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REPORT

OFGEM

TECHNICAL ASSESSMENT OF THE LINCS OFFSHORE WIND FARM TRANSMISSION ASSET

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LIST OF ABBREVIATIONS

AIS	Air Insulated Switchgear
BS	British Standard
BSP	Bulk Supply Point (Applies to DNO Network)
CDM	Construction Design and Management (Regulations)
CNE	Central Networks East (DNO)
DDR	Developer Data Room
DNO	Distribution Network Operator
DTS	Distributed Temperature Sensing
ENA	Electricity Networks Association
GIS	Gas Insulated Switchgear
GSP	Grid Supply Point (Applies to TSO/DNO Interface)
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IEC	International Electrotechnical Commission
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NETSSQSS	National Electricity Transmission System Security and Quality of Supply Standard
NGET	National Grid Electricity Transmission
OFSS	Offshore Substation
ONSS	Onshore Substation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SVC	Static VAR Compensator
TSO	Transmission System Operator
UKPN	UK Power Networks (DNO – previously known as EDF)
YEDL	Yorkshire Electricity Distribution Ltd (DNO)

1 EXECUTIVE SUMMARY

1.1 The purpose of this report is to review the design and costs of the Lincs transmission assets that will transfer to the OFTO and to provide an assessment of whether these can be considered to be ‘economic and efficient’.

1.2 It is intended that the report will be used by OFGEM to establish the indicative value for the Lincs transmission assets to be used in the Invitation To Tender (ITT) stage of the tender process for tender round two ‘Tranche A’ projects.

1.3 The report is based on a review of the data provided in the Developer Data Room (DDR) access to which has been provided by OFGEM, supplemented by an additional meeting with the developer, Centrica. A list of the principal documents reviewed is included in the reference section at the end of this report.

1.4 The principal areas considered in this report are the overall design philosophy, the rated capacity and electrical losses associated with the OFTO assets (i.e. export cables and onshore/offshore transformers) and the costs of each major element.

1.5 Although the Lincs offshore wind farm has been developed as a standalone asset certain aspects of Centrica’s development process has recognised the future development of the nearby Docking Shoal and Race Bank developments. In particular common offshore cable routes and landfalls have been considered together with a 400kV grid connection point capable of accepting all three developments.

1.6 It is noted that Centrica have applied the concept of whole life costing to the development of the Lincs project.

Whole life costing, also sometimes called life-cycle costing or through life costing, is a business process whereby the whole-life costs are considered in making business decisions on whether or not and on how to proceed with the construction and operation of an asset. Whole-life costs are the costs of acquiring (including consultancy, design and construction) and the costs of operating, maintaining and decommissioning – the total ownership costs [26][1]

1.7 This approach can lead to higher initial capital costs, but these are balanced by reduced operating costs over the life of the project and improved energy transfer during outage conditions.

1.8 The provision of two (2) 240MVA transformers at the Offshore Substation is justified on the basis of assumed MTBF/ MTTR figures and incremental capital cost of the equipment.

1.9 Whole life costing has also been applied to the 132kV export cables. Given that the estimated MTTR figures are less than those assumed for the transformers and the capital cost of the cables is significantly higher than the transformers, there is no economic justification to increase the export cable capacity (see Appendix A and B). GLND also notes that a DTS system is provided to monitor cable temperatures. This will allow production to be maximised during a single cable outage.

[1] [26] Whole-life costing and cost management: Achieving Excellence in Construction Procurement Guide. Office of Government Commerce (OGC) 2007

1.10 The transformer capacity provided at the onshore substation follows the same philosophy as adopted at the offshore substation, although there are no specific studies available in the DDR. GLND would expect MTTR figures for the onshore transformer to be less than for the offshore transformers, although these will be influenced by lack of manufacturing/repair capacity for 400kV transformers and transport restrictions affecting the Walpole substation site. GLND notes that the nominal nameplate rating of 300MVA for each onshore transformer allows for supplies to the reactive compensation equipment as well as the 250MW generation capacity.

1.11 The adoption of a 400kV connection introduces significant additional costs (transformers, 400kV switchgear and connections etc) not required for a 132kV connection. Only 3 of the 11 OFTO projects used by OFGEM to establish their benchmark costs have a 400kV connection so it is to be expected that the cost of this element is somewhat higher than the norm.

1.12 Analysis of the OFGEM benchmark costs for the Onshore Sub-Station Other Costs indicates that the 'normalised' values, i.e. the total figures after being adjusted for the additional technical requirements identified herein, are higher than the comparative values for similar projects given the information available. Although competitively tendered these particular costs, even after review and significant downward adjustment, are higher than the benchmark figure by a range of between £9.5 million and £12 million. In conclusion GLND notes that:

- The adoption of a 400kV point of connection has been influenced by consideration of the future Docking Shoal and Race Bank developments and has resulted in increased costs.
- The use of a common export cable route for Lincs, Docking Shoal and Race Bank assists in addressing environmental and planning concerns for all three projects. The time and effort spent at this stage will potentially reduce future costs for Docking Shoal and Race Bank.
- The use of whole life costing is an acceptable technique and justifies the provision of additional transformer capacity at Lincs
- The OFGEM median costs do not reflect the use of 400kV connections at the onshore substation
- The project costs for most components are generally within an acceptable range. However, GLND recommends that the onshore sub-station other costs be reviewed with the developer to fully understand the basis for the cost difference and that the costs be closely monitored during the remainder of the project.
- The developer should be requested to advise if the harmonic filters currently proposed are suitable for the duty as defined. [29][2]

[2] [29] Data Room 2.2 Appendix OF5 Site Specific Technical Conditions

2 INTRODUCTION

2.1 OBJECTIVE

2.1.1 OFGEM have requested GL Noble Denton (GLND) to provide a technical review of the electrical transmission assets of the Lincs Offshore Wind Farm Project (hereafter The Project) that will transfer to the OFTO.

2.1.2 The scope of work is set out in [1][3] and is outlined as follows:

a. Confirm compliance with industry codes and standards

b. Review design philosophy, with particular reference to:

- design options that were considered and evaluated and the reasoning behind the design option that was chosen.
- any cost/benefit analysis developed to support the chosen design option
- ratings of the transmission assets i.e. cables and transformers
- rationale for the level of redundancy built into the project's design
- chosen site and location of the onshore connection
- voltage connection

c. Review costs including outliers

2.1.3 It is intended that the report will be used by OFGEM to establish the indicative value for the Lincs transmission assets to be used in the Invitation-To-Tender (ITT) stage of the tender process.

[3] [1] OFGEM Contract - Technical Advisers for TR2 - Task Order #7

2.1.4 In preparing the report GLND has considered the following:

- Connection Options
- Compliance with Industry Codes and Standards
- Electrical Design Philosophy

  This includes analysis of factors such as

  - The operational performance requirements
  - Lifetime Costs
  - System availability,
  - The maximum capacity ratings of the transmission assets i.e. cables and transformers
  - The rationale for the level of redundancy built into the project's design
  - The chosen site and location of the onshore connection
  - Voltage of connection

- Comparison with other OFTO projects.
- Costs review including outliers

2.2 The report is based on a review of the data provided in the Developer Data Room (DDR) provided by OFGEM, supplemented by a meeting with the developer, Centrica.

2.3 OVERALL DESCRIPTION OF TRANSMISSION ASSETS

2.3.1 Lincs is a 250MW (nominal) offshore wind farm and is located approximately 8km off the Lincolnshire coast near Skegness adjacent to the existing operational Lynn and Inner Dowsing offshore wind farms.

2.3.2 The Project is comprised of 75 wind turbines, rated at 3.6MW each and manufactured by Siemens giving a total installed capacity of 270MW. GLND understands that this total includes 6 WTG's originally consented for the Lynn and Inner Dowsing (LID) project but not initially installed due to grid capacity limitations. These are now being installed within the LID area but will connect to the Lincs transmission system [24]. [redacted]

2.3.3 The transmission assets are illustrated by the overall single line diagram shown in Figure 2.1 on the following page.

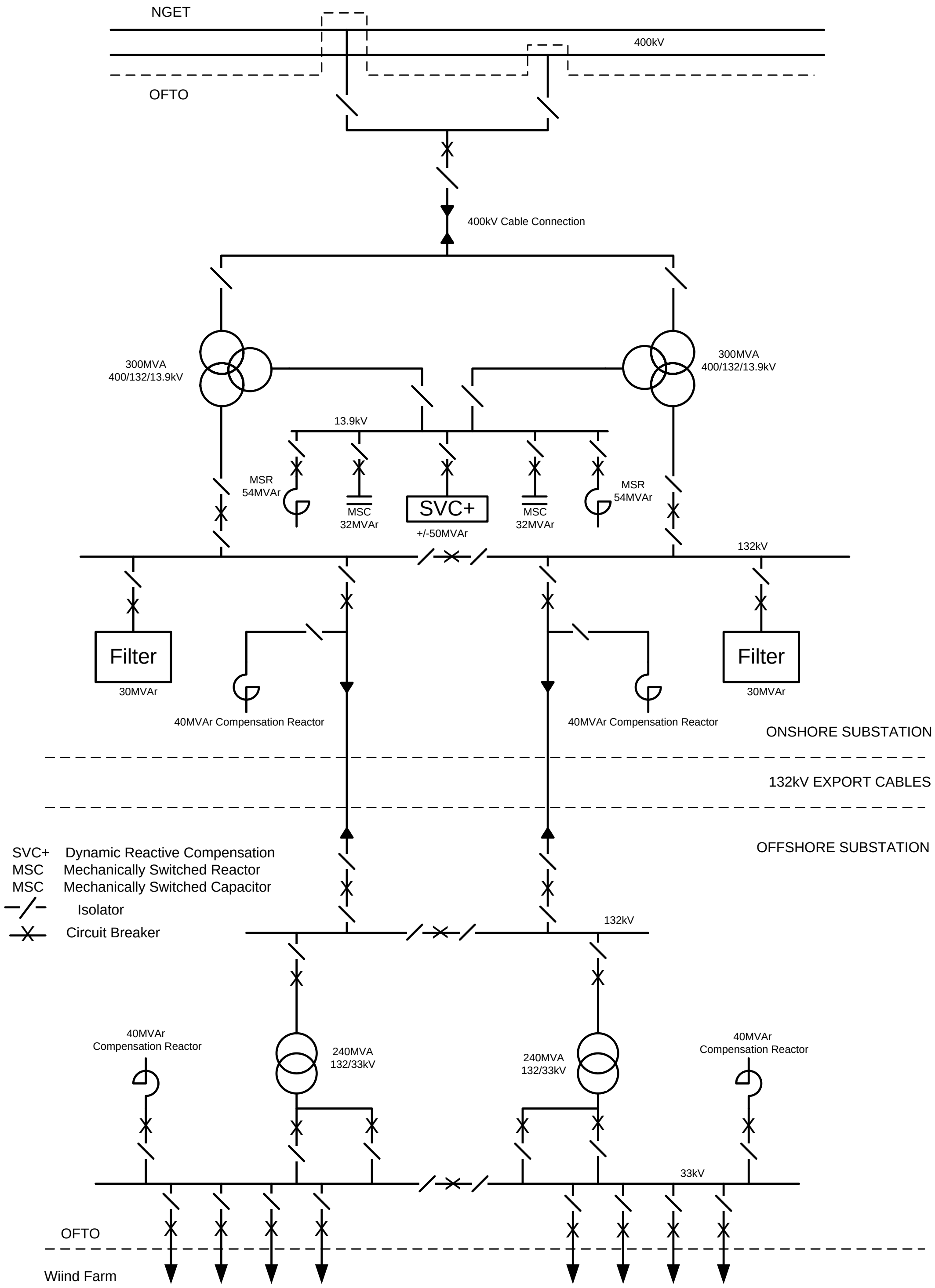


Figure 2.1 Overall Single Line Diagram for Lincs (Derived from Siemens Drawing [2][4])

[4] [2] "Operational Diagram – Lincs Wind Farm", Siemens Drg G855221-X0015-CA-S001, rev. D, 04/03/2010

2.3.4 The transmission assets comprise all equipment installed between the collection system cable connection to the 33kV bus-bars of the offshore substation (OFSS) and the connection at the NGET 400kV bus-bars at the onshore substation (ONSS).

