Western Power Distribution's

Distribution System Operability Framework

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WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Foreword

Welcome to Western Power Distribution's Distribution System Operability Framework (DSOF), an assessment of technical issues facing Distribution Network Operators (DNOs) as they become Distribution System Operators (DSOs). We are actively looking for future technical and commercial issues which could impair our ability to operate and maintain our networks efficiently whilst developing capacity for new connections. Raising awareness of these issues will enable us to seek new solutions and manage them efficiently and cost effectively.

Publishing insights on a variety of different topics affecting electrical networks will help the industry raise the profile of these technical issues. We will share our learning and discussions with other DNOs and Independent Distribution Network Operators (IDNOs), with a particular focus on collaboration through the Energy Networks Association (ENA) Open Networks programme.

Issues affecting electrical distribution networks can also affect electricity transmission networks and other energy vectors. We will work with National Grid as the Great Britain System Operator (GBSO), and other parties affected by these issues to further understand the impacts as they develop.

As we move towards becoming a DSO, we will increasingly work with customers to access resources and services that they may have at their disposal and which may benefit the network. Opening this dialogue at an early stage will enable us to work with customers to economically provide whole system solutions as they develop future Distribution Energy Resource (DER).

In the DSOF we consider a range of issues from network design through to real-time network operation. A key theme throughout the DSOF is the growing role of data capture and analysis in distribution system operation. The last ten years have seen unprecedented developments in distribution networks. The growth of distribution-connected generation has driven a major shift in Great Britain's generation mix towards renewables. Meanwhile, advances in control systems and power electronics are providing us with alternatives to conventional reinforcement when managing demand growth and providing new connections.

2018 Refresh

In the 2018 refresh of the DSOF, each of the articles is split into individual documents. The introduction, background and supplementary information is common to all articles and is included in this document. The table below contains links to all of the DSOF articles, which can also be found on our website at www.westernpower.co.uk/DSOF. As new articles are published and periodically refreshed, they will be added to the list below. Please register for our mailing list for updates as and when new articles are published.

Introduction

Aims and Objectives

The DSOF aims to highlight some of the technical and commercial challenges facing DNOs as they become DSOs. The challenges are presented as subject articles in the three core areas which are identified in WPD's Innovation Strategy [1]:

Assets – Issues in this category aim to answer the question of how best to utilise network assets. Innovation projects in this category collect data from the network to enhance modelling. They also test alternative investment strategies that can postpone expensive investments.

Network Operations – Issues in this category address how the changing use of the distribution network affects how it is operated. Innovation projects in this category demonstrate the direct benefits from smart grids for network performance and service delivery

Customers – Issues in this category analyse how the changing behaviour of customers affects the operability of the network. Innovation projects in this category involve developing new technologies and solutions to meet customer's needs, such as enabling the connection of Low Carbon Technologies (LCT).

Each article is split into the following headings:

- Background;
- Network Impact;
- Detailed Assessment;
- Short Term Mitigation and Solutions; and
- Long Term Solutions.

A glossary, diagram key and bibliography are given at the end of the report.

Context

The DSOF complements National Grid's *System Operability Framework (SOF)* [2], but focuses on issues affecting distribution networks and the interface with the transmission network. The DSOF sits within a suite of documents published by WPD:

- The *DSO Strategy* [3] outlines WPD's vision for the future management of the United Kingdom electricity network, with a DSO that is involved in system balancing and real time network management. It focuses on some of the technical and commercial challenges of implementing this transition to a DSO.
- The *Shaping Subtransmission to 2030* series of reports [4] [5] [6] [7] assess the impact of future distributed generation (DG) and demand growth on the subtransmission networks in each of WPD's licence areas. The studies underlying those reports have highlighted some operability issues which are discussed in the DSOF.

Background

How the UK Electricity Network is Changing

Traditional Network

Since the 1960s, electricity generation in Great Britain has been dominated by gigawatt-scale fossil-fuelled and nuclear power stations connected to the 400kV and 275kV transmission network around the country. The 400kV and 275kV networks supply subtransmission networks (normally 132kV) with a small number of large industrial demand customers and smaller or older power stations connected. In turn the subtransmission networks supply primary distribution networks (normally 33kV) with a few industrial demand customers connected. The primary distribution networks supply secondary distribution networks (normally 11kV) with some industrial and commercial demand customers connected. Finally the secondary distribution networks supply the low voltage distribution networks, which have the vast majority of demand customers connected (including domestic customers). Generation was very rarely connected to distribution networks; instead the distribution networks were designed for the optimal delivery of power from the transmission network to customers.

