Triton Knoll Offshore Wind Farm Limited

Triton Knoll Electrical System

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Appendix 29: Addendum A: Further detail regarding the TKES cable corridor Part 1

Date: 05 January 2016

Appendix 29 of the Applicant's response to Deadline 4

Triton Knoll Offshore Wind Farm Limited

Triton Knoll Electrical System

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Addendum A: Further detail regarding the TKES cable corridor

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Triton Knoll Offshore Wind Farm Limited

Triton Knoll Electrical System

Further detail regarding the TKES cable corridor

Appendix 29 of the Applicant's Response to Deadline 4

Date: 5 January 2016

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1. Introduction

1.1 This addendum supports the Onshore Export Cable Corridor Requirements – Explanatory Note (Appendix 28, which was submitted at Deadline 2 – 27 October 2015). This amplifies the explanation and justification behind the Applicant's having to plan for a 60 m-wide cable corridor being required during the construction and operational phases of the Triton Knoll Electrical System (TKES).

1.2 The location of the buried cable-circuits determines the extent of the final cable corridor during the operational phase of the TKES. This is important, as while standard agricultural operations can be undertaken above the buried cables, restrictions (in the form of restrictive covenants) are imposed on certain activities that could damage the cables or put the landowners' safety at risk but might otherwise be undertaken by landowners above the cables.

1.3 The number of cables that is eventually selected for the TKES will have an important effect on the corridor width. Beyond that, the final width of the corridor in any one place is determined by a number of factors:

- Whether the cables have been buried in a trench, or using a trenchless crossing technique;
- The safety buffer that is imposed either side of the cables (the closer the cables to the surface, the greater the safety buffer that is required);
- The soil conditions;
- Whether an unforeseen obstacle required the cables to deviate, taking more space than originally envisaged; and
- Where a trenchless crossing is used, the size and nature of the feature that is being crossed.

1.4 As explained by the Applicant in its Compulsory Acquisition Clarification Paper submitted at Deadline 3 [REP3-053], to ensure a proportionate approach to land acquisition, the Applicant proposes to use temporary possession powers for construction purposes and to only exercise powers of compulsory acquisition when the final width of the cable corridor is known. This is a common approach for linear schemes, and one which has been approved by the Secretary of State for projects such as the Thames Tideway Tunnel, Forewind's Dogger Bank Creyke Beck A&B

and Dogger Bank Teesside A&B Development Consent Orders. If it is possible to reduce the final permanent corridor width to less than 60m, the Applicant will do so and will only exercise powers of compulsory acquisition over the final width required for the authorised project.

2. Background

Need for the TKES

2.1 The TKES is required to connect the TKOWF array (consent granted in July 2013 by the Secretary of State (SoS)) into the national grid. The TKOWF array is a nationally significant infrastructure project (NSIP).

2.2 International climate change obligations, European and UK law and security of supply considerations provide a very strong and binding combination of drivers for the development of renewable energy, with offshore wind seen as having the potential to be one of the biggest contributors both to 2020 and 2030 targets.

2.3 These targets reinforce the principles and need case identified in the energy National Policy Statements (NPS) which state that the need for offshore wind has been proven. Furthermore the MPS and the relevant East Inshore and East Offshore Marine Plans identify the importance of realising the potential of renewable energy to achieve energy security and climate change aims.

2.4 Without the development of the TKES, the renewable energy benefits of the TKOWF array will not be realised. In granting consent for the Triton Knoll Offshore Wind Farm array the SoS has recognised the important contribution that it would make and has subsequently accepted that the TKES itself is nationally significant, by virtue of it being needed to secure the successful generation from the consented array. In other words, the need and justification for this offshore wind farm, and its cable connection, have been accepted.

Transmission Licence

2.5 The TKES comprises the transmission assets that will connect the Triton Knoll Offshore Wind Farm (TKOWF) into the national grid. All owners of a Transmission Licence are bound by a number of specific obligations.

2.6 Section 9 of the Electricity Act places specific duties on Licensees. For Transmission Licence holders these are:

"(a) to develop and maintain an efficient, co-ordinated and economical system of electricity transmission; and

(b) to facilitate competition in the supply and generation of electricity"

2.7 The latter duty is an overarching principle that ensures that the transmission costs, of electricity are kept as low as reasonably possible as ultimately these costs are met by the consumer.