2.3.5 The principal OFTO electrical assets are shown in Figure 2.1 and include the following items

- Offshore electrical substation (OFSS)

  33kV switchboard serving the WTG circuits
  Reactors for 132kV cable compensation
  2 x 240MVA, 132/33kV Transformers
  132kV GIS switchgear
- Export cable system, including

  2 x 3 core 630mm^2 copper conductor 132kV subsea AC cables incorporating integral fibre optic cable
  2 x 3 x 1 core 800mm^2 copper conductor 132kV onshore AC cables
- Onshore electrical substation (ONSS)

  132kV switchgear
  2 x 300MVA, 132/400/13kV three winding transformers
  400kV switchgear
  Reactors for 132kV cable compensation
  Harmonic filters
  Dynamic and static reactive compensation equipment required for grid code compliance

2.3.6 In addition to these principal assets other items are identified in the cost schedule [11][5].

2.4 OVERVIEW OF TENDER ROUND 2 OFTO PROJECTS

2.4.1 In compiling this report GLND has drawn comparison with other OFTO projects currently included in the transitional Round 1 and ‘Tranche 2A’ projects. GLND understands that OFGEM have used cost data from these projects to calculate benchmark costs for the transmission assets of each project.

2.4.2 The projects considered are listed in Table 2.1 on the following page.

[5] [11] LINCS Cost Report Template 2011-01-19

Table 2.1 Transitional Round 1 and Tranche 2A OFTO Projects

Project	Capacity(MW)	Tender Round
Robin Rigg	180	1
Sheringham	315	1
Lincs	270	2
Greater Gabbard	504	1
London Array 1	630	2
Thanet	300	1
Walney I	183.6	1
Walney II	183.6	
Gwynt y Mor	576	2
Ormonde	150	1
Gunfleet Sands	172	1

3 CONNECTION OPTIONS

3.1 LOCATION AND OPTIONS

In establishing the connection point for the Lincs Offshore Wind Farm it is clear from the terms of reference of the principal studies reviewed [3][6], [4][7], that Centrica have also considered the requirements for their nearby Docking Shoal and Race Bank developments. The location of these developments and potential grid connection points are shown in Figure 3.1 below. The associated connection studies are reviewed in Section 3.2.

Centrica's existing wind farms at Lynn and Inner Dowsing are just to the west of Lincs (see Figure 3.10) and they effectively fill up the 132kV circuit at Skegness which would otherwise have been the natural connection choice for Lincs.

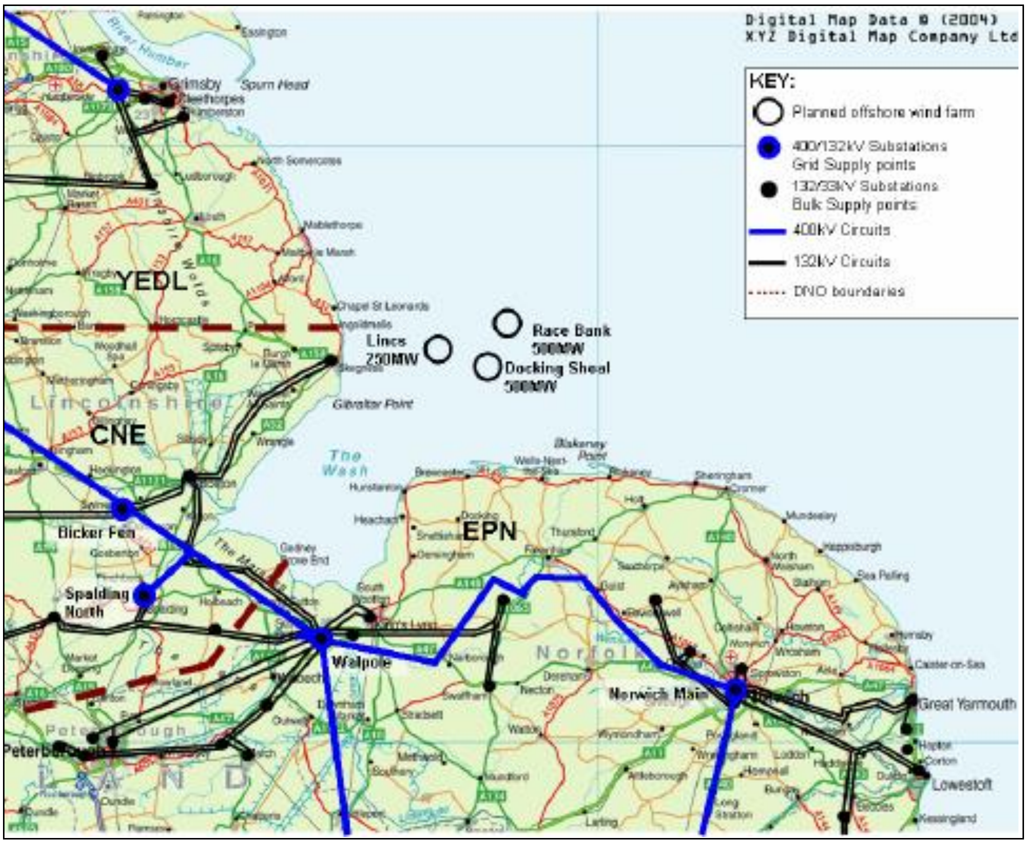


Figure 3.1 Transmission and Distribution Network

[6] [3] Econnect, "Review of Connection Options for Lincs, Docking Shoal and Race Bank Wind Farms", doc. 1965, rev. 1, 31/08/2007.

[7] [4] Mott MacDondald, "Electrical Construction Study – Centrica R2 Offshore Wind Farms Electrical System Design Studies", doc. JM/MB/222669/001, rev. C, 29/03/2006

3.2 CONNECTION STUDIES

3.2.1 The Connection Point to the National Grid is located at the Walpole substation, rated at 400kV. The connection is achieved through the installation of 132kV HVAC cables through the Wash to a landfall at Guys Head.

3.2.2 This final connection point has been chosen among 11 other connection options that were identified by various studies commissioned by the Developer, during the conceptual phase of the Project.

3.2.3 In particular the report by Econnect [3][8] considers the following options for grid connection, covering 8 points of connection with either 1, 2 or 3 associated cable route options:

Options 1 and 2	Bicker Fen Grid Supply Point (GSP)
Options 3 and 4	Skegness Bulk Supply Point (BSP) (CNE)
Options 5, 9 & 11	Walpole GSP (UKPN)
Option 6	Grimsby West GSP (YEDL)
Option 7	Sall BSP (UKPN)
Option 8	Kings Lynn BSP (UKPN)
Option 10	New 400kV GSP near Walpole (NGET)
Option 11	Alternative connection option: Spalding North GSP (CN)

3.2.4 The Econnect report considers issues raised in [17][9] as well as in [5][10] and [6][11]. The issues addressed include:

- Cable routes and total cable length;
- Connection point voltage level;
- Transmission infrastructure electrical losses;
- Infrastructure requirements; grid upgrade or substation construction and related timelines.

[8] [3] Econnect, "Review of Connection Options for Lincs, Docking Shoal and Race Bank Wind Farms", doc. 1965, rev. 1, 31/08/2007.
[9] [17] Mott MacDondald, "Electrical Construction Study – Centrica R2 Offshore Wind Farms Construction Parameters for Electrical Study", doc. JM/MB/222669/002, rev. C, 29/03/2006
[10] [5] "Cable Route Alternatives Study for Lincs, Race Bank and Docking Shoal Offshore Wind Farm Developments, RPS Energy, 22 May 2007 (Route Selection Survey, RSS)."
[11] [6] "Lincs Offshore Wind Farm: Environmental Statement, Vols 1 and 2, January 2007 (Lincs ES)."

3.2.5 GLND notes that the report considers the combined connection needs of the Lincs wind farm and two other projects: Docking Shoal and Race Bank amounting to 1.25GW of total installed power even though the three wind farms have been considered as totally independent and each requiring a dedicated connection.

3.2.6 The report concludes that the most suitable option is a connection to Walpole GSP through 48km of subsea cable to Guys Head, in the Great Wash, and 12 km of onshore cable to Walpole (Option 5). The principal reasons behind this conclusion are:

- There is sufficient capacity available at the Walpole busbars to accommodate up to 1.3GW of generation;
- Power losses are expected to be acceptable (i.e. below 2.5%) for each of the three projects; and
- The cable route selected is the most direct to Walpole substation whilst taking into consideration highly sensitive features within the Wash (see Section 3.3).

3.2.7 Of the other options considered using Walpole, Option 9 was rejected due to the excessive cable lengths required and Option 11 was rejected due to the requirement for directional drilling under the beach at the land fall.

3.2.8 The options considered in [3][12] are shown in Figures 3.2 to 3.9 on the following pages.

[12] [3] Econnect, "Review of Connection Options for Lincs, Docking Shoal and Race Bank Wind Farms", doc. 1965, rev. 1, 31/08/2007.

