

Comparison

HV

Trad rein (Primary switchgear only)	Trad rein (Primary switchgear, HV switchgear & cables)	Is-Limiter	Adaptive Protection	FCLS
HV	HV	HV	HV	HV
7.38	33.70	31.61	31.93	32.45
6.60	31.26	31.27	31.41	31.41
0.78	2.44	0.34	0.52	1.04
Trad rein	Trad rein	Is-Limiter	Adaptive Protec	FCLS
EHV	EHV	EHV	EHV	EHV
	9.21	9.50	9.12	7.75
	8.49	9.17	8.64	6.75
	0.72	0.34	0.48	1.00

NPV Comparison

HV - Primary switchgear only

	Is-Limiter HV	Adaptive Protec HV	FCLS HV
Total	-24.23	-24.55	-25.07
Asset	-24.67	-24.81	-24.81
Operations	-1.12	0.26	-0.26

HV - Primary switchgear, HV s

	Is-Limiter HV	Adaptive Protec HV	FCLS HV
NPV	2.09	1.77	1.25
Capex	-0.01	-0.15	-0.15
Opex	2.10	1.92	1.40

EHV

	Is-Limiter EHV	Adaptive Protec EHV	FCLS EHV
NPV	-0.30	0.09	1.45
Capex	-0.68	-0.15	1.73
Opex	0.38	0.24	-0.28

