Annex 4.3

Network Visibility Strategy

Northern Powergrid: our business plan for 2023-28

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Introduction

The purpose of network visibility is to:

- Understand the utilisation of the network and the nature of power and energy flows across the network in different time periods;
- Enable efficient and reliable operation of the network; and
- Enable efficient and effective asset lifecycle management decision making based on condition and performance.

The purpose of the network visibility strategy is to:

- Explain how network visibility is central to our DSO strategy[1] and how it contributes to the three defined DSO roles[2];
- Explain how both measured and modelled data on network visibility underpins the various forms of external information provided to stakeholders;
- Explain the existing level of network visibility available and how we are making enhancements to it over the 2023-28 period; and
- Provide further information on the specification of equipment used to provide network visibility.

Why do we need to enhance network visibility?

A smart and flexible network requires a sufficient level of network visibility and control to:

- Optimise network utilisation and use of network and customer flexibility (collectively referred to as flexibility) in order to enable customers to switch to and benefit from low carbon technologies;
- Facilitate the increasingly complex power and energy flows across the network, including the many diverse sources of generation across the network and new forms of flexible, low carbon technologies, which will ultimately result in a shift from uni-directional to bi-directional power flows; and
- Improve our visibility and understanding of power flows and year-round conditions so that we can safely and securely operate the network, where enhancements are targeted in the areas of the network where the complexities and magnitude of power flows warrant it. The drivers include:
    - Low voltage networks which will facilitate high levels of low carbon technologies (but which currently offer little visibility) are planned and operated with flexibility to facilitate net zero at lowest cost;
    - High voltage networks which deliver power to and control the voltage of the local low voltage networks, become increasingly important to our customers as further dependence on, and consumption of electricity will mandate improved planning and operation to ensure on-going safety and efficiency, whilst providing a step-change in reliability; and

[1] The linkage between the DSO Strategy and this Network Visibility Strategy is provided in Appendix 3. The DSO Strategy then links to the Digitalisation Strategy and Action Plan (DSAP) with the underlying and enabling technology development projects.
[2] Role 1: Planning and network development; Role 2: Network operation; Role 3: Market development.

- Sections of the network where flexibility are likely to be, or are adopted, requiring highly-granular network visibility to ensure the network is utilised safely and economically.

Network visibility enhancements during 2023-28 are therefore to be targeted at the right locations, at the right time, using the right equipment, in order to provide the optimal level of network visibility.

Sources and categories of network visibility

Network visibility is obtained using three primary sources:

- Sensors located on the distribution network directly measuring network parameters;
- Sensors located at entry or exit points to the network owned by other parties, such as smart meters; and
- Analysis to estimate network parameters using sensor data[3] and increasingly data from non-technical sources (particularly that relating to the businesses and communities we serve).

The main categories of network visibility explored further in this document are:

- Power flow visibility;
- Operational visibility;
- Fault level visibility;
- Power quality visibility; and
- Environmental visibility.

Note: There are other sources of data, ranging from data-sets that underpin our scenarios and forecasts (such as customer demographic data and low carbon technology adoption data), to data-sets that underpin our asset management activity (such as asset conditioning monitoring which includes online partial discharge monitoring, dissolved gas analysis, pressure gauges, transformer temperature, battery health measurements, etc.). These other sources of data are outside of the scope of the network visibility strategy, but play an important role as part of our asset management strategy.

The sensors or monitoring equipment used across the network can vary according to the voltage level of the network. Our 'Standard for the Application of System Monitoring'[4] provides extensive details of the network parameters derived from various network equipment, both historically and on new build assets. This document is aimed at stakeholders that want a detailed understanding of the underlying basis of our network monitoring, and it was developed as part of our 2015-23 smart grid enablers programme. These voltage levels are summarised as follows, alongside a high level overview of the current state of network visibility:

- **132kV -** typically the voltage supplied at the Grid Supply Point (GSPs).
  - Second-by-second network visibility with half-hourly information stored within the data historian for both power flow and operational visibility. Fault level visibility is modelled with detailed data-sets (many of which are from third parties), whilst power quality and environmental visibility are obtained in a targeted manner, as needed.

[3] Including inferring system parameters at the location at the sensors (such as combining voltage and current data to deduce power flow variables, and utilisation), to application of state estimation to infer system parameters at locations remote from the sensors (for example, determination of voltage downstream of a voltage regulation device) and the combination of this data to infer other parameters, such as distribution losses.
[4] IMP/001/017 – Standard for the Application of System Monitoring

- **132/EHV transformer -** which step down voltage from 132 kV to extra high voltage (EHV).
  - Similar network visibility to 132 kV.
- **EHV -** which consists of both 33kV and 66kV.
  - Similar network visibility to 132kV.
- **EHV/HV transformer** - which step down voltage from EHV to high voltage (HV).
  - Similar network visibility to 132kV.
- **HV -** which consists of both 11kV and 20kV (and some limited cases of 6kV).
  - Network visibility for HV feeders at the EHV/HV substation is similar to that of 132 kV with the notable difference being that only current and voltage magnitudes are generally obtained for power flow information. Downstream of the substation, HV equipment generally provides minimal (or often, no) power flow visibility, whilst other network visibility categories are obtained in a targeted manner, generally when upgrading or installing equipment, or driven by a specific need (e.g. a modelled constraint requiring further information to support the decision making process).
- **HV/LV transformer** - which step down voltage from HV to low voltage (LV).
  - Maximum demand indicators (for ground mounted transformers only) provide a snapshot of the peak loading, whilst energy consumption and other customer data (including from smart meters) is used alongside statistical techniques to model network parameters. This state estimation enables safe and economic operation, however with increasing penetration of LCTs, enhanced network visibility is required for a smart, flexible and efficient transition to net zero. Deployment of LV monitoring onto ground mounted substation LV boards provide a measurement of demand through the connected transformer.
- **LV** - which consists of 400V, or 230V single phase (i.e. the voltage to which domestic customers connect).
  - Unlike HV/LV transformers, there is no maximum demand data for LV circuits and so we rely on state estimation techniques unless we have installed LV monitoring or are able to harvest data from other connected devices. This lack of network visibility data and the increasingly complex (and significant) power flows is the driver for enhanced network visibility on LV networks.

