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Bramford to Twinstead Reinforcement

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1. Introduction

1.1.1 This Need Case has been prepared by National Grid Electricity Transmission plc (National Grid) to support an application to the Secretary of State for Energy Security and Net Zero (Secretary of State) for development consent for the Bramford to Twinstead Reinforcement ('the project').

1.1.2 This report provides an overview of the need case for the project setting out the drivers for change, including the increase in electricity generation and how this affects the National Electricity Transmission System. The report structure is as follows:

- Background – the policy context in which this Need Case is presented; an overview of National Grid's role and obligations as Transmission Owner (TO); an overview of the role of the Electricity System Operator (ESO); and an introduction to the National Electricity Transmission System (NETS) and the NETS Security and Quality of Supply Standard (SQSS) (**Section 2**);
- The Bramford to Twinstead Reinforcement Need Case, including an explanation of the transmission system analysis against the SQSS (**Section 3**); and
- Conclusions (**Section 4**).

1.1.3 In summary, this Need Case document demonstrates that, because of the significant growth in offshore wind generation, new nuclear, and interconnectors to Europe in line with the UK government's 2050 net zero target, reinforcement of the NETS in East Anglia is required. This is due to two SQSS compliance issues:

- Firstly, without reinforcement the capacity of the East Anglia existing network is insufficient to accommodate the connection of the proposed new power sources. The 'Thermal Boundary Export Limit' – the physical maximum energy capacity the system can accommodate during system faults – would be exceeded, preventing export of power to demand centres beyond East Anglia.
- Secondly, it would not be possible to operate the system without restrictions to prevent adverse impacts on generators or the network following faults. Given that supply in the area would significantly exceed demand and the limited number of circuits that connect East Anglia to the wider network, the 'Stability Export Limit' would be exceeded.

1.1.4 The costs of constraint actions that would be taken by the ESO are expected to significantly exceed those of the proposed reinforcements, and therefore investment in new infrastructure is economical. The ESO has identified the Bramford to Twinstead Reinforcement as a 'Holistic Network Design essential'

(HND essential) option, meaning that it considers the project as essential to meet the UK Government's 2030 offshore wind targets.

2. Background

2.1 Policy context

2.1.1 The project forms part of the wider decarbonisation agenda in the UK. In 2019 the Committee on Climate Change ('CCC') published its Net Zero report setting out recommendations to the UK Government on long-term greenhouse gas emissions targets for the UK. The Government subsequently made the Climate Change Act 2008 (2050 Target Amendment) Order 2019, which increased its pledge to 100% reduction in emissions by 2050. The Climate Change Act 2008 (as amended) now commits the UK Government by law to reducing greenhouse gas emissions by at least 100% from the 1990 baseline by 2050. This 2050 target is commonly known as 'net zero'.

2.1.2 One of the ways the net zero target will be achieved is through decarbonisation, including moving away from fossil fuel towards alternative sources of energy to power our homes, transport and businesses. The vision for a transition to clean energy was set out in December 2020 with the publication of the *Powering our Net Zero Future* Energy White Paper, which added further detail to the Prime Minister's *Ten Point Plan for a Green Industrial Revolution*.

2.1.3 As a result, electricity production is now moving towards reducing greenhouse gas emissions by increasing renewable and low carbon sources, such as offshore and onshore wind, solar energy and new nuclear generation. The National Infrastructure Commission (NIC) has published a report recommending to the UK Government that renewable generation can be increased to 65% of supply by 2030 at no adverse cost to consumers, enabling the decarbonisation in part of sectors such as transport and heating via electrification.

2.1.4 Following the publication of the NIC Report, the UK Government published the British Energy Security Strategy in April 2022 setting out a strategy for secure, clean and affordable British energy for the long term. Recent world events highlight that the transition away from reliance on natural gas is now not just a matter of meeting Great Britain's net zero targets, but is also important in terms of security of energy supply.

2.1.5 This Strategy sets out the UK's energy ambitions across several sectors including:

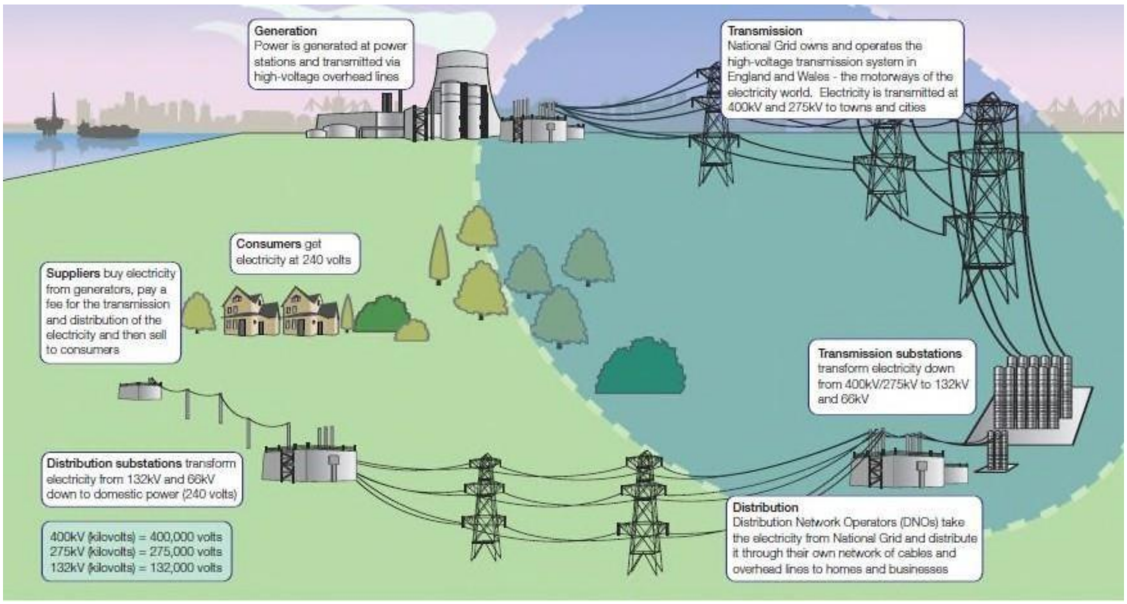
- Up to 50GW of offshore wind connected by 2030 including 5GW of which will be offshore floating wind;
- Up to eight new nuclear reactors reaching up to 24GW to be achieved by 2050;
- Up to 10GW of low carbon hydrogen production capacity by 2030, doubling the previous ambition; and

- 600,000 heat pump installations a year by 2028 and improving housing stock insulation.

2.2 The role of Transmission Owners

2.2.1 To facilitate these ambitions, electricity network infrastructure is needed to ensure that energy can be transported from where it is generated to where it is used. See Figure 2.1, below:

Figure 2.1 – The electricity system from generator to consumer



2.2.2 A single electricity market serves the whole of Great Britain. In this competitive wholesale market, generators and suppliers trade electricity on a half hourly basis. Generators produce electricity from a variety of energy sources, including gas, nuclear, coal and wind, and sell energy produced in the wholesale market. Suppliers purchase electricity in the wholesale market and supply to end customers.

2.2.3 Electricity can also be traded on the single market in Great Britain by generators and suppliers in other European countries. Existing submarine cable interconnectors with transmission systems in France, Ireland, Northern Ireland, Belgium, Norway and the Netherlands are used to import and/or export electricity between national transmission systems. Several further interconnectors between Great Britain and Denmark, France, Germany and Norway are proposed and have connection agreements.

2.2.4 Electricity is supplied to consumers by transmission and distribution networks. In England and Wales, the 'transmission system' operates at 400kV and 275kV and transports bulk supplies of electricity from generating stations to demand centres. This is distinct from the 'distribution systems' operating at 132kV and below, that are mainly used to transport electricity from bulk infeed points (interface points with the transmission system) to most end customers.

2.2.5 The Electricity Act 1989 (the 'Electricity Act') defines transmission of electricity within Great Britain and its offshore waters, as a prohibited activity which cannot be carried out without a transmission licence granted under Section 6(1)(b) of the Electricity Act. Each holder of a transmission licence is bound by legal obligations, which are primarily set out in the Electricity Act and the holder's transmission licence. These licence holders are known as Transmission Owners ('TOs'), with responsibility for owning and maintaining transmission assets. These TOs provide transmission services to a separate and distinct ESO in accordance with the detailed contractual arrangements set out in the System Operator – Transmission Owner Code ('STC'). As discussed further in the following section, the ESO is responsible for ensuring that supply meets demand to balance the system, managing connection agreements and the network planning process.

2.2.6 National Grid Electricity Transmission (generally referred to as 'National Grid' within this report) is the licenced TO for England and Wales and is a part of the National Grid Group of companies. National Grid has been granted a transmission licence that permits transmission system ownership activities in England and Wales. As a natural monopoly National Grid is regulated by the Office of Gas and Electricity Markets ('Ofgem') on behalf of consumers.