2.8 The OFTO regime imposed by OFGEM does not allow transmission assets for offshore wind farms to be owned the same owner as the generating assets (the offshore wind farm). Following completion of the construction and commissioning of the TKES (the TKOWF transmission infrastructure), TKOWFL will be obliged to sell the TKES to an "Offshore Transmission Owner" (OFTO). The OFTO is appointed by OFGEM following a competitive bid process.

2.9 Therefore, ultimately it will be the OFTO, not TKOWFL, which will hold the Transmission Licence and operate the TKES. However, in preparing a bid, the prospective OFTOs for the TKES will need to be satisfied that the necessary design standards have been met as required in the Transmission Licence. It is critical therefore that TKOWFL can demonstrate that the TKES has been developed and built in a way which will satisfy all of the obligations that are imposed on the final Transmission Licence holder.

2.10 Further, there is an obligation on licence holders to preserve Amenity and Fisheries; this is often referred to as the 'Schedule 9' obligation, since it is that schedule to the Electricity Act which subsequently provides that each Licence holder:

"(a) shall have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of special interest and of protecting sites, buildings and objects of architectural, historic or archaeological interest;

(b) shall do what he reasonably can to mitigate any effect which the proposals would have on the natural beauty of the countryside or on any such flora, fauna, features, sites, buildings or objects"

2.11 The obligations to develop an economic and efficient transmission system in accordance with Section 9 and the protection of the environment, in accordance with Schedule 9, are paramount and both have a very important influence on the overall design of the transmission system.

Procurement requirement

2.12 An effective and competitive procurement exercise for the provision of key plant and equipment is necessary to ensure that the supply chain is able to meet the capacity and timescale requirements of the project, as well as ensuring the optimum price for its supply. Additionally, a competitive tendering process also allows the supply chain to drive innovation through proposing alternative design solutions using technology or equipment that might not have been commercially available at the time of the wind farm consent stage, but still within the consent envelope. These are key factors in allowing the project to deliver the most competitive and optimised wind farm design, thereby ensuring the economic and efficient system solution and, consequently, lowest cost to the consumer.

3. Need for up to six cable circuits

3.1 The Triton Knoll Offshore Wind Farm will have a generating capacity of up to 900 megawatts (MW). The voltage range of operation for TK is between 132 kilovolts (kV) and 220 kV, to transmit power up to 900 MW.

3.2 A range of cables could be procured for the project and at this stage it is not possible to know which cable configuration will be taken forward. The size of cable ultimately selected will be determined by a number of factors including:

- Availability and cost of each of cable
- Identification of the most economic and efficient solution that is dependent upon:
  - Procurement
  - Detailed electrical design

3.3 132 kV is a standard UK voltage level and is a voltage level that has been used extensively for the connection existing offshore wind farm projects in the UK (Gwynt Y Mor, Robin Rigg, Barrow, Greater Gabbard, Humber Gateway). In marine cable applications, 132 kV makes use of proven, commercially available technology,

3.4 The 220 kV voltage option, while commercially available and used extensively on the continent onshore, is still an emerging technology in marine cable applications and has a far shorter track record – especially in the use of three-core cable for the route lengths that will be needed for the Triton Knoll Electrical System.

3.5 In addition to the higher technology risk associated with 220 kV, there are also fewer potential suppliers at this voltage level due to the specialist manufacturing process that is required at this higher voltage level. The reduced market competition for such a configuration carries with it a risk of less competitive prices for the cable supply or even of an inability for the supply chain to meet the project's programme requirements.

3.6 At present, the project needs to retain the ability to use 132 kV as an export voltage to ensure a deliverable wind farm design solution is maintained that is both economic and efficient. The final selection of export voltage cannot be taken before late 2016 at the earliest, prior to the project's commencing procurement activities for key items of plant.

3.7 Power is the product of voltage and current; and current is the limiting factor for a given cable. At a voltage of 132 kV the overall current is greater and, therefore, more circuits are required than would be the case at a higher voltage.

3.8 The lowest voltage cable that could feasibly be used is 132 kV. Prior construction experience of other offshore wind farms has set a practical transmission limit of approximately 150 MW per circuit at 132 kV. This results in a 6 circuit requirement for 132 kV (6 x 150 = 900).

3.9 It is impossible to be able to determine which cable is ultimately selected for the TK transmission infrastructure until a much later date when enough information exists to ensure that the most economic and efficient design is achieved.

