DECERNA

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Oxford New Energy Ltd

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DECERNA

1 Introduction

1.1 Decerna

Decerna were formally known as Narec Distributed Energy Ltd (NDE) and is an organisation which carries out a wide range of work within the renewable and low carbon sector. Our work covers renewable energy, low carbon/carbon-negative housing, energy storage and grid connection. Within these areas we deliver consultancy, training and testing.

In terms of grid connection, our work ranges from assisting single bespoke homes with connections, up to full multi-MW solar farms, wind farms and battery parks. Our clients include small installation companies, local authorities and multinationals. We assist our clients every step of the way, from initial assessment and budget enquiry, through to detailed negotiations with DNOs/National Grid, and arrangement of ICP works.

Decerna have been invited by Oxford New Energy Ltd to provide a technical overview of the connection of a new 18MW grid connection for a new 26.6MW DC capacity PV farm at Noke, Oxfordshire. The principal function of this report is to provide the Cherwell District Planning Engineers a deeper understanding of the issues, limitations and restrictions facing a solar farm development in the Cherwell Council area.

1.2 Personnel

Our expertise is based around our former Distribution Network Operator (DNO) trained staff with over 50 years of UK grid experience between them. The team delivering this report are -

Bryan Dixon

Bryan heads up the grid connection work at NDE. He has over 40 years' experience in the electricity industry and is an expert within his area. Bryan works on the full grid connection of wind, solar and battery projects, from the initial grid feasibility all the way to full grid applications, negotiations with DNOs and appointment of ICP's and IDNO's.

Prior to NDE, he worked as a Senior Network Design Engineer at Northern Powergrid for several years, working on network studies, grid connections, system analysis, preparation of budget estimates, firm quotations, preparation of scheme drawings, customer visits, and liaising with wayleaves and construction engineers.

Prior to this, Bryan was a Senior Authorised Person / Project Manager for Balfour Beatty Power Services and Bethell Power Services and a Contract Manager for Bethell Power Services.

Prior to joining Bethell Power Services in 2002 Bryan was the Public Lighting Faults Manager for Northern Electric (now Northern Powergrid) an Overhead Linesman which followed on from him joining the N.E.E.B. (now Northern Powergrid) as an Overhead Line apprentice in 1982.

Harvey Potter

Harvey has worked within the electrical industry for almost 6 years and is experienced at National Grid level.

Prior to working at Decerna, Harvey worked at Siemens Electrical Services where he was a Commissioning Engineer working on new substations for National Grid. This involved testing, documentation, logging and processing of electrical data and the use of test equipment and working under a Permit to Work system and a Sanction for Test regime.

Dr Tom Bradley

Tom has worked in the energy industry for over 12 years, working on a range of generation technologies, including wind, wave, tidal, ground source, biomass, heat pumps, photovoltaics and solar thermal. He has also worked on projects involving various grid and storage technologies.

Tom has experience of analysis of large and complex datasets, using various pieces of scientific software, and designing bespoke applications. He has a strong knowledge of industry and speaks at relevant conferences. Tom is one of the co-owners and founders of Decerna ltd.

2 Information sources

Decerna Ltd have undertaken this study based on the publicly available generation heat map data provided by National Grid Distribution (formerly Western Power Distribution or WPD), UK Power Networks (UKPN) and Scottish & Southern Electricity (SSE). We have also used data provided in the Long-Term Development Statements of all three DNOs and we have also referred to National Grid's (NGET) generation heat map to fully understand any upstream transmission constraints.

Note National Grid's disclaimer regarding the accuracy of the information provided –

> *'We have developed the network capacity map to assist you with connections applications in constrained areas. The map gives a general illustration of availability constraints only and cannot be relied upon to assess the terms of connection for specific premises. Whilst we use reasonable endeavours to ensure that the network capacity map and related information is accurate, we do not warrant, and do not accept any responsibility or liability for, the accuracy or completeness of the content or for any loss which may arise from reliance on the network capacity map or related information'.*

SSE also have a similar but less specific disclaimer -

> *'Please note that distribution network constraints may be caused by a number of issues such as thermal, fault level, voltage constraints. Other constraints can be caused by physical space limitations within SSE licence areas or limitations imposed by the Transmission System Operator'.*

UKPN declare –

> *'The Distributed Generation map shows the approximate locations of our 33kV and 132kV overhead electricity network towers and poles. It also shows where our 11kV, 33kV and 132kV substations are approximately in the East of England and the South East. Please note the data provided is indicative only'.*

Note - the sources of information we have used for our report are constantly changing and are regularly updated. Therefore, the information we have included in this report is only guaranteed to be accurate on the day of publication.

3 Assessment area

The area that we have considered for the availability of a grid scale generation connection is the Cherwell District Council geographical boundary. The area the Council covers has a total landmass of 588.8 square kilometres (227.3 square miles). This area is supplied electrically via both National Grid Distribution to the North, SSE to the South and is bordered by UKPN to the East. We have also considered all substations outside of this area which have a direct impact on substations within the outline boundary zone. This allows for a fair and accurate assessment of the total Cherwell District Council area.

This area is shown within Figure 1. (see following page)

In this revised assessment we have gone even further and have assessed the National Grid Electricity Transmission network well outside the area. These substations will ultimately supply some if not all of the substations in the Cherwell area as the network transfers from National Grid Transmission to the regional DNOs.

Figure 1: Cherwell District Council Boundary map

4 Assessment criteria

All the sites have been assessed purely from an electrical generation connection point of view only. All constraints, issues and limitations have been considered and the available generation connection points shown. No consideration has been given to planning, areas of outstanding natural beauty (AONB) or areas of special scientific interest (SSSI).

4.1 System voltage selection

We have assessed every Primary Substation, Bulk Supply Point and Grid Supply Point that have an influence on the electrical grid in the Cherwell Council area. Local or Secondary Substations as they are known have been discounted as they operate at 11kV (11,000 volts) and as such they are inadequate to distribute the amount of export required which in this instance is 18MW (18.95MVA). The absolute maximum feeder capacity at 11kV is generally regarded to be 8MVA. This is only available if the maximum cable size is installed (300mm triplex) and a 400A circuit breaker is fitted at the Primary Substation. Obviously if the cable size is smaller (very common) or a 250A (or smaller) circuit breaker is installed then this capacity will be significantly reduced. It should also be noted that large scale generators normally have to be connected to a dedicated feeder and not 'teed in' to an existing one due to the requirements of intertripping (intertripping is where in the event of a fault the feeder trips at both the source end (generator) and the export point (Point of Connection) to ensure a safe network condition exists).

This means that the only viable connection voltage for this project is 33kV. This is because a 33kV feeder is generally capable of catering for 25MW or more with large cables and circuit breaker combinations. A 132kV or 400kV connection were also discounted as the cost of a connection is prohibitively expensive due to significantly higher plant, cable and connection works.

5 Constraints

Like the rest of the UK the National Grid, UKPN and SSE distribution networks are under significant stress from the large number of renewable energy projects connected in their respective franchise areas. Due to the prevalence of high volts, fault level rating issues, thermal rating & current carrying capacity issues the distribution network has several heavily constrained areas. Many of the 132kV Grid and Bulk supply points and their associated primary substations have various restrictions to consider before a connection offer can be made for additional generation.

