D-Suite Alpha phase

Deliverable 3.1: Techno-Economic Framework & Standards Review

3/27/24

Future Networks

ABOUT REPORT

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Executive Summary

D-Suite is an innovation project funded through the Round 2 Strategic Innovation Fund (SIF) scheme that aims to increase the commercial viability of several types of low-voltage (LV) power electronic devices (PEDs), known here as the D-Suite technology. There are four devices included as part of the D-Suite for this report. These are:

- STATCOM (Shunt connected)
- 2-terminal soft-open-point (2T SOP)
- 3-terminal soft-open-point (3T SOP)
- Smart transformer

This report aims to explain the purpose, and development process of a novel tool related to these devices called a techno-economic framework (TEF). The TEF provides an overview of the 4 devices that could be used by a Planning Engineer to facilitate their investment decision making. The TEF does this by including information across several categories. These are:

- Use cases
- Installation considerations
- Financial costs

The report explains why such a tool is required, with the key justification being that although there have been several previous innovation projects investigating these devices, none of them have resulted in these devices becoming a commonly used business-as-usual solution for commercial reasons or due to their complex installation requirements.

This has meant that there hasn't been a need to complete full engagement with the business to build team's knowledge of the devices. Since the D-Suite project expects to mitigate these problems, it is expected that the TEF will be used as a tool to enable and facilitate the engagement process and can be used by those planning engineers to quickly evaluate whether a D-Suite device may be suitable for resolving the network issue they are working on.

The report also includes information on the benefits and drawbacks of the tool. The key benefits of the tool are that it is simple and easy to use so should provide nearly all relevant information for non-experts in LV PEDs to quickly assess if it may be suitable. The potential drawbacks are that it will require ongoing maintenance from UK Power Network's employees to review the latest innovation projects being completed, and the commercial products becoming available.

1. Introduction

1.1. Project background

As energy systems transition towards net zero, distribution network operators (DNOs) will have several growing types of issues on their networks to manage. On the low-voltage (LV) network these will primarily include maintaining thermal constraints of assets (e.g., transformers, cables or overhead lines), maintaining safe operating voltages for both customers and assets, and also ensuring high levels of power quality (e.g., voltage unbalance) to enable high utilization of sensitive loads.

Should uptake of low carbon technologies (such as electric vehicles and heat pumps) follow projections necessary to meet the UK government's carbon budgets, it has been estimated that up to £64 bn will need to be invested by 2050 to reinforce LV distribution networks alone.

To help mitigate these issues and minimise the reinforcement costs required, DNO's will need to utilise new technologies. One promising technology are LV power electronic devices (PEDs) which have been tested through several innovation projects by DNO's already, however, so far they have not become a typical business-as-usual (BAU) solution for a variety of technical or commercial reasons.

The D-Suite project aims to improve the viability of these devices by reducing the technical or commercial limitations they currently face and developing tools to facilitate their use.

One key aim of the project is to investigate the viability of manufacturing these devices in a modular fashion, whereby the power electronic components within the different D-Suite technologies can be manufactured at scale to help reduce their costs, with their functionality being changed with relatively minor software and hardware changes.

The D-Suite Alpha stage plan has several key objectives:

- Improve the TRL, so the D-Suite technologies are more readily available.
- Encourage the D-Suite supplier market's participation in a tender Pre-Qualification Questionnaire, so DNOs can understand the indicative costs before full tender in the Beta stage.
- Select several D-Suite technology trial sites within at least one UK DNO LV network.
- Develop and verify a fully evidenced Cost Benefit Analysis through desktop study D-Suite simulation results for technical benefits and use PQQ returns for the provision of indicative costs.
- Develop training pack inputs for LV design engineers, so they can easily design LV networks with D-Suite Technologies at the network planning and investment approval stage.

The product and service provided by the project includes:

- Kickstarting the LV PED market to produce innovative low-cost D-Suite designs based on modular DC- components.
- Developing D-Suite control and protection strategies to maximize benefits and equipment safety.
- Developing D-Suite design and planning tools.
- Developing operation and safety documents for novel D-Suite technologies.