4. Requirements where cables laid in trenches

Construction corridor where cables are trenched

4.1 The onshore construction corridor requires a maximum width of 60 m. This comprises:

- One temporary haul road of up to 6m width (crushed stone)
- Up to 6 cable trenches (one for each circuit), each of around 600mm in width
- Separation between each cable circuit
- Areas for stockpiling of topsoil
- Areas for stockpiling of subsoil

4.2 Figure 1 shows out how the 60 m construction corridor could be used during the construction phase.

4.3 The *Outline Landscape and Ecological Mitigation Plan* (Appendix 27 of the Applicant's Response to Deadline 4) commits to the reducing the working width to 30 m where possible for watercourses where protected species (i.e. water vole) have been detected (para 6.13) and for hedgerow crossing (para 6.16).

4.4 Figure 6 indicates the extent of the removal of a hedgerow where a trenched section of the cable corridor crosses through it. It shows that for very short distances it is possible to narrow the working width by stockpiling spoil in adjacent parts of the cable corridor which therefore allows for the potential for a maximum length of hedgerow of 30 m to be removed.

4.5 However, there may be some areas of the cable corridor where it is necessary to remove longer lengths of hedgerow within the working width, for example, where an obstacle is encountered during the construction phase that necessitates a greater separation between cable trenches. In this instance, this would result in a longer length of hedgerow will need to be removed.

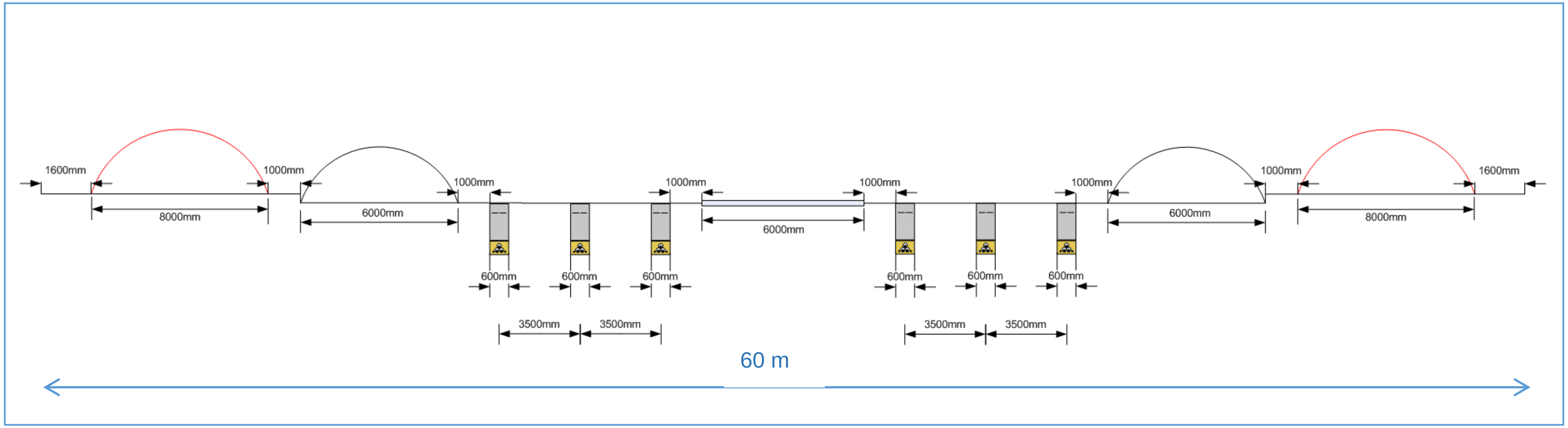

Figure 1 – Indicative layout of the 60 m-wide cable corridor during construction where cables are buried in trenches

Need for operational corridor where cable circuits are trenched

4.6 The width of the final permanent corridor may vary across the length of the cable corridor. Where the cable circuits are buried in trenches, the final overall width of the final permanent corridor boundary is dependent upon a number of factors including:

- Number of circuits (see paragraphs 3.1 to 3.7 above)
- Depth of burial of the circuits and therefore the required separation between circuits (see paragraphs 4.12 to 4.16 below)
- Location of the temporary haul road during the construction phase
- Whether there are any obstructions that require micrositing of cables
- Width of appropriate Safety zone (see paragraph 4.16 to 2.20 below)

Number of cable circuits

4.7 With the exception of the section of the cable corridor between the Triton Knoll substation and the existing National Grid Substation at Bicker Fen, the onshore cables will have a capacity of between 132 kV and 220 kV.

