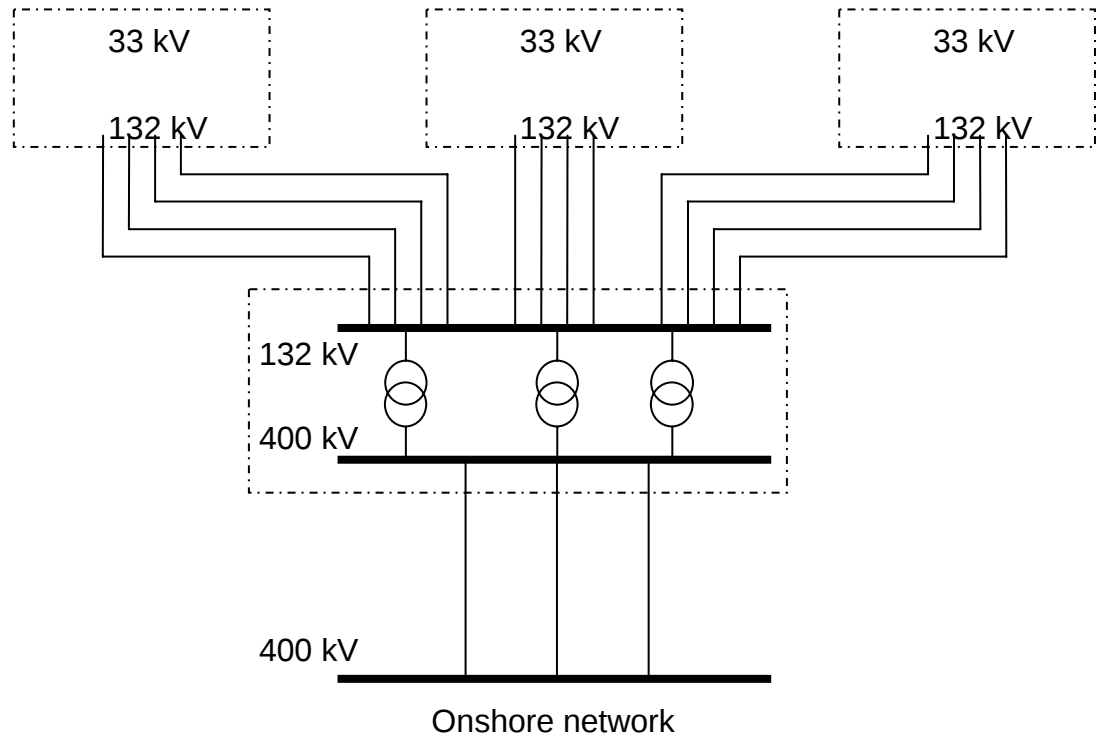
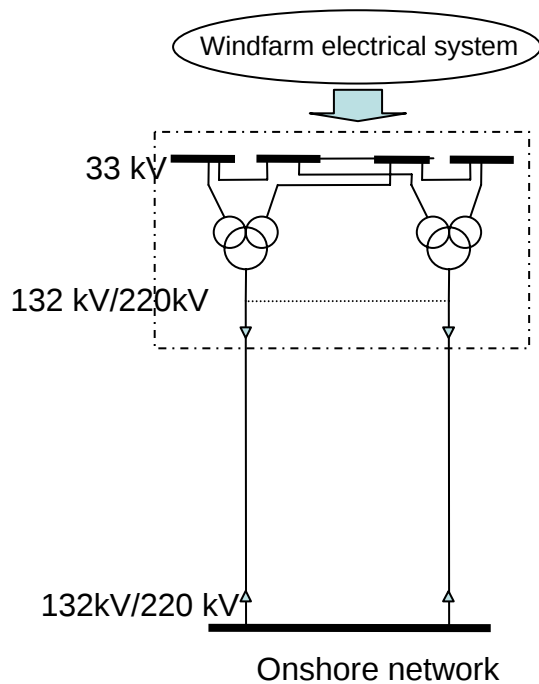


GB SQSS sub-group of OTEG

Illustration of cost benefit analysis results

Network arrangement examples

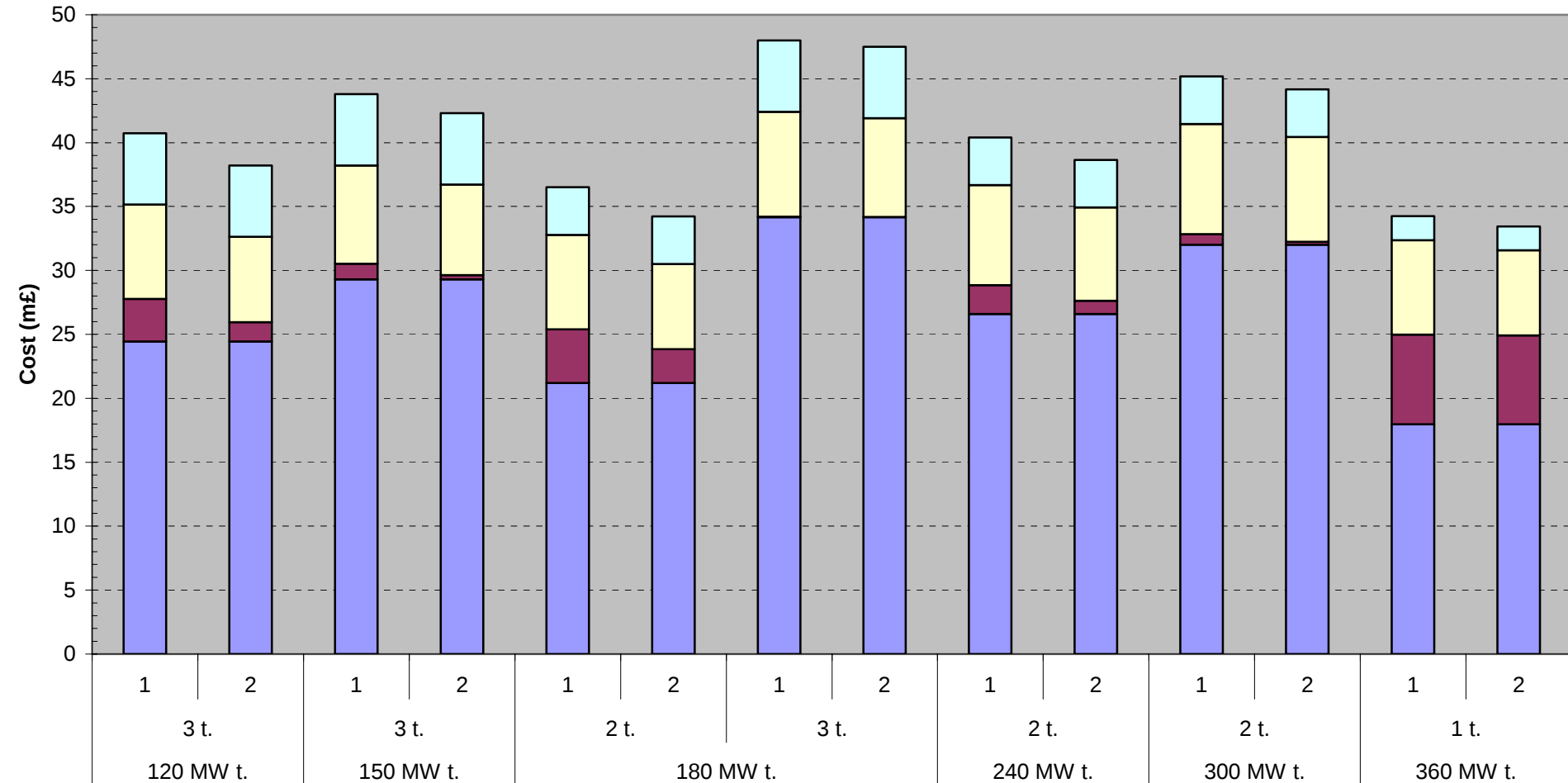


Platform design:
Number of transformers

1 SGT or 2 SGTs

One, two or three transformers (MTTR 3 months)