Figure 3.5

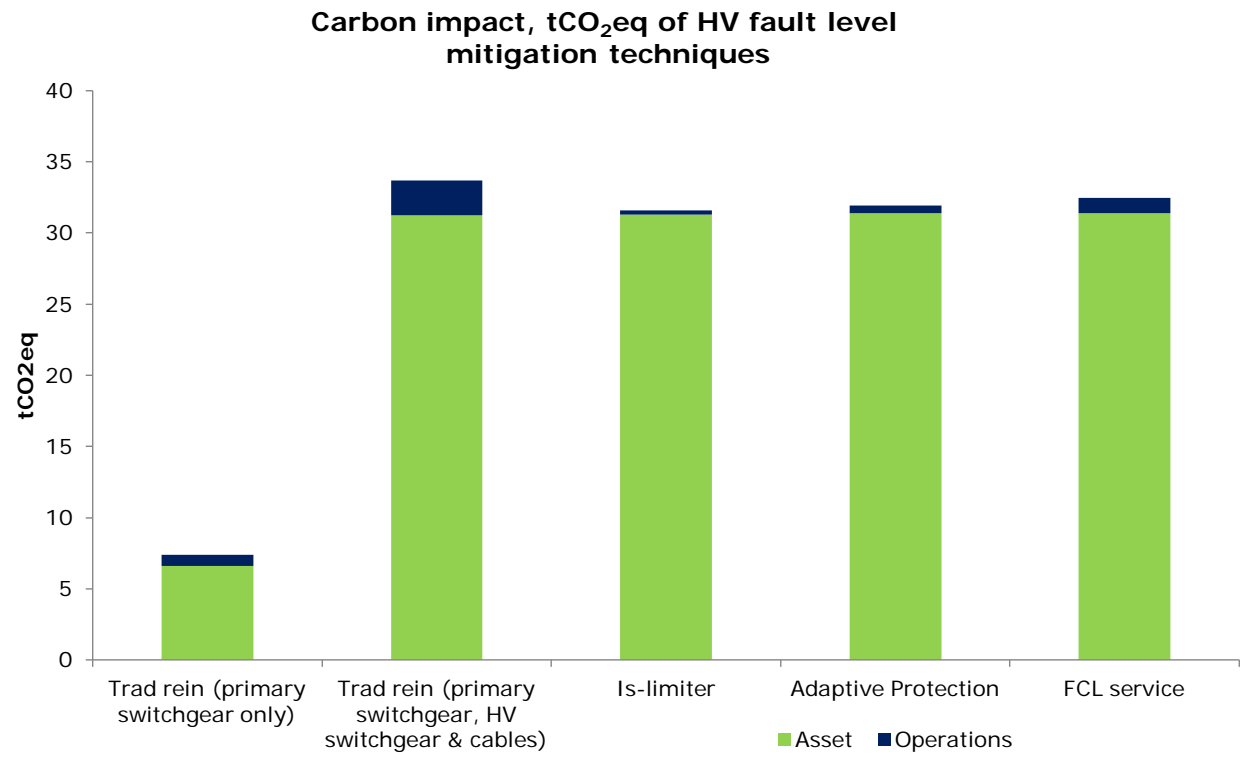
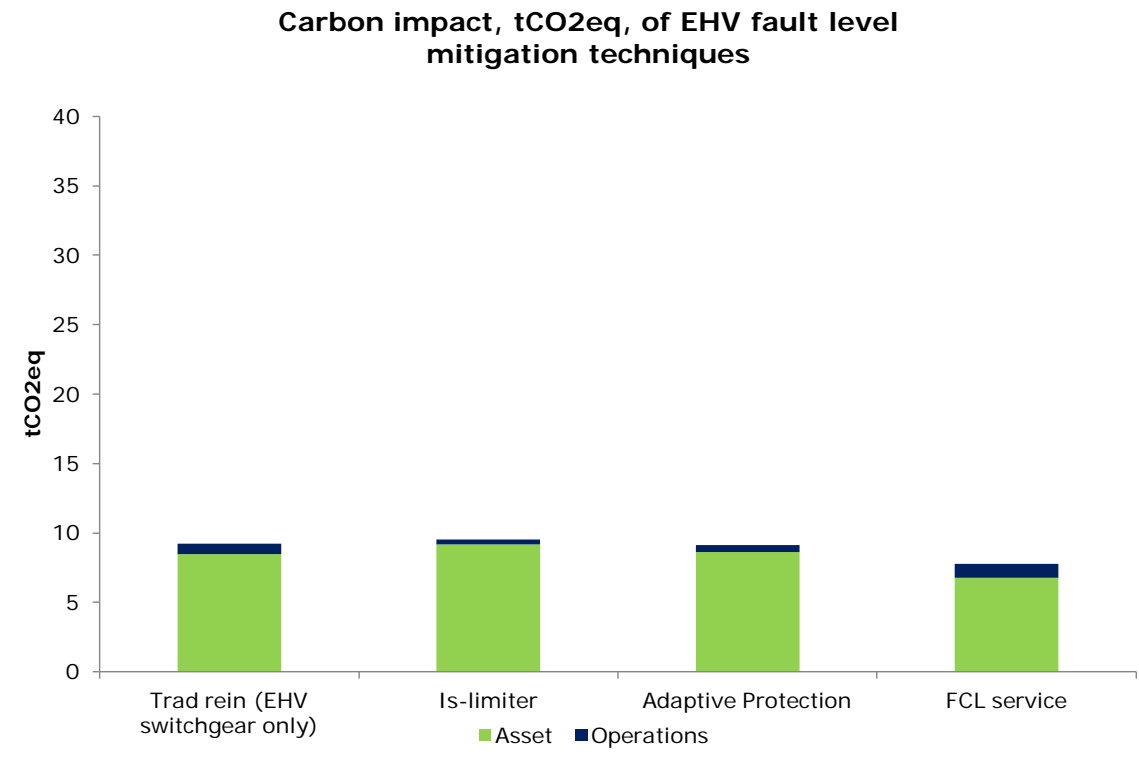
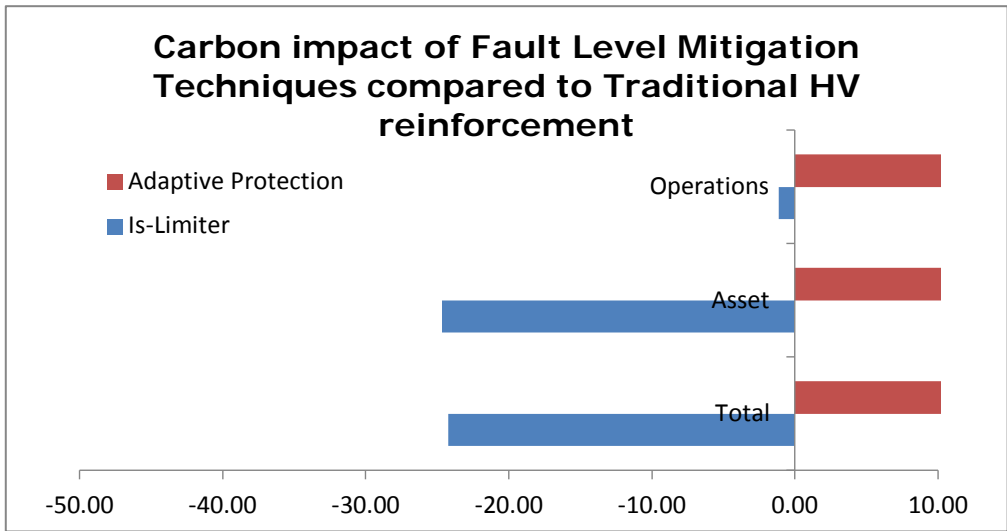