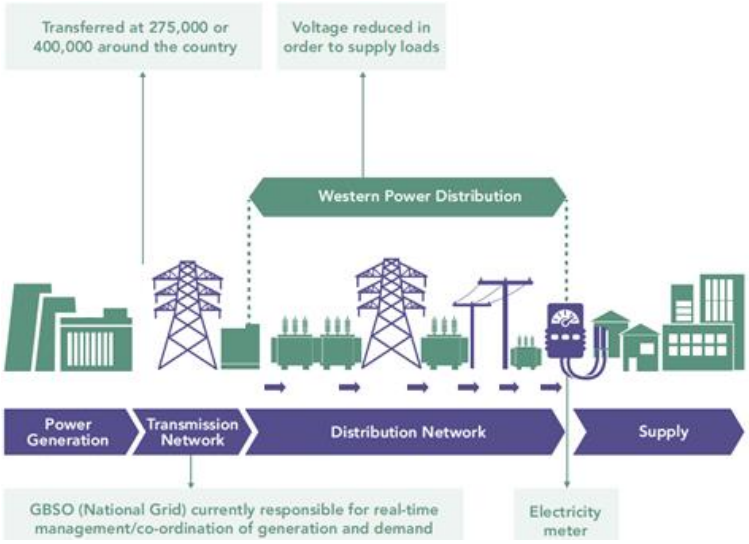


Figure 1: Traditional topology of the UK electricity network, with power delivered from transmission-connected generation to customers.

Changes to the Electricity Network

Generation

Electricity generation in the UK has changed significantly in recent years. Many large transmission-connected power stations have already closed, and more are expected to close in the coming years. This is due to power stations reaching the end of their design life, and changes in government policy such as the Industrial Emissions Directive [8].

This generation capacity has been replaced with smaller (and in some cases renewable) forms of electricity generation. Many of these new generators have been connected to the distribution network; Figure 2 and Figure 3 show the dramatic increase in generation connected to WPD's networks. Each bubble represents a generator; larger generators are depicted by a larger circle. Much of this generation is intermittent in nature, making flows across the electricity network more difficult to predict.