Figure 3.2 Options 1 & 2 - Bicker Fen GSP

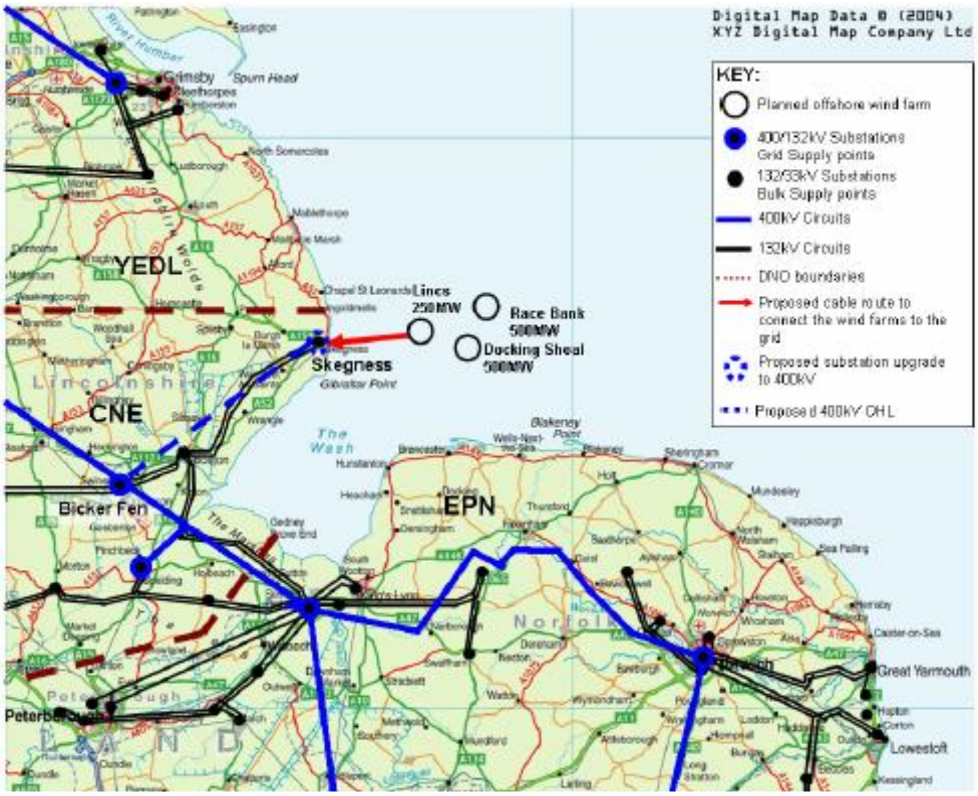


Figure 3.3 Options 3 & 4 - Skegness BSP

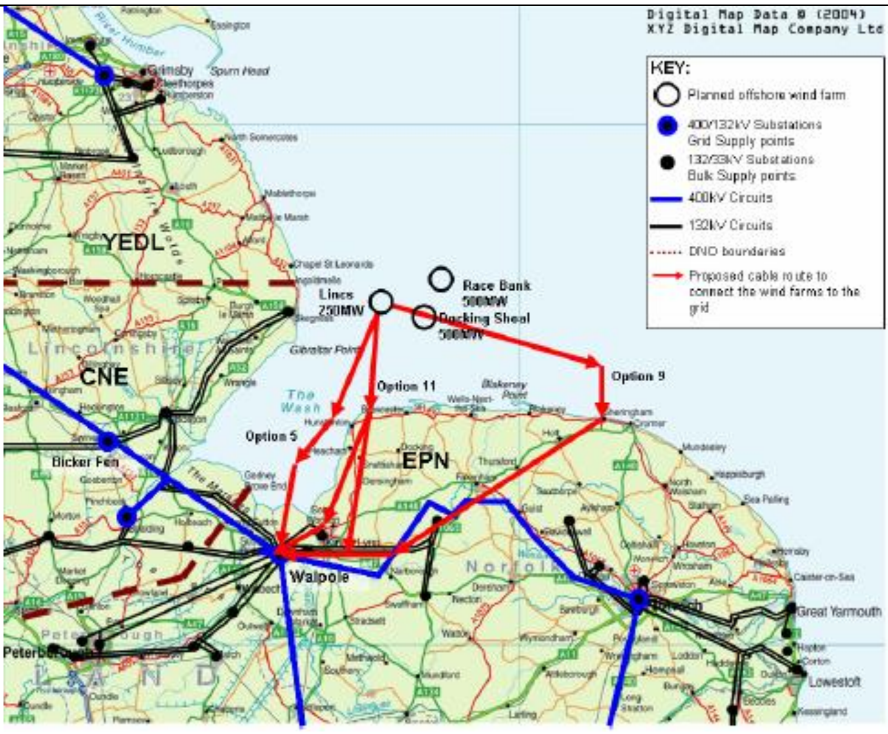


Figure 3.4 Options 5, 9 & 11 - Walpole GSP

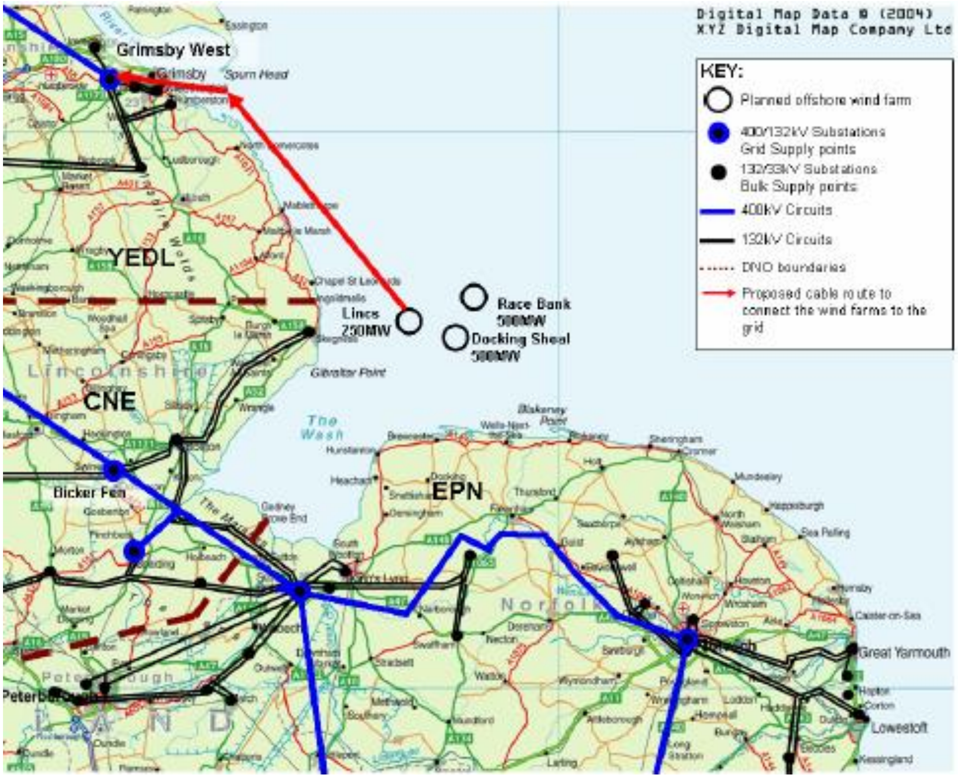


Figure 3.5 Option 6 - Grimsby West GSP

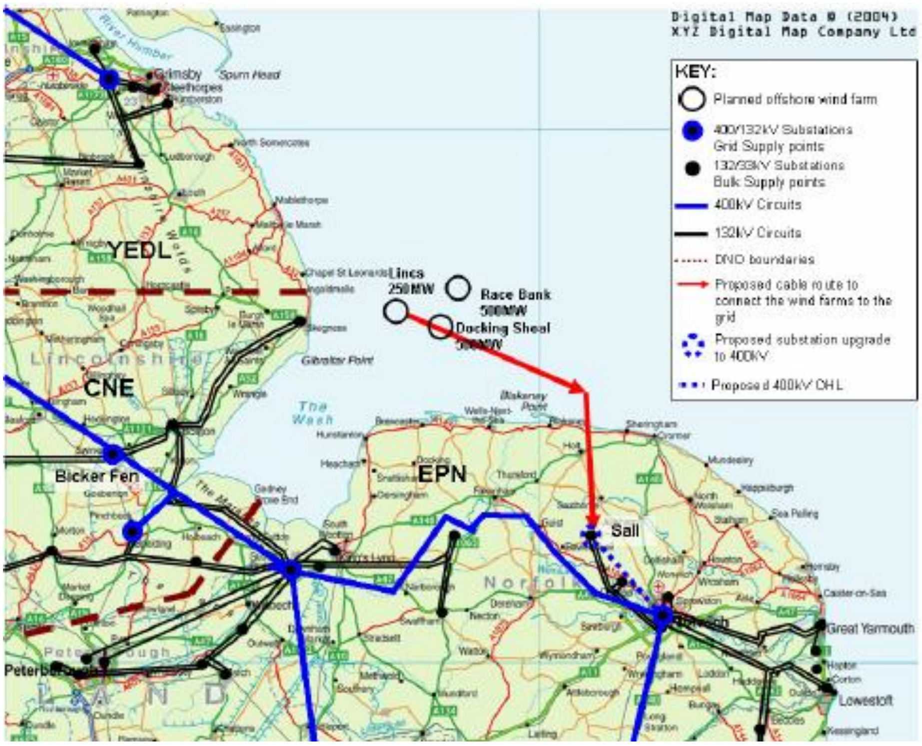


Figure 3.6 Option 7 - Sall BSP

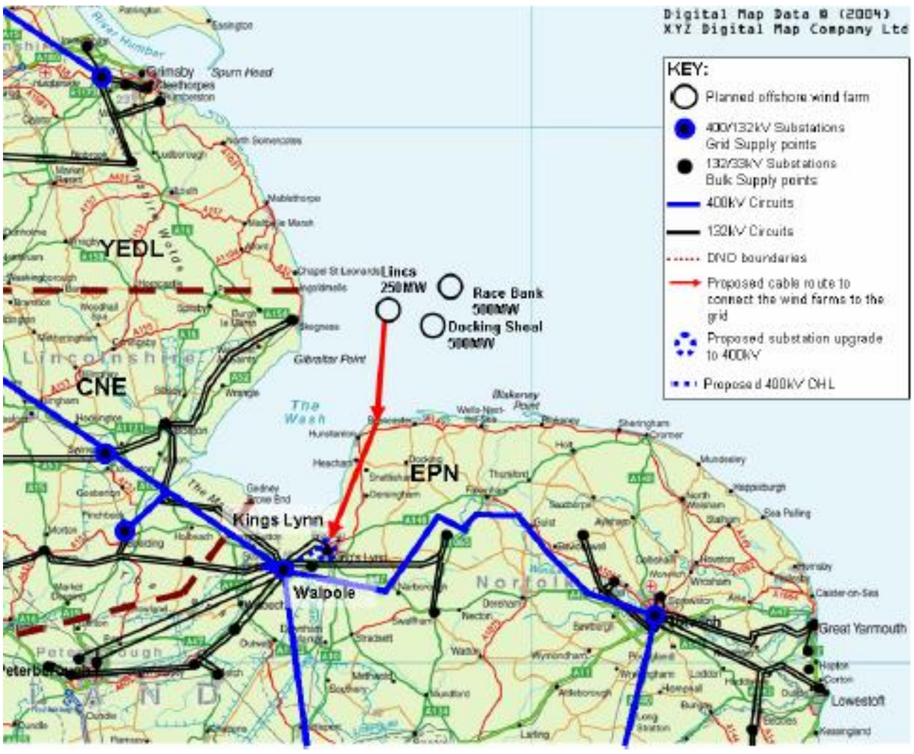


Figure 3.7 Option 8 Kings Lynn BSP (UKPN)

