LV ENGINE

Smart Transformer Technical Specifications

About Report

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Report Summary & Disclaimer

This report details the technical specification that forms Deliverable 1 for the LV Engine project. This will be used as part of the procurement for the SST Supplier in Work Package 2 in 2018/2019. As part of Work Package 6 of LV Engine, it is planned to update these technical requirements to account for the learnings generated within subsequent work packages within the project.

Contents

Definitions

Cold Load Pick-Up	A Phenomenon that the demand picked up by a transformer after outage is greater than pre-outage due to loss of demand diversity and energisation inrush current of devices.
Control Algorithm	The software component of the **Smart Control System.** The **Control Algorithm** may be different **in different LV Engine Schemes.**
Control Engineer	The party within SP Energy Networks who is responsible for operating the network.
Control Parameters	The input parameters calculated by the **SCS** or configured by **Control Engineer** which specify the output quantities of a plant.
Controlled Zone	Part of **LV** Network where the voltage should be maintained within a target Limits.
Core Functionalities	Those functions which are mandatory and the **Project Partner**(s) shall confirm that these can be achieved.
DC Voltage Set Point	A **Control Parameter** for the target voltage on the **LV DC Secondary Terminal** of the **SST**.
Desirable Functionalities	Those functions which are not a strict requirement, but which is desirable and would add tangible value.
High Voltage (HV)	In the context of this document, **High Voltage** refers any **Nominal Voltage** exceeding the range of **Low Voltage**; up to 33kV RMS Phase to Phase.
Highest voltage for equipment	Highest RMS phase to phase voltage in a three-phase system for which the insulation is designed
HV Voltage Set Point	A **Control Parameter** for the target voltage at the **HV Primary Terminal** of the **SST**.
Intelligence and Control System (ICS) Partner	The party responsible for development, testing and implementation of the **Smart Control System**.
Low Voltage (LV)	For any AC system, this refers to the **Nominal Voltage** range up to 1000V RMS Phase to Phase. For DC systems, **LV** refers to the **Nominal Voltage** up to1500V Pole to Pole.
LV AC Active Power set point	A **Control Parameter** for the target active power (kW) supplied to **LV AC Secondary Terminal**

LV AC reactive power set point	A **Control Parameter** for the target reactive power (kvar) supplied to **LV AC Secondary Terminal**
LV Engine	One of the SPEN's Innovation flagship projects funded through Network Innovation Competition (NIC) mechanism and aims to trial number of **Smart Transformer**s in **Secondary Substations** under different schemes. The project has started in January 2018 and is planned to be completed by December 2022.
LV Engine Schemes	The capability of the **Smart Transformer**s will be demonstrated in different network arrangements and under different control strategies called **LV Engine Scheme**s. There are 5 schemes planned to be trialled in **LV Engine**.
LV Voltage Set Point	A **Control Parameter** for the target voltage at the **LV AC Secondary Terminal** of the **SST**.
Meshed Network	A network which has one or more source of supply.in this document Meshed Network refers to a LV network which is supplied from two or more **Secondary Substations.**
Monitored Data	Those network parameters monitored by using appropriate monitoring equipment, they are listed in Section 3.12.1.
Nominal Voltage	The root mean square (RMS) voltage by which a system is designed or identified.
Normally Open Point (NOP)	A controllable section of circuit which is "normally open" i.e. no current will usually flow. A **NOP** can be closed to allow current flow by intervention.
Power Flow Control	The ability to manage and control the loading of network assets, in this document **ST** is a controllable device to provide this function.
Primary Substation	A substation at which the primary voltage is greater than HV and the secondary voltage is HV.
Project Partner	A party who will support SP Energy Networks in delivering **LV Engine** by bringing relevant specialist expertise to the project. **LV Engine** expects to bring an **Intelligence and Control System (ICS) Partner** and a **SST Manufacturing Partner** to the project.
Radial Network	A network which has only one source of supply. A **Meshed Network** may be operated radially by using **Normally Open Point**s.
Rated lightening impulse voltage	Value of the assigned test voltage applied in one of the standard dielectric tests that proves that the insulation complies with the assigned test voltage

Schedule of Tests	A list of tests taken from the relevant international standard and from the purchasers' specification document.
Secondary Substation	A substation at which the primary voltage is HV and the secondary voltage is LV.
Smart Control System (SCS)	The control system consisting of software and computing hardware which determines and communicate operation set points to the **Solid- State Transformer**(s) based on the **Monitored Data** and optimisation algorithms.
Smart Meter	An electricity meter which conforms to the Smart Meter Equipment Technical Specifications Version 2 (SMETS2).
Smart Transformer (ST)	An intelligent device with power electronics components which can potentially provide number of functionalities and controllability for an enhanced operation of LV networks. The **Smart Transformer** consists of two components the **Solid-State Transformer** and **Smart Control System**.
Solid-State Transformer (SST)	This unit includes digitally controlled power electronics and hardware which provide voltage conversion from **High Voltage** (11kV) to **Low Voltage** (0.4kV). A **SST** can control the power flow passing through itself and voltage at its terminals by adjusting the power electronics switching in response to set points received from the **Smart Control System**.
SST Manufacturing Partner	The party responsible for designing, manufacturing and testing **SST**s.
Test Plan	A document which describes in detail the test to be carried out including the purpose of the test, the method of carrying out the test and the acceptance criteria for the test. This document should also detail the connections required for the test in graphical form. Any precautions required to be taken when performing the test shall also be detailed in the test plan, e.g. terminals connected to earth via resistances during impulse testing. The Test Plan shall be agreed and approved by SPEN prior to the commencement SST manufacturing phase.
Thermal loading set point	A **Control Parameter** for the target current loading (A) of the SST

List of applicable standards and relevant documents

International Electrotechnical Commission Publications (IEC)

IEC 60529	Degrees of protection provided by enclosures
IEC 61099	Synthetic organic esters for electrical purposes
IEC 60076-1	Power Transformers – Part 1: General
IEC 60076-3	Power Transformers – Part 3: Insulation levels, dielectric tests and external clearances in air
IEC 60076-10	Power Transformers – Part 10: Determination of Sound Levels
IEC 60616	Terminal and Tapping Markings for Power Transformers
IEC 61000	Electromagnetic compatibility
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 60870-5-104	Transmission protocols –Network access for IEC 60870-5-101 using standard transport profiles
IEC 62351	Power systems management and associated information exchange - Data and communications security
IEC 61970	Common Information Model (CIM) / Energy Management
IEC 61968	Application integration at electric utilities – System interfaces for distribution management
IET 61850	Communication networks and systems for power utility automation
IEC 60071-1:1993	Insulation co-ordination – Part 1: Definitions, principles and rules
IEC 60071-2:1996,	Insulation co-ordination – Part 2: Application guide
IEC 60099-4:1991,	Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. Systems
IEC 60815	Selection and dimensioning of high-voltage insulators intended for use in polluted conditions
IEC 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
IEC 61000-6-3	Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments
IEC 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
IEC 60071	Insulation co-ordination
IEC 62477	Safety requirements for power electronic converter systems and equipment
IEC 62271-1	High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear

Energy Networks Association (ENA) Technical Specifications and British Standards

BS EN 50160	Voltage characteristics of electricity supplied by public electricity networks
BS 6121	Mechanical cable glands. Armour glands. Requirements and test methods.
BS EN 50180	Bushings above 1kV up to 36kV and from 250A to 3.15kA for liquid filled transformers.
BS EN 61000-4-30	Testing and measurement techniques – Power quality measurement methods.
BS 2562	Specification for cable boxes for Transformers and Reactors Building
BS EN 61010	Safety requirements for electrical equipment for measurement, control and laboratory use
BS 7671	Requirements for electrical installations
BS 5499	Safety signs
ENATS 35-1	Distribution transformers
ENATS 12-11	Dry cable Terminations in HV Switchgear for service rated voltages of 12 and 36kV
ENATS 50-18	Design and application of Ancillary Electrical Equipment
ENA ER G5/4	Planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission and distribution systems in the United Kingdom.

SP Energy Networks (SPEN) Specifications

SPEN TRAN-03-021	Specification for distribution transformers 6.6kV-11kV, 25kVA-1000kVA
SUB-03-009	ScottishPower Energy Networks Technical Specification for Mineral Insulating Oil for Transformers and Switchgear.

Other references

SPEN Network Overview

Trial Site Examples and Procedures

Section 1. LV Engine Introduction & General Requirements of Smart Transformer

1.1 Purpose

The purpose of this document is to outline the technical requirements of the **Smart Transformer (ST)** which will be designed, manufactured and trialled as part of the **LV Engine** project. **LV Engine** is the **SP Energy Networks**' (**SPEN**) flagship project which has been funded through Ofgem's Network Innovation Competition mechanism. It is envisaged that the **ST** consists of two main components:

1- **Solid-State Transformer** (**SST**): This unit includes digitally controlled power electronics and hardware which provide various network control functionalities. **SST** will be installed in the **Secondary Substations** and provide voltage conversion from (11kV) to **Low Voltage** (0.4kV). **SST** can control the power flow passing through itself and voltage at its terminals by adjusting the power electronics switching in response to set points received from the **Smart Control System** (**SCS**).

2- **Smart Control System** (**SCS**): This system includes a number of intelligent units which provide the control set points to **SST** based on the data monitored at different points in the **LV** and **HV** network. **SCS** has an operational supervisory capability to estimate the latest operation conditions and requirements within a regional control zone to satisfy network optimisation objectives and constraints.

This document covers the functional and technical requirements for **SST** and **SCS**. These requirements have been specified based on the **Core Functionalities** of the **ST**, the requirements for connection to grid and also understanding of available data and potential communication structure. However, due to the innovative nature of the project, it is expected that some of the requirements may be subject to change or new requirements may be introduced for the final **ST** design. This shall be considered by any **Project Partner(s)** which will provide the **ST** components.

In order to achieve the objectives of **LV Engine** project, SPEN intends to identify **SST Manufacturing Partner** and **Intelligence and Control System (ICS) Partner** who can deliver fit-for-purpose **ST**s and the associated smart grid control and successfully integrate them into the existing distribution network:

- **SST Manufacturing Partner** shall design, manufacture and deliver **SST** based on the requirements specified in Section 1 and Section 2.

- **ICS Partner** shall design, build and deliver the intelligent control system based on the requirements specified in Section 1 and Section 3.

It is required that each **Project Partners** fully recognise all sections in this document to understand the interaction and interfaces required between different **Project Partners** and also the equipment which they provide. It is possible that one organisation may have the technical capabilities to support the requirements for delivery of the scope of both **SST Manufacturing Partner** and **ICS Partner**.

1.2 LV Engine functional specifications document

Project Partner(s) shall recognise, read and understand the "SPEN Network Overview" document which is a complementary document to this technical specification document and presents operation and planning requirements within SP Energy Networks.

1.3 LV Engine overview

1.3.1 Project concept

LV Engine aims to enhance **LV** networks operation by adding intelligent controls and automation functionalities to the **Secondary Substations**. A general concept of the **LV Engine** is shown in Figure 1. **LV Engine** will trial **STs** in a number of schemes to demonstrate various functionalities including:

- *Phase Voltage Regulation* – The overall voltage profile of an **LV** feeder can be optimised by intelligently adjusting the phase voltage in real-time at the **Secondary Substation** in response to monitored voltage data points along the length of each **LV** feeder.
- *Power Flow Control* – STs have the capability to control power flow due to the inclusion of power electronics. This allows an **ST** to load share with nearby conventional transformers in real time for the purposes of reducing the thermal strain at peak times and maximising network capacity.
- *Reactive Power Control* – An **ST** can offer independent voltage regulations at the **LV** and **HV** terminals. Reactive power support and local voltage regulation at the **HV** terminal can be deployed to improve the voltage profile along the **HV** network. This function can be complementary to the conventional Automatic **Voltage Control** (AVC) scheme at the upstream **Primary Substations**.
- *Low Voltage DC Supply* – Conversion of voltage from **HV** to **LV** by use of power electronics provides access to a DC voltage at the **Secondary Substation**. A DC connection can be made available to satisfy any local DC demand, renewable energy sources (RES), or energy storage without repeated rectification from AC to DC and the resulting network and customer losses. Running the **LV** network at DC can also increase the transfer capacity of the network allowing more Electric Vehicle (EV) load to connect to the network before costly reinforcement is required.

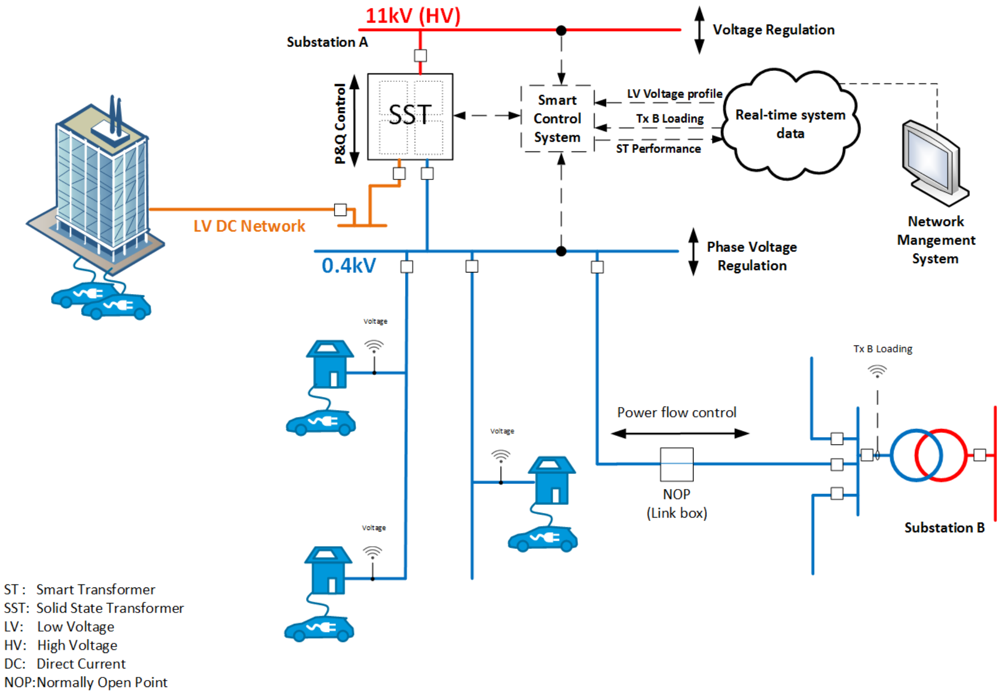


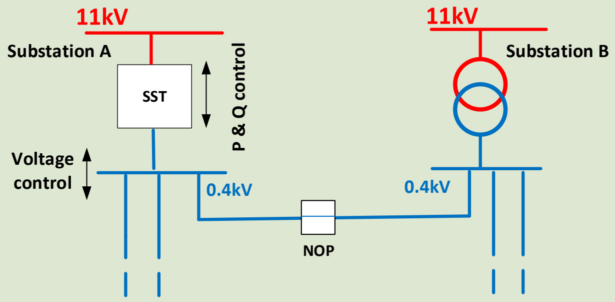
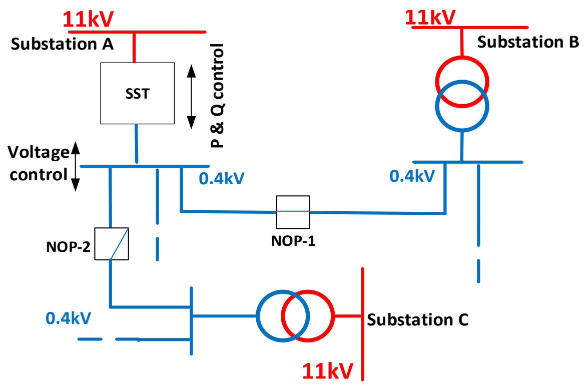
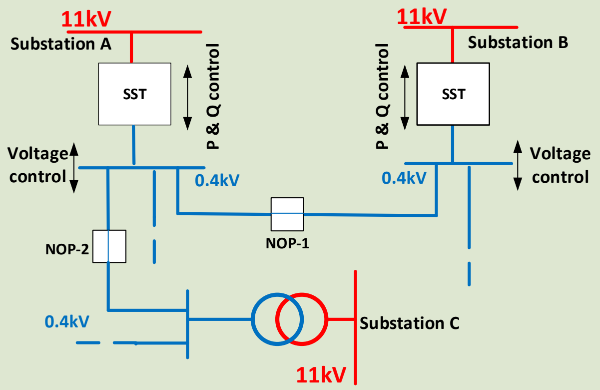
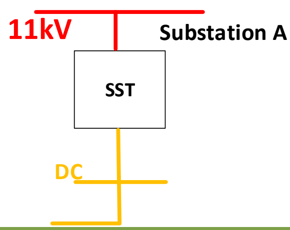
Figure 1 – General concept of LV Engine Solution

