SP ENERGY NETWORKS

LV ENGINE

Project Progress Report

Work carried out during 2023

About Report

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Report Progress

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1 Executive Summary

1.1 Background

SP Energy Networks, in collaboration with UKPN, submitted the proposal for LV Engine under the Network Innovation Competition (NIC) mechanism in 2017. WSP, University of Strathclyde, and University of Kiel have also provided technical support for the proposal preparation. Ofgem approved the proposal and issued the Project Direction on the 16th of January 2018.The project commenced in January 2018 and is currently due to conclude in December 2024.

The LV Engine innovation project intends to trial Smart Transformers (ST) within secondary substations as the central point of an active and intelligent 11kV and LV distribution network. The ST trialled during the project will bring together sophisticated power electronic hardware with intelligent network monitoring and control to maximise the performance and efficiency of the distribution network.

This is the sixth in the series of annual progress reports for the LV ENGINE project and covers the period January 2023 to January 2024, the “reporting period”.

1.2 LV Engine overview

A ST consists of a Solid-State Transformer (SST) and a Smart Control System (SCS). SST uses power electronic technologies to deliver several functionalities. SCS, however, provides the control set points to SST based on data gathered and analysed from different monitored points in the network. LV Engine aims to demonstrate the following Core Functionalities can be delivered by deploying SST at secondary substations:

- Voltage regulation at LV Networks;
- Capacity sharing with other substations;
- Cancellation of LV imbalance load seen by the HV network;
- Reactive power compensation and power factor correction at secondary substations;
- Provision of LV DC to supply rapid and ultra-rapid EV chargers.

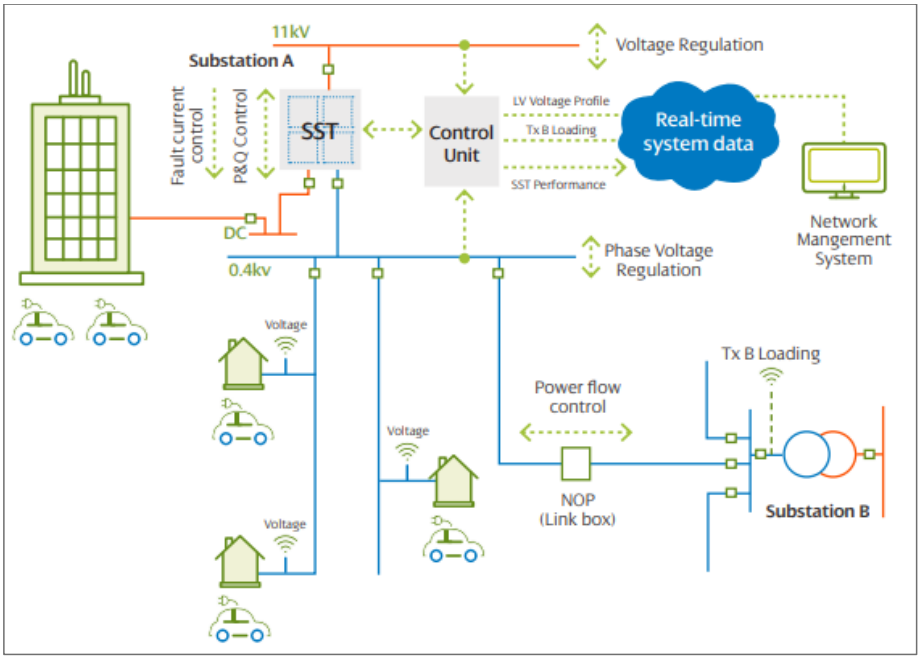

Figure 1 LV Engine project concept

LV Engine power electronics products

As the focus of the LV Engine project is to demonstrate the performance of the Core Functionalities required by the network, there are different possible SST topologies which have been considered as part of LV engine to deliver the stated core functionalities. The two topologies considered are summarised 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 electronics devices can be added to the existing distribution transformers to deliver the Core Functionalities of LV Engine. The aim is to enhance the Technology Readiness Level (TRL) of this product from 6 to 9.

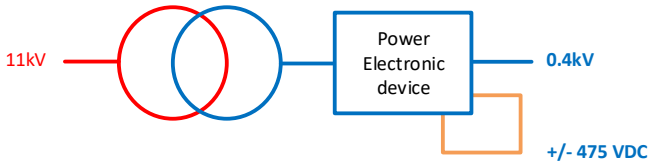

Figure 2 SST Topology 1

- ***Topology 2*** - *Topology using 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. The aim is to enhance the TRL of this product from 5 to 8.

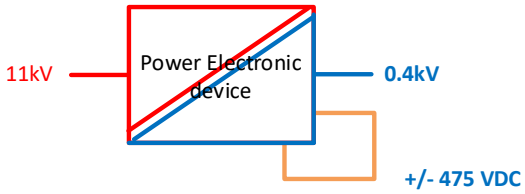

Figure 3 SST Topology 2

1.3 Project Highlights

The project progressed significantly during 2023 and it is currently planned to be completed by Dec 2024. The highlights in this reporting period are as follows:

- **SST Prototyping and testing (Deliverable #3) –** Manufacturing and factory testing of SST Topology 1 completed in 2023. After successful prototyping during the last reporting period, four SST Topology 1 units were manufactured and passed the factory tests. All units were delivered to SPEN by the end of 2023.

- **Trial site installation (Deliverable #5 and #6)**

    - **Falkirk Trial site (DC Schemes) –** All the civil works, equipment installation, cable jointing, and small wiring were completed in Dec 2023. The site was successfully commissioned on 21st Dec 2023.

- **Wrexham Trial sites (AC schemes) –** Installation has been planned on 31st Jan 2024. All the equipment has been delivered and resources have been booked for this installation and commissioning in early 2024.

- **Network Integration Testing (Deliverable #4) –** One of the key activities under this deliverable is to de-risk the customers' security of supply and ensure there is no operation issue with the LV Engine scheme by testing the performance of the LV Engine solution in a controlled laboratory environment. For this purpose, Power Networks Demonstration Centre (PNDC) was appointed to conduct the tests prior to live trials. We have carried out extensive network integration testing at PNDC in two stages. In the first stage (during June 2023), the first SST Topology 1 (S1) together with all other equipment designed and manufactured for the LV Engine solution were tested under extensive normal operation and fault scenarios. After upgrading the equipment, based on the tests in the first stage, tests were successfully repeated (Oct 2023) on LV Engine schemes to confirm all the issues have been addressed and the project can proceed with the live trial phase.