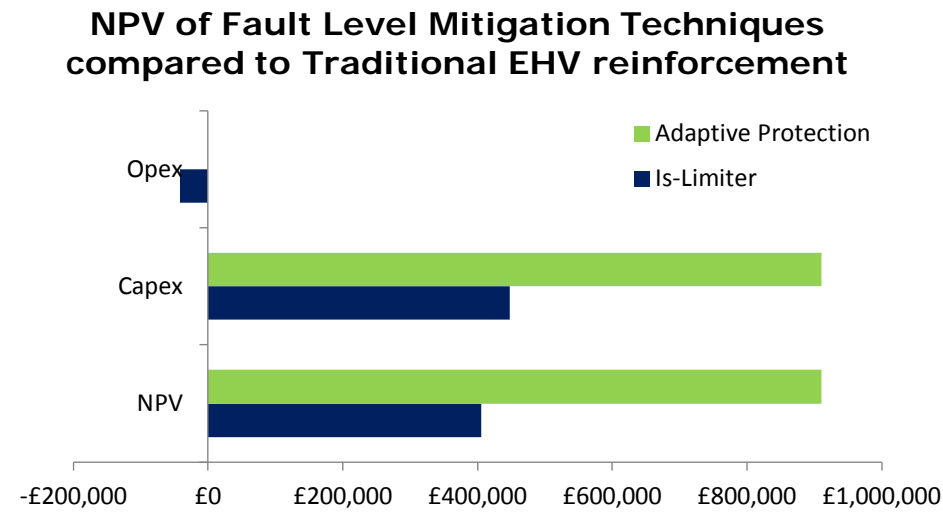
Figure 3.5



NOT USED



NOT USED



Method	Trad rein HV	Trad rein EHV	Trad rein HV	Is-Limiter HV	Is-Limiter EHV	pulse Protective HV	Protective EHV	FCLS HV	FCLS EHV	Trad rein HV
Voltage	HV-80kV/cable									LV
0	2015	EO	EO	EO	EO	EO	EO	EO	EO	E\$42,171
1	2016	E\$08,126	EO	E1,143,768	E304,457	E497,756	E11,871	E21,243	E2,499	E442,208
2	2017	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
3	2018	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
4	2019	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
5	2020	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
6	2021	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
7	2022	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
8	2023	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
9	2024	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
10	2025	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
11	2026	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
12	2027	EO	EO	EO	EO	E4,592	E9,185	EO	EO	E442,208
13	2028	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
14	2029	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
15	2030	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
16	2031	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
17	2032	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
18	2033	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
19	2034	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
20	2035	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
21	2036	EO	EO	EO	EO	EO	EO	EO	EO	E442,208
22	2037	EO	EO	EO	EO	EO	EO	EO	EO	EO
23	2038	EO	EO	EO	EO	EO	EO	EO	EO	EO
24	2039	EO	EO	EO	EO	E2,109	E4,218	EO	EO	EO
25	2040	EO	EO	EO	EO	EO	EO	EO	EO	EO
26	2041	EO	EO	EO	EO	EO	EO	EO	EO	EO
27	2042	EO	EO	EO	EO	EO	EO	EO	EO	EO
28	2043	EO	EO	EO	E88,213	E198,563	E88,213	E198,563	E88,213	E198,563
29	2044	EO	EO	EO	EO	EO	EO	EO	EO	EO
30	2045	EO	EO	EO	EO	EO	EO	EO	EO	EO
31	2046	EO	EO	EO	EO	EO	EO	EO	EO	EO
32	2047	EO	EO	EO	EO	EO	EO	EO	EO	EO
33	2048	EO	EO	EO	EO	EO	EO	EO	EO	EO
34	2049	EO	EO	EO	EO	EO	EO	EO	EO	EO
35	2050	EO	EO	EO	EO	EO	EO	EO	EO	EO
36	2051	EO	EO	EO	EO	EO	EO	EO	EO	EO
37	2052	EO	EO	EO	EO	EO	EO	EO	EO	EO
38	2053	EO	EO	EO	EO	EO	EO	EO	EO	EO
39	2054	EO	EO	EO	EO	EO	EO	EO	EO	EO
40	2055	EO	EO	EO	EO	EO	EO	EO	EO	EO
41	2056	EO	EO	EO	EO	EO	EO	EO	EO	EO
42	2057	EO	EO	EO	EO	EO	EO	EO	EO	EO
43	2058	EO	EO	EO	EO	EO	EO	EO	EO	EO
44	2059	EO	EO	EO	EO	EO	EO	EO	EO	EO
45	2060	EO	EO	EO	EO	EO	EO	EO	EO	E442,208

HV Capital costs

Legend:

- Trad rein HV
- Is-Limit HV
- Adaptive Protect

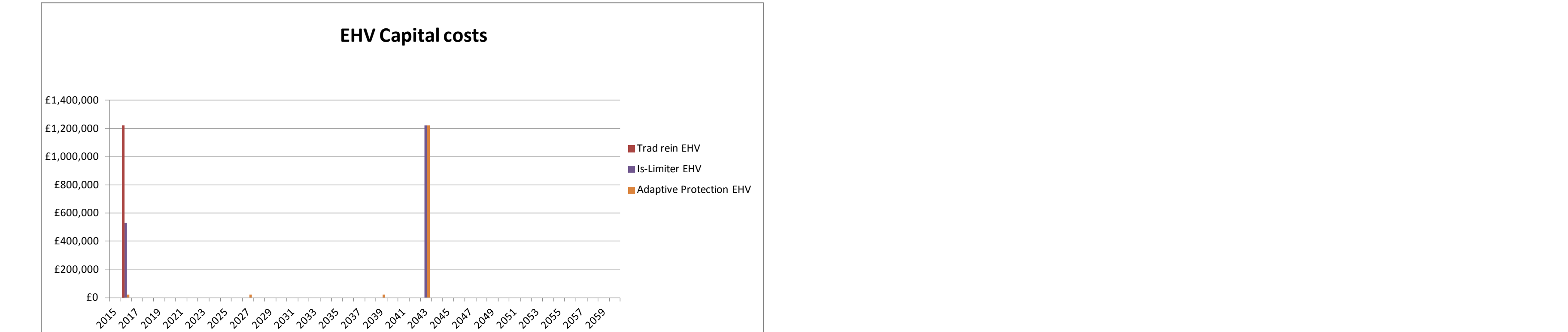
EHV Capital costs

Legend:

- Trad rein EHV
- Is-Limit EHV
- Adaptive Protect

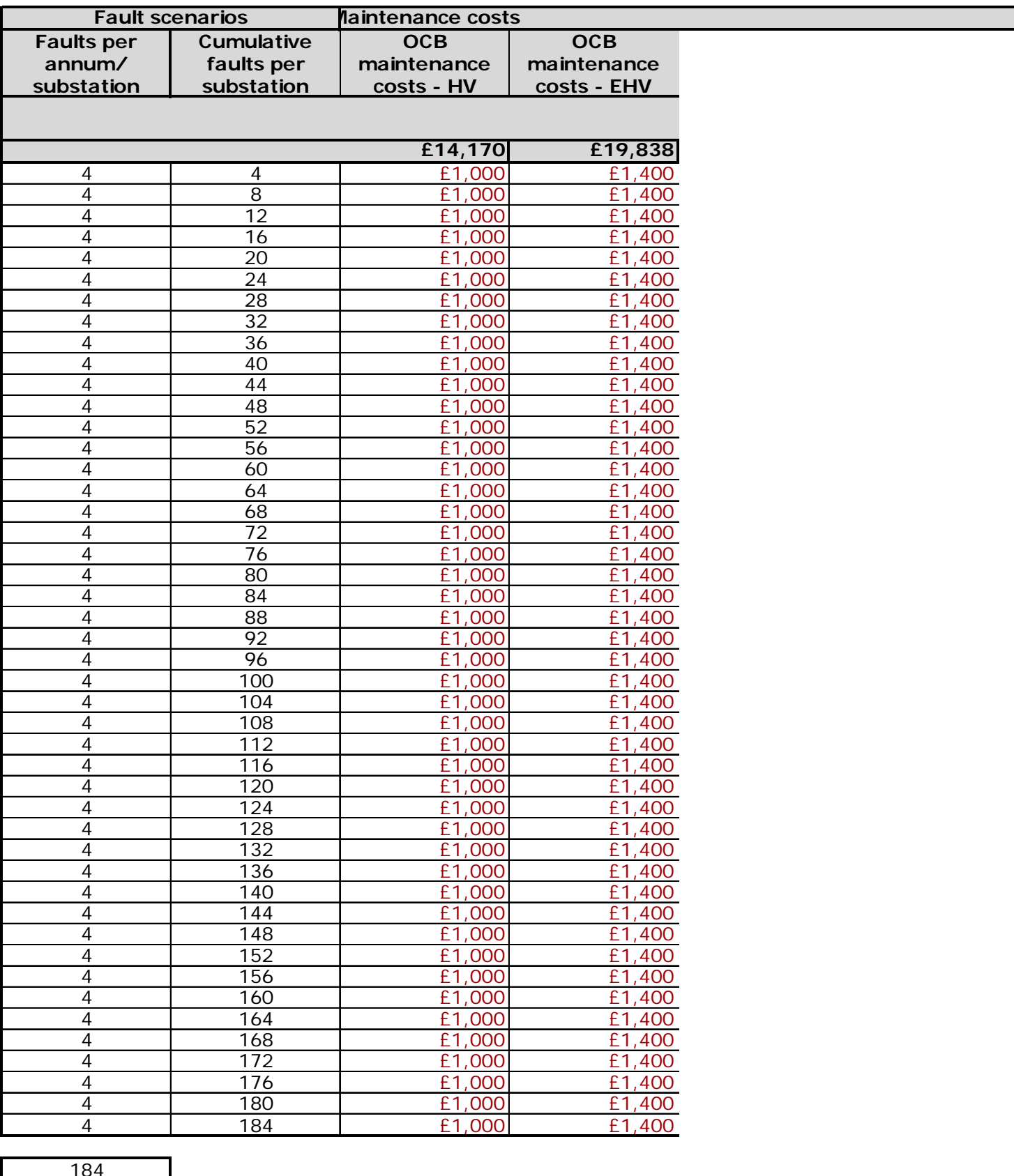
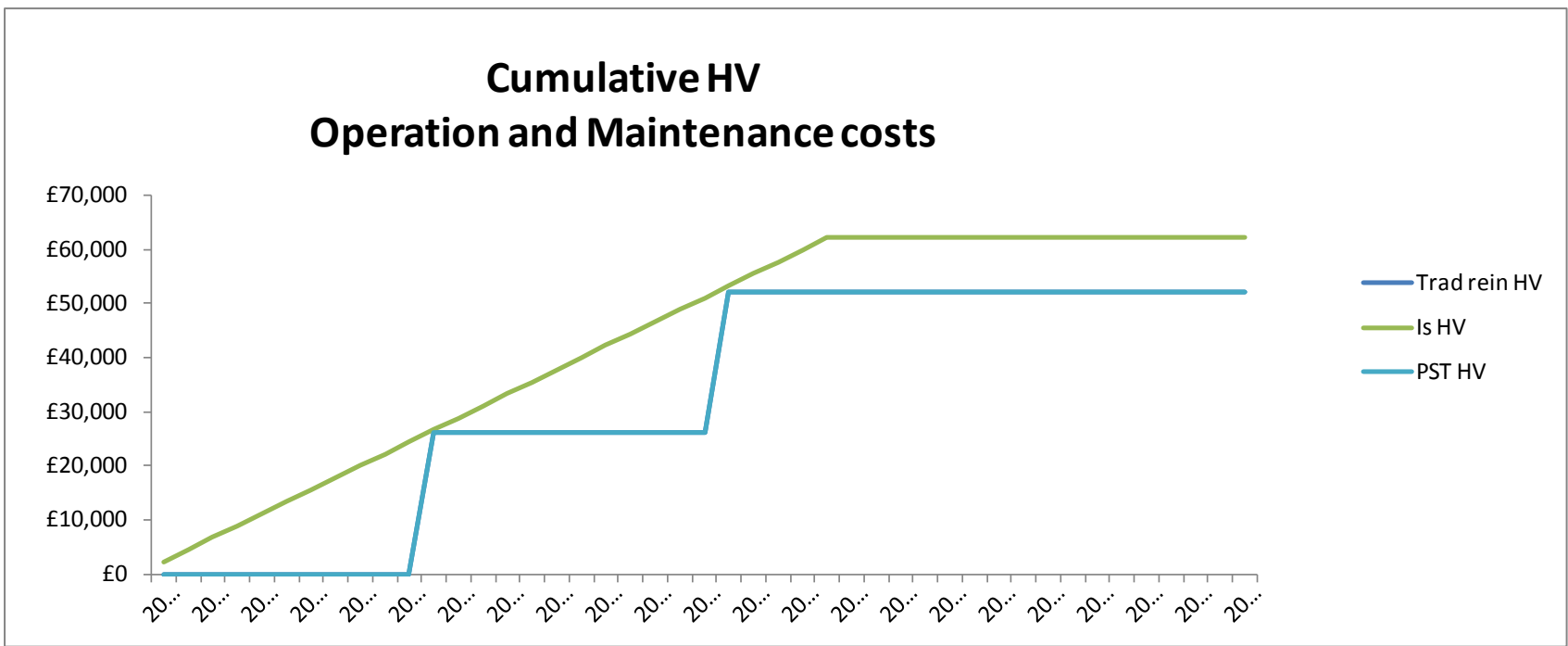
Year	Trad rein HV	Is-Limit HV	Adaptive Protect
2015	E1,220,400	E324,856	E531,106
2016	E1,220,400	E324,856	E531,106
2017	E1,220,400	E324,856	E531,106
2018	E1,220,400	E324,856	E531,106
2019	E1,220,400	E324,856	E531,106
2020	E1,220,400	E324,856	E531,106
2021	E1,220,400	E324,856	E531,106
2022	E1,220,400	E324,856	E531,106
2023	E1,220,400	E324,856	E531,106
2024	E1,220,400	E324,856	E531,106
2025	E1,220,400	E324,856	E531,106
2026	E1,220,400	E324,856	E531,106
2027	E1,220,400	E324,856	E531,106
2028	E1,220,400	E324,856	E531,106
2029	E1,220,400	E324,856	E531,106
2030	E1,220,400	E324,856	E531,106
2031	E1,220,400	E324,856	E531,106
2032	E1,220,400	E324,856	E531,106
2033	E1,220,400	E324,856	E531,106
2034	E1,220,400	E324,856	E531,106