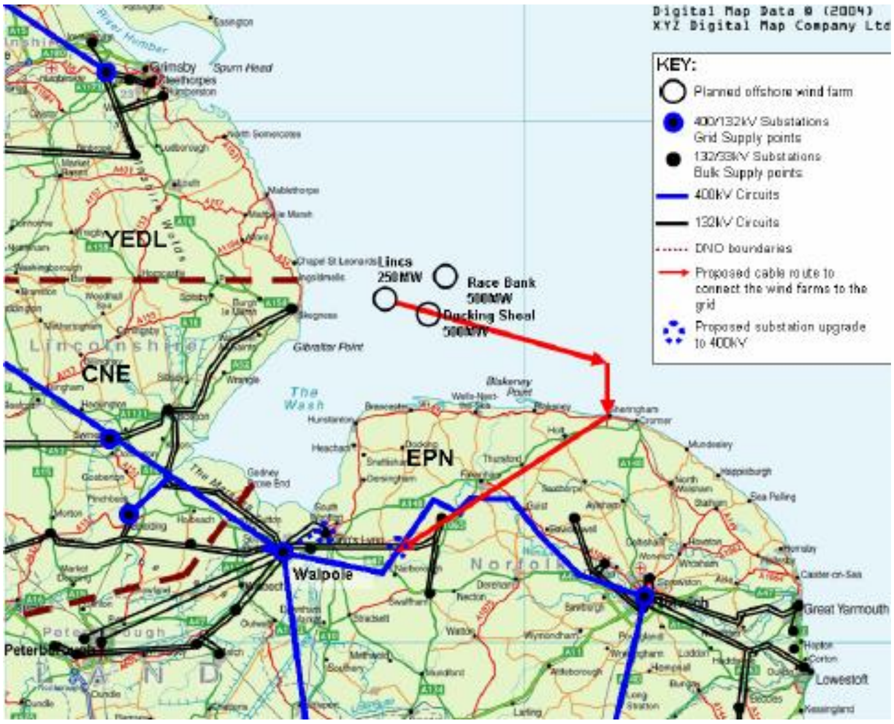


Figure 3.8 Option 10 - New 400kV GSP near Walpole

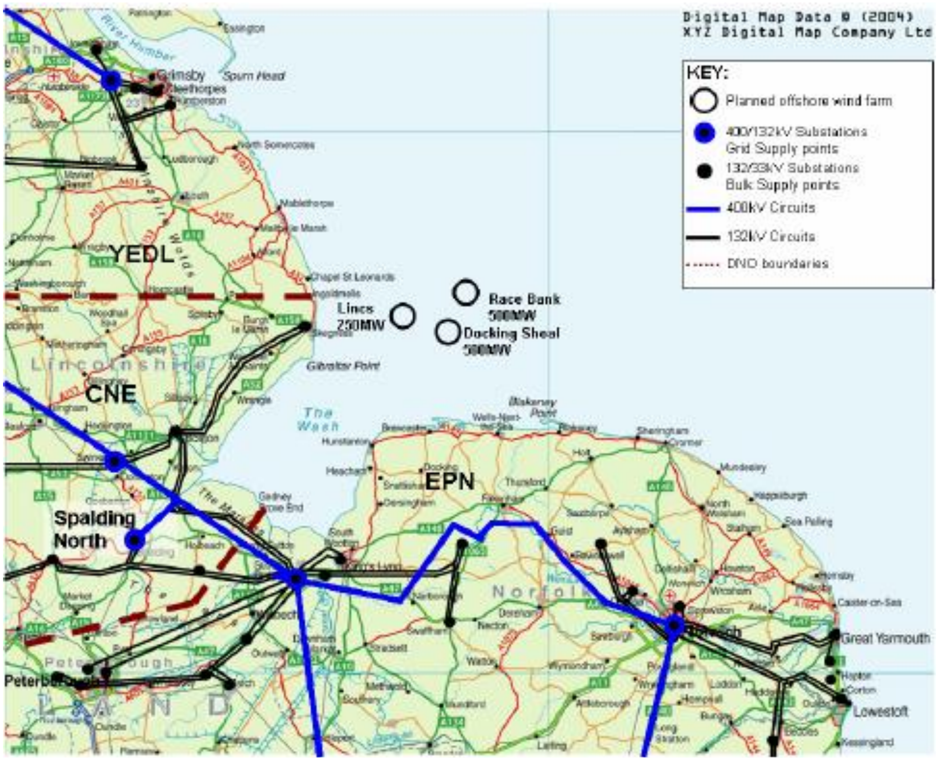


Figure 3.9 Option 11 Spalding North GSP

3.2.9 The report also suggests that HVDC should be considered. It is not known if this has been considered however GLND considers that for Lincs alone the additional cost of HVDC converter stations both onshore and offshore would have been greater than any potential savings.

3.2.10 GLND notes that the current NGET Seven Year Statement [23][13] confirms that all three Centrica projects (Lincs, Docking Shoal and Race Banks) have accepted connection offers for connection at Walpole. The associated NGET substation works are scheduled for completion as follows:

Table 3.1 Extract From NGET SYS 2010 Appendix B7-c

2010/11	Walpole	Connect Lincs offshore windfarm (250MW) at Walpole 400kV substation.
2011/12	Walpole	Connect Docking Shoal offshore Windfarm (500MW).
2013/14	Walpole	Connect Race Bank offshore windfarm (500MW) at Walpole 400kV substation.

3.2.11 There are a number of nearby wind farm projects which are in various stages of development. Wind farms requiring subsea cable land fall and grid connections in the area around the Wash are shown in Figure 3.10 below.

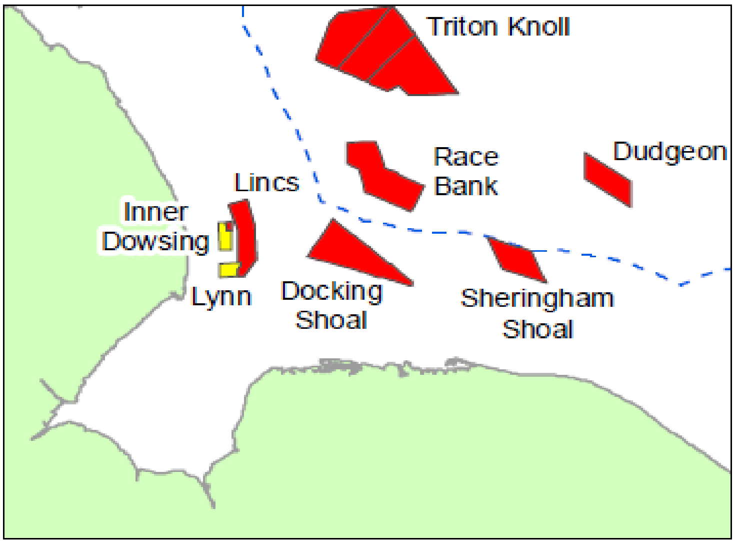


Figure 3.10 Wind Farms in the Wash

[13] [23] NGET Seven Year Statement 2010 Appendix B-7c

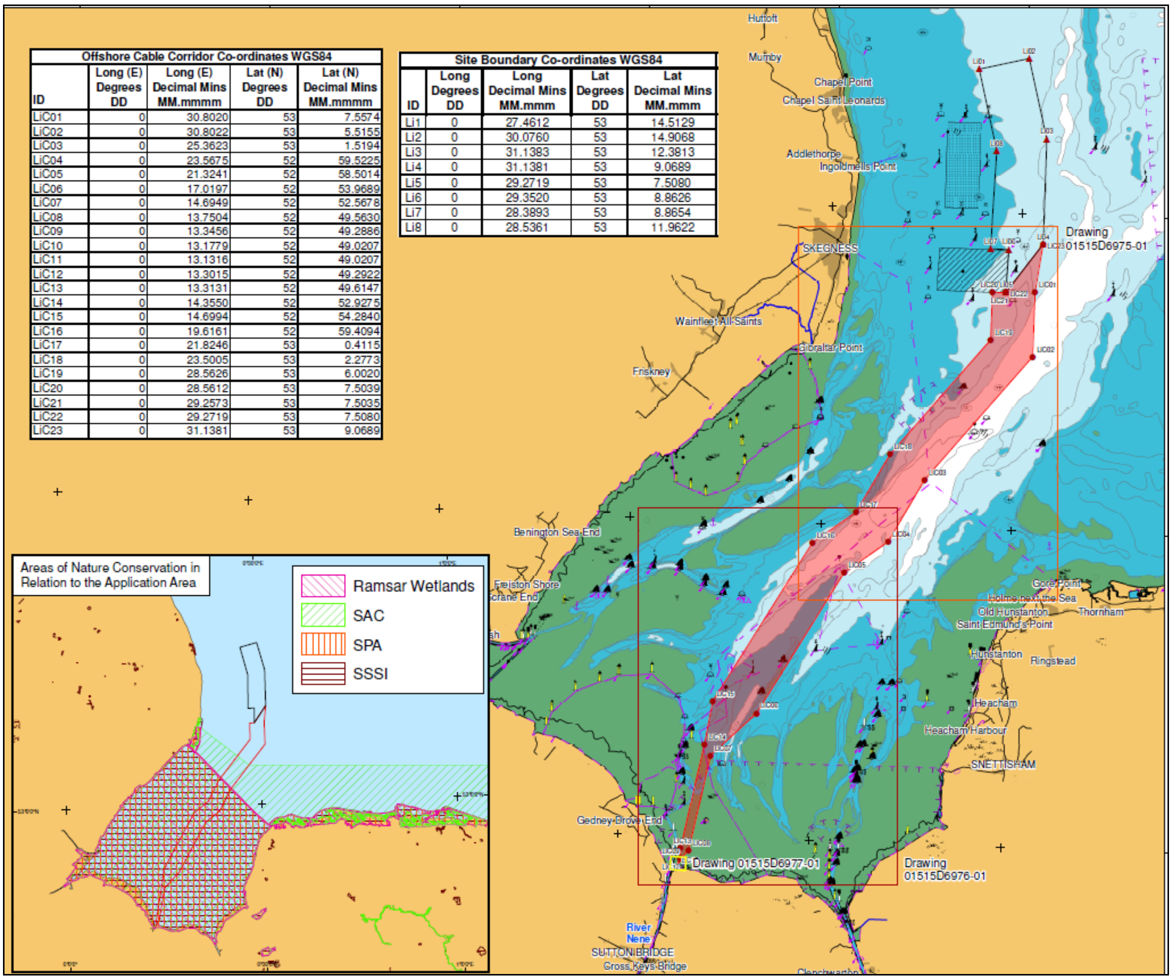
3.2.12 [23][14] indicates that the 1.2GW Triton Knoll project (see Figure 2.2) will connect to Bicker Fen via the new 400kV substation to be constructed at Mumby, north of Skegness. Sheringham Shoal will connect at Norwich Main and Dudgeon will connect at a new substation at Little Dunham between Norwich and Walpole.

[14] [23] NGET Seven Year Statement 2010 Appendix B-7c

3.3 CABLE ROUTE CONSIDERATIONS

3.3.1 The Wash is classified as a Site of Special Scientific Interest (SSSI) and is also a Special Area of Conservation (SAC) and a Special Protection Area (SPA) under European Union legislation with respect to wild life. As such it presents a significant challenge for subsea cable installation.

3.3.2 Centrica have carried out a number of environmental studies to establish acceptable offshore export cable routes capable of accommodating the requirements of the Lincs, Docking Shoal and Race Bank developments. The common cable route for Lincs, Docking Shoal and Race Bank through the sensitive area is shown as the area shaded red in Figure 3.11.



Offshore Cable Corridor Co-ordinates WGS84				
ID	Long (E) Degrees DD	Long (E) Decimal Mins MM.mmmm	Lat (N) Degrees DD	Lat (N) Decimal Mins MM.mmmm
LiC01	0	30.8020	53	7.5574
LiC02	0	30.8022	53	5.5155
LiC03	0	25.3623	53	1.5194
LiC04	0	23.5675	52	59.5225
LiC05	0	21.3241	52	58.5014
LiC06	0	17.0197	52	53.9689
LiC07	0	14.6949	52	52.5678
LiC08	0	13.7504	52	49.5630
LiC09	0	13.3456	52	49.2886
LiC10	0	13.1779	52	49.0207
LiC11	0	13.1316	52	49.0207
LiC12	0	13.3015	52	49.2922
LiC13	0	13.3131	52	49.6147
LiC14	0	14.3550	52	52.9275
LiC15	0	14.6994	52	54.2840
LiC16	0	19.6161	52	59.4094
LiC17	0	21.8246	53	0.4115
LiC18	0	23.5005	53	2.2773
LiC19	0	28.5626	53	6.0020
LiC20	0	28.5612	53	7.5039
LiC21	0	29.2573	53	7.5035
LiC22	0	29.2719	53	7.5080
LiC23	0	31.1381	53	9.0689

Site Boundary Co-ordinates WGS84				
ID	Long Degrees DD	Long Decimal Mins MM.mmm	Lat Degrees DD	Lat Decimal Mins MM.mmm
Li1	0	27.4612	53	14.5129
Li2	0	30.0760	53	14.9068
Li3	0	31.1383	53	12.3813
Li4	0	31.1381	53	9.0689
Li5	0	29.2719	53	7.5080
Li6	0	29.3520	53	8.8626
Li7	0	28.3893	53	8.8654
Li8	0	28.5361	53	11.9622

Figure 3.11 Offshore Cable Route

3.3.3 Centrica have advised [27][15] that extensive survey works have been undertaken to satisfy environmental impact assessment criteria, namely, geophysical surveys, geotechnical surveys, ecology surveys, bird & cetacean surveys, shipping and navigation surveys. The cost of such surveys (some of which were repeated monthly, seasonally or annually), plus the associated analysis and interpretation has been significant owing to the distance of the cable route (almost 50km offshore and 11km onshore).