5.1 Constraints explained.

There are many restrictions or constraints which affect the connection of large-scale grid generation. The main areas which cause a constraint or lack of available connection capacity are as follows –

- **Fault level** – this is the amount of energy that would be released in the event of a short circuit. This can be either a single phase to earth (the most onerous scenario) or a three-phase asymmetric fault to earth. The fault level limit is the upper rating of the connected equipment, with the usual 'weak link' being the switchgear. More generation = increased fault level.
- **High volts** – this is a situation on the distribution network where the amount of generation connected to the network causes the voltage to rise. If this exceeds statutory voltage levels then damage to consumers equipment may be caused and outages can occur. This is controlled by 'tap changers' at Primary Substations, however it is possible to run out of available tap settings and thus high voltages can occur.

- **Thermal rating** – this is where equipment (usually cables & conductors) heats up due to the amount of energy they are carrying. This can lead to failures and in the case of overhead lines it can also lead to low ground clearance issues due to excessive sag.
- **Current carrying capacity** – this is where the actual design limits of the equipment is exceeded which leads to accelerated wear and ultimately failure of a piece of plant or equipment.
- **Reverse powerflow capability** – certain grid transformers can often only cater for 50% of their normal working capacity as reverse powerflow. This is fairly common across the whole of the UK but it does reduce the amount of generation that may be connected.
- **Directional protection** – some Primary Substations have protection relays that only work in one direction and are therefore unsuitable to cater for any generation connections.

Generation projects which may have been accepted three to four years ago have now been fully constructed, commissioned and are now being energised; the amount of constraints on their respective distribution networks grows greater every day. Every update of the respective heat maps shows less & less opportunities to connect generation. This can literally vary from day to day, depending how often each DNO updates their respective heat maps. This is a very volatile and rapidly changing environment and it is only heading in one direction for the foreseeable future where eventually no further generation connections will be possible and the grid will be at saturation point.

To effectively manage the issues that they have on their respective networks and to maintain statutory voltage limits, National Grid Distribution, UKPN and SSE have several different ways (some of them will operate concurrently with each other) to actively manage their networks. Some of these are listed below.

5.2 Powerfactor

In order to allow DNOs to contain voltage within acceptable limits at the National Electricity Transmission System (NETS) / Distribution System interface, the Customer must ensure that the generators (>=1MW) have the capability to operate between 0.95 leading and 0.95 lagging power factor. Customers will be advised of the target Power Factor within this range.

5.3 Disconnection

National Grid Electricity Transmission (NGET) has instructed that all UK DNOs shall maintain a facility such that under emergency conditions on the National Electricity Transmission System (NETS), DNO' shall have the ability to de-energise embedded generation (>=1MW) upon instruction from NGET.

5.4 South West Operational Tripping Scheme National Grid Distribution area (SWOTS)

The Customer's generation will be included in the South West Operational Tripping Scheme (the SWOTS) required by National Grid Electricity Transmission (NGET). The SWOTS will automatically constrain the Customer's generation output to zero during N-3 outage conditions on the National Electricity Transmission System (NETS).

5.5 Active management

The Customer's generation will be included in the SGT Active Network Management Scheme (ANM). The ANM will automatically curtail the output of the Customer's generation in order to control power flow in reverse direction through the Supergrid Transformers (SGTs) at the Grid Supply Point.

5.6 Connect & Manage

The Customer's generation will be included in Connect & Manage arrangement to address transmission system constraints through NGET having better management, visibility and control of Distributed Energy Resources (DER).

6 Substations

The substations listed below are either in the Cherwell District Council geographic area or have a direct bearing on substations within the Cherwell District Council geographic area. The substations are listed with a note of any operational restrictions, constraints and limitations. Substations outside of the area and with no possible connection or influence on substations within the Cherwell District Council area have not been included in the list.

A GSP (Grid Supply Point) is where the DNO receives their incoming supply from National Grid (NGET). A BSP (Bulk Supply Point) is similar to a GSP but this is where the DNO supplies a number of its Primary Substations from. All other substations are Primary Substations which are where the DNO reduces their transmission voltage (usually 33kV down to 11kV) and then transmits this to Secondary or Local Distribution Substations. These Secondary or Local Substations then reduce the voltage to 230/400 volts.

6.1 National Grid Distribution substations

There are National Grid Distribution substations which have an influence on the Cherwell District Council geographical boundary.

- **East Claydon 132kV** – unable to accept additional demand or export connections due to the number of existing connections (both generation & demand).
- **Brackley 132kV BSP** – zero export / generation due to fault level issues.
- **Bloxham 66/11kV** - zero export / generation due to fault level issues.
- **Epwell 66/11kV** – zero export / generation due to fault level issues.
- **Thenford 33/11kV** – zero export / generation due to fault level issues.
- **Shipston 33/11kV** – zero export / generation due to fault level issues.
- **Moreton 66/11kV** – zero export / generation due to fault level issues.
- **Brackley Town 33kV** - zero export / generation due to fault level issues.
- **Calvert 33/11kV** - unable to accept additional demand or export connections due to the number of existing connections (both generation & demand).
- **Steeple Claydon Primary** - unable to accept additional demand or export connections due to the number of existing connection (both generation & demand).

6.2 SSE substations

There are eleven SSE substations which have an influence on the Cherwell District Council geographical boundary.

- **Headington** - now only able to accept a maximum of 0.77MVA of generation due to available capacity, reverse powerflow capability of the transformers (50%) & fault level issues.
- **Headington BSP** – heavily constrained, fault level almost at maximum rating 12.49kA against a maximum of 13.1kA. No generation connection was possible.
- **Yarnton** - unable to accept additional export connections due to upstream (higher voltage) constraints. No generation connection available.

- **Arncott** - unable to accept additional export connections due to upstream (higher voltage) constraints and thermal limit (conductor and/or cable size). No generation connection was available.
- **Upper Heyford** - unable to accept additional export connections due to upstream thermal limitations. Limited expansion space for Circuit Breaker extension connections (very small site). No generation connection was available.
- **Bicester** - unable to accept additional export connections due to upstream (higher voltage) constraints and thermal limit (conductor and/or cable size). No generation connection was available.
- **Bicester North BSP** - Constrained due to 132kV thermal limitations under FCO (Fault Current Operation). Close proximity to thermal rating on Bicester-Bicester North 33kV circuit. No generation connection was available.
- **Kiddington** – constrained due to voltage issues (exceeding statutory voltage limits). No generation connections were available.
- **Lovelace Road** - constrained due to upstream thermal limitations. Limited expansion space for CB connections. Only 50% reverse powerflow capability – max 6MW without other restrictions.
- **Cottisford** - constrained due to upstream thermal limitations (conductor and/or cable size). No generation connection was available.
- **Deddington** - unable to accept additional export connections due to upstream (higher voltage) constraints and thermal limit (conductor and/or cable size). No generation connection was available.

6.3 UKPN substations

There is only one substation which has an influence in the Cherwell District Council geographical boundary.