- **LV Engine system architecture and monitoring (Deliverable #5 and #6) –** Design and implementation of LV Engine system architecture was completed in this reporting period. LV Engine project designed and demonstrated a smart communication hub that can connect to equipment manufactured by different vendors. We have demonstrated that data can be collected from LV Circuit Breakers (CBs), Local Control System and SST Topology 1 at the substations and communicated to SPEN internal data historian and visualisation platforms.

- **UK Power Networks collaboration –** we continued collaboration with UK Power Networks by sharing the first-hand learnings between Active Response and LV Engine projects as agreed in the project full submission. Two key reports were developed as part of this collaboration:

    1. Report on the potential deployments of Active Response solutions in SPEN distribution networks. This report was part of the Active Response deliverable and prepared by the LV Engine team. This was submitted to Ofgem by UK Power Networks.

    2. Report on the potential deployments of LV Engine solutions on UK Power Networks distribution networks. This report is in its final review stage.

- **Best Operational practices of SST (Deliverable #7)**
  We continued detailed studies on selected LV networks, where reinforcement is required. These studies assessed whether the LV Engine solution is a better option technically and commercially compared to conventional reinforcement. This activity is in-line with Deliverable #7 objective providing SPEN with LV Engine BaU adoption guidance and recommendations.

- **Disseminations**
  Similar to previous years, we continued to share the learnings of the project via different platforms and through different events. That includes presentation at IET, Cigre, and the Energy Innovation Summit.

1.4 Project Issues

We did not encounter any major issue in this reporting period. The issues which caused project delay to date have been already reported in previous reporting period progress reports.

1.5 Key lessons learnt

- Integration testing for an innovation solution in which different vendors are providing key equipment is an essential development stage to ensure the overall solution functions as designed. The integration testing should adequately represent the final set up and operating conditions in the live trial to ensure minimum issues when the solution is part of the electricity system.
- Creating a smart hub for communication can facilitate the integration of monitoring and control solutions in secondary substations. Deploying a single smart hub (router) would be more efficient to manage.
- LVDC protection and metering remains the main challenge for rolling out the LVDC technologies by DNOs although learnings from LV Engine have significantly facilitated the progress to LVDC public networks.

1.6 Summary of key activity in next reporting period

In the next reporting period, the project's critical path will be to:

- Submit all LV Engine deliverables.
- Organise two key dissemination activities: DNO workshop, LV Engine close down dissemination event.
- Start preparation of close down report.
- Start preparation for business hand over to ensure LV Engine solution stays operational, if proven successful towards end of this reporting period.

2 Project Manager's Report

This section provides an overview on the project progress made in this reporting period (15th January 2023 – 16th January 2024). The key project highlights include successful completion of integration testing and installation of the first LV Engine scheme. The following section elaborates on progress and shares some of the learnings captured during this reporting period.

2.1 LV Engine equipment manufacturing

All the LV Engine equipment was manufactured and passed the factory acceptance tests.

2.1.1 SST Design and Manufacturing

The main focus in 2023 was to complete manufacturing of all SST Topology 1 units and carry out factory tests.

In order to achieve the final field SST Topology 1 products. The following steps were carried out:

- We first built four full-size prototypes (E1 to E4) to run various factory tests and prepare blueprints for the final product assembly. Having identical fully rated products allowed our manufacturing partner to run some of the factory tests in parallel and allow redundancy in case of any catastrophic failure which in fact happened to unit E3 during some of the tests.

- Learnings gathered from all the factory acceptance tests were then used to build the first complete unit, S1, which was considered suitable for network integration testing at PNDC. After these tests which were designed to replicate a real-life deployment of the LV Engine solution, we identified a number of improvements required. Those improvements were applied to the S2, S3 and S4 units which are earmarked for field deployment.

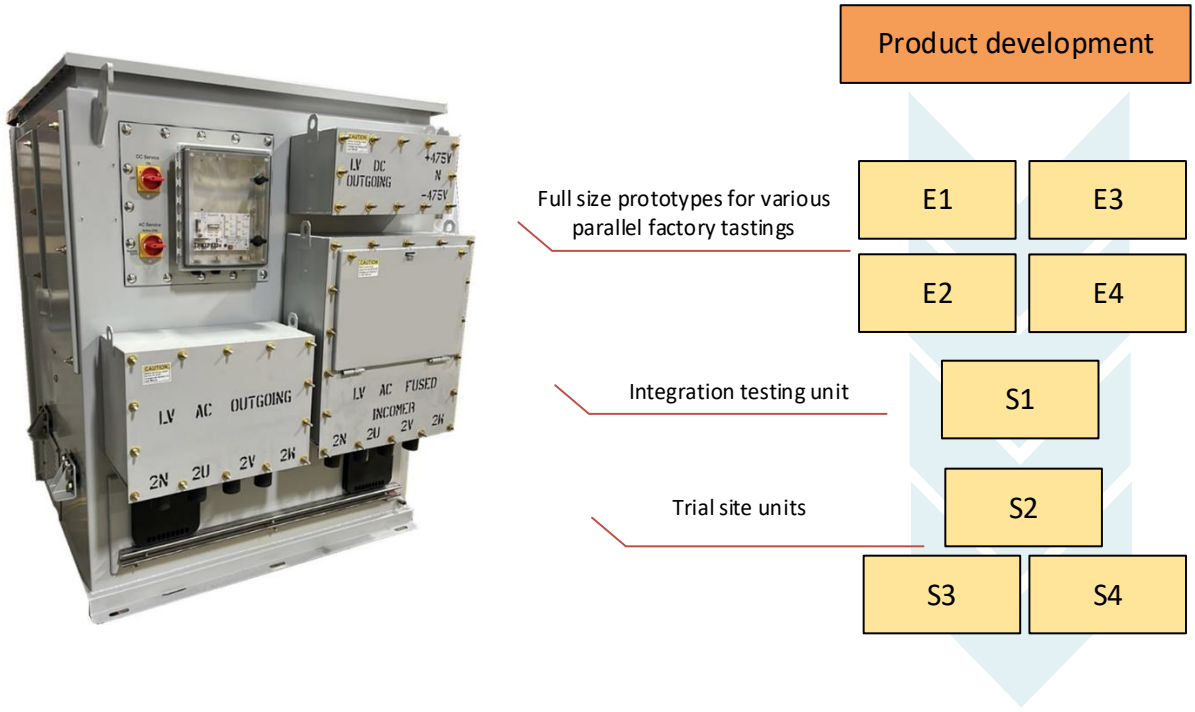

Figure 4 SST Topology 1 development and manufacturing process

All the units were safely delivered to the designated destinations in the UK. Figure 5 shows the delivery of the first unit, S1, being forklifted from lorry.