2.2.7 Through its transmission licence National Grid is responsible for ensuring compliance with the NETS SQSS, which sets out the criteria and methodology for planning and operating the system. Among other things, the SQSS requires that National Grid must ensure the system can be safely operated without damaging generators or the network and assess whether the capacity of the transmission system will be sufficient for changes to user requirements that are expected in future years.

2.3 The role of the Electricity System Operator

2.3.1 A single ESO transmission licence has been granted that permits transmission system operation within Great Britain and its offshore waters. The ESO is required to be independent of transmission ownership activities. The ESO transmission licence is held by National Grid ESO, which is a legally separate company from National Grid Electricity Transmission within the National Grid Group.

2.3.2 The ESO provides the contractual interface with demand customers, generators and interconnectors that are seeking to connect to, or are connected to, Great Britain's NETS. Customers can apply to the ESO for new or modified connections to the transmission system. Working with relevant TOs to confirm the scope of construction works required, the ESO will respond to each customer application with an offer for new or modified connection.

2.3.3 The ESO facilitates several roles on behalf of the electricity industry, which complement National Grid's strategic options appraisal process, including the publication each year of:

- the Future Energy Scenarios ('FES') which takes a number of energy industry views as part of a consultation process and develops a set of possible energy growth scenarios,
- the Electricity Ten Year Statement ('ETYS'), which sets out the system development requirements of the NETS over the next 10 years, and
- the Network Options Assessment ('NOA'), which is an economic assessment of the TOs' potential options for reinforcing the network.

2.3.4 The NOA process takes account of the ETYS and FES content to establish, via a Cost Benefit Analysis ('CBA') process, when options proposed by TOs to increase network capacity should be taken forward. This CBA considers capital costs of proposals, delivery timescales and constraint costs expected to be avoided by delivering the proposal (that is, the costs to consumers of compensation to generators to reduce their output in an area where there is insufficient system capacity to accommodate it, and additional payments to more costly generators outside of the area). This assessment is used by the ESO to make recommendations on when a proposed reinforcement becomes economically optimal way to deliver value to energy consumers within Great Britain. As NOA is based on the annual FES scenarios and assesses year round operating conditions, refinements of the schemes recommended and additional schemes are often required to ensure compliance with the SQSS. While the ESO provides recommendations for the options to meet system needs, the TOs, Ofgem and other relevant parties will ultimately decide on what, where, and when to invest. The specific designs of any option, such as the choice of equipment and route will be developed by the TOs.

2.3.5 The ESO published its Holistic Network Design ('HND') in summer 2022, an outcome of the Government's Offshore Transmission Network Review ('OTNR'). The OTNR considers how the transmission network is designed and delivered, to ensure that the transmission connections for offshore wind generation are delivered in the most appropriate way considering the increased ambition for offshore wind to achieve net zero. It considers environmental, social and economic costs. The HND sets out a single integrated transmission network design that supports the large-scale delivery of electricity generated from offshore wind.

2.3.6 The Bramford to Twinstead Reinforcement project has received consecutive 'proceed' recommendations from the ESO in the NOA process since NOA 2018/19, which means it is optimal to deliver by its 'earliest in service date' – that is, the earliest date when the project could be delivered and put into service, if investment in the project is started immediately (in the case of new projects) or investment is continued (in the case of projects with previous proceed signals). National Grid has therefore been developing this solution to meet its earliest in service date of 2028. The project has also been identified as an 'HND essential' option in the latest NOA Refresh (July 2022). This means that the ESO considers the project as essential to meet the UK Government's 2030 offshore wind targets discussed above.

2.3.7 After the HND and 2022 NOA Refresh, Ofgem published the *Accelerated Strategic Transmission Investment* (ASTI) decision, which aims to facilitate achieving government targets by streamlining the regulatory approval and funding process for ASTI projects. This project is identified as an ASTI project in this decision and is therefore subject to the new accelerated regulatory framework.

2.3.8 The ESO is also the code administrator for the SQSS. It chairs the SQSS review panel, comprising ESO, TOs, Offshore Transmission Owners (OFTOs) and developers, that reviews the standard and develops any proposals to amend it. All changes to the SQSS are submitted to and approved by Ofgem.

2.4 National Grid's existing transmission system

2.4.1 The existing transmission system was developed to transport electricity in bulk from power stations to demand centres. Much of National Grid's transmission system was originally constructed in the 1960s. Incremental changes to the transmission system have subsequently been made to meet increasing customer demand and to connect new power stations and interconnectors with other transmission systems.

2.4.2 National Grid's transmission system consists of approximately 7,200km of overhead lines and a further 700km of underground cabling, operating at 400kV and 275kV. In general, 400kV circuits have a higher power carrying capability than 275kV circuits. These overhead line and underground cable circuits connect between around 340 substations forming a highly interconnected transmission system. Further details of the transmission system including geographic and schematic representations are published by the ESO annually as part of the ETYS.

2.4.3 Circuits are those parts of the system used to connect between substations on the transmission system. The system is mostly composed of double-circuits (in the case of overhead lines, carried on two sides of a single pylon) as well as single-circuits. Substations provide points of connection to the transmission system for power stations, distribution networks, transmission connected demand customers (e.g. large industrial customers) and interconnectors.

2.5 The regulatory and licensing context for transmission system improvements

2.5.1 National Grid has a key role in providing a transmission system which benefits all consumers in England and Wales. This includes maintaining reliable electricity supplies and offering to make changes to its transmission system so that new sources of energy can be connected.

2.5.2 National Grid must ensure that its transmission system remains, at all times, capable of providing the level of transmission services required by the ESO. The transmission system needs to cater for demand, generation and interconnector changes.

2.5.3 Under the terms of section 9 of the Electricity Act 1989 and the transmission licence, National Grid is required to develop and maintain an efficient, co-ordinated and economical transmission system in England and Wales. It must also comply with Standard Condition D3 (‘Transmission system security standard and quality of service') of its Transmission Licence, which requires that transmission infrastructure must be capable of providing (and maintaining) a minimum level of security and quality of supply.

2.5.4 The concept of 'boundary capacity' plays an important role. A boundary notionally splits the system into two parts, crossing critical circuit paths that carry power between the areas where power flow limitations may be encountered. Where 'boundary capacity' – the capacity of the circuit(s) across the boundary – is exceeded against the standards, National Grid must resolve the capacity shortfall. The standards against which National Grid assesses these shortfalls are set out in the SQSS. The concept of system boundaries is explained further in Section 3.

2.5.5 Standard Condition D16 ('Requirements of a connect and manage connection') of the Transmission Licence, allows for constraints to remain on the system until they can be resolved to ensure the system complies with the SQSS. The ESO can manage any shortfall in boundary capacity by reducing the power flows. This is achieved by constraining generation and paying for generators to reduce output. The anticipated cost of these constraints is assessed and used to determine whether generators can connect ahead of all the required reinforcements being in place.

2.5.6 National Grid must also have regard to the desirability of preserving amenity, in line with the duties under section 38 of the Electricity Act. In developing new network infrastructure proposals, National Grid is therefore guided by the legislative and policy framework set by the UK Government.

2.6 Previous work on the Bramford to Twinstead Reinforcement project

2.6.1 Between 2009 and 2013 National Grid undertook work to develop proposals to add network capability in the East Anglia area. Changes to when planned new generation would come online in East Anglia meant that work was put on hold at the end of 2013.

2.6.2 A comparison between the current technical Need Case (as set out in Section 3) with the original Need Case prepared in 2011 is included as Appendix A.

3. Need for Network Reinforcement

3.1 Context

3.1.1 As explained in the previous section, the electricity industry in Great Britain is undergoing unprecedented change in transitioning away from reliance on fossil fuels towards low and no-carbon generation in order to achieve net zero and increased energy security. Closure of fossil fuel burning generation and end of life nuclear power stations means significant additional investment in new generating and interconnection capacity will be needed to ensure existing minimum standards of security and supply are maintained.

3.1.2 Growth in offshore wind generation, interconnectors to Europe, and new nuclear have seen a significant number of connections planned in East Anglia. The existing onshore transmission network cannot currently support this substantial growth.

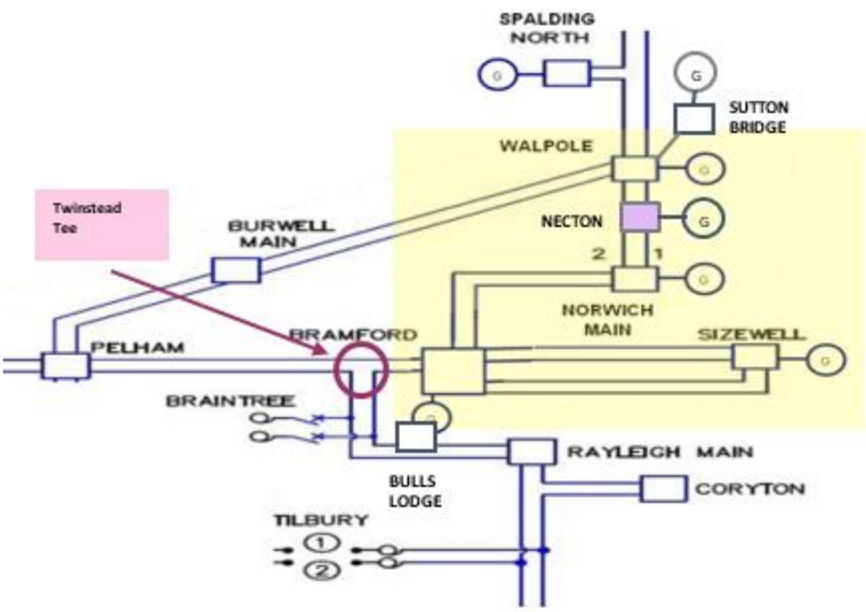
3.2 Existing East Anglia transmission network

3.2.1 The transmission system in East Anglia was primarily constructed in the 1960s, at the same time as much of the rest of National Grid's transmission system, and has remained largely unaltered since.