- **Thame Primary** - unable to accept any generation due to the type of directional overcurrent protection that is installed.

6.4 National Grid Electricity Transmission substations

There are a number of National Grid Electricity Transmission substation just outside the Cherwell Council area which have a direct impact on the substations in and around the area.

- **East Claydon 400kV** – No connections available before 2030 at the earliest.
- **Patford Bridge 400kV** - No connections available before 2030 at the earliest.

National Grid Transmission are heavily constrained across the whole of the UK and are struggling to keep up with connection demands. This not only affects large scale generation connections of 100MW+ but has a knock-on effect to the lower voltages operated by the UK DNOs. The situation has got so bad in some areas that new generation connection are not possible until as late as 2039.

6.5 Results

As it can clearly be seen from the substation information the situation in the area has significantly declined and only Headington Substation in the Cherwell District Council area is capable of catering for a connection of 18MW to support the proposed photovoltaic development as this has already been accepted by the client and the value is included in the SSE figures (accepted but not yet connected is the terminology). SSE have offered a connection on the Bicester – Headington 33kV feeder. This connection is very close to the maximum allowable at Headington Substation and is realistically the last significant generation connection that will be made in the Cherwell District Council area for the foreseeable future.

However, looking at the substations in the area any development of this type this must have already received a formal connection offer from one of the DNO's and this must have been accepted (accepted but not yet connected} by a developer/landowner as there is no possible connection for any generation above 0.77MW in the Cherwell area until after 2030 at the earliest.

Whilst the capacity to connect large generation assets to the higher voltage network will be very constrained, there will continue to be capacity to connect solar rooftop systems to the network for the following reasons: in many cases, most of the solar output will be consumed within the building where the panels are located, the systems will connect to the lower voltage network and most or all of the electricity exported by them to the network will be consumed locally before reaching the 33 kV network, and any surplus electricity that makes it way to the 33 kV network is unlikely to be large enough to create network management issues

7 33kV feeder route

The Bicester-Headington 33kV feeders run between substations in those two locations. The start and finish points are shown in Figures 2 and 3 below. National Grid Distribution identifies their 33kV feeders with a specific and unique character. In this case one of the feeders is identified as (black & white) and the other as (black & blue). This allows for easy identification of a feeder for the purpose of switching, operation, fault repairs and maintenance. The start and finish points are as shown within Figure 2 and Figure 3 below –