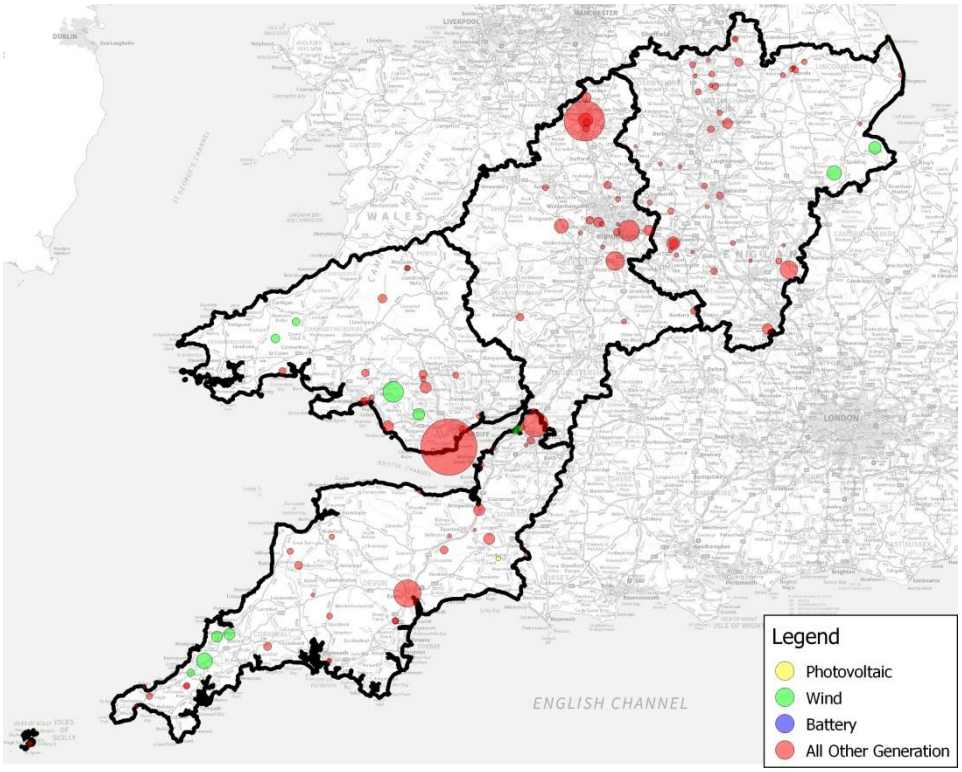


Figure 2: Map of distributed generation connected to WPD's network in 2007

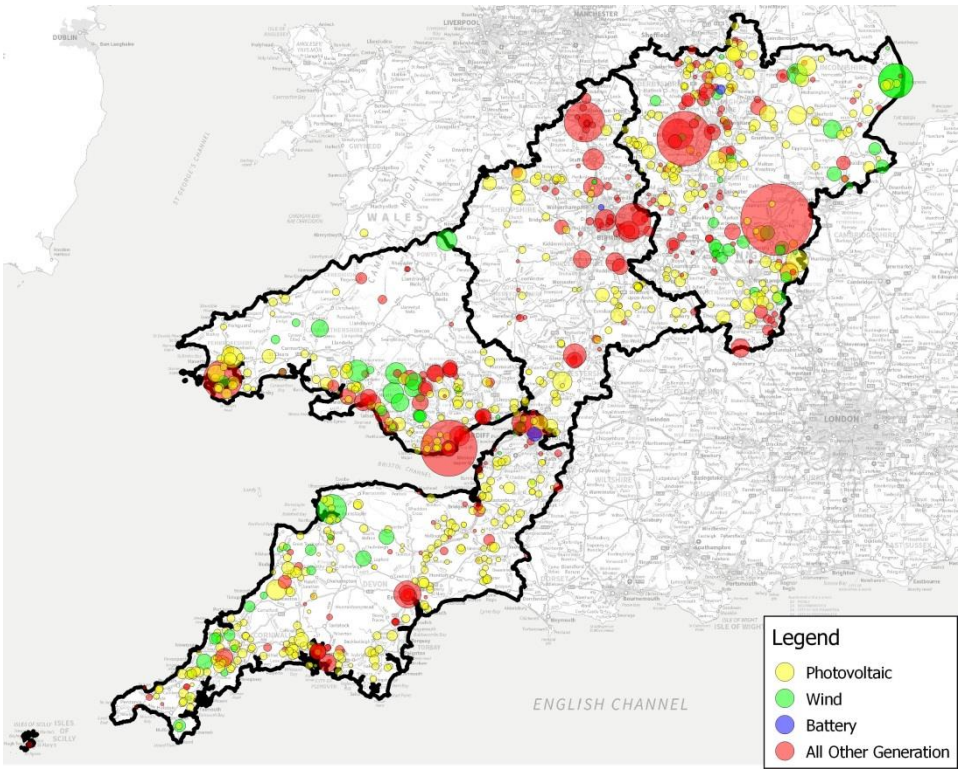


Figure 3: Map of distributed generation connected to WPD's network in 2017

Demand

The demand on the WPD network has been fairly constant over the past 10 years, with a slight downward trend. Demand growth from new connections has been offset by the improved efficiency of

domestic appliances and consumers' increased awareness of their energy usage. Figure 4 shows the historic, weather-corrected maximum demand for each of the four WPD licence areas in the last 9 years.

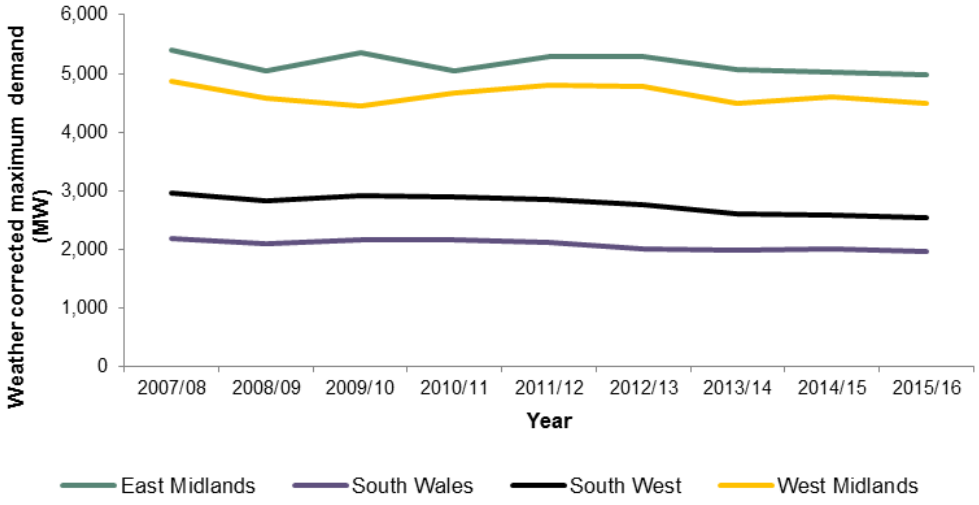


Figure 4: Historical weather correct maximum demands in each WPD licence area (MW)

However; the maximum demand on the network is forecasted to increase in the future. WPD's *Shaping Subtransmission to 2030* reports have highlighted significant potential demand growth, with the potential for winter peak demand to increase from around 15GW in 2016 to over 20GW by 2030 under the Gone Green scenario. This growth comes from the combination of new domestic, industrial and commercial premises and new uses for electricity including electric vehicles and heat pumps.