3.3.4 Negotiation of the land easements for the onshore cable route and onshore substation was a length and costly process involving eleven landowners.

3.3.5 Key stakeholders with a keen interest in the offshore cable route have demanded a lot of Centrica time, spent mainly in meetings and producing reports to determine the most appropriate location for the export cables within the defined cable corridor. Main concerns and the relevant stakeholder groups have been listed below by means of an example:

- Port Authorities - location of anchorage areas, channel movement in the inter-tidal area, cable burial depths.
- Natural England - presence of sabellaria reef, impact
- Fishermen - sterilisation of key fishing areas
- Environmental Agency - integrity of flood defences

3.3.6 A separate Environmental Statement (ES) was compiled and submitted for the onshore cable route and onshore substation. The cost of producing this ES incorporated the time of the Centrica Development Team, the RES Development Team and key sub-contractors. The Onshore Environmental Statement covers the onshore cable route for the proposed Race Bank, Lincs and Docking Shoal projects. All three projects share the same onshore cable route to the substation. Consent for these elements of the projects was granted in May 2007 [24][16].

3.3.7 In adopting a common export cable route for three projects there is potential for the additional cost expended on Lincs to result in cost savings on Docking Shoal and Race Bank.

[15] [27] Additional commentary and/or documentary information on the 40% allocation for development costs - 21st December 2010.

[16] [24] Centrica Website http://www.centrica.com/index.asp?pageid=923

4 TECHNICAL REVIEW

4.1 COMPARISON WITH OTHER PROJECTS

4.1.1 As noted in Section 2.3, the cost basis for Lincs is being compared with transitional round 1 and other Tranche 2a projects

4.1.2 The grid connection process described in Section 3.0 has resulted in the Lincs wind farm being connected at 400kV. The majority of similar sized projects are connected at 132kV. A 400kV connection requires 132/400kV transformers and 400kV switchgear which are not required for 132kV connections.

4.1.3 Another significant difference lies in the degree of redundancy provided, in the transformer rating. Lincs has provided a greater transformer capacity than other projects.

4.1.4 It is also noted that offshore reactive compensation equipment will be installed at the offshore substation. Greater Gabbard is the only transitional project with reactive compensation installed at the offshore substation.

4.1.5 These topics are discussed further in Sections 6.0 and 7.0.

4.2 DESIGN PHILOSOPHY

4.2.1 The design philosophy is dictated by a number of factors, including:

- Grid connection at 400kV

  The factors leading to the requirement for a 400kV connection are covered in Section 3.2.

- Connection Agreement [18][17]

  The connection agreement precludes the WTG's providing any reactive power to the system. This means that all reactive power requirements are to be met by additional equipment forming part of the transmission assets.

  The connection agreement imposes limits for harmonic currents and voltages so the developer needs to make provision for harmonic filters. The limits in the original connection agreement were ill defined, but they have subsequently been clarified. (See Section 5.3.3 for more details)

- Technology limits

  The design will be conditioned by practical limits on the maximum rating of switchgear, transformers and cables.

[17] [18] National Grid/Centrica, "The Connection and Use of System Code Bilateral Agreement For a Directly Connected Power Station in Respect of Lincs Wind Farm at Lincs 33kV Offshore Substation" – Appendix F, doc. A/OFFWPL/05/5198-1EN(6), January 2010.

- Equipment specification and redundancy

  The developer has a choice; to adopt a minimum capital cost approach or to adopt the principles of whole life costing. Both of these approaches are valid, with the chosen option being influenced by factors such as project financing.

4.2.2 Centrica have adopted the principles of whole life costing for the development of the Lincs project. This is discussed further in Section 4.3.

4.3 LIFE CYCLE OPTIMISATION

4.3.1 GLND has reviewed the Mott Macdonald Report [4][18] which describes the rationale behind the design of the Lincs electrical transmission system.

4.3.2 The main design criterion identified in the report, and in subsequent technical specifications [7[19], 8[20]] requires the design to optimise the performance requirements of the electrical system over the whole-life of the wind farm. Whole-life costs can be defined as the costs of acquiring, operating, maintaining and decommissioning a particular item or system [26][21]. However this report is concerned with costs associated with lost energy resulting:

- Fixed losses, typically independent of windfarm production output; e.g. Transformer Iron Losses
- Variable load losses, relating to the ohmic losses in cables and transformers;
- Energy not generated due to constraint imposed by electrical system unavailability (e.g. due to cable or transformer fault).

4.3.3 These losses are used to define three economic evaluation factors that help translate lost energy production into an equivalent initial capital cost. The method is described in [9][22].

4.3.4 The fixed loss factor (A) translates total no-load losses incurred by the windfarm into an equivalent initial capital cost value. Its units are £/kW and the value represents the maximum acceptable capital investment incurred in reducing the no load losses by 1kW. No-load losses are present at all times, when the windfarm is generating energy and when it is not.

Centrica have advised that the current fixed loss factor A = £ [redacted].

[18] [4] Mott MacDondald, “Electrical Construction Study – Centrica R2 Offshore Wind Farms Electrical System Design Studies”, doc. JM/MB/222669/001, rev. C, 29/03/2006
[19] [7] LINCS/CREL/T/300410 - Section 3.2 Technical Specification - Onshore Substation
[20] [8] LINCS/CREL/T/300408 - Section 3.2 Technical Specification - Offshore Substation
[21] [26] Whole-life costing and cost management: Achieving Excellence in Construction Procurement Guide. Office of Government Commerce (OGC) 2007
[22] [9] R.A.Walling, T.Ruddy – “Economic Optimisation of Offshore Windfarm Substations and Collection Systems”, V International Workshop on Large-Scale Integration of Wind Power, Glasgow, 2005.

4.3.5 The load loss factor (B) translates load-dependent losses, measured at rated load, to an initial capital cost equivalent. Its units are £/kW, and the value represents the maximum acceptable capital investment incurred in reducing the load dependent losses by 1kW. Unlike the (A) factor, the B factor depends on the windfarm production-duration curve.

Centrica have advised that the current load loss factor B = £ [redacted].

4.3.6 The unavailability factor (C) provides a means of converting annual expected lost energy production into an initial capital cost equivalent. Its units are £/kWh/yr, and the value represents the maximum acceptable capital investment incurred to avoid 1 kWh per year of lost energy production.

Centrica have advised that the current unavailability factor C = £ [redacted] kWhr/yr.

4.3.7 Further details on the derivation of these factors and their application to Lincs is provided in Appendices A and B.

4.3.8 GLND accept that this is a valid methodology for establishing the optimum design of the electrical system. As shown in Appendix B the (A) and (B) factors have most significance in comparing alternative designs for the same duty. The (A) and (B) factors are included in the transformer technical specifications. The (C) factor is more significant in establishing the optimum level of redundancy.

4.4 OPTIMISATION OF OFFSHORE TRANSFORMERS

4.4.1 Various factors, including NETSSQSS requirements, dictate the use of two (2) or more transformers. The report [4][23] considers various transformer ratings between 120 and 170MVA rating and concludes that the lowest life cycle cost is achieved with two 170MVA transformers. The summary on page 4-5 states '*typically the larger the rating of the transformer on platforms the lower the Total Evaluated Cost , and hence the better*'.

4.4.2 A subsequent report by RES [10][24] which uses the same methodology and considers transformers rated up to 240MVA, comes to a similar conclusion.

4.4.3 The calculations used in [10][25] are presented in Appendix B from which Table 4.1 is derived. Table 4.1 applies the current value of Factor C to the lost energy figures calculated in [10][25] for transformers rated at 140, 180 and 240MVA, to give the total estimated cost of lost energy over a 20 year project life.

[23] [4] Mott MacDondald, "Electrical Construction Study – Centrica R2 Offshore Wind Farms Electrical System Design Studies", doc. JM/MB/222669/001, rev. C, 29/03/2006

[24] [10] RES Memorandum "Economic Optimisation Methodology Used For Lincs Electrical System Design" – 1st May 2008

[redacted]

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

[redacted] Table 4.1 indicates that the use of OFSS transformers rated at 240MVA is justifiable provided the incremental cost over the cost of the minimum acceptable transformer (140MVA) is less than [redacted]

4.4.5 GLND notes that the total cost of the two 240MVA offshore transformers is £5.8M [11][25] which indicates that any saving achieved by reducing the transformer size would be significantly less than the potential cost of lost energy

4.4.6 The lost energy calculation assumes a transformer failure rate [redacted] and a Mean Time To Repair (MTTR) of [redacted] [redacted] These values are used in both [4][26] and [10][26] The MTTR figure assumes the requirement to mobilise a heavy lift vessel to remove and subsequently replace the transformer. GLND notes that MTTR times could be reduced, but they would need to be in the order of 3 months before the incremental transformer cost and lost energy costs become equal.

[25] [11] LINCS Cost Report Template 2011-01-19

[26] [4] Mott MacDondald, "Electrical Construction Study – Centrica R2 Offshore Wind Farms Electrical System Design Studies", doc. JM/MB/222669/001, rev. C, 29/03/2006

4.5 OPTIMISATION OF 132 KV EXPORT CABLING

4.5.1 The currently accepted maximum 132kV subsea cable size and rating is 1200mm^2 and 209MVA [12][27]. This indicates that two cables are a minimum requirement for 250MW irrespective of any requirement to comply with the GBSQSS requirements. Options available from the cable supplier, Nexans, at the time of order placement (December 2008), are shown in Table 4.2 below.

Table 4.1 Nominal 132kV Cable Ratings

	Nominal Rating	
Cable Size	**Current (A)**	**MVA**
500mm^2	680	155
630mm^2	745	170
800mm^2	805	184
1000mm^2	850	194

4.5.2 GLND notes that 2 × 500mm^2 cable appear adequate for the duty but given the wide range of installation conditions likely to be encountered and which would affect the current rating of the cable the use of 630mm^2 seems to be an acceptable engineering decision.

4.5.3 The calculations used in [10][28] are presented in Appendix B from which Table 4.3 is derived.

4.5.4 The calculation is based on cable failure rates and MTTR values [redacted] and assuming the commercial availability of cables rated at 240MVA.

[redacted]

Cable Rating (MVA)	Capacity Factor	Lost Energy on Single Cable Failure (MWhr/yr)	Cost of Lost Energy over 20 years (£)
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

4.5.5 The result of this analysis indicates that the use of 240MVA cable (if available) would be justifiable provided the incremental cost over the installed cable size is less than [redacted] Given that the cost of the 630mm^2 subsea cable is £42M this is unlikely to be achieved.

[27] [12] NGET 2010 Offshore Development Information Statement Appendix A3
[28] [10] RES Memorandum "Economic Optimisation Methodology Used For Lincs Electrical System Design" – 1st May 2008

4.5.6 GLND notes that achieving the MTTR value assumed is dependent on the availability of spare 132kV subsea cable and associated repair joints. Centrica are unable to confirm the availability of spare 132kV subsea cable

4.5.7 GLND also notes that a Distributed Temperature Sensing (DTS) is being provided [13][29] This uses the thermal properties of the fibre optic cores incorporated in the export cable to monitor the cable temperature along its length. This will allow the short term overloading of the cable during single circuit operation to maximise energy production.