A map of the transmission system in the East Anglia region is shown in Figure 3.1, while Figure 3.2 shows a diagrammatic representation of the electrical connections in the same area.

Figure 3.1 – Map of the transmission system in East Anglia

Figure 3.2 – Diagram of transmission system in East Anglia



3.2.2 The transmission system in East Anglia consists of a 212km loop of circuits connecting Walpole, Necton, Norwich Main, Bramford, Pelham and Burwell Main substations. This loop connects to the rest of the transmission system to the north at Walpole; the south at the Twinstead Tee; and the south and west at Pelham. This loop connects substations to the transmission system by more than one route, thereby improving security of supply for local demand and the reliability of connection for generation in the region.

3.2.3 The transmission system in East Anglia was built primarily to serve consumer demand from homes and businesses in the region. Peak demand by 2029/30 is anticipated to be approximately 1,767MW (total for demand substations of Walpole, Norwich Main and Bramford and with only minor demand being consumed at Sizewell). The demand area served from these substations, referred to as the East Anglia Demand Area, is indicated by the yellow shaded area in Figure 3.2.

3.2.4 For many years the only significant power stations generating in the East Anglia region were the Sizewell A and the Sizewell B nuclear power stations, Spalding North and Sutton Bridge gas fired power stations, and some further smaller 132kV connected gas fired power stations.

3.2.5 This generation capacity has recently been added to by several offshore windfarms with the existing generation totalling 7,687.4MW of installed capacity. This is expected to grow substantially in coming years, as discussed further below.

3.3 Need for future Reinforcement of the East Anglia Transmission System

3.3.1 As explained in Section 2, National Grid is responsible for ensuring compliance with the NETS SQSS, which sets out the criteria and methodology for planning and operating the system. The rest of this section explains how National Grid has assessed the network in East Anglia for SQSS compliance. In summary, reinforcement of the network in East Anglia is needed for two main reasons:

- Firstly, without reinforcement the capacity of the East Anglia existing network is insufficient to accommodate the connection of the proposed new power sources. The ‘Thermal Boundary Export Limit’ – the physical maximum energy capacity the system can accommodate during planned system faults – would be exceeded, preventing export of power to demand centres beyond East Anglia.
- Secondly, it would not be possible to operate the system without restrictions to prevent adverse impacts on generators or the network following faults. Given that supply in the area would significantly exceed demand and the limited number of circuits that connect East Anglia to the wider network, the ‘Stability Export Limit’ would be exceeded.

3.3.2 To address these SQSS compliance issues reinforcement of the network is required. Without reinforcement, in some conditions generators connecting in the area would be required to reduce their output. Generators would then have to be compensated via a 'constraint' payment, and additional payments made to non-constrained generators outside of the area to ensure that supply matches demand. These costs would be passed on to end consumers. ESO analysis shows that, in this case, predicted constraint costs are likely to significantly exceed those of reinforcement, providing a further driver to reinforce the system in addition to meeting the criteria of the SQSS.

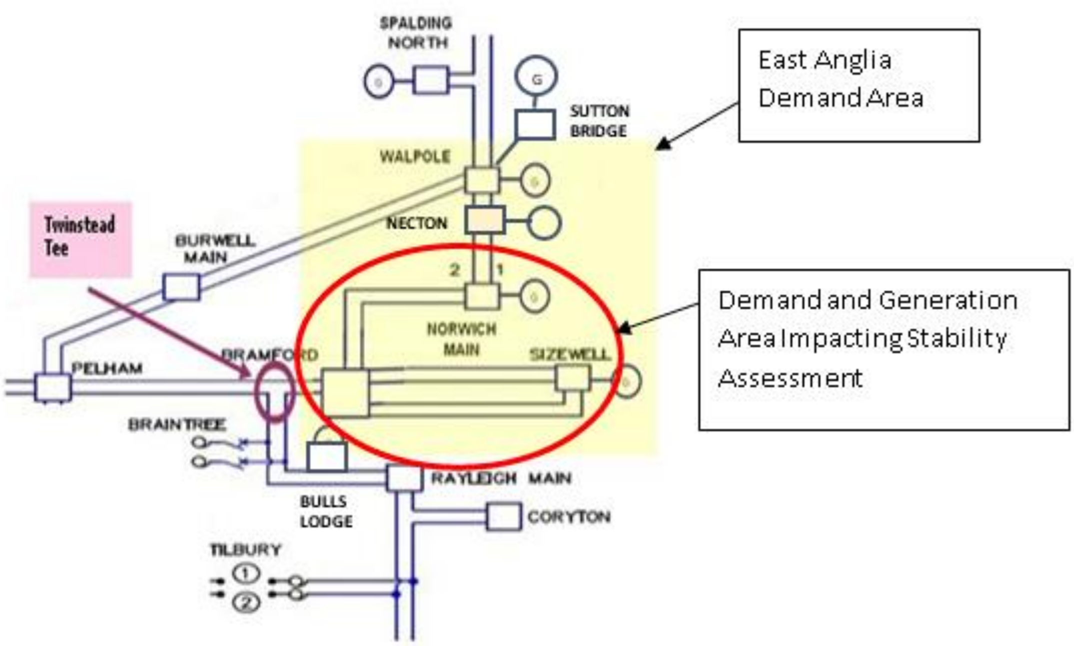
3.4 Transmission system and SQSS analysis

3.4.1 National Grid must assess whether the transmission system will be sufficient for changes to user requirements that are expected in future years such as to ensure that the transmission system remains compliant with the NETS SQSS.

3.4.2 The SQSS considers various criteria when assessing the operation of the NETS. These include thermal capacity and transient stability. These concepts are fully explained in Appendix B of this report.

3.4.3 The yellow shaded area in Figure 3.3 below shows the part of the East Anglia Demand Area where National Grid will incur NETS SQSS compliance issues as demand and generation increases. The area enclosed by the red circle in Figure 3.3 shows the specific part of the transmission system which, due to the number of circuits, will have an impact on the stability assessment and experience compliance issues, as set out in the NETS SQSS.

Figure 3.3 – Diagram of transmission system in East Anglia showing East Anglia Demand Area and Demand and Generation Area impacting stability



3.4.4 The following sections describe the demand and supply in and out of the East Anglia area, and then compare these to assess SQSS compliance, in particular against standards on Thermal and Stability capability.

Demand in East Anglia

3.4.5 As described above, peak demand by 2029/30 in the East Anglia region is predicted to be approximately 1,767MW. This peak demand is forecasted to occur over the next 8 years rising from 1,411MW recorded in 2022/23.

3.4.6 Table 3.1 below shows the changes for the East Anglia Demand Area and the changes to the part of the East Anglia demand that impact on the stability assessment to 2030.

3.4.7 The area impacting on the stability assessment comprises an area of the East Anglia Demand Area that, due to the limited number of circuits that connect it to the wider network (four circuits, made up of two double circuit overhead lines), is vulnerable to stability compliance issues (transient stability is discussed later in this report). This is made up of the Norwich Main, Sizewell and Bramford substations (i.e. it does not include Walpole Substation), and is illustrated by the red circle in Figure 3.3.

3.4.8 Demand in the East Anglia Demand Area as a whole is expected to increase from 1,411MW in 2022/23 to 1,767MW in 2029/30 and the demand in the area impacting the stability assessment is expected to increase from 1,062MW in 2022/23 to 1,320MW in 2029/30.

Table 3.1 – 2022 WK24 Forecast Demand for the East Anglia Region

	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29	2029/30
East Anglia Demand (MW)	1,411	1,416	1,431	1,463	1,519	1,598	1,690	1,767
East Anglia Demand impacting stability assessment (MW)	1,062	1,066	1,078	1,102	1,142	1,199	1,260	1,320

Generation connecting in East Anglia

3.4.9 The increases in local demand are relatively modest while significant expansion of generation is expected in the region. In the East Anglia region, connection agreements have been signed in respect of 17,310.1MW of new generation (total generation of 24,997.5MW minus Existing Generation of 7,687.4MW). These future connection agreements comprise a large volume of offshore wind generation (including East Anglia Offshore Wind), gas-fired generation, energy storage projects, and a nuclear power station (at Sizewell C). Table 3.2 below gives details.