Figure 5 Delivery of first unit, S1

2.1.2 Other equipment

There were two more key components that finished manufacturing and testing stages during this reporting period.

LVDC switchboard – This switchboard was designed collaboratively and manufactured by Schneider Electric. The switchboard accepts the DC output from the SST Topology 1. The main function of the switchboard is to distribute power to DC customers. Additionally, the switchboard houses protection and isolation equipment. The LVDC distribution board is fitted with disconnectors, Moulded Case Circuit Breakers (MCCB) and under-voltage release relays. Furthermore, an earth leakage protection relay is installed in the distribution board measuring current through the earth-neutral link. The Bender RCMB301 earth leakage protection relay has been selected to deliver this function. The suitability of this relay has been confirmed previously following tests carried out at PNDC.

Local Control System (LCS) - This is an Alarm Display Panel and Telecoms cabinet designed specifically for LV Engine. The aim of this Alarm Panel is to provide an overview about the status of the various devices in the substation. The router communicating the monitored data can also be fitted in this cabinet. This product has been the result of collaborative work between SPEN and Nortech Management Ltd.

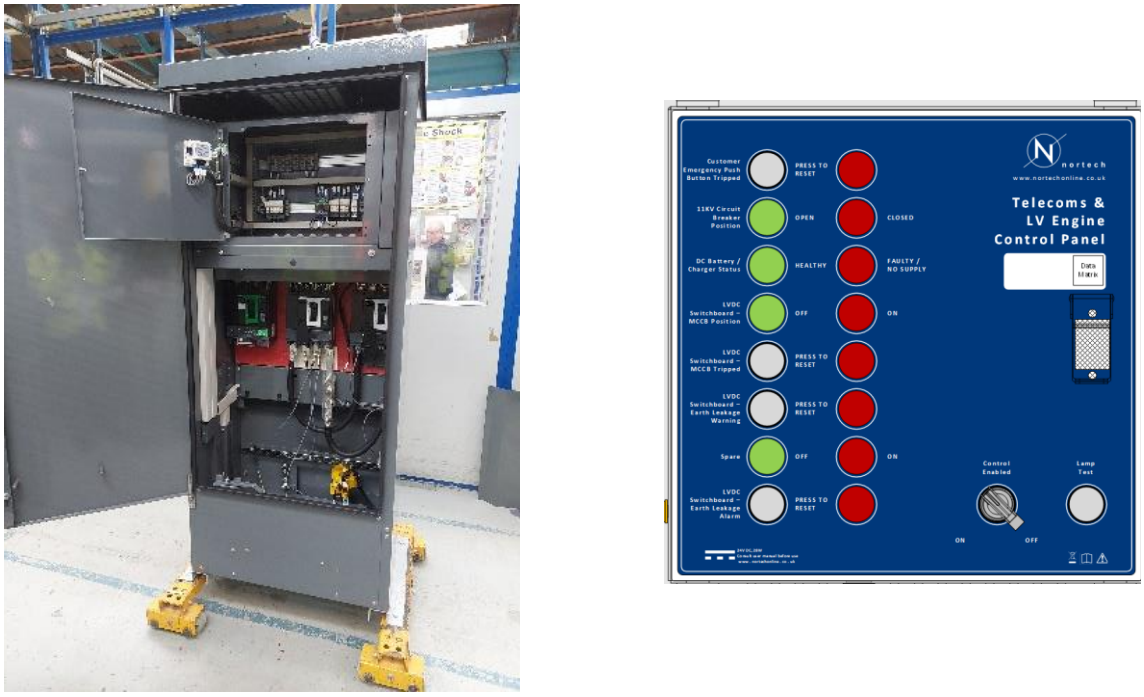

Figure 6 LVDC switchboard (right), local control system (left)

2.2 Network integration testing

Successful network integration testing was a significant achievement for LV Engine during this reporting period. This test allowed us to confirm the overall performance of the LV Engine solution which relies on different equipment manufactured for the first time by different vendors. The overall performance of the LV Engine solution was demonstrated in a controlled laboratory environment replicating real network conditions. The lab-based testing enabled the validation of all the designs and studies de-risking key LV Engine schemes prior to live trials. The overall lab set up is shown in Figure 7.

The lab-based testing was completed in two phases with initial integration testing completed on first LV Engine solution (S1) and subsequent regression testing was completed on version 2 (S2). In each phase of testing, the AC and DC output of the LV Engine solution was investigated over a range of different test cases. A summary of the final test status of the LV Engine solution following the conclusion of lab testing is outlined in Table 1.

Apart from successful operation during AC and DC faults, LV Engine equipment was extensively tested under different normal operating conditions. Figure 8 shows the operation of the LV Engine when AC load banks and DC charger are supplied at the same time. While SST Topology 1 supplying both DC and AC loads, AC voltage regulation has achieved the target voltages which were changed at various set points during the test.

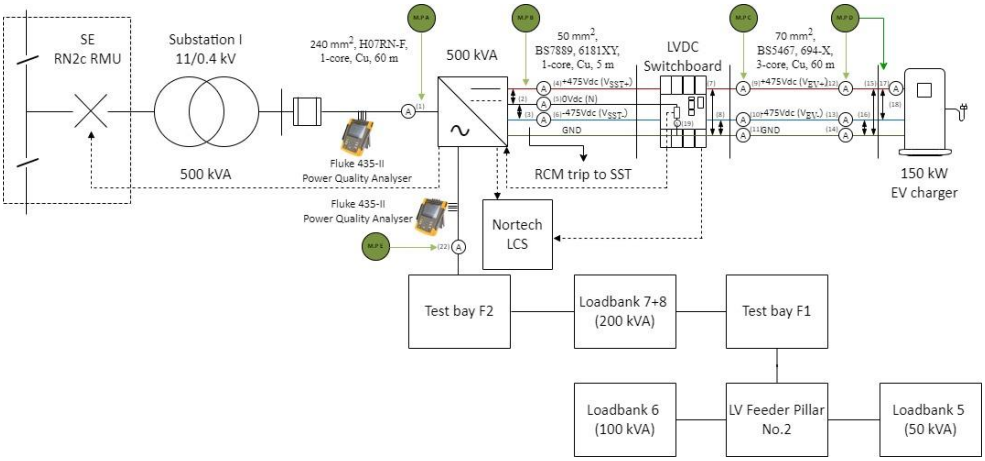

Figure 7 Network integration testing set up at PNDC

Table 1: LV Engine solution Integration Test status following the conclusion of lab-based testing