There are also number of **Desirable Functionalities** which can be considered for the trial of the **ST** within **LV Engine schemes.**

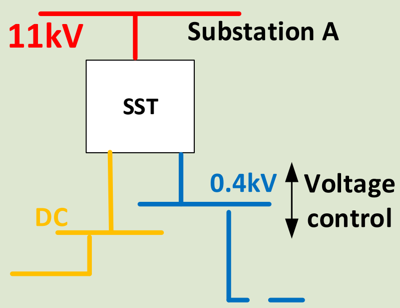
1.3.2 LV Engine schemes

LV Engine solution will be trialled in 5 schemes which can be different in terms of control functionalities and the type of customers supplied. Table 1 summarises the schemes which will be trialled in **LV Engine** project. The trial sites and locations for each scheme will be different. An initial candidate trial sites have been identified but the final sites for each scheme are yet to be confirmed.

Table 1 – Summary of LV Engine Schemes

Scheme description	Scheme diagram
Scheme 1 - This scheme aims to demonstrate the **Voltage Control** and capacity sharing functionalities of a **ST**. The **Normally Open Point** (**NOP**) between a conventional substation and the **ST** will be closed to create a solid interconnector between the two substations. The power flow control at the **ST** with the **NOP** closed will allow a controlled exchange of power between **LV** networks supplied by Substation A and Substation B.	
Scheme 2 - This scheme provides further flexibility to that offered in Scheme 1. It aims to demonstrate the optimum **LV Voltage Control** and capacity sharing functionalities of the **ST** conventional transformers. In this scheme, the **ST** will share the power with only one conventional transformer at a time which will be managed by the controlled remote switching of **NOP**-1 and **NOP**-2.	
Scheme 3 - This scheme provides a condition when two **SST**s in neighbouring areas are operational. Scheme 3 aims to demonstrate the optimum **LV Voltage Control** and capacity sharing functionalities of two STs with one conventional transformer. In this scheme, the **NOP** between the three substations will be closed providing two solid interconnectors. The real-time **Power Flow Control** at STs will provide a controlled power exchange among the **LV** networks supplied by substations A,B, and C.	
Scheme 4 - This scheme aims to demonstrate the DC supply capability of the **ST**. The aim is to provide a DC supply for exclusively DC customers. This scheme will demonstrate the requirements for design, installation and operation of an **LVDC** network using a **ST**.	

<table>
<tr><th>Scheme description</th><th>Scheme diagram</th></tr>
<tr><td>Scheme 5 - This scheme aims to demonstrate the hybrid AC/DC functionality of the ST by supplying DC customers along with AC customers.

This scheme will demonstrate the optimal design, installation and operation of a hybrid LVDC/AC network. The same LVDC configuration of Scheme 4 may be applied in this Scheme but further consideration to the earthing arrangements and galvanic isolation will be required.</td><td></td></tr>
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1.4 Business as Usual (BaU) adoption vision

LV Engine provides an opportunity to demonstrate the performance and benefits of **STs** in different network conditions. SPEN aims to ensure the final **LV Engine** solution, and in particular the **ST** design, can be deployed for BaU adoption. If successful, as reflected in the **LV Engine** Full Submission Proposal[1] to Ofgem, **LV Engine** solution can potentially be deployed in over 1,700 ground mounted substations by 2035 within SPEN to facilitate the growing integration of Low Carbon Technologies. The roll-out within UK is projected to be as high as 15,300 units deployed by 2035.

1.5 General Requirements

This section provides the general requirements of the **ST** which can be applicable to both **SST** and **SCS.** The more detailed technical and functional specifications of **SST** and **SCS** are given in Section Section 2 and Section 3 respectively.

1.6 Design Type

Two **ST** design types are required:

- **Design Type A** – **ST** with **HV Primary Terminal** connected to 11kV **HV** AC network and **Secondary Terminal**s consists of **Secondary LV AC Terminal** and **Secondary LV DC Terminal.** The **Secondary LV AC Terminal** connects to the 0.4kV **LV** AC network and the **Secondary LV DC Terminal** supplies the **LV** DC network (see Figure 2). This is a hybrid design that can be deployed for direct connections of AC and DC customers which are geographically located in the same area.

- **Design Type B** – **ST** with **HV Primary Terminal** connected to the 11kV **HV** AC network and the secondary terminal only include **Secondary LV DC Terminal** which supplies **LV** DC network (see Figure 3). This design is solely considered for the connection of DC customers and where the full capacity of the **ST** should be allocated to DC customers.

[1] https://www.ofgem.gov.uk/system/files/docs/2017/11/LV_engine_2017_nic_full_resubmission_-_clean_redacted.pdf

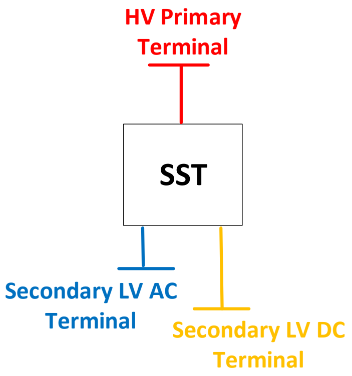


Figure 2 – Design Type A

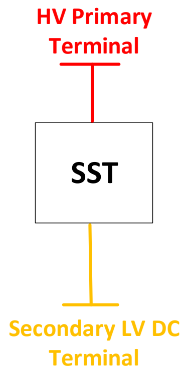


Figure 3 – Design Type B

Design Type A will be trialled in **LV Engine Scheme** 1, 2, 3 and 5. It should be noted that the connection of DC customers will not be trialled in Scheme 1, 2, 3, therefore there is no connection and power consumption at **Secondary LV DC Terminal**. However, Scheme 5 will specifically demonstrate the full hybrid AC/DC capability of this design and both secondary terminals will be utilised.

Design Type B will be trialled in **LV Engine Scheme** 4 where only connection of DC customers to the **ST** will be demonstrated.

It is desirable to have a flexible design of **ST** to allow **Design Type A** to be converted to **Design Type B** and vice versa by adding or removing converter blocks where required.

1.6.1 Key electrical parameters

The key electrical parameters of the **ST** are as follows

- HV Primary Terminal .... 3 phase AC
- Secondary Terminals
  - Design Type A .... 3 phase AC and Neutral (4 wire) & Bipolar DC and Neutral (3 wire)
  - Design Type B .... Bipolar DC
- Nominal Phase to Phase Primary Voltage (RMS) 11.0kV
- Nominal Phase to Phase Secondary AC Voltage (RMS) 0.40kV
- Maximum Nominal Secondary DC voltage*............ ±750.0V
- Nominal Frequency HV Primary Terminal 50.0Hz
- Nominal Frequency LV AC Secondary Terminal 50.0Hz
- Nominal Continuous Rating 500kVA
- Vector Group DYn11
- HV system design fault level 250MVA
- LV system design fault level 25MVA

* The exact nominal DC voltage will be selected during design phase and based on trial site requirements

1.6.2 Service conditions

The **STs** shall be suitable for operation within permanent brick-built enclosure and also preferably suitable for containerised and Glass Reinforced Plastic (GRP) enclosures which are classified as outdoor environment.

The **ST** shall remain operational at its nominal ratings and deliver all its **Core Functionalities** for ambient temperature between -25°C and 40°C.

The **ST** shall have a minimum degree of ingress protection of IP55 for outdoor application where specified in this document as defined in IEC 60529. When any doors are open, the degree of protection for persons against access to hazardous parts shall be at least to IP2X according to IEC 60529. The door shall have adequate weather resistant gaskets fitted to ensure a weatherproof seal. The ingress protection shall be maintained during the service life and **SPEN** reserve the right to request relevant evidences from **Project Partner**(s).

All the **ST** equipment shall be suitable to operate in pollution class “d.” (Heavy) as defined in IEC 60815.

1.6.3 Health and Safety requirements

All the designs, tests, installations and commissioning of **ST** components shall comply with applicable Health and Safety requirements at the time of tendering. As a minimum the requirements specified in the following documents shall be met.

- The Electricity Safety Quality and Continuity Regulations 2002
- Scottish Power Safety Rules (Electrical and Mechanical) 4th Edition
- The Electricity at Work Regulation 1989
- SHE Standard 07, Model Distribution Safety Rules 2016
- The Health & Safety at Work Act 1974
- The Construction (Design & Management) Regulations 2015

The **Project Partners** shall provide any additional safety documents and data sheets where required, in addition to those that will be specified by SPEN in the course of project delivery.

In addition, where the aforementioned documents do not provide health and safety compliance requirements, the following safety standards shall be complied with for design and testing of **ST** after approval by SPEN:

- IEC 62477-1: Safety requirements for power electronic converter systems and equipment - Part 1: General;

- IEC 62477-2: Safety requirements for power semiconductor converter systems - Part 2: Power Electronic Converters from 1000 V AC or 1500 V DC up to 36 kV AC or 54 kV DC;

- BS EN 61010 Safety requirements for electrical equipment for measurement, control and laboratory use;

ST components shall not be flammable or provoke flames or fire after faults or from the breaking down of components. The flammability properties of materials used within **ST** shall be tested in accordance with IEC 62477-1.

1.6.4 Core functionalities

ST shall be capable of delivering the following **Core Functionalities**:

- *Voltage conversion* – **ST** shall provide a voltage conversion function similar to 11kV/0.4kV conventional transformers;

- *Provision of **LV** DC supply* – **ST** shall provide bi-polar **LV** DC voltage at the **Secondary LV DC Terminal.** The exact voltage level shall be determined in the design phase; however, the maximum possible DC voltage can be as high as ±750V;

- ***LV** AC Phase Voltage Regulation* **–** **ST** shall have the capability to optimally control the voltage at the **Secondary LV AC Terminal** for each phase (Phase to Neutral) independently in response to voltages monitored at different locations along the **LV** network. For details of technical requirements, please see Section 2.3 and Section 3.8.2;

- ***LV*** *DC Voltage Regulation* **– ST** shall have the capability to optimally control the voltage at the **Secondary LV DC Terminal**. For technical requirement details, please see Section 2.3 and Section 3.8.2;
- *HV Voltage Control* – **ST** shall have the capability to regulate the voltage at the **HV Primary Terminal** by injecting or absorbing reactive power. For technical requirement details, please see Section 2.3 and Section 3.8.3;
- *Power Flow Control* – **ST** shall have the capability to optimally control power flow within a meshed network to share the network capacity with other STs and/or conventional transformer. For more details, see Section 2.4 and Section 3.8.4;
- *Bi-directional power flow* – **ST** shall be capable of allowing bi-directional power flow with no limitation from **HV Primary Terminal** to **Secondary LV AC Terminal** and **Secondary LV DC Terminal**, or vice versa. This also include the case where a **Secondary LV AC terminal** is exporting power and a **Secondary LV DC terminal** is importing power, or vice versa, in this case the balance of the Secondary import/export power shall be provided by the **HV Primary Terminal**;
- ***HV*** *Load Balance* – **ST** shall have the capability to eliminate any load imbalance transfer from **Secondary LV AC Terminal** to **HV Primary Terminal**;

Core Functionalities shall be delivered in **Normal Operating Conditions** regardless of whether the **ST** operations within an **LV Radial Network** or **LV Meshed Network**.

1.6.5 Desirable Functionalities

The **ST** shall be capable of delivering the following **Desirable Functionalities**:

- *Active Harmonic Filtering* – It is desirable that the **ST** is capable of performing as an active harmonic filter to alleviate voltage harmonic distortion in the **LV** networks or **HV** networks to achieve compliance with individual harmonic order limits and **Total Harmonic Distortion** target.
- *Phase shift adjustment* – It is desirable that the phase relationship between **HV Primary Terminal** and **LV AC Secondary Terminal** can be flexibly adjusted in 30 Degree steps to allow mesh operation of **LV** networks where out of phase relationship exist. This function allows the emulation of a desirable vector group of a conventional transformer.
- *Scalability* – It is desirable that the **SST** design includes **Capacity Blocks** arrangement to allow the flexibility of adding or removing **Capacity Blocks** into **SST**.

1.6.6 Availability and Reliability

The **ST** shall be highly reliable, available and robust to ensure the minimum impact on continuity and quality of supply to **LV** customers. **ST** is required to operate 365 days and 24 hours per day annually. The following performance targets shall be required:

- Reliability > %99.9
- Forced Outage Rate < 3 outages per annum
- Availability > %99.9
- Scheduled Outage Rate < 2 outages per annum

Failure in any major components of **ST**, **SST** or **SCS** shall not have any impact on other network assets, monitoring equipment, protection system or any device interacting with **ST** beyond anticipated operational protection requirements.

Project Partners shall provide the expected reliability and availability of the **ST**'s main components, **SST** and **SCS**, in the tender response and the approach they have been calculated.

The service life time of the **ST** shall be over 30 years with limited part replacements. The manufacturing partner shall provide expected **ST** life time, annual maintenance and part replacement requirements in the tender response.