It is also important to note that the means by which data is communicated, both communications medium and protocols, will influence the timeliness and accuracy of the network parameters. This in turn influences the suitability of the data for various use cases.

Our 2015-23 smart grid enablers programme is aimed at adding additional network sensors, harvesting more data from existing sensors and upgrading the entire operational telecommunications infrastructure used to transmit that data and real-time control instructions.

Appendix 2 to this document provides a summary of the enhancements to network visibility that we plan to deliver in the 2023-28 period. It also contains cross reference to the other business plan documents that provide more detailed information (e.g. Engineering Justification Papers).

Power flow visibility

The visibility of power flow information is crucial to the planning and operation of a safe and efficient system. It ensures that equipment is operated within its capability at all times, and that the network facilitates our customers' energy needs economically and efficiently. This visibility is a fundamental input for power systems analysis tools as we continue to transition to a more active, bi-directional and highly utilised system.

Power flow - parameters

The following power flow measurements are ideally per phase and directional[5], with a time resolution applicable for the circumstances. This typically results in half-hourly averages for network development and planning, and second-by second (by exception and/or on request) for network operations:

- **Active power (P)**, measured in units of Watts (W);
- **Reactive power (Q)**, typically measured in units of volt-amperes-reactive (var);
- **Apparent power (S)**, typically measured in units of volt-amperes (VA);
- **Power factor (pf)**, the ratio of 'P' to 'S', measures as a number between 0 and 1;
- **Voltage (V)**, measured in volts (V), is a key input to determine P, Q and S, and is itself a key system parameter;
- **Current (I)**, measured in amperes (A), is another key input to determine P, Q and S (along with the measured phase angle between V and I)

Note: Our 'Standard for the Application of System Monitoring' defines the convention for defining the direction of power flow based on a four-quadrant diagram. Adoption of this convention has been completed in our systems (including NMS) during 2015-23.

Specifically for transformers, which ultimately control the voltage on the network, the following parameters are visible particularly in operational timescales:

- **Tap position**, measured as an integer between 1 and the number of taps on a transformer;
- **Tap count**, measured as an integer of the number of tap change operations;
- **Target voltage (V)**, measured in volts, is the voltage that the transformer changes its tap position to provide at the lower voltage busbar.
- **Frequency (f)**, measured in Hertz (Hz).

[5] Where historically, as the network was a more passive, uni-directional distribution network; this has been the case at the highest voltage levels, but not at the lowest voltage levels. More detail is provided for each voltage level in this section.

Power flow – network visibility strategy

132 kV & EHV network, 132/EHV & EHV/HV transformers

Present state

- Transformer level availability of all data types is available. For feeders, there are generally only current measurements, which can be combined with busbar voltage to give apparent power information. Full visibility is being installed as standard for new or upgraded substations, and targeted enhancements are undertaken as required (particularly in areas with high volumes of distributed generation).

- Live 'real-time' readings are provided to the network management system (NMS) for network operations, whilst half-hourly averages are recorded in the data historian. We collect similar information to that provided at our substations from monitoring (metering) devices at customer connection sites. This information is available in NMS for network operations and is also integrated into the data historian.

- During 2015-2023 as part of our smart grid enablers programme, we are targeting specific enhancements:

  - Installing new automatic voltage controllers (AVCs) to enable voltage and loading data to be interrogated down to 5 second intervals[6], along with enabling all sites to report the transformer parameters (listed above), together with the ability to modify tap positions from the control room;

  - upgrading the monitoring equipment (notably, transducers) such that directional power flow information is available (rather than just a magnitude);

  - retrieving more granular (than half-hourly) data from customers and key locations in active network management (ANM) zones;

  - Analysis and modelling of tap positions during 2015-2023 to ensure sufficient taps are available for voltage control and to ensure compliance with Grid Code OC6 obligations.

- Note: Smart grid enabler investment also includes upgraded communications infrastructure and remote terminal units at substations.

How we are going to enhance

- We will develop our power systems analysis capability in the remainder of the 2015-23 period, specifically as part of our distribution system analysis tool (DSAT) upgrades; which will underpin our transition to developing a digital twin of the system (c.f. DSO deliverable 2.4). This will result in a pivot away from studying cardinal points (typically summer minimum and winter peak) to time series analyses, which will enable probabilistic decision making (DSO Strategy - initiative 2.3).

- We will continue to enhance network visibility on a targeted basis, such as for ANM rollout, or as part of substation upgrades (e.g. installing higher accuracy CTs and VTs). In general, the enhancements will be incremental as we have comprehensive power flow data being retrieved in general. Any enhancements will be targeted, and aligned to protection upgrades and as part of customer connections.

- We will use data analytics to further improve the data within our data historian, so that corrupted data is corrected and will develop automated (and intelligent) means of assessing gross maximum demands.

- We will enhance our analysis and modelling to further optimise voltage (and taps available) on our network, which will also facilitate the rollout of voltage optimisation (See Whole systems strategy).

[6] Values only reported to NMS when exceeding a set tolerance (i.e. by exception), with full data-sets available for download from the AVC.

DSO alignment

- Power flow visibility is fundamental to planning and development, and provides the starting point for future scenarios and forecasts. This information is central to our strategy outlined in the 'Scenarios and Investment' annex, and underpins the quantification of customer flexibility requirements. In addition to defining the customer flexibility requirements, the deployment of customer flexibility is triggered by use of this data.
- Network operation depends on the existing information to ensure safe and efficient operation of the network. Further to this, flexible technique such ANM is dependent on this network visibility. Of particular note, transformer visibility (and control) is critical to both voltage compliance and voltage optimisation. This enhanced operation would represent a significant step change in how voltage is managed across the network.
- This information is crucial for defining the network capability to support further connections, whilst identifying the required flexibility needs of the system and providing market signals to support flexibility markets and efficient development of customer projects.