2035	E1,220,400	E324,856	E531,106
2036	E1,220,400	E324,856	E531,106
2037	E1,220,400	E324,856	E531,106
2038	E1,220,400	E324,856	E531,106
2039	E1,220,400	E324,856	E531,106
2040	E1,220,400	E324,856	E531,106
2041	E1,220,400	E324,856	E531,106
2042	E1,220,400	E324,856	E531,106
2043	E1,220,400	E324,856	E531,106
2044	E1,220,400	E324,856	E531,106
2045	E1,220,400	E324,856	E531,106
2046	E1,220,400	E324,856	E531,106
2047	E1,220,400	E324,856	E531,106
2048	E1,220,400	E324,856	E531,106
2049	E1,220,400	E324,856	E531,106
2050	E1,220,400	E324,856	E531,106
2051	E1,220,400	E324,856	E531,106
2052	E1,220,400	E324,856	E531,106
2053	E1,220,400	E324,856	E531,106
2054	E1,220,400	E324,856	E531,106
2055	E1,220,400	E324,856	E531,106
2056	E1,220,400	E324,856	E531,106
2057	E1,220,400	E324,856	E531,106
2058	E1,220,400	E324,856	E531,106
2059	E1,220,400	E324,856	E531,106
2060	E1,220,400	E324,856	E531,106