Name of test	Test Status	Name of test	Test Status
System start up	PASS	Resistive pole to earth fault	PASS
System shut down	PASS	Operation outside statutory limits	PASS
LVDC Switchboard MCCB position	PASS	Reactive power compensation	PASS
Inter-Trip Test	PASS	Leakage relay tuning	PASS
Functional Test	PASS	Enspec (extra LV DC fault detection solution) tuning	PASS
Solid Pole to Pole Fault	PASS	Voltage regulation	PASS
Solid Pole to Earth Fault	PASS	Power Sharing	PASS
Solid pole to neutral fault	PASS	AC fault testing	PASS

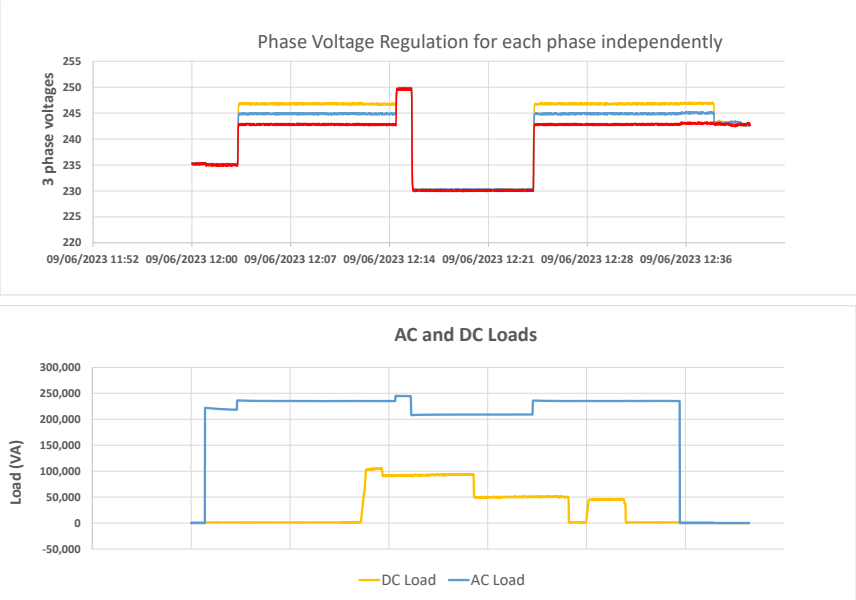

Figure 8 Results of AC/DC supply during the test at PNDC

2.3 Trial site

We progressed significantly on trial site installations during this reporting period.

2.3.1 Falkirk

Falkirk trial site is earmarked to demonstrate two LV Engine schemes covering LVAC and LVDC supply arrangements. For this site, civil works, equipment landing, enclosure installation, cabling and small wiring were completed in Dec 2023. Following the installation, the substation was commissioned on 21st Dec 2023. The LVDC switchboard and LVAC switchboard were both energised. The DC EV charger was not energised in this reporting period as we were waiting for the customer's confirmation on their BS 7671 compliance report.

The key learning from this installation, which is unique compared to conventional secondary substations, is to ensure all the civil design and wiring diagrams are thoroughly reviewed and understood by each contractor in advance of the work. This early engagement with contractors and time spent on design materials helped significantly to smooth the installation and commissioning process.

As part of training, we also ran open day sessions for local operational staff to ensure adequate operational familiarisation, backed with documentation that have been passed to our District staff. We continue training, knowledge sharing and performance monitoring with District staff to ensure business hand over can be as smooth as possible when the NIC project is completed.