Table 3.2 - Planned Generation for East Anglia Generation Data from the ESO TEC registers as of 28/02/23 (*Generation located within stability assessment area, $Generation using Fossil Fuels)								
Completion Year	**Generation Name**	**Substation**	**Plant Type**	**Total Installed Capacity (MW)**	**Availability Factor**	**Scaled Generation Capacity (MW)**		
Existing	Sizewell B	Sizewell 132kV	Nuclear	1,230.0 MW	0.85	1,045.5 MW	*	
Existing	Greater Gabbard Offshore Wind	Lieston 400kV	Wind	500.0 MW	0.7	350.0 MW	*	
Existing	Great Yarmouth	Norwich 400kV	CCGT	420.0 MW	0.83	348.6 MW	*	$
Existing	Sherringham Schoal Offshore Wind	Necton 400kV	Wind	315.0 MW	0.7	220.5 MW	*	
Existing	Gunfleet Sands II	Gunfleet	Wind	64.0 MW	0.7	44.8 MW	*	
Existing	Gunfleet Sands I	Gunfleet	Wind	99.9 MW	0.7	69.9 MW	*	
Existing	Kings Lynn A	Walpole 132kV	CCGT	395.0 MW	0.83	327.9 MW		$
Existing	Sutton Bridge A	Sutton Bridge 400kV	CCGT	850.0 MW	0.83	705.5 MW		$
Existing	Peterborough	Walpole 132kV	CCGT	245.0 MW	0.83	203.4 MW		$
Existing	Spalding North Power Station	Spalding North 400kV	CCGT	950.0 MW	0.83	788.5 MW		$
Existing	Spalding Energy Extension	Spalding North 400kV	CCGT	299.0 MW	0.83	248.2 MW		$
Existing	Dudgeon Wind Farm	Necton 400kV	Wind	400.0 MW	0.7	280.0 MW	*	
Existing	Peak Gen	Walpole 132kV	AGT	20.5 MW	0.83	17.0 MW		$
Existing	Race Bank Windfarm	Walpole 400kV	Wind	565.0 MW	0.7	395.5 MW		
Existing	Lincs Wind Farm	Walpole 400kV	Wind	265.0 MW	0.7	185.5 MW		
Existing	Galloper Windfarm	Sizewell 132kV	Wind	348.0 MW	0.7	243.6 MW	*	
Existing	EPR Thetford	Bramford 400kV	Biomass	41.0 MW	0.83	34.0 MW	*	
Existing	East Anglia One	Bramford 400kV	Wind	680.0 MW	0.7	476.0 MW	*	
2022	Pivoted Power (Walpole)	Walpole 400kV	Energy Storage	49.9 MW	0.83	41.4 MW	*	
2022	Brook Farm BESS	Bramford 400kV	Energy Storage	49.9 MW	0.83	41.4 MW	*	
2023	Walpole Green Ltd	Walpole 400kV	Energy Storage	49.9 MW	0.83	41.4 MW	*	
2023	Pivoted Power (Bramford)	Bramford 400kV	Energy Storage	49.9 MW	0.83	41.4 MW	*	
2023	Bramford Green Stg 1	Bramford 400kV	Energy Storage	49.9 MW	0.83	41.4 MW	*	
2023	Yare Power	Norwich 400kV	CCGT	49.5 MW	0.83	41.1 MW	*	$
2024	ENSO Green Holdings	Walpole 400kV	Energy Storage	100.0 MW	0.83	83.0 MW	*	
2024	Bramford Green stg 2	Bramford 400kV	Energy Storage	7.1 MW	0.83	5.9 MW	*	
2024	Eurolink	Lieston/Sizewell	Interconnector	1,600.0 MW	1	1,600.0 MW	*	
2025	East Anglia Two	Bramford 400kV	Wind	860.0 MW	0.7	602.0 MW	*	
2025	Kings Lynn B	Kings Lynn 400kV	CCGT	1,700.0 MW	0.83	1,411.0 MW	*	$
2025	Vanguard	Necton 400kV	Wind	1,320.0 MW	0.7	924.0 MW	*	
2026	East Anglia One North	Bramford 400kV	Wind	860.0 MW	0.7	602.0 MW	*	
2026	East Anglia Three	Bramford 400kV	Wind	1,200.0 MW	0.7	840.0 MW	*	
2026	Norfolk Boreas	Necton 400kV	Wind	1,320.0 MW	0.7	924.0 MW	*	
2027	Vanguard East 1	Necton 400kV	Wind	960.0 MW	0.7	672.0 MW	*	
2027	Equinor	Norwich 400kV	Wind	719.0 MW	0.7	503.3 MW	*	
2027	Nautilus	Lieston/Sizewell	Interconnector	1,500.0 MW	1	1,500.0 MW	*	
2028	Vanguard East 2	Necton 400kV	Wind	360.0 MW	0.7	252.0 MW	*	
2029	Sizewell C Stage 1	Sizewell 400kV	Nuclear	1,670.0 MW	0.85	1,419.5 MW	*	
2030	Race Bank Extension	Walpole	Wind	565.0 MW	0.7	395.5 MW		
2030	Sizewell C Stage 2	Sizewell 400kV	Nuclear	1,670.0 MW	0.85	1,419.5 MW	*	
2030	Alcemi Bramford Battery	Bramford 400kV	Energy Storage	500.0 MW	0.83	415.0 MW	*	
2031	Norwich 100MW BESS	Norwich 400kV	Energy Storage	100.0 MW	0.83	83.0 MW	*	
Total Existing Generation (MW)				**7,687.4 MW**		**5,984.3 MW**		
Total Generation Impacting Stability* (MW)				**20,843.0 MW**		**16,617.3 MW**		
Total Genration Existing and Contracted with No Fossil Fuel Contribution $ (MW)				**20,068.5 MW**		**15,793.1 MW**		
Total Generation Existing and Contracted				**24,997.5 MW**		**19,884.2 MW**		
Forecast ACS Peak Demand 2029/30						**1,767.0 MW**		
Forecast ACS Peak Demand 2029/30 Impacting Stability Area*						**1,320.0 MW**		
Existing Planned Transfer at ACS Peak with All Generation (Existing Generation - Existing Demand)						**4,573.3 MW**		
Transfer at ACS Peak with All Generation Impacting Stability Area (Total Generation* - Peak Demand*)						**15,297.3 MW**		
Minimum Planned Transfer at ACS Peak with All Generation (Total Generation ($ excl fossil fuel) - Peak Demand)						**14,026.1 MW**		
Maximum Planned Transfer at ACS Peak with All Generation (Total Generation - Peak Demand)						**18,564.2 MW**		

Planned Transfers

3.4.10 To assess SQSS compliance, National Grid is first required to assess power flows between regions of the transmission system ('Planned Transfers'), which are calculated by deducting expected demand in the region from expected supply from generators. Both 'Security Planned Transfer' (based on meeting peak demand) and 'Economy Planned Transfer' (based on expected year round conditions) are used. These is explained further below.

3.4.11 The extra generation connecting in the East Anglia region will be significantly more than the demand in the area, and will therefore be exported from the region to demand areas in the Eastern, South Midlands and the South-East areas of England. This energy will be transported via the NETS to areas where power is required by demand users.

3.4.12 From a security of supply perspective ('Economy Planned Transfer'), National Grid will seek to ensure that transmission system infrastructure is adequate to meet national demand and customer generation requirements during operating conditions that could reasonably occur. It is generally the case that if the capacity of the transmission system is sufficient to meet Average Cold Spell (ACS) Peak demand it will have sufficient capacity to meet lower levels of demand.

3.4.13 The total generation capacity typically connected to the NETS exceeds maximum demand. This is known as 'Plant Margin'. Historically, Plant Margin has been a minimum 120% of peak demand (i.e. there is 20% more generation installed than required to meet demand). This allows the operation of generation below its maximum output to cover for breakdowns of generators, intermittency of energy source (wind) and to cover faults of generation while in service. Current generation market arrangements mean that simultaneous generation at maximum output is unlikely and National Grid is, therefore, not required by SQSS to provide transmission system infrastructure capable of accommodating the total output from all connected generators.

3.4.14 The amount of power expected to be transferred between two areas of the transmission system during normal operation is referred to as the 'Economy Planned Transfer'. The Economy Planned Transfer is derived by applying an Availability Scaling Factor (or 'scaling factor') to the installed capacity of each power station according to the type of generation.

3.4.15 The SQSS defines the technique that should be used to scale generation outputs for certain types of generators. Generators with fixed scaling factors (D_T) are:

- Nuclear and fossil fuel power with carbon capture and storage $D_T = 0.85$
- Wind, Wave and Tidal $D_T = 0.7$
- Pumped Storage $D_T = 0.5$
- Interconnectors Considered importing at Peak $D_T = 1.0$

3.4.16 Other plant types (such as gas turbines, biomass and energy storage) are not subject to fixed scaling factors in the SQSS. It is therefore necessary to make assumptions about the extent to which this generation would be available. As shown in Table 3.2 above, in the East Anglia Region, the Transmission Entry Capacity Register (‘TEC') includes approximately 5GW of gas turbine (CCGT and AGT) plant, 1GW of energy storage and a small amount of biomass (41MW).

