scores which is then confirmed on another look up table.

F_D Defect Factor $= \text{Sum}(DS_1, DS_2, DS_{3, \ldots})$

$= 1 + 3 + 4 + \ldots$

$= 8 + \ldots$

On a Look-Up table this would equate to a Defect factor of 1.05

<u>We do not have defect data for any asset and therefore the default is set to 1.</u>

1.1.1.1.10. FIND VISUAL CONDITION FACTOR – (F_V) – [TABLE 12.4.8]

Using a look up table you can change the visual condition results in to individual factor values which are then combined in a Maximum Multiple Increment function to determine in an overall factor value

IF Any Factors ≤ 1, THEN MinMI Calcs, ELSE MaxMI Calcs

Factors (1, 1, 1, 1, 1) $FMin_{DIV} = 1.5$

V_1 (Minimum) $= 1$

V_2 (2nd Minimum) $= 1$

V_3 $= (V_2 - 1) / FMin_{DIV}$

$= (1 - 1) / 1.5$

$= 0$

F_V $= V_3 + V_1$

$= 0 + 1$

<u>= 1</u>

1.1.1.1.11. FIND DGA FACTOR – (F_{DGA}) – [TABLE 12.4.9]

S_{DGA} = SUM (Chemical PPM * Calibrated Multiplier)

= (2*50) + (4*120) + (4*30) + (4*30) + (0*30)

= 820

<u>Which Equates to a factor of 1.10 on a look up table</u>

Unlike with transformers as there are no FFA present in the tap changer we include the DGA factor as part of our EoL_2 Calculation and not as a separate stage used to calculate Eol_{y0} as in a Main Tank.

1.1.1.1.12. FIND OVERALL CONDITION FACTOR – (FV_1)

With all the previous factor values using a Maximal Minimum function can determine an overall factor value.

IF Any Factors ≤ 1, THEN MinMI Calcs, ELSE MaxMI Calcs

Factors (0.9, 1, 1, 1, 1, 1, 1.10) $FMAX_{DIV} = 3$

V_1 (Maximum) = 1.10

V_2 = Sum where other factors - 1 > 0 (0)

= 0

V_3 = $(V_2) / FMAX_{DIV}$

= (0) / 2

= 0 / 2

= 0

FV_1 = $V_3 + V$

= 0 + 1.1

= 1.1

1.1.1.1.13. FIND INTERMEDIATE END OF LIFE VALUE – (EOL_2)

Multiply the Overall Factor Value with the Initial End of Life modifier to generate the Intermediate End of Life modifier.

EoL_2 = $EoL_1 * FV_1$

= 2.8 * 1.1

= 3.09

EoL_2 = 3.09

12.7.2.1. END OF LIFE VALUE FINAL – (TCEOL$_{Y0}$)

1.1.1.1.14. DETERMINE THE CHANGE BETWEEN EOL$_2$ AND TCEOL$_{Y0}$

= Min (Max [EoL$_2$, Max of the Minimum EoL's], Max EoL$_{y0}$]
= Min (Max [3.09, 0.5], 10]
= Min (3.09 ,10)
= 3.09

TcEoL$_{y0}$ = 3.09

12.7.2.2. FORECASTING FUTURE EOL – (TCEOL$_{YN}$)

EoL$_{New}$	**EoL value of a new asset**	**= 0.5**
EoL$_{Max}$	**EoL value of an asset at end of life**	**= 7**
L$_E$	**Expected Life**	**= 50**
Age	**Age of an asset**	**= 36**
Age$_{Thres}$	**Threshold age of a new asset**	**= 10**
B$_I$	**Initial aging rate**	**= 0.04796**
B$_{y0Cap}$	**Recalculation Cap**	**= 1.5**
B$_{y0Col}$	**Recalculation Collar**	**= 0.75**
F$_{age,lo}$	**Lower increasing age threshold**	**= 1.0**
F$_{age,up}$	**Highest increasing age threshold**	**= 1.5**
EoL$_{lo}$	**Lower value where age increases**	**= 2.0**
EoL$_{up}$	**Upper value where age increases**	**= 5.5**
Δt	**Years to age (Future Year – Present)**	**= 3**

1.1.1.1.15. CHECK TO SEE IF AGE LIES BELOW THRESHOLD AGE

If asset age is less than the threshold age of a new asset, then find Initial aging rate. Else recalculate a new aging rate. Then jump to Step 6.