Test 1 Technology AC Voltage (kV) (All) Wind generation (MW) 400 MW



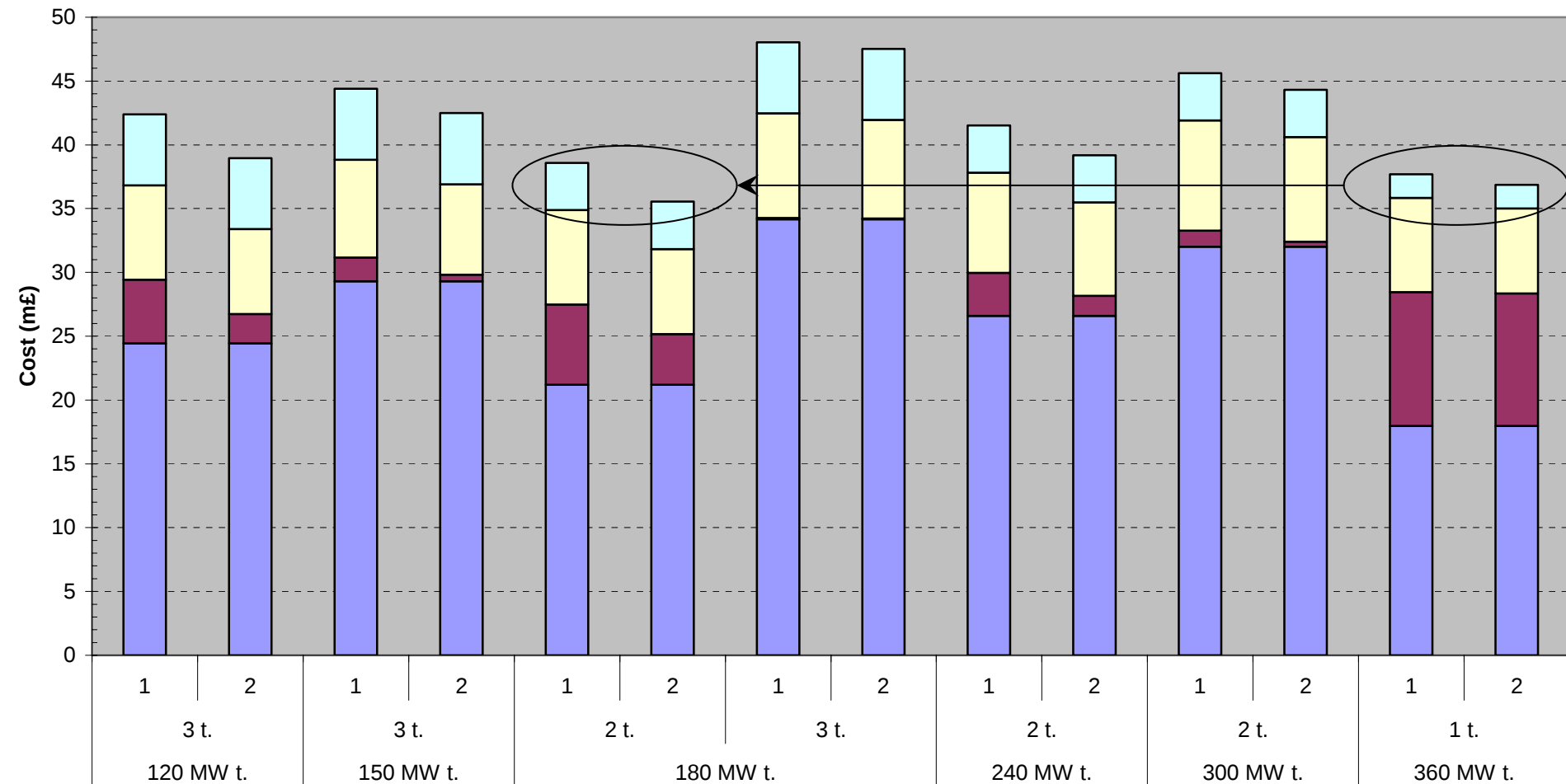
Data

Platform & plant cost (m£) EEC cost (m£) Losses cost (m£) Maintenance cost (m£)

Transformer rating (MW) Number of transformers Wind profile index

One, two or three transformers (MTTR 4.5 months)

Test 1 Technology AC Voltage (kV) (All) Wind generation (MW) 400 MW



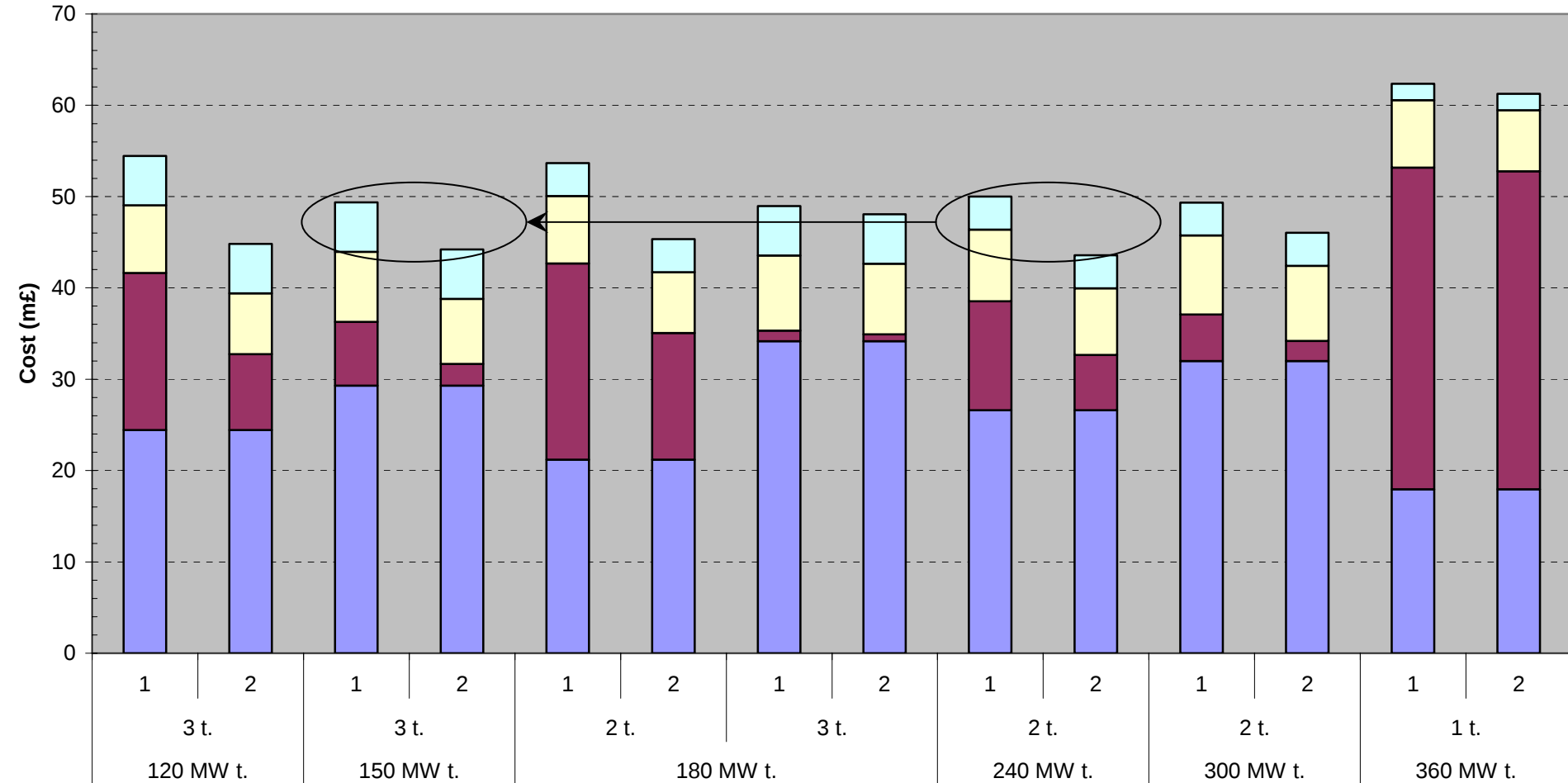
Data

Platform & plant cost (m£) EEC cost (m£) Losses cost (m£) Maintenance cost (m£)

Transformer rating (MW) Number of transformers Wind profile index

One, two or three transformers (MTTR 15.5 months)

Test 1 Technology AC Voltage (kV) (All) Wind generation (MW) 400 MW



Data

Platform & plant cost (m£) EEC cost (m£) Losses cost (m£) Maintenance cost (m£)

Transformer rating (MW) Number of transformers Wind profile index

Break-even MTTR for Transformers

MTTR (months)	Energy cost (£/MWh)		
Substation solution	50	75	100
1x360 MW	< 6.5	< 4.5	< 3.2
2x180 MW	< 15.5	< 10.5	< 8
2x240 MW	< 23.5	< 15.5	< 11.5
3x150 MW	< 34	< 23	< 17.5
3x180 MW	-	-	-

Conclusion

- For cost (value) of wind energy of £75/MWh and MTTR above 4.5 months (£100/MWh and 3.2 months), N-1 justified for AC solutions

Cable system design:

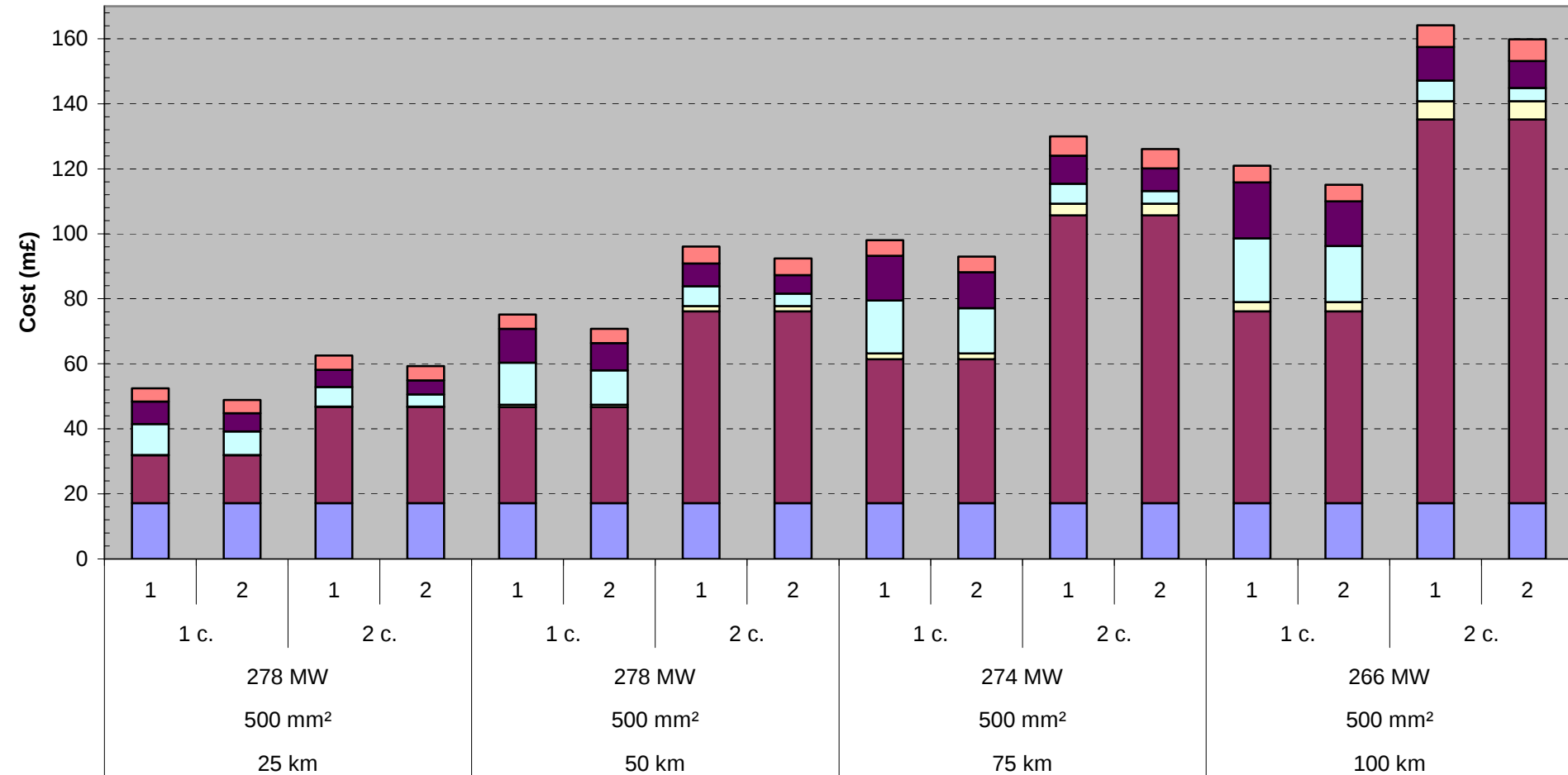
Number of cables

1 or 2 cables

MTTR and cost of energy that
favour N-1 over N-0

N-1 versus N-0 (MTTR 2 months)

Test	1	Technology	AC	Voltage (kV)	220 kV	Wind generation (MW)	280 MW	Transformer rating (MW)	135 MW t.	Number of transformers	2 t.
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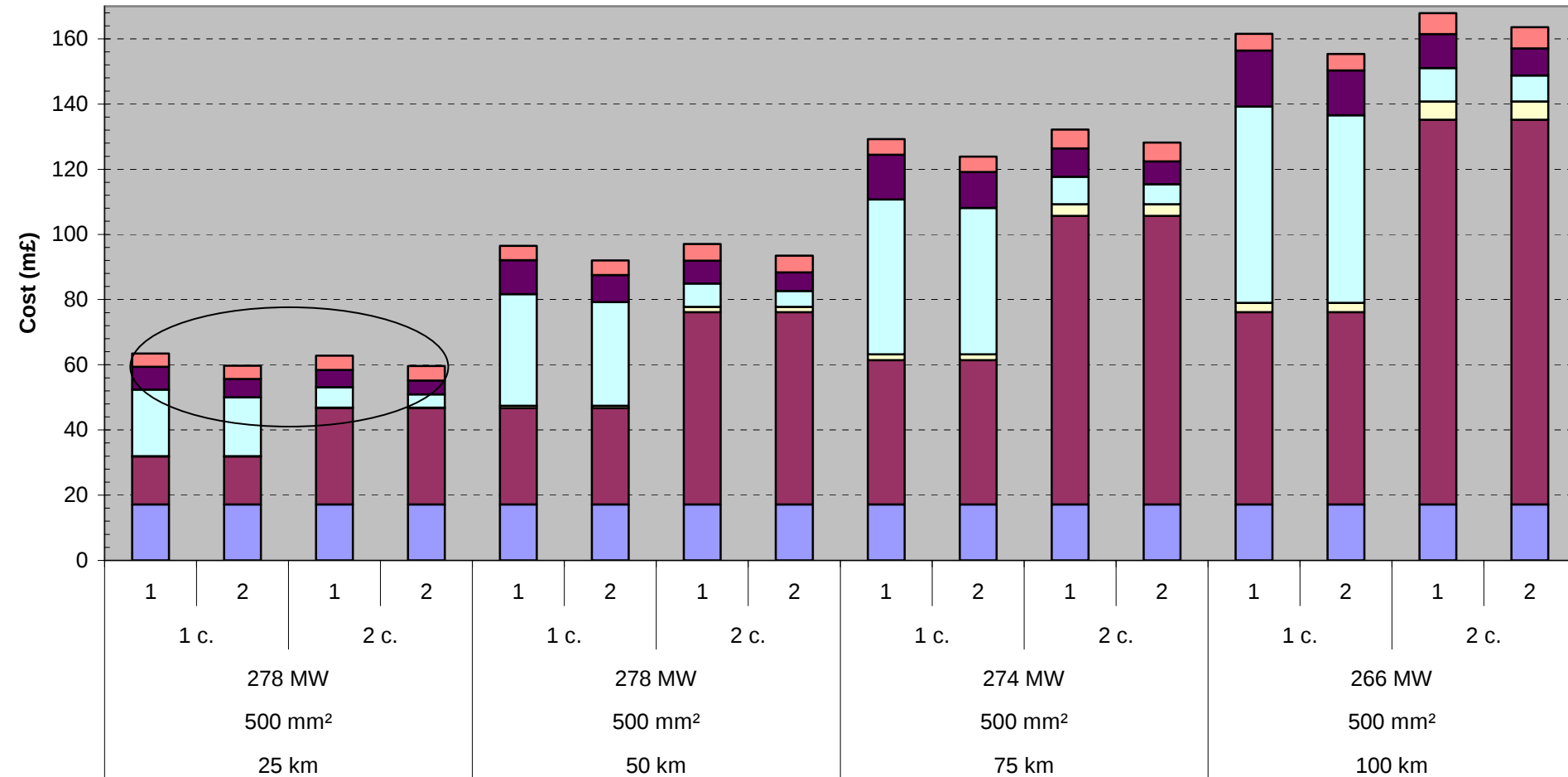


Data					
Platform & plant cost (m£)	Cables cost (m£)	MVArS cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)

Cable length (km)	Cable size (mm²)	Cable capability (MW)	Number of cables	Wind profile index
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N-1 versus N-0 (MTTR 8.5 months)