The project involves end users (network design, planning and control engineers), PED suppliers, PE consultancies, network design and standards teams, local authorities, and academic partners to ensure that the D-Suite technologies are fit for purpose at the deployment stage. A deployment of D-Suite devices at the LV voltage level, would be a first for UK DNOs and would represent a leap forward in active LV network control using PEDs.

1.2.The D-Suite Solution

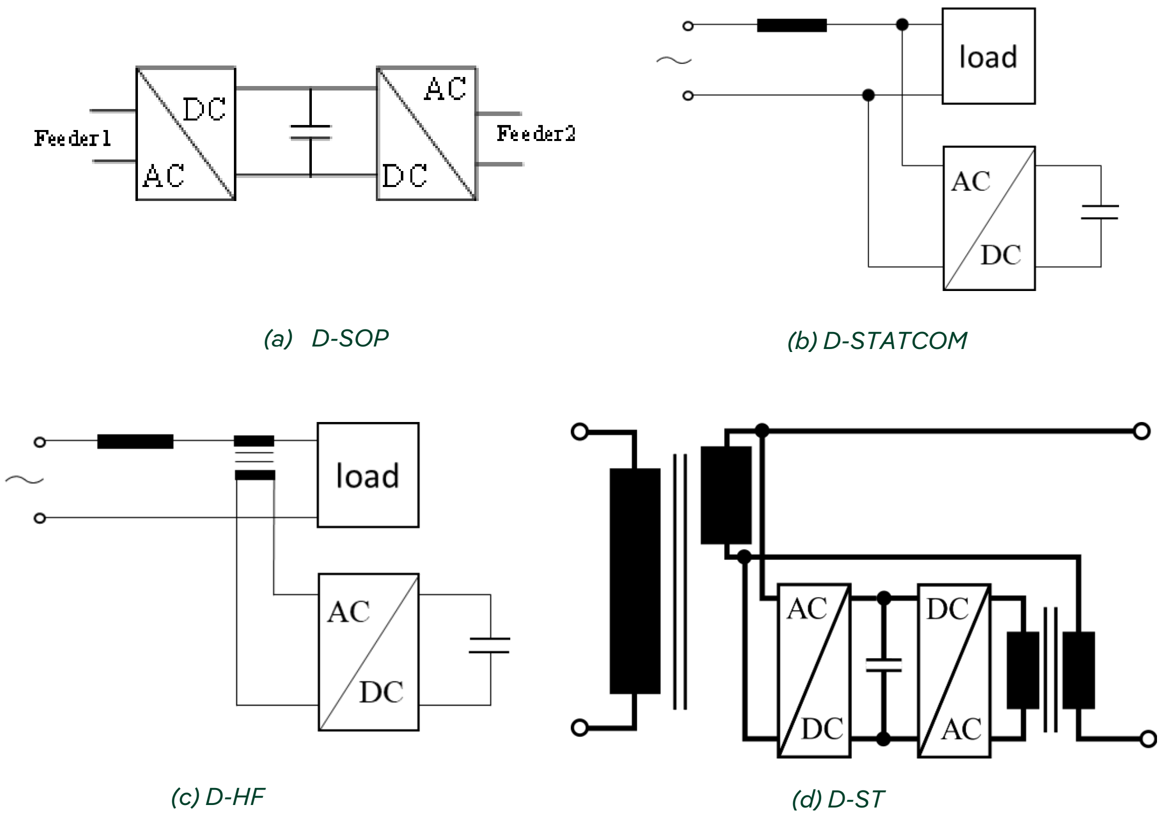
There are three D-Suite devices considered in this report:

- Smart Transformer – D-ST
- Static Compensator (STATCOM) - D-STATCOM
- Soft Open Point (SOP) - D-SOP

These devices can address some or all of the following issues: voltage magnitude (VM) congestion, thermal congestion on feeders (Th-F), thermal congestion in substation transformers (Th-SS), and voltage unbalance (VUB). They therefore have potential to mitigate congestion caused by low carbon technologies.