If	Age <	Age$_{Thres}$	**Then**	$B_{final} = B_i$
			Else	$B_{final} = B_{y0}$
36	≠	10	∴	$B_{final} = B_{y0}$

1.1.1.1.16. FIND INITIAL AGING RATE (B_I)

B_i $= \ln (EoL_{END}/EoL_{NEW}) / L_E$

$= \ln (5.5 / 0.5) / 5$

$= 0.04796$

Jump immediately to Step 6.

1.1.1.1.17. FIND RECALCULATED AGING RATE (B_{Y0})

B_{y0} $= \ln (EoL_{y0} / EoL_{NEW}) / Age$

$= \ln (3.09 / 0.5) / 36$

$= 0.0506$

1.1.1.1.18. CALCULATE THE AGING RATIO (B_{RATIO})

B_{ratio} $= B_{y0} / B_i$

$= 0.0506 / 0.04796$

$= 1.06$

1.1.1.1.19. FIND IF (B_{RATIO}) IS CLOSER TO CAP (B_{Y0CAP}) OR COLLAR (B_{Y0COL})

If	$B_{ratio} > B_{y0Cap}$	Then	$B_{final} = B_i * B_{y0Cap}$
Else	$B_{ratio} < B_{y0Col}$	Then	$B_{final} = B_i * B_{y0Col}$
Else	$B_{y0Col} < B_{ratio} < B_{y0Cap}$	Then	$B_{y0} = B_{Final}$

0.75 < 1.06 < 1.5 ∴ Bfinal = By0

= **0.0506**

1.1.1.1.20. CALCULATE AGING REDUCTION FACTOR – (F_{AGE})

F_{age} $= F_{AGE, LO} + ((EoL_{y0} - EoL_{lo})/(EoL_{up} - EoL_{lo})) * (F_{age,up} - F_{age,up})$

$=1.0 + ((3.09 – 2.0) / (5.5 – 2.0)) * (1.5 - 1)$

$= 1.1557$

$= 1.16$

1.1.1.1.21. CALCULATE AGEING CONSTANT FOR FUTURE YEARS – (B_{YN})

B_{yn} $= B_{final} / F_{age}$
$= 0.0506 / 1.16$
= 0.0437

1.1.1.1.22. CALCULATE THE EOL VALUE FOR YEAR N – (EOL_{Y3})

$TxEoL_{y3}$ = EoLy0 * e^ (B_{yn} * 3)
= 3.09 * e^ (0.0437 * 3)
= 3.52

$TxEoL_{y3}$ = 3.52

1.1.1.1.23. CALCULATE YEARS TO REACH NOMINAL END OF LIFE.

Years to EoL = ln (EoL_{Max} / EoL_{y0}) / B_{yn}
= ln (7 / 3.09) / 0.0437
= 18.71 Years

YEARS TO NOMINAL END OF LIFE = 18.71 Years

12.8. OVERALL TRANSFORMER SYSTEM

12.8.1. FINAL EOL VALUE – ($TEOL_{Y0}$)

12.8.1.1. CALCULATE OVERALL EOL_{Y0} VALUES

TEoLy0 = Max [$TxEoL_{y0}$, $TcEoL_{yn}$]
= Max [1.56, 3.09]
= 3.09

$TEoL_{y0}$ = 3.09

12.8.2. FUTURE EOL VALUE – ($TEOL_{YN}$)

12.8.2.1. CALCULATE OVERALL EOL_{YN} VALUES

TEoLy0 = Max [$TxEoL_{y0}$, $TcEoL_{yn}$]
= Max [1.74, 3.53]
= 3.53

$TEoL_{yn}$ = 3.53

12.8.3. OFGEM CONVERSION

Eol_{yx} Value	Ofgem Category
0-1.5	**1**
1.5-4	**2**
4-6	**3**
6-7.5	**4**
7.5-15	**5**

Both values would suggest this asset has an Ofgem health of 2

12.9. PROBABILITY OF FAILURE FOR THE SYSTEM

12.9.1. CONDITIONAL PROBABILITY OF FAILURE

$TEoL_{y0}$	**Overall Transformer EoL**	**= 3.09**
Fr_{D}	**Defect Failure Rate in system**	**= 0.05**
Fr_{Mi}	**Minor Failure Rate in system**	**= 0.00488**
Fr_{S}	**Significant Failure Rate in system**	**= 0.00188**
Fr_{Ma}	**Major Failure Rate in system**	**= 0.00075**
C	**C value for system**	**= 1.086**
EoL_{Lim}	**End of Life Limit for a Failure**	**= 4**
EoL_{Avg}	**Average End of Life for a Failure**	**= 4**
Mod_{X}	**The Failure Modifier**	**= 1**
K_{D}	**Calculated K Value of a Defect**	**= 0.00135**
K_{Mi}	**Calculated K Value of a Minor**	**= 0.00013**
K_{S}	**Calculated K Value of a Significant**	**= 0.00005**
K_{Ma}	**Calculated K Value of a Major**	**= 0.00002**

For defect failure rates, greater than zero.