Current Network

As a consequence of the changes to the electricity network, the result is a less centralised and more complex network. Figure 5 shows a more up to date depiction of the current state of the network. Although the core topology of the network has not changed, there is now significant generation connected at all voltage levels on the network and new types of demand including electric vehicles.

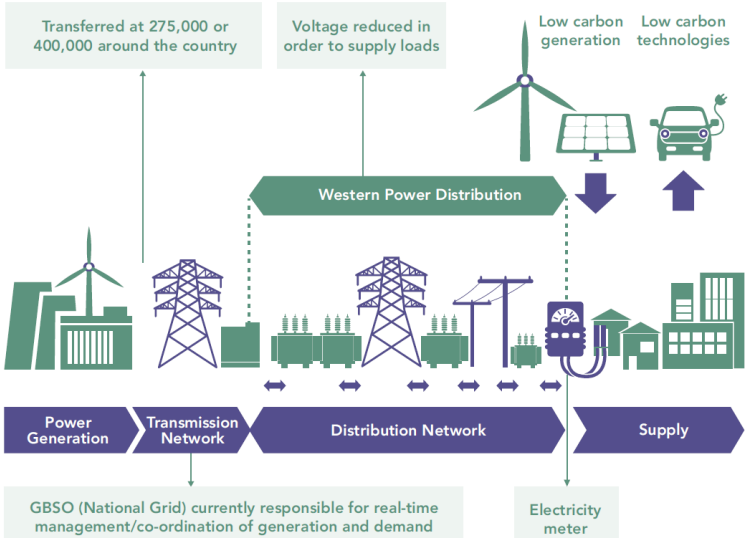


Figure 5: Changing topology of the UK electricity network, with more low carbon technologies and distributed generation, leading to bi-directional power-flow.

The network no longer follows a 'top-down' approach of power flowing from transmission-connected power stations to distribution-connected demand. This has led to some network conditions not previously encountered, such as bi-directional power-flow. At times of high solar and wind generation output, it has become possible for power to flow from the distribution network onto the transmission network in some areas.

Transition from a Distribution Network Operator to a Distribution System Operator

The increasing decentralisation of the UKs energy system, with more small-scale renewable generation and demand side management activity, would mean that the role of the GBSO will become more difficult. Currently, the GBSO is responsible for country wide frequency management and ensuring the supply of electricity meets demand on a second-by-second basis. With the increased levels of generation at different voltage levels on the distribution network, the balancing of load and demand on a national scale becomes more difficult to coordinate.

Traditional DNO operations would require very substantial investments in passive grid infrastructure, which would be underutilised much of the time. Continued construction, maintenance and operation of passive distribution networks are no longer going to deliver the best outcomes for UK electricity bill payers. DNOs therefore need to transition to becoming DSOs in order to operate and maintain efficient, economic and co-ordinated networks. WPD plans to be at the forefront of this transformation.

Office for Gas and Electricity Markets (Ofgem) have given a clear signal in section 3.5 of their Smart Systems and Flexibility Plan, published in July 2017 [9], that they expect DNOs to use flexibility to operate the network cost effectively:

> ***"Issue:*** *As the system changes, network and system operation need to evolve to ensure that the system as whole is managed efficiently. There are a range of areas where opportunities for efficiency savings are expected, including through active use of new technologies, providers and solutions and through greater coordination across the transmission and distribution boundary.*
>
> ***Action:*** *DNOs must make more efficient use of new technologies, providers and solutions, as part of their evolution to Distribution System Operators (DSOs). It is critical that DSOs, transmission owners (TOs) and the GBSO develop timely and appropriate reforms to the way they plan, operate and engage with one another and customers, in order to manage the networks more efficiently and minimise whole system costs. RIIO35, and the broader regulatory regime, contain incentives to do this, and we are seeing progress now (such as growth in Active Network Management and greater coordination), but further demonstrable progress must be made. Efficient decisions must be facilitated by informed consideration of the full range of solutions available."*

In order to facilitate the transition from DNO to DSO there are many capabilities WPD will need to develop:

- An understanding of historic and real time energy flows;
- Forecasting future energy volumes across the network (under different scenarios) to highlight opportunities for flexibility, operability issues and to identify when strategic reinforcement will be needed;
- Actively reconfigure the system depending on the system requirements (ranging from seasonal through to fine adjustments);
- Contracting and dispatching Distributed Energy Resources (demand, generation or storage) through commercial arrangement;
- Co-ordinating and providing services through DSO operations with the GBSO; and

- Maintaining a platform for energy suppliers, communities and other market participants to have visibility of network congestion (and to offer the DSO flexible demand or distributed generation solutions).

