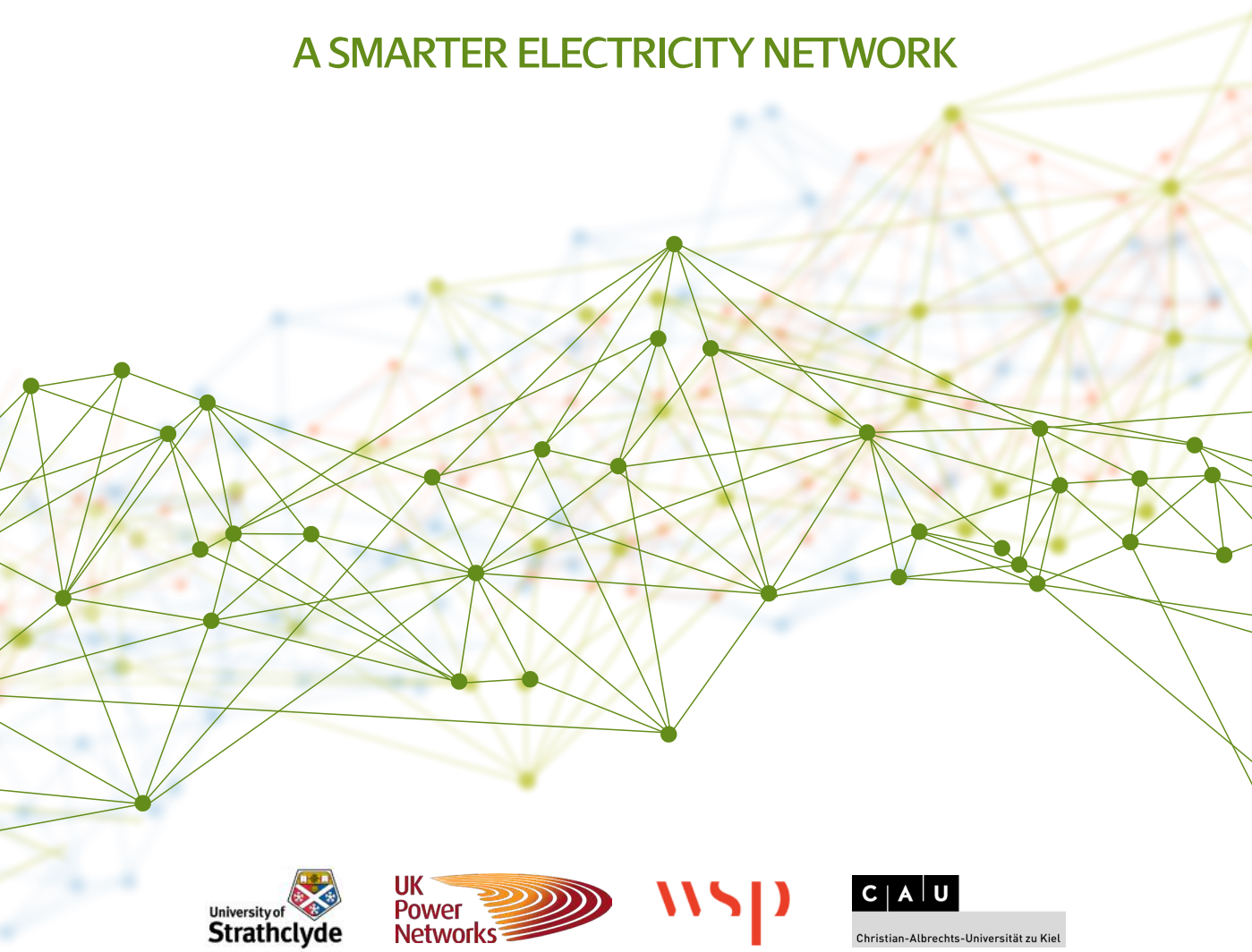
SP ENERGY NETWORKS

RIIO NIC NETWORK INNOVATION COMPETITION

# LV ENGINE

## A SMARTER ELECTRICITY NETWORK



University of Strathclyde

UK Power Networks

WSP

CAU Christian-Albrechts-Universität zu Kiel

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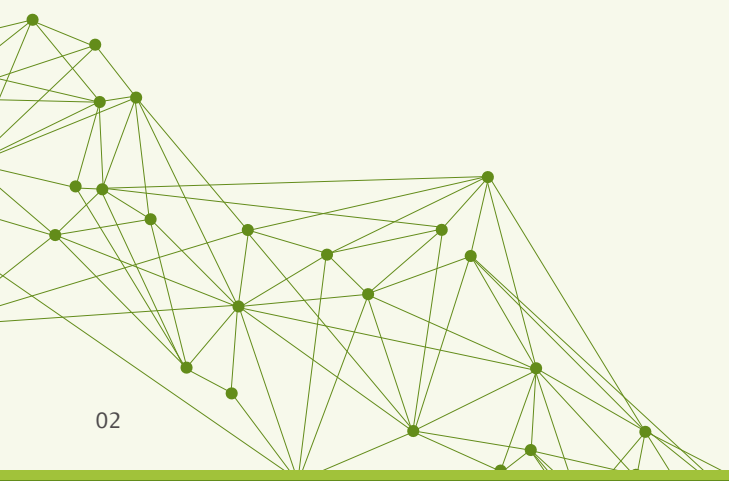


# 1 | Executive Summary

## We are changing the way we generate, distribute and use electricity.

**At SP Energy Networks we recognise the need to facilitate the transition to a low carbon economy. To enable this transition SP Energy Networks must ensure that our electricity network is able to facilitate the increasing uptake of various Low Carbon Technologies (LCTs) such as Electric Vehicles and Photovoltaics. These LCTs often connect to the 11kV and Low Voltage (LV) distribution networks and can cause a strain if not properly managed. This transition is in line with the UK governments CO2 reduction targets which are driving an increase in the electrification of both the heat and transport sectors.**

This shift in how the distribution network is being utilised is creating a number of important challenges which required innovative solutions. These challenges include:

- An increasing strain on the existing 11kV & Low Voltage (LV) networks causing operation out with voltage statutory limits and the thermal capacity of our assets.
- Difficulties ensuring cost effective network design due to the uncertainty in the uptake of LCTs such as electric vehicles.
- An increasing demand for LV Direct Current (DC) connections and the associated network and customer benefits, such as lower network losses.

LV Engine is a flagship innovation project funded via Ofgem Network Innovation Competition (NIC) and led by SP Energy Networks. The project intends to provide an innovative solution to address these challenges and could be a key enabler of a future Distribution System Operator (DSO) model. The project began in 2018 and will carry