3.4.17 Typically, these sources of energy have been scaled by National Grid in SQSS planning using a straight scaling factor of 0.83 (based on assumed plant margin at 120% - i.e. 1/120%). However, given the planned transition towards low-carbon sources of energy and the 2050 net zero target, this is likely to represent an overestimate as fossil fuel-based generators will gradually reduce their contribution and generation such as offshore wind will be more prevalent.

3.4.18 The assessment presented here therefore applies a range to the scaling factor for gas turbine generation. 0.83 is assumed as the top of the range (i.e. the maximum availability possible), and consideration that fossil fuel contribution will ultimately be phased out over the coming 25 years. Therefore, the bottom of the range assumes no contribution from fossil fuelled stations such as gas fired stations). Such a low availability factor will likely represent a significant underestimate of the availability of gas plant given that significant amounts of current and contracted future generation will be connected to the system in the short to medium term. However, this is considered an appropriate approach to demonstrate the robustness of need for reinforcement.

3.4.19 The Planned Transfer from the region is calculated by taking the ACS peak demand in the region from the total scaled generation. The Planned Transfer is therefore the amount of power which will flow out of the region at ACS peak. Planned Transfer calculations will always consider the power flows for ACS peak demand conditions, as less generation will be entering the market when demand is lower.

3.4.20 The results of the analysis of the Economy Planned Transfer for the East Anglia region are shown in Table 3.2 above, which captures the latest forecast demand data for 2029/30 generation connection dates recorded on the TEC and Interconnector Register publicly available on the ESO website at the time of publication of this document. These show connections of generators and interconnectors up to 2031. Gas turbine generators are included with a scaling factor of 0.83 but as discussed above a minimum planned transfer figure has also been provided assuming contribution for gas fired station is zero.

3.4.21 The total maximum contracted scaled generation in East Anglia (i.e. including gas plant) at the time of maximum demand is forecast to be 19,884.2MW as compared to 24,997.5MW of installed generation capacity. The demand in the region at the time of system peak will be 1,767MW.

- This results in a forecast maximum Planned Transfer in 2031 of 18,564.2.2MW export (19,884.2MW minus 1,767MW).
- The minimum forecast planned transfer with no contribution from fossil fuels in 2031 would be 14,026.1MW export (15,793.1MW minus 1,767MW).
- Both the maximum and minimum forecast planned transfers are significant increases on the existing Planned Transfer export condition of 4,573.3MW.

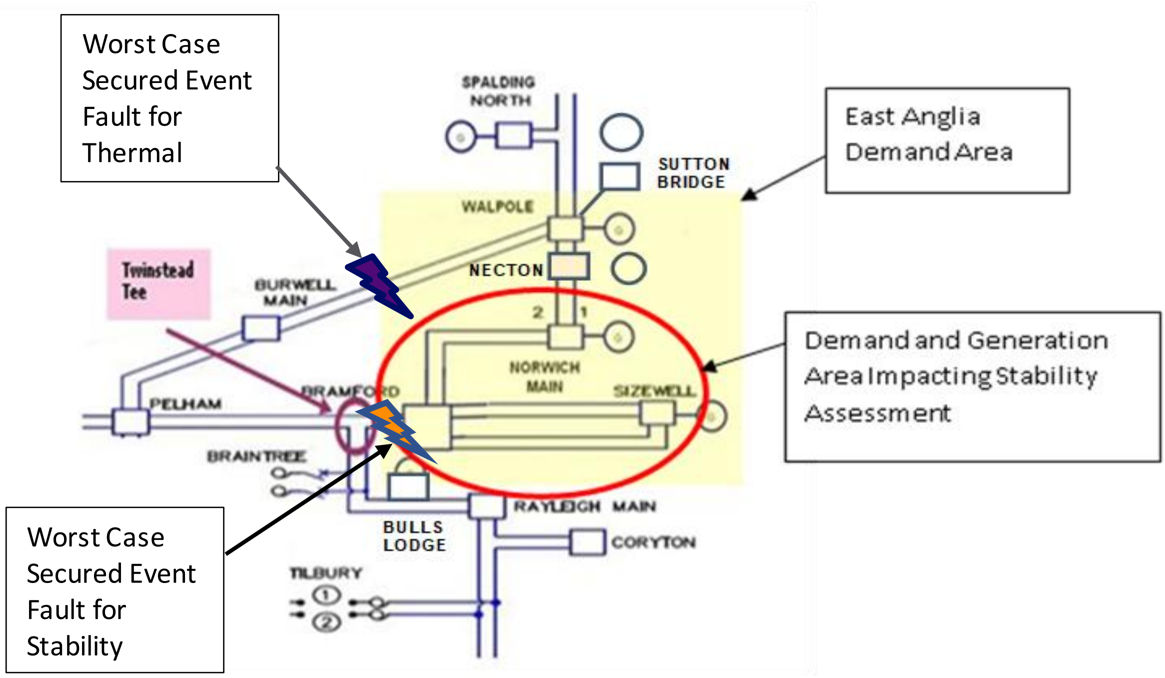
Stability and thermal capability - background

3.4.22 As discussed, above, in this case there are two issues to address in East Anglia. Firstly, there is the East Anglia Thermal Boundary capability. This is the physical maximum energy capacity the system can accommodate during system faults. This is similar to circuits in homes, which have a limit on the power the circuits can accommodate often given as a current rating (i.e. 32Amp ring-main in a house). The demand area considered for assessing thermal boundary capability is shown in the shaded area in Figure 3.4 below.

3.4.23 Secondly, there is a Stability Export Limit, which is the ability to accommodate faults without damaging generators or the network. This is shown as the area enclosed by the red circle in Figure 3.4. This part of the network only has 4 circuits and significant amounts of generation are contracted to connect.

3.4.24 Boundary Capability is the maximum permissible Planned Transfer from one part of the NETS to the neighbouring part of the NETS. For ease of understanding National Grid has used the geographical term of East Anglia (equating to the East Anglia Demand Area) to describe thermal issues associated with this part of the NETS.

Figure 3.4 – Diagram of transmission system in East Anglia showing East Anglia Demand Area and Demand and Generation impacting stability and worst faults



3.4.25 There are many types of electrical stability issues but “generator transient stability” – the ability of the generator to stay synchronised with the rest of the system following a large disturbance – is of particular importance when designing the transmission system for the connection of new generation. Generator transient stability issues occur when a fault that disrupts the electrical power flows on the system in the vicinity of any generator, and this causes the generator to accelerate. The generator accelerates because during the fault the electrical power output from the generator reduces to a level that is effectively very small. The mechanical power being put into the generator by the fuel source (steam, wind etc.) remains the same and the generator accelerates. The electrical fault would normally be cleared in tenths of a second, but during this time, the generator may have accelerated to such an extent that it is no longer synchronised with the rest of the transmission system, which can result in damage to generators as well as potential interruptions to power supplies. A more detailed explanation of this issue is set out in Appendix B.

3.4.26 Transient stability is more severe when the combined output of the generators affected by a fault is higher. The volume of combined output affects the rate at which these generators will accelerate during the fault. Conversely, transient stability issues can be reduced by the electrical characteristics of the transmission system circuits affected by the fault and the connections to the rest of the transmission system. The strength of the transmission system will affect how quickly the extra energy of the accelerated generators can be absorbed by the system and the generators brought back into synchronism. The level of demand connected to the transmission system affected by the fault will impact on transient stability. Significantly higher local demand will both slow the acceleration of the affected generators and increase the rate at which the extra energy is dissipated, therefore improving transient stability.

3.4.27 Any transmission system is susceptible to faults that interfere with the ability of transmission circuits to carry power. Most faults are temporary, many are related to weather conditions such as lightning or severe weather, and many circuits can be restored to operation automatically in minutes after a fault. Other faults may be of longer duration and would require repair or replacement of failed electrical equipment.

3.4.28 Whilst some of these faults may be more likely than others, faults may occur at any time and it would not be acceptable to have a significant interruption to supplies because of credible fault conditions including combinations of faults. The principle underlying the NETS SQSS is that the NETS should have sufficient spare capability or “redundancy” such that credible fault conditions do not result in widespread supply interruptions. The level of security of supply has been determined to ensure that the risk of supply interruptions is managed to a level that maintains a minimum standard of transmission system performance. The faults National Grid needs to design the system to be compliant with are called “Secured Events”.

3.4.29 The NETS SQSS defines the performance required of the NETS in terms of Quality and Security of Supply for secured events such that at all times:

- Electricity system frequency should be maintained within statutory limits
- No part of the NETS should be overloaded beyond its capability.
- Voltage performance should be within acceptable statutory limits; and
- The system should remain electrically stable.

Thermal capability

3.4.30 The existing transmission system in East Anglia has been designed to be compliant with the NETS SQSS and is sufficient to support the Economy Planned Transfers for 2022/23.