4.8 As described at paragraph 3.9 above, the lowest voltage cable that could feasibly be used is 132 kV; prior construction experience of other offshore wind farms and basic electrical principles set a practical transmission limit of approximately 150 MW per circuit at 132 kV. Thus there is a six-circuit requirement for 132 kV for 900 MW capacity wind farm (6 x 150 = 900).

4.9 Were a 220 kV cable solution to be used, up to 4 cable circuits would be necessary to accommodate up to 900 MW of generation capacity. Fewer circuits are required at 220 kV because, due to the increased voltage allowing a higher MW capacity for a given current, fewer circuits are required to transmit the equivalent power (900 MW) compared to 132 kV. It is not possible to use a higher voltage than 220 kV as the maximum voltage commercially available for the three core marine cable required for the offshore section of the export system is 220 kV.

4.10 In the Triton Knoll substation, the voltage of the transmission of the electricity will be stepped up to 400 kV so that it matches the standard operating voltage of the UK's national grid. Therefore, in the 1.5 km-long section of the cable corridor between the Triton Knoll substation and the National Grid Bicker Fen substation, cables with a voltage of 400 kV will be installed.

4.11 To transmit 900 MW of generation using 400 kV cables, up to four cable circuits are required. Within the National Grid Bicker Fen substation, at 400 kV the connection point consists of two substation bays. It may be necessary to provide two circuits into each connection point (bay), connected in parallel; hence four circuits in total. There are two reasons for requiring the flexibility to install parallel circuits at this stage:

- as there are two connection points (two bays) within the National Grid substation, the power is shared equally, at 450 MW per bay. Therefore, considering this high power capacity per bay and factors such as the potential cable de-rating issues, triggered by the close proximity of circuits and other plant and internal equipment within the substation, parallel circuits may be necessary to achieve the required MW capacity; and

- the electrical characteristics of two parallel cables are different to that of a single large cable. For technical reasons relating to the control of power quality (itself a regulatory requirement), it may be necessary to exploit these electrical characteristics making it necessary to install two parallel circuits, rather than one circuit of a larger cable size.

Separation between circuits

4.12 The lateral separation that is required between individual cable circuits varies with cable capacity and burial depth.

4.13 An important consideration for the separation between circuits is the effect of heat on the operation of individual cable circuits. The higher the current in the cable the higher the losses and the more the cable heats up. The deeper the cable is installed, the more difficult it is to dissipate the heat; hence the cable needs to carry a lower current (same as saying the ampacity decreases), thereby potentially reducing the amount of the electricity that can be put into the national grid. For instance, if the wind speed is high and the wind turbines are operating at maximum installed capacity (maximum output, such as 900 MW), the cable circuits must be able to transmit the electricity at their full capacity to ensure that all of the electricity generated reaches the national grid.

4.14 The rating of the cable can reduce if the temperature of the cables is too high. The temperature of cables can be affected by:

- The proximity of one cable circuit to another - it is important therefore that each cable circuit is “thermally independent”. Cables heat up when current flows through them (similar to a tyre on a car due to friction). If they are too close together, the thermal independence of the circuits is lost and the operating temperature of one can affect the other.

- Installed cable burial depth - the ability to dissipate heat is a function of the distance to the surface as well as the composition of the surrounding environment. Figure 2 below shows a theoretical example of the reduction in capacity with an increase in cable burial depth for two operational voltages.

- Soil type – the nature and composition of the soil has an important effect on rate of heat dissipation, (known as the “resistivity” of the soil).