out a globally innovative trial of Smart Transformers within secondary substations on the distribution network. The use of these power electronic transformers will allow network companies to better facilitate the uptake of important LCTs by intelligently regulating important network parameters from our secondary substations.

During this innovative network trial we will compare the performance of Smart Transformers with that of conventional transformers. This comparison will lead to a number of technical guidance documents and methodologies to inform the optimal selection of secondary transformers given the functionality required at each location.

We will ensure that the Smart Transformers designed within this project are fit-for-purpose within secondary substations and can be reliably deployed as standard once the project is complete. The network trial will take place within both the SP Manweb and SP Distribution licenced areas and demonstrate the additional capacity that can be achieved through the use of this technology.

LV Engine will significantly enhance the flexibility and adaptability of LV networks to facilitate the uptake of low carbon technologies. This will provide us with an innovation solution to avoid costly network reinforcement where possible and keep electricity distribution costs low and stable for our customers.

LV Engine will deliver savings to our customers by facilitating the uptake of LCTs within the 11kV and LV networks. The project will demonstrate how Smart Transformers can be a competitive alternative to conventional reinforcement. The project will stimulate a competitive market place for power electronics and Smart Transformers within the UK Distribution network. If successful, the roll out of our LV Engine solution could represent a potential saving of £62m by 2030 and £528m by 2050 for GB electricity consumers. The project will also generate valuable learnings for future power electronic and LVDC innovation projects.