3.4.31 The maximum capability of the existing power lines flowing south and west out of the East Anglia region is 12,243MW as shown in Table 3.3 below. Circuits to the north do not provide export capability from the East Anglia region as flows of power come into the area from the north. Under fault conditions, power flows to and from East Anglia will still flow in a southerly and westerly direction. This intact transmission system (i.e. the system in a no fault scenario) in East Anglia is compliant with capability requirements for current Planned Transfer conditions.

Table 3.3 – Circuit Ratings for flows out of East Anglia to the South and West

Overhead Line	Circuit	Rating
Walpole - Burwell - Pelham	Walpole - Burwell - Pelham 1	3,035 MW
	Walpole - Burwell - Pelham 2	3,326 MW
Bramford - Pelham/Rayleigh Main (via Twinstead tee)	Bramford – Pelham	3,102 MW
	Bramford - Braintree - Rayleigh Main	2,780 MW
Total Capacity of Existing Transmission Circuits		12,243 MW
Total Capacity less the worst double-circuit fault (Walpole - Burwell - Pelham 1 & 2)		5,882 MW

3.4.32 However, the NETS SQSS requires that the capability of the system is sufficient following secured event faults, including a double circuit fault which is a simultaneous fault on both circuits on a double-circuit overhead line, anywhere on the system.

3.4.33 For the transmission system in East Anglia as a whole, the most onerous double-circuit fault condition identified is a double-circuit fault on the existing transmission line out of Walpole running to Burwell and Pelham. For this fault condition, the thermal capability of the transmission system in East Anglia reduces to 5,882MW as the region is only connected to the wider transmission system by a double-circuit line from Bramford, as the circuits on this section feed to Pelham and Rayleigh Main. This capability is sufficient for the Planned Transfer in 2022 but would become insufficient as additional generation connects to this part of the transmission system. The Maximum Planned Transfer in 2031 of 18,564.2MW would therefore breach the thermal limit of 5,882MW.

3.4.34 Existing circuits can be upgraded by installing conductors of higher ratings. However, this expected thermal issue could not simply be resolved by upgrade of the existing double-circuit line from Bramford and circuits terminating at

Pelham/Rayleigh Main with circuits that have a higher rating. The highest thermal rating permissible on the transmission system currently is 3,465MW per circuit, limited by equipment carrying circa 5,000 Amps of electrical current. While National Grid is undertaking works to maximise the capacity of the NETS, the 17,310.1MW of proposed new generation connection capacity (24,997.5MW of total generation less 7,687.4MW of currently existing generation in the area), would still breach the highest achievable rating of 6,930 MW double circuit (i.e. 2 no. 3,465MW circuits) if the circuits from Bramford were uprated to this maximum capability.

Stability

3.4.35 Thermal performance is not the only compliance issue forecast for the transmission system in East Anglia. The analysis of the transmission system in East Anglia also needed to consider stability issues (the demand and generation Area impacting stability is shown in Figure 3.4).

3.4.36 Double-circuit faults on the circuits from Bramford feeding to Pelham and Rayleigh, following the connection of new contracted generation, would cause stability issues for the generators connected at Sizewell, Bramford and Norwich. When Planned Transfers exceed 3,850MW in total, along the two remaining circuits between Norwich and Walpole, which carry the full power export following the fault. This stability limit of 3,850MW has been identified through detailed stability study work undertaken by National Grid on its power system study software, as discussed below.

3.4.37 Analysis work was carried out for the stability impact area (shown in Figure 3.4 above). The assessment for the stability impact area considered a maximum total of 16,617.3MW generation (generation output reduced by applicable scaling factors and excluding generation connected outside the stability area at Spalding and Walpole) and 1,320MW of demand. The resultant flows out of the stability impact area are 15,297.3MW (being 16,617.3MW – 1,320MW), which is well in excess of the existing 3,850 MW stability limit for the most onerous fault condition. The Planned Transfer of 15,297.3MW would therefore breach the stability limit of 3,850MW.

3.4.38 NETS SQSS compliance is assessed at ACS peak demand conditions, but National Grid also considers the Planned Transfer conditions that could arise during lower demand conditions, in particular for parts of the electricity transmission system where there is much more generation than demand. National Grid is required to ensure that its transmission system complies with the NETS SQSS requirements at all times of the year for conditions that can be reasonably foreseen.

3.4.39 It is possible for the most onerous operating conditions for the electricity transmission system to occur other than at times of peak demand. However, it should be noted that generation output required at other times of the year will be lower and suppliers balance the amount of generation they are buying to match the amount of demand at any time of the year. The ESO can selectively balance the system by buying on and off generation through the Balancing Market, some of these market balancing actions will be for the purposes of managing system constraints described earlier. Based on normal operation of the electricity market, National Grid considers that it is reasonable to expect generators to reduce their output or turn off as demand levels decrease and storage system to start charging during these periods. Daily peak demands vary across the year between 100-60% of their ACS peak winter value.

Generation compared to Thermal and Stability Export Limits

3.4.40 Graph 3.1 below illustrates how the connection of new generation in the region is predicted to grow over time based on contracted connection dates provided in Table 3.2. The predicted growth in cumulative generation is compared to the thermal boundary and stability capability limits ("Export Limits"). These Boundary Export Limits are equal to the transmission stability and thermal "Boundary Capability" described above plus the local demand. Boundary Export Limits show the amount of electrical power that can be produced safely by generators in East Anglia without exceeding the relevant transmission system capability limits.

3.4.41 In this case, the local demand is 1,767MW for thermal assessment and 1,320MW for stability assessment. The transmission "Capabilities" are 5,882MW (thermal Boundary) and 3,700MW (stability).

3.4.42 The thermal Boundary and stability "Export Limits" shown in Graph 3.1 are therefore 7,649MW (being 5,882MW + 1,767MW) and 5,170MW (being 3,850MW + 1,320MW) respectively. The graph illustrates that both these limits are expected to be breached soon.

3.4.43 Replacement of the existing double-circuit line from Bramford with circuits terminating at Pelham and Rayleigh Main would not resolve the stability issue, as there are not sufficient connections to the system to improve the 3,850MW limit. As both the thermal and stability compliance issues have been forecast, solutions need to be identified to resolve each issue. National Grid's design approach seeks to identify comprehensive solution options for both stability and thermal issues.

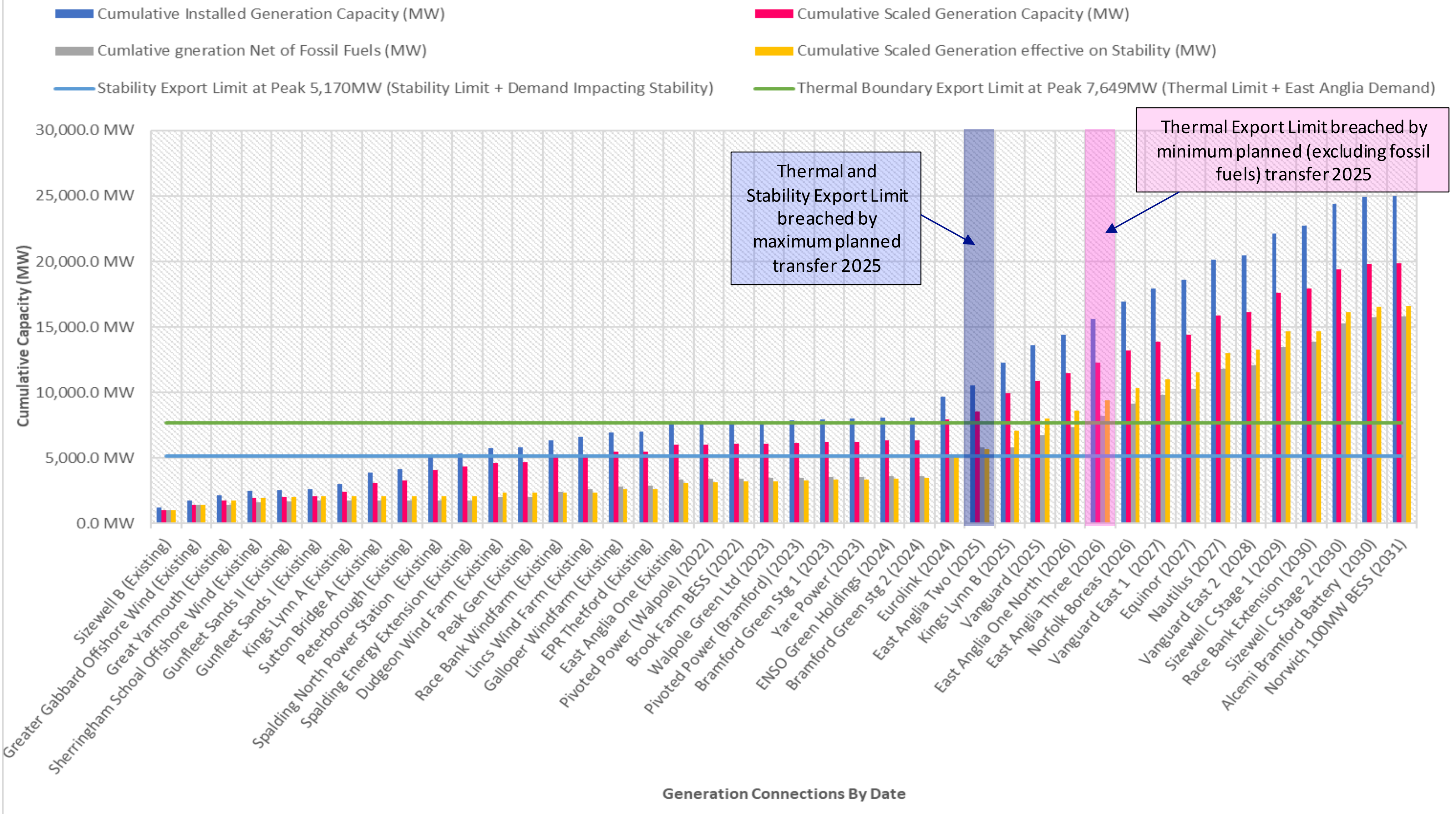
3.4.44 Graph 3.1 shows the build-up of generation from the existing generation to 2031.

