## Report on the Recommendations Arising from Additional Cost Benefit Analyses

### Introduction

1. The GBSQSS sub group presented their recommendations to OTEG on Friday 29th September 2006. Those recommendations formed a basis for the BERR / Ofgem Initial Consultation on a Security Standard for Offshore Transmission Networks dated 13 December 2006. In their response to the consultation, published in April 2007, the Government decided that the cost benefit analyses completed by the GB SQSS sub group is a sound basis for the development of the offshore standard and accepted the initial recommendations except for two, which were subsequently modified in line with the Government's findings. Appendix 1 provides a summary of the recommendations as modified by the Government's response.

2. The above initial recommendations are in respect of offshore wind farms only and cover offshore transmission circuits (AC and DC) on the offshore platform and the cable offshore transmission circuits (AC and DC) from the offshore platform to the shore.

3. The Government also approved further assessment work to identify minimum requirements for points (a) through (e), below:
   a) Connection of alternative generation technologies i.e. gas fired generation;
   b) Security implications when an offshore transmission system contains an onshore overhead line (OHL) section;
   c) Security at the interface between the offshore and onshore electricity systems;
   d) Voltage step change limits on the offshore transmission system; and
   e) Substation configuration and switching arrangements on the offshore transmission system.

4. Consistent with the previous work carried out by the GBSQSS sub-group, the Sustainable Energy and Distributed Generation (SEDG) centre carried out a cost benefit analysis, to determine the optimum economic solution, with the recommendations being made from the results.

5. The cost benefit analyses (CBA) for the further work have now been completed. In conducting the new CBA, it was recognised that the previous analyses, which underlie the initial recommendations, did not take account of energy curtailed due to planned outages for maintenance. Accordingly, a review of the previous CBA was conducted to include planned maintenance and to ensure that the initial recommendations remain valid.

6. This report provides an outline of the additional CBA assessment, including key assumptions used, scope and recommendations arising from the analyses. Essentially, these recommendations cover items (a), (b) and (c) listed above in paragraph 3. The results of further work in relation to voltage step change limits is also considered as is substation configuration and switching arrangements. This work covers items (d) and (e) of paragraph 3.

7. As with the previous work carried out in this area, the consequential impact of these recommendations on the access rights, compensation arrangements and transmission charging for offshore generation is outside scope and has therefore not been considered.

**The Additional Cost Benefit Analyses**

Background

8. The methodology for the cost benefit analysis previously carried out for the GBSQSS sub group by the SEDG centre was extended to assess the additional scope of works noted in paragraph 3. This takes account of the need to build an offshore transmission system that is economic, efficient, and resilient to all secured events stated, whilst also stipulating the maximum loss of power infeed that can occur for outages of offshore transmission system assets.
9. Whilst addressing the further areas of work, it became apparent that an inappropriate consideration of timescales relating to planned plant maintenance and of resultant costs had been made in the analyses underlying the initial recommendations. In view of this, a review of the original CBA work was undertaken to take due account of planned maintenance. One of the recommendations arising from this review has led to a proposal to revise one of the initial recommendations (paragraph 18 (a) i refers).
10. Generic offshore wind farms and gas turbine connections have both been modelled. A revised dataset has been compiled for the purpose of the additional works, a full copy of which has been included in Appendix 2.
11. Based on this input data the analyses compare the cost of installing additional offshore assets against the value of energy curtailed as a result of reduced network capacity. The long run marginal costs of providing transmission capacity and the benefits arising from short run marginal savings of estimated energy curtailed during planned and fault outages have been taken into account.
12. This analysis has not considered the apportionment of the costs associated with energy curtailed.

Key Assumptions

13. The further analyses, and recommendations arising, set out in this report are based on a number of working assumptions and are listed below.
    a) No consideration has been given to the financial compensation arrangements for loss of transmission system access or the relevant offshore transmission charging arrangements;
    b) No consideration has been given to the security of connection on the distribution network should offshore transmission systems connect to a DNO network;
    c) There will be no customer demand connected to the offshore transmission network; and
    d) Input assumptions and limits to the cost benefit analysis, which are included in Appendix 2; and
    e) Due to the nature of HVDC, it is assumed that recommendations relating to AC/DC conversion facilities at the onshore terminus of the offshore transmission system are the same those for AC/DC facilities on the offshore platform which are given in paragraph 4 of Appendix 1 of the initial recommendation.

## Scope

14. The scope of the analyses was bounded by certain pragmatic assumptions which recognise currently available technology. These assumptions include limiting the cumulative capacity from wind farms at the offshore grid entry point to a maximum of 1500MW and limiting the capacity of offshore gas turbines to a maximum of 200MW per offshore platform.

15. In addition, the distance from the offshore grid entry point on the offshore platform to the onshore grid entry point at the first onshore substation is assumed to be limited to between 25km and 100km with the length of any overhead line section of the offshore transmission system once the cables reach the shore limited to between 1km and 50km.

16. On the basis of the results of the cost benefit analysis, the security for offshore transmission networks has been assessed according to the four basic functional parts of an offshore transmission system, namely:

    a) the offshore platform (including AC transformers or DC converters);

    b) the cable offshore transmission circuits (AC or DC) connecting the offshore platform to the shore;

    c) Any overhead line section (AC only) of the incoming offshore transmission circuit connecting the cable offshore transmission circuits either directly to the first onshore substation or transformation facilities; and

    d) The onshore terminus facilities forming part of the offshore transmission system, which may include AC/DC conversion facilities or AC transformation facilities where the voltage of the offshore transmission system is not the same as the onshore system to which it is connecting.

17. The initial cost benefit analyses and recommendations, which were in respect to offshore wind farm generation only, cover items (a) and (b) above. The scope of these further cost benefit analyses, which are the subject of this report, includes items (c) and (d) for both offshore wind farm generation and offshore gas turbine generation.

**Recommendations Arising from the Additional Cost Benefit Analyses**

18. The recommendations arising from the results of the cost benefit analyses to cover the additional work identified in paragraph 17 are presented below in accordance with the functional parts of the offshore transmission system to which they apply. The justification underlying the following recommendations is included as Appendix 3. For ease of reference, each of the following recommendations is cross referenced to the relevant section of Appendix 3.

a) Offshore platform (AC transformers and AC platform interconnection circuits) – Based on Appendix 3, Section 1.

   i. For wind farms of 90MW or greater, there should be a minimum of 2 transformers installed on the offshore platform, with the capacity such that following a planned or fault outage of a transformer there is a minimum of 50% of installed platform capacity remaining.

   ii. For gas turbines of 90MW or greater, there should be a minimum of 2 transformers installed on the offshore platform, with the capacity such that following a planned or fault outage of a single transformer there is no loss of capacity.

b) Cable Offshore Transmission Circuits (AC / DC) – Based on Appendix 3, Section 2.

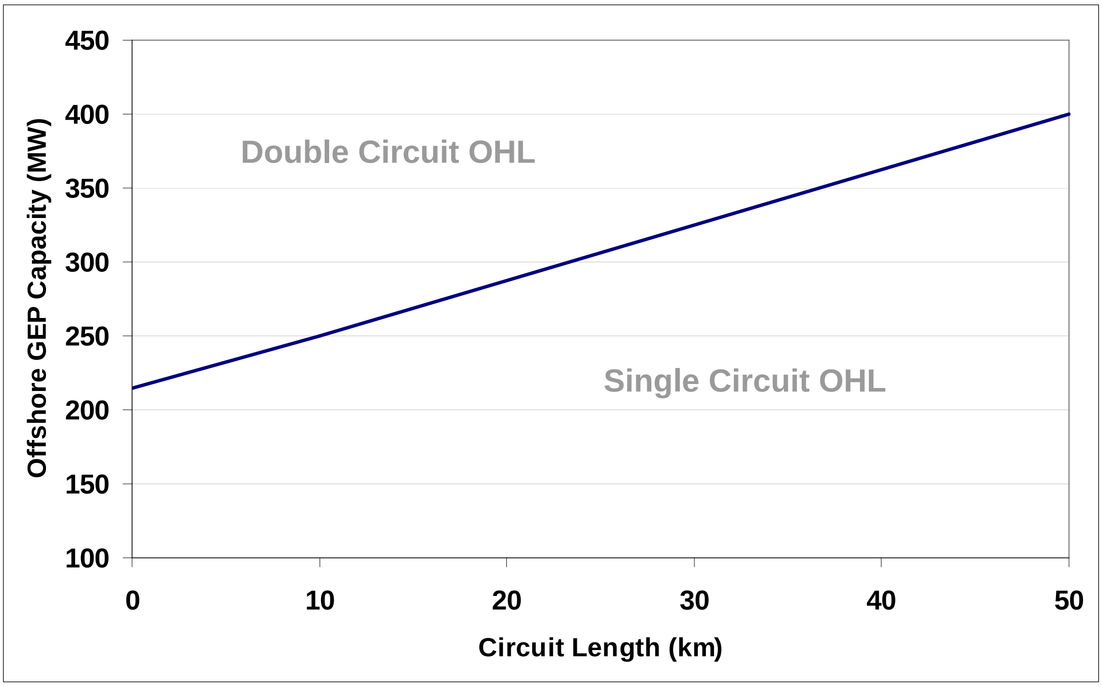
   i. For the connection of gas turbines and wind farms, for the planned or fault outage of a single cable circuit, the loss of power infeed shall not exceed 1320MW.

   ii. For the connection of gas turbines, following the fault outage of a single cable circuit during the planned outage of an offshore transmission cable circuit, the reduction in circuit capacity shall not exceed 1320MW

c) Overhead Line Sections (AC) – Based on Appendix 3, Section 3.

   i. In the case of 220KV and above, and for generation capacities of up to 1250MW, all onshore lines shall be of single circuit construction.

   ii. In the case of 132kV, the requirement for a single or double circuit overhead line is a function of both the route length and the level of generation capacity connected for both gas turbines and wind farms. This is illustrated in the graph below with the area above the line representing a double circuit requirement as a minimum and the area below the line representing a single circuit requirement.




d) <u>Onshore terminus Facilities / substation connection requirements (AC) – Based on Appendix 3, Section 4.</u>

   i. For wind farms of 120MW or greater, there should be a minimum of 2 transformers installed onshore, with the capacity such that following a planned or fault outage of a transformer there is a minimum of 50% of installed platform capacity remaining. For the avoidance of doubt, this should not exceed 1000MW.

   ii. For all gas turbines, there should be a minimum of 1 transformer installed onshore, and following a planned or fault outage of the transformer, the loss of power infeed shall not exceed 1000MW.