1.3. Overview of D-suite technologies

As the LV network is expecting a large uptake of heat pumps, EV chargers and distributed generation, the problems in LV networks will mainly be voltage rise and high circuit and transformer stress due to low carbon technologies. D-suite technologies, which include D-SOPs, D-STATCOMs, D-HFs and D-STs, can mitigate these issues on the LV networks (see Figure 1).



(a) D-SOP

(b) D-STATCOM

(c) D-HF

(d) D-ST

Figure 1 – The D-Suite technology being considered.

The D-SOP is a power electronic interface that has gained significant attention, due to its ability to enhance the integration of distributed energy resources (DERs) and improve the overall flexibility and reliability of the grid. D-SOPs are designed to enable active control of power flow and voltage in distribution networks, facilitating the integration of renewable energy sources, energy storage systems, and other DERs.

The D-STATCOM can adopt either a shunt or series configuration to control the system current or voltage, by exchanging real and reactive power with the AC system, thereby maintaining the desired voltage level.

The D-HFs are advanced power-quality devices, designed to mitigate the detrimental effects of harmonics in distribution networks. When connected in parallel with feeders, D-HFs can actively detect and counteract harmonic currents generated by non-linear loads, such as electronic equipment and variable speed drives, thereby ensuring a clean and stable power supply to connected loads.

The D-ST is a combination of a line-frequency transformer (LFT) with PEDs, which was used to enhance the limited functionalities of the LFT. The D-ST allows the integration of a conventional LFT's high efficiency and low cost with the flexibility of PEDs.

2. Techno-economic framework

2.1.Purpose of Tool

The techno-economic framework (TEF) is a tool that aims to build the understanding of D-Suite technology in a clear and fast manner for DNO planning engineers. who are considering their options when trying to resolve a variety of potential network issues.

The reason this has been identified as a need, is that there have been several innovation projects within the industry completed by both UK Power Networks and other DNO's including SPEN, investigating the use cases and benefits of LV power electronics. It has been found however, that although the technology's benefits were demonstrated, the devices have not become a widely used BAU solution.

The reasons for this are complex and specific to each of the individual devices, however, the common theme has been that the technology was not commercially viable yet in most scenarios either because it is not cost competitive compared to a traditional reinforcement approach, or because there are complex installation requirements that make them impractical to use.

One other potential issue that has arisen is that the innovation projects where the D-Suite devices are tested are only done on a small scale. This means that since the technology is novel and is not widely used or known, only a specific project team will become familiar with them. This means the practical knowledge of the technology such as how to install them, what their use cases and benefits are, and the lessons learned from previous projects is not widely known across the entire business.

Although it would be possible to complete engagement with the business and training on how the devices work, since the projects demonstrated that the devices are not commercially viable yet, it was determined that it was not the optimal time to begin this process.

These conclusions exemplify the importance of the D-Suite project and the TEF. The D-Suite project expects to significantly reduce the costs of D-Suite technology, while also enabling faster and more accurate identification of locations that it would be beneficial to install them. With these innovations being developed, the value and importance of the TEF is highlighted.

Through the innovations of the D-Suite technology, it is becoming more important to begin engaging with relevant business stakeholders so improve their knowledge of the technology, and to facilitate its use.

The TEF aims to help bridge the gap between innovation projects and BAU rollout by explaining the use cases, benefits, requirements, and costs of the different devices in a fast and easily accessible way for engineers who are not familiar with the technology.