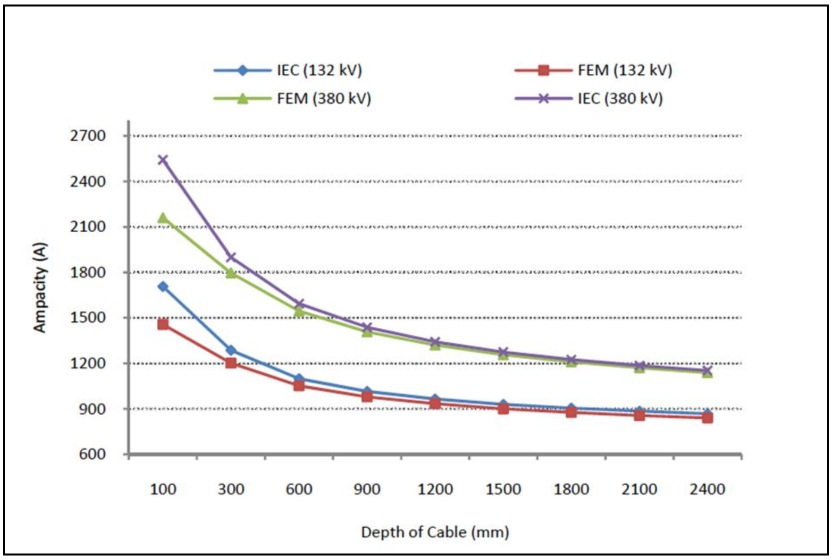

Figure 2 – Effect of burial depth on operational performance of the cables[1]

4.15 As set out above, cable circuit spacing is required to ensure thermal independence between circuits. A rule of thumb applied as a starting point is that the distance between the circuits is twice the depth of cable installation, such that zero heat transfer is obtained.

4.16 Figure 3 provides a cross section of the cable corridor using 132 kV cable circuits where the cables are trenched. It demonstrates the separation that is required between six 132 kV cable circuits. The green circles indicate the separation required between cable circuits to ensure that each circuit remains thermally independent

[1] Comparison of Finite-Element and IEC Methods for Cable Thermal Analysis under Various Operating Environments (M. S. Baazzim, M. S. Al-Saud, M. A. El-Kady) - World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:8, No:3, 2014

4.17 In addition to the spacing requirements to retain thermal independence of adjacent circuits, the requirement to maintain system resilience is also a key factor in determining circuit spacing, particularly at higher export voltages where the number of export circuits may be reduced.

4.18 For example, in a 132 kV, six-export circuit system with spacing of 3.5 m between circuits, an external event that causes damage to two circuits would result in approximately 33 % of the wind farm's export capability being lost. If a similar event were to occur to two adjacent circuits on a four-circuit, 220 kV system with the same spacing between circuits, the loss of wind farm export capability would be approximately 50 %.

4.19 As the number of circuits used reduces, the circuit spacing needs to increase to ensure that appropriate system resilience is maintained, as a higher proportion of the power from the wind farm is being carried on each circuit and therefore at risk of a single event damaging a circuit.

4.20 In the event of a catastrophic accident where a circuit is taken out of operation, given the type of mechanical machinery that could cause such an incident, it is considered that a separation of 3.5 m is not sufficient to ensure that the incident is isolated to just one circuit.

4.21 It is important that the spacing between circuits is adequate to ensure that in the event of a catastrophic accident, the overall impact is minimised. TKOWFL has determined that a separation of 7 m between individual 220 kV circuits (and 400 kV circuits where relevant) is necessary to ensure that an incident that affects one circuit would be very unlikely to affect another circuit. An indicative arrangement of the trenched 220 kV cable circuits is shown in Figure 4.

4.22 An adequate spacing between export circuits is based on an assessment of the potential events that pose a risk to the cable system given the land use along the route, and the impact on the loss of export capacity for such events which is linked to the number of circuits installed. Using this risk assessment, a suitable circuit spacing is identified using engineering experience to reduce the impact of an event that has potential to damage the installed cable system to as low as reasonably practicable.

4.23 The construction phase of the TKES requires a haul road in the middle of the circuits to ensure that construction activities are optimised through allowing access to two work faces either side of the haul road simultaneously. It is also necessary for a space to be maintained between the cables during the operational phase of the wind farm to ensure that it is possible to access all cable circuits in the event of needing to remedy cable faults during the operational phase. Repair of cable faults will require similar plant and equipment to that needed for the initial construction phase, therefore access and laydown requirements for remedial works during the operational phase will be equivalent to those required during construction.

Cable burial depth

4.24 Figures 3, 4 and 5 show that in a standard trenched burial, the minimum burial depth of the onshore cables for the Triton Knoll Electrical System will be 1.2 m below the surface of the ground, assuming an average topsoil depth of 300 mm. This minimum burial depth is sufficient to provide adequate cover to the top of cables to accommodate all standard agricultural practices and provide sufficient spacing between cables and land drainage. However, final burial depth will be assessed on a field by field basis and, where there is a greater depth of topsoil encountered or land drainage systems are installed deeper into the subsoil, then the cable circuits will be buried to a depth greater than the minimum burial depth of 1.2 m.