Becoming a DSO will enable WPD to manage our network on a local level and better utilise our assets through Active Network Management (ANM) and the dispatch of flexibility services as an alternative to some reinforcements. A side-effect of increased asset utilisation might be to exacerbate those problems which cannot yet be actively managed. Whilst some of the issues identified in this document are not directly triggered by the transition to a DSO, the increasing complexity of the distribution network and increased utilisation of assets may highlight the relevance of these issues earlier than previously expected.

Bibliography

[1] Western Power Distribution, “Innovation Strategy,” February 2017.

[2] National Grid plc, “System Operability Framework”.

[3] Western Power Distribution, “DSO Strategy,” July 2017.

[4] Western Power Distribution, “Shaping Subtransmission to 2030, South West,” July 2016.

[5] Western Power Distribution, “Shaping Subtransmission to 2030, South Wales,” January 2017.

[6] Western Power Distribution, “Shaping Subtransmission to 2030, East Midlands,” June 2017.

[7] Western Power Distribution, “Shaping Subtransmission to 2030, West Midlands,” January 2018.

[8] The European Parliament and Council, *Directive 2010/75/EU on industrial emissions (integrated polution prevention and control).*

[9] Ofgem, “Upgrading Our Energy System – Smart Systems and Flexibility Plan,” July 2017.

[10] The Energy Networks Association, “Active Network Management Good Practice Guide,” 2015.

Supplementary Information

Table of Units

Term	Definition
kV	Kilovolt, a unit of Voltage ($x10^3$)
LV	This refers to voltages up to, but not including, 1kV
HV	Voltages over 1kV up to, but not including, 22kV
EHV	Voltages over 20kV up to, but not including, 132kV
kW	Kilowatt, a unit of Power ($x10^3$)
MW	Megawatt, a unit of Active Power ($x10^6$)
GW	Gigawatt, a unit of Active Power ($x10^9$)
MVA	Mega volt-ampere, a unit of Apparent Power ($x10^6$)
MVAr	Mega volt-ampere (reactive), a unit of Reactive Power ($x10^6$)
MWh	Megawatt hour, a unit of energy ($x10^6$). Equivalent to a constant 1MW of Active Power delivered for an hour
MVArh	Mega volt-ampere (reactive) hour, the duration or persistence of reactive power flows. Equivalent to a constant 1MVAr of Reactive Power delivered for an hour
Hz	Hertz, the unit of frequency. The number of cycles per second.

Glossary

Acronym/ Initialism	Term	Definition
AC	Alternating Current	An electric current which periodically reverses its direction, having a magnitude that varies continuously. The rate at which the current's direction changes is known as the frequency. The frequency for UK power systems is 50Hz.
ALT	Automatic Load Transfer	A technique used to move the position of normally open points on the 11kV network in an effort to improve the networks performance. Moving normally open points has an effect on the networks losses, voltage and capacity headroom.
ANM	Active Network Management	The ENA Active Network Management Good Practice Guide [10] summarises ANM as: *Using flexible network customers autonomously and in real-time to increase the utilisation of network assets without breaching operational limits, thereby reducing the need for reinforcement, speeding up connections and reducing costs.*
–	Access Window	The period of spring, summer and autumn in which arranged outages are normally taken
ASC	Arc Suppression Coil	An adjustable reactor of between several tens of ohms and several thousand ohms, which can be used to earth the neutral of a three-phase power system.
AVC	Automatic Voltage Control	Automatic adjustment of transformer tap position required for transformers on the Primary Distribution and Subtransmission networks to maintain system voltage within limits as the demand changes.
BS	British Standard	The specification of recommended procedure, quality of output, terminology, and other details in a particular field, drawn up and published by the British Standards Institute (BSI).