Test	1	Technology	AC	Voltage (kV)	220 kV	Wind generation (MW)	280 MW	Transformer rating (MW)	135 MW t.	Number of transformers	2 t.
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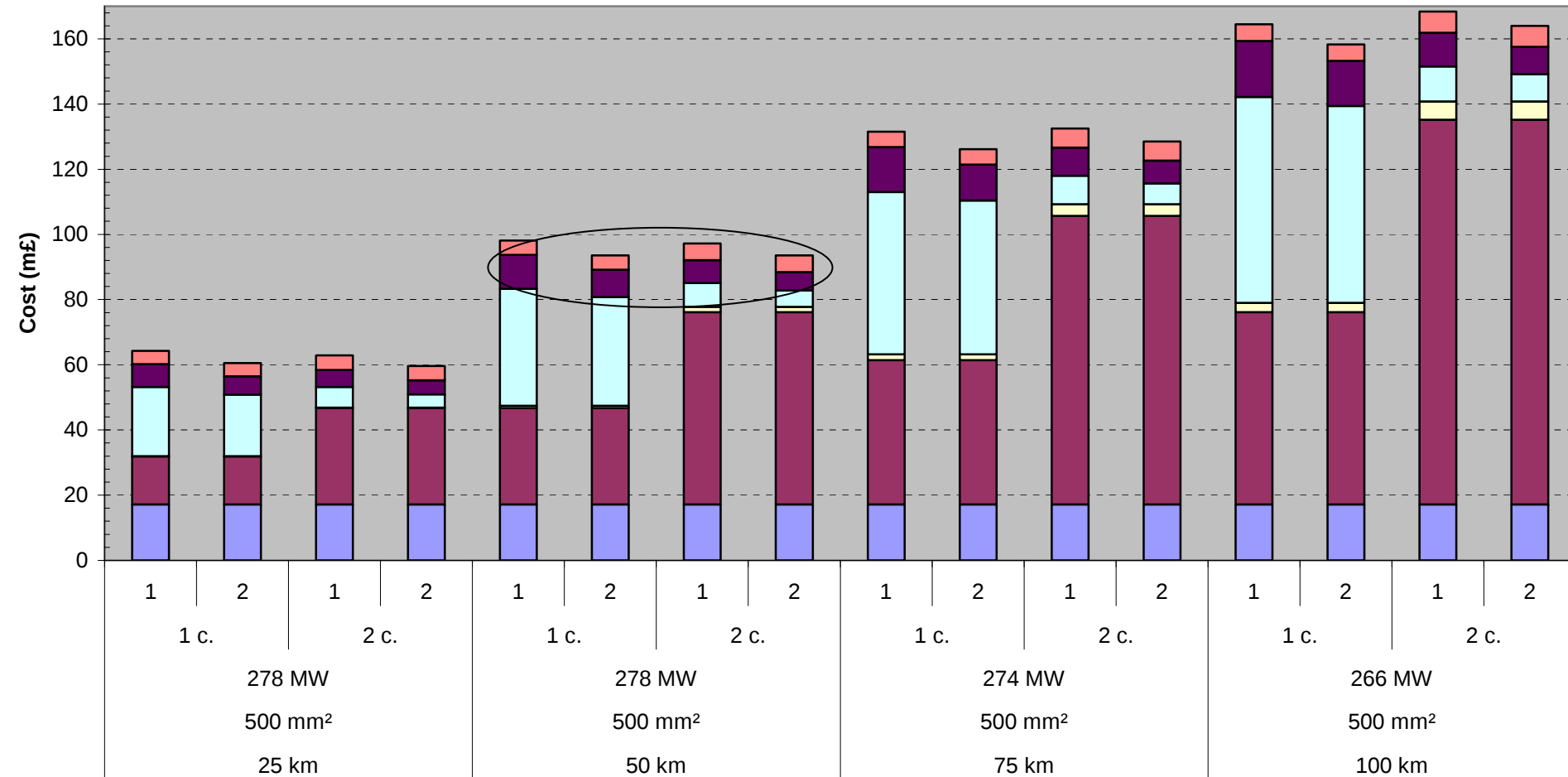


Data					
Platform & plant cost (m£)	Cables cost (m£)	MVAr cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)

Cable length (km)	Cable size (mm²)	Cable capability (MW)	Number of cables	Wind profile index
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N-1 versus N-0 (MTTR 9 months)

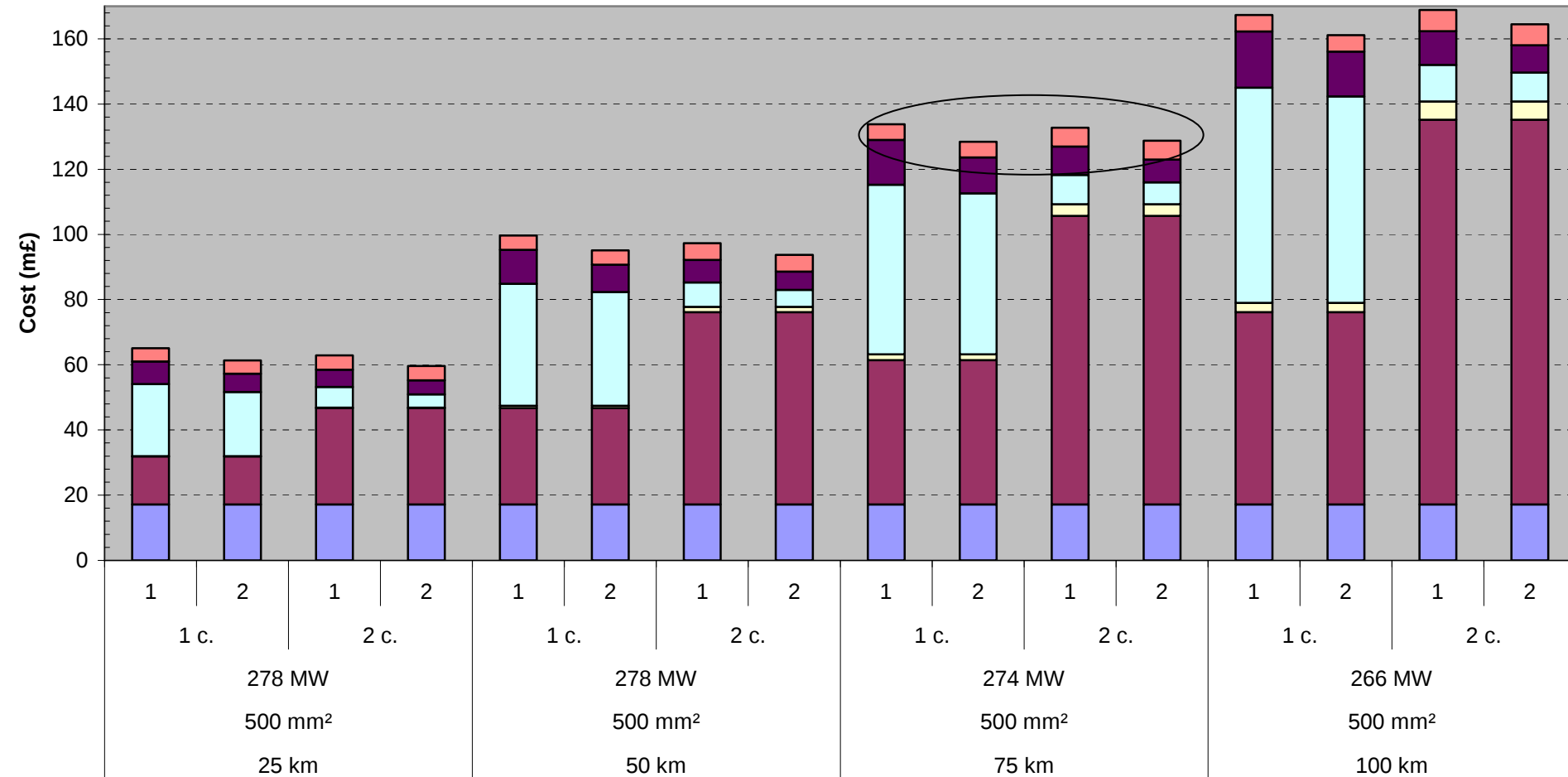
Test	1	Technology	AC	Voltage (kV)	220 kV	Wind generation (MW)	280 MW	Transformer rating (MW)	135 MW t.	Number of transformers	2 t.
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Data					
Platform & plant cost (m£)	Cables cost (m£)	MVArS cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)
Cable length (km)	Cable size (mm²)	Cable capability (MW)	Number of cables	Wind profile index	

N-1 versus N-0 (MTTR 9.5 months)

Test	1	Technology	AC	Voltage (kV)	220 kV	Wind generation (MW)	280 MW	Transformer rating (MW)	135 MW t.	Number of transformers	2 t.
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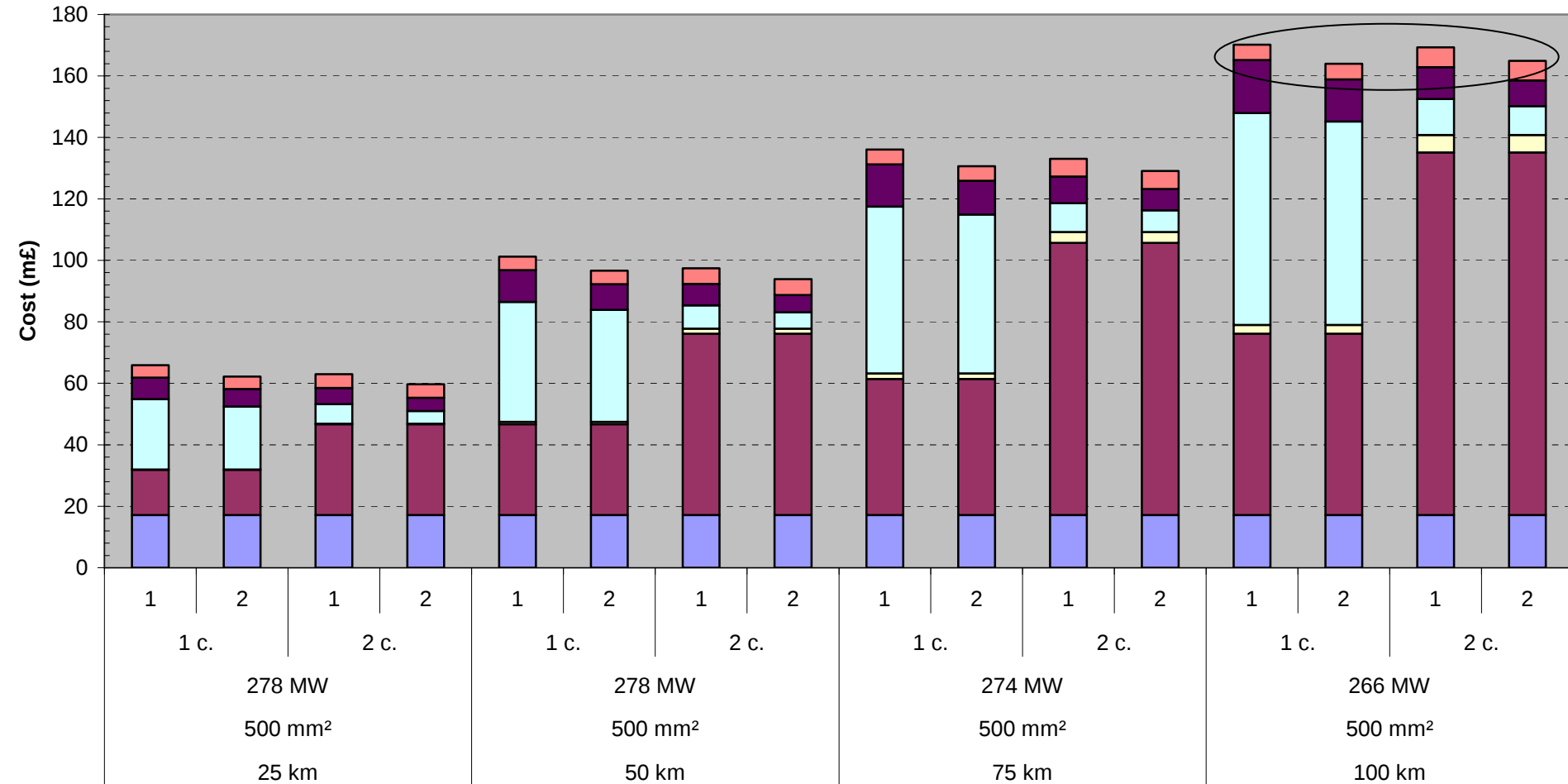