4.25 In a standard trenched burial, the thermal impendence achieved through adequate horizontal spacing between cable circuits ensures circuit rating is not affected by small deviations in burial depth.

Accounting for obstacles

4.26 There will always be unknown features which, despite all reasonable efforts, are not discovered until after the completion of pre-construction surveys at the detailed design stage or even during the construction itself. These include but are not limited to:

- Previously unknown archaeology
- Disused infrastructure, such as water mains
- Discovery of unexploded ordnance (UXO)
- Discovery of WWII air raid shelter or similar
- Unforeseen or localised soil conditions that are significantly more challenging from an installation perspective, such as discovery of “bog oak” – common on some sections of the TKES cable corridor and very often not possible to remove from the ground.

4.27 Figures 6 and 7 provide indicative examples of deviations to trenched cable corridor layouts using 132 kV cables and 220 kV cables that could result from the discovery of obstacles within the cable corridor. The exact extent of any diversion will vary depending on the size and nature of obstacle. However, it is important that the maximum width of the cable corridor is available for any diversions that may be required.

Determining appropriate safety zone

4.28 As explained above, all standard agricultural activities can be undertaken above the buried cables as usual. However, restrictive covenants are imposed within the final cable corridor in order to:

- safeguard what will be a nationally significant asset, that will be part of the national electricity transmission network, meeting a renewable energy need that is firmly enshrined in government policy via the National Policy Statements;
- protect the physical integrity of the TKES, by preventing interference with/damage to it, and by ensuring that it can be easily accessed for maintenance;
- ensure the continued transmission of electricity so as not to compromise the national yield; and
- prevent injury to members of the public which may result from damage to or interference with the installed infrastructure.

4.29 As explained in the Applicant’s response to the ExA’s Second Questions CA 2.10, the restrictive covenants will restrict:

- the erection of buildings or other works requiring foundations and footings which may damage or prevent access to TKES;
- the laying of hard surfaces above the cables which could damage or prevent access to TKES;
  - excavations and certain agricultural practices that exceed 600 mm in depth above the cables so as to protect the apparatus from interference and/or damage and to protect members of the public/landowners from associated injury;
  - the planting of deep rooted trees and other vegetation which could damage the TKES; and
  - prevent any works which may render TKES or any part of it in breach of the relevant regulatory framework.

4.30 The restrictive covenants are to imposed over the land immediately above the installed cable circuits and also across a safety buffer at either side of the cables. The size of the safety buffer is determined largely by the depth of the burial of the cables.

4.31 All utility infrastructure is protected by safety zones that restrict activities above the cables. For instance, in the draft Protective Provisions (PPs) that are being negotiated between TKOWFL and National Grid (NGET and NGG[2]), a 15m buffer from National Grid assets has been agreed, within which clauses within the PPs, relating to work undertaken by the Applicant in proximity to NGs assets, are triggered.

4.32 In determining the appropriate safety buffer, the following issues will be taken into account:

- burial depth;
- protection already afforded to it;
- activities likely to be undertaken within the vicinity of the infrastructure.

4.33 Where the cables are buried in a trench, they are relatively close to the surface. As such, a safety buffer of around 7.5 m either side of the cable is considered appropriate. Figure 3, 4, 5, 6 and 7 show an indicative layout of the final permanent boundary where cables have been buried, including 7.5 m either side.

4.34 In the case of trenched burial where the cables are relatively close to the surface (ie up to 2 m), TKOWFL considers that a 7.5 m safety buffer is appropriate to protect human safety and the operation of the cables. This buffer zone allows access to the outermost cable circuits in the event of needing to carry out any remedial works to the circuit, as well as providing adequate spacing between the circuits and any future activities adjacent to the corridor over which the project has no control.

Indicative overall width of Final Permanent Boundary where cable is trenched

[2] National Grid Electricity Transmission and National Grid Gas

4.35 The total width of the Final Permanent Boundary may vary depending upon the number of circuits installed and the capacity of each circuit. This in turn is dependent upon the final total capacity of the wind farm and the capacity of the cables that are selected.

4.36 Figures 3 and 6 indicate that where six circuits at 132 kV capacity are trenched, a final permanent cable corridor of around **40 m** could be required, even if one were, imprudently at this stage, to assume an absence of obstacles; where obstacles are encountered, the need for the full 60m remains.

4.37 Figures 4 and 7 indicate that where three circuits at 220 kV capacity are trenched, a final permanent cable corridor of around **37 m** could be required; again the same point about obstacles remains.