2.2. Development of Tool

The first step taken was to clearly define the aims and objectives of the TEF. Once this was done, a plan was created on how to develop it. Initially, a search was undertaken within the business to identify similar tools that may exist to use as a reference point, however, no similar tools were found. It was therefore determined that the TEF would be developed from the ground up in an iterative approach, utilising two high level methods:

1. Engagement with relevant stakeholders.
2. Reviewing of relevant documentation.

In line with this, engagement was done through several channels. These were:

- Engagement with the target audience of the tool to ensure it met their needs.
- Engagement with stakeholders within UK Power Networks that had worked on similar projects utilising D-Suite technology to gain insights into their requirements, benefits, and challenges.
- Engagement with suppliers in the market to gain an up-to-date view of commercially available products.
- Engagement with the D-Suite project team, utilising their expertise to build knowledge and validate information within the TEF.

In addition to this, important information was accessed through documentation available from a variety of projects. This included:

- Reviewing of documentation produced as part of the D-Suite project as these provided a strong summary of the use cases and benefits of the devices.
- Reviewing documentation from previous related projects which provided information on installation requirements, and benefits & challenges of the devices, plus financial information.

A full list of documentation that has been reviewed during the formation of the TEF is listed in Appendix A.

During the initial formation of the TEF, a list of categories was proposed with several subtopics and open questions that were expected to be useful. Prior to discussing this with the relevant teams, it was identified that it would be worthwhile to provide an overview of the different devices, to build up common knowledge, as this would provide context for the categories and questions being posed. This information was primarily gathered by reviewing previous D-Suite documents themselves.

Once that core information was built up, it was condensed into a concise document to enable engagement which was done through presentations and a discussion. After this meeting, the direction of the TEF was validated and then further work went into reviewing additional documents and completing engagement with other stakeholders.

The TEF was developed in this iterative way, utilising several subsequent meetings to discuss its content and approach until a final format was agreed. During this iterative approach, one method considered, was to utilise a flow-diagram as a useful structure for the tool, however it was identified that this would require several variations, which would go against the core requirement of simplicity.

2.3. The Techno-economic Framework

Through the iterative process defined, the TEF's final format was decided to be a one-page PowerPoint slide. This was chosen as it satisfied the requirements of:

- Favouring simplicity to ensure the use cases, benefits, and requirements of the D-Suite devices could be easily and quickly understood.
- Having all information in a single page, preventing the need for referencing multiple documents.

D-Suite – decision matrix

Category	Sub-category	STATCOM (Shunt connected)	SOP		Smart Tx (Reactive power control only)
			2T SOP	3T SOP	
Use cases	Resolving localised voltage constraints	✓	✓	✓	✓
	Resolving network wide voltage constraints *(Requires additional monitoring / control)*	✓	✓	✓	✓
	Resolving thermal constraints at substation	X	Can reduce load at a substation by drawing power from an interconnected sub across a NOP.		X
	Resolving thermal constraints on a feeder	✓	✓	✓	X
	Improving phase current imbalance	✓	✓	✓	X
	Resolving specific Harmonics issues	✓	✓	✓	✓
Installation considerations	Interconnected / radial / both?	Both	Radial	Radial	Both
	Where to install?	Pole-mounted	Street furniture – across a NOP	Secondary sub. Across a NOP	Secondary substation
	Difficulty / complexity to install	Plug and play	New link boxes	Big space requirements inside sub. Stronger foundations + cabling	Large space + clearance requirements. Stronger foundations. Potential tree cutting + access requirements
	Rating	30 kVA	240 kVA	400 kVA	800 kVA
Costs	Unit cost + installation = total	[redacted]	[redacted]	[redacted]	[redacted]
	£ / kW	£[redacted] / kVA	£[redacted] / kVA	£[redacted] / kVA	£[redacted] / kVA

Figure 2 - The D-Suite TEF - labelled as a decision matrix for Planning Engineers

The cost information for the devices has been redacted in this report as the information is commercially sensitive for suppliers who have requested that it not be published.

The D-Suite device: Harmonic filter was not included in the TEF as it was determined that all the other devices have that functionality enabled already, so in practice a DNO is unlikely to ever utilise a harmonic filter on its own.