**Anthony Donoghue**
LV Engine Project Lead

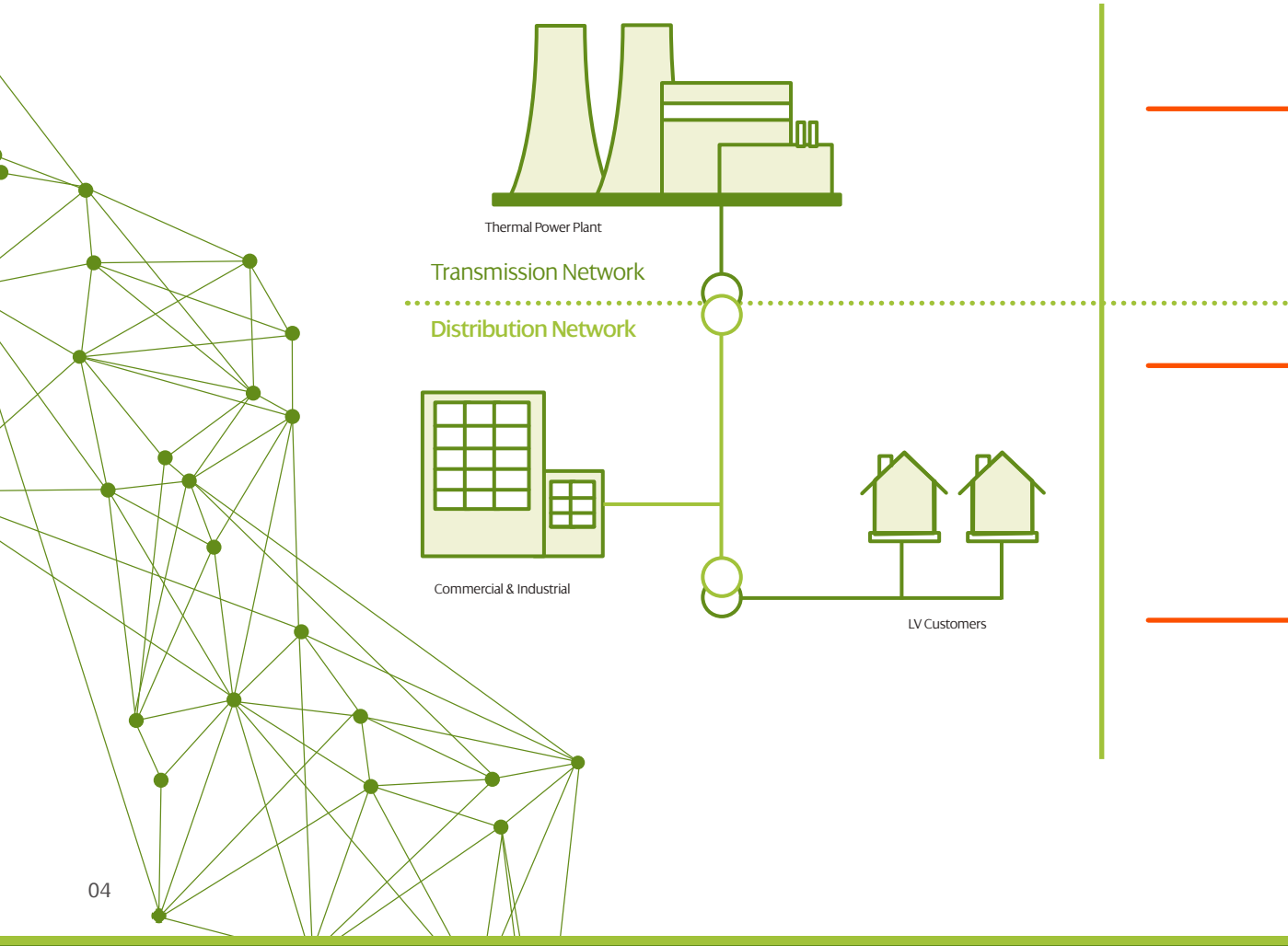
# 2 | Introduction

**Within the UK, the government has ambitious targets to combat climate change. This is driving the electrification of both the heat and transport sectors and the connection of renewable generation. This renewable generation is causing a shift in how electricity has traditionally been generated and distributed.**

A conventional 'fit-and-forget' design approach no longer represents value for money for UK electricity consumers. We must transition from a passive distribution network to a more intelligent active system which can accommodate reverse power flows caused by small scale renewable generation.