Acronym/ Initialism	Term	Definition
BSP	Bulk Supply Point	A substation comprising one or more Grid Transformers and associated switchgear
CI	Customer Interruption	Ofgem describes Customer Interruptions as: *The Number of customers interrupted per year (CI). The number of customers whose supplies have been interrupted per 100 customer per year over all incidents, where an interruption last for three minutes or longer, excluding the re-interruption of supply of customers interrupted during the same incident.*
CIM	Common Information Model	An open standard that defines how managed elements in an IT environment are represented as a common sets of objects and the relationships between them.
CLASS	Customer Load Active System Services	A project funded by Ofgem's Low Carbon Networks funding mechanism. The project was carried out by Electricity North West to demonstrate a range of demand response capabilities
CML	Customer Minutes Lost	Ofgem describes Customer Minutes Lost as: *The duration of interruptions to supply per year (CML).This is the average customer minutes lost per customer per year, where an interruption of supply to customer(s) lasts for three minutes or longer.*
CT	Current Transformer	An instrument transformer that is designed to produce an alternating current in its secondary winding that is proportional to the current being measured in its primary. Current transformers are commonly used to provide current measurements to protective and monitoring devices.
CVT	Capacitive Voltage Transformer	A device used to step down extra high voltage signals and provide low voltage signals for electricity metering and protective devices. A capacitive voltage transformer is made up of a capacitive voltage divider, tuning inductor and an isolation voltage transformer. Capacitive voltage transformers may only be used to step down voltages.
–	Demand	The consumption of electrical energy.
DAR	Dynamic Asset Rating	A method of assessing asset thermal ratings based on ambient temperature to increase capacity head room and enable the connection of distributed generation. Overhead lines and underground cables, for example, have seasonal thermal ratings which mean they can be loaded differently at different times of the year.
DC	Direct Current	An electrical current that flows in a constant direction.
DCAT	Distribution Constraint Analysis Tool	DCAT is a bespoke energy curtailment estimation tool, used to provide curtailment estimates to customers who have applied for ANM generator connections.
DER	Distributed Energy Resource	Distribution-connected demand, generation and storage.
DSR	Demand Side Response	Ofgem led tariffs and schemes which incentivise customers to change their electricity usage habits
DG	Distributed Generation	Generation connected to a distribution network. Sometimes known as Embedded Generation.
DLR	Dynamic Line Rating	The application of dynamic ratings to overhead lines in response to changing parameters such as ambient temperature, weather conditions and prior loading.
–	Distribution Transformer	A transformer that steps voltage down from 11kV or 6.6kV to LV

Acronym/ Initialism	Term	Definition
DOC	Directional Over Current	Overcurrent protection which only responds to current flowing in a particular direction. Commonly fitted on the LV side of GTs and primary transformers to detect and operate for faults on the network supply the HV winding.
DNMS	Distribution Network Management System	A collection of applications designed to monitor and control the entire distribution network effectively and reliable.
DNO	Distribution Network Operator	A company licenced by Ofgem to distribute electricity in the United Kingdom who has a defined Distribution Services Area.
DSO	Distribution System Operator	A role which may be established in the future whereby the DNO undertakes some of the roles of the GBSO at a regional level to balance supply and demand.
DSOF	Distribution System Operability Framework	A document published by Western Power Distribution that assesses the technical issues facing Distribution Network Operators as they transition to Distribution System Operators (DSO).
–	Distribution Substation	A substation comprising one or more Distribution Transformers and associated switchgear
EMC	Electromagnetic Compatibility	The correct operation of electrical equipment in a common electromagnetic environment. EMC may also be thought of as the control of Electromagnetic Interference (EMI) so that unwanted effects are prevented.
ENA	Energy Networks Association	The Energy Networks Association is an industry association funded by gas or distribution or transmission licence holders.
ER	Engineering Recommendation	A document published by the Energy Networks Association.
EV	Electric Vehicle	A vehicle which uses electric motors as its method of propulsion
FACTS	Flexible Alternating Current Transmission System	A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.
FCL	Fault Current Limiter	A device which may be used on electricity networks to limit the prospective fault current when a fault occurs.
FCO	First Circuit Outage	P2/6 defines a First Circuit Outage as: *…a fault or an arranged Circuit outage…* Also referred to as N-1 in some contexts.
–	Footroom	The difference between the lower limit of a constraint and existing utilisation. Normally applied to lower limits of voltage constraints. See also *headroom*.
FES	Future Energy Scenarios	A set of scenarios developed by Nation Grid to represent credible future paths for the energy development of the United Kingdom.
FPL	Flexible Power Link	A power electronic device that enables control of real power transfer between two AC networks. The device is an AC-DC-AC converter. Reactive power control may also be achieved at each AC side.
GB	Great Britain	A geographical, social and economic grouping of countries that contains England, Scotland and Wales.
GBSO	Great Britain System Operator	National Grid is the system operator for the National Electricity Transmission System (NETS) in Great Britain. Responsible for coordinating power station output, system security and managing system frequency.
GSP	Grid Supply Point	A substation comprising one or more Super Grid Transformers and associated switchgear