4.38 Figure 5 indicates that where four circuits at 400 kV capacity are trenched on the 1.5 km stretch between the Triton Knoll substation and the NGET substation, a final permanent cable corridor of around **37 m** could be required where no obstacles are encountered.

5. Requirements where cables installed using a trenchless crossing

5.1 A brief explanation regarding the cable corridor width that is required where a trenchless burial technique is used is set out in paragraphs 4.8 to 4.12 of the Onshore Export Cable Corridor Requirements – Explanatory Note. Further information is provided below.

5.2 Trenchless burials are generally used where the corridor crosses a feature that it is not possible or appropriate to trench through. For instance, in order to minimise disruption to the local road network in the vicinity of the cable corridor, a commitment has been made to cross all public roads using trenchless crossing techniques. Trenchless crossings will also be used for many drains, and for all rivers and railways.

5.3 The Crossing Schedule (Appendix 45 to the Applicant's Response to Deadline 4) identifies which features TKOWFL has committed to cross using trenchless crossing techniques. This includes every public road and also 115 individual drainage ditches as well as the railways. However, it may the case that very many more drains are crossed using trenchless crossings. At the detailed design phase an assessment will be undertaken of every feature that the cables need to pass underneath to determine whether it can be crossed by a trench, or whether it is necessary to use a trenchless crossing such as HDD. In taking the decision, the following factors will be considered:

- the ground conditions, including profile of the feature being crossed, such as drain depth and height of banks;
- the size of the feature, potentially including proximity to other adjacent features that need to be crossed;
- the depth in which the feature needs to be passed, including any minimum depth of cover requirements to cover future maintenance of the feature;
- the environmental impact of such deviation (e.g. impact of open cut trenching across a small drain versus the additional laydown reinstatement needed each side of the feature if a trenchless technique is used;
- the health and safety impacts on all involved, such as required depth and scale of excavations;
- the impact on the landowner; and

- the requirements of the electrical system, such as utilisation of a large cable for deeper trenchless crossings

5.4 Across the cable corridor, drains border every field and it is very likely that the number of trenchless crossings that are undertaken within the cable corridor, will significantly exceed the number of crossings that are identified in the existing Crossing Schedule. However, it will only be possible to identify which features could be crossed using trenchless crossing techniques at the detailed design stage.

5.5 All trenchless crossings are constructed and accommodated wholly within the construction corridor. The installation is constrained by a number of factors including the siting of the drill entry and exit compounds, cable alignments and size and nature of the feature(s) that is/are being crossed. This in turn determines the burial depth and can affect the spacing in between each cable circuit.

5.6 The principal technique used for trenchless crossings is a horizontal directional drill (HDD). The location of the starting point of each HDD will be determined largely by the size of the boring machine and associated ancillary equipment, including processing of material that is removed during the drilling process, temporary power units and drill casing storage. This overall drill spread has a significantly larger footprint compared to the standard trenched installation spread which, in turn, drives a wider circuit spacing for the sections of the route that make use of trenchless installation techniques.

5.7 In addition to the physical size of the trenchless installation spread, ground stability will also be factor in determining circuit spacing. Given the increased depth of the trenchless installations, and the potential for these techniques to cover several hundred metres, spacing of the circuits may need to be increased to ensure the integrity of the drill bores are maintained. Ground stability will be assessed using borehole information gained through a combination of the pre-construction site investigation works and historic data during the detailed design stage, which will inform the design of the layout and design of the drilling activities, which therefore determines the circuit spacing. Softer ground will require a greater distance of separation either horizontally or vertically, or a combination of both, to achieve a successful drill and maintain bore integrity, as some bore stabilisation may be required during the operation.

5.8 The relevant historic data that has been analysed, local knowledge of soil conditions within Lincolnshire and experience of other similar projects indicates that the 9 m separation would allow for this a successful bore to be achieved using this methodology.