We are identifying new opportunities and challenges within our electricity network. One of the challenges we are faced with is the unpredictable and intermittent nature of many Low Carbon

Passive distribution network with unidirectional power flows

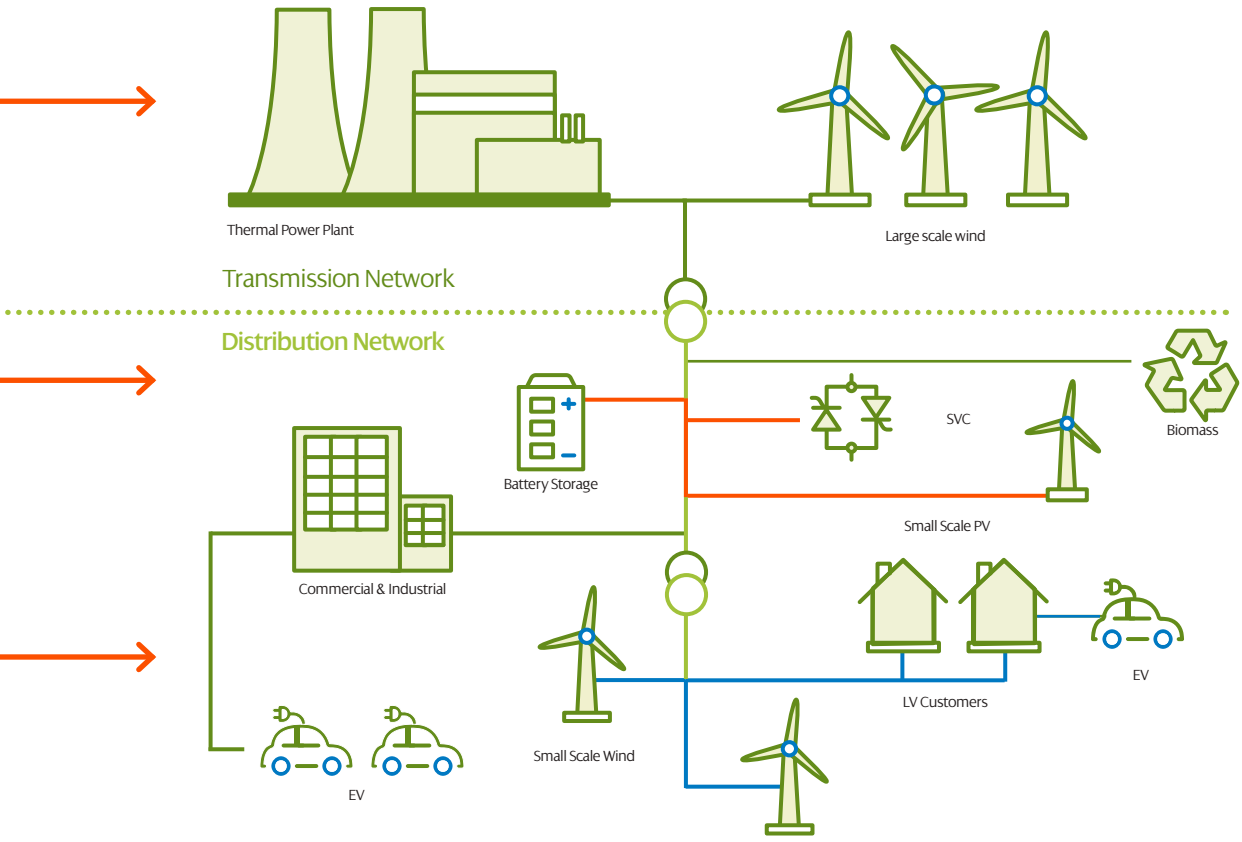


Technologies (LCTs). Renewable generation and demand must be balanced at all times to ensure a reliable customer supply. A more active distribution network will allow us to ensure a reliable network long into the future whilst accommodating the connection of new innovative technologies.