HV network

Present state

- Feeder level availability of all data types at new or upgraded substations. Feeder level data is limited to non-directional 'volts' and 'amps' at legacy substations that have not been upgraded, whilst downstream on the feeder itself, there is often little-to-no power flow visibility. Statistical techniques and state estimation are used to estimate power flow parameters across the HV network.
- At locations where network visibility is available, live readings are provided to NMS for network operations, whilst half-hourly averages are recorded in the data historian.
- We also retrieve half-hourly active and reactive consumption data (kWh and kvarh) from customer metering data-flows.
- During 2015-2023 as part of our smart grid enablers programme, we are targeting specific enhancements:
  - HV regulators are being upgraded to provide power flow visibility;
  - Targeted pole mounted switches are being upgraded to provide power flow data where capable; and
  - The secondary communications network is being upgraded to facilitate the enhanced network visibility (and control) requirements.

How we are going to enhance

- Similar to EHV voltage and above, the enhanced network visibility is fundamental to improved power systems analysis, which underpins the digital twin deliverables, probabilistic decision making, and the other initiatives and deliverables defined in our DSO Strategy. This will also see us pivot from using this information for primarily design purposes, but for operational purposes, including the economic and efficient application of flexibility in operational timescales.
- Install 2,580 pole mounted switches which will provide not just enhanced network control, but power flow information. Our Investment in HV automation annex provides the detailed justification (driven by reliability considerations, where the network visibility enhancements are a secondary, but important benefit);
- Install 2,000 units of the next generation of overhead fault passage indicators, which will provide potentially all, if not most of the power flow measurement data. 'EJP 5.4 Remotely Indicating Fault Flow Indicators (RIFFIs)' provides the detailed justification;

- Continue to enhance network visibility on a targeted basis, such as for new connections, or as part of substation upgrades (e.g. installing higher accuracy CTs and VTs), particularly as part of protection upgrades.

- Use data analytics to further enhance the data available on our data historian, so that corrupted data is corrected.

- Targeted replacement of pole mounted switch controllers (based on asset health and criticality) with more capable, modern controllers, which will subsequently enable retrieval of power flow information. We will also seek to retrieve more information from existing pole mounted switch controllers, leveraging the additional capability of the new secondary communications infrastructure.

DSO alignment

- The optimal planning and development for HV feeders is facilitated by both existing network visibility and the enhanced network visibility, particularly for long, highly utilised overhead lines.

- Network operation depends on power flow visibility to ensure safe and efficient operation of the network. Further to this, flexible techniques such as APRS and automatic load transfers (c.f. DSO 4.3) are dependent on this network visibility.

- This information is crucial for defining the network capability to support further connections, whilst identifying the required flexibility needs of the system.

HV/LV transformers, LV network

Present state

- Manual reads from ground mounted substation transformer maximum demand indicators (MDIs) are combined with statistical analysis which incorporates customer data (including consumption data; both annualised advances and half-hourly settlement data). State estimation is therefore used to estimate power flow parameters across the network.

- We anticipate overlaying smart meter data as this becomes available. We currently do not use data specifically from smart meters, and are actively developing our capabilities – including the retrieval of voltage data. It should be noted that smart meter data is likely to augment rather than completely replace settlement sources due to privacy constraints

- We ensure voltage compliance based on upstream voltage information, and loading parameters alongside analysis and modelling. Voltage compliance is ensured through analysis and modelling, with ad-hoc portable monitors used as required, and customer complaints (e.g. voltage) used as an input for further analysis.

- During 2015-2023, we are targeting specific enhancements:

  - Using learning from the Customer-Led Network Revolution (CLNR)[7] innovation project, we have refined the statistical assessment of demand;

  - Install 2,700 units of 'LV monitors' at ground mounted substations (as part of our smart grid enablers programme) providing all power flow data measurements, for each phase of each feeder, at a time granularity of 10 minutes. The requirement for 10 minute granularity was identified as part of the CLNR project, which confirmed that due to the complexity and variability of power flows within half-hour periods, 10 minute resolution was required.[8] This results in power flow visibility for feeders and the transformer. Because HV/LV transformers on our network do not have on-load-tap-changers, we

[7] CLNR was a ground-breaking Northern Powergrid innovation project that developed and trialled many smart grid customer and network solutions such that the learning generated significantly influenced our 2015-23 plans and continues to influence our actions through 2023-28

[8] Refer to 'CLNR-L232 Enhanced Network Monitoring Report', available at http://www.networkrevolution.co.uk/project-library/enhanced-network-monitoring-report/

do not require real-time transformer (tap-changer) parameters as we do for EHV/HV transformers;

- Progressing our smart meter infrastructure readiness programme (to ready our internal systems, the key system being the 'smart meter gateway'), alongside gaining approval (in December 2020) for our Data Privacy Plan[9] which provides further information regarding our proposed use of smart meter consumption data.

- Undertaking an innovation project (Boston Spa Energy Efficiency Trial; BEET), which is seeking to use near-real-time voltage data (including voltage and power outage alerts) from smart meters, which will then result in an optimal voltage being applied at the primary substation.

How we are going to enhance

- Install 10,000 ground mounted substation LV monitors targeted at areas at high risk of overload. 'EJP_5.3a_Monitoring' provides the detailed justification.

- Trial pole mounted transformer LV monitoring. Our base assumption is that we will utilise smart metering data where this is available, alongside enhanced data analysis enabled by the learning from the rollout of ground mounted LV monitor.

- Subject to BEET being successful and the smart meter infrastructure operating as required; we will roll-out voltage optimisation across the wider network, targeting 30% of LV customers during 2023-28 and a further 50% during 2028-33. Further information is available in the Whole systems strategy.

- We are also planning to utilise both smart meter data and LV monitoring data to better understand losses, and by working with third parties we will analyse and then target theft reduction initiatives. Further information is available in the Losses strategy.

DSO alignment

- The optimal planning and development for HV/LV transformers and LV feeders is facilitated by both existing network visibility and the enhanced network visibility, particularly for equipment potentially close to its capability. By developing an operational model of the LV network (c.f. DSO2.4: 'digital twin'), we will convert the billions of data points (from LV monitoring and smart meters) into valuable information about the state of the network; which then supports all three DSO roles.

- Network operation depends on power flow visibility to ensure safe and efficient operation of the network. Further to this, flexible techniques such as APRS and automatic load transfers are dependent on this network visibility.

- This information is crucial for defining the network capability to support further connections, whilst identifying and signposting the required flexibility needs of the network, and the subsequent implementation of flexibility services.