Data					
Platform & plant cost (m£)	Cables cost (m£)	MVArS cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)

Cable length (km)	Cable size (mm ²)	Cable capability (MW)	Number of cables	Wind profile index
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N-1 v. N-0 (MTTR 10 months)

Test	1	Technology	AC	Voltage (kV)	220 kV	Wind generation (MW)	280 MW	Transformer rating (MW)	135 MW t.	Number of transformers	2 t.
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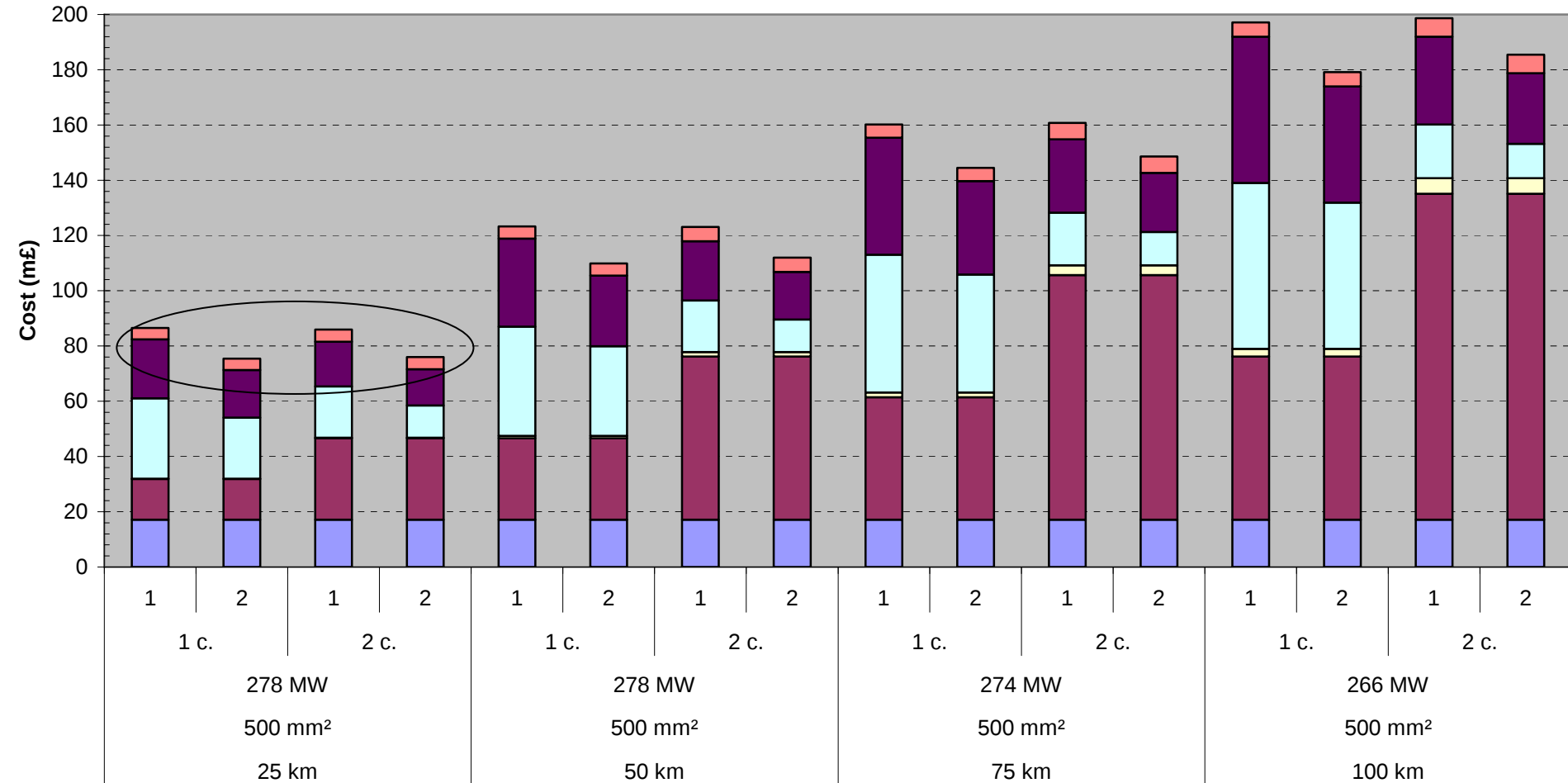


Data					
Platform & plant cost (m£)	Cables cost (m£)	MVArS cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)

Cable length (km)	Cable size (mm²)	Cable capability (MW)	Number of cables	Wind profile index
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N-1 versus N-0 (energy cost 230£/MWh)

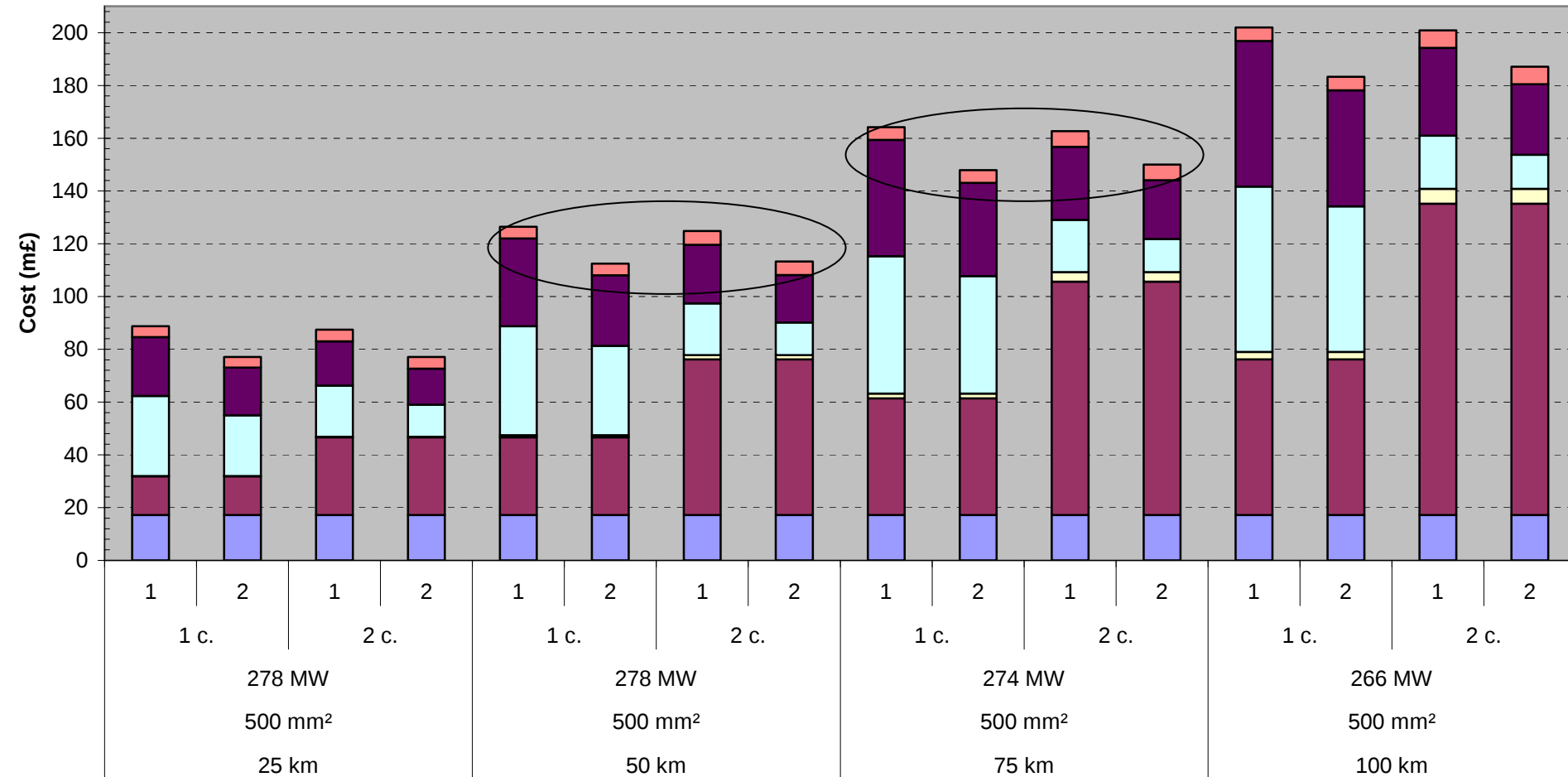
Test 1 Technology AC Voltage (kV) 220 kV Wind generation (MW) 280 MW Transformer rating (MW) 135 MW t. Number of transformers 2 t.