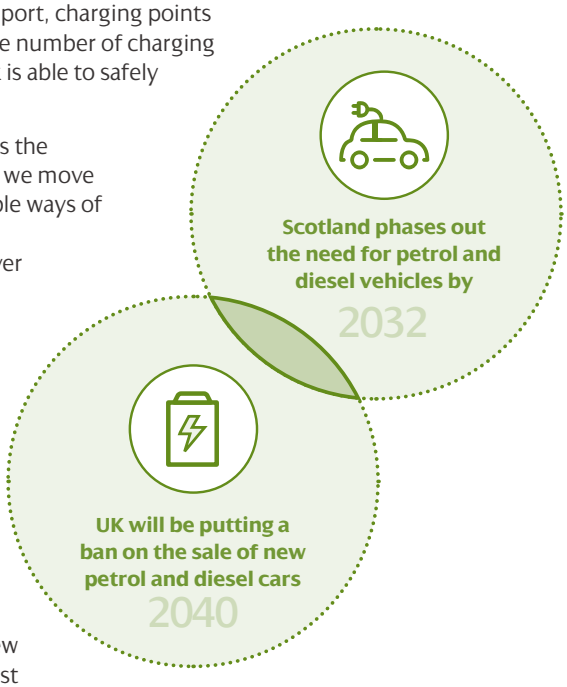
Renewable generation from LCTs such as wind turbines and photovoltaics is continuing to increase as more customers take the opportunity to generate their own green electricity. Our customers are now becoming prosumers (produce and consume electricity). Should our prosumers generate more electricity than their household or business require at any one time we need to facilitate a bidirectional flow of electricity so the energy generated can be distributed locally to other neighbouring consumers.

Through innovation projects like LV Engine we will create a smarter and flexible network that can facilitate the move to a low carbon economy as demanded by society.

## Active distribution network with bidirectional power flows



Furthermore, electric vehicles are expected to grow significantly within the UK as Scotland phases out petrol and diesel vehicles by 2032 and the UK bans the sale of new petrol and diesel cars in 2040. To enable this electrification of transport, charging points must be connected across our electricity network. As the number of charging points increases we must ensure our electricity network is able to safely accommodate this significant growth in the demand.




Electric heat pumps are also becoming more desirable as the primary method to heat households and businesses. As we move from the traditional use of fossil fuels to more sustainable ways of powering our communities we are in need of low cost solutions to reinforce our network and continue to deliver value to our customers.

Historically, electricity networks have provided an AC customer supply. However, many LCTs and household devices now operate on a DC voltage. This requires conversion from an AC to DC voltage which creates costly losses. The demand from DC devices and appliances is only expected to increase particularly as the uptake of LCTs accelerates.

LV Engine intends to design a Smart Transformer which can provide a low voltage DC supply to our customers for the first time whilst maximising the use of our existing AC network. The project will provide a new solution for reinforcing the existing network at lower cost whilst ensuring that the electricity network is able to facilitate the changing needs of our customers.

The project will investigate the benefits of using Smart Transformers within our secondary substations. These transformers are expected to add flexibility and release additional capacity within the existing distribution network. The project will unlock new opportunities to accommodate the capacity required by renewable distributed generation including important technologies such as Electric Vehicles, Solar Panels and Heat Pumps. LV Engine will create a scalable, flexible and adaptable solution.

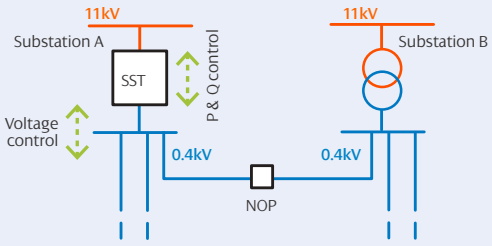
To date the use of Smart Transformers has never been demonstrated within any electricity network around the world. Consequently, the project will ensure the design of the Smart Transformers is suitable for use within a distribution network and can be relied upon all year round. During the live network trial of the technology we will ensure our customers supply is not compromised by implementing a number of risk mitigating control measures including parallel operation with existing conventional transformers.

# 3 | About LV Engine

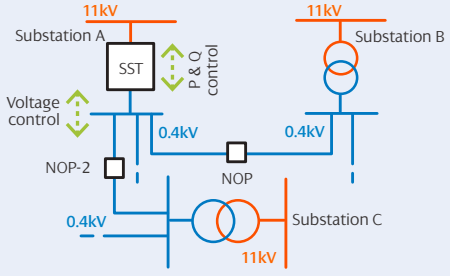
**Within LV Engine we will design, manufacture and trial a number of fit-for-purpose Smart Transformers for use within our secondary substations. This is the first UK grid application of Smart Transformers and will allow us to enhance the flexibility of our electricity network and release more capacity for the connection of Low Carbon Technologies (LCTs). The project will inform the future design and selection of the most cost effective secondary transformer solution given the network and customer requirements.**

Smart design tools will be produced to enable the efficient reinforcement of the future LV network. Smart Transformers will be trialled within five different schemes and their performance will be technically and financially compared against conventional reinforcement and transformers fitted with On-Load-Tap-Changers (OLTC). The comparison of the two solutions will inform a series of technical and financial guidance documents for the selection of the future LV network reinforcement solutions which deliver the best value for money for UK electricity customers.