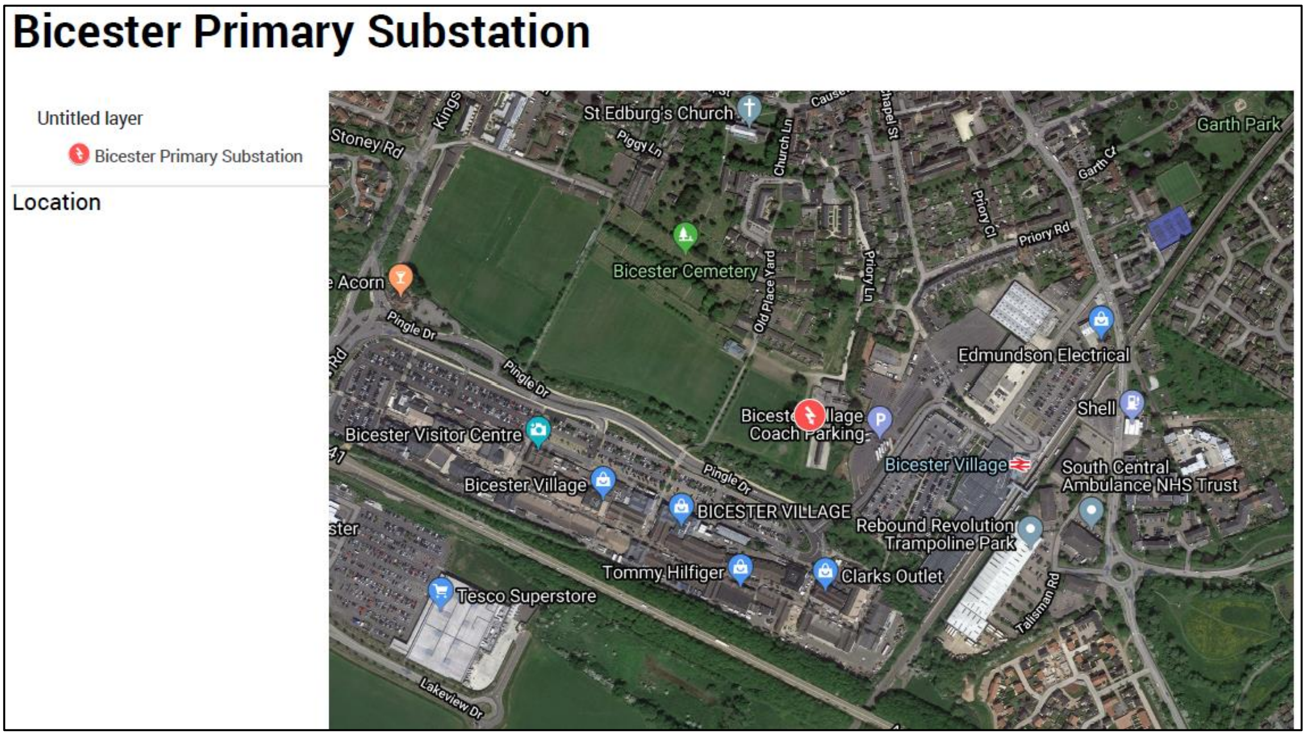

Figure 2: Bicester primary substation courtesy of Google maps

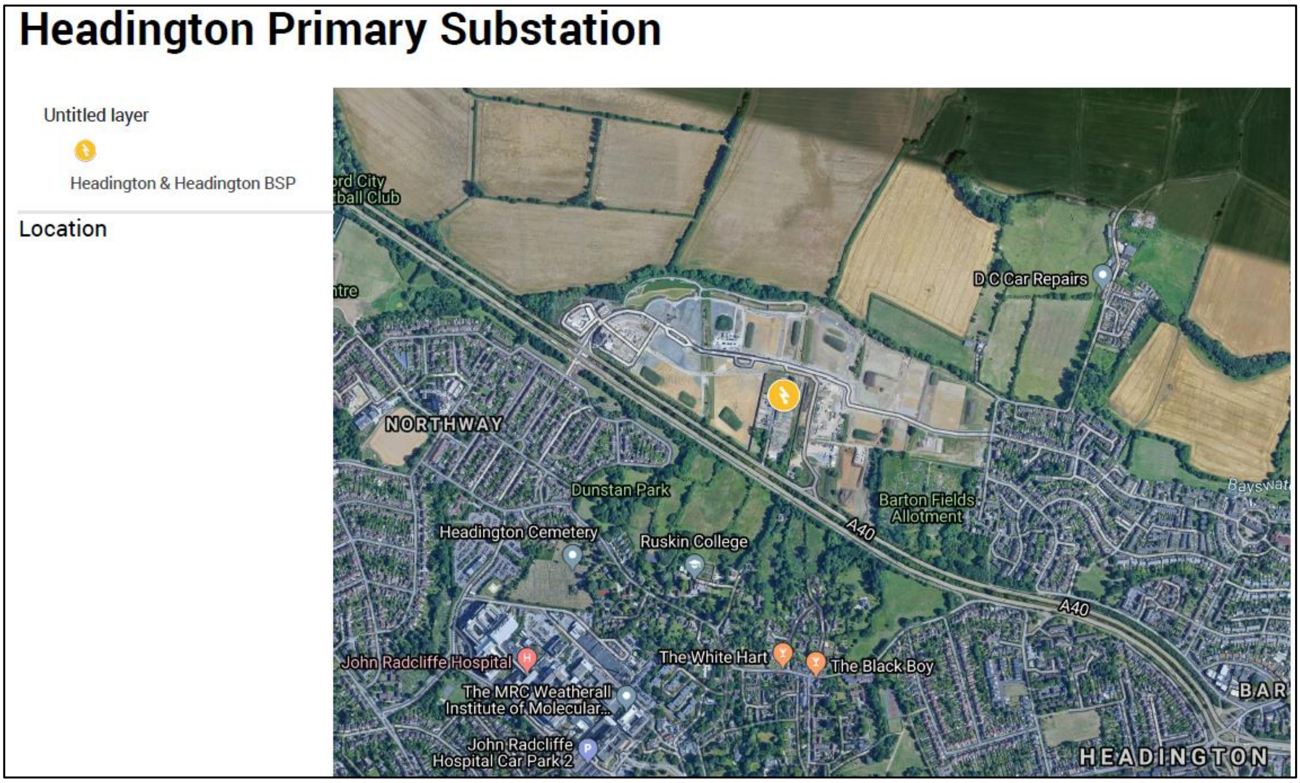

Figure 3: Headington primary substation courtesy of Google maps

The Bicester – Headington (black & white) 33kV feeder Figure 4, is a double circuit feeder and is a mixture of overhead lines (OHL) and underground cables (U/G) and is a link between the two Primary Substations. Its sister feeder is the Bicester – Headington (black & blue) 33kV feeder, which operates totally independently of the black & white feeder. Bicester Substation is unable to accept additional export connections due to upstream constraints and thermal limits (see section 6 for details).

This means that a NOP (Normal Open Point) is to be established by SSE at Bicester Primary Substation so that the supply is always provided by Headington Primary Substation. This is a standard operational procedure for a DNO to perform and all HV circuits operate this way with an open point at some part of the circuit. This is for safety reasons so that in the event of a failure the point of the fault is not supplied from two directions, increasing the inrushing current.

Note – only one of the circuits, in this case the black & white feeder was identified as suitable for an 18MW export connection.

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Figure 4: Bicester – Headington 33kV feeders' courtesy of Google maps

The Route which is within the boundary of Cherwell District Council is shown on separate maps provided by Pegasus. The circuit enters Cherwell District Councils area to the South around the Woodeaton area and heads North as an OHL, crossing Mr Pelton's land. Shortly after leaving Mr Pelton's land the OHL transitions underground until it has crossed the railway line at Kidlington level crossing. A connection to a 33kV cable will not be financially viable due to the significant extra costs of plant and equipment required, relative to an overhead connection. An underground 'loop in' connection would be in the region of 4 to 5 times more expensive than the overhead line equivalent, making the scheme unviable. From this point the circuit then continues adjacent to the railway line as an OHL.

The area which borders the railway line on each side is unsuitable for the installation of a large-scale source of generation. This is due to an electrical phenomenon called Rise of Earth Potential (RoEP). This is a situation whereby a large generator can impart a voltage through the surrounding mass of earth which can affect other equipment, in this case railway signalling equipment. To ensure this does not happen establishing a generation connection in this zone should be avoided. This will ensure that in the event of an incident or fault at the solar farm stray voltage does not adversely affect the adjacent railway. Further technical guidance on this subject can be found in EREC S34, EREC S36, BS EN 50522, ENA 41-24, EC61508 and IEC/TS 61000-2:2008 and chapter 8 of this report.

The existing overhead lines that are constructed in this area are built to an unearthed construction so do not pose a hazard from an RoEP perspective. A generator would need to establish a single point of earthing which will need to fully consider imparted voltages and a full earthing study for the site will be required in due course as part of the construction process.

The OHL then transitions to an underground cable shortly after running parallel with the railway line. From this point onwards an electrical connection will not be viable as previously discussed.

This therefore leaves a very small pocket of land suitable for an 18MW solar farm, the bulk of which is on Mr Pelton's land.

8 Rise of Earth Potential – RoEP

A rise of earth potential is caused by electrical faults that occur at electrical substations, power plants, or high-voltage transmission lines. In the event of a fault, short-circuit current flows through the plant structure and equipment and into the earthing electrode. Since the local Soil Resistivity is not zero Ohms and has a resistance value of 'X' Ohms then any current injected into the earth at the earth electrode position produces a Rise of Earth Potential or RoEP, Figure 5. This earth potential rise is concerning and can cause hazardous voltages, often many hundreds of metres away from the actual fault location. Therefore, many factors determine the level of hazard Including available fault current, voltage, soil resistivity and underlying rock layers. Rural 33kV substations can be problematic to earth safely. Problems can arise from sites that are fed entirely, or in part, by overhead line. This provides no return path for the fault current via a cable sheath for example, which is instead injected into the ground. Another consideration is the clearing time to interrupt the fault, also known as circuit breaker operating time or clearance time.