2.4. Benefits and Drawbacks

Some benefits of the tool, in addition those defined in the Purpose of the tool, include:

- A red-amber-green (RAG) colour coding approach was utilized, as this should enable planning engineers who are unfamiliar with the technology to quickly understand each device's potential use cases and their requirements.
- Financial cost information was deemed high priority information for the tool, because the relatively high cost of the D-Suite technologies has previously been a blocker to their uptake. Including this information here, can enable planning engineers to quickly estimate if a D-Suite device would be a solution of approximately similar cost to traditional reinforcement.

Some drawbacks to the tool include:

- Since the tool is designed to be simple, easy to use, with all information on a single page, some of the detail is necessarily lost, meaning edge-cases for the devices use-cases are not clearly defined.

- Likewise, some of the detail behind the installation requirements is also not clearly defined here. For example, with the current accepted design for Smart Transformers, under the 'Difficulty / complexity to install' category, specific clearance distances have not been as this was deemed unnecessary detail.

- The information included in the tool is accurate as of the date of writing for UKPN PED. As new products get released, or suppliers come to market, the information in the tool will become out of date. This means it will require maintaining if it is to become a well-used BAU tool. The TEF will also need to be kept up to date, because it currently shows that as explained above, the D-Suite devices are only likely to be utilised for the most expensive reinforcement cases due to their relatively high costs and their additional installation requirements.

3. Next Steps

3.1. Utilising the Tool

The tool has been developed in collaboration with colleagues from the relevant teams in the business, the Strategic Planning Engineers. This team works across geographic regions and are responsible for reinforcement investments required for anticipated load growth. Due to this location-agnostic approach, they have a more holistic view of the planning requirements within the business and are therefore well placed to identify locations requiring novel technologies.

3.2. Managing Over Time

One drawback of the tool is that with the current commercially available LV PEDs on the market, for most circumstances they will not be the most cost-effective solution and are unlikely to be commonly used unless the costs come down as D-Suite intends.

The effect of this, is that it is important that the tool is updated over time, especially with new financial cost information, as well as updated installation requirements, as these are both likely to change and will have a direct impact on the likelihood of a D-Suite PED being identified as a worthwhile solution.

Completing these updates, will need to be done in a collaborative manner between the Innovation team and the Strategic Planning team, as it is likely that the next D-Suite PED, that are tested by UK Power Networks, will come through the Innovation team. For example, through the D-Suite Beta Phase, or through the new Round 3 project Strategic Innovation Fund (SIF) project 'Balancer' which is investigating the combination of STATCOMs with batteries.

The tool will be managed in this way, for at least one year, to determine the outcome of upcoming projects and the updating market. At this point, a review will be done to determine how the market has matured as once the devices become more commercially competitive with traditional reinforcement options, then there will be a need to build knowledge within the business on the technology.

3.3. Rolling Out Across the Business

Once the D-Suite devices are more commercially competitive, the TEF will be used as a tool to build that knowledge within the business of the technology, and it will be provided to them as a tool to assist them with identifying potential locations to utilise a D-Suite technology.

This will be done by creating and Engagement Plan to define the different communication routes that should be taken to ensure key stakeholders are aware of the tool and to encourage its use.

Appendix A. List of Documents Reviewed for TEF

Project / Document Source	Document name	Device relevant for	Publicly available?	Use
D-Suite Discovery Phase	WP1 Customer Requirements and Core LV Network Functions v1.0 20230607	All	Yes	Background information on devices, including use cases and benefits
	WP2 Literature Review and Supplier Engagement v1.1 20230601		Yes	Background information on devices, including use cases and benefits
	WP3 Design Specifications of Hardware and Control Algorithms v1.0		Yes	Background information on devices, including use cases and benefits
	WP4 Roadmap to Commercialisation v1.0		Yes	Information on likely route for
D-Suite Alpha phase	WP1 Control Algorithm: Control Architecture and Performance	All	Yes	Background information on devices, including use cases and benefits
	WP1 D-Suite Devices: Technical Benefits		No	Background information on devices, including use cases and benefits
	WP1.3 Network agnostic CBA		Yes	Background information on devices, including use cases and benefits
STRATUS Project - (UK Power Network's Smart Transformer Project)	EDS 07-0116 Fire Protection Standard for UK Power Networks Property and Operational Sites	Smart Transformer	No	Tech Engineering Design Standard - General design requirements
	ETS 04-0120 Specification for Smart Transformers		No	Specific engineering technical requirements
	EAS 04-0121 AMPX Smart Transformer		No	Authorisation for the Amp-X manufactured device to be installed
	ECS 04-0123 Installation of Smart Transformers		No	Installation process
	ECP 11-0625 Smart Transformers		No	Commissioning process
	EOS 04-0124 Operation of Smart Transformer		No	Operating device (through HMI etc)