Data					
■ Platform & plant cost (m£)	■ Cables cost (m£)	■ MVArS cost (m£)	■ EEC cost (m£)	■ Losses cost (m£)	■ Mainenance cost (m£)
Cable length (km)	Cable size (mm²)	Cable capability (MW)	Number of cables	Wind profile index	

N-1 versus N-0 (energy cost 240£/MWh)

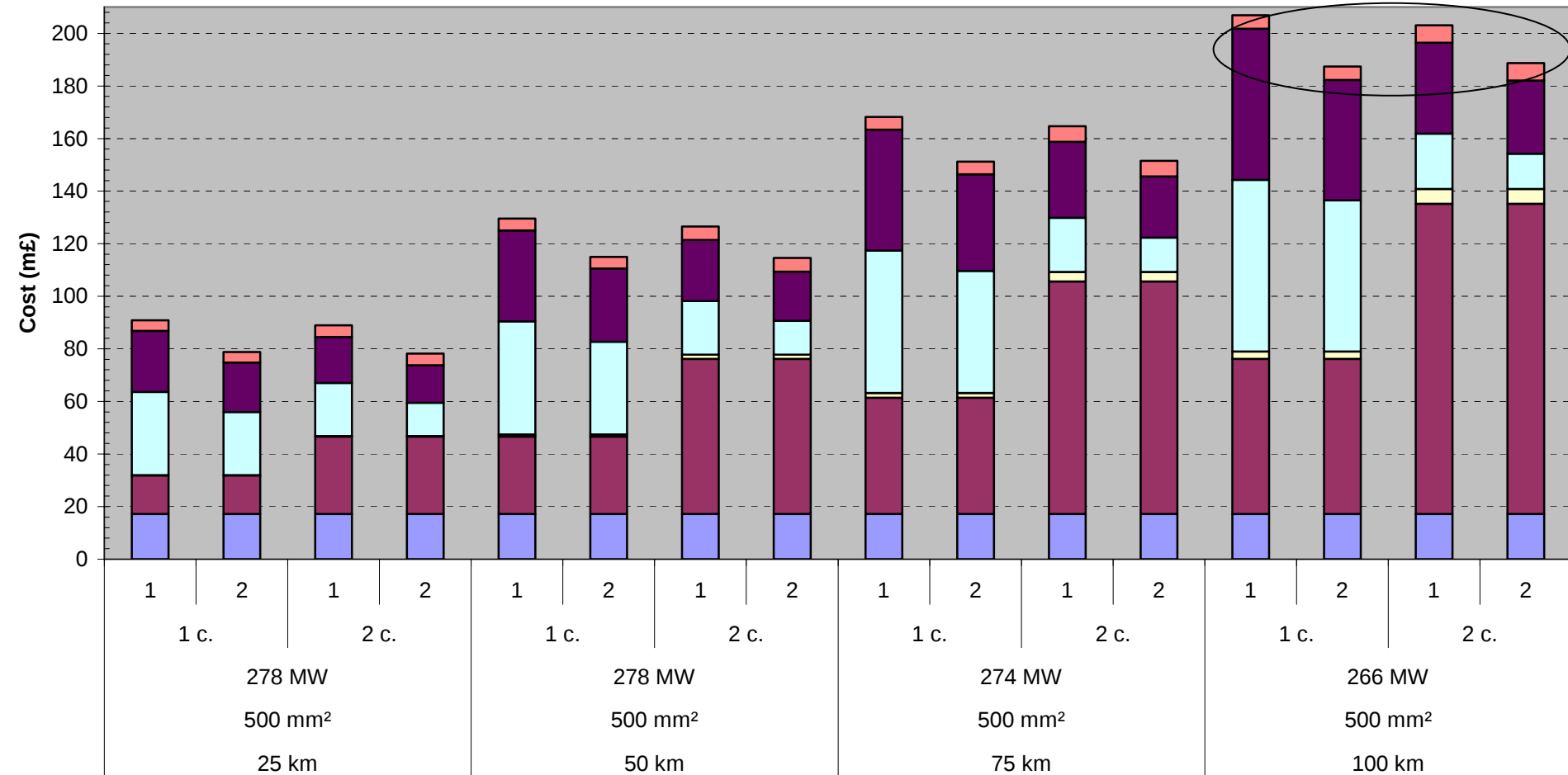
Test 1 Technology AC Voltage (kV) 220 kV Wind generation (MW) 180 MW Transformer rating (MW) 135 MW t. Number of transformers 2 t.



Data					
■ Platform & plant cost (m£)	■ Cables cost (m£)	■ MVArS cost (m£)	■ EEC cost (m£)	■ Losses cost (m£)	■ Mainenance cost (m£)
Cable length (km)	Cable size (mm²)	Cable capability (MW)	Number of cables	Wind profile index	

N-1 versus N-0 (energy cost 250£/MWh)

Test 1 Technology AC Voltage (kV) 220 kV Wind generation (MW) 280 MW Transformer rating (MW) 135 MW t. Number of transformers 2 t.



Data					
Platform & plant cost (m£)	Cables cost (m£)	MVArS cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)

Cable length (km) Cable size (mm²) Cable capability (MW) Number of cables Wind profile index

1 or 2 Cables: summary

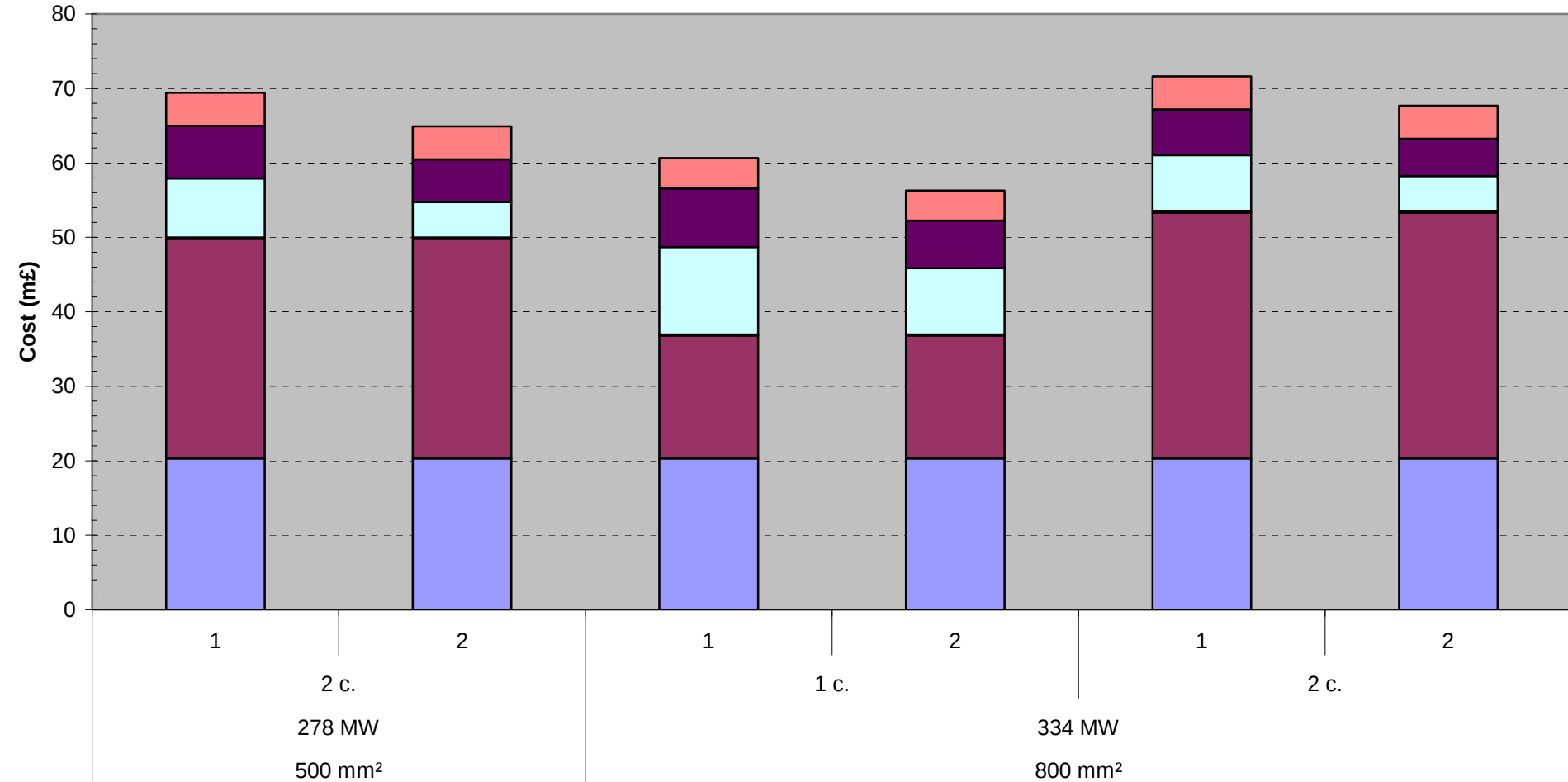
Length	MTTR	Energy cost
km	months	£/MWh
25	13	50
50	14.5	50
75	16	50
100	18	50
25	8.5	75
50	9	75
75	9.5	75
100	10	75
25	6	100
50	6	100
75	6.5	100
100	7	100
25	2	230
50	2	240
75	2	240
100	2	250