[29] [13] Lincs Contract No. Lincs/C/300433 for Cable Temperature Sensing System

5 OTHER PROJECT SPECIFIC TECHNICAL ISSUES

5.1 OFFSHORE SUBSTATION (OFSS) - STRUCTURAL DESIGN LIFE

The Developer has informed GLND [14][30] that the OFSS structure has been built for a 40 years lifetime as opposed to the standard 20-25 years lifetime of wind projects. The structure can represent a valuable asset in view of the possible future wind farm upgrade or replacement. The structure lifetime of 40 years was an optional item within the Offshore Sub-station contract [15][31] which carried a contract value of [redacted]

5.2 REACTIVE COMPENSATION

5.2.1 Cable Compensation

5.2.1.1 Reactors are provided at both the OFSS and ONSS to compensate for the charging (capacitive) current which flows in the 132kV cable. The total compensation required could be supplied at either the OFSS or ONSS only, but splitting the compensation requirement between the two substations will result in minimum cable losses associated with this current.

5.2.1.2 Depending on the characteristics of the WTG's they are frequently used to provide the offshore compensating current. However the terms of the Connection Agreement for Lincs [18][32] specifically excludes this possibility

5.2.1.3 It must be noted that the reactive compensation cost is related to its size, which in turns depends upon the cable length.

5.2.2 Dynamic Compensation - Grid Code Compliance

5.2.2.1 Reactive compensation is also required to meet the Grid Code connection conditions. This is best placed close to the point of connection at the ONSS. Typically the rating of this equipment, in MVAr, will be in the range 35% - 40% of the wind farm MW capacity. This applies to both the reactive and capacitive components required to provide a power factor range of +/-0.95. The Grid Code requires that the system provides a rapid response to an MVAr demand so it is common practice to provide a combination of static devices (reactors and capacitors) plus a Static Var Compensator (SVC) to provide the dynamic reactive power required to control voltage swings under various system conditions

5.2.2.2 As noted above the connection agreement precludes the use of the WTG's in contributing to this requirement.

5.2.2.3 The equipment provided at the ONSS is consistent with these requirements.

[30] [14] Meeting GLND - Centrica, Windsor 29/03/11
[31] [15] Section 3.1 - Scope of Work, 3.21.1 Extended Operating Life, and Section 4 – Remuneration; 4.5 Optional Prices
[32] [18] National Grid/Centrica, "The Connection and Use of System Code Bilateral Agreement For a Directly Connected Power Station in Respect of Lincs Wind Farm at Lincs 33kV Offshore Substation" – Appendix F, doc. A/OFFWPL/05/5198-1EN(6), January 2010.

5.3 ONSHORE SUBSTATION (ONSS)

5.3.1 Connection Voltage

5.3.1.1 As noted previously the connection options considered the Lincs wind farm and two other projects, Docking Shoal and Race Banks, amounting to 1.25GW of total installed power.

5.3.1.2 The future projects would almost certainly require a 400kV connection and this has influenced the decision to connect Lincs at 400kV.

5.3.1.3 Similar sized projects have typically been connected at 132kV and the higher voltage implies higher overall substation costs. In particular a 400kV connection will require 132/400kV transformers and 400kV switchgear not required for a 132kV connection.

5.3.2 Onshore Transformers

5.3.2.1 GLND understands that the onshore transformers have been subject to a life cycle cost analysis similar to that applied to the offshore transformers as described in Section 5.1.

5.3.2.2 GLND would expect failure rates to be the same as for the offshore transformer, but would expect a lower the MTTR value. GLND notes that there are transport difficulties for large equipment travelling to/from the Walpole site. This plus the limited manufacture/repair/test facilities available for 400kV transformers suggest that a MTTR value of 6 months would be appropriate. This is 60% of the MTTR used in the analysis of the offshore transformers.

5.3.2.3 GLND has not seen any detailed calculations for the onshore transformer but would expect that the use of uprated transformers would be justifiable if the incremental cost is less than £ [redacted]., i.e. 60% of the offshore figure. The total cost of the onshore transformers is reported as £ [redacted] [11][33] which indicates that this criterion would be met.

5.3.2.4 Figure 2.1 shows that the onshore transformers also supply the reactive compensation equipment required for grid code compliance through a tertiary winding. This accounts for the higher rating of the onshore transformers. The rating of 300MVA on each, allows for the nominal 250MW wind farm capacity plus up to 150MVAr of reactive compensation. GLND notes that each transformer can supply the total installed reactive compensation requirement, so that Grid Code compliance is maintained even with one transformer out of service.

5.3.3 Harmonic Filters

5.3.3.1 The ONSS is also provided with two harmonic filters units rated at 30MVAr each. The installation of harmonic filters has been necessary meet the requirements of G5/4 [19][34] as specified in the connection agreement. The original connection agreement [18][35] expressed this as a general requirement but no existing background harmonic levels were provided. As such the requirements were originally ill defined.

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[33] [11] LINCS Cost Report Template 2011-01-19

[34] [19] Engineering Recommendation G5/4-1 Planning and Compatibility Limits for Harmonics

[35] [18] National Grid/Centrica, "The Connection and Use of System Code Bilateral Agreement For a Directly Connected Power Station in Respect of Lincs Wind Farm at Lincs 33kV Offshore Substation" – Appendix F,

5.3.3.2 A revision to Appendix OF5 [29][36] of the connection agreement has recently been issued which provides both background harmonic levels and specific limits.

5.3.3.3 Centrica should be requested to advise if the harmonic filters currently proposed are suitable for this defined duty.

5.3.4 Layout and Civil Works

5.3.4.1 There are two (2) main options to be considered for HV switchgear to be used at the ONSS, AIS (Air Insulated Switchgear) or GIS (Gas Insulated Switchgear).

5.3.4.2 The use of AIS is characterised by a large footprint requirement, large safety clearances and the use of overhead busbars to connect the main items of equipment.

5.3.4.3 GIS offers a significant reduction in space requirement and can offer an easier passage through the planning process. However it is significantly more expensive. Connections between the main items of equipment is typically by gas filled busduct or HV cable which again adds to cost. As an example the cost of the 400kV cable connection shown in Figure 2.1 is [redacted]

5.3.4.4 GLND estimates that the use of 400kV AIS switchgear in place of GIS could have saved approximately £2.5M in equipment cost but would increase the substation area by approximately 50%. This is probably economically neutral and the use of GIS can be justified in terms of planning considerations.

5.3.4.5 Connection at 400kV and the requirement to provide additional transformers and switchgear is noted elsewhere, but it also has a significant effect on the substation layout and civils works. As can be seen from Figure 5.1 approximately 30% of the Lincs substation area is associated with the 400kV equipment. This portion will also have a relatively high civils cost due to the transformer weight, transformer oil drainage and retention, fire fighting etc.

[36] [29]Data Room 2.2 Appendix OF5 Site Specific Technical Conditions

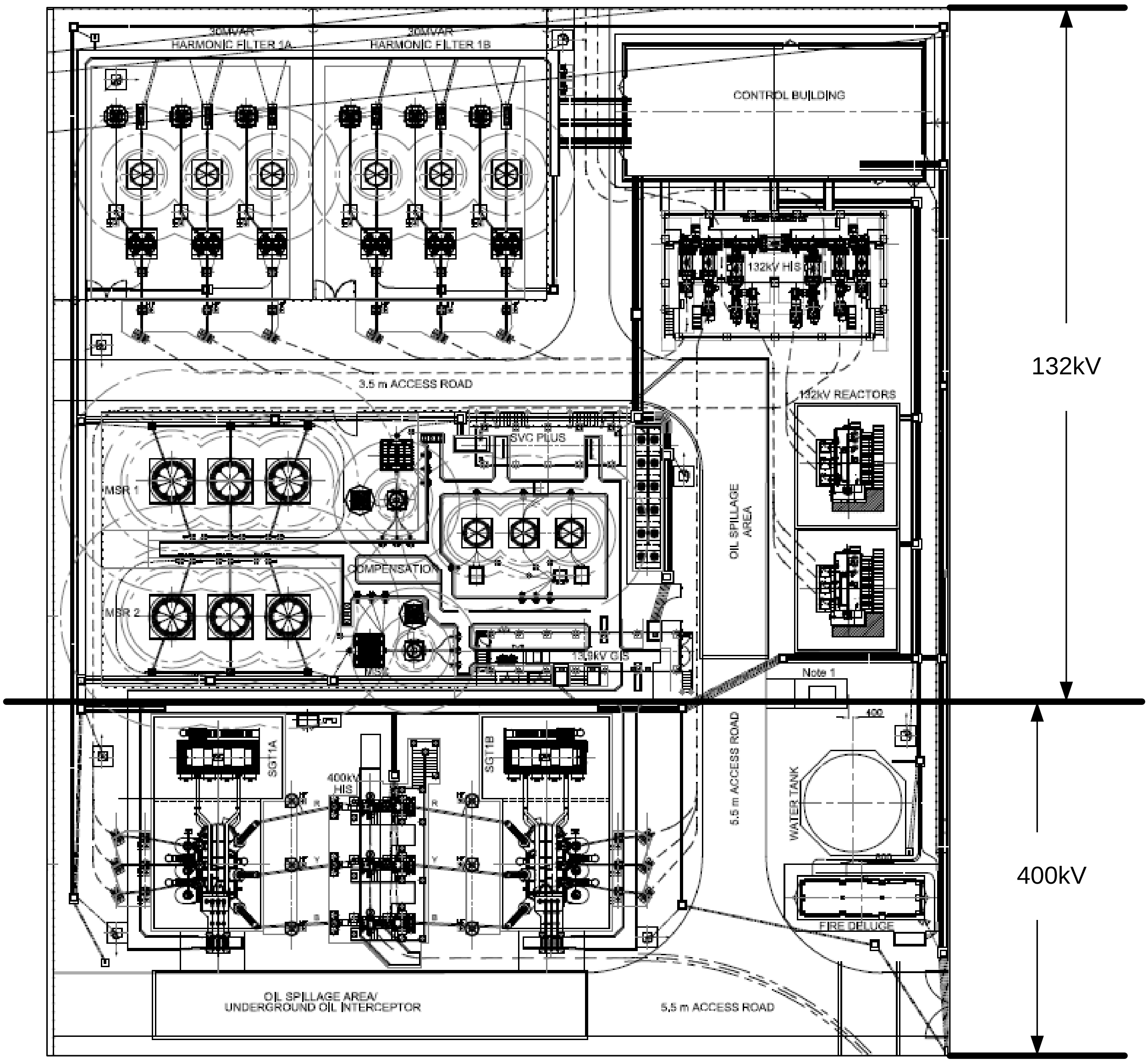

Figure 5.1 Lincs Substation Layout

5.3.4.6 GLND has learnt [14][37] that the ONSS was also subject to significant specific requirements, such as:

- A land drainage system has been built in the ONSS area;
- Landscaping and environmental requirements has forced the installation of noise enclosures;
- The ONSS civil engineering works cost is high due to the amount of piling required.

[37] [14] Meeting GLND - Centrica, Windsor 29/03/11

6 PROJECT MANAGEMENT ISSUES

6.1 PROCUREMENT AND PROJECT COST APPROVAL

6.1.1 The procurement of the OFTO assets for the Lincs project has been subject to competitive tendering process followed by in-house cost approval. GLND has identified the following bid analysis and requests for authorisation:

[redacted]

6.1.2 Each document provides a review of the bidding process and a bid evaluation.

6.1.3 Individual ITT's were issued for the Onshore Substation (2 bidders), the Offshore Substation (5 bidders) the Offshore Cable (3 bidders) and the Onshore Cable (5 bidders). The ITT bid lists were based on a market survey of potential bidder's experience, capability and availability.