Project Partners shall indicate any potential obsolescence of the technology provided and if so at what point in the equipment lifetime it is anticipated that some components or systems will need to be up-graded.

1.6.7 Sound level

The sound power level of a 500kVA **ST** shall not exceed 56dBA as specified in ENA TS-35. The sound levels shall be tested in accordance with IEC 60076-10 and consider the full operation of all components of the **ST**.

The **Project Partners** shall provide the guaranteed sound level with expected tolerances of **ST** and any proposed method for sound level reduction.

1.6.8 Electromagnetic compatibility

The **ST** shall not cause Radio Frequency Interference (RFI) in the substation and radiated emission shall comply with CISPR/TR 18-2.

The electromagnetic interference level of the **ST** shall comply with the requirements in IEC 61000-6-3.

All the auxiliary, control and protection equipment of **ST** shall be immune to electromagnetic interference in accordance with ENA TS 48-05 and the requirements specified in IEC 61000-6-5.

1.7 Warranty

The **Project Partner**s shall provide warranty for the full duration of **LV Engine** project. The warranty period will cover troubleshooting, replacements of all components due to equipment failure and required regular maintenance. A call-off agreement shall be considered for maintenance after warranty period.

1.8 Third party access

It is required that **Project Partner**s shall be able to have remote access to **ST** components (**SST** and **SCS**) for any diagnostic, firmware update and troubleshooting requirements. Any third-party access is required to be via a dedicated point to point VPN link into SPEN secure network and via terminating in a Jump Server before making a new connection onwards on to the relevant field equipment.

1.9 Auxiliary power

The **Project Partner**s shall confirm the maximum level of auxiliary AC and DC power and its nominal voltage supply requirements. It is desirable that the primary source of auxiliary power will be from existing 11kV or 0.4kV network within the **Secondary Substation**.

The **Project Partner**s shall confirm any backup auxiliary supply requirements in different operating conditions of **ST**.

1.10 Project location

LV Engine trial sites will be located within SP Manweb or SP Distribution licence areas which include Central and South Scotland, Merseyside & North Wales in the UK. **Project Partner**s shall be responsible for delivery of the equipment to any trial site specified by SPEN.

A preliminarily list of potential trial sites for each **LV Engine** scheme has been prepared and reported in *Trial Site Examples and Procedures* document.

1.11 Packaging for shipment

All equipment shall be packed with appropriate protection to avoid any damage to the equipment during transit and storage.

The **Project Partner**s shall deliver all the equipment, with a record of no damage, to the trial sites specified by SPEN prior to delivery.

Delivery Duty Paid (DDP) incoterms 2010 shall be applied to all deliverable equipment.

1.12 Drawings and Documentation

The **Project Partner**s shall provide all appropriate operation, maintenance and health and safety documentations for all the equipment provided.

Operational clearances and physical layout of the equipment on **LV Engine** trial sites with corresponding labels shall be reflected in the final drawings and sketches provided by the **Project Partner**s.

The **Project Partner**s shall provide the sketches and drawings of all the wiring and connectivity of electrical and communication equipment.

The **Project Partner**s shall provide a complete troubleshooting and maintenance document based on the implemented system architecture including system shutdown, system safe isolation and system restoration.

All the documentations shall be provided in electronic formats approved by SPEN. As a guideline, drawings and sketches shall be provided in AutoCAD and PDF format with the software versions approved by SPEN. The reports shall be provided in Microsoft Word and PDF format with the software versions approved by SPEN.

The **Project Partner**s may be also requested to provide a printed format of the documentation.

Section 2. Technical specifications of Solid State Transformer

2.1 General functionality requirements

SST shall be able to provide **Core Functionalities** in both **Radial Network** and **Meshed Network** arrangements and fulfil the objectives of **LV Engine schemes**.

In Design Type A, **SST**'s **HV Primary Terminal** will be connected to the nominal voltage of 11kV and the **Secondary LV AC Terminal** will be connected to the nominal voltage of 0.4kV. The **Secondary LV DC Terminal** will be connected to a maximum bi-polar voltage of ±750VDC. The exact DC voltage will be selected during design stage and depending on the customer requirements.

In Design Type B, **SST**'s **HV Primary Terminal** will be connected to the nominal voltage of 11kV and. the **Secondary LV DC Terminal** will be connected to a maximum bi-polar voltage of ±750VDC. The exact DC voltage will be selected during design stage and depending on the customer requirements.

2.2 SST Topology

The focus of the **LV Engine** project is demonstrating the performance of the **Core Functionalities** required by the network. As such any innovative approaches that provide these **Core Functionalities** in an efficient and reliable manner will be considered. There are different possible **SST** topologies that have been proposed two of which are described below:

- *Topology 1 - Topology using a conventional low frequency 50Hz (LF) transformer* –This topology uses power electronics devices at the secondary side of conventional LF transformers (11kV/0.4kV). The power electronic devices can be added to the existing distribution transformers to deliver the **Core Functionalities** of **LV Engine**. **SST Manufacturing Partner** is required to provide the conventional transformer and the power electronic units.

- *Topology 2 - Topology using a High Frequency (HF) transformers* – Using HF Transformers and power electronics may allow a modular and compact design while delivering the **LV Engine Core Functionalities**. SPEN recognises that this topology may require a larger effort for design and manufacturing compared to the approach of retrofitting an LF transformer with power electronics.

LV Engine aims to trial both topologies and create the opportunity to compare their performance, inform cost benefit analysis and planning process for selecting the suitable topology.

The conventional transformer provided in Topology 1 shall be in full compliance with SPEN TRAN-03-02.

The technical requirements specified in this document shall not be specific to any particular **SST** topology and shall be applicable to both aforementioned topologies.

The **SST Manufacturing Partner** shall provide the costing breakdown associated with each topology as specified within the pricing schedule.

2.3 Voltage control capabilities

It is required that **SST** shall deliver **Voltage Control** requirements in **Normal Operating Conditions** when **ST** operates within a **LV Radial Network** or **LV Meshed Network**.

2.3.1 Voltage control range

The **SST** shall have the capability of **Voltage Control** at the **Secondary AC Terminal** within the range of **-** 10% to +10% of nominal voltage (0.4kV) in response to **LV Voltage Set Points** for each phase received from **SCS**. This **Voltage Control** capability shall be achievable in all loading conditions (No-load to full load) when the primary nominal voltage (11kV) with -%15 to +%15 tolerance is applied to the **HV Primary Terminal**.

The **SST** shall be capable of controlling the voltage of each phase (phase-neutral) at the **Secondary AC Terminal** independently. The **Voltage Control** capability range at the **Secondary AC Terminal** (see above) shall be applicable to each phase independently.

The **SST** shall have the capability of **Voltage Control** at the **Secondary DC Terminal** within the range of - 10% to +10% of nominal voltage (which will be selected during design stage) in response to **DC Voltage Set Points** received from **SCS**. This **Voltage Control** capability shall be achievable in all loading conditions (No-load to full load) when the primary nominal voltage (11kV) with -%15 to +%15 tolerance is applied to the **HV Primary Terminal**.

The **SST** shall be capable of **Voltage Control** at **HV Primary Terminal** by injecting/absorbing reactive power from/to the 11kV network. The level of reactive power injection/absorption shall be optimally determined by the **SST** internal algorithm considering the **Power Capability of SST** and **HV Voltage Set Point** received form **SCS.** The **HV** voltage capability is expected to be similar to STATCOM performance, as shown in Figure 4. The optimum dead band settings shall be determined by the **SST Manufacturing Partner** during the **SST** design phase.

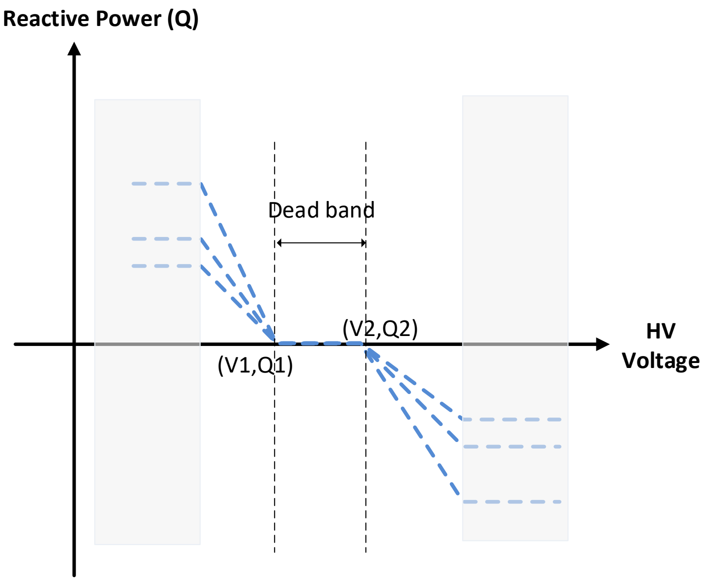


Figure 4 –Typical STATCOM voltage control performance

It is required that voltage regulation capability is independent at each **SST** terminal and not affected by the voltage set points at other terminals. For example, operating at particular **LV** AC voltage Set Points shall not limit the **Voltage Control** range capability at the **Secondary DC Terminal.**

SST shall be capable of operating within full lead/lag power factor range (0 to 1.0) at both the **HV Primary Terminal** and the **Secondary AC Terminal** within the **Power Capability of SST**, as described in section 2.6.

2.3.2 Response time

SST's **Response Time** for voltage regulation at the **Secondary AC Terminal** shall be less than 2.0 seconds upon receiving the **LV Voltage Set Point** from **SCS**.

SST's **Response Time** for voltage regulation at the **Secondary DC Terminal** shall be less than 2.0 seconds upon receiving the **DC Voltage Set Point** from **SCS**.

SST's **Response Time** for **SST** to perform optimal reactive power injection/absorption from the **Primary Terminal** shall be less than 2.0 seconds upon receiving the **HV Voltage Set Point** from **SCS**.

It is desirable that **SST** is capable of performing voltage regulation at all terminals simultaneously and independently.

2.3.3 Accuracy & granularity

The accuracy of the **Voltage Control** provided by **SST** shall be less than ± 0.5% of the nominal voltage at the **SST** terminals. This requirement shall be applicable for the controlled voltage at the **AC Secondary Terminal** and **DC Secondary Terminal**.

The accuracy of the reactive power injection /absorption from **HV Primary Terminal** shall be less than ± 0.5% of the **SST** nominal rating (500kVA).

The accuracy of **Voltage Control** shall remain within the specified limits in all loading conditions (from no-load to full-load) within **Power Capability of SST**.

SST shall be capable of applying a step change (coarse) and continuous change (fine) in voltage at the **SST** terminals. This should be configurable by the appropriate commands received from **SCS**.

SST shall be capable of applying continuous voltage change or voltage step change (increase and decrease) between 1.0% to 2.5% of nominal voltage at the controlled terminal. **SST** shall consider a configurable minimum delay time (in seconds) between two subsequent step changes.

2.4 Power flow control capabilities

SST shall be capable of controlling active power and reactive power supplied to **LV AC Terminal** in response to **Active Power Set Point** and **Reactive Power Set Point** received from **SCS**.

SST shall be capable of controlling the active power and reactive power in the complete full range and with any ratio between active power and reactive power within **Power Capability** of **SST**.

SST is required to have bi-directional **Power Flow Control** capability that allows controlling active power and reactive power in full range independently and in any direction, to **LV AC Terminal** or from **LV DC Terminal**.

SST's **Response Time** for **Power Flow Control** shall be less than 2.0 seconds upon receiving **Active Power Set Point** and **Reactive Power Set Point** received from **SCS**.

The accuracy of the **Power Flow Control** provided by **SST** shall be less than ± 0.5% of the **Active Power Set Point** and **Reactive Power Set Point** received from **SCS**.

2.5 Load balance capability

The aggregated load supplied by a transformer at the **Secondary Substation** may be unbalance due to uneven connection of customers to different phases or outage of faulted phase(s) in **LV** circuits. This unbalance load is usually transferred to the **HV** network and may cause additional losses in the **HV** network or impact on **HV** earth fault protection. **SST** shall be capable of eliminating any unbalance **LV** load that may be otherwise transferred to **HV Primary Terminal**.

2.6 Power Capability

The nominal continuous rating of both **SST** types (Type A and Type B) shall be 500kVA with four quadrant operation capability as shown in Figure 5. Any limitation in the full four quadrant operation capability (A to G points in Figure 5) shall be declared in the tender response.

SST shall be capable of supplying bi-directional active power and reactive power in the full range of loading conditions (No-load to nominal rating) regardless of the direction of active and reactive power and also the ratio between them.

SST shall be able to supply the demand variations in **LV** network immediately as they occur without compromising the **Core Functionalities** and supply quality requirements specified by ESQCR.

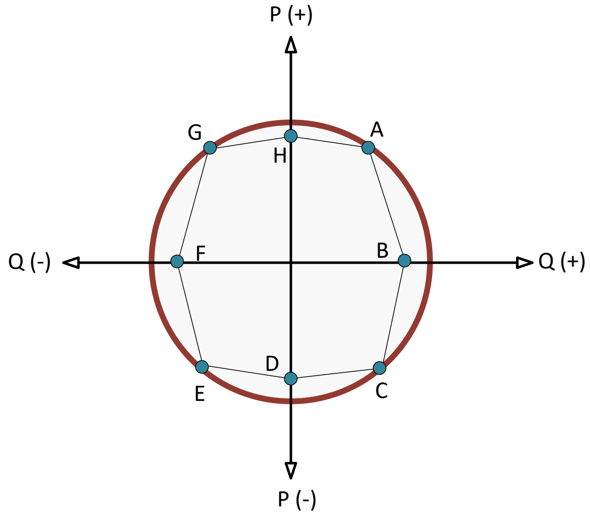


Figure 5 – Power capability of SST

SST Design consist of three systems as shown in Figure 6 and their nominal ratings are as follows:

- *AC Primary System*: This system is connected to the **HV Primary Terminal**. The nominal continuous rating for this system is 500kVA and it is capable of suppling bi-directional active power and reactive power for the full range of loading conditions (no-load to nominal rating) in Normal Operating Conditions.
- *AC Secondary System*: This system is directly connected to the **LV AC Secondary Terminal**. The nominal continuous rating for this system is 500kVA for **SST** Design Type A trialled in **LV Engine** schemes 1,2, and 3. For the **SST** trialled in **LV Engine** scheme 5, the nominal rating of this system will be 350 kVA, however, this is subject to change depending on the selected trial site. This system shall be capable of supplying bi-directional active power and reactive power for full range of loading conditions (no-load to nominal rating) in **Normal Operating Conditions**. This system is not part of **SST** Design Type B.
- *DC Secondary System*: This system is directly connected to the **LV DC Secondary Terminal**. The nominal continuous rating for this system shall be 150kW for Design Type A trialled in **LV Engine** scheme 5 and 500kW for Design Type B. This system shall be capable of supplying bi-directional active power for full range of loading conditions (no-load to nominal rating) in Normal Operating Conditions.