- Break-even parameters are in red

Cable Redundancy Analysis

N-1 versus N-0 (MTTR 2 months)

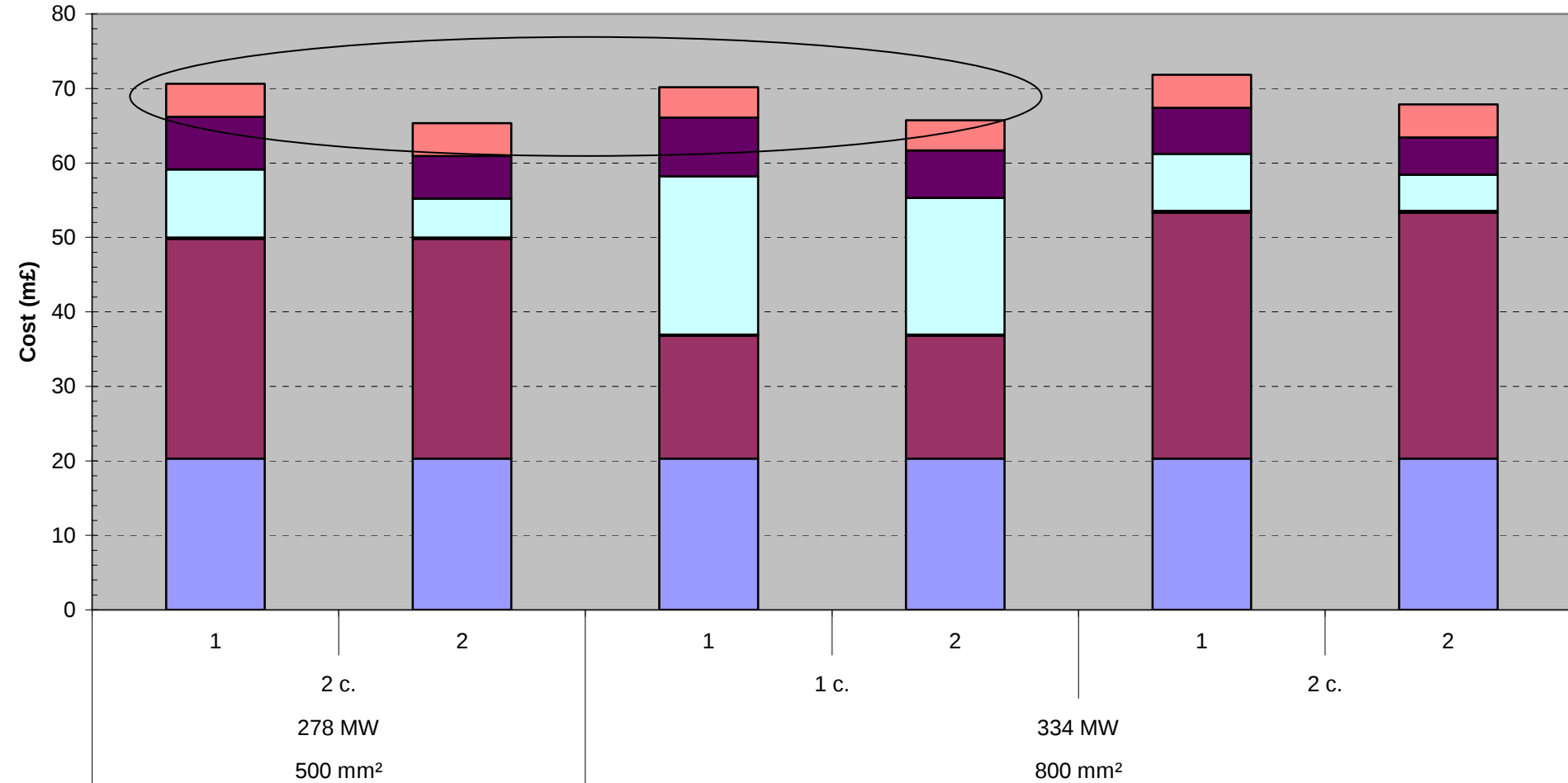
Test 1	Technology AC	Voltage (kV) 220 kV	Wind generation (MW) 350 MW	Transformer rating (MV) 170 MW t.	Number of transformer 2 t.	Cable length (km) 25 km
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Data					
Platform & plant cost (m£)	Cables cost (m£)	MVARs cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)
Cable size (mm²)	Cable capacity (MW)	Number of cables	Wind profile index		

N-1 versus N-0 (MTTR 6.5 months)

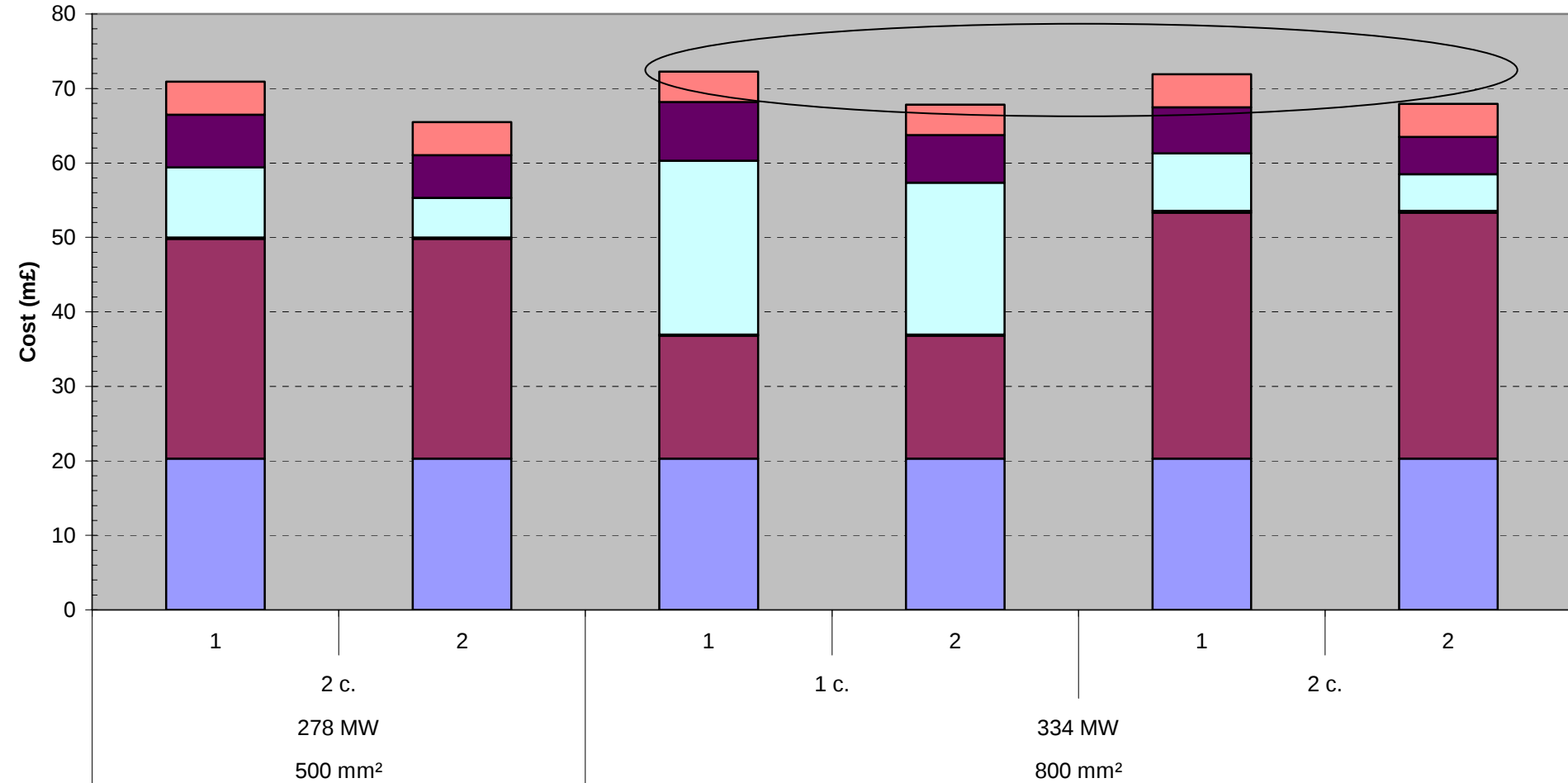
Test 1	Technology AC	Voltage (kV) 220 kV	Wind generation (MW) 350 MW	Transformer rating (MV) 170 MW t.	Number of transformer 2 t.	Cable length (km) 25 km
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Data					
Platform & plant cost (m£)	Cables cost (m£)	MVARs cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)
Cable size (mm²)	Cable capability (MW)	Number of cables	Wind profile index		