protein HIV
filter HIV
tive Protection HIV



[illegible]

184	£39,000	£50,400	£39,000	£36,000	£2,151	1.84	1.84	0.00	0.00	0.00	0.00	0.78	0.72	0.55
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Unit Cost Assumptions	Primary	13
Capital	BSP	12

	Category	Units	Indicative Costs	Total Installation Time	Comments	Asset Carbon /tCO2 per unit	Comments	Source
Base	Traditional reinforcement							
	HV Switchgear replacement	per item	£34,016			0.51	RIIO-ED1 price - needs to be inflated as in 2012/13 price base	CV3 - Asset Replacement table - row 33
	Standard Primary Substation - 13 HV cbs	per s/s	£442,208	390		6.60	Calculation	
	RMU Switchgear replacement	per item	£10,800			0.77	RIIO-ED1 price - needs to be inflated as in 2012/13 price base	CV3 - Asset Replacement table - row 38
	HV cable - 300mmsq (CITY CENTRE)	per m	£129		1.25 multiplier	0.04		
	HV cable - 300mmsq	per m	£103			0.04	RIIO-ED1 price - needs to be inflated as in 2012/13 price base	CV3 - Asset Replacement table - row 30
	HV cable joint	per item	£500		Guess		included as above	
	33kV Switchgear replacement	per item	£101,700			0.71	RIIO-ED1 price - needs to be inflated as in 2012/13 price base	CV3 - Asset Replacement table - row 71
	Standard BSP substation - 12 EHV cbs	per s/s	£1,220,400	390		8.49	Calculation	
Method	Is limiters							
	In series with Bus-section - HV	per item	£322,189		See below	0.68	Bradgate container option cost halved	Added 100kg Tripping cabinet, 90% steel as not power electronics
	In series with Transformer circuit - HV	per item	£322,189			0.68	Costs copied from above	Added 100kg Tripping cabinet, 90% steel as not power electronics
	In series with Bus-section - EHV	per item	£528,439		Guess - needs updating	0.68		Added 100kg Tripping cabinet, 90% steel as not power electronics
	In series with Transformer circuit - EHV	per item	£528,439		Guess	0.68		Added 100kg Tripping cabinet, 90% steel as not power electronics
	Adaptive protection - distribution network							
	HV new relay	per item	£10,000		Guess	0.05	No such item in CV3 table of RIIO-ED1	Check value
	EHV new relay	per item	£20,000		Guess	0.05	No such item in CV3 table of RIIO-ED1	Check value
	HV new protection setting only	per item	£1,500		PB Power	0.02	No such item in CV3 table of RIIO-ED1	Check value
	EHV new protection setting only	per item	£3,000		PB Power	0.02	No such item in CV3 table of RIIO-ED1	Check value
	Adaptive protection - machine protection							
	New relay	per item	£10,000			0.05	No such item in CV3 table of RIIO-ED1	
	HV new protection setting only	per item	£1,500			0.02	No such item in CV3 table of RIIO-ED1	
	Fault Level Analysis Software		£ 1,200,000					
	Contribution per trial substation	20	£ 60,000					
	Contribution across substation	450	£ 2,667					
	Server Hardware	per 400W server rack		400			4x servers shared between trial feeders	
	Server Hardware	project	£75k					
Operation and Maintenance								
	Category	Units	Indicative Costs	Total Installation Time	Comments	Asset Carbon /tCO2 per unit	Comments	
	Switchgear Maintenance							
	RMU Switchgear maintenance	per item	£717			0.184	RIIO-ED1 price - needs to be inflated as in 2012/13 price base	ENW info + EcoInvent Lubrication oil
	HV Switchgear maintenance (oil)	per item	£1,000			0.061		ENW info + EcoInvent Lubrication oil
	33kV Switchgear maintenance (oil)	per item	£1,400			0.245		ENW info + EcoInvent Lubrication oil
	HV Switchgear maintenance (oil)	per s/s	£13,000			0.793		Check value
	33kV Switchgear maintenance (oil)	per s/s	£16,800			2.94		Check value
	Is limiters							
	Replacement fuse - HV	per item	£1,850			0.01		Check value
	Replacement fuse - EHV	per item	£4,060			0.01		Check value
	Protection maintenance							
	HV -Electromechanical relay/ Modern digital relay	per item	£1,000			0.02		Check value
	HV -Electromechanical relay/ Modern digital relay	per s/s	£13,000			0.26		Check value
	EHV -Electromechanical relay/ Modern digital relay	per item	£1,000			0.02		Check value
	EHV -Electromechanical relay/ Modern digital relay	per s/s	£12,000			0.24		Check value

11kV Is-Limiter installation		
ABB costs - Bamber Bridge substation installation		
6.6kV 1250A switchboard		
1250A Is Limiter, CB Panel, plus spare inserts	£175,775	Information from ABB
Installation		
Installation of panels and pre-commissioning of switchboard, i	£9,412	Information from ABB
Supply and delivery		
Supply and deliver (not offload) of steel Bradgate container	£89,397	Information from ABB
Offload	£8,125	Information from ABB
Cable	£23	£5,520 Information from Mike Turner via DrGB
Cable installation	£200	£4,000 Estimate
Joints	£1,060	£2,120 Information from Mike Turner via DrGB
Cable terminations	£13,920	£27,840 Information from Mike Turner via DrGB
		£322,189

33kV Is-Limiter installation		
ABB costs - Bamber Bridge substation installation		
33kV 2000A switchboard		
2000A Is Limiter, CB Panel, plus spare inserts	£346,817	Information from ABB
Installation		
Installation of panels and pre-commissioning of switchboard, i	£12,900	Information from ABB
Supply and delivery		
Supply and deliver (not offload) of steel Bradgate container	£89,397	Information from ABB
Offload	£8,125	Information from ABB
Cable	£23	£5,520 Information from Mike Turner via DrGB
Cable installation	£200	£4,000 Estimate
Joints	£3,000	£6,000 Information from Mike Turner via DrGB
Cable terminations	£27,840	£55,680 Information from Mike Turner via DrGB
		£528,439

Sources: Summary sheets of Switchgear, Transformer, OH and UG data sets. Asset data (masses of different materials) and transport distances/ modes as calculated by ENWL in 2007/08 (Mark Vesey), updated (Rita Shaw) for most recent available carbon benchmarks (DECC/DEFRA GHG reporting factors, plus University of Bath ICE dataset for embodied carbon).