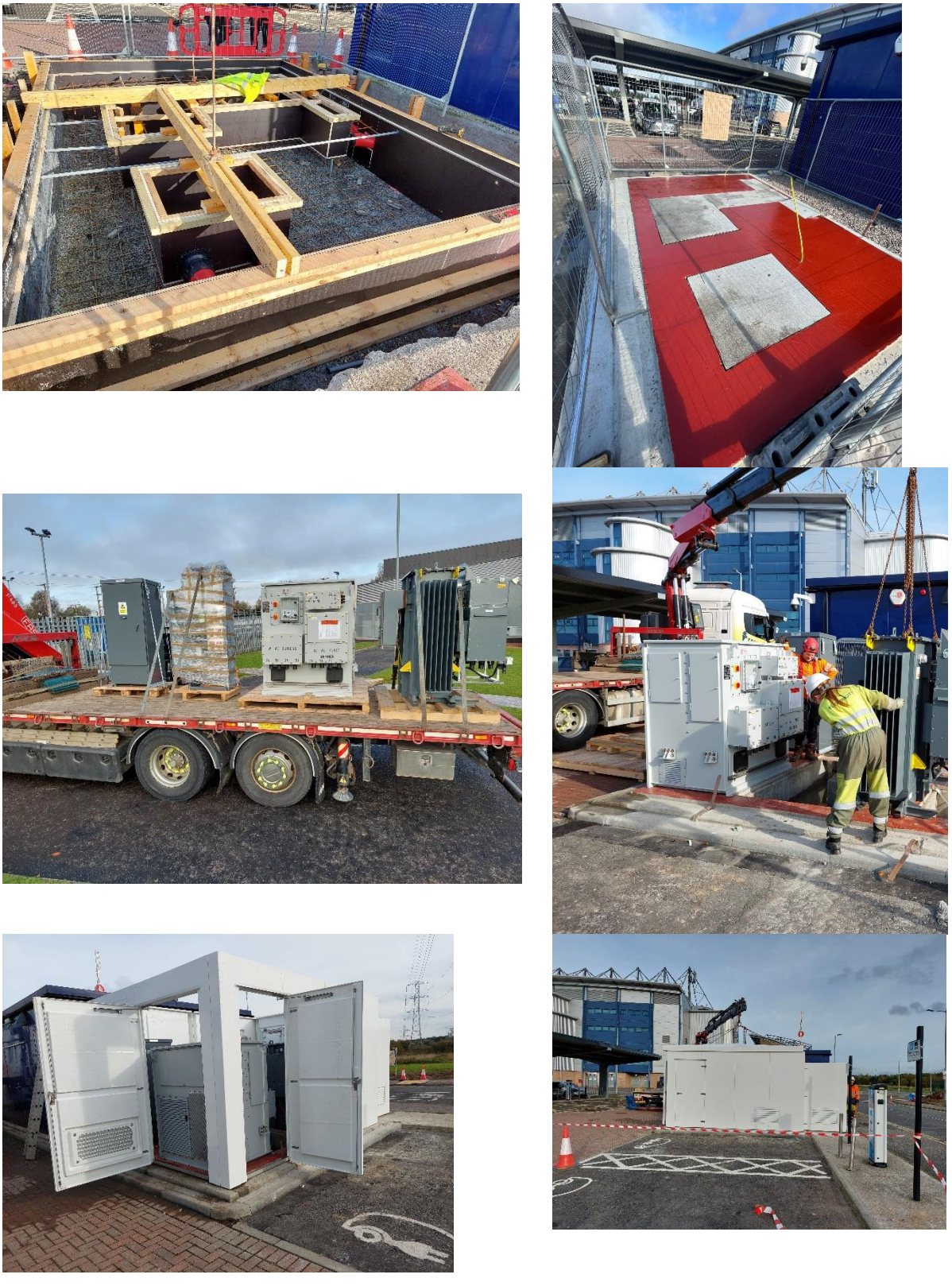

Figure 9 Installation at Falkirk substation

2.3.2 Wrexham

The two SST Topology 1 units (S3 and S4) earmarked for Wrexham have been delivered. Installation, local training, and commissioning is planned in Q1 2024. Figure 10shows the S3 and

S4 units crated by Ermco team and ready for shipment to the UK. These units were delivered in this reporting period.

Figure 10 S3 and S4 crated and ready for shipment to the UK

2.4 Monitoring and system integration

In line with LV Engine Deliverable #5 “Establish the system architecture of LV Engine schemes” we completed and successfully tested LV Engine system architecture and integration of monitored data into our IT system. LV Engine created a smart hub communication where different vendors can plug into a router to communicate the monitored data to our data historian. We are now receiving the 5-minute performance data from the Falkirk site which will help significantly with performance evaluation and troubleshooting. Figure 11 shows the simplified architecture and Figure 12 shows the voltage regulation data received from Falkirk substation.

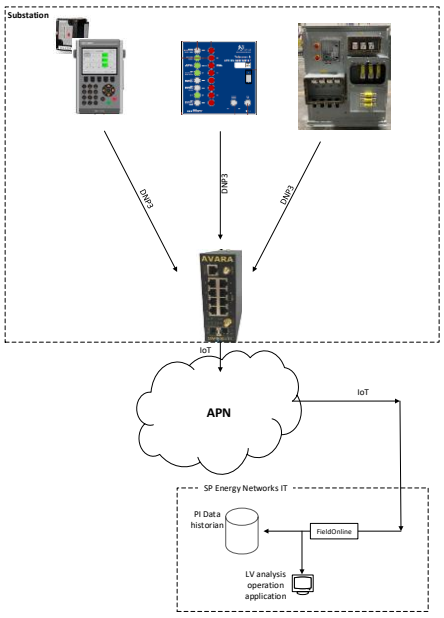

Figure 11 Simplified LV Engine system architecture

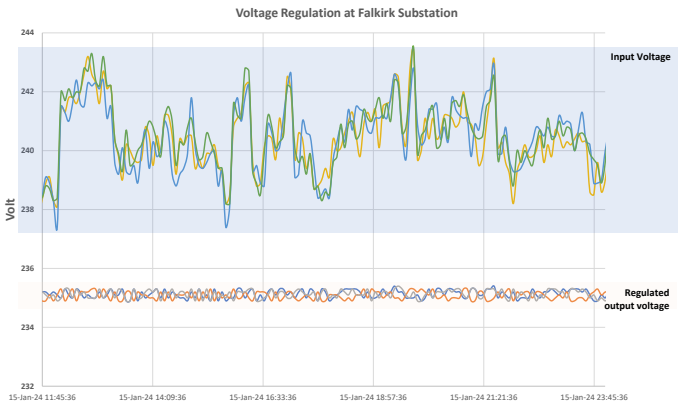

Figure 12 voltage data received from Falkirk substation

In total the following data are monitored and received through the smart communication hub designed and built by LV Engine team:

- SST Topology 1: 83 parameters
- Local Control system: 11 parameters – status of circuit breakers at DC, leakage relay, substation temperature, humidity etc
- Each AC feeder fitted with Kelvatek devices – 45 parameters

2.5 BaU integration

The project team aims to hand over an operational product to the SPEN business, providing we successfully demonstrate the operation during the trial period. We have already progressed in the following activities to ensure the LV Engine solution can be integrated into Business-as-Usual (BaU) processes:

- Developed safety documentation related to operation and work on apparatus
- Developed installation and commissioning method statements
- Developed data return forms and asset model in line with BaU asset database and data collection procedures
- Trained staff in the substation and produced training material

We continue the BaU integration further to include spare parts, maintenance procedures and contracts and additional trainings.

2.6 Disseminations

Knowledge sharing continues to be a core element of LV Engine's activities to ensure our internal and external stakeholders are aware of project progress, project learnings and challenges. Key highlights on dissemination activities during this reporting period are as follows:

EIS – We had the opportunity to present the latest project learnings and some technical challenges during the Energy Innovation Summit in 2023.

IET Power Electronics, Machines and Drives – We presented LV Engine keynote speaker session and shared the learnings and use cases of LV Engine. The focus of this conference was on new developments and technologies in power electronics which was relevant to core technology developed in LV Engine project.

IET Powering Net Zero Glasgow – We had an opportunity to present LV Engine project achievements and learnings through presentation sessions and exhibition in this IET conference.

Awards – LV Engine's novelty and the efforts of the project team were successfully recognised at the IET Excellence and Innovation Awards where the project received the prestigious Gold award. LV Engine was also shortlisted for a Utility Week Award in the Innovation category.

eGrid2023 – LV Engine was invited for presentation and discussions in eGrid2023 industrial panel where focus was on LVDC technologies. We received a great interest from the audiences about learnings and developments conducted by the LV Engine team.