[9] https://www.ofgem.gov.uk/sites/default/files/docs/2021/01/npg_data_privacy_plan_-_approved_november_2020_final.pdf

Operational visibility

The visibility of operational information is crucial to the real-time operation of the system, and supports the long term planning and development of an efficient system. It ensures that the network is operated reliably, safely and efficiently; where system abnormalities (e.g. faults) result in as little disruption as possible to our customers.

Operational visibility - parameters

The following operational visibility parameters are used:

- **Switch positions:** open, closed and normally open visibility[10];
- **Protection operation and alarms:** to indicate system abnormalities detected by protection (including the status and activation/de-activation in operational timescales of protection schemes, such as delayed auto-reclose);
- **Sequence of events:** Where in addition to switch and protection operation, disturbance recorders (often referred to as fault loggers), can provide higher resolution information regarding the sequence of events;
- **Fault passage indication:** a 'yes/no' indication of fault current detection on HV networks;
- **Power outage:** Includes live indication of network 'off-supply', customer contact information (e.g. contacting us directly), and smart meter power outage alerts; and
- **Pre-fault:** A new area of innovation, and relates to the visibility of real-time system abnormalities that are experienced before an asset permanently 'faults'.

Operational visibility – network visibility strategy

132 kV & EHV networks and HV primary substations
Present state
– The live status of all 132 kV, EHV and HV circuit breakers are visible in NMS, where a status change is shown in NMS within 10 seconds of the change occurring. Because the both power flow parameters and switch positions are fully visible to control engineers; power outages are easily identified. – Switch position data is not available in the data historian, where instead, network studies utilise the power flow parameters (volts and amps) from the data historian, and then by comparing with data from adjacent sections of network; non-standard configurations are then apparent based on this 'swing' in power flow between network sections. – For more detailed analysis, and for post-fault analysis (including for determining quality of supply performance, or following a protection failure), the operational information of switches (and protection operation and alarms) is available for further analysis and modelling. This is further enhanced by the use of disturbance recorders. – Roughly 90% of primary substations have disturbance recorders, which can provide (to a varying degree) waveform capture and series of event information to retrospectively analyse a network fault. Fault information is used for reliability analysis and modelling, and to understand the operation of protection and switches, and ensure that any issues are resolved. Information from disturbance recorders is analysed to understand system disturbances and is shared with other third parties where appropriate (for example, following the 9th August 2019 power outage).

[10] Together with the open/close statuses of switches provides visibility of abnormal conditions.

- Roughly three quarters of our protection relays are electro-mechanical relays, which do not provide visibility of status (including settings), alarms and activity via SCADA. At these substations we rely heavily on disturbance recorders and switch status data, where alongside information recorded from site visits; we can understand the health and performance of our assets (including the protection relays).

How we are going to enhance

- The primary areas for enhancements are relating to optimising the performance of protection systems:
  - Install 231 modern disturbance recorders at key locations during 2023-28. This will better enable us to capture enhanced disturbance information, together with a limited number of sites seeking to provide 'Foresight' capability. For further information, refer to EJP_5.3c_Disturbance_Recorders.
  - Replace 750 protection relay panels at sites targeted at locations, where the additional capability of modern intelligent electronic device (IED) type relays will enhance the visibility of protection systems for both operational timescales, and for post-fault analysis. For further information, refer to EJP_5.1_Protection_Relays.
- Note: The primary driver for disturbance recorder investment is enhance network visibility, whereas for protection relays it is to ensure on-going reliability of protection systems, with enhanced network visibility being a secondary benefit.

DSO alignment

- The sharing of operational status with the ESO and other network operators is fundamental to operating an efficient and coordinated system, particularly as it is the abnormal situations resulting from the operation status which then drives the need for action from network operators and customers; either through manual or automated means.
- Customer flexibility may be triggered by faults, which then result in switches to open and close to reconfigure the network. The key input for the flexibility response may be switch position, and therefore on-going visibility is key.

HV feeders

Present state

- HV feeders operational visibility downstream of the primary substation is based on either ground mounted switches (as part of ring main units (RMUs) and remote indicating ground mounted fault passage indicators (FPIs), or pole mounted switches (including air break switch disconnectors (ABSDs) and circuit breakers). During 2015-2023, we are targeting specific enhancements:
  - Retrofitting automation to RMUs (‘urban’ automation). RMU switches have no built-in telecontrol capability. We now have over 7,000 automated switches, which can be controlled remotely, alongside providing visibility of their status remotely. For devices with no automation retrofitted, any change of state is coordinated between field operatives (undertaking switching) and control engineers; therefore the status is always defined.
  - Replaced over 10,000 ground mounted FPIs with modern, electronic FPIs. All substations retrofitted with automation will have modern, electronic FPIs which can then transfer fault passage data to NMS (known as remote indication);
  - Targeted installation of pole mounted circuit breakers (‘rural’ automation). Pole mounted circuit breakers provide real-time visibility, are tele-controlled, and have protection relays, graded to ensure coordination with other devices on the feeder. These devices connect via radio network to provide status information into NMS, and this can include fault passage information.

  - Continued use of pole mounted FPIs which can indicate fault status into NMS, including the use of temporary FPIs to determine the location of faults on overhead networks.

– Loss of supply information is visible when the loss of supply is the result of a tele-controlled switch operating (which then reports the 'open' status' (together with a NMS alarm for protection operation); however there are large sections of rural networks which utilise automatic sectionalising links (ASLs) or fuses, which do not report in their status. Subsequently, we combine data sources from the HV network (including power flow information and from field operatives), alongside LV network information (which is explored below).

– Successfully trialled automatic power restoration system (APRS) within NMS in 2015, and then commenced rollout thereafter. APRS utilises remotely indicated FPI data together with tele-controlled switching points to determine faulty sections of network, isolate them and restore supplies to healthy parts of the network by automatic reconfiguration. The key input to APRS is network visibility of fault passage data.