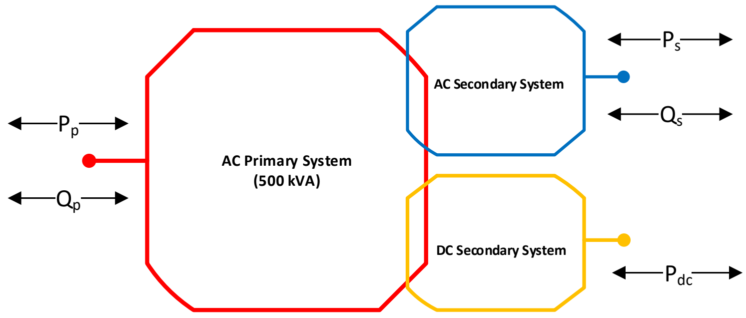


Figure 6 – Power capability

2.7 Scalability

It is desirable **SST** design includes a building **Capacity Blocks** arrangement to flexibly allow adding or removing **Capacity Blocks** into **SST** for any of the following purposes:

1- Supplying larger **LV** AC demand/generation
2- Providing larger reactive power injection/absorption at **HV** network
3- Supplying larger **LV** DC demand/generation

It is desirable that **SST** design shall be flexible to allow adding or removing the **Capacity Blocks** for each of the purposes listed above independently. It should be noted due to the system requirements; the nominal capacity of the **AC Secondary System** may be different from the capacity of the **AC Primary System**. For example, the **AC Primary System** may be upgraded just to provide further voltage support (reactive power injection/absorption) to the **HV** network while there are no requirements for **AC Secondary System** rating upgrade.

SST Manufacturing Partner shall specify the **Capacity Blocks** considered in their proposed solutions for increasing the capacity of AC Primary System, AC Secondary System and DC secondary System.

2.8 Redundancy

It is desirable to provide a modular design that can allow a level of redundancy of **SST** components and improve the overall reliability and availability of **SST**. This may include series or parallel redundancy of power electronic modules.

It is desirable that the replacement of any faulted module does not require de-energisation of **SST** and can be conducted while **SST** operates normally.

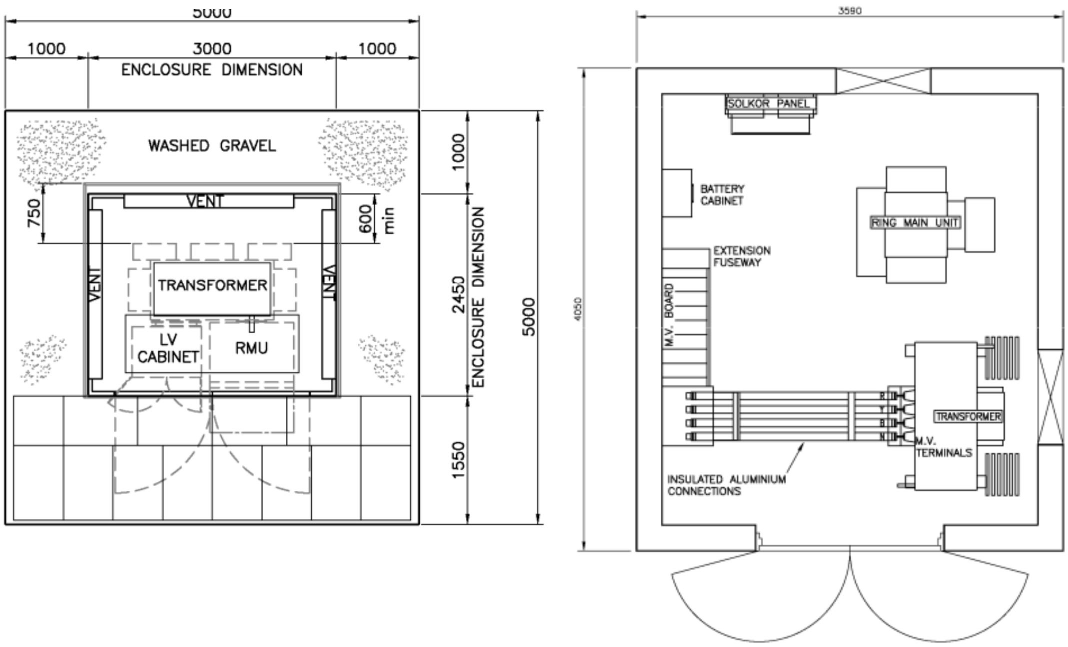
2.9 Cooling system

SST shall deploy a low maintenance and reliable cooling system. The manufacturing partner shall design a cooling strategy that would be fit for purpose for application in **Secondary Substations** and fulfil the cooling requirements of the **SST** for operation in all network conditions and delivery of its **Core Functionalities**.

The cooling system shall include a design that avoids creating any obstruction with cable boxes, terminals, flanges and fittings or has adverse impact on the existing plant and equipment within the substation.

2.10 Construction & foot print & volume

SST size shall be suitable for installation in the **Secondary Substations** along with other typical existing **LV** and **HV** plant equipment. The typical **Secondary Substation** layouts for outdoor and indoor designs are shown in Figure 7.



(a) Layout of outdoor direct coupled substation within GRP enclosure

b) Typical layout of indoor substation within brick building

Figure 7 – Typical substation layout (all dimensions are in mm)

ENA TS 35-1 Part 3 provides limiting dimensions for ground mounted substations with two different **HV** and **LV** terminal arrangements: i) **HV** and **LV** terminals are on opposite sides, ii) **HV** and **LV** terminals are on the same side. Figure 8 and Table 2 show the limiting dimensions for the two terminal arrangements. In addition to the ground mounted transformer types detailed in ENA TS 35-1, Part 3 a special “Tall type” transformer is deployed by the SP Energy Networks. The dimensions of the Tall type transformer are shown in Figure 9.

The limiting dimensions presented in Table 2, Figure 8 and Figure 9 shall be used as a guideline by the **SST Manufacturing Partner** to design an acceptable **SST** size. The manufacturing partner shall provide the estimated dimensions of their proposed **SST** design with realistic tolerances in the tendering response.

As specified in Section 2.2 **LV Engine** aims to trial two **SST** topologies:

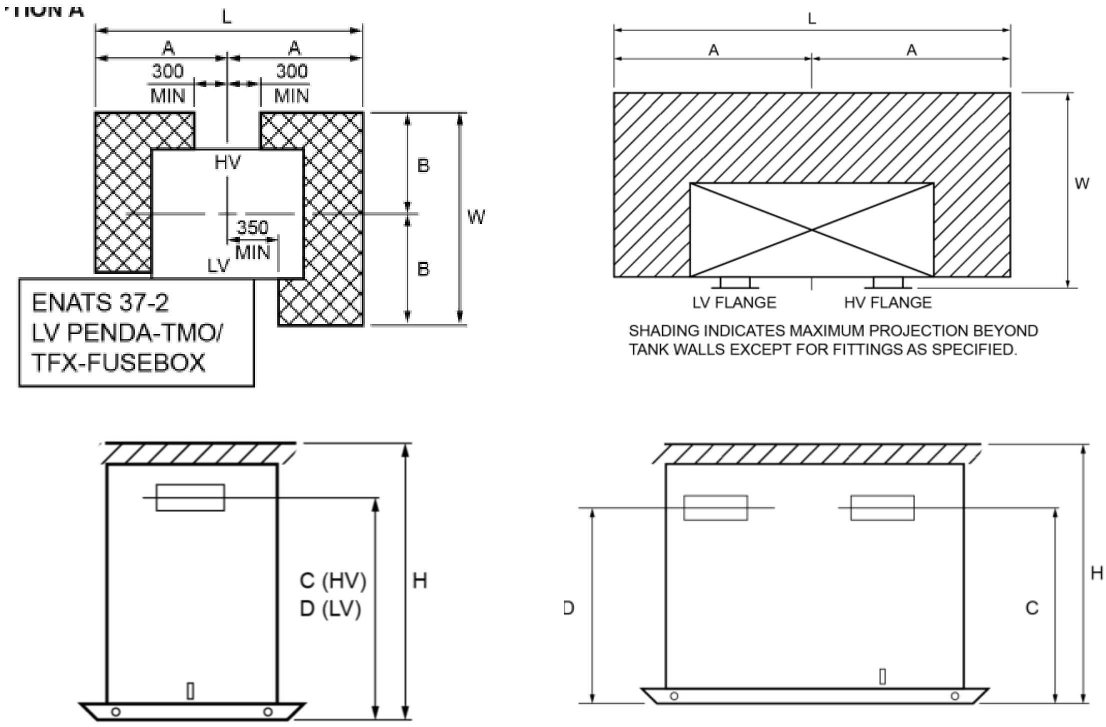
- Topology 1 shall be suitable for both indoor and outdoor arrangements shown in Figure 7. Topology 1 shall be a compact design that can be fitted within the majority of the existing substations.

- It is also desirable that Topology 2 is suitable for both indoor and outdoor applications. It is very likely that Topology 2 to be trialled only within brick built substations (indoor environment) during **LV Engine** project. Nonetheless, **SST Manufacturing Partner** shall describe the effort required to enhance Topology 2 design for outdoor applications beyond **LV Engine** project.

Table 2 – Limiting Dimensions for 500kVA ground mounted transformer (ENA TS 35-1)

	L (Max)	A (Max)	W (Max)	B (Max)	C (HV)	D (LV)	H (Max)
Figure 8 (a) - Ground Mounted Transformer with HV and LV terminals on opposite sides	1700	990	1220	710	1320	1320	1830
Figure 8 (b) - Ground Mounted Transformer with HV and LV terminals on the same sides	1900	1150	970	-	1320	1320	1750

All dimensions are in mm



(a) **(b)**

Figure 8 – Dimensions of typical ground mounted transformer

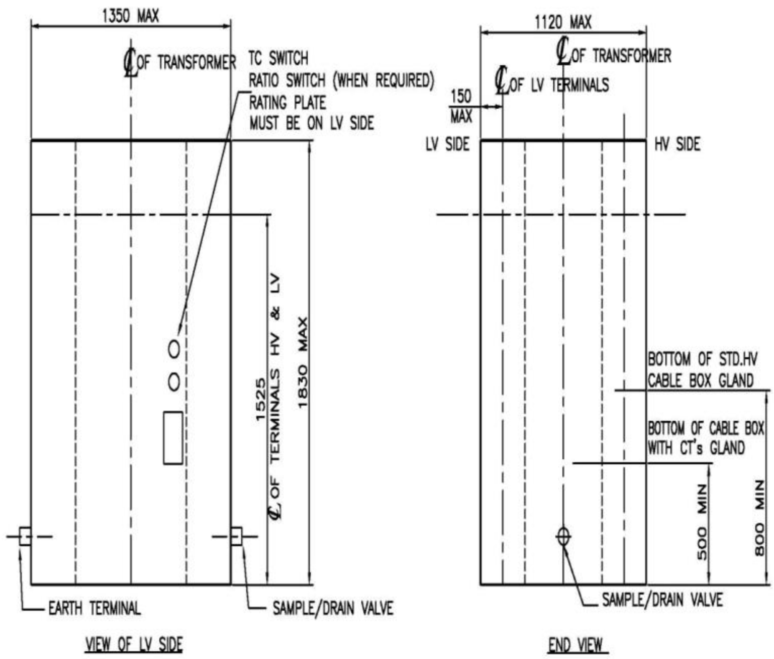


Figure 9 – Dimension of tall ground mounted transformer

2.11 Alarms and alerts

SST shall be able to identify the following operation status, as a minimum, and provide appropriate alarms and alerts:

- Internal **SST** faults/trip – Fault and trip alarms shall contain information about specific type of fault location and source of trip.
- Overheating conditions – The maximum temperature threshold which triggers this alarm shall be configurable
- Overloading – The maximum loading threshold which triggers this alarm shall be configurable
- Cooling system alarms – An alarm stage, to forestall a future trip is required.

2.12 Built in Monitoring requirements

SST shall be fitted with number of monitoring devices to provide following measurements:

- RMS voltage at all terminals
- Current, active power and reactive power at all terminals
- **Total Harmonic Distortion** at all terminals
- Voltage phase angles at **HV Primary Terminal** and **Secondary AC Terminal**
- Temperature measurement at hot spots inside **SST**

In addition to real-time monitoring capability, **SST** shall be able to determine and provide average values of monitored parameters over a configurable time period (as low as 1 minute) to **SCS** with appropriate time stamp.

All the measurement values shall comply with requirements specified by BS EN 61000-4-30.

2.13 Display

SST shall be fitted with appropriate LED display which can show, as a minimum, the following parameters:

- Status of **SST** (Active/Standby/Starting Up)
- Monitored parameters listed in section 2.12
- Alarms and alerts listed in section 2.11
- Overall loading of the **SST**

2.14 Operating losses

SST operation losses is an imperative criterion for evaluating the **SST** design. The cost of **SST** losses will be considered for the commercial evaluation of tender response. The **SST** losses data provided by manufacturing partners will be capitalised by **SPEN**, considering the losses cost coefficient specified in Table 3.

Table 3 – Losses coefficients cost

	% of nominal loading (500kW)					
	15%	25%	35%	50%	80%	100%
Losses coefficient (£/kW)	1,250	2,500	3,751	3,751	1,000	250

The following formula will be used to calculate the overall cost of a **SST** unit:

$$Total\ cost\ of\ a\ single\ unit\ SST\ (£) = Proposed\ unit\ cost\ (£) + \sum (L_i * C_i)$$

L_i : Losses at loading i (kW)

C_i : Losses coefficient at load level I (£/kW)

The **SST Manufacturing Partner** shall provide the **SST Efficiency** and **expected tolerances.** The efficiency shall include the operation of all the components of SST including the power electronics units, cooling systems, high frequency or low frequency transformers, auxiliary power etc.

SST Efficiency shall be provided for Topology 1 and Topology 2 of both Designs: Design Type A and Design Type 2 in the tendering response.

2.15 Normal Operating Conditions

SST shall be capable of delivering its **Core Functionalities** to the full extent in Normal Operating Conditions without causing any interruption to security, quality and continuity of supply to electricity customers in accordance with ESQCR. As a minimum, the conditions shown in Table 4 are considered the network's Normal Operating Conditions:

Table 4 – Network Normal Operation Conditions

Network variable	Normal variation range	
	Lower bound	Upper bound
System Frequency	47.0Hz	52.0 Hz
HV Network Voltage (% of nominal voltage)	85.0%	115.0%
LV Network Voltage (% of nominal voltage)	85.0%	110.0%
Unbalance HV Voltage (% of nominal voltage)	0.0%	3.0%
Unbalance LV Load	0.0%	100.0%
Total Harmonic Voltage Distortion	0.0%	8.0%
Design fault levels		
HV (11kV) network design 3-ph fault level	250MVA	
HV (11kV) network design 1-ph fault level	250MVA	
LV (0.4kV) network design 3-ph fault level	25MVA	
LV (0.4kV) network design 1-ph fault level	25MVA	

2.15.1 Total System Frequency range

Total System Frequency range is between 47.0Hz to 52.0Hz for 100% of the time. For the purpose of **SST** design, this range is considered as the normal frequency variations within the network. It should be noted that the Total System Frequency is between 49.5 to 50.5 for 95% of the time.