Acronym/ Initialism	Term	Definition
GT	Grid Transformer	A transformer that steps voltage down from 132kV to 66kV, 33kV or 11kV.
–	Harmonic Filter	A device used to remove or reduce harmonic distortion in an AC power system. Harmonic filters may be passive or active devices depending on their design.
–	Headroom	The difference between the upper limit of a constraint and existing utilisation. See also *footroom*.
HP	Heat Pump	Extracts heat from surroundings which can then be used to produce hot water or space heating. There are a number of types of heat pumps; the common air source heat pumps absorb heat from the outside air.
ICCP	Inter-Control Centre Communication Protocol	IEC 60870 or Inter-Control Centre Communication Protocol is an international standard published by the International Electrotechnical Commission (IEC). ICCP allows standardised communications between control centres for the exchange of real time data such as status and control data, measured values and operator messages.
IDNO	Independent Distribution Network Operator	A company licenced by Ofgem to distribute electricity in the United Kingdom who does not have a defined Distribution Services Area.
IEC	International Electrotechnical Commission	An organisation that prepares and publishes international standards for all electrical, electronic and related technologies.
–	Large Power Station	As defined by the Grid Code: *A power station which is connected to a system notionally connected to a Grid Supply Point in Nation Grid Electricity Transmission plc's transmission area with a registered capacity of 100MW or more.*
LCNF	Low Carbon Network Fund	A £500m fund to support projects sponsored by the DNOs to try new technology, operating and commercial arrangements.
LCT	Low Carbon Technologies	A grouping of equipment and/or processes that form a particular technology, generation or demand related, and produce low carbon dioxide emissions when operating normally.
LFDD	Low Frequency Demand Disconnect	A scheme designed to limit a fall in system frequency by reducing demand. The demand subject to LFDD is predetermined and distributed across each of WPDs licence areas
LIFO	Last In, First Out	A stack order model used in ANM. The principal of the LIFO stack is that the last generator to apply for connection is the first to be curtailed when curtailment is necessary.
LoM	Loss of Mains	A general term for network protection (including under voltage, over voltage and frequency protection) which is used to detect a loss of the main utility electricity supply and prevent power islanding.
LTDS	Long Term Development Statement	A document published by all DNO's to assist current and future users of the distribution network to identify and assess opportunities available to them for making new or addition use of the network.
–	Medium Power Station	As defined by the Grid Code: *A power station which is connected to a system notionally connected to a Grid Supply Point in Nation Grid Electricity Transmission plc's transmission area with a registered capacity of 50MW or more but less than 100MW*
–	National Grid	The Transmission Network Operator in England and Wales.

Acronym/ Initialism	Term	Definition
NVD	Neutral Voltage Displacement	A form of network protection which measures the voltage from each phase to earth; a significant imbalance between these voltages signifies an earth fault and triggers the de-energisation of the circuit. NVD is normally fitted where there is a risk that an earth fault could be energised through an unearthed transformer winding.
Ofcom	Office of Communications	Ofcom is responsible for regulating the broadcasting, telecommunications and postal industries in the United Kingdom. Ofcom represents the interests of citizens and consumers and promotes market competition.
Ofgem	Office for Gas and Electricity Markets	Ofgem is responsible for regulating the gas and electricity markets in the United Kingdom to ensure customers' needs are protected and promotes market competition.
–	Open Networks	From http://www.energynetworks.org/electricity/futures/open-networks-project/open-networks-project-overview/ : *The Open Networks Project is a major energy industry initiative that will transform the way our energy networks work, underpinning the delivery of the smart grid. This project brings together 9 of UK and Ireland's electricity grid operators, respected academics, NGOs, Government departments and the energy regulator Ofgem.* Note: Open Networks was previously known as the ENA TSO-DSO Project.
PCC	Point of Common Coupling	As defined by G59: *The point on a distribution system, electrically nearest the customer's installation, at which other customer are, or may be, connected.*
PF	Power Factor	The ratio of real power to apparent power flowing in an electrical AC power system.
–	Primary Distribution	The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution. In WPD's East Midlands network the 33kV circuits and Primary Substations are considered to be Primary Distribution.
–	Primary Substation	A substation comprising one or more primary transformers and associated switchgear
–	Primary Transformer	A transformer that steps voltage down from 66 or 33kV to 11kV or 6.6kV
PWM	Pulse Width Modulation	A modulation or switching technique used to encode an analogue value as a digital pulse that has a variable duty cycle. The duty cycle of the digital pulse is proportional to the magnitude of the analogue value. AC voltages may be represented as a series of digital pulses with a varying duty cycle. PWM is commonly used in DC-AC converters for variable frequency drives and invertors.
PV	Photovoltaic	Type of distributed generation which uses solar irradiance to generate electricity.
RDP	Regional Development Plan	A joint study between National Grid and WPD on possible 132kV reinforcement options in the South West.
RoCoF	Rate of change of frequency	A type of network protection that detects how quickly the system frequency is changing by continuously sampling the frequency of the system voltage
RTU	Remote Terminal Unit	A device in a substation or other remote location which acts as an interface between the DNMS and onsite equipment such as switchgear and transducers.