CIGRE UK Webinar – CIGRE UK was another forum we used to share the learnings from the project, promote the achievements and appreciate the opportunities for developing innovations through the funding mechanism Ofgem has provided. A combination of academics, industry experts, manufacturers and consultancies attended the webinar.

Videos - We also raised awareness about the project progress and achievements via promotional videos which were posted on LV Engine website.

Figure 13 – IET Powering Net Zero

Figure 14 – LV Engine won Gold IET Excellence and Innovation Award

2.7 Project reports and materials

During the reporting period the following reports and materials have been produced to document the learnings generated within the project to date:

Document	Summary
Network Integration Testing and results **Deliverable #4**	This report reflects the extensive work carried out for testing LV Engine schemes at PNDC
Identify potential trial sites for replicating LV Engine within UK Power Networks (This will be part of **Deliverable #8** submission)	This report covers the potential deployments within UK Power Networks. The report has been finalised but waiting for the UK power Networks signed off.
LV Engine commissioning method statement and safety requirements	This document provides the steps which should be taken for installation and commissioning the LV Engine solution. Also, the safety precautions have been provided.
Independent design assessment for compliance with BS7671	In our Falkirk site, we supply a fixed equipment (EV Charger) owned by the customer, we decided to appoint an independent assessor to ensure the overall end-to-end design complies with BS 7671 IET Wiring Regulations.
A set of drawings forming the design pack of the LV Engine solution	Each site has its own design pack set of drawings

These documents can be made available to interested parties upon request, in line with SP Energy Networks Data Sharing Policy[1].

[1] https://www.spenergynetworks.co.uk/pages/data_sharing_policy.aspx#:~:text=It%20is%20our%20intention%20to,commercial%20confidentiality%20or%20other%20sensitivity.

2.8 Project Issues

No major issues to be reported in this reporting period.

2.9 Outlook to the next reporting period

In the next reporting period, the project critical path will be to:

- Submit all LV Engine Deliverables
- Install second and third LV Engine substation in Wrexham

The following progress is planned in the next reporting period under specific work packages:

Work Package 3 – Design and Manufacturing of SST

- Upgrade the S1 unit which was initially tested at PNDC and ship to the UK.

Work Package 5 – Live Trials

- Install and commission second and third LV Engine trial site

Work Package 6 – Novel approach for transformer selection

- Update the safety documents required for commissioning and operation of LV DC and SST.
- Continue provision of necessary training to delivery and operation staff to adopt new technology.
- Prepare SST performance report contributing directly to Deliverable #6.
- Provide recommendations on selection of LV Engine solution by comparing with other competitive solutions

Work Package 7 – Dissemination

- Organise and hold UK DNO workshop to share lessons learnt.
- Produce technical papers for relevant conferences and articles.
- Share lessons learnt at ENIC (or similar event/conference).
- Continue to share project progress and lessons learnt with stakeholders within SPEN.
- Update the LV Engine website with the new document created by the project team.

3 Business Case Update

There has been no reported change to the Business Case submitted in the Full Submission Proposal (FSP) during the reporting period. We aim to have a revised business case developed after reviewing the performance of LV Engine solution in the live trial. The updated business case will be reported in project close down report after project completion.

4 Progress against plan

4.1 Key Achievements and project highlights

4.1.1 SST prototyping and manufacturing

Project successfully progressed on the SST manufacturing and factory testing. The following key highlights have been achieved:

- 4 x full-size SST units were manufactured, tested and delivered to the UK for live trials.
- All units were upgraded based on the lessons learnt from Network Integration Testing

4.1.2 Trial Site Developments

- First LV Engine substation, where first DC supply and later hybrid AC/DC supply is planned, have been installed and commissioned.
- Commissioning method statements and safety procedures were agreed and documented.

4.1.3 Pre-trial network integration testing

- Extensive tests were carried out on SST Topology 1 unit in two stages.
    - First unit (S1) together with other LV Engine equipment were tested under different scheme operations. The improvement points were identified and reflected to the manufacturers.
    - Second unit (S2) together with improved LV Engine equipment were again tested extensively under normal and fault conditions to confirm readiness for live trial.

4.1.4 IT/OT integration

End to end tests on LV Engine IT architecture were carried out during the Integration Testing and confirmed all the devices can communicate with the smart router and send the performance data to PI Data Historian.

4.2 Project issues

No major issue to be reported in this stage of project.

4.3 Key activities planned for upcoming reporting period (2023/24)

As summarised in Section 2.9, the key activities in the next reporting period are planned to achieve the following:

- Install and commission further two LV Engine substation
- Submit all LV Engine deliverables;
- Prepare the close down report;
- Dissemination as planned in the project.

5 Progress against budget [CONFIDENTIAL]

6 Project Bank Account [Confidential]

7 Project Deliverables

The project deliverables set out in the Project Direction links with the Project Milestones and the identified targets directly. These project deliverables are used to check the progress of the project delivery and state of progress against the original proposal.

Table 2 shows a summary of the LV Engine deliverables defined in the Project Direction.

Table 2 LV Engine project deliverables

	Project Deliverable	Initial target delivery date	Status	Expected delivery date
1	Technical specification of SST and functional specification of the LV Engine schemes' including relevant control algorithms	10/12/18	**Completed**	-
2	Detailed technical design of SST by the manufacturer and life cycle assessment	22/12/19	**Completed**	-
3	Manufacture SSTs for LV Engine schemes	11/01/21	**Manufacturing Completed (a report on learning will be submitted on 3/07/2024)**	-
4	Complete network integration tests	28/09/20	**Completed (a report on learning will be submitted on 20/05/2023)**	-
5	Establish the system architecture of LV Engine schemes	20/06/21	**Completed (a report on learning will be submitted on 3/07/2024)**	-
6	Demonstrate the functionalities of SST	20/06/22	**In progress**	13/11/2024
7	Best operational practices of SSTs	07/11/22	**In Progress**	13/11/2024
8	Identify a trial site for replicating LV Engine solution within UK Power Networks	26/09/22	**Completed (a report on learning will be submitted on 20/05/2023)**	-
N/A	Comply with knowledge transfer requirements of the Governance Document.	End of project	**Not Started**	15/12/2024

SPEN confirm that adequate resources for project management and project delivery have been planned for upcoming deliverables. Resources are available internally in different parts of SPEN organisation and also additional support will be provided by our project partners.