Project / Document Source	Document name	Device relevant for	Publicly available?	Use
	NIA_UKPN0080 Close Down Report 2023-07-24 12_19		Yes	Overview of device and project
Active Response project - UK Power Network's SOP project	Active Response – SOP Summary of findings	2T and 3T Soft Open Point	No	Installation requirements, use cases and Benefits
	Active Response Deliverable 5 - Initial Learning from the Installation and Commissioning of the Active Response Hardware		Yes	Installation requirements of SOPs
	Active Response Deliverable 8 - Presentation of findings from the project trials		Yes	Use cases and Benefits of SOPs
	Active Response Deliverable 9 - Review of solution applications and project business case		Yes	Financial costs of SOPs
Discussions with STATCOM supplier	Meeting notes and emails	STATCOM	No	Use cases, benefits, installation requirements, costs

Appendix B. DNO Standards Review

Table 1. Standards review for D-ST, by comparing UK Power Networks and SP Energy Networks technical specifications.

Document/Code	Title	Used By SP Energy Networks?	Used By UK Power Networks?
BS 2562	Specification for cable boxes for Transformers and Reactors Building	✓	
BS 4142	Methods for rating and assessing industrial and commercial sound	✓	
BS EN 50160	Voltage characteristics of electricity supplied by public electricity networks	✓	
BS EN 50180	Bushings above 1kV up to 36kV and from 250A to 3.15kA for liquid filled transformers.	✓	
BS 5499	Safety signs	✓	
BS EN 60071-1	Insulation co-ordination: Definitions, principles, and rules	✓	
BS EN 60071-2	Insulation co-ordination: Application guide	✓	
BS EN 60076-1	Power transformers. General	✓	✓
BS EN 60076-2	Power Transformers – Temperature rise		✓
BS EN 60076-3	Power Transformers – Part 3: Insulation levels, dielectric tests and external clearances in air	✓	✓
BS EN 60076-5	Power Transformers – Ability to Withstand Short Circuit		✓
BS EN 60076-7	Guide to Loading of Oil Immersed Power Transformers		
BS EN 60076-10	Power Transformers – Part 10: Determination of Sound Levels	✓	✓
BS EN 60255	Measuring relays and protection equipment - Part 1: Common requirements	✓	
BS EN 60269-1	Low-voltage fuses. General requirements	✓	
BS EN 60269-2	Low-voltage fuses. Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application). Examples of standardized systems of fuses A to K.	✓	

Document/Code	Title	Used By SP Energy Networks?	Used By UK Power Networks?
BS EN 60529	Degrees of protection provided by enclosures	✓	
BS EN 60616	Terminal and Tapping Markings for Power Transformers	✓	
BS EN 60654	Industrial-process measurement and control equipment. Operating conditions	✓	
BS EN 60747-1	Semiconductor devices - Part 1: General	✓	
BS EN 60815	Selection and dimensioning of high-voltage insulators intended for use in polluted conditions	✓	
BS EN 60947-7-1	Ancillary equipment - Terminal blocks for copper conductors	✓	
BS EN 61000-4-30	Testing and measurement techniques – Power quality measurement methods.	✓	
BS EN 61000-6-2	Electromagnetic compatibility (EMC). Generic standards. Immunity for industrial environments	✓	
BS EN 61000-6-3	Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments	✓	
BS EN 61000-6-4	Electromagnetic compatibility (EMC). Generic standards. Emission standard for industrial environments	✓	
BS EN 61000-6-5	Electromagnetic compatibility (EMC) – Part 6-5: Generic standards – Immunity for equipment used in power station and substation environment	✓	
IEC 61000-4-7	Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto	✓	
BS EN 61010	Safety requirements for electrical equipment for measurement, control and laboratory use	✓	
BS EN 61071	Capacitors for power electronics	✓	