Acronym/ Initialism	Term	Definition
SCO	Second Circuit Outage	P2/6 defines a Second Circuit Outage as: *…a fault following an arranged Circuit outage.* Also referred to as N-1-1 or N-2 in some contexts.
SCR	Silicon Controlled Rectifier	A semiconductor rectifier whose forward current between two electrodes, the anode and cathode, is initiated by means of a signal applied to a third electrode, the gate. The current subsequently becomes independent of the signal. It is a type of Thyristor.
–	Small Power Station	As define by the Grid Code: *A power station which is connected to a system notionally connected to a Grid Supply Point in Nation Grid Electricity Transmission plc's transmission area with a registered capacity of less than 50MW.*
SMPS	Switch Mode Power Supply	A type of power electronic convertor used transfer power from a DC or AC source to DC loads. Commonly used in computers, servers, LED lighting, and machine power supplies.
–	Secondary Distribution	The final section of an electrical distribution network which provides the interface between Subtransmission or Primary Distribution and most final customers. In WPD's East Midlands network the 11kV, 6.6kV and LV circuits and the distribution substations are considered to be Secondary Distribution.
SOF	System Operability Framework	A document published by National Grid that identifies system operability requirements that are needed to accommodate the changing energy landscape in the United Kingdom.
SVO	System Voltage Optimisation	This system will use a real-time monitoring and analysis tool to evaluate the real-time network situation on the 11kV and 33kV network to optimise the voltage at primary and Bulk Supply Point (BSP) substations.
–	Subtransmission	The sections of an electrical distribution network which provide the interface between transmission and primary or Secondary Distribution. In WPD's East Midlands network the GSPs, 132kV circuits, and BSPs are considered to be Subtransmission.
SGT	Super Grid Transformer	A transformer that steps voltage down from 400kV or 275kV to 132kV, 66kV or 33kV
–	VAR Compensator	A device which may be used on electricity networks to provide reactive power at particular point to adjust system voltage or perform power factor correction.
TER	Transmission Energy Resources	Large-scale power generation sources connected directly to the Transmission Network.
THD	Total Harmonic Distortion	Engineering Recommendation G5/4-1 defines THD as: *The RMS value of individual harmonic voltages expressed as a percentage of the fundamental RMS voltage, and calculated using the following expressions:* $THD = \sqrt{\sum_{h=2}^{h=50} Vh^2}$ *For harmonic voltages up to the 50th order.*
TOUT	Time Of Use tariff	National Grid's FES 2016 defines a Time Of Use Tariff as: *A charging system that is established in order to incentivise residential consumers to alter their consumption behaviour, usually away from high power demand times.*

Acronym/ Initialism	Term	Definition
TO	Transmission Owner	A company licenced by Ofgem to transmit electricity in the United Kingdom.
TSDS	Time Series Data Store	Historian software that collects time-series data needed to analyse the network.
UK	United Kingdom	A geographical, social and economic grouping of countries that contains England, Scotland, Wales and Northern Ireland.
VR	Voltage Reduction	A technique which uses a reduction in system voltage in an effort to decrease instantaneous power demand.
VS	Vector Shift	A type of network protection that detects sudden changes in the system voltage angle, which can be caused by a change in output from generating plant or changes to demand connected to the network.
VT	Voltage Transformer	An instrument transformer that is designed to produce an alternating voltage across its secondary winding that is proportional to the voltage across its primary. Current transformers are commonly used to provide voltage measurements to protective and monitoring devices.
WPD	Western Power Distribution	A Distribution Network Operator (DNO) company that is licenced by Ofgem to distributed electricity in the East Midlands, West Midlands, South West, and South Wales regions of United Kingdom.
XML	Extensible Markup Language	A metalanguage that allows a user to define a set of rules for encoding documents that is both human-readable and machine-readable.
X/R	X/R Ratio	The ratio of reactance to resistance in an AC circuit. Commonly used in fault level calculations to calculate the magnitude of DC component current.

Diagram key

The DSOF uses a range of circuit diagrams to represent different network scenarios. These range from indicative single line diagrams, to more complex three phase representations. Each of the symbols used are defined in the tables below.

Single Line Diagram Key

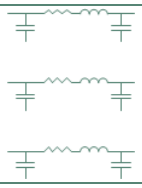
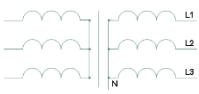
Symbol	Definition
	In service line (voltage marked on diagram)
	Out of service line (voltage marked on diagram)
	Super Grid Transformer
	Transformer

Symbol	Definition
	Closed Circuit Breaker
	Open Circuit Breaker
	Tower
	Relay

	Generator
	Capacitor Bank
	Series Reactor

	Load
	Network fault

Three Phase Diagram Key

Symbol	Definition
	Arc Suppression Coil
	In service line
	Three winding transformer

Symbol	Definition
	Neutral Earthing Resistor
	Closed Circuit Breaker

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