- In 2025 following the proposed connection of East Anglia Two and Kings Lynn B power station, it is clear that the maximum cumulative scaled generation (Red on the graph) breaks through the Thermal boundary export limit (Green line on the graph).
- In 2026 following the connection of East Anglia Three, it is clear that the cumulative generation net of fossil fuels, indicating the minimum scaled generation (grey on the graph) breaks through the Thermal boundary export limit (Green line on the graph).

3.4.45 Graph 3.1 also shows that for the connection of East Anglia Two and Kings Lynn power station in 2025 the Cumulative scaled generation effective on stability (Orange on the graph), breaches the Stability Export Limit (Blue Line on the graph).

3.4.46 Therefore, the system between 2025 and 2026 will not meet with the requirements of the NETS SQSS and the system will need to be made compliant as soon as possible to limit increasing costs to consumers through system constraints being required.

Graph 3.1 Changes to East Anglia Generation Export, Thermal and Stability Boundary Limits



3.4.47 It is clear from Graph 3.1 that all the generation contracted to connect beyond 2024/2026 (dependent on the assumptions made on gas plant connecting) would have to fall away for there to be no need for reinforcement. This is very unlikely, particularly given the need to achieve the government's Net Zero targets to which this contracted generation significantly contributes.

3.4.48 As part of the ESO annual ETYS, FES and NOA assessment, the ESO has established from the data National Grid provides consistent with this need case that the limits described here would add constraint costs exceeding the costs of reinforcement of the network. Furthermore, the ETYS has identified over 15,300MW of boundary capability is required by 2030 generation to achieve net zero targets.

3.4.49 As these constraint costs ultimately feed through to consumer and business energy bills, the system NETS SQSS compliance issues must be resolved.

3.4.50 The ESO NOA indicates the NETS SQSS compliance issues described by this needs case should be resolved by 2028 (the earliest in service date for the project). This should be done by the provision of additional circuit capacity in the East Anglia region with the immediate requirement to install 400kV high capacity, double circuit of 6,930MW (i.e. 2 no. 3,465MW circuits), which will completely resolve the Stability issues in the East Anglia region and raise the existing thermal boundary capacity of 5,882MW to a minimum 12,243MW of capacity matching the existing intact system capacity shown in Table 3.3.

4. Conclusions

4.1.1 National Grid has obligations under its Transmission Licence to provide an efficient, co-ordinated and economical transmission system in England and Wales. National Grid is required at all times to plan and develop the transmission system in accordance with the NETS SQSS and to offer connections to and/or use of the transmission system via the ESO.

4.1.2 In line with the UK government's legal commitment to achieve net zero by 2050, growth in offshore wind generation, new nuclear, and interconnectors to Europe has seen a significant increase in the number of connections planned in East Anglia.

4.1.3 The existing electricity transmission network was not designed to transfer the increasing volume of generation capacity from East Anglia to major centres of electricity demand across central and southern England. The network will require significant reinforcement in the East Anglia area to provide capacity for these connections to ensure that power can be transferred securely to onshore demand centres to meet the needs of Great Britain's electricity consumers and businesses.

4.1.4 This anticipated growth in generation means that between 2025 and 2026, the limits of the East Anglia transmission system will exceed their current capacity. In summary this leads to two issues that need to be resolved.

4.1.5 Firstly, the Thermal Boundary Export Limit would be exceeded. It is forecasted that 24,997.4MW of generation will be connected to the transmission system in East Anglia (existing and contracted to connect). This leads to a Planned Transfer of between 14,026.1MW and 18,564.2MW being required in the East Anglia area by 2031. This is significantly more than the current thermal boundary export limit of 7,649MW.

4.1.6 Secondly, the Stability Export Limit would be exceeded. It is anticipated that the quantity of generation (existing and contracted to connect) impacting stability of the network will rise to a maximum of 16,617.3MW. This leads to planned transfers of 15,297.3MW from the area impacted by stability. This is significantly more than the current stability export limit of 5,170MW.

4.1.7 In the period between the system experiencing NETS SQSS compliance issues and operation of the new reinforcement, the ESO manages shortfalls in boundary capacity by reducing power flows and constraining generation. This is achieved by paying generators to reduce their outputs, known as 'constraint costs'. Ultimately, constraint costs are passed on to consumers and businesses through electricity bills. When constraint costs become higher than the cost of investment required to reinforce the network (and remove the need for constraint costs) it is economically optimal to proceed with investment for reinforcement.

4.1.8 Without the required reinforcement, multiple contracted customers who have connection offers which are reliant on reinforcement of the network before they could proceed with an unconstrained connection to the network will be impacted. Indeed, National Grid is obliged to provide reinforcement to comply with its licence obligations, the NETS SQSS and to facilitate generation connections.

4.1.9 The ESO NOA indicates the NETS SQSS compliance issues described by this needs case should be resolved by 2028. This should be done by the provision of additional circuit capacity in the East Anglia region with the immediate requirement to install a 400 kV high capacity, double circuit of 6,930MW (i.e. 2 no. 3,465MW circuits). This will resolve the Stability issues in the East Anglia Region and raise the existing thermal boundary capacity of 5,882MW to a minimum 12,243MW of capacity matching the existing intact system capacity shown in Table 3.3.

4.1.10 The Bramford to Twinstead Reinforcement project has received consecutive ‘proceed’ recommendations in the NOA process since NOA 2018/19, which means it is optimal to deliver by its ‘earliest in service’ date. The project has also been identified as an ‘HND essential’ option in the latest NOA Refresh (July 2022). This means that the ESO considers the project as essential to meet the UK Government’s 2030 offshore wind targets discussed above.

4.1.11 There is therefore an urgent need to reinforce the network in the East Anglia area by 2028. This is to enable connection of multiple contracted generation customers; ensure these future connections of generation can be made without incurring significant constraint costs; support the facilitation of UK Government net zero ambitions; and meet National Grid's transmission licence obligations.

4.1.12 This document has set out the need to reinforce the transmission network in East Anglia. The Strategic Options Report (June 2011) (**application document 7.2.2**) considers the technology and spatial options for providing this additional capability.

5. References

Committee on Climate Change, Net Zero the UK's Contribution to stopping global warming (2019). (Online)

Climate Change Act 2008 (2050 Target Amendment) Order 2019. (Online)

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National Infrastructure Commission, Operability of highly renewable electricity systems (2021). (Online)

HM Government (2022). Department for Business, Energy & Industrial Strategy. Policy paper: British energy security strategy. (Online)

Appendix A
Comparison to 2011 Need Case

In 2011, the need case concluded that between 2016 - 2021 the East Anglia region would require new transmission capacity in excess of 8,000MW to comply with the requirements of the NETS SQSS.

The existing transmission system would have become insufficient to meet customer requirements in 2016. National Grid’s analysis had identified NETS SQSS compliance issues with both thermal and stability boundary limits, due to over 20GW of installed generation capacity contracted at that time to be connecting in East Anglia by 2021, including the later stages East Anglia Offshore Wind Farm in 2016, and Sizewell C new nuclear power station in 2020.

Subsequently, both East Anglia Offshore Wind and Sizewell C modified their connection dates and National Grid put the new reinforcement project on hold in East Anglia as the need had moved further out than originally indicated in 2011. In advance of the new reinforcement, National Grid continued to maximise the existing network in the area and accommodate new connections.

This has moved the generation background on from the 2011 position. More generation has connected, while the generation connection dates of both new applicants and 2011 generators which modified their application are drawing closer. This results in a Planned Transfer that exceeds the capacity of the network by an even greater margin that was identified in 2011, meaning that the need for the reinforcement has not only re-emerged but is stronger than that which triggered the project previously.

Appendix B
Technical Explanation of Security and Quality of Supply

A number of assessment criteria are referenced in this report.

This appendix provides further technical explanation of a number of issues that can impact the need for infrastructure all or some of which may be referred to in this report:

- Thermal capability
- System security
- Transient stability
- Negative phase sequence currents

Thermal Capability

All metallic electrical conductors expand with increasing temperature and have electrical resistance which causes heat to be generated when electrical current flows through the conductor. Overhead and underground conductors are designed to operate up to a certain temperature. For each conductor type, there will be a maximum current which can flow without exceeding the upper operating temperature. This maximum rating will depend on the ambient air or ground temperature, wind speed and any special cooling equipment utilised or specialist materials used to bury conductors.