**Areas not Specifically Addressed by Cost Benefit Analyses**

19 The additional cost benefit analyses did not specifically address the following areas:

a) The appropriate loss of power infeed, in the case of gas turbines connected to an AC offshore platform, following the unplanned outage of a single offshore transmission platform circuit during the planned outage of an offshore transmission circuit.

   This is taken to be 1320MW (the infrequent infeed loss risk), which is the same as in the case of the equivalent recommendation for wind farm connections (item 5 of Appendix 1 refers).

b) The appropriate loss of power infeed, in the case of gas turbines connected to an DC offshore platform, following the unplanned outage of a single offshore transmission platform circuit during the planned outage of an offshore transmission circuit.

   This is taken to be 1320MW (the infrequent infeed loss risk), which is the same as in the case of the equivalent recommendation for wind farm connections (item 5 of Appendix 1 again refers).

c) The appropriate loss of power infeed, in the case of onshore DC conversion facilities, following a secured event.

These are taken to be the same as in the case of DC conversion facilities on the offshore platform (items 4 and 5 of Appendix A refer).

d) The justification for double circuit or single circuit onshore DC overhead line sections of the offshore transmission system.

The equivalent for onshore AC overhead line sections is given in paragraph 18 (c). The maximum permitted loss of power infeed following a secured event on an AC overhead line section is taken to be 1320MW (the infrequent infeed loss risk). This level of permitted loss of power infeed reflects the perceived frequency of the secured event coupled with the likelihood of the secured event being coincident with the power station (e.g. wind farm) generating at full capacity. In the case of DC there is no equivalent justification for double circuit or single circuit onshore overhead line sections. The level of permitted loss of power infeed following a secured event on a DC overhead line section is taken to be the same as in the case of AC overhead line sections (i.e. 1320MW).

e) The connection of both wind farms and gas turbines to the same offshore transmission system.

In the case of mixed connections to a single offshore transmission system, two sets of generation connection criteria will overlap (i.e. gas turbine and wind farm connection criteria) that differ in certain respects. In such cases, both sets of criteria must be met. This is in line with the existing GB SQSS where, for example, in paragraph 2.2 of Section 2 it is explained that “in those parts of the GB transmission system where the criteria of Section 3 and/or Section 4 also apply, those criteria must also be met”.

As explained in paragraph 7, the consequential impact of these recommendations on the access rights, compensation arrangements and transmission charging for offshore generation is outside scope and has therefore not been considered.

**Voltage Step Change Limits on the Offshore transmission System**

20 In order to ensure the voltage limits to be applied for offshore transmission systems are appropriate, consideration has been given to recommendations for both steady state limits and step change limits.

21 The Grid Code review group presented their recommendations to Ofgem in August 2007 and recommended a steady state voltage limit of +/- 10% of nominal voltage. The further work detailed in this report reviewed the information provided by the Grid Code review group and has provided a recommendation that, since there is not anticipated to be any customer demand connected to offshore transmission networks, no voltage step change limits should apply. However the voltage levels must at all times remain below the upper limit of + 10% of nominal.

**Substation Configuration and Switching Arrangements** – Based on Appendix 3, Section 5.

22 Given the requirement of Offshore Transmission Owners (OFTOs) and operators to maintain the security of supply whilst maintaining equipment installed on the offshore platform, all substations connecting wind farms should be of double busbar design.

23 In the case of a connection of one gas turbine, all substations should be of single busbar design. In the case of multiple connections of gas turbines, substations should be of a double busbar design.

24 In the case of double busbar designs, the maximum loss of power infeed for a fault outage of any single section of busbar or mesh corner shall not exceed the 1320MW (the infrequent infeed loss risk). This represents an increase relative to the equivalent onshore criterion 2.6.3 of the current GBSQSS, which limits the loss of power infeed for a fault outage of a single section of busbar to 1000MW (the normal infeed loss risk). This is the only difference between the onshore and offshore criteria with regard to substation and switching arrangements, justification for which is outlined in Appendix 3, Section 5.

25 Guidance on the design requirements of offshore transmission substations will be included in a new ‘Part 2’ of Appendix A (Recommended Substation Configuration and Switching Arrangements) of the GBSQSS.

### *Customer Choice*

26 In line with the existing GBSQSS, it is recommended that the offshore transmission system security standards allow the offshore transmission licensee to meet a Generator’s request for security above or below the minimum planning standard provided there is no adverse impact on any other user.

## Appendix 1

## Summary of Initial Recommendations for Offshore Wind Farm Generation Connections

The results of cost benefit analyses and the subsequent recommendations of the GB SQSS Sub Group as modified by the 'Government's Response to the Joint BERR/Ofgem Initial Consultation on a Security Standard for Offshore Transmission Networks' dated April 2007 are summarised below. These recommendations, which are in respect of offshore wind farms, cover the offshore transmission circuits (AC & DC) on the offshore platform and the cable offshore transmission circuits (AC & DC) from the offshore platform to the shore.

**Offshore platform (AC transformers, AC platform interconnection circuits and DC converters):**

1. AC platforms should be designed such that the High Voltage and Low Voltage terminals of the platform circuits are interconnected to allow for full flexibility of use of assets housed upon it.

2. Platform capacity should be planned to accept 100% of the cumulative installed capacity of the wind farms connected, with no equipment loadings exceeding their pre-fault rating.

3. For AC platform designs; for wind farms with a cumulative installed capacity of *120MW* or above, following the outage (planned or unplanned) of a single offshore platform AC circuit, the reduction in platform export capacity should not exceed 50% of the installed platform capacity. For the avoidance of doubt, this should not exceed 1000MW.

   *Note: the above* ***120****MW threshold has been subsequently modified to* ***90****MW to reflect the results of the further analyses which, unlike the initial analyses, takes due account of planned maintenance.*

4. For DC platform designs; platform capacity should be planned such that following the outage (planned or unplanned) of a single offshore platform DC converter module, the loss of power infeed shall not exceed existing onshore Normal Infeed Loss Risk (1000MW).

5. Following the unplanned outage of a single offshore transmission platform circuit during the planned outage of an offshore transmission platform circuit, the reduction in platform capacity should not exceed 1320MW.

**Offshore network capacity (AC /DC cables)**

6. The transmission cable circuit capacity should be planned to accept the export capacity of the wind farm with no equipment loadings exceeding their pre-fault rating.

7. Following the outage of a single offshore transmission cable circuit, the reduction in cable circuit capacity should not exceed 1320MW.

8. Follow the unplanned outage of a single offshore transmission cable circuit during the planned outage of an offshore transmission cable circuit, the reduction in circuit capacity should not exceed 1320MW.

## Appendix 2

## Cost Benefit Analysis Data Set

### General

**Energy cost**

Winter - £45/MWh
Summer - £35/MWh
ROC value - £30/MWh

**Wind farm output**

Load factor during forced outages – 40%
Load factor during planned outages – 24%

**Limits to analysis**

Up to 100km from the 1st onshore substation
Up to 50km onshore OHL section
Up to 1500MW wind farm capacity
Up to 200MW gas turbine capacity

### Transformers

**Offshore transformers (for revised work)**

Losses: load 0.6%, no-load 0.03%

Failure rate 3%
Mean Time To Repair 6 months
Repair cost per fault - £2.5m

Cost - £29/kVA (for two transformers on a platform)
20% additional cost for third and each successive transformer
20% decrease in cost for just one transformer on a platform

Platform cost - £5m per platform plus
£23/kVA (for two transformers on a platform)
20% additional cost for each additional transformer

**Onshore transformers**

Failure rate 2% - *(**Source** - CIGRE WG 12.05 concluded the average failure rate for units installed on systems operating at voltage lower than 700 kV)*
Mean time to repair 2 months *(**Source** - National Grid)*

Maintenance requirements – 5 days per annum *(**Source** - National Grid)*

Electrical parameters; *(**Source** - National Grid)*
400/220 - X=1.6% R=0.02% on 100MVA base *(assumed the same as 400/275 unit)*
400/132 - X=8% R=0.14% on 100MVA base
220/132 - X=9% R=0.16% on 100MVA base *(assumed the same as 275/132 unit)*

**C**ost; *(**Source** - National Grid)*
400/220 (assumed the same as 400/275 unit) £2.7m (1100MVA which is Maximum permissible)

400/132 £2.5m (240MVA – Maximum permissible 460MVA)
275/132 £2.1m (240MVA – Maximum permissible 460MVA)

0.12% of cost per MVA change in rating above 240MVA up to maximum permissible

HV bay for transformer, to include CB: *(**Source** - National Grid)*
400kV – £1.8m
220 / 275kV - £1.6m

**Overhead lines**

Electrical parameters;
R = $2.9\times10^{-3}$% on 100MVA base
X = 0.386% on 100MVA base
Reliability; (220 assumed same as 275, 275 and 400 very similar)
Single cct faults – 0.6714 / 100cct km / yr
Double cct faults - 0.02659 /100km/yr
M.T.T.R. – 56 hours (figure does not include all those that closed on DAR)

132kV *(**Source** – As agreed with onshore TO's)*

| Fault type | Fault rate /100km p.a. | Repair cost (£k) | M.T.T.R. (worst case) |
|---|---|---|---|
| Minor(insulator damage, damage to arcing horns etc) | 0.09 | 20 | 20hrs |
| Semi major (conductor damage, broken conductor etc) | 0.01 | 40 | 36hrs |
| Major (tower damage etc) | 0.01 | 400 | 72hrs |

Cost; (400 / 275 / 220 all assumed the same) *(**Source** - National Grid)*
Towers – £360k each spaced 400m apart
Conductor - £300k per cct km

400kV conductor – single cct rating would be above 1500MVA continuous in summer therefore assume cost covers this due to limit in analysis.

275kV / 220kV – single cct rated at 1250MVA continuous in summer.

Conductor system and towers could be the same for both voltages therefore tower cost kept the same, assume costs are for the ratings as given i.e. 1500MVA at 400, 1250MVA at 220/275. These costs are for standard sized conductors therefore these would normally be used in each case.