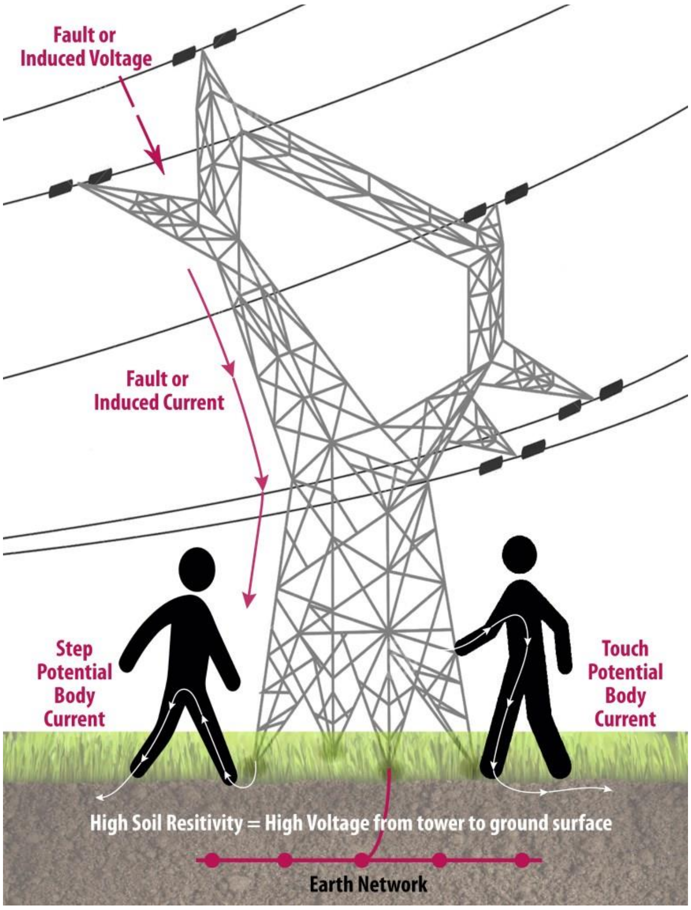


Figure 5: Indicative RoEP diagram courtesy of Greymatters

The rise of earth potential is a safety issue in the co-ordination of power and telecommunications devices, including railway signals. A RoEP event at a site such as an electrical distribution substation and its greater connected network (i.e., a solar farm and its associated panels & mounting framework) may expose personnel, users or structures to potentially hazardous voltages. This risk is mitigated by avoiding areas where an imparted voltage may cause issues, in this instance by locating the solar farm away from the railway line. The effects of RoEP are similar to the effect of a stone thrown into a still lake. The voltage gradients decrease like ripples until the voltage imparted is minimal. Note that this can easily be hundreds of meters and the higher the voltage the greater the ripples spread.

See Figure 6 below, –

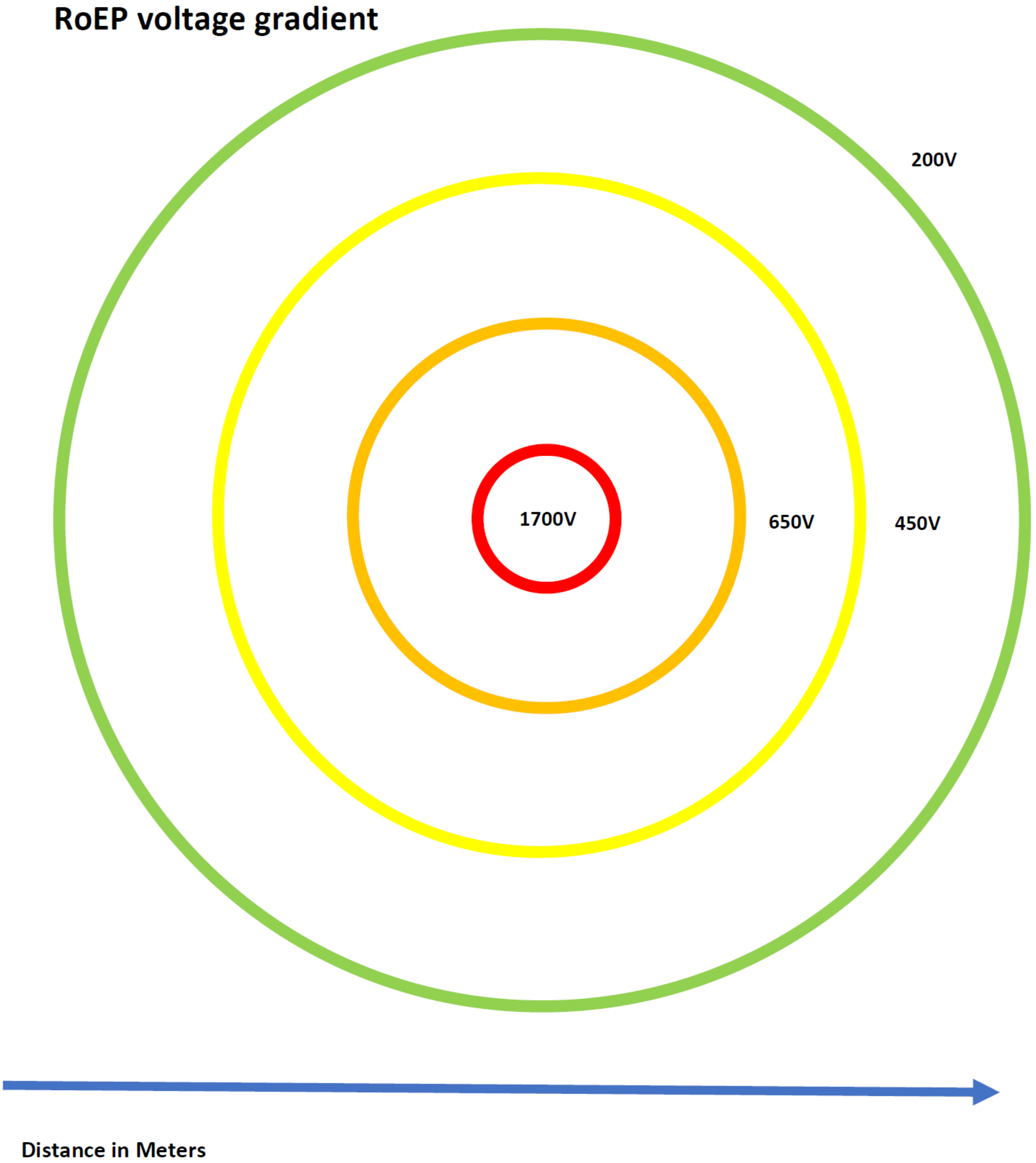


Figure 6: RoEP gradients

An extract from EREC S36 states –

Special precautions must be taken with telecommunication plant and strict working procedures adopted in the immediate vicinity of substations where the rise of local earth potential could, under the most severe earth fault conditions, exceed 430V rms. The limit of 430V may be extended to 650V rms if the power circuits contributing to the earth fault currents are high reliability type, having an operating voltage of 33kV or greater and controlled by switchgear with main protection that will clear both a line or busbar earth-fault current within 500ms and generally within 200ms.

Engineering Recommendation (EREC) is the technical supplement to ENA TS 41-24 (2017), providing formulae, guidelines and examples of the calculations necessary to estimate the technical parameters associated with earth potential rise (EPR). ENA TS 41-24 provides the overall rules, the design process, safety limit values and links with legislation and other standards.
When using formulae to calculate earth resistances, caution is necessary because they do not normally account for proximity effects or the longitudinal impedance of conductors. For first estimates, the overall impedance ZE of separate electrodes with respect to reference earth is taken as the sum of their separate values in parallel. For the example shown in Figure1 this would be:

ZE = (1/RES + 1/ZCH1 + 1/ZCH2+ ⋯) −1

In reality, ZE will be higher if the separate electrodes are close enough that there is significant interaction between them (proximity effect). Proximity effects can be accounted for in most advanced software packages. When relying on standard formulae, the following techniques can help to account for proximity when calculating ZE:

- Include any radial electrodes that are short in relation to the substation size, into the overall calculation of the earth grid resistance.
- For radial spur electrodes or cables with an electrode effect, assume the first part of its length is insulated over a distance similar to the substation equivalent diameter. Calculate the earth resistance of the remainder of the electrode/cable and add the longitudinal impedance of the insulated part in series.
- For a tower line, assume that the line starts after one span of overhead earth wire (the longitudinal impedance of this earth wire/span would be placed in series with the tower line chain impedance).