2.15.2 Voltage range

The voltage variation within **HV** network (11kV) is considered acceptable to be within 85% to 115% of the nominal rating.

The voltage variation within **LV** network (0.4kV) is considered acceptable to be within 85% to 110% of the nominal rating.

2.15.3 Unbalanced HV voltage

Network design standards, as specified in ER P29, allow 2% unbalanced phase voltage at **HV** networks (11kV). However, the unbalanced voltage can occasionally be as low as 3%. The 3% unbalanced phase **HV** voltage is considered acceptable in Normal Operation Conditions.

2.15.4 Unbalanced LV Load

Unbalanced load is normal in **LV** networks and it can be as high as 100% between any 2 phases i.e. one phase fully loaded and the other phase at no-load. It is required that **SST** continues its normal operation with extreme load imbalance conditions in the **LV** network.

2.15.5 Harmonic voltage distortion

As specified in BS EN 50160, the Total Harmonic Distortion in the network can be up to 8% under the normal operating conditions. **SST** shall operate normally under this harmonic voltage distortion level at either, or both, the **HV Primary Terminal** and the **LV AC Terminal** together with individual harmonic orders limits given in Table 5.

Table 5 –Values of individual harmonic voltages at the supply terminals for orders up to 25 given in percent of the fundamental voltage, as specified in EN50160

Odd harmonics				Even harmonics	
Not multiples of 3		Multiples of 3			
Order h	Relative amplitude u_h	Order h	Relative amplitude u_h	Order h	Relative amplitude u_h
5	6,0 %	3	5,0 %	2	2,0 %
7	5,0 %	9	1,5 %	4	1,0 %
11	3,5 %	15	0,5 %	6 … 24	0,5 %
13	3,0 %	21	0,5 %		
17	2,0 %				
19	1,5 %				
23	1,5 %				
25	1,5 %				
NOTE No values are given for harmonics of order higher than 25, as they are usually small, but largely unpredictable due to resonance effects.					

2.15.6 Fault levels

System fault levels shall be constrained within the design limits for each voltage level which are summarised in Table 4. Design fault levels shall be considered in overall **SST** component design and protection requirements (for example internal protection).

2.16 Operation under over voltage and under voltage conditions

Voltage dips usually occur in the **HV** (11kV) network due to the fault or energisation of particular devices. Voltage dips due to fault can be severe and depending on the proximity of the fault location, may temporirly reduce the voltage at the **HV Primary Terminal** to as low as 1.0% of the nominal voltage for around 3.0 seconds. As a minimum, **SST** shall remain stable and connected to the network (no need to restart) during this period. However, it is acceptable that:

- The temporary voltage dip at the **HV Primary Terminal** is transferred to the **AC Secondary Terminal** with no worse than equivalent voltage drop considering nominal conversion ratio (11.0kV/0.4kV).

- **SST** switches to standby mode in which it does not supply (no active or reactive power) to **LV** network with no **Voltage Control** at the **AC Secondary Terminal** when the voltage dip is greater than 20% of nominal **HV** voltage and lasts for longer than 3.0 second.

SST shall remain stable and connected to the network during any temporary voltage dip that occurs at the **AC Secondary Terminal** due to a LV network fault or energisation of particular devices.

Temporary overvoltage may occur in the **HV** network as a result of network asset switching or phase to ground faults at **HV** network. The phase to ground fault may cause overvoltage that is twice the nominal voltage (2 p.u) on the healthy phases and it lasts for the duration of the fault. **SST** shall remain stable and connected to the network (no need to restart in post-fault) during this temporary overvoltage, in addition:

- The temporary overvoltage at the **AC Secondary Terminal** shall not exceed 115% of nominal voltage as a result of overvoltage transfer from the **HV Primary Terminal**.

- It is acceptable that **SST** provides a permissive operation during temporary overvoltage between 120% to 150% of nominal voltage at **HV Primary terminal**. Details of permissive operation will be developed by **SST Manufacturing Partner** and shall be approved by SPEN before implementation.

- It is acceptable that **SST** switches to standby mode in which it does not supply (no active or reactive power) to **LV** network with no **Voltage Control** at the **AC Secondary Terminal** when the overvoltage is greater than 150% of nominal **HV** voltage and lasts for longer than 3.0 second.

The SST Manufacturing Partner shall recognise and consider all the voltage disturbances described in BS EN 50160 for desiging **SST** and selecting relevant equipment for installation on or connected to the distribution network to ensure **SST** remain stable, intact and operational during various voltage distrurbances.

It is desirable that **SST** provides transient voltage support by injecting/absorbing reactive power during transient voltage dip or overvoltage conditions within **Power Capability** of **SST**.

SST shall return to its normal operating conditions and deliver its **Core Functionalities** immediately after transient overvoltage or under voltage conditions are over.

2.17 Fail-safe

The **SST** shall have configurable default failsafe levels in case it fails to communicate with **SCS** or command received from **Control Engineer** remotely or locally. **SST Manufacturing Partner** shall provide a failsafe levels analysis to provide recommendations to SPEN which parameters shall be considered for the default failsafe operation. SPEN need to approve the failsafe settings before implementation by **SST Manufacturing Partner**.

2.18 Harmonic distortion

The harmonic emissions generated by **SST** at **HV** Primary Terminal and **LV** AC Secondary Terminal shall comply with the limits specified in ER G5/4 for 0.4kV and 11kV system voltage levels.

The harmonic voltage distortion contribution from **SST** shall not cause THD and individual harmonic orders to exceed the planning levels specified in ER G5/4 for 0.4kV and 11kV system voltage levels at the AC Secondary Terminal and the **HV** Primary Terminal, respectively.

The harmonic emissions and harmonic voltage distortions shall be measured by the manufacturing partner at the time of installation for the harmonic orders up to 50^{th} in accordance with methodology specified in IEC 61000-4-7.

2.19 Short term thermal rating

It is desirable that **SST** can provide short-term (> 1.0 minute) overload capability. The short-term overload capability may be required for short term demand increase due to **Cold Load Pick-Up** or load transfer between substations.

The manufacturing partner shall provide the short-term overload capability of their solution in the tender response.

2.20 Insulation requirements

The insulation requirements of **SST** shall comply with IEC 60076-3, IEC 62477-1, and IEC 62477-2 where applicable. Table 6 shows the insulation requirements for conventional transformers as specified IEC 60076-3.

Table 6 –Insulation requirements for conventional transformers

Highest Voltage for equipment (kV r.m.s)	**Nominal voltage** (kV)	**Rated lightning impulse voltage** (LI) (kV Peak)	**50 Hz withstand voltage** (kV r.m.s)
1.1	0.40/0.23	-	3.0
7.2	6.6	60.0	20.0
12.0	11.0	75.0	28.0

The SST **Manufacturing Partner** shall be responsible for carrying out all the insulation coordination studies according to IEC 60071 and providing results to SPEN.

All the clearances between phases, phase- earth and phase to neutral at the terminations and between them shall comply with IEC 60076-3-1 and IEC 62477 where applicable.

2.21 Shut down and Start up

Start up and shut down process of **SST** shall not be associated with any hazard or safety risk. The **SST Manufacturing Partner** shall consider the necessary interlocks, alarms and protection procedure required to be in place for a safe shut down and start up.

Start up and shut down of **SST** shall have no impact on service life time or operation and maintenance of **SST** i.e. Impact on hardware and software of **SST** shall not be acceptable.

SST shall be able to start up and shut down in all following options:

- Locally, by operation personnel on site locally
- Remotely, by **Control Engineer** sending necessary commands
- Automatically, by defining start up or shut down logics e.g. **SST** starts up after **HV** network is energised and stable **HV** voltage is applied. The **SST Manufacturing Partner** shall develop the logics and request approval from SPEN before implementation.
- Receiving appropriate command from **SCS**

SST shall be capable of starting up immediately after receiving commands in one of the aforementioned options. No delay shall be required following multiple consecutive start up and shut down events.

A soft start up for **SST** is required and start up shall not result in Inrush Current or voltage depression in **HV** network worse than those caused by conventional transformers. The existing **HV** protection settings usually allow some level of Inrush Current due to magnetisation of conventional transformers (typically 10 times of transformer rating for 100ms), hence, starting up **SST** shall not trip **HV** protection.

The time required for **SST** start up process from fully de-energised condition to fully live and functional condition shall not exceed 5.0 seconds.

In case any battery is required for **SST** start up, it shall be provided by the **SST Manufacturing Partner**. The battery shall be fitted within the **SST** enclosure with all the necessary charging equipment.

2.22 Enclosure

All marshalling kiosks, enclosures and control cabinets shall be manufactured from stainless steel of the appropriate grade or 2.5mm thick galvanised steel plate. Cabinets, enclosures or cubicles made up of plastic are not acceptable. The design shall take suitable precautions to ensure condensation and corrosion are prevented, and there is adequate ventilation and free air circulation over all equipment. For outdoor design applications, the degree of protection required for the accommodation against the ingress of solid foreign objects and water shall be at least to IP 55 according to IEC 60529. When any doors are open, the degree of protection for persons against access to hazardous parts shall be at least to IP 2X according to IEC 60529. The door shall have adequate oil and weather resistant gaskets fitted to ensure a weatherproof seal.

Tanks, conservators, pipework etc. shall be cleaned by an appropriate means and treated with weather resistant paint to C5, design life/durability VH, as detailed in ISO 12944.

2.23 Handling

The **SST** design shall allow movement in a stable and safe manner. The design shall allow movement to be achieved using a pinch bar and rollers, or any handling methodology approved by SPEN.

The **SST Manufacturing Partner** shall provide a detailed instruction document and training for handling the **SST** in a safe manner to prevent any staff injury and damage to the equipment.

All parts within **SST** shall stay stable and fixed securely during handling and installation.

2.24 Labelling

All enclosures shall be marked in accordance with Clause 5-10 of IEC 62271-1 as referred to in ENA TS 50-18.

A label showing black letters on a white background shall be affixed adjacent to each fitting and terminal, to indicate the function. In the case of a relay, if there is a visible internal label, no additional label is required.

The **SST** enclosure shall be identified by a non-corroding, indelibly marked data plate giving the following information specified in IEC 60076-1, and marked in accordance with ENA TS 50-18:

Safety-warning labels shall comply with BS 5499 referenced in ENA TS 50-18.

2.25 Terminations

The layout of the **SST** terminations shall be approved by SPEN through the design process and it is desirable that Primary (11kV) AC terminals are on the opposite side of Secondary AC (0.4kV) Terminal and Secondary DC Terminal. However, SPEN may consider alternative terminations arrangements proposed by the **SST Manufacturing Partner**.

The exact location of terminals shall be finalised in the design stage by the **SST Manufacturing Partner** and that should be approval by SPEN. The design shall provide appropriate interfacing with other **HV** and **LV** equipment within substation.

All terminals shall be marked and labelled in accordance with ENA TS 50-18.

2.25.1 HV Termination

For connection of **HV** cables, **SST** shall be fitted with a dry type cable box complying with ENA TS 12-11, and suitable for the termination of XLPE single core cables (typically for up to 300mm2 cross section).

Associated cables have a Cu wire screen of 35mm2, and the cable box shall have a tin plated Cu screen termination bar with M12 hex head fixing screws to accept the earth screen lugs, fixed to the inner face of the gland plate on the outside of the cables. The cable screen termination bar shall provide a means of externally connecting the main substation earth using an M12 fixing. **SST Manufacturing Partner** shall ensure that cable boxes offered have adequate space for the termination of HV cables. It is recommended that cable box depth is greater than 270mm and that distance from centre of bushing to the point cable can be worked on (bottom of cable box / top of CTs if installed) is greater than 450mm.

The gland plates shall be non-magnetic. Where provided, split gland plates design shall ensure that all parts are effectively earthed. The gland plate shall be supplied with either suitably sized heat shrink glands or with non-metallic mechanical compression glands of size and type to approval, to suit cables with an outside dia. of 28mm – 32.2mm.

Transformers shall be fitted with HV bushings of the outside cone, plug-in type, rated for 250A, with sliding contact mechanism and interface type A, as defined in BS EN 50180-1, Table 14. Connector bail holders shall be provided. Transformers shall use an HV bushing flange complying with type E to BS 2562.

2.25.2 LV AC and DC Terminations

For connection of **LV** cables, **SST** shall be fitted with a dry type cable box complying with ENA TS 12-11, and suitable for the termination of XLPE single core cables (typically for up to 740mm2 cross section).

2.26 Interface with SCS

SST shall be fitted with appropriate data management and communication unit to communicate directly with **SCS** via a secure hardwired or wireless communication solutions as specified by SPEN in collaboration with **ICS partner**. **SST** data management and communication unit shall send or receive, as a minimum, the following information:

- All measurement data specified in section 2.12 together with relevant time stamps. The device shall use a network time synchronisation to ensure that events and logs are time-stamped accurately.
- Necessary handshaking and device authentications signals
- Set points of controlled parameters determined by SCS that includes:
    a. **LV Voltage Set Points** for each phase and corresponding tolerances
    b. **DC voltage set points** and corresponding tolerances
    c. **HV voltage set points** and corresponding tolerances
    d. **Thermal loading set point** and corresponding tolerances
    e. **LV AC Active Power set point** and corresponding tolerances
    f. **LV AC reactive power set point** and corresponding tolerances
- Alarms, alerts and SST status

The **SST Manufacturing Partner** shall provide **SST** communication and data management unit that supports different protocols e.g.

- IEC 60870-5-104, IEC 61850, DNP3, 101 serial connections
- MQTT, AMQP, TCP, CoAP, WebSocket, HTTP(S)

The exact communication protocol and communication solution shall be approved by SPEN in collaboration with the **ICS Partner.**

All communication and data management equipment shall be appropriately fitted within **SST** enclosure.

2.27 Earthing

The **SST** design shall comply with ENA TS 41-24 to facilitate the requirements for earthing system in the substation and ENA TS 37-2 where appropriate.

Any metalwork enclosing and supporting associated with **SST** which is not intended to serve as a phase conductor shall be connected with earth. This is also applicable to any auxiliary equipment. Appropriate termination for connection to earth through a 70mm^2 cable shall be considered in the **SST** design.

SST LV AC Secondary Terminal shall be connected to a 4-wire system consisting of the 3 phases and neutral wire. The **SST** neutral point provided at the **LV AC Secondary Terminal** will be connected to the neutral bar in **LV** pillar.