6.1.4 Following a comprehensive bid evaluation process the Onshore substation and cabling elements and the Offshore substation were awarded to STDL. The Offshore cable supply was awarded to Nexans with installation awarded to Sub Ocean.

6.1.5 GLND considers that the processes undertaken by Centrica were appropriate.

6.2 COMPLIANCE WITH TECHNICAL STANDARDS

6.2.1 GLND has reviewed the main design contracts applicable to the OFTO assets for Lincs as follows:

- Onshore Substation [redacted]
- Onshore Cable [redacted]
- Offshore Cable Installation [redacted]
- Offshore Substation [redacted]

6.2.2 In each case equipment and systems are required to comply with relevant BS, IEC, NGET and ENA standards. A list of the referenced standards is provided in Appendix A.

6.2.3 GLND concludes that the technical standards and specifications invoked in the main contracts are appropriate and indicate compliance with industry practice.

6.3 COMPLIANCE WITH HEALTH AND SAFETY STANDARDS

6.3.1 GLND has reviewed the main design and installation contracts applicable to the OFTO assets for Lincs as follows:

- Onshore Substation [redacted]

- Onshore Cable [redacted]
- Offshore Cable Installation [redacted]
- Offshore Substation [redacted]
- Offshore Substation (Installation) [redacted]

6.3.2 In each case the contracts make appropriate references to HSE Management requirements.

6.3.3 Compliance with CDM Regulations is required in all contracts except that for the Offshore Substation installation. It is possible that CDM regulations were not applicable to this portion of the work due to the time duration (<30 days).

6.3.4 In the other contracts a CDM co-ordinator was to be appointed by the Owner. Siemens were named as Principal Contractor for the Onshore Substation and Onshore Cable. The Owner was to appoint the Principal Contractor for the Offshore Substation and Offshore Cable contracts.

6.3.5 GLND concludes that the health and safety standards invoked in the main contracts are appropriate and indicate compliance with industry practice.

7 COST REVIEW INCLUDING OUTLIERS

7.1 GENERAL

7.1.1 OFGEM has undertaken internal benchmarking which has identified asset categories where projects are material cost outliers in comparison with adjusted industry medians (derived from offshore TR1 and TR2 projects).

7.1.2 The principal characteristics of these projects are summarised in Table 7.1. This shows that only 3 out of the 11 projects considered have a 400kV connection.

7.1.3 The key areas of focus are the cost outliers, specifically the ONSS "other" costs, which appears greater than the median by a factor of 3.4 and the overall OFSS costs which appear greater than the median costs by a factor of 1.6. These can be seen in Table 7.2 which summarises the key elements of the OFGEM outlier assessment.

7.1.4 After carrying out the technical assessment contained within this report and looking at the benchmarks used it is clear that to carry out a like for like comparison some normalisation of the costs is required.

7.1.5 This normalisation is done in two stages. Firstly by reviewing the cost data being input for the Lincs project to ensure the correct base costs are being allocated to the correct categories. Then, secondly, by adjusting the costs for those areas of technical difference between Lincs and the other benchmark projects as identified in Sections 4.0 and 5.0.

Table 7.1 Summary of UK Offshore Wind Farms (table redacted)

Table 7.2 Extract From OFGEM Cost Outlier Report (3rd June 2011) (Table redacted)

Table 7.3 Comparison of Onshore Substations for Various OFTO Projects (Table redacted)

7.2 EVALUATION OF ONSHORE SUB-STATION

7.2.1 CORRECTED BASE COST

In the initial assessment of outliers, the onshore sub-station "other costs" was assessed at a rating of 250MW and with a cost for this item of [redacted] see Table 7.2. This gives a benchmark value of [redacted] per MW as opposed to £ [redacted] per MW for the Median. However within the "other costs" is a value of [redacted] for transformer related costs which should be located within the "onshore transformer cost" figure. Moving this gives a resultant total for "other costs" of [redacted] and a benchmark figure of [redacted] per MW. This adjustment is explained in more detail in Appendix C, Section 1.0.

7.2.2 NORMALISING FOR TECHNICAL DIFFERENCES

7.2.2.1 As has been explained within Sections 4.0 and 5.0 of this report, there are a number of technical requirements creating greater cost for the Lincs project. In Appendix C these are identified in Table C.2 and a detailed adjustment carried out to give a normalised comparative figure.

7.2.2.2 In summary, the technical items adjusted and the adjustment values are:

400kV connection requirements	[redacted]
Voltage Control System	[redacted]
Harmonic Filters	[redacted]
Noise Enclosures	[redacted]
Civil Construction costs	[redacted]

7.2.2.3 The resultant comparative figure is [redacted] which gives a benchmark figure per MW of [redacted] and a comparative factor of [redacted] (i.e. some [redacted] of costs is not explained).

7.2.3 POTENTIAL NORMALISATION FOR TIME DIFFERENCE

7.2.3.1 A simple figure of approximately [redacted] % higher than the median value is a cause for concern. The timing for the start date of Lincs, March 2009, is in line with the average for the other projects. However, the contract for the onshore sub-station was placed in February 2010 and the elapsed time between this commitment and the other comparison projects has had some effect. By making an allowance for cost increases over time using some indicative indices a further adjustment of an %[redacted] reduction results in a comparative total figure of [redacted] and a comparative factor of 1.9 as detailed in Appendix C. The change in difference with this allowance is between an estimated overage of [redacted] and an estimated overage of [redacted] .

7.2.3.2 The reasonable timing of order placement would have been expected to fall somewhere between March 2009 and February 2010. Further investigation into the procurement process would be required to identify a more accurate figure. Currently the estimates of [redacted] should be treated as the upper and lower limits of a range.

7.3 EVALUATION OF OFFSHORE SUB-STATION

7.3.1 ADJUSTMENT OF BASE COST

The total value for the Offshore Sub-station is adjusted to a value of £[redacted] as explained in Appendix C.

7.3.2 NORMALISING FOR TECHNICAL DIFFERENCES

7.3.2.1 The costs for the offshore sub-station then require normalising for technical differences as outlined within this report. The elements and values to be adjusted are:

Transformer Capacity	£[redacted]
40 year life time costs	£ [redacted]
Extra costs for transformer weight	£ [redacted]
Offshore Reactive Compensation	£[redacted]

The basis for these is explained in Appendix C.

7.3.2.2 Applying these adjustments gives a total cost, for comparative purposes, of £ [redacted] resulting in a benchmark figure of £ [redacted] per MW and a comparative factor of 1.4 ([redacted]).

8 CONCLUSIONS

8.1 The report reviews the costs of the Lincs OFTO assets and compares them with the OFTO benchmark values being applied to other OFTO Round 2 Transactions

8.2 The design philosophy adopted by Centrica impacts on the project costs due to the following key factors.

8.3 ADOPTION OF WHOLE LIFE COSTING

8.3.1 GLND note that this is an acceptable philosophy and considers that its use is compatible with the Developer's position as an established integrated energy supplier. The Developer will retain the principal benefit of maximising production during circuit outages after transfer of the OFTO assets

8.3.2 However taking each of the key OFTO elements in turn GLND draws the following conclusions

Offshore Substation

The provision of additional transformer capacity is justified and assessment of the normalised costs indicates that they are within a reasonable range of comparison projects.

Export Cable

The cable design is appropriate to the duty required and costs are acceptable for the size and route selected.

Full redundancy is neither provided nor required.

Onshore Substation

The substation costs are increased by the additional equipment required by the 400kV connection and by the site specific civils requirements.

8.3.3 Assessment of the costs, using normalised figures, indicate that they are within an acceptable range of similar projects given the time differential between projects and the additional technical complexity for this project. However, should these costs increase significantly over the life of the project a re-evaluation is recommended.

8.4 CONSIDERATION OF FUTURE PROJECTS

Consideration of the future Docking Shoals and Race Bank developments has influenced the selection of the grid connection point possible that a 250MW connection could have been established at 132kV elsewhere on the system. Consideration of 1,25GW dictates a 400kV connection, with additional cost implications as described above.

This report is intended for the sole use of the person or company to whom it is addressed and no liability of any nature whatsoever shall be assumed to any other party in respect of its contents.

GL NOBLE DENTON

Signed: ____________________

Terry Foster / Peter Watson

Countersigned: ____________________

James Dingwall

Dated: London, 1st August 2011

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[3] Econnect, "Review of Connection Options for Lincs, Docking Shoal and Race Bank Wind Farms", doc. 1965, rev. 1, 31/08/2007.

[4] Mott MacDondald, "Electrical Construction Study – Centrica R2 Offshore Wind Farms Electrical System Design Studies", doc. JM/MB/222669/001, rev. C, 29/03/2006

[5] "Cable Route Alternatives Study for Lincs, Race Bank and Docking Shoal Offshore Wind Farm Developments, RPS Energy, 22 May 2007 (Route Selection Survey, RSS)."

[6] "Lincs Offshore Wind Farm: Environmental Statement, Vols 1 and 2, January 2007 (Lincs ES)."

[7] LINCS/CREL/T/300410 - Section 3.2 Technical Specification - Onshore Substation

[8] LINCS/CREL/T/300408 - Section 3.2 Technical Specification - Offshore Substation

[9] R.A.Walling, T.Ruddy – "Economic Optimisation of Offshore Windfarm Substations and Collection Systems", V International Workshop on Large-Scale Integration of Wind Power, Glasgow, 2005.

[10] RES Memorandum "Economic Optimisation Methodology Used For Lincs Electrical System Design" – 1st May 2008

[11] LINCS Cost Report Template 2011-01-17 Post - GT Audit

[12] NGET 2010 Offshore Development Information Statement Appendix A3

[13] Lincs Contract No. Lincs/C/300433 for Cable Temperature Sensing System

[14] Meeting GLND - Centrica, Windsor 29/03/11

[15] Section 3.1 - Scope of Work, 3.21.1 Extended Operating Life, and Section 4 – Remuneration; 4.5 Optional Prices

[16] OFGEM, "Information memorandum – Lincs Wind Farm Offshore Transmission Assets", January 2011.

[17] Mott MacDondald, "Electrical Construction Study – Centrica R2 Offshore Wind Farms Construction Parameters for Electrical Study", doc. JM/MB/222669/002, rev. C, 29/03/2006

[18] National Grid/Centrica, "The Connection and Use of System Code Bilateral Agreement For a Directly Connected Power Station in Respect of Lincs Wind Farm at Lincs 33kV Offshore Substation" – Appendix F, doc. A/OFFWPL/05/5198-1EN(6), January 2010.

[19] Engineering Recommendation G5/4-1 Planning and Compatibility Limits for Harmonics

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[23] NGET Seven Year Statement 2010 Appendix B-7c

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[27] Additional commentary and/or documentary information on the 40% allocation for development costs - 21st December 2010.

[28] Not Used

[29] Data Room 2.2 Appendix OF5 Site Specific Technical Conditions

APPENDICES

APPENDIX A DERIVATION OF ECONOMIC LOSS FACTORS

The whole life cost evaluation of the Lincs transmission assets is based on the application of economic loss factors as defined in [9][38]

The purpose of this Appendix is to describe the derivation of these factors.