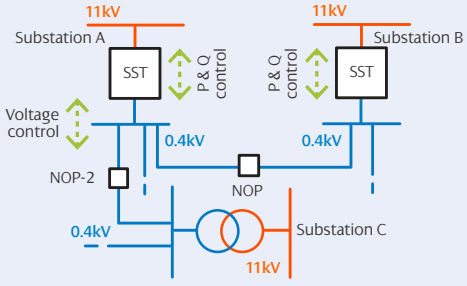
**Scheme 1**



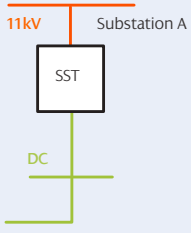

**Scheme 2**



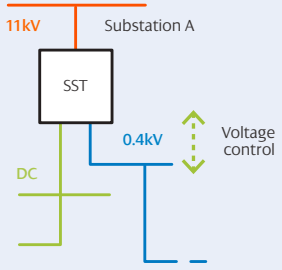

**Scheme 3**




**Scheme 4**




**Scheme 5**



**Smart Transformers have the ability to provide multiple functionalities that can bring value to the 11kV and LV networks. LV Engine will demonstrate the following preliminary Smart Transformer functionalities under different network conditions. We believe these functionalities could be key enablers of a DSO future.**

- Optimum real-time phase voltage regulation in LV networks
- Capacity sharing between secondary substations with complementary load profiles where spare capacity is available
- Fault level control to allow meshed LV network operation
- Provision of LVDC supply for electric vehicle charging and LED street lighting
- Phase balancing to reduce voltage imbalance between phases.

**LV Engine will enable the LV network to be scalable, flexible and adaptable to accommodate the uptake of various LCTs. The high level objectives of LV Engine includes:**

- Design and trial of the first UK grid connected Smart Transformers for application within secondary substations.
- Provide functional specifications and control strategies for deploying the smart functionalities which a Smart Transformer can provide in different network conditions.
- Compare the performance and functionalities of Smart Transformers with those of conventional reinforcement and transformers fitted with OLTCs.
- Provide technical guidance, policy documents, a cost benefit analysis methodology and tools for the intelligent selection of future secondary transformers to ensure the Business as Usual (BaU) adoption of Smart Transformer technology.
- Provide functional specifications of a fit-for-purpose network design to inform the provision of LVDC supplies to UK electricity customers from Smart Transformers.
- Demonstrate the protection of LV networks where power electronics are used.
- Stimulate the Smart Transformer market for future competitive production of this technology.
- Provide performance data together with the control algorithms to universities for further academic research and development.
- Up-skill internal staff on power electronics technologies and applications within distribution networks and the value it can bring.
- Knowledge dissemination to UK Distribution Network Operators (DNO) and the UK power electronics industry to facilitate the replication of the LV Engine solution across GB.
- Collaborate with our project partner, UK Power Networks, to develop a solution which can be adopted by all UK DNOs for BaU planning and operation of LV networks.