132kV; *(**Source** – As agreed with onshore TO's)*
Single Circuit OHL per km (i.e. a wood pole type): £450k (150MVA); £600k (250MVA) or £900k (400MVA)

Double Circuit OHL per km: £700k (150MVA); £950k (250MVA) or £1250k (400MVA)

If Double Circuit OHL per km is built with one circuit strung the typical costs are £600k (150MVA); £850k (250MVA) or £1100 (400MVA)

Incremental cost for the second circuit to be strung on a Double Circuit with one circuit existing per km is £150k (150MVA); £200k (250MVA) or £250 (400MVA).

Cable Sealing ends – Approx £150k for 132kV, £300k for 275kV £500k for 400kV

**Onshore cable costs**

132kV

| Cable Size ($mm^2$) | Urban (£k/km) | Rural (£k/km) |
|---|---|---|
| 500 | 1137 | 890 |
| 800 | 1364 | 1117 |
| 1200 | 1516 | 1268 |

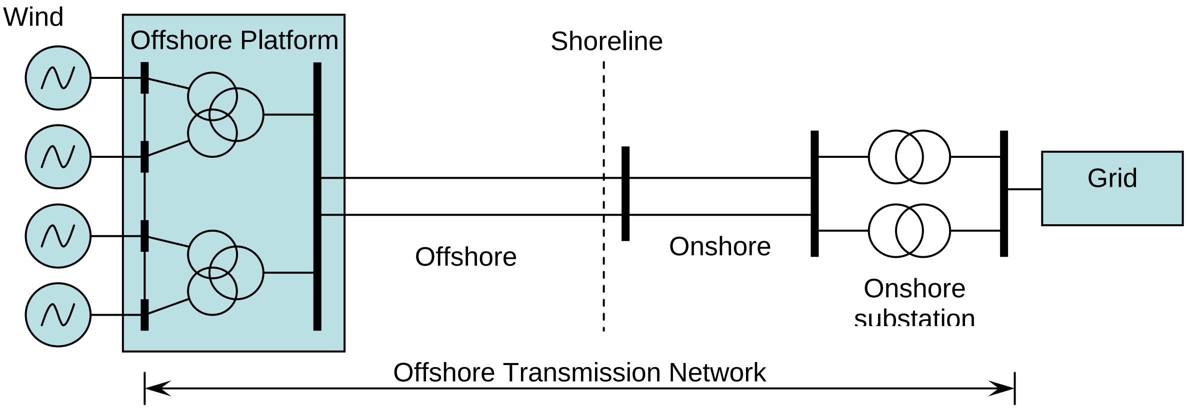
**Appendix 3**

**Results from Cost Benefit Analysis**

The cost benefit analysis for the further recommendations was carried out in the same fashion as that for the initial recommendations. This methodology was agreed as a sound basis for development of an offshore standard. This appendix outlines the results coming out of this analysis in greater detail.

Each of the four areas outlined in the scope, shown below, have been address in this section.

**Scope**




Results for the further recommendations are outlined below:

**1) Offshore Platform**

**i) Wind farms**

Analysis builds on that previously carried out for the initial recommendation. It compares additional capital investment cost for 2 transformers with 50% installed capacity as opposed to 1 transformer with 100% installed capacity against the benefit of a reduction in estimated energy curtailed (EEC) cost for forced and planned outages capitalised over 25 years. 2 transformers become favourable to 1 transformer when the benefit outweighs the additional investment (in £m).

The availability of turbines is assumed to be 90%.

The previous recommendation did not include provision of EEC for planned outages. These outages are assumed to be taken in the summer months when the load factor of the wind farm is lower.

**60MW Wind farm**

| Offshore platform (MVA) | | **1x60** | **2x30** | **2x45** |
|---|---|---|---|---|
| Additional investment (£m) | | **0** | **0.94** | **1.79** |
| | | | | |
| Corrective maintenance/repair cost (£m) | | 0.74 | 1.48 | 1.48 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 2.07 | 0.70 | 0.13 |
| | Planned outage 10 h | 0.09 | 0.01 | 0.00 |
| | Planned outage 58 h | 0.52 | 0.08 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 2.9/3.32 | 2.2/2.26 | 1.61/1.61 |
| Benefit (£m) | | **0/0** | **0.7/1.06** | **1.29/1.71** |

**90MW Wind farm**

| Offshore platform (MVA) | | **1x90** | **2x45** | **2x60** |
|---|---|---|---|---|
| Additional investment (£m) | | **0** | **1.05** | **2.02** |
| | | | | |
| Corrective maintenance/repair cost (£m) | | 0.74 | 1.48 | 1.48 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 3.10 | 1.05 | 0.38 |
| | Planned outage 10 h | 0.13 | 0.02 | 0.00 |
| | Planned outage 58 h | 0.77 | 0.12 | 0.01 |
| Total PO 10 h / PO 58 h (£m) | | 3.97/4.61 | 2.55/2.65 | 1.86/1.86 |
| Benefit (£m) | | **0/0** | **1.42/1.96** | **2.12/2.75** |

**120MW Wind farm**

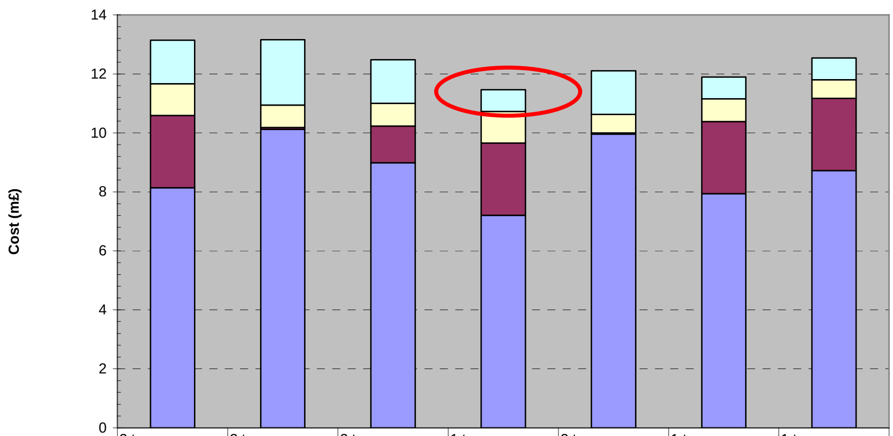
| Offshore platform (MVA) | | **1x120** | **2x60** | **2x90** |
|---|---|---|---|---|
| Additional investment (£m) | | **0** | **1.24** | **2.98** |
| | | | | |
| Corrective maintenance/repair cost (£m) | | 0.74 | 1.48 | 1.48 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 4.13 | 1.40 | 0.26 |
| | Planned outage 10 h | 0.18 | 0.03 | 0.00 |
| | Planned outage 58 h | 1.03 | 0.16 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 5.05/5.73 | 2.91/3.01 | 1.74/1.74 |
| Benefit (£m) | | 0/0 | 2.14/2.71 | 3.31/3.99 |

The conclusion drawn from these results are dependent on the assumptions made for the duration of planned outages. Scenarios for 10hrs and 58hrs per annum are investigated and demonstrate that the point at which a second transformer becomes favourable is with a wind farm of 90MW capacity. The rating of each transformer should be no less than 50% of wind farm capacity.

**ii) Gas turbines**

Analysis investigates the maximum rating of a single transformer at the offshore substation for the connection of gas turbines.

## 60MW Gas Turbine

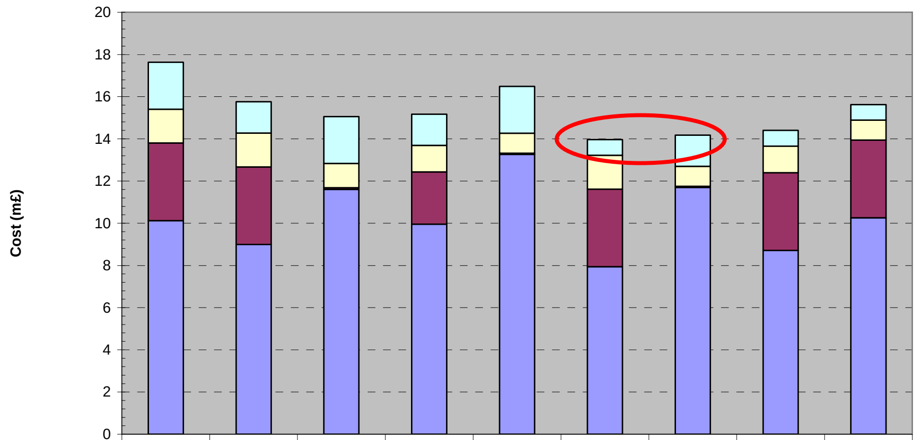



| | 30 MW t. | | 45 MW t. | 60 MW t. | | 90 MW t. | 120 MW t. |
|---|---|---|---|---|---|---|---|
| | 2 t. | 3 t. | 2 t. | 1 t. | 2 t. | 1 t. | 1 t. |
| Mainenance cost (m£) | 1.48 | 2.22 | 1.48 | 0.74 | 1.48 | 0.74 | 0.74 |
| Losses cost (m£) | 1.07 | 0.77 | 0.77 | 1.07 | 0.63 | 0.77 | 0.63 |
| EEC cost (m£) | 2.45 | 0.05 | 1.24 | 2.45 | 0.04 | 2.45 | 2.45 |
| Platform & plant cost (m£) | 8.14 | 10.12 | 8.99 | 7.20 | 9.96 | 7.94 | 8.72 |

Transformer rating (MW) Number of transformers

Above graph demonstrates that for the connection of a 60MW gas turbine, one 60MVA transformer is clearly the most economic.