How we are going to enhance

– Install a further 8,600 switches (remote control actuators), consisting of an additional 6,020 ground mounted actuators and 2,580 pole mounted remote control switches. 'Investment in HV automation' and 'EJP10.1 HV Network Remote Control and Automation' provides the detailed justification, (driven by reliability considerations, where the network visibility enhancements are a secondary, but important benefit);

– Install 2,000 units of the next generation of overhead remote indicating fault passage indicators, which will provide more reliable fault passage information alongside wave-form capture (pre-fault) capability. 'EJP 5.4 Remotely Indicating Fault Flow Indicators (RIFFIs)' provides the detailed justification;

– Install over 4,000 directional ground mounted remote indicating FPIs and 1,500 4G enabled remote indicating FPIs, which will provide enhanced fault information to provide more granular visibility to determine fault locations;

– Install 231 modern disturbance recorders at key locations (particularly at primary substations) during 2023-28. This will better enable us to capture enhanced disturbance information, together with a limited number of sites seeking to provide 'Foresight' capability. For further information, refer to EJP 5.3c Disturbance Recorders.

– Continue to rollout APRS, which will leverage the enhanced fault passage information and additional remote control points to further reduce customer interruptions and customer minutes lost.

– Commence the application of automatic load transfers ('ALT', a form of network flexibility), which will utilise the power flow information alongside the expanded switching capability to optimise power flows on the network; ultimately enabling the network to be pushed harder before reinforcement would otherwise be triggered (see our DSO Strategy and the DSO section of our business plan for 2023-28 – specifically DSO 4.3).

DSO alignment

– Network operation relies on live switch status information, together with enhanced switching capability' and this will become increasingly important as network flexibility solutions (including APRS and ALT) become more widespread. These network flexibility solutions are a key part of the toolkit used as part of planning and network development.

LV network

Present state

– LV networks do not have telecontrol, and are typically radial networks with relatively few points of interconnection. Where there is interconnection, this is provided by manual switching points such as at link boxes and feeder pillars. The LV network is therefore not depicted on NMS, and therefore other systems and processes are used for LV visibility; which involves management by local engineers coordinating topology changes with control engineers.

- The majority of LV feeders utilise fuses for protection, and therefore there is also no 'alarm' or other real-time indication that the protection device has operated (i.e. 'blown').
- During 2015-2023 we are targeting specific enhancements:
    - Targeted the use of 2,000 fault management devices, which have the capability to re-close on faults (noting that majority of fuse operations are 'non-damage' faults), and can provide fault location information and waveform capture, whilst also communicating their status to field operatives.
    - Completed the NIA 'Foresight' project, which has developed and proven the technology, the application of, and benefit of pro-active fault management using pre-fault information.
    - Install 1,000 low-cost (pre-) fault monitors, targeted on high-risk LV feeders, by the end of the period, building on from the success of the Foresight project.
    - Install 2,700 LV 'load' monitors, which can identify the 'power flow' status of each LV feeder, which could be used as a proxy for energisation status. Much of the hardware for these monitors is similar to that of the low-cost fault monitors, and therefore provides the capability to upgrade the firmware to also provide this capability where required.
- For loss of supply (power outage) information, we are investigating the developing our use smart meter power outage alerts (and voltage alerts). Noting that for customers without smart meters (or where smart metering infrastructure may not provide the necessary performance), there is no visibility of this loss of supply, and we rely on customers contacting us, and will continue to do so. We combine this with information about our upstream network (including protection and HV switch operations) to determine the appropriate response.

How we are going to enhance

- Fault monitoring devices targeted at a total of 7,000 ground mounted substations by the end of the period;
- Enhance the functionality of 2,000 LV load monitors to provide pre-fault capability, therefore increasing the total number of substations providing fault monitoring to 9,000;
- Expand the number of fault management devices to 9,085 units, replacing traditional fuses and therefore providing enhanced switching capability along with remote visibility of the switch status. 'EJP10.2 LV Technology' provides the detailed justification for the fault monitoring and fault management device investment;
- Progress our systems and capability to seek to embed smart meter power alerts into our operational response to power cuts. As the smart meter programme continues to progress, we will continue to update our internal systems, with an ambition to be able to be able to respond to loss of power in real-time. For sites with LV fault or load monitoring this will by complementary, but for sites with no monitoring, the use of smart meter alerts (e.g. power outage alerts) will be a key form of data.

DSO alignment

- Implementation of LV Foresight and an enhanced understanding of network status will ensure that we are able to improve the reliability of supply, which is increasingly critical as customers become more reliant on electricity.
- Understanding of network operating conditions will be important for the dispatching of LV flexibility.
- The network status provides a fundamental building block for the development of more active network management in future at LV.

Fault level visibility

Fault level information is used to ensure that the network is always operated within its short-circuit capability; and ensures the ability to facilitate net zero and to operate a flexible network.

Fault level - parameters

The following fault information is relevant:

- Short-circuit 'make' current (kA);
- Short-circuit 'break' current (kA);
- Direct current (DC) time constant (ms), also used as 'X/R ratio' (no unit). This component represents how quickly the 'DC' component of the short-circuit current (separate to the 'make' and 'break' values, above) attenuates. A higher value results in slower attenuation; and
- Earth loop impedance (ohms), which is important for LV networks in particular as it defines the fault level on LV networks.

Fault levels are inferred from other, numerous data sources and are calculated in accordance with Engineering Recommendation G74, which provides a prospective (worst case) value. This is an industry standard approach, and has served the industry well to date. Other network operators, customers, manufacturers and industry working groups provide up-to-date system data that is critical to the determination of fault levels. This information includes new customers providing fault infeed data for their assets, and NGESO providing fault infeed data from the transmission network (as part of the annual Grid Code 'week 24 and week 42' process).

Fault level – network visibility strategy

132kV, EHV & HV network
Present state
– Prospective short circuit levels (fault levels), and the subsequent duty that could be imposed on equipment is determined via analysis and modelling – i.e. state estimation. We have a small number of portable fault level monitors at present, and use these to better understand fault levels – where eventually we envisage that real time visibility of fault levels will become more widespread in specific circumstances.
How we are going to enhance
– We will seek to implement fault level monitors at sites operating close to their ratings or where we have uncertainty with data where there is a risk of operating close to ratings, and will continue to engage with third parties to ensure fault level modelling is continuously improved. This will include working across industry (including manufacturers of equipment) to understand the fault level impact of low carbon technologies. Improved fault level information will result in improved management of high fault levels, including better targeting of fault level monitors. – We will use the advanced scripting and modelling facilities delivered through our DSAT project to provide a forecast of future fault levels based on our DFES.
DSO alignment
– Enhanced fault level assessment and forecasting will optimise planning and development; and ultimately removes barriers for net zero when restrictions caused by high fault levels are mitigated.