A value of soil resistivity is needed and for the formulae in Appendix B, this should be a uniform equivalent (see ENA TS 41-24, Section 7.4.) For soils that are clearly of a multi-layer structure with significant resistivity variations between layers, the formulae should be used with caution and it is generally better to use dedicated software that accounts for this to provide results of the required level of accuracy.

On top of the requirements from the DNO side to reduce any RoEP infringements the railway network will have its own standards and limitations and will also have a voltage gradient which could extend into the same zone we have identified. Assessment of this is beyond the scope of this report but should be taken into consideration. However, as with anything electrical where there is any form of doubt avoidance is always the best option.

AC interference from high voltage power lines can impair the proper operation of signalling and protection systems of a railway during both normal operation and fault conditions, if the level of the current is too high and if there is a rail unbalance condition. A simplified analysis can lead to either significant unnecessary expense due to overdesign of assets or an inadequate system which will lead to voltage impression on adjacent assets in the event of a fault.

Locating a connection to a solar farm where a 33kV line runs adjacent to the railway can be a significant technical challenge due to Rise of the Earth potential. The main issue is the actual point of connection due to the need for a system earth to stabilise voltage & provide the necessary safety in the event of a fault on any part of the system. This includes on-site faults (both DC & AC) and grid side faults. While this is not a regulatory matter, it does require the strict adherence to a number of electrical standards and codes of practice which are mentioned elsewhere in this paragraph. This is for the Design Engineer to consider both from the DNO perspective and from the solar farm perspective. This does not prevent a solar farm from bordering a railway line, but it does add a significant amount of technical complexity and cost in calculating the likely RoEP from any fault on the PV farm. To avoid a lot of costly measurements, simulation studies, cross-referencing railway codes of practices and indeed liaising with the railway authorities themselves it is much better to simply find a connection point on the system that avoids these issues altogether.

Just because an existing solar farm is located near to a railway line does not mean that it is safe! The phenomena of RoEP has only relatively recently been recognised as an issue and it is quite possible that it may not have been considered at all. The regulation in place at the time of its construction may well not have been as onerous as they are today, allowing for the site to effectively ignore the impact of RoEP. Current standards ensure that all new installations are safe, resilient and reliable under all fault condition scenarios.

As well as grid standards the Rail network has a number of standards which they and external parties (solar farms for example) must comply with.

BS EN 50122: Railway applications (Fixed installations, Electrical safety, earthing and the return circuit)

BS EN 50522: Earthing of power installations (exceeding 1 kV AC)

These Rail specific standards support the detailed content to provide the necessary design guidance required to meet the expectation and achieve compliance during construction & maintenance of the rail network. As you will be aware, the land owned by the rail company is usually restricted to a corridor to accommodate the rail network and associated infrastructure. So, the typical rail 'footprint' tends to be located in a long and elongated patch of land. Some common Earthing Design challenges for Rail are:

- Size and shape of the footprint
- Relatively high fault level to control (encroachment, hot site)
- Elongated conductive structures (rails, etc.) that readily transfer hazardous voltages, including those from lightning.
- Public accessibility
- Track formation
- Theft
- Stray current and enhanced corrosion
- The interface between AC and DC traction systems

This situation means that trying to contain and control a fault current can be like trying to "squeeze a Quart into a Pint glass, i.e., leading to spillage of energy into areas where you do not want it to go. So, the Earthing Design and RoEP study will really have to be incredibly thorough as there are many safety concerns to factor in that are unique to Rail and can make construction a real challenge.

It should be noted that an RoEP study will be carried out for the proposed PV farm and that all land adjacent to the site will be entirely safe for members of the public and outside of any RoEP zones.

9 Complexity of circuits

Both National Grid (Transmission) and all of the UK DNOs have rules over the complexity and connectivity of circuits. The higher the voltage the more uniform the circuits must be to maintain security & reliability of supply. Each DNO and National Grid have their own versions of this code of practice but they are effectively the same set of rules & regulations.

Requirements of the Electricity Act 1989 places an obligation on Distribution Network Operators to develop and maintain an efficient, co-ordinated and economical system of electricity distribution and to facilitate competition in the supply and generation of electricity.

The Health and Safety at Work Act 1974 also states that 'It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees.' Section 3(1) also states that 'It shall be the duty of every employer to conduct his undertaking in such a way as to ensure, so far as is reasonably practicable, that persons not in his employment who may be affected thereby are not thereby exposed to risks to their health or safety.'

This is addressed in this Code of Practice by:

- Providing guidance on substation location;
- Requiring consideration to be given to the level of risk to which employees and the public are exposed by a proposed overhead line route; and
- Requiring that circuits and plant have appropriate cyclic, continuous and short circuit ratings.

As well as complying with the above the requirements of The Electricity Safety, Quality and Continuity (ESQCR) Regulations impose a number of obligations on the business, mainly relating to safety and quality of supply. All the requirements of the ESQCR Regulations that are applicable to the design and development of the EHV system shall be complied with.

Requirements of the Distribution Code

As a distribution licence holder any DNO must maintain and comply with the Distribution Code of Licensed Distribution Network Operators of Great Britain. The Distribution Code covers all material technical aspects relating to connections to and the operation and use of the distribution systems of the Distribution Network Operators. The Distribution Code is prepared by the Distribution Code Review Panel and is specifically designed to:

- permit the development, maintenance and operation of an efficient co-ordinated and economic system for the distribution of electricity;
- facilitate competition in the generation and supply of electricity; and
- efficiently discharge the obligations imposed upon DNOs by the distribution licence and comply with the Regulation and any relevant legally binding decision of the European Commission and/or Agency for the Co-operation of Energy Regulators.

This objective is particularly relevant given the introduction of a suite of European Network Codes which place additional obligations on Generators and DNOs. Compliance with this Code of Practice will help to ensure that the relevant requirements of the Distribution Code are satisfied.

Key Policy Requirements

The general objective in developing the EHV system is to obtain a simple and robust system having minimum overall cost, taking into account:

- the initial capital investment;
- the annual cost of any flexibility services, expressed in net present value for the duration of the service; and
- system losses and the maintainability and operability over the life of the asset.

Any development of the EHV system should seek to improve the quality and reliability of the supply provided i.e., reduce the number of potential Customer Interruptions (i.e., to improve reliability) and Customer Minutes Lost (i.e., to improve availability). This Code of Practice is written to help ensure that all EHV system developments are made in such a way as to:

- prevent danger to members of the public and Northern Powergrid staff and our sub-contractors;
- optimise system security, reliability and availability;
- optimise power quality experienced by Customers;
- discharge the obligation under section 9 of the Act, and specifically to have due regard to future requirements and network performance;
- facilitate the use of standardised plant and equipment;

- facilitate the use of flexibility services as an alternative to Northern Powergrid plant and equipment;
- minimise environmental pollution and statutory nuisance; and
- satisfy all other relevant obligations.

The design of the EHV system shall ensure that the technical characteristics associated with:

- voltage levels,
- voltage and waveform quality,
- neutral earthing,
- system phasing, rotation and vector groups, and
- short circuit levels

Detailed design studies to assess the impact of potentially disturbing loads and generation such as large motors, welders, inverters and other harmonic producing equipment shall be carried out as part of the application process for connecting such loads or generation and when modifications to the systems are being considered. The earthing arrangements at the EHV source shall be such that the earth fault current does not exceed the full load current of the transformer. In consequence, the short circuit rating of equipment on the 33kV system need only take account of the maximum short circuit phase to phase fault current.