SST LV DC Secondary Terminal shall be connected to a 3-wire system with one wire dedicated to neutral point.

The earthing point of the **LV** DC and **LV** AC neutral point may be the same in the **Secondary Substation**. **SST Manufacturing Partner** shall adapt the **SST** design based on this arrangement and advise on any issue that common earthing may cause considering their proposed design of **SST**.

2.28 Protection requirements

It is envisaged that the prospective fault level at LV network significantly reduces if **SST** is deployed. This may result in non-compliance with BS 7671 which requires clearing any LV fault from supply side within 5 seconds. Traditionally LV networks in the UK are protected by fuses:

- Cut-out fuses providing protection just before the customer premises and their internal metering/protection equipment. These are typically 100 A fuses with the characteristic shown in Figure 10.

- Fuses protecting LV circuits located on the fuseboard in a **Secondary Substation**. These are typically 400 A fuses with the characteristic shown in Figure 11.

SPEN recognise that low fault infeed capability of **SST** may impose a significant challenge to the meet the protection requirements, hence, **SST Manufacturing Partner** is required to provide a **SST** design that meet the protection requirements within **LV** network. SPEN is planning to replace the existing **LV** feeder protection (400A fuses) with **LV** circuit breakers (**LV**CB) which allow a flexible protection setting input. However, the new **LV** feeder protection grading need to consider the operation time of existing 100A fuses and should be fitted within the area (between Green and Red lines) shown in Figure 11. **SST** shall be capable of providing adequate fault infeed to allow the new protection settings for the **LV** feeder.

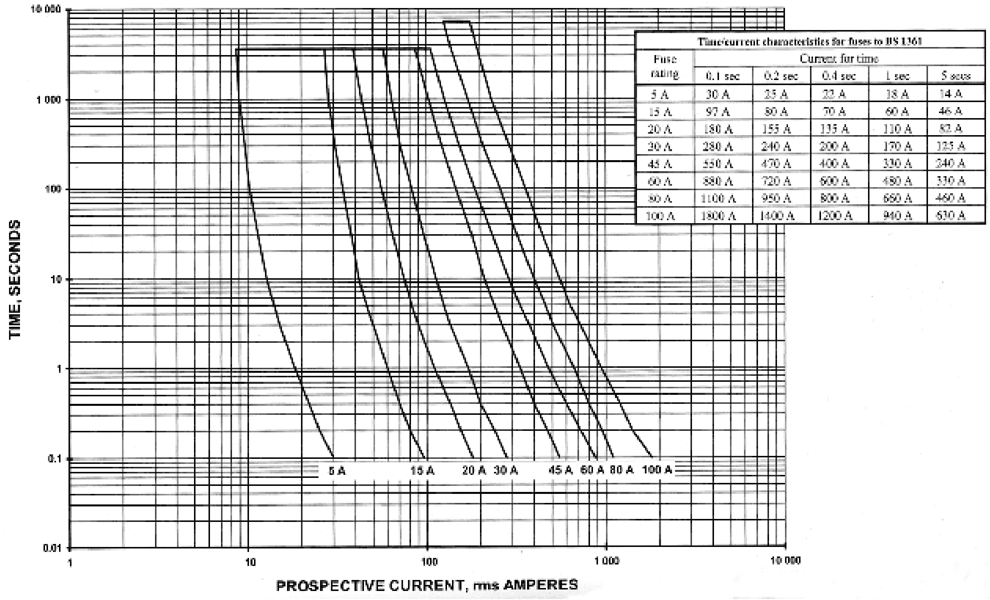


Figure 10 – Fuse time-current characteristics for current ratings 5A-100A fuses

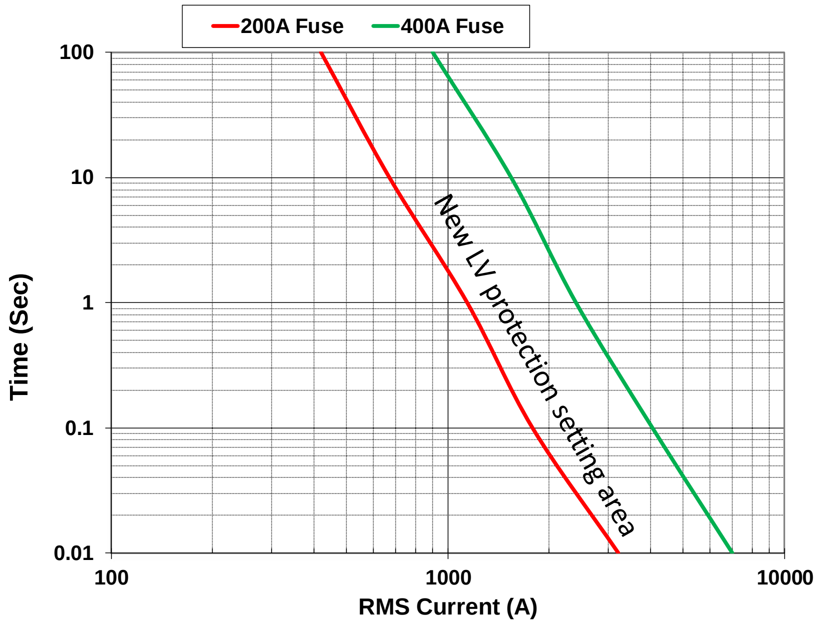


Figure 11 – Fuse Time-current zones for current ratings 200A, and 400A

Traditional **HV** protection at **Secondary Substations** will unlikely provide sufficient protection against **ST** internal faults. **SST** shall be capable of identifying the internal fault immediately and protect its internal components together with providing a tripping signal to the **HV** circuits breaker (e.g. Ring Main Unit).

SST will be operated in a **Meshed Network**; therefore, any internal fault may result in fault current contributions from **HV** network and **LV** network to the **SST** internal faulted point. As the fault infeed from **LV** network can be significant, **SST Manufacturing Partner** shall provide a solution to protect the **SST** against **LV** infeed for internal faults.

Any CT and PT required for detecting and protecting internal faults shall be considered in the **SST** design and fitted within **SST** enclosure.

2.29 Drawings

In addition to those specified in section 1.12, **SST Manufacturing Partner** shall provide, as a minimum, the following drawings:

- Foundation plan drawing and outline drawing for each type of STT, Type 1 and Type 2.
- General arrangement of cable entry boxes and disconnecting units (if applicable).
- General arrangement of enclosures/cabinets
- Arrangement of neutral bushing and all the terminals.
- Internal arrangement drawings covering all equipment **HV** side, **LV** AC and **LV** DC side and plan view.
- Rating and diagram plate showing connections of **SST** and associated equipment and the relation of leads taken out of the **SST** enclosure.
- Details and diagram of connections of protection and monitoring devices.
- Details diagram of communication and data management unit
- Schematic diagram of alarms, trips and indications.
- All wiring diagrams.
- Outline drawing showing the **SST** accommodation arrangement for transportation to site

2.30 Test requirements

2.30.1 General

The equipment shall be subject to all routine, type and special tests required in accordance with the latest relevant IEC or BS EN standards, where appropriate.

SPEN shall have, at all reasonable times, access to inspect and examine the materials and workmanship of portions of equipment during manufacture and testing.

The **TEST Plan** shall be prepared by the **SST Manufacturing Partner**. SPEN will review and provide any modification required. SPEN requires at least 2 months' notice, for witnessing factory acceptance tests in order that SPEN representative may be present.

The **Test Plan** shall detail the connections required for the test, the test methodology and the voltages to be supplied to the **SST** during the specific test. Full details of the test methodology shall be supplied to SPEN in the **Test Plan**.

The factory inspections and testing shall in no way relieve or reduce the responsibility and liability of the **SST Manufacturing Partner** for any defects found after the delivery and installation of the **SST** and its associated equipment.

If the equipment fails a test, the **SST Manufacturing Partner** shall bear all costs associated with forensic investigation, rectification works, reinspection and re-testing including the cost of witnessing of all re-testing.

The **SST Manufacturing Partner** shall carry out the site tests after delivery and installation of all the components of the **SST** to verify proper operation and performance.

Any proposed variation of tests shall be subject to approval by SPEN.

The **SST Manufacturing Partner** shall provide test reports to SPEN within 2 weeks of the test completion. That includes all the test results, measured parameters and raw test data in an agreed format with SPEN.

The **SST Manufacturing Partner** shall make available to the SPEN all information, test data, and evidence relating to the test results including failure or cause of the non-compliance. In case of any failure or damage to equipment, the **SST Manufacturing Partner** shall repair the failure (or resolve the non-compliance) and shall replace any part that may have been damaged or contaminated.

2.30.2 Summary of tests

Individual major components of the **SST** shall be tested in accordance with the relevant equipment standards. This shall include semiconductor devices, DC capacitors, high frequency transformers, etc.

SPEN will send their representative to witness the tests of the complete **SST**.

The **SST Manufacturing Partner** shall propose the **Schedule of Test** in the tendering response, however, as a minimum, following tests shall be conducted by the **SST Manufacturing Partner**:

1. Energisation
    - HV Terminal energisation
    - LV AC energisation
    - LV DC energisation
2. Voltage Ratio
3. Power flow
    - Power supply only LV AC
    - Power supply only LV DC
    - Power supply both LV AC and LV DC
    - Reverse power flow control LV AC and LV DC
4. Power capability
    - Reactive power
    - Active power
    - Power factor range
5. Vector Group
6. Short-circuit withstand
    - 3ph short circuit at LV terminal
    - 3ph short circuit at HV terminal
    - Pole to Pole fault at DC terminal
    - Internal short circuit
7. Protection capability
8. Losses
9. Dielectric
10. Voltage control
    - LV DC voltage control
    - LV AC voltage control
    - HV voltage control
11. Power flow control
    - LV AC supply power control
    - LV DC supply power control
12. Operational performance
    - Sound Power
    - LV unbalance load operation
    - HV unbalance voltage operation
    - Harmonic injection
    - Radio frequency interference
    - Temporary loading capability

Any additional test required to be considered shall be declared in the tender response.

Section 3. Technical & Functional specifications of Smart Control System

3.1 General requirements

A **Smart Control System** (**SCS**) shall provide **Control Parameter** set-points to **SSTs** and control **LV** network configuration (where required) to improve utilisation of network assets, release network capacity, reduce network losses and ensure that electricity customers are delivered voltage within **Control Parameter** limits as specified by the **Control Engineer**.

A **Smart Control System** shall be capable of:

- Aggregating the data communicated from various monitoring points in the **LV** network. This includes the monitored parameters from neighbouring **Secondary Substation**s, specific locations within the **LV** circuits e.g. link boxes; and from domestic **Smart Meter**s;
- Cleansing recorded data, by identifying and correcting obvious and systematic errors in monitored input data;
- Determining the **Control Parameter** set points for **SST**s and status of controllable switches in the local **LV** network; using the most recent and historic data available and intelligent voltage and **Power Flow Control Algorithm** for enhanced network operation;
- Short-term forecasting network state based on historic assets loading and nodal voltages to inform **Control Parameter** change decisions
- Securely relaying the **Control Parameter** signals to **SST**s and controllable switches immediately as described in section 3.7.
- Providing reliable and robust performance under normal communication system operation and being resilient to failure of communication and monitoring systems;
- Using Artificial Intelligence (AI), machine learning and state estimation techniques to develop a numerical representative model of the local network and demand by considering the historic **Monitored Data** and limited fixed network data inputs. This capability can support the **SCS** decision making process for enhanced network operation and also operation under communications failure conditions; and
- Operate the network with the primarily considering branch loading and node voltage constraints and secondarily in accordance with optimisation objective as set by the **Control Engineer**;
- Override control functionality, allowing a network to operate with supplied power and/or voltage set-points upon request by **Control Engineers**.

3.2 Specification Scope

This tender comprises of the software and hardware components required to interface and control **SST**s within **LV Engine** schemes, but excludes communications and network monitoring equipment. However, the **ICS Partner** shall work closely with **LV Engine team** and **SST Manufacturing Partner** to provide recommendation on detailed technical specifications of monitoring and communication requirements.

3.3 System Architecture

The exact system architecture of an **SCS** shall be developed by the **ICS Partner.** However, it is envisaged that an **SCS** will consist of a regional smart controller and a local smart controller. The level of intelligent and computation required in the regional level and local level shall be designed by the **ICS** by considering the required data transmission, redundancy, overall system reliability and optimum performance of system. A general representation of an **SCS** is shown in Figure 12.

[redacted]

Figure 12 – A general representation of SCS architecture

The proposed solution by the **ICS Partner** shall support:

- Confidentiality – shall include encryption of data both in transit and at rest
- Integrity – shall include the prevention of unauthorised third-party modification of data which could affect response systems or control room reaction
- Availability – Shall include a secure, high availability architecture at all levels and ensuring the service will continue to function in the event of scenarios including:
    - Device / component failure
    - Device management operations (e.g. firmware updates, software releases, configuration changes)
    - Communications link issues
    - Denial of Service attacks

The interface between any local smart controller and **SST** could be through hardwired or local wireless connectivity (hardwired is more likely to be reliable) to the communication and data management unit of **SST.** The exact connectivity shall be recommended by the **ICS Partner** considering solution with low risk of communication failure between **SCS** and **SST**.

The smart regional controller could be responsible for supplying the local controllers with the relevant **Control Parameters**. Equipped with **Control Algorithm**s and considering the values of recent and historical measurements, the smart regional controller could determine the **Control Parameter**s set points to be observed by each **SST**. The regional smart controller shall then transmit the relevant **Control Parameters** to each local controller.

The smart regional controller could request **Monitored Data** from the metering devices connected the **LV** network at an appropriate frequency.

The smart regional controller may be located remotely, such as at a **Primary Substation** or housed in SPEN corporate network. If the smart regional controller is unavailable to a smart local controller, the smart local controller shall be able to provide revert to the default failsafe configuration and operational modes.

A **SCS** and its components shall support network time synchronisation to ensure that events and logs are time-stamped accurately.

The standard for Operating Systems is to use Redhat Linux 7.3 onwards or Windows 2016 with SQL Server or Oracle 12c databases. Application servers (if required) shall be based on Redhat EAP (JBOSS) for java based systems.

3.4 Fail-safe

The **ICS Partner** shall conduct a full failure modes and effects analysis to define the fail-safes which shall be approved by SPEN before implementation.

3.5 Scalability

The **SCS** solution design as implemented by the **ICS partner** shall be capable of operating a minimum of 5 **LV Engine Scheme**s (minimum of 6 **SST**s) which may be situated in different locations within a geographical area as described in Section 1.10.

The **ICS partner** shall propose a scalable **SCS** to facilitate roll out of the **LV Engine** solution and the connection of further **SST**s.

The ICS partner shall state the limitation of scalability with their proposed design in terms of the maximum number of **LV Engine Scheme**s it may support.

The **ICS partner** shall provide the breakdown hardware and software cost for integrating any additional **SST** to the proposed **SCS** solution.