12.9.1.1. DETERMINE CALCULATION TO USE WHEN FINDING RELATIVE FAILURE

If **$TEoL_{y0} < EoL_{LIM}$** **Then**

$(1 + (C*EoL_{Avg}) + ((C*EoL_{Avg})\ \hat{}2) / 2 + ((C*EoL_{Avg}))\ \hat{}3 / 6) * Mod_{X}$

Else

$(1 + (C*EoL_{y0}) + ((C*EoL_{y0})\ \hat{}2) / 2 + ((C*EoL_{y0}))\ \hat{}3 / 6) * Mod_{X}$

12.9.1.2. PERFORM EACH CALCULATION FOR RELATIVE FAILURE – (R_{X})

3.09 < 4 ∴ R_{X} =

$= (1 + (C*EoL_{Avg}) + ((C*EoL_{Avg})\ \hat{}2) / 2 + ((C*EoL_{Avg}))\ \hat{}3 / 6) * Mod_{X}$

= 1+(1.086*4) + (1.086*4) ^2 / 2 + (1.086*4) ^3 / 6 * 1
= 5.344 + 9.435 + 13.662 * 1
R_x **= 28.44**

Ordinarily there would be different average and limit numbers per failure mode based on the failure modifier (Mod_X) value changing per failure, but our model at this moment has incomplete data so it is returning the same results for each relative PoF value.

12.9.1.3. CALCULATE POF PER FAILURE – (POF_X)

Defect - PoF_D = R_D * K_D
= 28.44 * 0.00135
= 0.03833

Minor - PoF_{Mi} = R_{Mi} * K_{Mi}
= 28.44 * 0.00013
= 0.003697

Significant - PoF_S = R_S * K_S
= 28.44 * 0.00005
= 0.00142

Major - PoF_{Ma} = R_{Ma} * K_{Ma}
= 28.44 * 0.00002
= 0.000568

12.9.1.4. CALCULATE CONDITIONAL PROBABILITY OF FAILURE – (POF_{COND})

PoF_{Cond} = Sum (Po_{FD}, PoF_{Mi}, PoF_S, Pof_{Ma})
= 0.03833 + 0.003697 + 0.00142 + 0.000568
= 0.04409

12.9.2. NON-CONDITIONAL PROBABILITY OF FAILURE

Fr_D	**Defect Failure Rate in system**	**= 0.001**
Fr_{Mi}	**Minor Failure Rate in system**	**= 0.0015**
Fr_S	**Significant Failure Rate in system**	**= 0.0007**
Fr_{Ma}	**Major Failure Rate in system**	**= 0.0002**
EoL_{Lim}	**End of Life Limit for a Failure**	**= 4**
EoL_{Avg}	**Average End of Life for a Failure**	**= 4**
Mod_F	**The failure modifier**	**= 1**

12.9.2.1. FIND PROBABILITY OF FAILURE FOR EACH FAILURE – (POF_X)

PoF_D

= Mod_F, / EoL_{Avg} * Fr_D
= (1 / 1) * 0.001
= 0.001

PoF_{Mi}

= Mod_F, / EoL_{Avg} * Fr_{Mi}
= (1 / 1) * 0.0015
= 0.0015

PoF_S

= Mod_F, / EoL_{Avg} * Fr_S
= (1 / 1) * 0.0007
= 0.0007

PoF_{Ma}

= Mod_F, / EoL_{Avg} * Fr_{Ma}
= (1 / 1) * 0.0002
= 0.0002

12.9.2.2. CALCULATE NON - CONDITIONAL PROBABILITY OF FAILURE – (POF_{NONC})

PoF_{Nonc}

= Sum (PoF_D, PoF_{Mi}, PoF_S, PoF_{Ma})
= 0.001 + 0.0015 + 0.0007 + 0.0002
= 0.0034

12.9.3. OVERALL PROBABILITY OF FAILURE FOR THE ASSET

12.9.3.1. CALCULATE PROBABILITY OF FAILURE – (POF)

PoF for Asset = Sum (PoF_{Cond}, PoF_{Nonc})
= 0.04409 + 0.0034
= 0.04749

PoF OF ENTIRE ASSET = 0.04749