Data Required

The following information is required

Sales price of electrical energy (SP £/MWhr)

This should take account of any uplift (ROC's etc) and tax liabilities

Discount rate (DR %)

The discount rate takes into account the time value of money (the idea that money available now is worth more than the same amount of money available in the future because it could be earning interest) and the risk or uncertainty of the anticipated future cash flows (which might be less than expected). It is used to express the future value of money in present value (PV) terms

Most major companies would set a corporate discount rate appropriate to their needs

Project life time (T years)

Capacity Factor (K_{cap}) - derived from annual production profile

Loss Factor (K_{loss}) - derived from annual production profile

Assumptions

For the purposes of this exercise the following assumptions are made

Sales price of electricity	£100/MWHr
Discount rate	10%
Project life time	20 years
Production profile	See Fig A.1

[38] R.A.Walling, T.Ruddy – "Economic Optimisation of Offshore Windfarm Substations and Collection Systems", V International Workshop on Large-Scale Integration of Wind Power, Glasgow, 2005.

Fig A.1 represents the annual production profile for a UK offshore wind turbine, The annual average output (or capacity factor K_{cap}) for this distribution is 47% (0.47)

Fig A.2 represents the load loss distribution. This is derived from Fig A.1 noting that load losses are proportional to $(Output)^2$.

The average loss (or loss factor K_{loss}) calculated for this distribution is 36% (0.36)

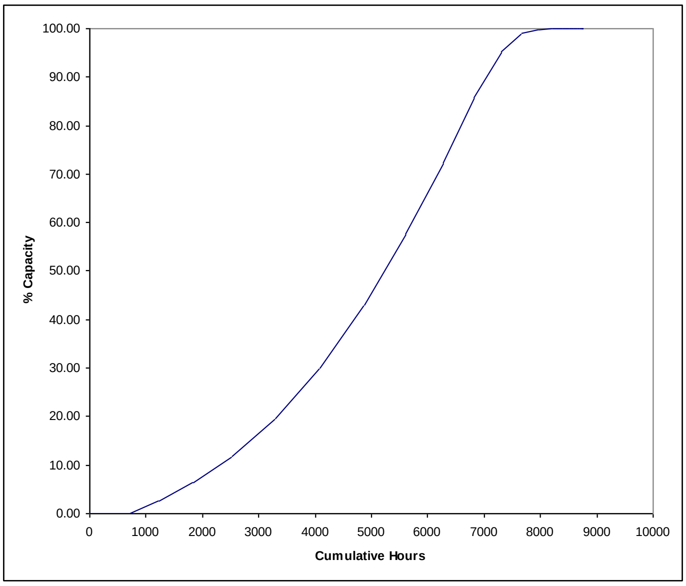

Figure A.1 Typical Offshore WTG Annual Production Curve

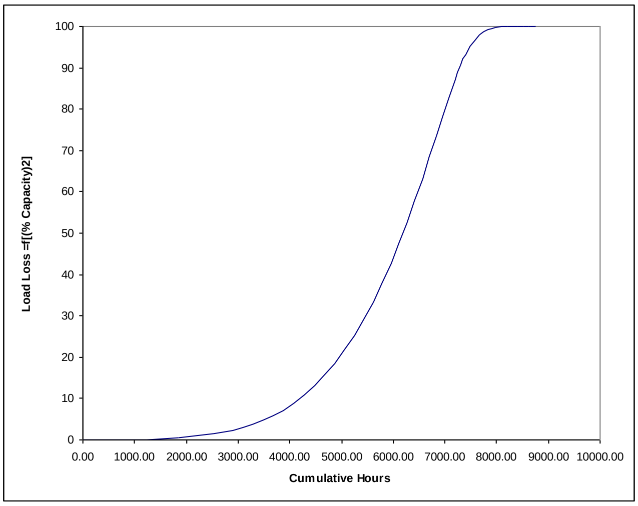

Figure A.2 Typical Load Loss Distribution Curve

Fixed Loss Factor (A)

Fixed losses are independent of wind farm production. These losses are principally associated with transformer iron (no load) loss.

Consider a 1KW continuous loss as representing an annual lost sales opportunity of 8760 KWhrs

The annual value (AV) of this loss is $\frac{8760 \times SP}{10^3} = \frac{8760 \times 100}{10^3}$ =£876/kW

The Fixed Loss Factor (A) is the total value of this annual loss over the project lifetime expressed in present value terms. It is given by the expression

$$A = \sum_0^T \frac{AV}{(1+DR)^t} = \text{£8203/kW}$$

The current Centrica value for Loss Factor (A) is £ [redacted] (based on actual Lincs power profile and Centrica current sales price, tax details, discount rates etc.)

Variable Load Loss Factor (B)

Load losses vary with the square of the wind farm output. They are principally associated with the load current (I) and the electrical resistance (R) of conductors in transformers and cables

Loss = I^2 x R

Again one 1KW loss represents a lost sales opportunity. If the loss at rated capacity is 1KW the average loss over the year is 1 x $K_{loss.}$

Therefore Loss Factor (B) = K_{loss} x Loss Factor (A)

= 0.36 x £8203

= £2953/kW

The current Centrica value for Loss Factor (B) is £ [redacted]based on actual Lincs power profile and Centrica current sales price, tax details, discount rates etc.)

Unavailability Factor (C)

Energy sales opportunities may be lost due to the unavailability of key items of the transmission system, due to faults or maintenance.

Statistical data can be used to calculate the anticipated lost energy (E_{lost}) in kWhr/year over a defined period

The Unavailability Factor (C) is the present value of one (1) unit (kWhr) of energy for each year in the specified period.

The current Centrica value for Unavailability Factor (C) is 0.88 (£ [redacted] (based on actual Lincs power profile and Centrica current sales price, tax details, discount rates etc.)

[GLND notes that the Centrica value of [redacted] is significantly higher than values used in previous reports [4][39] and [10][40]. Centrica have acknowledged an error in these previous calculations. GLND further notes that the higher value of "C" reinforces the case to provide additional transformer capacity].

[39] [4] Mott MacDondald, "Electrical Construction Study – Centrica R2 Offshore Wind Farms Electrical System Design Studies", doc. JM/MB/222669/001, rev. C, 29/03/2006

[40] [10] RES Memorandum "Economic Optimisation Methodology Used For Lincs Electrical System Design" – 1st May 2008

APPENDIX B REDACTED

APPENDIX C REDACTED

APPENDIX D LIST OF STANDARDS

LIST OF STANDARDS USED IN THE LINCS TECHNICAL SPECIFICATIONS

British Standards

BS 3297	Characteristics of indoor and outdoor post insulators for systems with nominal voltage greater than 1000V
BS 6627	Cables with extruded cross-linked polyethylene or ethylene propylene rubber insulation for rated voltage from 3800/6600V up to 19000/33000V
BS 6724	Specification for 600/1000V and 1900/3300V armoured electric cables having thermosetting insulation and low emission of smoke and corrosive gases when affected by fire
BS 7254	Code of practice for the design of high voltage open terminal stations
BS 7671	Requirements for electrical installations. IEE wiring regulations 17th edition
BS EN 60044-1	Instrument transformers – Part 1: Current Transformers
BS EN 60044-2	Instrument transformers – Part 2: Inductive Voltage Transformers
BS EN 60071-1	Insulation co-ordination: Definitions, principles and rules
BS EN 60071-2	Insulation co-ordination: Application guide
BS EN 60076	Power transformers
BS EN 60099-4	Surge Arresters Part 4: Metal-oxide surge arresters without gaps for AC systems
BS EN 60129	AC disconnectors and earthing switches of rated voltage above 1kV
BS EN 60289	Reactors
BS EN 60517	Gas insulated metal enclosed switchgear for rated voltage of 72.5kV and above
BS EN 60694	Common specification for high voltage switchgear and controlgear standards

International Electrotechnical, IEC, standards

IEC 60044	Instrument transformers
IEC 60060	High-voltage test techniques: Parts 1, 2, 3 and 4
IEC 60099-1	Surge Arrestors Part 1: Non-linear resistor type gapped arresters for AC systems (BS EN 60099-1)
IEC 60099-4	Surge Arrestors Part 4: Metal-oxide surge arresters without gaps for AC systems (BS EN 60099-4)
IEC 60255-6	Electric Relays: Part 6 Measuring Relays & Protection Equipment
IEC 60265-1	High voltage switches – Part 1: Switches for rated voltages above 1kV and less than 52kV
IEC 60273	Characteristics of indoor and outdoor post insulators for systems

	with nominal voltages greater than 1000V
IEC 60275	High-voltage switches
IEC 60282	High-voltage fuses
IEC 60287	Electric cables – Calculation of the current rating – Part 2-1: Thermal resistance – Calculation of thermal resistance
IEC 60298	AC metal enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 52kV
IEC 70420	High-voltage alternating current switch-fuse combinations
IEC 60427	Synthetic testing of high-voltage alternating current circuit breakers
IEC 60529	Classification degrees of protection provided by enclosures (IP code)
IEC 60694	Common specifications for high-voltage switchgear and controlgear standards
IEC 61000-3-4	Electromagnetic compatibility (EMC) limits. Limitation of emission of harmonic currents in low voltage power supply systems for equipment with rated current greater than 16A
IEC 61936-1	Power installations exceeding 1kV – common rules
IEC 62271-100	High-voltage alternating-current circuit breaker
IEC 62271-102	Alternating current disconnectors and earthing switches
IEC 62271-105	High-voltage switchgear and controlgear. Alternating current switch-fuse combinations
IEC 62271-200	AC metal-enclosed switchgear and control gear for rated voltages above 1kV and up to and including 52kV
IEC 62271-308	High-Voltage Switchgear and Controlgear - Part 308: Guide for Asymmetrical Short-Circuit Breaking Test Duty T100a
IEC 60507	Artificial pollution tests on high-voltage insulators to be used on AC systems
IEC 62305	Protection against lightning

National Grid Technical Specifications,

NGTS 1	Ratings and general requirements for plant, equipment, apparatus and services for the National Grid System and connection points to it
NGTS 2.1	Substations
NGTS 2.12	Substation Auxiliary Supplies
NGTS 2.2	Switchgear for the National Grid System
NGTS 2.3	Transformers and Reactors for use on 132kV and 400kV Systems
NGTS 2.5	Cable Systems
NGTS 2.6	Protection
NGTS 2.11	Static VAR compensators for connection to 275kV and 400kV systems
NGTS 2.12	Substation Auxiliary Supplies

NGTS 2.19	Ancillary Light Current Equipment
NGTS 3.1.1	Substation Interlocking Schemes
NGTS 3.1.2	Earthing
NGTS 3.1.4	Busbar Systems for AIS Substations
NGTS 3.1.5	Busbar Clamps and Components
NGTS 3.2.1	Circuit Breakers
NGTS 3.2.2	Disconnectors and Earthing Switches
NGTS 3.2.4	Current Transformers for protection and general use of the 132, 275 and400kV systems
NGTS 3.2.5	Voltage transformers for use on the 132, 275 and 400kV systems
NGTS 3.2.6	Current transformers, voltage transformers and combined instrument transformers for settlement metering.
NGTS 3.12.1	48V DC Supplies
NGTS 3.12.2	110V DC Supplies
NGTS 3.12.3	Substation LVAC Supplies

Energy Networks Association Technical Specifications

ENATS 41-10	Switchgear for use on 66 and 132kV distribution systems
ENATS 41-36	Distribution switchgear for service up to 36kV (Cable and overhead conductor connected)

Engineering Guides and Recommendations

IET Recommendations for the Electrical Equipment of Offshore Installations

G5/4-1 Planning and Compatibility Limits for Harmonics

P28 Planning Limits for Voltage Fluctuations

Guidance Notes for Power Park Developers

GB Grid Code and Connection Agreement