3.6 SST capability model

The **ICS Partner** shall design an **SCS** that is able to consider the full functionalities and limitations of **SST**s to ensure the **Control Algorithm**s determines feasible values for **Control Parameter**s.

The valid **Control Parameter** range defining the functionalities and limitations of **SST** within the **SST** model shall be configurable by the **Control Engineer**. These parameters shall be configurable for every **SST**s individually to allow integration of **SST**s with different capability model as they may be supplied by different manufacturers.

3.7 Interface with SST

SCS shall be able to communicate with **SST** directly via a secure hardwired or wireless communication solutions which will be specified by SPEN in collaboration with **SST Manufacturing Partner**. As a minimum the following information shall be communicated:

1- All measurement data by **SST** specified in section 2.12 together with their time stamps.
2- Necessary handshaking and device authentications signals
3- Set points of controlled parameters determined by **SCS**
4- Alarms, alerts and **SST** status

SCS shall be able to communicate via one of the industry standards protocols which need to be approved by SPEN:

- IEC 60870-5-104, IEC 61850, DNP3, 101 serial connections
- MQTT, AMQP, TCP, CoAP, WebSocket, HTTP(S)

3.8 Functional Requirements

LV Engine will demonstrate the performance of **SST**s in different network arrangements specified in the **LV Engine Schemes**. **SST**s may operate within a **Radial Network** or a **Meshed Network**. The configuration of the network may dictate a different control mode and limitations on **Control Parameter**s of the **SST**. An **SCS** shall be able to recognise the current state of network configuration and asset connectivity by analysing the recent data received from various monitored nodes without manual intervention.

The **Intelligence and Control System Partner** shall work closely with **SST Manufacturing Partner** to identify the possible **SST Control Mode** of operations. As a minimum, the **SCS** shall be capable of providing **Control Parameter**s to achieve the primary objectives:

- **Power Flow Control**: The ability to **Load Share** between **SSTs** and/or conventional substations (see section 3.8.4) and maintain current loadings within equipment constraints.

- **Voltage Control**: Ensuring that all nodes within the **HV** AC, **LV** AC and **LV** DC **Controlled Zone**s are within the defined constraints (see section 3.8.2, 3.8.3).

The two objectives are not exclusive and an **SCS** shall be capable of providing **Control Parameter**s to fulfil both objectives simultaneously.

In addition to the primary objectives; an **SCS** shall be able to determine the **Control Parameter**s to optimise network operation as a secondary objective, as a minimum the following secondary objectives shall be considered:

- Optimisation of the network losses;
- Optimisation of line and transformer utilisation;
- Demand reduction or inflation (e.g. Demand Side Response) by **Voltage Control**

The **ICS Partner** shall provide the list of objectives functions which may considered in their proposed solution.

It shall be possible for the **Control Engineer** to override the determined **Control Parameter**s and manually provide set points.

3.8.1 Response Time

It is required that an **SCS** is able to determine **Control Parameter** set points in less than 10 seconds after receiving the input **Metering Data**. The **SCS** shall then determine a confidence level for the estimated node voltages and power flows with the prospective **Control Parameter**s, based on the quality and availability of the input data. If the confidence level is sufficient, then new **Control Parameter** set-point values shall be communicated to **SST**s. If the confidence level is insufficient, change in **Control Parameter**s shall be decelerated and communicated to **SST**s. The confidence level will be a **Control Parameter**, and the mechanism will be agreed with the **ICS Partner**. An **SCS** shall determine the **Control Parameters** periodically or at a request; the frequency of calculations shall be configurable and can be as low as 10 seconds.

3.8.2 Voltage Control Functionality

The **Control Algorithm** shall be capable of determining an optimum voltage set point for each phase on **AC LV Terminal** and **LV DC Terminal** of **SST**s on a real-time basis to ensure the voltage at all nodes within the **Controlled Zone**s is maintained within the defined voltage limits to fulfil the primary objective and optimised in accordance with secondary objectives.

The voltage limits (V_{lim}, max/min) shall be configurable **Control Parameter**s which can be set remotely or locally by the **Control Engineer**, allowing for more stringent limits than statutory requirements.

An **SCS** shall be capable of determining the extremes of measured voltage (V_{meas}, max/min) at any time for each group of nodes within the **Controlled Zone** using all available metered data from local and remote terminals. The headroom and legroom margins on nodes within the **Controlled Zone** can then be calculated. These margins are the difference between the operator defined limits (V_{lim}) and measured maximum or minimum values (V_{meas}). Figure 13 below illustrates a snapshot of voltage readings from metering points nodes within the **Controlled Zone**. The voltage data may be received from dedicated voltage measuring device and **Smart Meter**s connected at different phase and locations in an **LV** network.

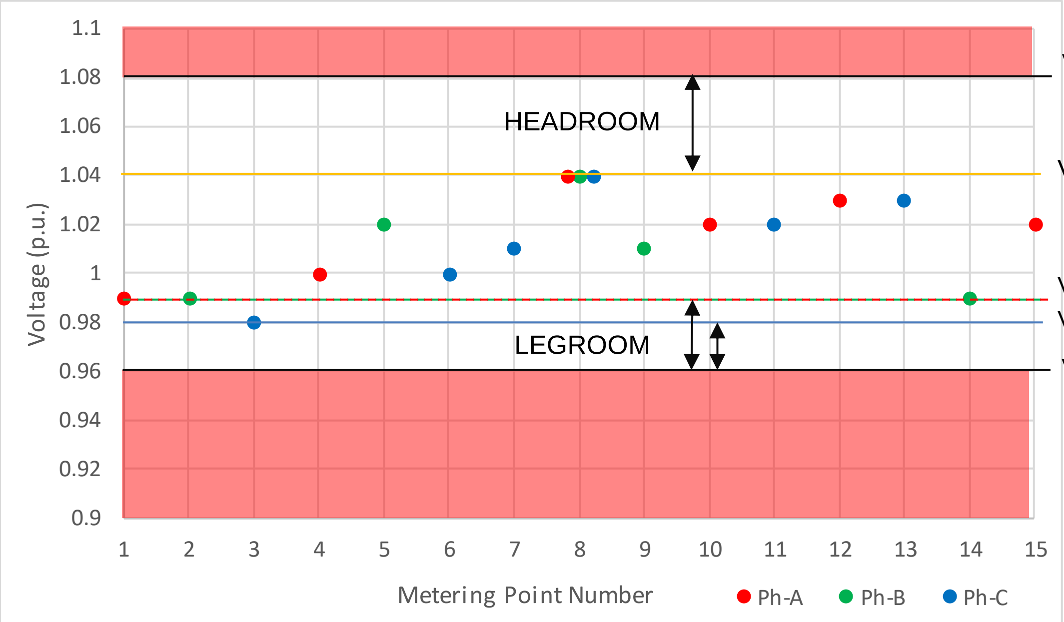


Figure 13 – LV Network Metering Point Voltage Data for Three Separate Phases

An **SCS** shall directly determine valid voltage set-point **Control Parameter**s for each phase on **LV AC Terminal** of **SST**s; using recent **Monitored Data**, relying upon as little feedback from remote metering and iterative adjustment as possible due to expectations of remote metering sampling rate and communication latency. In order to provide this functionality, the **SCS** shall be capable of using AI, machine learning or state estimation techniques together with recent and historic **Monitored Data**.

An **SCS** shall also determine the voltage set points based on configurable objective functions set by the **Control Engineer**. A primary objective could be to maintain a voltage within a defined tolerance of one of the voltage limit parameters; which may result in one or more node voltages being held at or close to one (upper or lower) limit, or the objective may be to provide the greatest margin for voltage step in either direction.

An **SCS** shall consider the maximum permissible voltage step change when calculating voltage set point **Control Parameter**s to the **SST**s. The maximum step where confidence in the future state is low, perhaps due to variability of load, 'deceleration' of any change to **Control Parameter** voltage set points may be required to prevent exceeding statutory voltage limits.

In addition to respect of voltage criteria, the **SCS** shall have due consideration of the thermal rating of other network assets (e.g. parallel transformers and interconnecting circuits). In a **Meshed Network** operation, the voltage variations will have an impact on Active Power and Reactive Power flows. Active Power and Reactive Power flows which unnecessarily contribute to loading of the assets and losses shall be minimised based on the overall objective functions. The **Voltage Control Algorithm** of **SCS** shall be able to minimise the losses and respect thermal rating of assets and voltage criteria.

An **SCS** shall be capable of providing both continuous (ramp up or ramp-down) voltage and voltage step change regulation set points to **SST**. **SCS** shall consider the limits in voltage change at **LV** and **HV** networks as specified in BS EN50160. The voltage step change shall be limited to 3.0% of nominal voltage within 1.0 sec. **SCS** shall consider a configurable minimum delay time (in second) between two subsequent voltage step changes.

3.8.3 HV Voltage Support Functionality

The **SCS** shall use the innate capabilities of **SST** power electronics to inject or absorb reactive power to/from the **HV** voltage independently of the load supplied to **LV AC Terminal**. The **HV Voltage Set Point** shall be configurable to be a fixed value or can be optimally determined considering the monitored voltage points in of **HV** network, it is understood that the capacity for optimisation of the **HV** network voltage will be limited; and that meeting the **LV** demand is the priority.

It is required that **SCS** shall allow **Control Engineer** to manually dictate the desired kVAr level or voltage set point at the **HV** interface remotely via manual override.

The **SCS** shall be configurable to accommodate **HV** voltage support or other **LV Engine Core Functionalities**.

3.8.4 Load sharing control functionality

When operating a **Meshed Network**, the **SCS** shall be capable of determining active and reactive power set points for each **SST** within the network; to optimally share load between substations in coordination with primary and secondary objectives set by the **Control Engineer**.

SCS shall consider metered voltage data (as described in section 3.12.1) from local and remote locations to determine the optimum power sharing between **SST**s and conventional transformers. will be available.

The **Load Sharing** function of the **SCS** shall be capable of determining active power, reactive power, voltage angle and voltage magnitude set points for **SST**s. There are dependencies between the aforementioned parameters, therefore changing one parameter may have impact on requirements of the other parameters. It is crucial when an **SST** operates in a **Meshed Network**, the **Load Sharing** and **Voltage Control** functionalities shall operate coincidently.

The **Load Sharing** algorithm shall:

- Have due consideration to thermal limitations of parallel transformers and interconnecting circuits.
- Determine the most appropriate status of **LV** network switches (open or close) e.g. switches which are currently at **NOP** and **LV** feeder circuit breaker. Switch status modification may be required to constrain the loading on transformers in neighbouring substations to be within a thermal rating.
- Incorporate the **Voltage Control** functionality by modulating voltage magnitude and reactive power output.
- Determine the appropriate set points to match the voltage magnitude and phase difference across open points prior to closing a switch to prevent reactive power flow in the interconnection and minimise voltage step change. It is likely that a synch check switches which can include tests for voltage magnitude and phase angle difference will be used in the **Normally Open Points**.
- Use metering data and relying upon as little feedback from remote metering and iterative adjustment as possible due to expectations of remote metering sampling rate and communication latency. In order to provide this functionality, the **SCS** shall be capable of using AI, machine learning or state estimation techniques together with recent and historic **Monitored Data**.

3.8.5 Network and Load Characterisation

An **SCS** shall be capable of estimating the voltage profile of and power interchanges within a network considering currently available and historic metered data and network configuration.

The resulting numerical model shall be determined by the **SCS** which will characterise the time variance of feeder element current flow and node voltages. The model shall be continuously improved as new metering data is received.

An **SCS** shall be required to use state estimation and/or artificial intelligence (AI) techniques such as machine learning or heuristic algorithms.

This characterisation shall be used to support the network optimisation functionality but will be critical for continuous operation in the event of loss of communications; where metering data may only be available from a sub-set of nodes or there may be no metering data available at all.

Some network electrical data (network connectivity, impedance, load etc) can be available before commissioning and operation to support numerical model development of trial sites, however, it should be noted that some of the data may be missing or may not be accurate. The **ICS Partner** may use the network data for initial training of the AI or demonstration of **Control Algorithm** in each scheme.

The **SCS** shall be able to run a period of learning before network optimisation routines would be employed and before any **SCS** was required to operate autonomously in absence of remote metering. Any historic and/or typical current and voltage metering which has been recorded in advance of installation will be available to aid the learning process.

3.9 IT requirements

3.9.1 Security requirements

An appropriate security architecture model shall be presented to SPEN during the design phase for approval. Critical points of communication and security measures shall be highlighted by the **ICS Partner.** The final security architecture and requirements shall be discussed and agreed with SPEN.

Access to **SCS** parameters, data and control interfaces shall be limited by role-based access control (RBAC). The rights to connect to, communicate with and manage devices shall be limited to named personnel or groups of authenticated users. The actions permitted and roles will be agreed at design stage with the successful **ICS Partner.**

User Identity shall be authenticated using Single Sign On such as Lightweight Directory Access Protocol (LDAP) or Microsoft Active Directory. **SCS** Devices shall be able to carry out authentication using digital certificates, and authorisation of actions (e.g. connect, send events etc.). This shall be enforced using associated Role Based Access Controls which are configured for the device. Revocation of access for the device, for example during the decommissioning process (e.g. End of Life or due to maintenance), shall also be possible.

Further validation of certificates shall occur prior to any control action which could affect network operation. Any control actions taken by a device or user shall also be recorded within an event log (audit trail). The audit trail (log) shall be available for authenticated users to view, and search.

The data communicated shall be secured and encrypted. Any HTTP services shall use TLS v1.2 or higher (forced use and optional). File transfer / remote file systems for data access shall require SSH File Transfer Protocol (SFTP). Alternatively, or in addition to this, VPN connection will be accepted.

Inclusion and checking of signatures shall ensure the integrity of the message sent before processing (e.g. set point information).

The solution shall be resilient against common 'cyber' attacks such as Denial of Service (DoS), Spoofing and Man-in-the-Middle (MITM).

The solution shall be hardened against potential security vulnerabilities which are subsequently found in any bespoke or dependent software, library, module, operating system etc.

All the components of the **SCS**, especially local devices in the **Secondary Substations**, shall be physically secured to prevent any unauthorised access.

3.9.2 Software and firmware maintenance

The **ICS Partner** is required to provide software patches and firmware updates as necessary. It shall be possible to install such patches remotely and from a local interface. It shall be possible to quickly deploy these updates and configuration changes to a single device or at scale. The code signature of any update shall be verified by the remote device prior to any update.

The solution shall maintain availability of service during updates to software, firmware or configuration; and during other routine maintenance activities.

The solution shall have the ability to rollback software and firmware changes; and operational configuration parameters should a change result in unexpected behaviour.

Any changes to the software or firmware shall be considered an auditable control action; and the status of any software push shall be confirmed by message to a remote user and recorded within event logs.

3.9.3 Storage

SCS shall have the storage capability at both the local and regional level to store historic **Monitored Data** and calculated set points. The store data can be used for any fail-safe operation in case of any failure within part of **SCS** or communication system.