Exceeding the upper operating temperature in overhead lines will cause conductors to sag and safe clearances between the conductors and the ground will no longer be maintained; also, this may cause lasting damage to the conductor system. Exceeding the upper operating temperature of underground cables and Gas Insulated Lines (GIL) causes damage to the conductor system and risks ultimate failure.

The maximum power that can be carried by any electrical circuit is directly proportional to the maximum current and is referred to as the “thermal limit”.

System Security

Any transmission system is susceptible to faults that interfere with the ability of transmission circuits to carry power. Most faults are temporary. Any electrical terminals exposed to the air including overhead lines, cable terminations and air insulated substation equipment may experience faults related to weather conditions such as lightning or severe storms. Many circuits can be restored to operation automatically in minutes following these faults.

Other faults may be of longer duration and restoration of the circuit would require repair or replacement of a piece of failed electrical equipment such as a conductor, cable or transformer.

The principle underlying the NETS SQSS is that the transmission system should be secure against such faults and certain combinations of such faults. “Secure” in this context means that the supplies of electricity will not be interrupted or that interruption will be limited to a defined amount of demand and that generation connections will be maintained to the system to prevent further supply interruptions. The principle underlying the NETS SQSS is that the transmission system should have sufficient duplication or “redundancy” such that it is robust against these faults and certain combinations of faults. The level of security of supply has been determined to ensure that supply interruptions are minimised to a sufficient level to maintain widespread supplies during such faults.

To comply with the NETS SQSS it is necessary that the transmission system is designed to have a certain level of duplication or “redundancy” of circuits and other equipment. Following any fault or combination of faults against which the system must be secured, there must be sufficient capacity in the remaining circuits to accommodate the anticipated power flows without causing overloads or, for certain more severe combinations of faults, sufficient capacity allowing for the disconnection of no more than a defined amount of demand or generation.

Transient stability

The majority of generation, connected to the NETS is made up of large “synchronous machines”. These machines maintain a speed which outputs electrical power at the mains frequency of 50 hertz (50 positive and negative cycles per second) and remain in synchronism with this frequency. The NETS SQSS (see Appendix 3) requires that at all times the system remains “electrically stable”. There are many types of electrical stability issues but of particular importance when designing the transmission system for the connection of new generation is “generator transient stability”, which is about maintaining the synchronism of generation following a large disturbance to the power system, for example the fault of transmission circuit.

The alternating voltage at every point on the system is in synchronism (or “synchronised”) with the alternating voltage at every other point on the system. In effect, during normal operation the entire transmission system, together with all the local distribution systems, generators and synchronous motors are “on the same electrical cycle”.

Generator transient stability issues occur when a fault disrupts the electrical power flows on the system in the vicinity of any generator and this causes the generator to accelerate. The generator accelerates because during the fault the electrical power output from the generator reduces to a level that is effectively very small whilst the mechanical power being put into the generator by the fuel source (steam, wind etc.) remains the same. The electrical fault would normally be cleared in tenths of a second, but during this time, the generator may have accelerated to such an extent that it is no longer synchronised with the rest of the transmission system which can result in damage to the generators affected, as multiple generators in area will experience stability issues described, as well as potential interruptions to power supplies.

If a generator accelerates so much that its inertia is too strong (i.e. its mass is moving too fast), a situation called “pole slipping” can arise. In this case the generator loses synchronism with the system and the forces involved can cause both electrical damage and mechanical damage to the generator experiencing pole slipping.

The mechanical analogy is a train of gear wheels under a high load skipping a tooth; the gears may succeed at meshing again on the next tooth, but it is possible that the gears will carry on slipping from one tooth to the next, inducing severe vibration in the gear train and anything connected to it.

Generators close to the fault will be affected more generators further away. Here, the analogy is to liken the transmission system to a network of narrow hydraulic pipes with power being transmitted as a flow of very high pressure water. Generators are the pumps that pressurise the water and cause it to flow. Under normal circumstances, a stable pattern of flows will be established but should a pipe rupture, the ruptured pipe can no longer transmit hydraulic power. Pumps in the vicinity of the rupture will be pumping against much reduced resistance and will speed up, with pumps closest to the rupture being more affected than those further away.

Faults on transmission circuits are cleared, meaning that the short- circuited line is disconnected from the system, typically within tenths of a second. Unless the fault is cleared this quickly - in the hydraulic analogy, the rupture is repaired – a generator close to the fault would have accelerated with so much inertia that pole slipping occurs.

The greater a generator’s power output at the time of the fault the more it will accelerate during the fault. Once the fault is cleared, the number and electrical characteristics of the circuits connecting an affected generator to the rest of the system will determine how quickly the extra energy of the accelerated generator can be absorbed into the rest of the system. Increasing the capacity of the circuits could resolve a generator transient stability issue. However, in the hydraulic analogy this would require increasing the capacity of all pipes (circuits) within the local area, whereas adding a new pipe would resolve the issue. Strengthening the system by using pipes with thicker walls means that a loss would still reduce capacity during the fault: in a 2 pipe system 50% capacity would be lost following a permanent fault of a pipe. However, by adding an additional pipe following equivalent permanent fault of a pipe in a 3 pipe system would reduce capacity by only 33%. In the electrical system this difference in post fault capacity would ensure robust stability performance.

Within electrical systems the maximum electrical thermal capacity, which restricts current flow, is reached before other electrical parameters of the system are exceeded. So repeatedly increasing the size of conductors in the system is not appropriate because it would mean that all the conductors in an area would have much more electrical power capability than could be used to thermally transport power.

Also, the physical load carrying capability of existing infrastructure would not be sufficient for very large conductors and would require major rebuilding of the entire system in an area to manage the increased capacity with larger, heavier pylons. The distance over which the electrical circuits traverse also affects the electrical parameters as resistance and reactance (key electrical parameters) increase proportionally with distance. Therefore, the addition of circuits is often the most efficient way to change system parameters to a point where stability can be maintained and especially where thermal capacity issues also need to be resolved.

The precise behaviour of generators prior to, during and following a fault is unique to: their individual locations on the transmission system; the control systems used to manage each generator; and its physical design. They therefore have to be considered in particular detail when planning any new connection to the transmission system.

Quality of supply – Negative Phase Sequence (NPS) Currents

Pylons (Transmission Towers) have a circuit on each side of the tower (as described in section 4) and power of significant magnitude can flow in opposite directions on these circuits. When power flows in opposite directions, additional alternating currents ("Negative Phase Sequence Currents") can be induced in each circuit. The Grid code defines maximum permissible limits for the level of these induced currents as at higher level they can cause mechanical stresses and damage in generators and industrial motors.

An alternating current in a conductor will induce alternating currents in another conductor in close proximity. This phenomenon underpins the operation of generators, electric motors and transformers.

The phenomenon applies also to the conductors of a transmission line. Over many kilometres of a transmission line, the current in one conductor will induce currents in the other conductors. This applies both between the conductors that make up the different phases of a single circuit and between the conductors comprising the circuit on one side of a transmission line and the conductors comprising the circuit on the other. Moreover, the strength of the effect, and hence of the currents induced, is dependent on the physical position of the conductors and the magnitude of the currents flowing in each conductor. Each conductor (top; middle; and low) induces different currents in each of the other conductors.

If uncorrected these different induction effects can lead to imbalances between the currents in the different phases of each circuit. These imbalances create negative phase sequence currents and these can, in turn, give rise to imbalanced stresses in generators and industrial motors with excessive heat being generated within them. National Grid is required as a condition of its licence to have in force the Grid Code, which, amongst many other technical requirements, stipulates maximum limits to these imbalance currents to protect the equipment of users connected to the transmission system (and to local distribution systems which are connected to the transmission system). The connected parties' equipment must be capable of withstanding imbalance currents to the limits set in the Grid Code.

National Grid seeks to keep these imbalance currents within the specified limits by switching the position (or "transposing") the phases of transmission lines where possible. Typically, overhead lines are arranged such that the overall effect is mitigated across the network. However, this arrangement which works effectively when the currents in both circuits is flowing in the same direction will not be effective when the currents in the two circuits are flowing in opposite directions, and especially when the magnitudes of these opposing currents are large. Moreover, the compensation will be less effective even when there is current flowing in one circuit but not in the other due, say, to the second circuit being on outage.

Negative phase sequence currents can be eliminated by ensuring situations which cause power to flow in opposing directions on the transmission system are removed. This can be done by removing complex system configurations such as teed circuits, or circuits on the same pylon connecting to different locations. Removing complex configurations is normally achieved by construction of new substations, new circuits or if possible, reconfiguration of existing system circuits.

National Grid plc
National Grid House,
Warwick Technology Park,
Gallows Hill, Warwick.
CV34 6DA United Kingdom

Registered in England and Wales
No. 4031152
nationalgrid.com