Document/Code	Title	Used By SP Energy Networks?	Used By UK Power Networks?
BS EN 6121	Mechanical cable glands. Armour glands. Requirements and test methods.	✓	
BS EN 61810	Electromechanical elementary relays. General and safety requirements	✓	
BS EN 61850	Communication networks and systems for power utility automation	✓	
BS EN 61099	Synthetic organic esters for electrical purposes	✓	
BS EN 61869-2	Instrument transformers. Additional requirements for current transformers	✓	
BS EN 61869-3	Instrument transformers. Additional requirements for inductive voltage transformers	✓	
BS EN 61936-1	Power installations exceeding 1kV a.c. Common rules	✓	
BS EN 61968	Application integration at electric utilities – System interfaces for distribution management	✓	
BS EN 61970	Common Information Model (CIM) / Energy Management	✓	
BS EN 62477-1	Safety requirements for power electronic converter systems and equipment – Part 1: General	✓	
IEC 62477-2	Safety requirements for power electronic converter systems and equipment – Part 2: Power electronic converters from 1000 V AC or 1500 V DC up to 36 kV AC or 54 kV DC	✓	
BS EN 62927	Voltage sourced converter (VSC) valves for static synchronous compensator	✓	
BS 7671	Requirements for electrical installations	✓	
BS EN ISO 12944-2	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Classification of environments	✓	
BS EN ISO 3746	Acoustics - determination of sound power levels of noise sources using sound pressure - survey method using an enveloping measurement surface over a reflecting plane	✓	

Document/Code	Title	Used By SP Energy Networks?	Used By UK Power Networks?
BS EN ISO 9614	Acoustics – determination of sound power levels of noise sources using sound intensity	✓	
ICNIRP (1998)	For limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 GHz)	✓	
IEC/TS 60815-2	Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 2: Ceramic and glass insulators for a.c. systems	✓	
IEC 62351	Industrial communication networks – Network and system security.	✓	
IEC 62443	Power systems management and associated information exchange – Data and communications security	✓	
BS EN 13599	Copper and copper alloys – Copper Plate, Sheet and Strip for Electrical Purposes		✓
BS EN ISO 9001	BS EN ISO 9001		✓
BS 7079	Preparation of Steel Substrates Before Application of Paints and Related Products.		✓
ENA TS 35-1 Issue 6 (2014)	Electricity Networks Association Technical Specification for distribution transformers (from 16kVA to 2000kVA)		✓
ENA TS 37-1 Issue 3 2014	400 V a.c. switchgear, control gear and fuse gear assemblies		✓
ENA TS 37-2 Issue 4 (2005)	LV Distribution Fuse-Boards		✓
ENA TS 41-36 Issue 2 (2004)	Distribution Switchgear for Service up to 36kV (cable connected)		✓
ENA TS 98-1 Issue 2 (1999)	Surface preparation and paint finishing		✓
HSE HSG224	The Construction (Design & Management) Regulations 2007	✓	✓
HSE	The Electricity at Work Regulations 1989	✓	✓

Document/Code	Title	Used By SP Energy Networks?	Used By UK Power Networks?
HSE	The Health & Safety at Work Act 1974	✓	✓
HSE	The Control of Substances Hazardous to Health Regulations – 2002	✓	✓
HSE PUWER 1998	Provision and use of work equipment regulations	✓	✓
BS EN 60296: 2003	Specification for Unused and Reclaimed Mineral Insulating Oils for Transformers and Switchgear		✓