8 Data access details

The Publicly Available Data Sharing Policy is available via SPEN's website: https://www.spenergynetworks.co.uk/pages/data_sharing_policy.aspx. LV Engine website is accessible via: www.spenergynetworks.co.uk/pages/lvengine.aspx

9 IPR

LV Engine complies with the Ofgem default position regarding the IPR ownership and no further IPR is to reported at this stage. However, we are working with project partners to finalise the list of IPRs and the type of IPRs generated in LV Engine that will be reported in the final project close down report.

10 Risk Management [CONFIDENTIAL]

The summary of key risks and mitigation plans which have been identified through the project have been listed below.

Risk No.	Issue	Risk Description	Potential Impact	Control measures applied during reporting period
1	Cyber security	SST control and functions can be affected by cyber attacks	Damage to the SST equipment, adverse impact on customers by applying unwanted voltage control, outage of SST and adverse impact on customer supply	1) Involved IT to review the security of proposed system architecture including third party remote access 2) Develop security logic within SST firmware to identify unusual control commands 3) Ensure adequate encryption and security included in the router
2	Cooling system	The cooling system for the SST converters proves to be unreliable	The project fails to demonstrate that the SST can achieve reliable performance with minimum maintenance, SST outages with customers off supply	1) Work with suppliers to understand the design of the cooling system and how its reliability can be increased 2) Prolonged testing at network integration facility to demonstrate reliability 3) Review of cooling system design by project partners 4) Review track record of similar cooling systems to ascertain reliability and performance
3	Delay in delivery of SST to trial sites	Delay in the prototype development leads to delays in the manufacture and delivery of the production SSTs	The project fails to achieve its targeted programme installation at the trial sites and project cost overspend resulting in late delivery of project objectives	1) Delivery plan considers contingency time for production of SSTs 2) Effective monitoring of the manufacturing process and define set dates for factory acceptance tests at time of contract

				3) Include appropriate penalties in terms and conditions to protect the project against late delivery of the products 4) Carry out competitive tendering to identify competent manufacturer with proven track record of delivering similar technologies
4	Maintenance requirements	SST is a complex system that is difficult to maintain in reasonable timescales and costs	Likely interruptions of supply to customers; and increased costs for additional resources in maintenance teams	1) Work closely with manufacturers to understand maintenance requirements and the impact on the design or selection of components 2) Deliver detailed training of SSTs to relevant staff members throughout duration of project 3) Provide adequate spares
5	Design order	SST Topology 2 cannot be fitted inside substation	Site limitations may impact capability of SST	Select a new substation rather than existing ones to allow for adequate footprint
6	Equipment out of production	Linkbox switches cannot be used in the project due to communication and low TRL of the existing products	LV Engine Schemes for capacity sharing demonstrations cannot be trialled	Remove requirement for LV linkboxes switches and rely on LVCBs at substations for open/close of LV interconnection
7	Control System Complexity	The control system proves to not be able to demonstrate the proposed functionality	Material change/delay/increased cost	1) Ensure SST can operate autonomously with no dependency on control system 2) Run adequate FAT before commissioning any control system

8	COVID-19 pandemic	As a result of COVID-19, there is a risk of delays to the project - from staff sickness, working conditions, access to workshop and test benches and procurement of equipment & services	Cumulative delays which would result in a material change	1) Keep business and Ofgem informed 2) Seek alternatives where possible and accelerate programme where possible to mitigate
9	Procuring a transformer for SST Topology 1	Seeking to procure transformer for Topology 1; due to COVID-19 the factories have closed and expect longer lead times	Cumulative delays which would result in a material change	Seeking alternative manufacturers within framework to mitigate the delay
10	Risk of Topology 2 non-delivery	EGB are unable to deliver the HV module which is critical to design the SST Topology 2	Non delivery of Topology 2 and lacking demonstration of scheme 4 and 5	1) Continue working with EGB and ensure delivery; ensure site delivery is flexible to account for Topology 1 option if needed 2) consideration of SST Topology 1 substitute in case of non-delivery of Topology 1
11	COVID-19 Supply Chain	Supply chain delay due to Covid 19 (16-23 weeks lead time for some of the components)	Delay in bench testing, prototyping and manufacturing	EGB is ordering more than usual to go to priority list in the supplier
13	Sought certificate is not awarded due to failure in network integration testing centre	SST does not pass the some of the tests and requires re-design or re-testing	Additional cost via variations or delays which scope is agreed	Agree scope in advance and advise EGB of planned testing criteria to capture and mitigate in design; ensure adequate factory testing before shipping to network integration centre
14	Cost of tests exceeds forecast	The scope of works results in quote significantly beyond what was expected	Increased cost or decreased scope (question over minimum value)	Market engagement to determine best possible course of action; identify cost savings in other areas of project

15	Integration to SPEN RTS	The equipment provided by different vendors does not comply with the security requirements and communication protocols used by SPEN corporate systems	Delay in the project delivery, additional cost to redesign the system architecture and purchase new fit-for-purpose IT equipment	1) Early engagement with IT to review the LV Engine schemes technical specifications 2) Provide clear requirements for integration into SPEN IT/OT systems as part of tendering documents 3) Review of tendering responses by IT team to ensure compliance
6	Lack of data	Lack of smart meter data	Insufficient smart meter data to demonstrate SST control algorithms using this data to make judgments/control measures, not able to demonstrate full functionality.	Evaluating the use of alarms, model data and predictive data
52	Power Supply	For scheme 4 (DC only substation at Falkirk) and topology 2 (no conventional transformer) it is not clear where the power will come from to supply heating, during an SST outage	During a prolonged outage, varying and low temperatures can lead to varying humidity, condensation, and equipment corrosion. The SST and expensive electronics may be particularly susceptible.	1) SST design will be reviewed for environmental strength 2) Consider part of testing scope
56	Power Supply	For scheme 4, there is still a requirement to power LED lighting, provide a tripping supply for the HV circuit breaker, and power the virtual access router.	The SST needs to provide a +24V DC output.	The SST design will incorporate a +24V DC output for topology 1 & 2.