Because of earthing arrangements on the source EHV transformer, the prospective short circuit currents on the EHV system will generally be higher for phase-to-phase faults than for phase-to-earth faults, thus the short circuit ratings of circuits and switchgear shall be chosen with particular care to avoid overstressing under phase-to-phase fault conditions. When assessing the capability of 33kV switchgear, consideration should be given to the X/R ratios on the system; where the X/R ratio is higher than 14.1, the capability of circuit breakers may be less than its nameplate rating.

When designing new or modifying existing EHV systems, care shall be given to ensure that any development is consistent with known proposals for new connections, authorised asset replacement or system reinforcement schemes and that consideration is given to the longer-term future system requirements. Consideration should be given to the impact of different credible upstream running arrangements, which for instance increase fault-levels, and their impact on the design. Reference should be made to Network Development Strategies, Distribution Load Estimates and Future Energy Scenarios to ensure that EHV system designs take account of demand growth and generation plant connections that can reasonably be expected and facilitates the transition towards the Government's 2050 net greenhouse gas emissions target.

In general, radial transformer feeder circuits from the nearest EHV source shall be the preferred circuit arrangement for 33kV systems. Provided that the system can be protected in accordance with the Policy for Protection of Distribution Networks, a single teed connection from an EHV circuit can be used to provide supplies to an individual demand and/or generation customer who only requires single circuit security. When assessing such an arrangement consideration should be given to:

- The possibility of receiving requests for new demand or generation connections in the foreseeable future which may be better serviced via a looped substation rather than a teed substation;
- The number and duration of outages that would result in the customer being off-supply. These may be for prolonged periods, potentially several weeks for asset replacement and new construction work. If a customer has agreed to a single circuit security it would be unreasonable to incur significant additional costs to minimise outage frequency and duration;
- Whether it may be possible to install pole mounted switchgear, to isolate equipment. This may enable isolation of a new teed circuit to maintain supplies to existing customers or to maintain supplies to customers supplied via a new teed connection for an outage of the EHV system downstream of the tee-off point;

- Ensuring compliance with the principles of Engineering Recommendation P18. The presence of multiple tee-offs on a circuit increases the number of sites that need to be visited to isolate the circuit. Distances between sites, particularly in relation to 33kV circuits, can be significant and creating new tees may impact on travelling times / resources required to isolate and restore circuits back to service; and
- The costs of complying with the Policy for Protection of Distribution Networks
- This may require the normal distance protection to be replaced by a three ended unit protection scheme. The communications required to implement the three ended protection must be sufficiently stable, reliable and available so that there isn't excessive reliance on backup protection, which would be less discriminatory than the main protection. Experience has shown that UHF digital radio systems are not sufficiently stable to be used as the communications link for a unit protection scheme, and a fibre wrap or microwave communications link, together with the associated towers (which may require planning permission) is typically required.

To summarise, the extension of any DNOs network to incorporate a new customer needs to be financially viable, technically suitable for the system and any likely future arrangement and it must also comply with all current design policy & standards applicable today. An underground cable connection in this instance would fail to comply with the Complexity of Circuits regulations by virtue of being;

- Too complex, a simple OHL tee arrangement will be more than suitable.
- No future plans for circuit extension.
- Financial viability, an underground 'loop in' would be financially unviable, this would be in the region of 4 to 5 times more expensive than the overhead line equivalent.
- The additional cable could adversely affect the X/R ratio, an OHL option would not (due to negligible cable capacitance)
- An OHL connection alongside the railway would add unnecessary and entirely avoidable technical issues (RoEP, imparted voltage, signalling interference risk etc)
- No unnecessary assets are installed (as close as possible to the PV farm).

Therefore, the only connection point suitable and the reason SSE have offered an OHL connection at pole 34 of the Bicester – Headington (black/white) 33kV feeder, is to comply with the Complexity of Circuits regulations.