## 90MW Gas Turbine

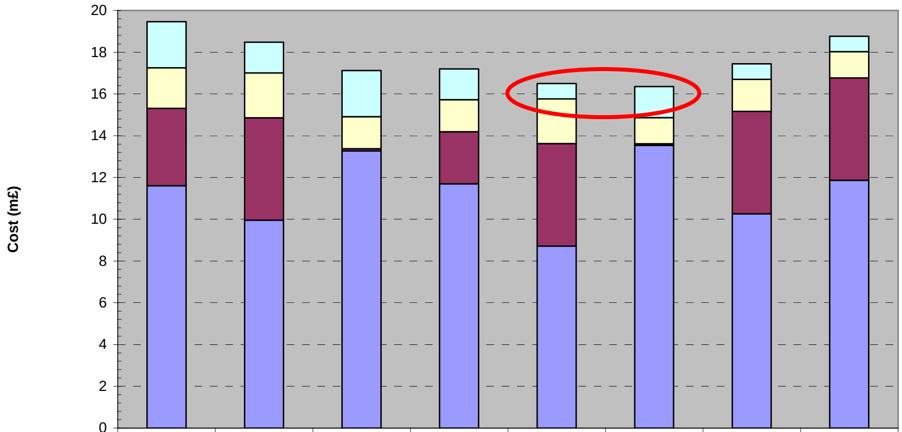



| | 30 MW t. | 45 MW t. | | 60 MW t. | | 90 MW t. | | 120 MW t. | 180 MW t. |
|---|---|---|---|---|---|---|---|---|---|
| | 3 t. | 2 t. | 3 t. | 2 t. | 3 t. | 1 t. | 2 t. | 1 t. | 1 t. |
| Mainenance cost (m£) | 2.22 | 1.48 | 2.22 | 1.48 | 2.22 | 0.74 | 1.48 | 0.74 | 0.74 |
| Losses cost (m£) | 1.61 | 1.61 | 1.15 | 1.26 | 0.95 | 1.61 | 0.95 | 1.26 | 0.95 |
| EEC cost (m£) | 3.68 | 3.68 | 0.08 | 2.47 | 0.05 | 3.68 | 0.05 | 3.68 | 3.68 |
| Platform & plant cost (m£) | 10.12 | 8.99 | 11.61 | 9.96 | 13.27 | 7.94 | 11.70 | 8.72 | 10.26 |

Transformer rating (MW) Number of transformers

Above graph demonstrates that for the connection of a 90MW gas turbine, one 90MVA transformer is marginally the most economic (by ~ £0.2m).

**<u>120MW Gas Turbine</u>**




| | 3 t. 45 MW t. | 2 t. 60 MW t. | 3 t. 60 MW t. | 2 t. 90 MW t. | 1 t. 120 MW t. | 2 t. 120 MW t. | 1 t. 180 MW t. | 1 t. 240 MW t. |
|---|---|---|---|---|---|---|---|---|
| Mainenance cost (m£) | 2.22 | 1.48 | 2.22 | 1.48 | 0.74 | 1.48 | 0.74 | 0.74 |
| Losses cost (m£) | 1.94 | 2.14 | 1.53 | 1.53 | 2.14 | 1.26 | 1.53 | 1.26 |
| EEC cost (m£) | 3.70 | 4.90 | 0.11 | 2.49 | 4.90 | 0.07 | 4.90 | 4.90 |
| Platform & plant cost (m£) | 11.61 | 9.96 | 13.27 | 11.70 | 8.72 | 13.54 | 10.26 | 11.87 |

Transformer rating (MW) | Number of transformers

Above graph demonstrates that for the connection of a 120MW gas turbine, two 120MVA transformers are marginally the most economic (by ~ £0.15m).

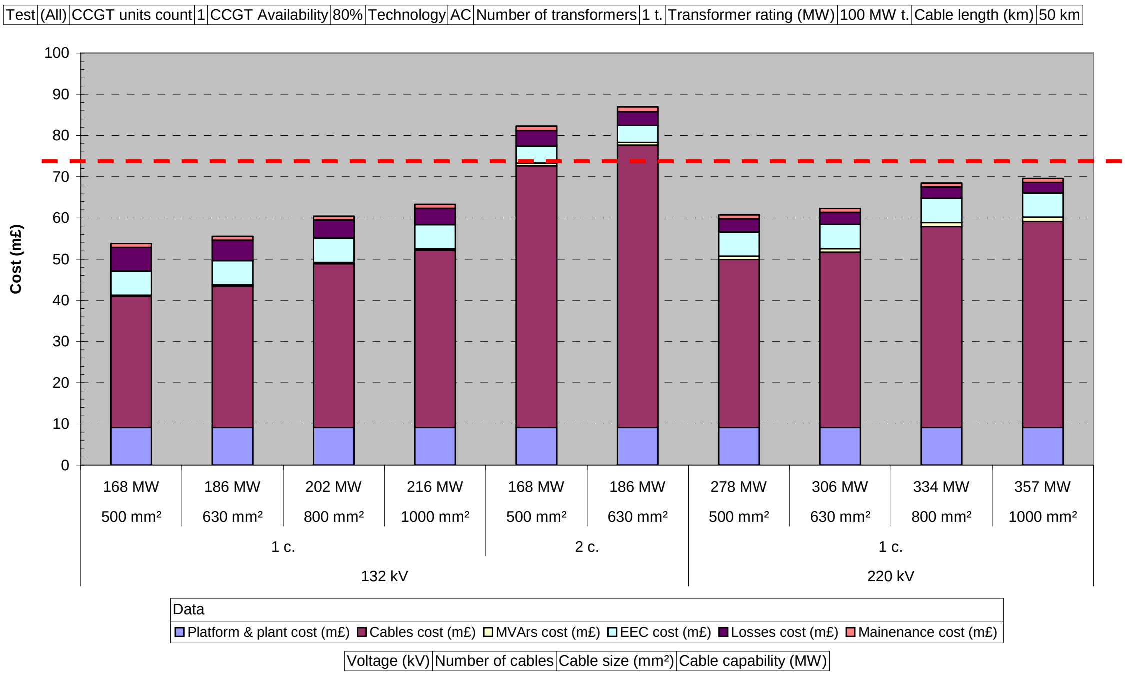
Given the extremely close nature of the results between 90 and 120MW (within 1% of total cost) and the variance that would result from small changes in planned outage duration assumptions, it was concluded that a minimum of 2 transformers, both with a rating of 100% of installed capacity should be installed for gas turbine installations of 90MW or above.

## 2) Offshore Cable

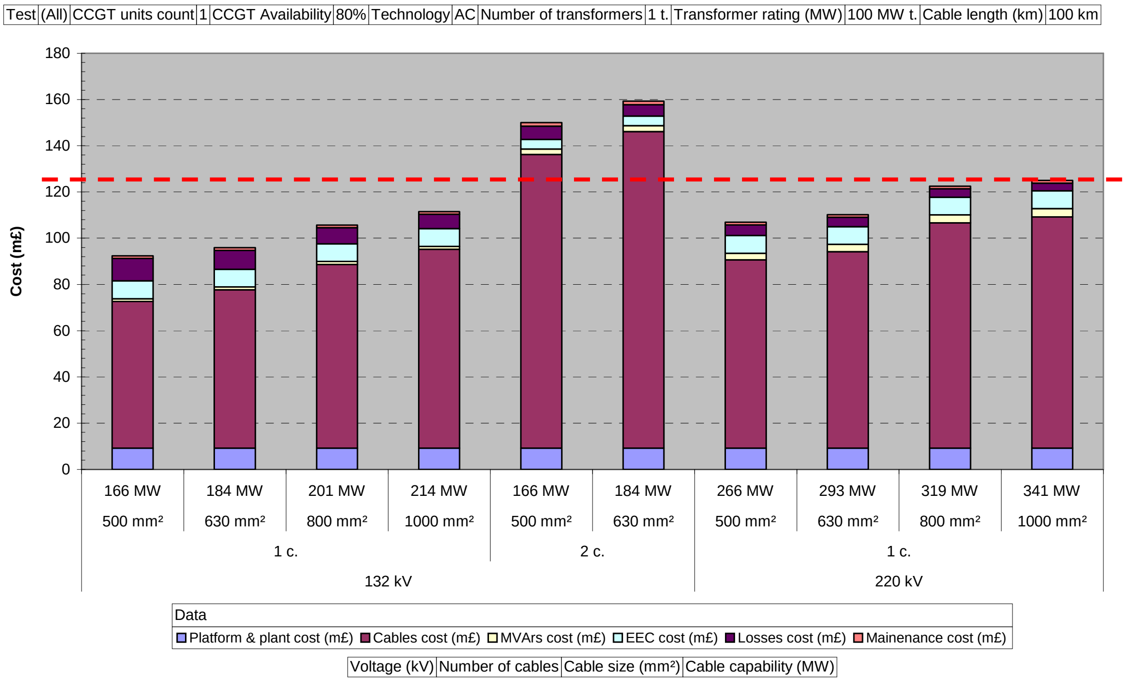
### i) Gas turbines

The design of the sub-sea cable for the connection of offshore wind farms was decided upon in the initial recommendations. The further work aimed to confirm if this was still the case for the connection of a single 100MW or two 100MW gas turbines offshore. Gas turbine availability was assumed to be 80% for this analysis, as per the input data specified in Appendix 2.