- Operational restrictions can limit the capacity and network flexibility (inhibiting techniques such as APRS and automatic load transfers); therefore fault level management supports enhanced network operation.

- We will continue to share fault level information (along with plans for fault level mitigation works) as this provides further information to customers via our heat maps, LTDS and NDP. We will continue to explore how customer flexibility services could aid fault level management.

- We also work with the ESO and other network operators on fault level 'in-feeds' into our distribution network and evaluate solutions on their networks to solving problems on our network. This whole systems approach to fault level management can provide a more cost effective way of managing distribution fault levels.

LV network

Present state

- Prospective short circuit levels (fault levels), and the subsequent duty that could be imposed on equipment is determined via analysis and modelling using earth loop impedance calculations.

- Unlike higher voltage network where the primary concern is fault level being too high for the switchgear to safely disconnect a faulted section of network, for low voltage networks, the primarily concern is the fault level being too low at the remote ends of circuits for the fuse to 'blow'. This is ensured by maintaining a sufficiently low network impedance (i.e. earth loop impedance), and use of correctly rated fuses.

- Another key consideration is that a high fault level is critical to ensure power quality; in particular voltage fluctuations and flicker are minimised with a high fault level (i.e. a 'strong' system). As the penetration of non-linear, disturbing loads increases (i.e. power electronic equipment, such as that for electric vehicles); the risk of power quality issues (exacerbated by low fault level) increases. This could be impacted in future by the loss of diversity, where aggregation services or price signals drive identical power swings from EVs, which in turn results in voltage fluctuations on the network.

How we are going to enhance

- Continue to ensure minimum fault levels on LV network (are maintained) by ensuring maximum earth loop impedances are not exceeded as part of network planning and design (for example, during customer connections);

- Potential innovation to develop functionality of load monitors to provide indicative measurement of LV & HV fault levels based upon natural disturbing events.

- Continue to work collaboratively with stakeholders (including equipment manufacturers) to understand and forecast future fault levels.

DSO alignment

- All three DSO roles require consideration of the potential for unintended consequences, and therefore the potential for power quality issues exacerbated by low fault level is an area for further work.

Power quality visibility

Power quality information is used to ensure that i) the network is operated within the planning and compatibility levels for harmonics (engineering recommendation G5) and that ii) voltage fluctuations are within limits (engineering recommendation P28).

Power quality - parameters

The following power quality information is relevant:

- Total harmonic distortion (%[11]), for both current and voltage;
- Individual harmonic values (%), for harmonics up to the 100th order;
- Imbalance (%), where high levels result in higher than required (inefficient) network utilisation, higher losses, detrimental impact on protection operation and on the normal operation of three phase machines;
- Voltage step change (%) and voltage notches, which can cause nuisance, including the perceived 'flicker'.
- Note: power quality is linked to fault level.

Power quality – network visibility strategy

132kV, EHV & HV network

Present state

- Our application of power quality (harmonics) monitoring includes:
  - Disturbance recorders installed at approximately 90% of major substations, which provide varying degrees of power quality information. Older (legacy) recorders (which are targeted for replacement in 2023-28) generally do not provide any power quality visibility, whereas modern recorders provide 10 minute minimum, maximum and average harmonic information up-to the 50th order.
  - Since 2015, for customer connections above 200 kW we install fixed power quality loggers (a 'slimmed-down' modern disturbance recorder), where we collect the similar information as collected by our modern disturbance recorders. This information is available both locally and, where possible, remotely on a data historian. The specific requirements are detailed in the standard for the application of system monitoring.
  - For specific sites of concern, we will also temporarily install power quality loggers, similar to those used for customer connections.
- Note: Harmonics are assessed using measured values and not modelled values.
- Imbalance is measured directly from power flow information on the transformer (for example, using individual phase information from power flow monitoring). For HV feeders, there is no monitoring on individual phases, and therefore in areas at high risk of imbalance (i.e. those with a high prevalence of split-phase networks), modelling is undertaken (using state estimation) to infer the level of imbalance.
- Voltage step change is modelled using up-to-date network data, and is similar to fault level modelling in that a worst-case (prospective) voltage step change is modelled. Power system modelling information from third parties is primarily fault level based, and includes summer minimum models from ESO and operational information from

[11] Where the percentage is with respect to fundamental frequency, 50 Hz.

customers (e.g. BESS ramp rates).

How we are going to enhance

- Install 231 modern disturbance recorders at key locations during the 2023-28 period. This will better enable us to capture enhanced power quality information. Further information detailed in EJP 5.3c Disturbance Recorders.
- We will seek to integrate the captured data with that from portable monitors and other network visibility data as part of our digital twin deliverable (DSO 2.4).
- The implementation of our new distribution system analysis tool (DSAT), combined with enhanced network data (including from HV feeder locations, and secondary substations, and enhanced data exchange with third parties, including NGESO[12]) will enable improved imbalance and voltage step change studies.

DSO alignment

- Understanding the power quality across the network can identify the level of available harmonic 'headroom', and we could then take more proactive steps to improve the power quality on a network such that it does not become a blocker to connection of low carbon technologies.
- Alongside heatmap information for other parameters, this information will be shared openly with customers to ensure economic and efficient development of the network.

LV network

Present state

- For specific sites of concern, we temporarily install power quality loggers, which can provide detailed harmonic information.
- As part of the smart grid enablers programme, the LV load monitors provide total harmonic distortion (THD) information over 10 minute periods, alongside per phase voltage and current loading information, thus enabling determination of imbalance.
- Voltage step change is not currently captured, and this is ensured at present by modelling of system parameters, which is primarily concerned with ensuring a minimum fault level to ensure a minimum power quality.

How we are going to enhance

- Install 10,000 ground mounted substation LV monitors targeted at areas at high risk of overload, where these sites are those with generally those with high update of LCTs, and therefore at high risk of power quality deteriorating in future. 'EJP 5.3a Monitoring' provides the detailed justification.