57	Supply Chain	limited suppliers have indicated that they can provide a complete LVDC switchboard with their circuit breakers and DC switch disconnectors.	The non-compliance or technical issues are likely if the LVDC boards is ordered from one supplier and the circuit breaker from another.	Approach LV switchboard manufacturer and ask to design a complete solution which meets requirements
58	DC Metering	There is no approved DC meter by Elexon	energy supplier cannot meter the DC customers and LV Engine DC scheme fails	1) Using DC meter pulsing approved AC meter Propose an arrangement to meter energy before conversion at AC side
59	Over current protection	Over current protection may not work on the LVDC switchboard feeder circuit breakers due to low fault levels.	Unable to clear LV cable faults.	1) Could use undervoltage protection or shunt trip release from the SST 2) Appoint a supplier to develop a solution in parallel based on current above load level
60	Earth fault detection	Unable to detect earth faults due to low earth fault currents	In conventional AC systems earth faults would usually develop into three phase faults causing the fuse to blow.	Look into specifying separate earth fault leakage protection.
61	Delays to Scheme 4 site result in FCC losing access to their funding for the project	All works on LV by FCC must be done by Q1 2022 so that FCC can utilise their budget, otherwise no funding for site	Financial impact and potentially loss of trial site	SPEN to ensure all dependant works covered so they can progress, answering RFI from WSP BS
72	LV Engine trial site	Trial site is no longer available to the project	New customer demand is required to equip the substation different from what has been planned for LV Engine	Work with District delivery team to influence the design and find a solution that in addition to customer demand the LV Engine can be also satisfied

73	LVDC protection	LV DC protection strategy cannot pass the test in Network Integration testing	Falkirk site commissioning will be delayed	Run extensive simulations to ensure the protection strategy is feasible, share the strategy with manufacturers and other project partners to capture any issue in advance Develop alternative solution as Plan B in case original plan does not work

11 Accuracy Assurance Statement

I therefore confirm that processes in place and steps taken to prepare the PPR are sufficiently robust and that the information provided is accurate and complete.

Signature: _____

Name (Print): _____

Title: _____

Date: _____

Signature: _____

Name (Print): _____

Title: _____

Date: _____

12 Material Change Information

We initially plan to complete the project by December 2022 in line with Project Direction. However, due to very unexpected COVID 19 pandemics, we faced number of significant challenges in supply chain and resources availabilities that delayed the project. This was in addition to challenges we naturally had for a uniquely innovative development.

In order to complete LV Engine deliverables and achieve the target learnings, we requested Ofgem for the project deadline to be extended with target for completion by 31 December 2024. This extension will be in line with NIC Governance allowing 2 years delay in project completion.

13 Other

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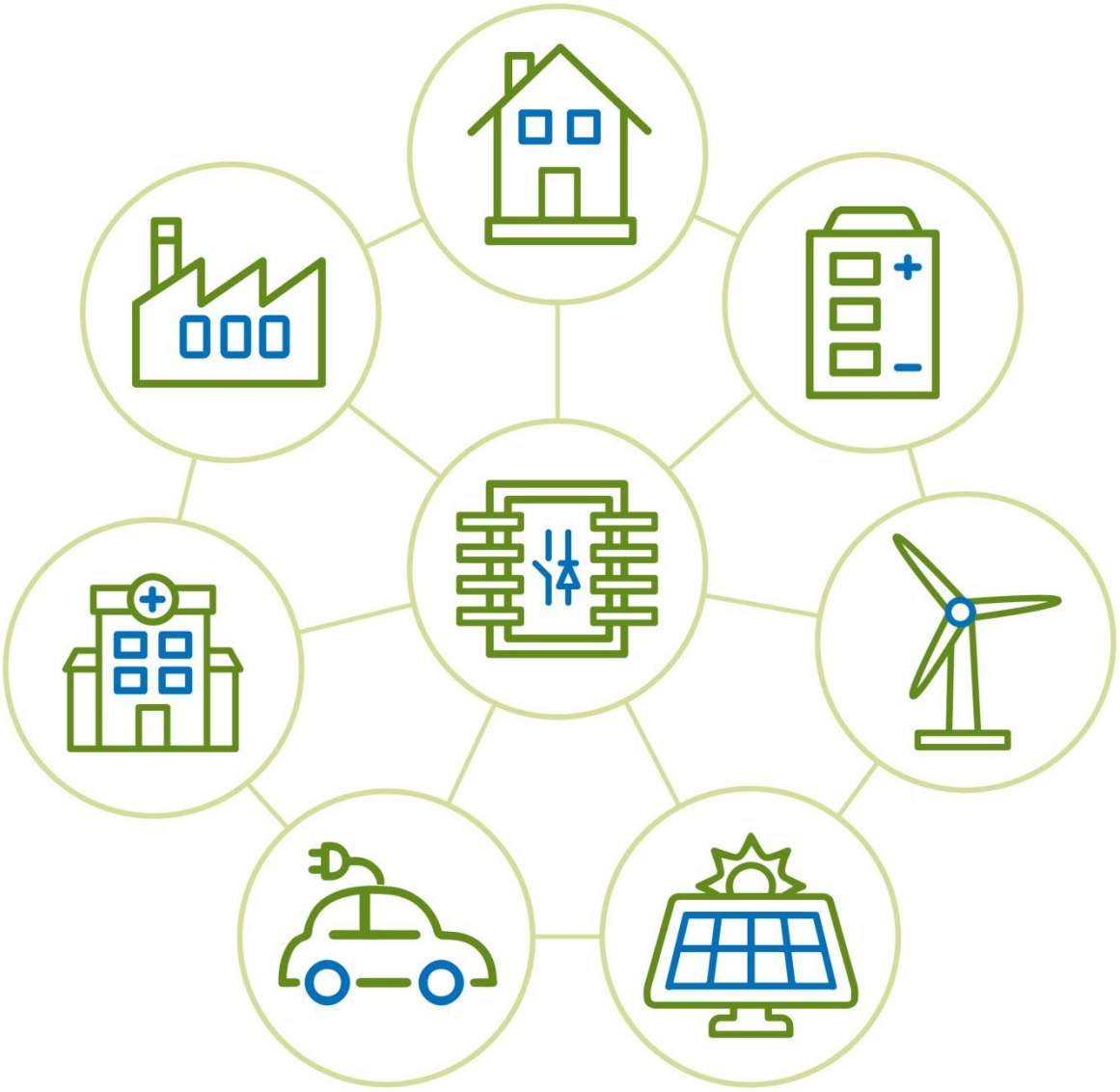

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