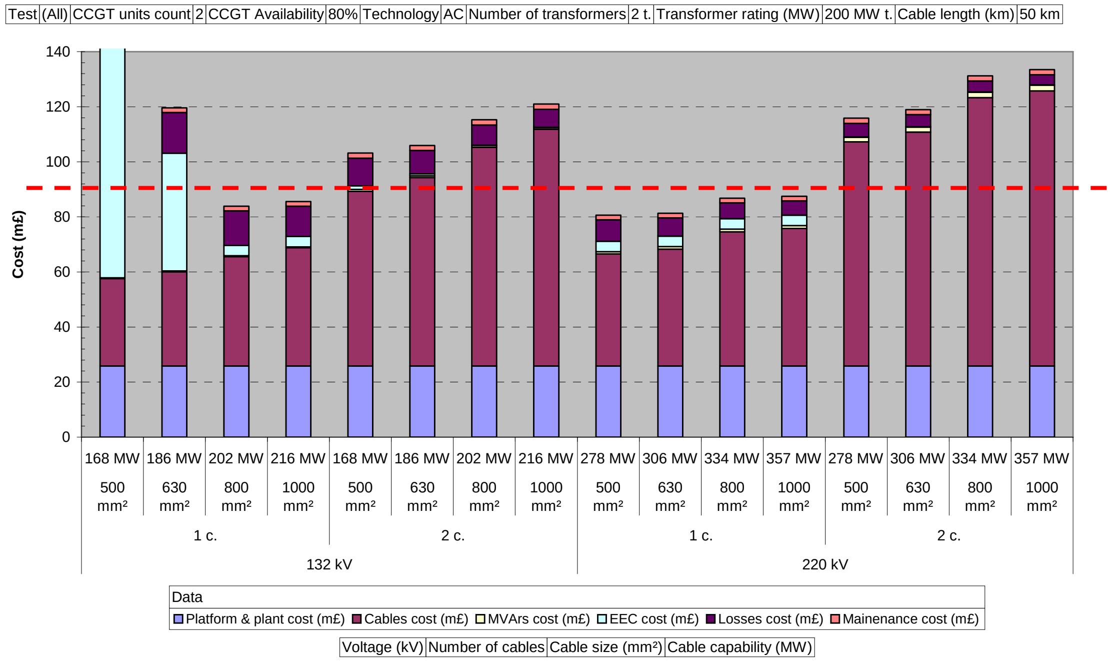
## 1 x 100MW gas turbine – 50km cable



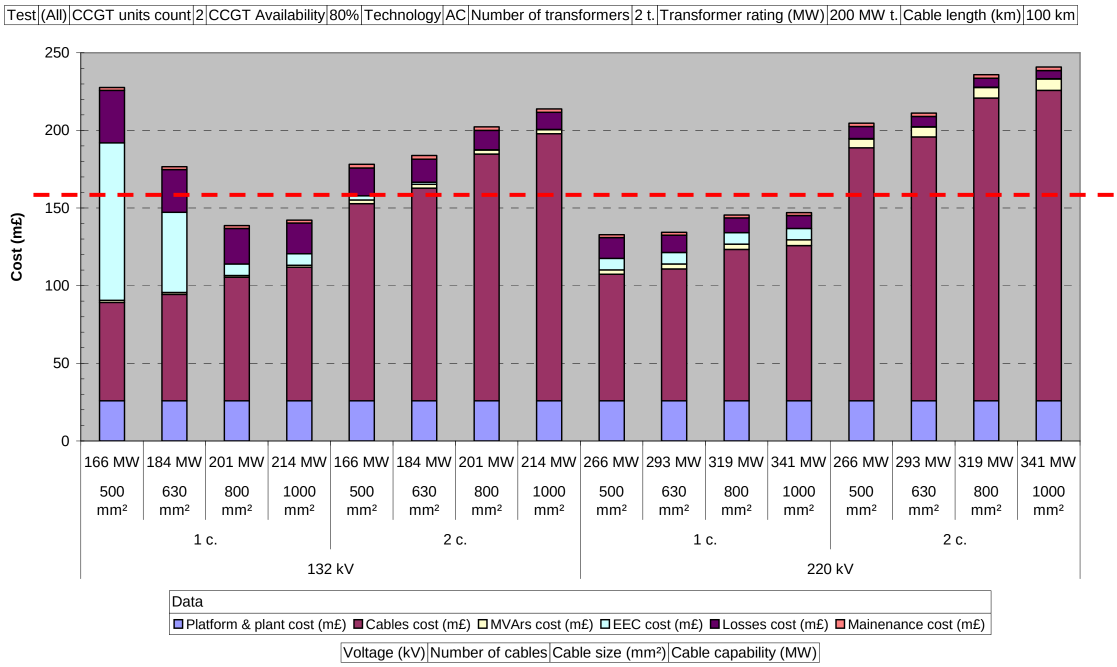

## 1 x 100MW gas turbine – 100km cable



## 2 x 100MW gas turbine – 50km cable




## 2 x 100MW gas turbine – 100km cable




From the above graphs it is clear that the recommendation for a single cable connecting the offshore platform to the shore remains valid for connections of offshore gas turbines.

### 3) Onshore Overhead Line

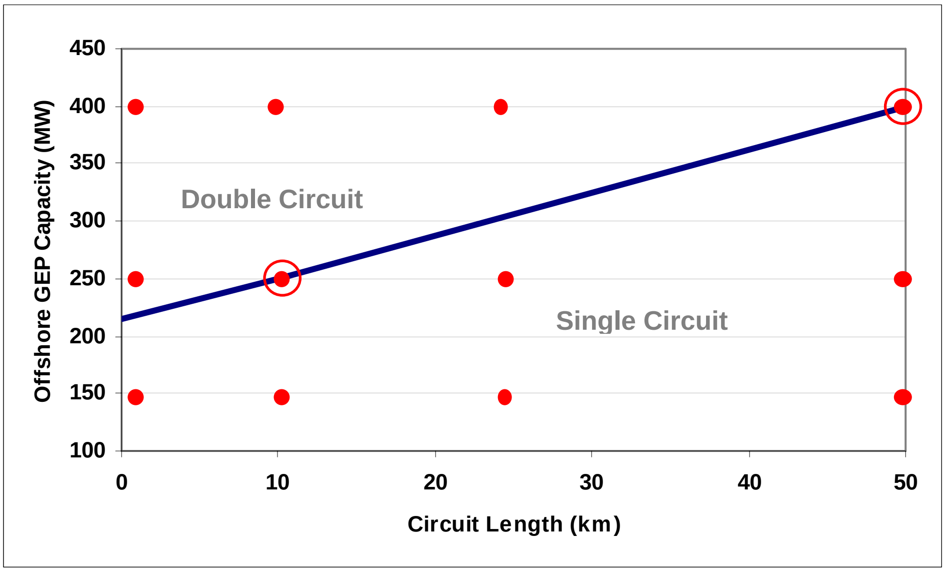
#### i) Wind farms

When a cable from an offshore platform comes onto shore, it is quite possible that an offshore transmission owner may decide to transfer to overhead lines for the remainder of the circuit to the onshore substation, given the large cost saving between overhead lines and cables. To address the minimum security requirements for this scenario the SEDG centre carried out an analysis of various levels of installed wind capacity and overhead line lengths for voltage levels of 132 and 220kV.

The premise of this analysis is similar to that for offshore platform transformer requirements in that it compares the additional capital investment of double or a single circuit versus the benefit achieved in reduced estimated energy curtailed. A summary of the results for 132kV is shown in the table below.

| Length (km) | Wind Farm Capacity (MW) | | |
|---|---|---|---|
| | **150** | **250** | **400** |
| **1** | SC | DC | DC |
| **10** | SC | SC/DC | DC |
| **25** | SC | SC | DC |
| **50** | SC | SC | SC/DC |

This table was used to formulate the line graph appearing in the recommendation which aims to put criteria in place for all line lengths up to the maximum 50km scope by plotting the data points studied and drawing a 'best fit' line through them so that all criteria are met. When the results demonstrate that the minimum requirement is close between single and double circuit (SC/DC), these points fall directly on the line, as shown below.




What follows are the tables with the detailed results that were used to create the summary table.

## 150 MW Wind farm – 1km OHL

| Onshore circuit | | 1SC=150MVA | 1DC=300MVA | 2SC=300MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0** | **0.25** | **0.45** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.01 | 0.00 | 0.00 |
| **Onshore circuits** maintenance cost (£m) | | 0.00 | 0.00 | 0.00 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.00 | 0.00 | 0.00 |
| | Planned outage 10 h | 0.22 | 0.00 | 0.00 |
| | Planned outage 58 h | 1.29 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 0.23/1.3 | 0.01/0.01 | 0.01/0.01 |
| Benefit (£m) | | **0/0** | **0.23/1.29** | **0.23/1.29** |

## 150 MW Wind farm – 10km OHL

| Onshore circuit | | 1SC=150MVA | 1DC=300MVA | 2SC=300MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0** | **2.50** | **4.50** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.08 | 0.04 | 0.04 |
| **Onshore circuits** maintenance cost (£m) | | 0.01 | 0.01 | 0.01 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.01 | 0.00 | 0.00 |
| | Planned outage 10 h | 0.22 | 0.00 | 0.00 |
| | Planned outage 58 h | 1.29 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 0.32/1.39 | 0.05/0.05 | 0.05/0.05 |
| Benefit (£m) | | **0/0** | **0.27/1.34** | **0.27/1.34** |

## 150 MW Wind farm – 25km OHL

| Onshore circuit | | 1SC=150MVA | 1DC=300MVA | 2SC=300MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **6.25** | **11.25** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.21 | 0.10 | 0.10 |
| **Onshore circuits** maintenance cost (£m) | | 0.02 | 0.02 | 0.03 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.03 | 0.01 | 0.00 |
| | Planned outage 10 h | 0.22 | 0.00 | 0.00 |
| | Planned outage 58 h | 1.29 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 0.47/1.54 | 0.13/0.13 | 0.13/0.13 |
| Benefit (£m) | | **0/0** | **0.34/1.41** | **0.34/1.41** |

**150 MW Wind farm – 50km OHL**

| Onshore circuit | | 1SC=150MVA | 1DC=300MVA | 2SC=300MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **12.50** | **22.50** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.42 | 0.21 | 0.21 |
| **Onshore circuits** maintenance cost (£m) | | 0.03 | 0.04 | 0.06 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.06 | 0.01 | 0.00 |
| | Planned outage 10 h | 0.22 | 0.00 | 0.00 |
| | Planned outage 58 h | 1.29 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 0.73/1.79 | 0.26/0.26 | 0.27/0.27 |
| Benefit (£m) | | **0/0** | **0.46/1.53** | **0.46/1.52** |

**250 MW Wind farm – 1km OHL**

| Onshore circuit | | 1SC=250MVA | 1DC=300MVA | 2SC=250MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **0.10** | **0.60** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.02 | 0.01 | 0.01 |
| **Onshore circuits** maintenance cost (£m) | | 0.00 | 0.00 | 0.00 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.00 | 0.00 | 0.00 |
| | Planned outage 10 h | 0.37 | 0.00 | 0.00 |
| | Planned outage 58 h | 2.15 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 0.4/2.17 | 0.01/0.01 | 0.01/0.01 |
| Benefit (£m) | | **0/0** | **0.38/2.16** | **0.38/2.16** |

**250 MW Wind farm – 10km OHL**

| Onshore circuit | | 1SC=250MVA | 1DC=300MVA | 2SC=250MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **1.00** | **6.00** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.23 | 0.12 | 0.12 |
| **Onshore circuits** maintenance cost (£m) | | 0.01 | 0.01 | 0.01 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.02 | 0.01 | 0.00 |
| | Planned outage 10 h | 0.37 | 0.00 | 0.00 |
| | Planned outage 58 h | 2.15 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 0.63/2.4 | 0.13/0.13 | 0.13/0.13 |
| Benefit (£m) | | **0/0** | **0.5/2.27** | **0.5/2.28** |

**250 MW Wind farm – 25km OHL**

| Onshore circuit | | 1SC=250MVA | 1DC=300MVA | 2SC=250MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **2.50** | **15.00** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.58 | 0.29 | 0.29 |
| **Onshore circuits** maintenance cost (£m) | | 0.02 | 0.02 | 0.03 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.05 | 0.02 | 0.00 |
| | Planned outage 10 h | 0.37 | 0.00 | 0.00 |
| | Planned outage 58 h | 2.15 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 1.01/2.79 | 0.33/0.33 | 0.32/0.32 |
| Benefit (£m) | | **0/0** | **0.68/2.46** | **0.69/2.47** |