[Switchgear per unit](#)
[Transformer per unit](#)
[OH poles per unit](#)
[OH lines per km](#)
[UG cables per km](#)

Switchgear per unit

Voltage / kV	Description	Embodied carbon Impact / tCO2eq	Transport carbon impact / tCO2eq
132	CB (indoor GIS)	2.06	0.183
132	Disconnecter & earthing switches	0.97	0.086
33	CB (indoor GIS)	0.65	0.058
33	Switches	0.54	0.004
11	RMU	0.76	0.015
11	CB	0.50	0.010
11	Switches	0.54	0.004
11	PM autorecloser	0.31	0.006
11	PM disconnectors	0.17	0.003
11	PM fuses/links	0.01	0.000
11	PM switches & autosectionalisers	0.17	0.003
11/6.6	Remote control point (actuator)	0.03	0.001
LV	Feeder pillars (indoor & outdoor)	0.03	0.001
LV	Open busbar type boards	0.01	0.000
LV	Underground link boxes	0.03	0.001

OH poles per unit

"Average" wooden pole and steel cross arm (LV, HV, 33kV)

Embodied carbon Impact / tCO2eq	Transport carbon impact / tCO2eq
0.25	0.032

132kV tower - not calculated

Transformers per unit (excluding insulating oil)

kVA rating	90,000	38,000	23,000	1,500	1,000	800	500	315	200	100	50	25	500	200	100
Embodied carbon per transformer / tCO2eq (oil excluded)															
132kV	166.49														
33kV		75.78	56.98												56.98
11/6.6kV (GM)				7.34	5.22	4.58	3.05	1.99	1.71	1.04	0.67	0.67			0.67
11/6.6kV (PM Three phase)					5.22	4.58	2.94		1.50	1.02	0.77	0.52		0.52	0.52
11/6.6kV (PM Single phase)										1.31	0.52	0.32	0.15	0.13	0.13
Transport carbon per transformer / tCO2eq (oil excluded)															
132kV	20.594														
33kV		1.302	0.898												0.898
11/6.6kV (GM)				0.867	0.611	0.530	0.360	0.239	0.207	0.131	0.088	0.088			0.088
11/6.6kV (PM Three phase)					0.130	0.113	0.077		0.045	0.032	0.025	0.017		0.017	0.017
11/6.6kV (PM Single phase)										0.036	0.017	0.011	0.005	0.004	0.004

OH line per km

Voltage	Cross sectional area / mm2												
	16	25	32	35	38	50	70	95	100	120	175	200	300
Conductor embodied carbon / tCO2eq km-1													
LV service	1.05			1.98		2.67		5.13					
LV mains				3.96		5.34		10.25					
HV (6.6 & 11kV)	1.57	2.25	3.15		3.74	4.47	6.88		8.30		15.16		
HV CC						3.93				9.45			
EHV (33kV)											15.16	17.88	
132kV											15.16	17.88	27.04
Conductor transport carbon / tCO2eq km-1													
LV service	0.07			0.07		0.09		0.17					
LV mains				0.14		0.18		0.34					
HV (6.6 & 11kV)	0.11	0.06	0.22		0.26	0.13	0.47		0.31		0.66		
HV CC						0.04				0.08			
EHV (33kV)											0.44	0.35	
132kV											0.44	0.35	0.52

UG cables carbon impact per km

Sheet	Description	Cores		4	16	25	35	95	185	240	300	400	500	630	1000
Embodied carbon Impact / tCO2eq km-1 (conductor + joints/terminations + fill/tarmac)															
LV serv	CNE	1	Aluminium or C	7.34	7.83	8.16	8.61								
LV mains	CNE Waveform	3	Aluminium					22.25	32.83		43.00				
HV		Triplex	Aluminium					24.74	32.21		41.51				
33kV	Polymeric single cor	1	Copper						25.56	27.94	30.37	34.01	37.89	42.87	
132kV	Polymeric single cor	1	Copper								41.39	44.89	49.10	54.84	68.91
Transport carbon Impact / tCO2eq km-1 (conductor + joints/ terminations + fill/tarmac + excavations)															
LV serv	CNE	1	Aluminium or C	0.99	1.04	1.03	1.04								
LV mains	CNE Waveform	3	Aluminium					1.85	2.20		2.47				
HV		Triplex	Aluminium					2.58	2.85		3.17				
33kV	Polymeric single cor	1	Copper						3.39	3.45	3.52	3.60	3.70	3.82	
132kV	Polymeric single cor	1	Copper								4.43	4.51	4.62	4.77	5.11

Measuring and tripping device

Voltage / kV	Description	Mass / kg	Carbon Impact / tCO ₂ e				Carbon Impact / tCO ₂ eq
11	Switches	Total	Copper	Steel	Copper	Steel	Total
		100	10	90	0.04	0.13	0.17

The measuring and tripping device is accommodated in a sheet steel control cabinet (Figure 3) or in the low voltage compartment of the IS-limiter panel.