Any data and software stored on remote devices i.e. outside of SPEN systems shall be stored in encrypted file systems. The cryptographic algorithm used for storage will be agreed with the ISC Partner for initial installations.

Encryption and decryption of data shall be made in software as it is foreseeable that any selected algorithm may need to be replaced in time as vulnerabilities are discovered.

All the data shall be stored with the relevant time stamps reflecting the exact time of events or monitoring.

3.9.4 Device Management

The solution shall be compatible with DNP3 and 101 serial connection. Authentication for serial local access shall be through a per-device code rather than through LDAP.

Repeated failed login attempts to local access shall lock out local connections for a specified duration or permanently as required by SPEN. The number of attempts and duration of lock out shall be configurable parameters.

The solution shall allow the user to:

- Change the service status of the transformer through predefined routine.
- Manually set individual operational parameters
- Upload configuration files;
- Allow the user to replace software and firmware components

3.10 Alarm and notification

SCS shall be capable of monitoring the health of communication systems and diagnose the source of communications failure. That may achieve by different units within **SCS** supporting heartbeat signals. Appropriate alarm and notification shall be communicated with SDIF via Field Online using AMQP or MQTT protocols or a web service API (using HTTPS).

3.11 Communication

The **SCS** shall operate upon data from external devices and services to determine automated control actions. As described in Section 3.12; such data will include the monitored parameters from neighbouring **Secondary Substations** as well as the voltage monitored at customer premises or specific locations along the **LV** circuits e.g. link boxes. The **SCS** shall also interface with SPEN systems, including Field Online, data historian and/or SCADA directly for data processing and persistent long-term storage.

The solution shall support Common Information Model as the data exchange protocol between the device and other IT/OT systems; adhering to IEC 61970 and IEC 61968 as applicable.

3.11.1 Communication with Normally Open Points

The **SCS** shall determine the most appropriate status for **LV** switches placed in **LV** feeder **Normally Open Points** (**NOP**s) based on the network requirements; business rules or algorithms which are deployed to the **SCS**.

Switch status shall be remotely controlled (open/close) using the appropriate communication solution which will be installed by SPEN. The status (open/close) and the voltage magnitude and phase angle either side of the switch shall be communicated to the **SCS**.

The quantity of **NOP** switches whose state shall be readable and managed are expected to be 1 point on each feeder or around 5 for each substation. to be in the order of 1-5 minutes; with a latency on communication of approximately 30 seconds.

3.11.2 Communication with other Substations

The **SCS** will require data from multiple substations who share common connectivity; either on **HV** or **LV** networks.

Secondary Substations will exchange outgoing feeder metering currents and bus voltage measurements. External **STs** will communicate their set point parameters.

The frequency of data communication from other **SST** and conventional substations is expected to be up to 1 minute. A maximum of 15 parallel substations will provide such data; with a latency of approximately 30 seconds.

3.11.3 Communication with Customers

The quantity of voltage monitoring units (linkbox or customer premises) whose state shall be readable to be up to 12 points per feeder or 60 for each substation. The frequency of communication is expected to be in the order of 1-5 minutes; with a latency of approximately 60 seconds.

3.12 Data Requirements

3.12.1 Monitored Data

To facilitate the functionality required as stated in Section 3.13.8, it is expected that the following data will be available to the **SCS**.

From local substation where **ST** installed and neighbouring substations:

- Phase to phase RMS voltages at **HV Primary Terminal** (kV rms)
- Phase to neutral voltages at **LV AC Secondary Terminal** (V rms)
- Pole to pole voltage at **LV DC Secondary Terminal**
- Voltage Frequency (Hz) at **HV Primary Terminal** and **LV AC Secondary Terminal**
- RMS currents and phase angle (A rms, degrees) at **HV Primary Terminal**, **LV AC Secondary Terminal and LV DC Terminal**
- RMS currents and phase angle (A rms, degrees) of each **LV** feeder connected to **LV AC Secondary Terminal**
- Real Power (kW) export or import at at **HV Primary Terminal**, **LV AC Secondary Terminal and LV DC Terminal**
- Reactive Power (kVAr) export or import at **HV Primary Terminal**, **LV AC Secondary Terminal and LV DC Terminal**
- Current and

- Loading versus rating (%)
- **HV** plant status
- Switch Over status

From Controllable Switch e.g. **Normally Open Point** (**NOP**) and Feeder Circuit Breaker:

- Disconnector / Switch status
- Phase to phase RMS voltages and phase angle difference at terminals
- Current (A rms) flowing through switch when closed.

From domestic **Smart Meter**s:

- **LV** phase-neutral (single phase) voltage (V rms)

Monitored Data may be transmitted through hard wired connected directly any unit of **SCS** or using any other communication solution.

Some meters may be dedicated for **LV Engine** and may offer high frequency sampling; **Smart Meter**s may be slower; furthermore, data from metering points may not arrive coincidently. The **SCS** shall consider the time of measurements so that the most recent readings are prioritised, and moderate those which are relatively old.

3.12.2 Data Cleansing

Recorded data from local or remote sources can contain errors such as:

- Consecutive errors due to failure of communication,
- Systematic errors in instrumentation;
- Reconciliation errors due to lack of synchronisation between metering devices.

The **SCS** shall be able to identify (anomaly detection) and correct errors in individual device meter readings by comparison with other devices in the same locality.

3.12.3 Data Management

The management of data shall be secure and compliant with SPEN policies.

The **SCS** shall store a complete time stamped archive of measurement data to allow development of network / load model relationships. The measurement data shall be easily linkable with physical assets and their location.

The **SCS** shall be able to also store a complete time stamped archive of changes to all **Control Parameters.** The data shall be stored for minimum duration of 1 year, determined on a rolling basis. The data shall be accessible for offline processing at any time.

3.12.4 Data Reporting

To allow for auditing and manual tuning of **Control Algorithm**s. Statistics such as mean and standard deviation of measured quantities shall be reportable upon demand.

3.13 Interface with existing systems

There are number of ongoing developments within SPEN to allow better communication and data management and also facilitate the integration of Smart Grid technologies. **ICS Partner** shall require recognising these developments and their functionalities for inclusion in **LV Engine** control system architecture:

1- Smart Data Integration Fabric (SDIF): This is an intelligent data management and event process platform located within SPEN corporate network that can manage, store and process the data collected from **Smart Meter**s or other field monitoring equipment.

2- Field Online: This system will be used to publish key events from the field which are of interest to internal IT/OT systems. Field online acts as bridge between OT and IT to allow different monitoring and control equipment communicate the necessary data through different protocols and method depending on the data volumes, frequencies etc.

In addition, the following exiting systems shall be considered in **LV Engine SCS** architecture:

3- EnergyIP – Communicates with Data Communication Centre (DCC) to manage the integration of **Smart Meter**s data and their configurations. **Smart Meter**s can provide voltage quality data to **LV Engine** via EnergyIP and SDIF platform.

4- OSI Soft PI Data Historian – Time Series data historian which store and manage analogue data from the SCADA or data provided by SDIF.

Figure 14 shows the required interface with the other IT/OT SPEN systems.

[redacted]

Figure 14 – High level presentation of LV Engine SCS interaction with existing SPEN IT/OT systems

3.13.1 Communication Methods

It is expected that high data volume exchange such as **Smart Meter** voltage readings would require internet protocol (IP) network communication by fixed line or mobile broadband; however, a secondary method such as Power Line Carrier (PLC) technology shall be facilitated for security of signalling.

3.13.2 Control Parameters

The parameters which a **Control Engineer** shall be able to configure are as follows:

- Network Voltage Magnitude Limits (max/min, p.u)
- Maximum Permissible Voltage Step
- Primary and Secondary optimisation objective(s)
- **Control Algorithm** tuning parameters e.g. switch off, deceleration factor, rate of adjustment

The default values of network voltage limits shall be in accordance with ESQCR.

In accordance with the control requirements, the **SCS** shall be able to dictate the following input parameters for **SST** devices.

- **LV Voltage Set Points** for each phase and corresponding tolerances
- **DC voltage set points** and corresponding tolerances
- **HV voltage set points** and corresponding tolerances
- **Thermal loading set point** and corresponding tolerances
- **LV AC Active Power set point** and corresponding tolerances
- **LV AC reactive power set point** and corresponding tolerances

It shall be possible for a **Control Engineer** in a remote location to override the set points determined by the **SCS**.

3.13.3 User Interface

The **Intelligence and Control System Partner** shall provide a Human Machin Interface (HMI) which provides visibility and control of each logically separate **LV** system.

It shall be possible to:

- View real-time power flow and voltage at **SST** terminals and metered nodes within **Controlled Zone**s. This should be visible on (simplified) topographical network maps.
- Manually adjust **Control Parameters**
- View a graphical display of historical/predicted demand and previous/impending actions which have been or are to be taken.
- Download time-series data for offline analysis.

There shall not be any limit on the number of users can be connected to the **SCS** HMI.

3.14 Testing Requirements

Testing of **SCS** software and hardware shall be extensively performed in prior to installation and commissioning in the field. **ICS Partner** shall provide appropriated test environment which can simulate the real-life performance **SCS** for different **LV Engine schemes**.

The test set up shall be capable of providing similar field conditions in terms of behaviour of **SST**, regional and local **SCS** units, data flows and their latencies and communication performance etc. The tests schedule and test scenarios shall be agreed with the **SPEN** prior to acceptance test. The test schedule includes but not limited to:

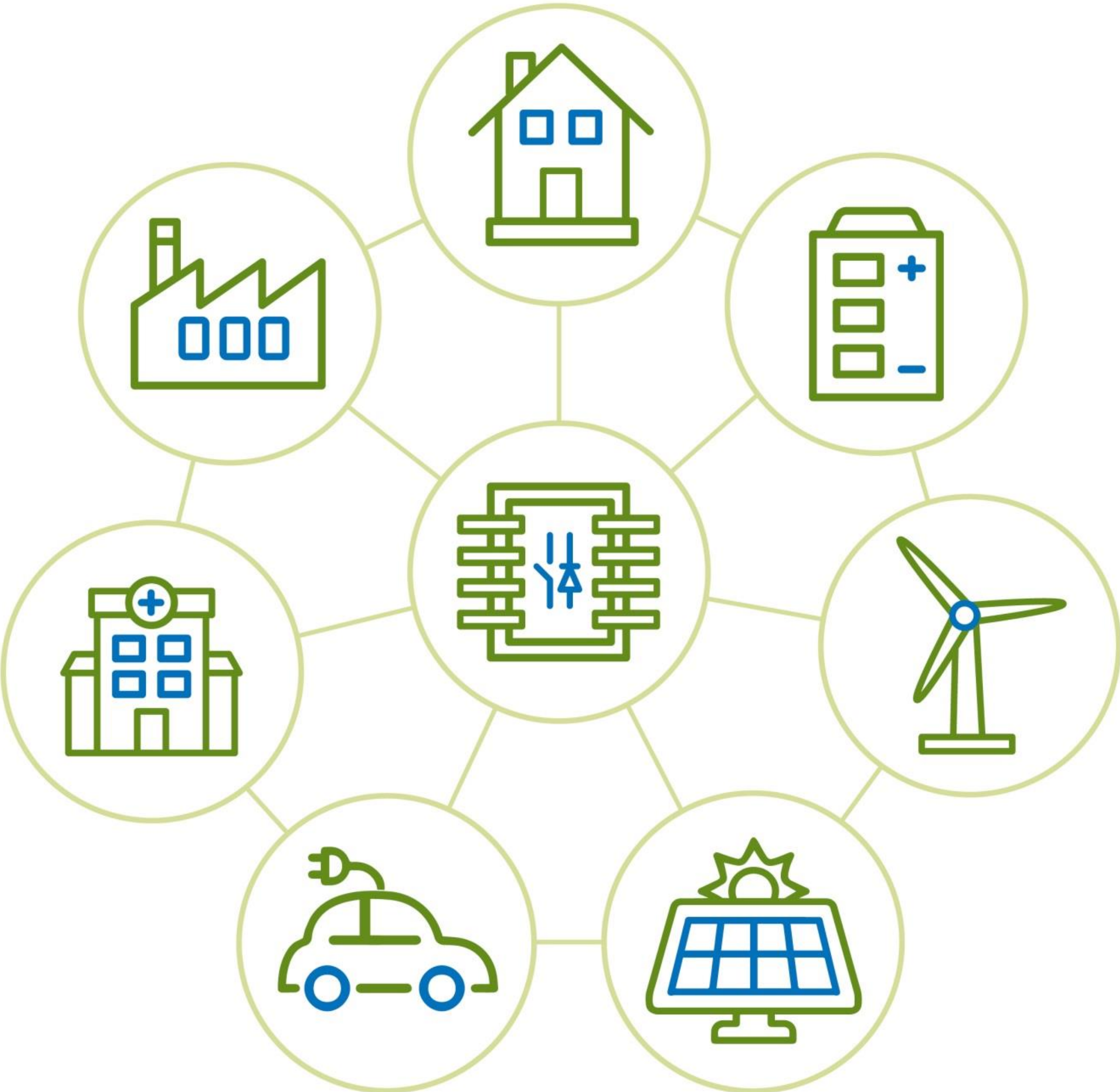
- Functional / Unit testing – This test shall ensure the performance of each individual unit within **SCS** architecture. The test will be decided upon by software/hardware developers and full code coverage may be expected.

- Performance Testing – This test shall cover all the performance of the **SCS** (whole system) and its **Control Algorithm**s to fulfil the functionalities specified in this document. It is expected the functionalities shall be demonstrated for all the **LV Engine schemes**. the performance testing shall include but not limited:

    - LV Engine core functionalities testing - This test will demonstrate the capability of **SCS** for delivery of core functionalities of **LV Engine** and control requirements specified in this document. The test will be for various extensive scenarios considering time series variations in demand/generation and network parameters. The test scenarios shall cover all the **LV Engine Schemes** expected performance. Test scenarios shall be developed by **ICS Partner** and shall be approved by SPEN before tests are conducted.

- Computational test capability - The hardware running **Control Algorithm**s shall have sufficient processing capability to meet the described time limits considering **LV Engine schemes** in operation. Also, the scalability of the solution will be tested to ensure **SCS** can accommodate further **LV Engine** solutions without no impact on computational time.
- Anomaly test – This test will demonstrate the capability of the SCS to identify errors in monitored data and carry out suitable actions to eliminate the impact of bad data on the computation process.

- Security Testing – This test check software and hardware design for vulnerabilities to known threats. Security requirement specified within this document will be also part of this test.
- Integration Testing – This test will check the complete **SCS** with all components in situ within simulated and real test networks proposed by **the ICS Partner** and approved by SPEN.
- Destructive Testing – Testing with the mindset of an attitude to break or crash software, the details of this test shall be developed by ICS Partner and submitted to SPEN for approval.



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