**250 MW Wind farm – 50km OHL**

| Onshore circuit | | 1SC=250MVA | 1DC=300MVA | 2SC=250MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **5.00** | **30.00** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 1.15 | 0.58 | 0.58 |
| **Onshore circuits** maintenance cost (£m) | | 0.03 | 0.04 | 0.06 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.10 | 0.04 | 0.00 |
| | Planned outage 10 h | 0.37 | 0.00 | 0.00 |
| | Planned outage 58 h | 2.15 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 1.65/3.43 | 0.66/0.66 | 0.64/0.64 |
| Benefit (£m) | | **0/0** | **1/2.77** | **1.01/2.79** |

**400 MW Wind farm – 1km OHL**

| Onshore circuit | | 1SC=400MVA | 1DC=500MVA | 2SC=400MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **0.05** | **0.90** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.06 | 0.03 | 0.03 |
| **Onshore circuits** maintenance cost (£m) | | 0.00 | 0.00 | 0.00 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.00 | 0.00 | 0.00 |
| | Planned outage 10 h | 0.59 | 0.00 | 0.00 |
| | Planned outage 58 h | 3.44 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 0.66/3.5 | 0.03/0.03 | 0.03/0.03 |
| Benefit (£m) | | **0/0** | **0.62/3.47** | **0.62/3.47** |

**400 MW Wind farm – 10km OHL**

| Onshore circuit | | 1SC=400MVA | 1DC=500MVA | 2SC=400MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **0.50** | **9.00** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 0.59 | 0.30 | 0.30 |
| **Onshore circuits** maintenance cost (£m) | | 0.01 | 0.01 | 0.01 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.03 | 0.01 | 0.00 |
| | Planned outage 10 h | 0.59 | 0.00 | 0.00 |
| | Planned outage 58 h | 3.44 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 1.22/4.07 | 0.31/0.31 | 0.31/0.31 |
| Benefit (£m) | | **0/0** | **0.91/3.75** | **0.91/3.76** |

**400 MW Wind farm – 25km OHL**

| Onshore circuit | | 1SC=400MVA | 1DC=500MVA | 2SC=400MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **1.25** | **22.50** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 1.48 | 0.74 | 0.74 |
| **Onshore circuits** maintenance cost (£m) | | 0.02 | 0.02 | 0.03 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.08 | 0.03 | 0.00 |
| | Planned outage 10 h | 0.59 | 0.00 | 0.00 |
| | Planned outage 58 h | 3.44 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 2.16/5.01 | 0.79/0.79 | 0.77/0.77 |
| Benefit (£m) | | **0/0** | **1.37/4.22** | **1.39/4.24** |

**400 MW Wind farm – 50km OHL**

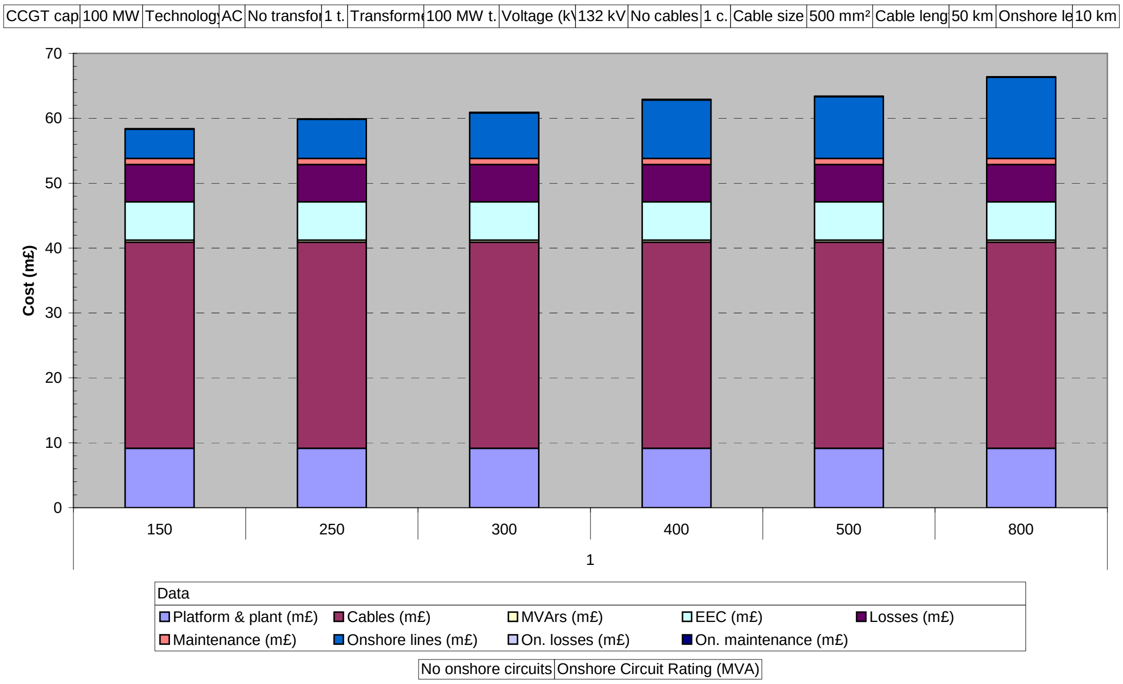
| Onshore circuit | | 1SC=400MVA | 1DC=500MVA | 2SC=400MVA |
|---|---|---|---|---|
| Additional investment (£m) | | **0.00** | **2.50** | **45.00** |
| | | | | |
| Cost of **onshore circuits** losses (£m) | | 2.95 | 1.48 | 1.48 |
| **Onshore circuits** maintenance cost (£m) | | 0.03 | 0.04 | 0.06 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.15 | 0.06 | 0.00 |
| | Planned outage 10 h | 0.59 | 0.00 | 0.00 |
| | Planned outage 58 h | 3.44 | 0.00 | 0.00 |
| Total PO 10 h / PO 58 h (£m) | | 3.73/6.58 | 1.57/1.57 | 1.54/1.54 |
| Benefit (£m) | | **0/0** | **2.16/5** | **2.19/5.04** |

**ii) Gas turbines**

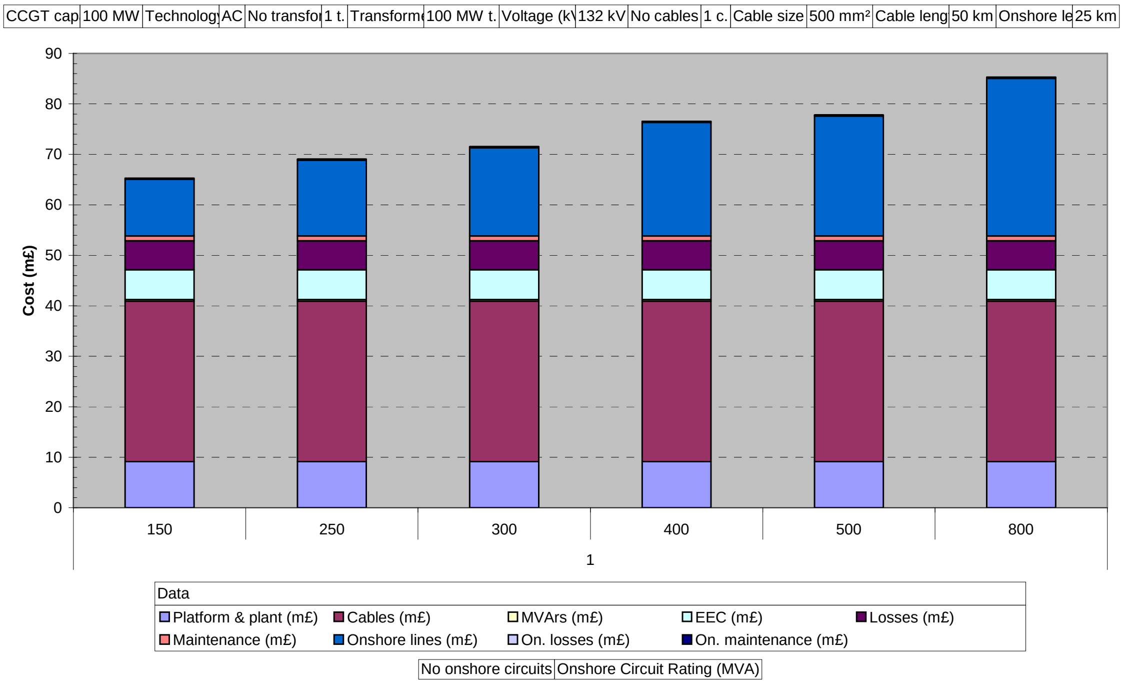
Unlike wind farms comprised of multiple turbines, when a gas turbine is taken out for maintenance there will be no power output. The duration and frequency of this maintenance outage is assumed to be long enough to accommodate an alignment of outages for maintenance of all components of the circuit connecting it to shore. The effect this will have is one of reducing the value estimated energy curtailed. This, coupled with the maximum 200MW scope for gas turbines, has led to the conclusion that an onshore OHL section of the offshore network connecting a gas turbine should as a minimum be a single circuit for all voltages.

The SEDG centre has also carried out an analysis for various conductor sizes over and above the full rating of the turbine, the results of which are shown below. These simply demonstrate the expected result that there is no benefit in increasing the rating of the conductor over and above the installed capacity offshore.