C. Fixed mounted IS-limiter in a switchgear panel
The IS-limiters for low voltage, 12 kV, 17.5 kV and 24 kV are also available as fixed mounted equipment in a metal enclosed switchgear panel. The three IS-limiter insert holders with the IS-limiter inserts and the three tripping current transforme are fixed mounted in the panel.
The measuring and tripping device is mounted in the low voltage compartment. The IS-limiter (fixed mounted) for 36 kV/40.5 kV is available in a metal-enclosed switchgear panel. Same as for loose equipment supply, the measuring and tripping device is installed in a separate sheet steel cabinet (Figure 3).

Transport / tCO ₂ eq
0.004

%	
Copper	Steel
10%	90%

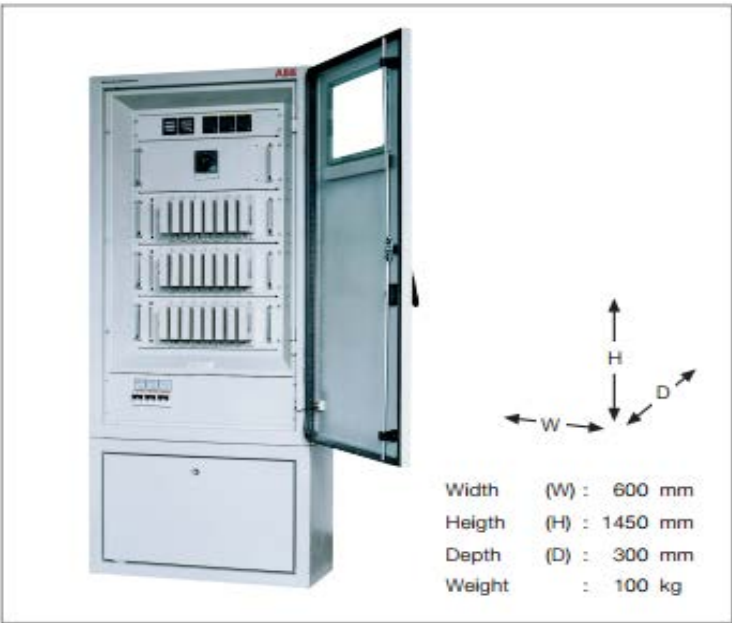


Figure 3: Measuring and tripping device



Truck mounted I_s-limiter in a switchgear panel

The functional groups within the control cabinet or low voltage compartment are combined such as to form replaceable units and are partly mounted on hinged frames.
The measuring and tripping device includes:
— a power unit to provide the necessary auxiliary DC voltages, a main switch which allows the tripping system to be switched on and off at any time, and additionally a monitoring module,
— one tripping unit for each phase, which monitors the current flowing in the relevant phase and on tripping provides the energy for triggering of the charge in the corresponding IS-limiter insert,
— an indication unit with five flag indicator relays:
—one relay per phase for trip signalling,
—one relay for monitoring of readiness for operation,
—one relay for monitoring of the supply voltages,
— an anti-interference unit to protect the measuring and tripping assemblies from interference pulses from the outside, which could possibly cause malfunction. The connecting wires from the measuring and tripping device to the current transformers, to the IS-limiter insert holders and to the AC voltage supplies are routed via the anti-interference unit.

Transformer Oil

BS EN 60296:2012
Search for “Insulating liquids” for “power transformers” but perhaps just a simple C15 / napthenic / naptha oil from the chemical feedstock. Ecoinvent has a category "used mineral oil" but the moisture content is much higher than the properties required by the BS. "lubrication oil" is used as a proxy for transformer oil in Jorge et al 2011.

Cradle to gate airborne fossil carbon emissions are estimated at 0.044 kg CO2/kg oil
For GHG using the CML 2001 baseline impact assessment method 1 kg of oil is expected to embody 1.04 kg CO2e under a 100 year timeframe.

15 gallons for OCB HV maintenance, 45 gallons for a RMU maintenance and 60 gallons for OCB EHV maintenance				
0.864 kg/L				
	gal	l	kg	CML 2001 GHG impact /kgCO2e
OCB HV Maintenance	15	68	59	61
RMU maintenance	45	205	177	184
OCB EHV Maintenance	60	273	236	245

disposal? PCB level from legacy equipment
Now processing on site
UKPN trialled a transformer with bio-oil

Rated voltage kV	Rated current A	Rated power-frequency withstand voltage kV	Rated lightning impulse withstand voltage kV	Dimensions			Weight including I _s -limiter truck kg
				Height mm	Width mm	Depth mm	
12	1250	28	75	2500	1000	1300	approx. 1200
	2000						
	2500						
	3000 ¹⁾						
	3000					1350	
	4000 ¹⁾					1350	
17.5	1250	38	95	2200	1000	1300	approx. 1200
	2000						
	3000 ¹⁾						
	3000					1350	
	4000 ¹⁾					1350	
24	1250	50	125	2325	1000	1500	approx. 1300
	1600						
	2000						
	2500 ¹⁾						

¹⁾ With cooling fan

For higher currents, insert holders with inserts are connected in parallel.