DSO alignment

- Alongside heatmap information for other parameters, this information will be shared openly with customers to ensure economic and efficient development of the network.

[12] In particular, summer minimum fault level models, which are crucial for power quality and stability studies.

Environmental visibility

Environmental information is a new area of interest as it directly impacts the network parameters. Historically, seasonal assumptions are used to determine parameters such as asset ratings, however as we move to a smarter, more flexible network, we recognise that visibility of environmental information is a key enabler to optimising the operation of the network. For example, the application of real time thermal ratings is dependent on environmental parameters.

Environmental - parameters

The following environmental information is relevant:

- **Temperature (°C)**, of locations as required, such ambient substation, soil temperature (together with asset temperatures, e.g. transformer tank);
- **Humidity (%)**, of the location of assets in question;
- **Wind speed (m/s) and wind direction**;
- **Solar gain (watts) and daylight hours**;
- **Rainfall (mm)**; and
- **Lightning strike data.**

Environmental – network visibility strategy

132 kV, EHV & HV network
Present state
– The majority of the data we use for network operation and planning is data obtained from third parties, such as Met Office weather stations, as follows: – The most notable area we utilise this data is preparing for and responding to adverse weather events. The use of forecasting information means that we are mobilised, and ready to respond to faults on the network as they occur. This information is then also used for power outage (post-fault) analysis to better understand how we can continue to improve the reliability and availability of our network. Where the weather event is classes as 'extreme', this is accounted for when determining next steps to enhance our network. – Another area we utilise this data is for climate adaptation, where this data is combined with long term modelling to determine the future climate change risk (in particular, flooding). The result of which is used to determine investment, such as flood mitigation. – As part of our CLNR project, we gathered a significant volume of environmental information, and combined this with detailed power flow information, alongside direct measurements of the state of equipment (i.e. temperature of conductors). This enabled rating enhancements through either bespoke thermal ratings or real-time thermal ratings based on the prevailing conditions at that time. Subsequently, we have guidance for how the use of bespoke and real-time thermal ratings can be applied, and detailed technical specifications for the application on specific asset types (refer to Appendix 1 - Specifications).
How we are going to enhance
– We will continue to progress bespoke and real-time thermal ratings during 2023-28 as part of our deployment of smart solutions in response to network constraints. Determining the right balance of using internal environmental measurements against third party data will be important. Such measurements will only be implemented on a case-

by-case basis. Whilst these parameters are not 'network parameters', they directly impact network assets (e.g. temperature), and are therefore a key network visibility consideration, particularly as smarter solutions become more widespread.

- Environmental measurements internal to our substations will be explored as part of our losses strategy to undertake energy efficiency assessments at our major substations. We envisage that such measurements would be beneficial to optimising energy efficiency whilst also ensuring long-term asset health of our assets (such as preventing condensation).

DSO alignment

- Enhanced asset ratings (both bespoke, and real-time) are network flexibility solutions which provided increased network utilisation for customers.

- Enhanced ratings are implemented in real-time, and therefore real-time environmental visibility provides benefit. For network operations, it is not necessary for environmental parameters to be visible on NMS on the basis that the real-time rating calculations account for these.

- Ensuring efficient energy use at our substations whilst ensuring the internal environment maintains long term asset health.

LV network

Present state

- We currently focus environmental information visibility on HV networks and above, however building on CLNR and the learning from other projects such as ENW Celsius, we have determined that there is future value in targeted environmental visibility.

How we are going to enhance

- Together with our LV monitoring investment, we will seek to utilise environmental information (where beneficial) together with the installation of (active) cooling equipment to improve the thermal performance of secondary transformers, thus achieving higher capacities. We plan for this smart solution will be applied to 168 transformers. For further information, refer to EJP 11.1 HV/LV Network Reinforcement.

DSO alignment

- Enhanced asset ratings (both bespoke, and real-time) are network flexibility solutions which provided increased network utilisation for customers.

- Ensuring efficient energy use at our substations whilst ensuring the internal environment maintains long term asset health.

Appendix 1 - Specifications

The specifications below provide further detail relating to i) detail on the data captured, ii) frequency of polling, and iii) the mode of communicating data:

IMP/001/017	Standard for the Application of System Monitoring*
CLNR L232	Enhanced Network Monitoring Report
IMP/001/016	CoP for the application of ANM
IMP/007/003	SCADA Code of Practice
NPS/005/002	Technical specification for remote terminal units (RTUs) for use at primary substations
NPS/005/003	Technical specification for an IP communications solution to serve remote terminal units (RTUs) at primary substations
NPS/007/004	TS for an overhead line real time thermal rating system
NPS/007/005	TS for a primary transformer real time thermal rating system
NPS/007/006	TS for a secondary transformer real time thermal rating system
NPS/007/007	TS for an underground cable real time thermal rating system
NPS/007/008	TS for enhanced automatic voltage control (EAVC) of a primary transformer and on load tap changer
NPS/007/009	TS for a ground mounted in-line regulator with enhanced automatic voltage control (EAVC)
NPS/007/015	TS for network monitoring at HV customers
NPS/007/016	TS for network monitoring of secondary substations
NPS/007/021	Technical Specification for Secondary Distribution Substation Monitoring Systems
NPS/007/020	Technical specification for active network management schemes

*This document, alongside other documents in the 'IMP' suite, are not generally public. Copies of these documents can be made available.