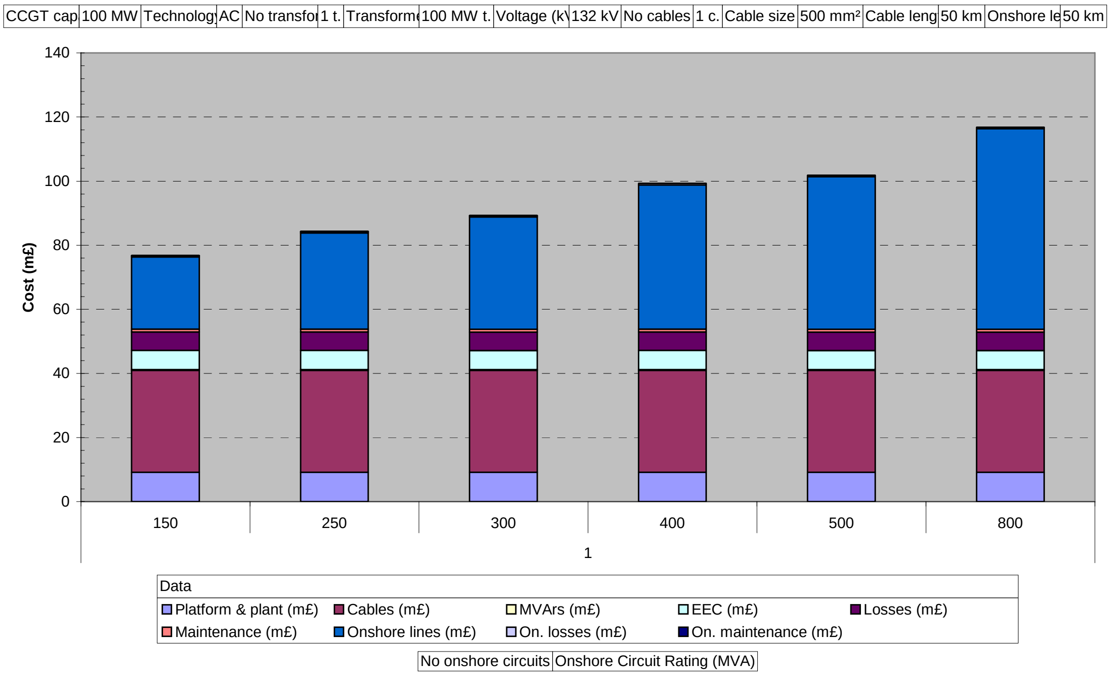
**1 x 100MW gas turbine – 10km OHL**



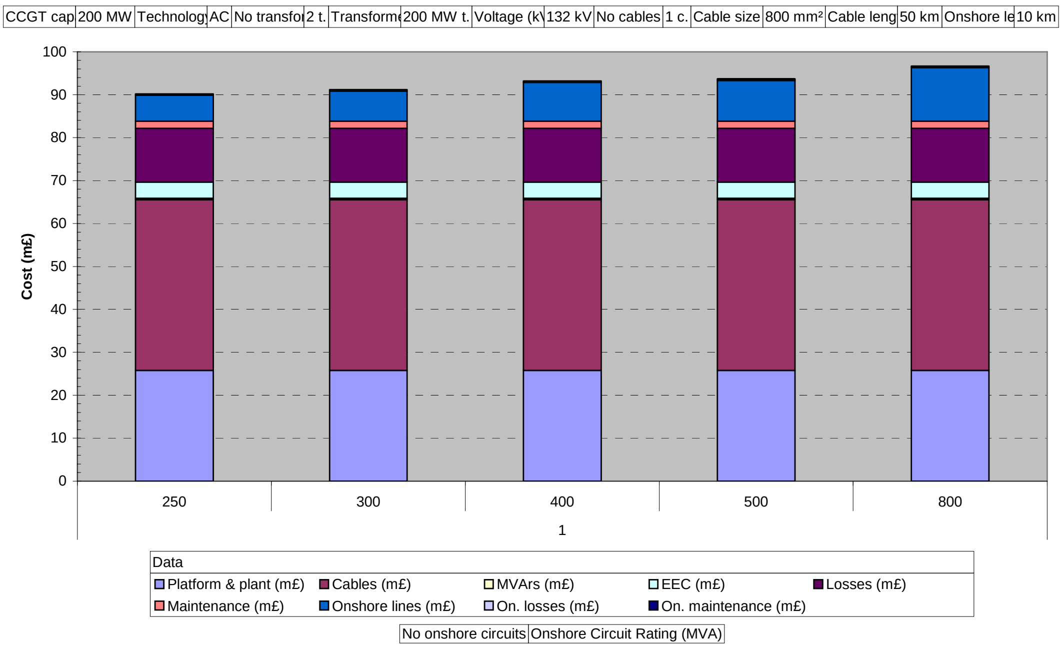

**1 x 100MW gas turbine – 25km OHL**



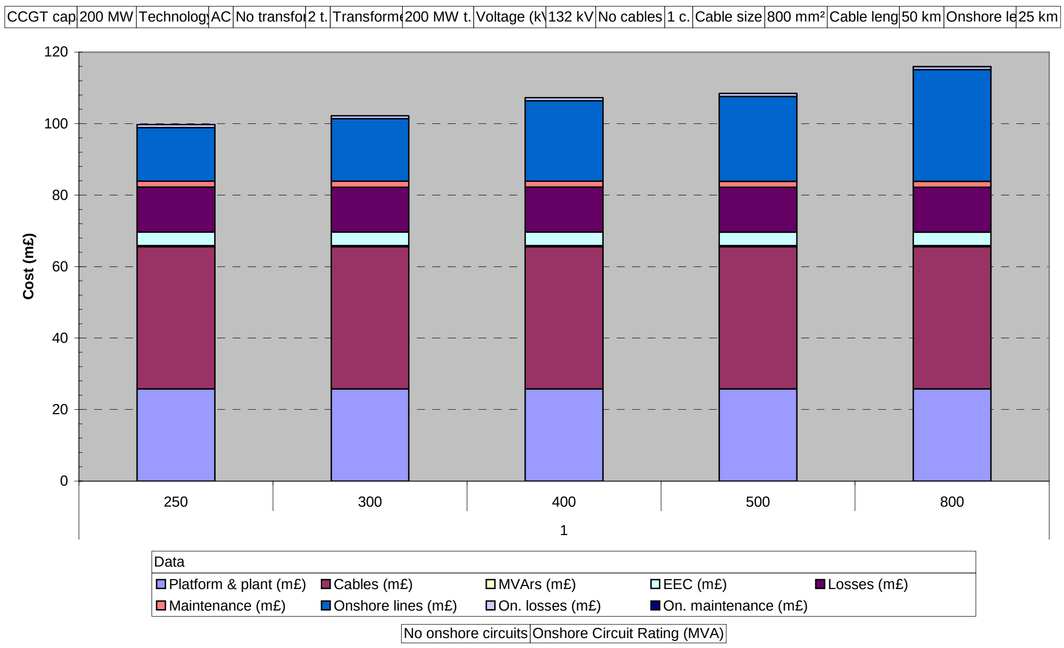
## 1 x 100MW gas turbine – 50km OHL



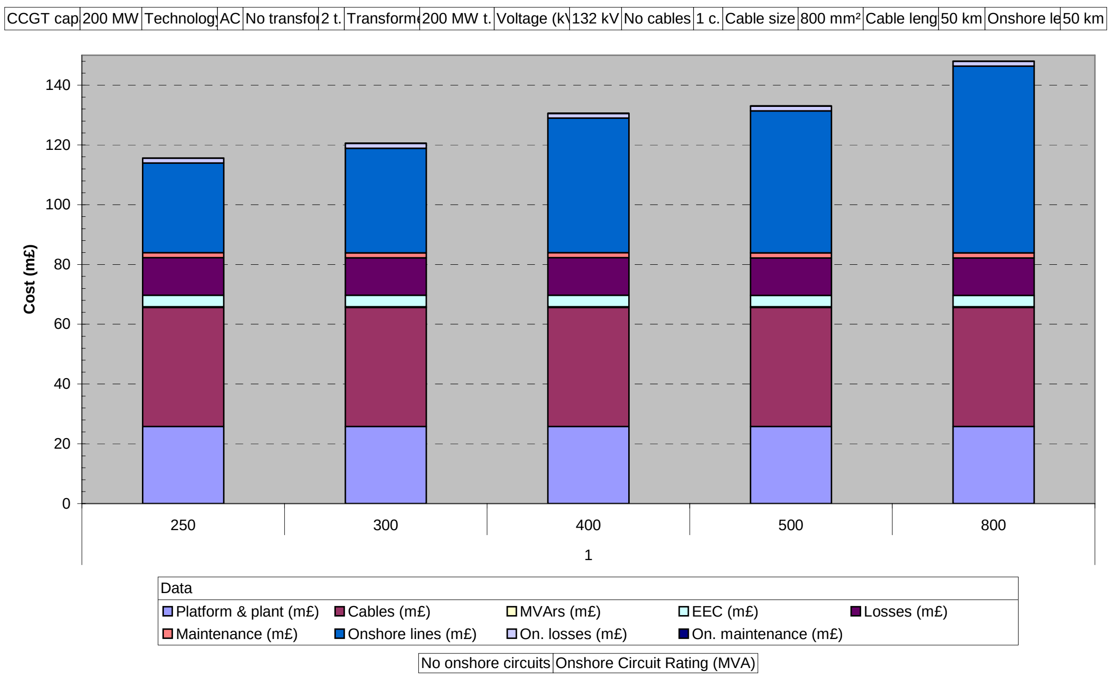

## 2 x 100MW gas turbines – 10km OHL



## 2 x 100MW gas turbines – 25km OHL




## 2 x 100MW gas turbines – 50km OHL




## 4) Onshore Terminus Facilities

### i) Wind Farms

As with the analysis for offshore transformer requirements this SEDG centre study compares additional capital investment cost for 2 transformers as opposed to 1 transformer against the benefit of a reduction in estimated energy curtailed (EEC) cost for forced and planned outages capitalised over 25 years.