N-1 versus N-0 (MTTR 7.5 months)

Test 1	Technology AC	Voltage (kV) 220 kV	Wind generation (MW) 350 MW	Transformer rating (MV) 170 MW t.	Number of transformer 2 t.	Cable length (km) 25 km
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Data					
Platform & plant cost (m£)	Cables cost (m£)	MVARs cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)
Cable size (mm²)	Cable capacity (MW)	Number of cables	Wind profile index		

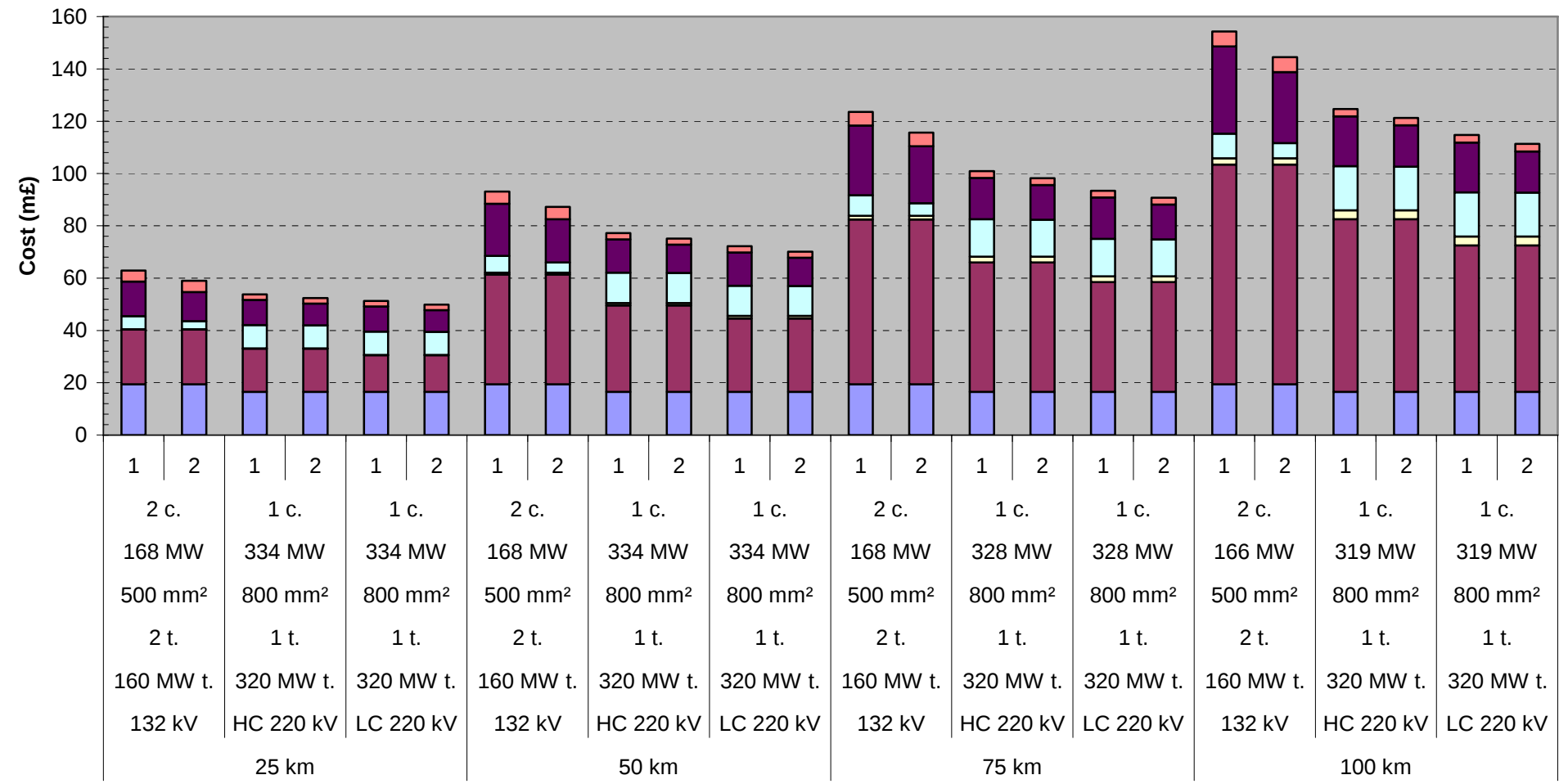
Case Study

350 MW Wind Farm

1 circuit of 220kV or 2 circuits of 132kV

Total costs

Test	1	Technology	AC	Wind generation (MW)	350 MW
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Data							
Platform & plant cost (m£)	Cables cost (m£)	MVAr cost (m£)	EEC cost (m£)	Losses cost (m£)	Maintenance cost (m£)		

Cable length (km)	Voltage (kV)	Transformer rating (MVA)	Number of transformers	Cable size (mm ²)	Cable capability (MW)	Number of cables	Wind profile index
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Sensitivity of failure rate

Break-even MTTR of Cables

MTTR (months)		1 or 2 cables			2 or 3 cables		
Energy cost	Length	Failure rate (1/year.100km)					
£/MWh	km	0.04	0.08	0.12	0.04	0.08	0.12
50	25	39	19.5	13	45	23	15.5
	50	43	21	14.5	48	24.5	16.5
	75	47	23.5	16	50	25.5	17
	100	52	26.5	18	51	26	17.5
75	25	24	12.5	8.5	28	14.5	9.5
	50	26	13	9	30	15	10
	75	28	14	9.5	30	15.5	10.5
	100	29	15	10	30	15	10
100	25	17	9	6	20	10	7
	50	18	9.5	6	21	10.5	7
	75	19	9.5	6.5	21	10.5	7
	100	20	10	7	21	10.5	7

Break-even Energy Costs

Energy cost (£/MWh)		1 or 2 cables			2 or 3 cables		
MTTR	Length	Failure rate (1/year.100km)					
months	km	0.04	0.08	0.12	0.04	0.08	0.12
2	25	420	300	230	410	310	250
	50	430	300	240	420	320	250
	75	430	310	240	420	310	250
	100	440	310	250	420	310	250

Summary

- Cost of wind energy lost (losses + constrained energy) should be valued at forward price from brown electricity + ROC (BM prices should not be used)
- Sensitivity approach used: determine critical values of driving parameters that change the design:
 - Parameters analysed:
 - Mean Time to Repair for Transformers
 - Cost of energy lost
 - Mean Time to Repair for Cables
 - Distance from shore
 - Cost parameters kept constant
- Design of platform for AC solution
 - For cost of wind energy above 75£/MWh and MTTR greater than 4.5 months (or £100/MWh and 3.2 months)
 - N-2 not justified for any of the values of the parameters analyzed
 - N-1 not justified for DC solutions
- Design of cable networks:
 - N-0, minimum number of circuits

Size limit of a single circuit connection

- **Recommendation:** Limit single circuit cable connection to **1500MW**
 - Loss of 1500MW of offshore wind farm capacity connected to a single cable circuit is **infrequent**:
 - On average, less than 1 event of 1500MW loss in 25-31 years, per 1500MW wind farm
 - Failure rates of cables 0.08failures/100km.year
 - Probability that a wind farm of 1500MW capacity will generate above 1000MW is between 16% and 20%
 - Cost of additional response for handling losses above 1320MW of a 1500MW wind farm is 5 times smaller than the cost of additional circuit (cost of response is assumed to be extremely high)

Probability that the output of a wind farm of a given capacity is above 1000MW level

Wind Capacity (MW)	Probability
1050	0.00
1160	0.03
1260	0.08
1370	0.12
1470	0.16
1580	0.20

Singe and double circuit HVDC costs (capitalised) and additional annual response costs

HVDC singe and double circuit costs (1500MW)
(includes both capital and operating cost of the design)

Total cost (m£)		Distance (km)			
No cables	Cable size (mm2)	25	50	75	100
1	2000	343	390	436	483
2	1000	365	417	469	522
Cost difference (m£)		22	27	33	39

Wind farm capacity [MW]	Annual additional cost of reserve [m£]
1395	0
1421	0.04
1447	0.12
1474	0.23
1500	0.43