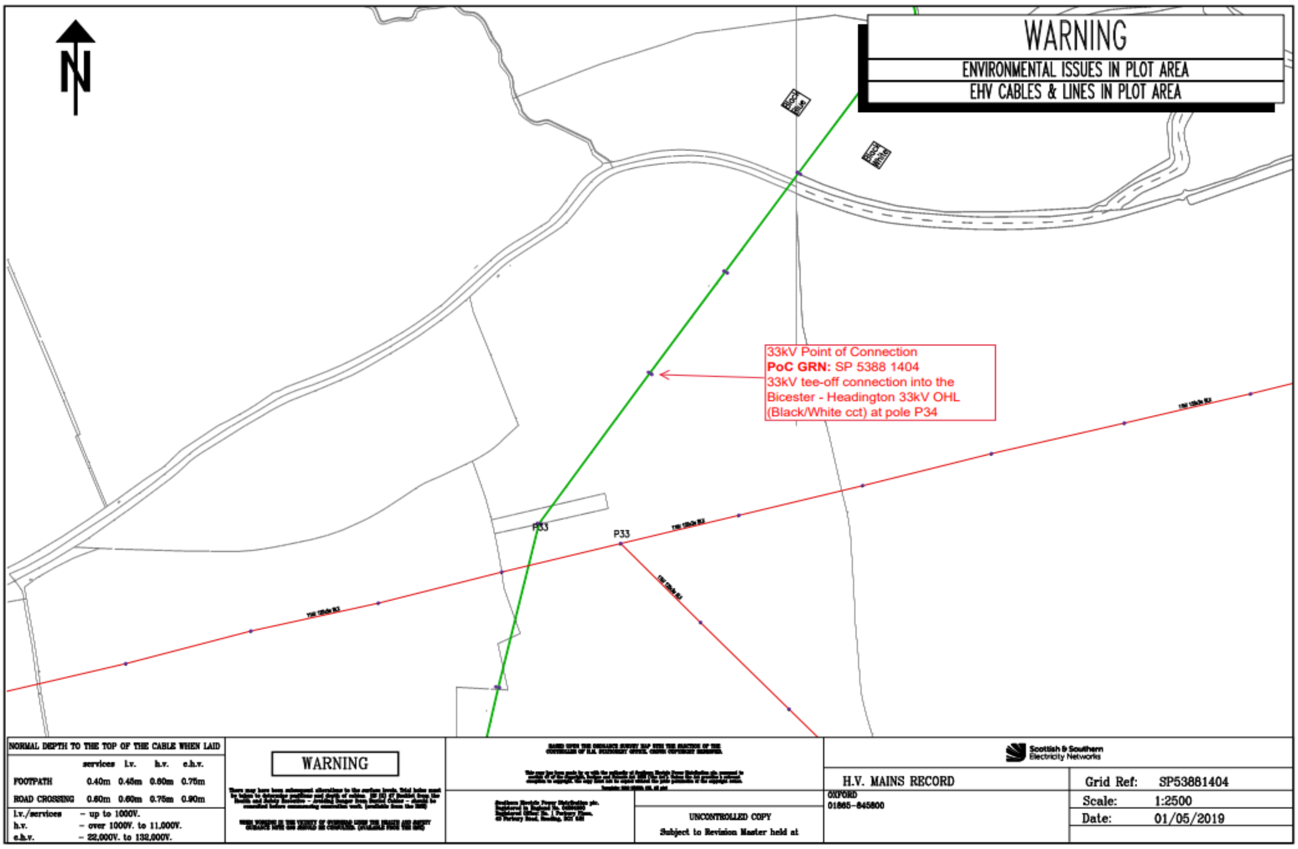


Figure 7: SSE P.O.C. drawing

10 Conclusion

As we have shown for both technical & geographical reasons there is only one viable connection point within the Cherwell District Council area for the proposed 18MW AC/26.6 MW DC solar farm and it is from a site North of Noke proposed by the applicant, using the 33kV Headington-Bicester line into the Headington Primary Substation. This has only been possible because the connection offer was accepted before the network became heavily constrained. From an electrical viewpoint the whole area is heavily constrained, and export (generation) constraints will still remain for the foreseeable future. In fact we find that there are no possible new connections (to be accepted by DNOs) for any generation above 0.77MW in the Cherwell area until after 2030 at the earliest. This application will be the last significant connection accepted from a grid connection perspective for the foreseeable future.

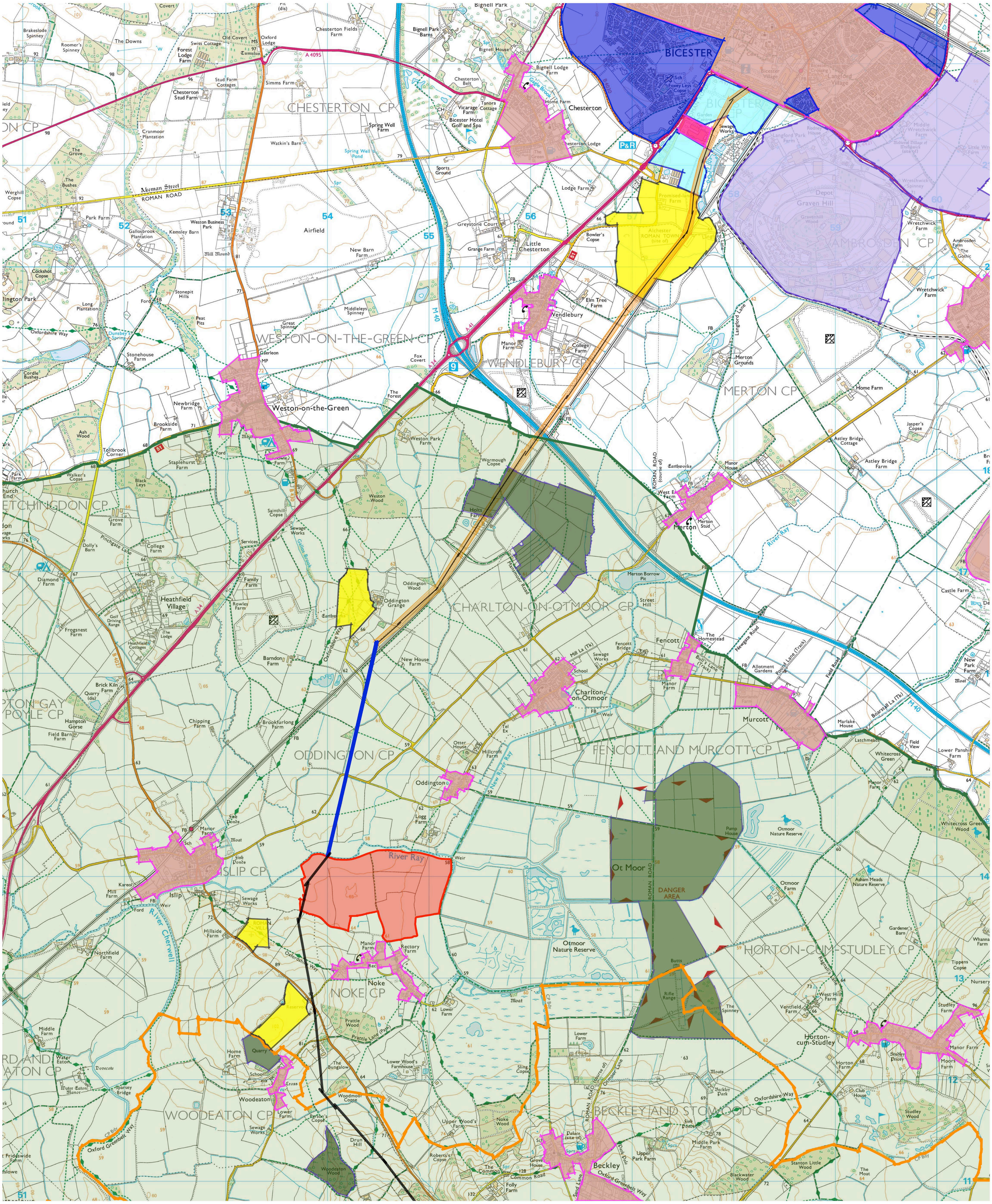
Looking at the substations in the area any development of this type must have already received a formal connection offer from one of the DNOs and this must have been accepted (accepted but not yet connected) by a developer/landowner. Indeed, any large-scale connections cannot be made before 2030 due to grid restrictions & issues and it may even be several years after that date before any additional connections are possible.

National Grid Electricity Transmission (NGET) and National Grid Electricity System Operator (NGESO) are struggling to accommodate the vast numbers of connection requests for renewable generation across the whole of the UK. The situation has got to a critical point and NGESO have started operating a Progression Plan to limit applications and manage connection dates. This affects connections at DNO level all the way down to 6.6/11kV networks, a situation previously unheard of.

Solar is a key part of the UK's renewable energy strategy, and this is an opportunity to help to reduce the carbon footprint of Cherwell District Council and assist in the Councils fight against the climate emergency they have declared.

11 Appendix

See associated document ‘Connection power line constraints map’.



KEY

SITE LOCATION (TBC) 232.11 ACRES / 93.93 HECTARES	EXISTING RETAIL PARK	APPROXIMATE LOCATION OF RoEP ZONE
OXFORD GREEN BELT BOUNDARY	APPROVED AND STRATEGIC HOUSING SITES	SITE OF SPECIAL SCIENTIFIC INTEREST
CHERWELL DISTRICT BOUNDARY	NEW AND APPROVED EMPLOYMENT SITES	SCHEDULED ANCIENT MONUMENTS
EXISTING SETTLEMENT BOUNDARIES	APPROXIMATE ROUTE OF 33 KV POWERCABLE	
MIXED USE HOUSING AND EMPLOYMENT ALLOCATION	APPROXIMATE UNDERGROUND CABLE ROUTE	

Pegasus Group

LAND AT MANOR FARM, NOKE - **CONNECTION POWER LINE CONSTRAINTS MAP**

Delivering, unlocking, advancing the low-carbon economy

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