**125MW Wind farm**

| | | | |
|---|---|---|---|
| Onshore substation | | **1x120 MVA** | **2x120 MVA** |
| Additional investment (£m) | | **0** | **3.94** |
| | | | |
| Onshore transformers corrective maintenance cost (£m) | | 0.25 | 0.50 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 0.95 | 0.00 |
| | Planned outage 10/58/106/154 h | 0.19/1.07/1.96/2.85 | 0.00 |
| Total (£m) | | 1.47/2.75/4.03/5.31 | 0.5/0.5/0.5/0.5 |
| Benefit (£m) | | **0** | **0.97/2.25/3.53/4.81** |

**180MW Wind farm**

| | | | |
|---|---|---|---|
| Onshore substation | | **1x180 MVA** | **2x120 MVA** |
| Additional investment (£m) | | **0** | **3.76** |
| | | | |
| Onshore transformers corrective maintenance cost (£m) | | 0.25 | 0.50 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 1.37 | 0.15 |
| | Planned outage 10/58/106/154 h | 0.27/1.55/2.83/4.11 | 0.00 |
| Total (£m) | | **1.89/3.17/4.45/5.73** | **0.65/0.65/0.65/0.65** |
| Benefit (£m) | | **0** | **1.24/2.52/3.8/5.08** |

**250MW Wind farm**

| | | | |
|---|---|---|---|
| Onshore substation | | **1x240 MVA** | **2x120 MVA** |
| Additional investment (£m) | | **0** | **3.58** |
| | | | |
| Onshore transformers corrective maintenance cost (£m) | | 0.25 | 0.50 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 1.91 | 0.70 |
| | Planned outage 10/58/106/154 h | 0.37/2.15/3.93/5.71 | 0/0.01/0.02/0.03 |
| Total (£m) | | **2.43/3.71/4.99/6.27** | **1.2/1.21/1.21/1.22** |
| Benefit (£m) | | **0** | **1.23/2.5/3.78/5.05** |

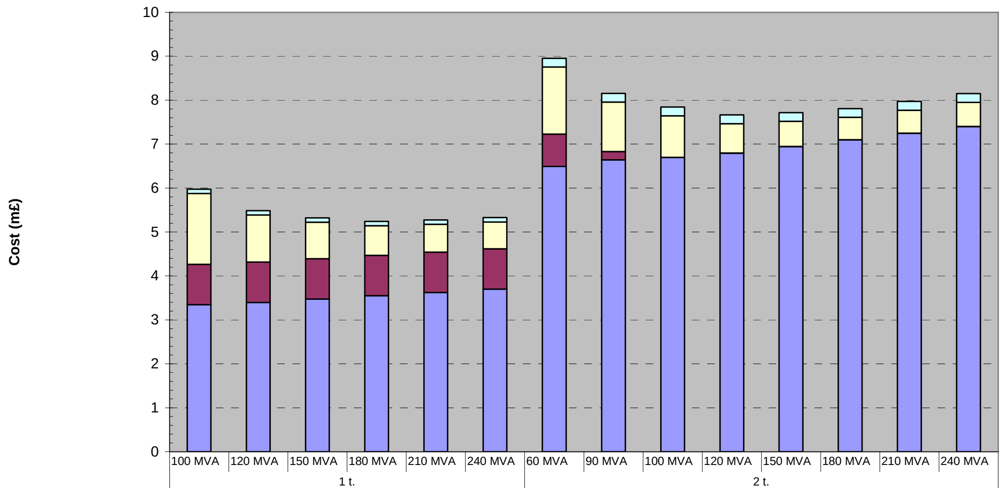
**310MW Wind farm**

| Onshore substation | | 1x300 MVA | 2x180 MVA |
|---|---|---|---|
| Additional investment (£m) | | **0** | **3.76** |
| | | | |
| Onshore transformers corrective maintenance cost (£m) | | 0.25 | 0.50 |
| EEC cost (£m, capitalised over 25 years) | Forced outage | 2.37 | 0.49 |
| | Planned outage 10/58/106/154 h | 0.46/2.66/4.87/7.08 | 0/0.01/0.01/0.02 |
| Total (£m) | | **2.89/4.17/5.45/6.73** | **0.99/0.99/0.99/1** |
| Benefit (£m) | | **0** | **1.9/3.17/4.45/5.73** |

### ii) Gas turbines

The analysis carried out by the SEDG centre for onshore transformer requirements is summarised in the graphs below. This covers the remit of one 100MW and two 100MW gas turbines connected to one platform offshore. An ability to align outages of both gas turbine units for maintenance was assumed. The effect of this assumption is to reduce the value of estimated energy curtailed. An analysis which does not make this assumption for two units connected to the same platform was left as further work, to be carried out at some date in the future, as required.

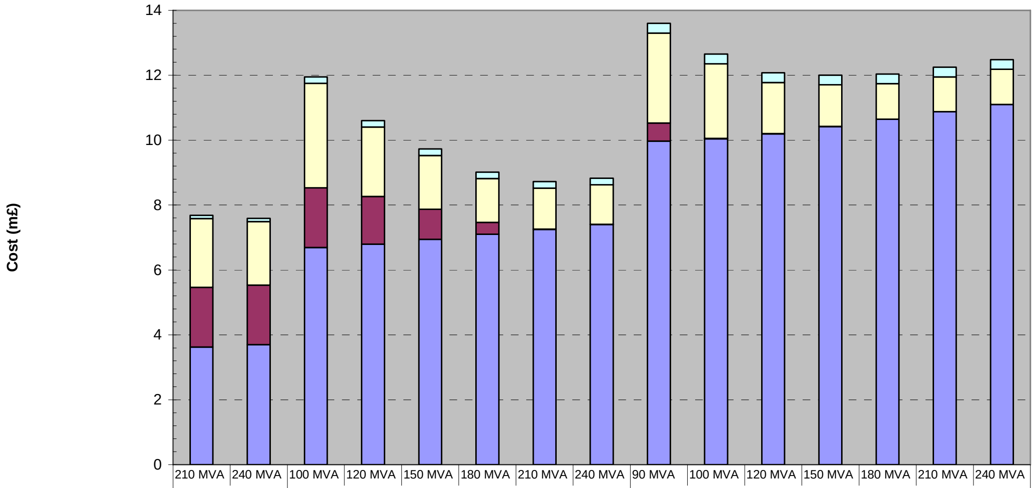
**100MW gas turbine**




| Number of transformers / Transformer rating (MVA) | 1 t. 100 MVA | 1 t. 120 MVA | 1 t. 150 MVA | 1 t. 180 MVA | 1 t. 210 MVA | 1 t. 240 MVA | 2 t. 60 MVA | 2 t. 90 MVA | 2 t. 100 MVA | 2 t. 120 MVA | 2 t. 150 MVA | 2 t. 180 MVA | 2 t. 210 MVA | 2 t. 240 MVA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mainenance cost (m£) | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 |
| Losses cost (m£) | 1.61 | 1.07 | 0.83 | 0.67 | 0.63 | 0.61 | 1.53 | 1.12 | 0.95 | 0.67 | 0.57 | 0.51 | 0.52 | 0.55 |
| EEC cost (m£) | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.92 | 0.74 | 0.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transformers cost (m£) | 3.35 | 3.40 | 3.47 | 3.55 | 3.62 | 3.70 | 6.49 | 6.64 | 6.69 | 6.80 | 6.95 | 7.10 | 7.25 | 7.40 |

Number of transformers | Transformer rating (MVA)

## 2 x 100MW gas turbines




| | 1 t. | | 2 t. | | | | | | 3 t. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 210 MVA | 240 MVA | 100 MVA | 120 MVA | 150 MVA | 180 MVA | 210 MVA | 240 MVA | 90 MVA | 100 MVA | 120 MVA | 150 MVA | 180 MVA | 210 MVA | 240 MVA |
| Mainenance cost (m£) | 0.10 | 0.10 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Losses cost (m£) | 2.12 | 1.96 | 3.22 | 2.14 | 1.66 | 1.35 | 1.27 | 1.22 | 2.78 | 2.30 | 1.57 | 1.28 | 1.09 | 1.07 | 1.08 |
| EEC cost (m£) | 1.84 | 1.84 | 1.84 | 1.47 | 0.92 | 0.37 | 0.01 | 0.01 | 0.56 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| Transformers cost (m£) | 3.62 | 3.70 | 6.69 | 6.80 | 6.95 | 7.10 | 7.25 | 7.40 | 9.97 | 10.04 | 10.19 | 10.42 | 10.65 | 10.87 | 11.10 |

Number of transformers | Transformer rating (MVA)

The above graphs show that for a maximum of 200MW of gas turbines installed on the same offshore platform, that the minimum requirement is a single transformer with a rating of 100% installed capacity.  Any benefit arising from decreasing losses due to investment above minimum criteria would have to be justified by further cost benefit analysis.

## 5) Substation Configuration and Switching Arrangements

The following highlights each of the areas noted in chapter 2 of the existing GBSQSS which relate to the switching arrangements that are to be modified for offshore platforms, in particular the level of generation that can be lost for switchgear and / or busbar faults. A commentary is supplied for each point to justify conclusions:

*2.6.2 following the planned outage of any single section of busbar or mesh corner, no loss of power infeed shall occur.*

- Existing wind farm design indicates that at 33kV the substations proposed to be installed are of single busbar design, therefore for the planned outage of any single section of busbar a loss of power infeed will occur, resulting in a need for cost benefit analysis to justify single versus double busbar substation design.

- The cost differential between installing a typical 5 bay single busbar substation and a double busbar substation is £125k at 33kV (£25 k per bay), £400k at 132kV (£80k per bay) and £800k at 220kV (£160k per bay). Assuming a 5 day maintenance requirement every 5 years (i.e. 24 hours per annum) for a 150 MW connection onto a single busbar would lead to energy curtailed annually of £56k, £562k for comparison with capital investment for a wind farm.

- Therefore, the requirement for a double busbar substation design as a minimum is justified in the majority of cases for 33kV and 132kV. As it is anticipated that generation connected to 220kV substations will be of a much larger size in terms output than 150 MW, the resulting increase in energy output will certainly justify a double busbar solution at this voltage level.

- The estimated cost of energy curtailed for fault outages has a minimal effect on the total estimated energy curtailed as its duration is approximately 80 times less than the time out of service for planned outages. This still holds, even given the reduced load factor of generation that could be assumed during maintenance periods.

- In the case of a gas turbine it is expected that it's maintenance would be scheduled at the same time as generation maintenance, therefore a single busbar design on the LV could be justified. This would equally apply to the HV busbars if it was the only generator connected. Where there is more than one gas turbine connecting, the busbar outages could not necessarily be aligned. Therefore, the curtailed energy would be £108k annually, £1.1m for comparison with the cost of capital. Therefore a double busbar substation at the point of common coupling between the two turbines can be justified in this case.

*2.6.3 following a fault outage of any single generation circuit or single section of busbar or mesh corner, the loss of power infeed shall not exceed the normal infeed loss risk.*

- Generation circuits are outside the scope of the offshore SQSS.

- Based on the assumption that all offshore substations will be of a gas insulated switchgear (GIS) construction, only reliability figures for GIS have been taken into account.

- The failure rate of cables is 0.08 per 100km. Therefore for a single cable connection (assuming a maximum length of 50km) the failure rate would be 0.04 per annum. The failure rate for GIS switchgear is 0.0033 per annum per bay, which is a factor of 10 less than that of cables. Therefore, on the same justification as that for a single cable connection, it is recommended to increase this limit for offshore substations to 1320MW for the loss of a single section of busbar of mesh corner.