Appendix 2 - 2023-28 enhancements in visibility

Network visibility is becoming increasingly critical at the lower voltage levels, and it is becoming increasingly important to have visibility of parameters beyond 'amps' and 'volts'. This strategy has identified numerous enhancements taking place during 2015-23, and additional enhancements required during 2023-28 in order to enable the DSO transition. The table below provides a summary of the main enhancements:

Enhancement	Primary Benefit	Justification (Annex / EJPs)
Install **10,000 units of LV monitors**, target at highly utilised substations, and combine with Foresight technology at 2,000 sites.	Optimal management and investment for LV networks that will become highly utilised (and overloaded).	EJP_5.3a_Monitoring
Install **231 disturbance recorders** targeted at high-risk substations, of which we will seek to install units with HV Foresight capability at selected sites.	Improved operational visibility for faults and system events, and power quality information.	EJP_5.3c_Disturbance_Recorders
Replace **750 protection relay panels** with modern IED-type relays	Enhance the visibility of protection systems for both operational timescales, and for post-fault analysis	EJP_5.1_Protection_Relays
Install over **4,000 directional ground mounted FPIs and 1,500 4G enabled FPIs**	Enhanced fault information to provide more granular visibility to determine fault locations	N/A
Install **2,000 units of pole mounted next-generation fault passage indicator**s	Enhance network visibility in areas that are generally rural, and where there is otherwise no visibility	EJP_5.4_Remotely_Indicating_Fault_Flow_Indicators_(RIFFIs)
Fault monitoring devices targeted at a total of 7,000 ground mounted **substations**	Pro-active fault management	EJP10.2_LV_Technology
Enhance the functionality of **2,000 LV load monitors to provide pre-fault capability**	Pro-active fault management	EJP10.2_LV_Technology
Expand the number of **fault management devices to 9,085 units**	Enhanced LV switching (and non-damage fault performance) capability	EJP10.2_LV_Technology
installation of (active) **cooling equipment on 168 transformers** that are highly utilised	Enhanced capacity of secondary transformers	EJP_11.1_HV/LV_Network_Reinforcement
Install **6,020 ground mounted actuators and upgraded fault passage indicators**	Improved quality of supply (CI and CML) for customers.	Reliability and Availability Improvement Plan Investment in HV automation
Install **2,580 pole mounted switches**	Improved quality of supply (CI and CML) for customers.	Investment in HV automation
Use **smart meter voltage and power alert data**	Energy efficiency improvement for customers (via voltage optimisation), improved voltage profile, improved power outage response.	Whole Systems Strategy; Detail on our CVPs

Smart meters are a key enabler for both optimised planning and network development and the voltage optimisation initiative. There is a risk that smart meters (whilst already limited in their reach, as their installation is not mandated) and the capability of smart meter infrastructure in general may not be as anticipated in the northern region. This is presently being investigated and discussed with the DCC.

Therefore some of our planning and network development may be adversely impacted such as voltage optimisation. This is further exacerbated by the lack of accurate phase information for each smart meter. LV monitors therefore provide a key means of mitigating the risks associated with smart meter performance being lower than anticipated.

Appendix 3 - DSO Strategy alignment with Network Visibility Strategy

		Ofgem DSO roles			Power flow			Operational visibility			Fault level		Power quality		Environmental	
	Title	1	2	3	132 kV & EHV network, 132/EHV & EHV/HV transformers	HV network	HV/LV transformers, LV network	132 kV & EHV networks and HV primary substations	HV feeders	LV network	132 kV, EHV & HV network	LV network	132 kV, EHV & HV network	LV network	132 kV, EHV & HV network	LV network
DSO1.1	Enhanced technical data capture and integrated data management	✓	✓	●	←	←	←	←	←	←	→	→	←	←	←	←
DSO1.2	Improved two-way stakeholder information exchange and collaboration	✓		✓	↔	↔	↔	↔	↔	↔	↔	↔				
DSO1.3	Targeted low voltage (LV) monitoring	✓	✓			→	→		→	→				→		
IN1.4	Enhanced flexibility services market data capture		●	✓												
DSO2.1	Enhanced low voltage (LV) data analytics	✓	✓	●			←			←				←		←
DSO2.2	Enhanced high voltage (HV), extra high voltage (EHV) and 132kV data analytics	✓	✓	●	←	←		←	←		←		←		←	
DSO2.3	Improved planning and operational forecasting	✓	✓	✓	←	←	←	←	←	←	→	→			←	←
DSO2.4	Create a digital twin of our network for strategic planning	✓	✓	✓	←	←	←	←	←	←	←	←	←	←	←	←
DSO2.5	Improved format and consistency of information we share with stakeholders	✓	●	✓												
IN2.6	Neutral assessment of network and market solutions	✓		✓	←	←	←	←	←	←						
IN2.7	Probabilistic decision making, risk and externality quantification	✓	●	●	←	←	←	←	←	←	←	←	←	←	←	←
DSO3.1	Open Insights data portal	✓	✓	✓	←	←	←	←	←	←	←	←	←	←		
DSO3.2	Recruit Local Area Energy Plan (LAEP) advisors	✓														
IN3.3	Decision making transparency	✓		✓												
IN3.4	Enhanced data exchange between DNOs and the ESO	✓	✓	●												
DSO4.1	Flexibility services processes and dispatch system		✓		←	←	←	←	←	←						
DSO4.2	Enhanced enterprise Active Network Management (ANM)	✓	✓		←	←	←	←	←	←						
DSO4.3	Develop network flexibility solutions	✓	✓		←	←	←	←	←	←					←	←
DSO4.4	Architecture and processes for effective deployment of flexibility services across transmission and distribution networks		✓	●												
DSO4.5	Upskill and recruit engineers to use whole systems thinking	✓	✓	✓												
DSO4.6	Provide flexibility services to the ESO	✓	✓		←	←	←	←	←	←						
IN4.7	Emergency assistance and contingency planning	✓	✓	●	←	←	←	←	←	←						
IN4.8	Validation of existing network resilience systems	✓	✓		←	←	←	←	←	←						
DSO5.1	Collaborate with the wider energy industry to facilitate non-DSO services and network access rights	✓	✓	✓	←	←	←	←	←	←	←	←				
DSO5.2	Improved development and procurement of flexibility services		✓	✓												
DSO5.3	Develop a flexibility information provision and engagement platform		✓	✓	←	←	←	←	←	←						
DSO5.4	Automatic settlement of flexibility services		✓	✓	←	←	←	←	←	←						
DSO5.5	Recruit specialist flexibility customer account managers	✓	✓	✓												
IN5.6	Project and change management to support the DSO transition	✓	✓	✓												

Key

✓	Directly applicable (DSO Strategy initiative/deliverable with respect to Ofgem DSO role)
●	Enables (DSO Strategy initiative/deliverable with respect to Ofgem DSO role)
←	Enables DSO initiative/deliverable
→	Enabled by DSO initiative/deliverable
↔	Both enables and is enabled by DSO initiative/deliverable

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