5.9 The depth and nature of an obstacle (drain, ditch, river, road or railway line) will affect the distance required away from the obstacle to achieve the target depth. The installation will require several calculations:

- the ground composition - If there is a suitable layer of material which is better to drill through, without compromising the target depth required, i.e. clay v silt, rock v running sand
- the minimum bending radius allowed to be applied to the cable (this will be a requirement by the cable manufacture and differs from cable to cable).
- an overall estimated towing tension for the section of cable in which the HDD is to be performed. The selected cable will have a maximum towing tension (namely the force which can be applied to it during installation through the ducting). This maximum tension can vary from location to location; for example, every time you apply a bend to the cable route either vertically or horizontally it increases the tension required to pull the cable through the duct network. By altering the angle of repose during an HDD this effect can be decreased. It is common practice for the installation contractor to restrict this angle to 11.5 degrees. Occasionally, up to 22 degrees can be used, but this would depend on all the other factors mentioned above being favourable, .including the position of the bend in relation to the installation direction i.e. close to end of a pull is better than a bend at mid-point.

5.10 The design of the HDD operation will take account of the specific characteristics of the feature that needs to be crossed. Three indicative examples are shown below of the effect that the nature and size of a feature to be crossed can have on the design of an HDD.

1. Crossing small drain or river.

5.11 Figure 8 shows an indicative plan layout of a trenchless crossing for a small drain or river where there are six 132 kV cable circuits. It demonstrates that for the smallest features to be crossed, a set-back distance of around 20 m could be required between the river or drain and the drilling rig.

5.12 Figure 8 demonstrates that even for a relatively small crossing, an indicative separation of 9 m between the cable circuits is likely to be necessary owing to the size of the drilling rigs and the need to for them to be located off-set to each other to maintain soil stability. This figure further demonstrates that for a trenchless crossing of this scale, a very limited stretch of hedgerow will need to be removed, to accommodate the haul road only. The hedgerow can remain where a drill passes underneath.

5.13 Figure 9 shows an indicative cross section for a drill for a smaller crossing such as this.

2. Crossing a road and river/ large drain in single crossing

5.14 Figure 10 shows an indicative plan layout of a trenchless crossing for a small drain or river where there are six 132 kV cable circuits. It demonstrates that for larger scale-features, a set-back distance of around 30 m could be required between the river or drain and the drilling rig. This figure further demonstrates that for a trenchless crossing of this scale, a very limited stretch of hedgerow will need to be removed, to accommodate the haul road only. The hedgerow can remain where a drill passes underneath.

5.15 Figure 11 shows at indicative cross section for a smaller crossing such as this.

3. Crossing a large railway or large watercourse

5.16 Some of the largest features will include railway lines and or large roads and ditches. There are some crossings where there are multiple large features that need to be crossed.

5.17 Where the largest drills are undertaken, owing to the size of the machinery, greater space is required to accommodate the drilling rigs. This is shown in the indicative layout at Figure 10 which provides for individual rigs of 9 m by 18 m.

5.18 Figures 12 and 13 provide an indicative arrangement of six 132kV cable circuits where the cables cross a railway line, although a drill of this scale could also be necessary for a very large drain/river, or where a number of features are being crossed in a single drill.

5.19 In permitting a drill and installation of cables beneath operational railway lines, Network Rail impose highly prescriptive tolerances on the permitted vertical movement of the railway line (settlement). The allowable “settlement” will be determined by Network Rail and this could be less than 5 mm. Again calculations based on the ground information will be translated into a design that will need the approval of Network Rail. Track-movement monitoring will be in place, prior to, during and following completion of installation to ensure the design parameters have been successfully achieved (including settlement of no more than 5 mm).

5.20 Figure 14 has been provided to demonstrate the potential layout where four 220 kV cable circuits are used.

Determining appropriate safety zone

5.21 Paragraphs 4.26 to 4.30 above describe the principles of safety zones. Where the cables are buried using a trenchless technique, they are buried at a greater depth below the surface than the trenched technique. As such, a smaller safety buffer is required as the circuits will not be as much at risk from activities over or adjacent to the circuits due to a combination of their greater depth and that the technique tends to be used at locations where a feature or obstacle exists that would inherently limit activity close to the circuits. TKOWFL considers that a buffer of 3.5 m either side of the cables is considered appropriate, given this reduced risk to the cable .

6. Conclusion

6.1 It is necessary for TKOWFL to seek powers of compulsory acquisition which correspond with the scope of the scheduled works for which development consent is sought. Taking the factors in this paper into account, it is not possible to reduce the scope of acquisition within the limits of those scheduled works without putting at risk the deliverability of the entire project. Given the very high number of trenchless crossings that are needed and the number of imponderables, such as spacing depth and rating of cable circuits; the potential number of constraints/obstructions which will need to be routed around; it is essential that the compulsory acquisition of rights is authorised over the entire 60m corridor.