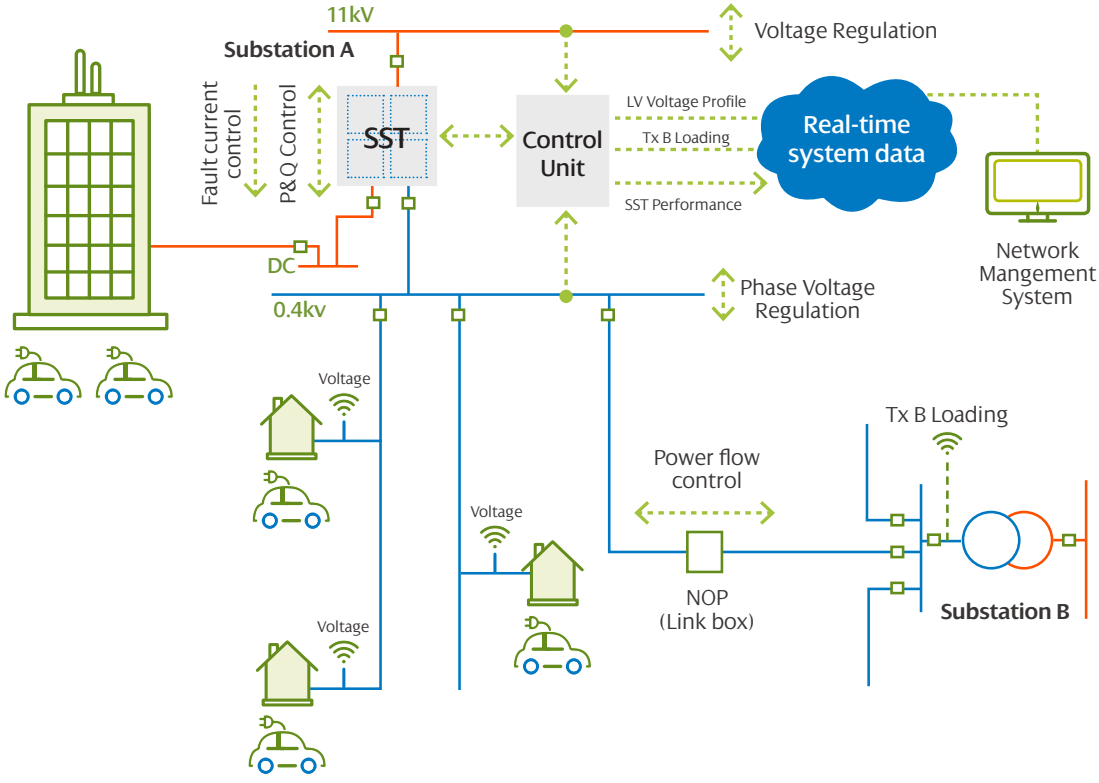
**A general concept of the proposed method is illustrated on page 9. Smart Transformers provide functionalities which can be deployed for enhanced network operation, more efficient use of networks assets and a more intelligent way to facilitate the connection of various LCTs.**

## Smart Transformer Functionalities

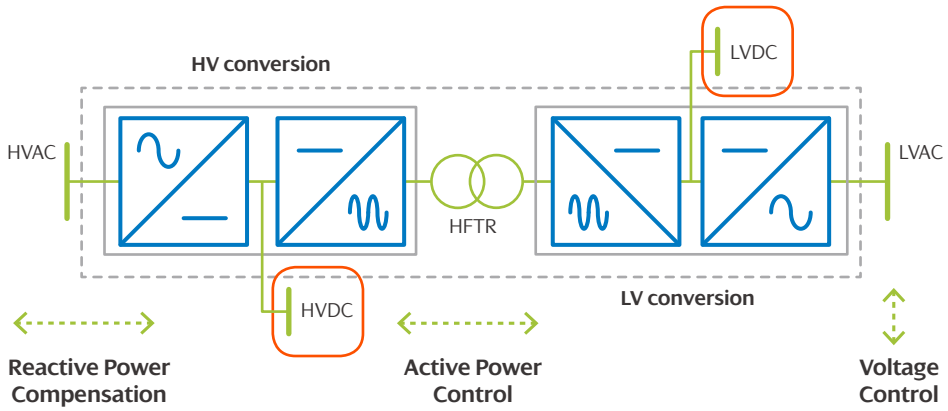
- Optimum LV phase voltage regulation
- Optimum active power sharing between neighbouring substations
- Voltage regulation at MV (11kV) network
- Provision of a LVDC customer supply.
- Modular design and scalability

The Smart Transformers used within the project will gather important data points from around the network to establish the optimum solution for controlling the network. This data will be used to control the various functionalities provided by the Smart Transformers. We intend to take advantage of the data provided by SMETS2 smart meters to gain an insight into the voltage profile along the length of the LV network. This valuable data will allow the Smart Transformers to operate the existing network optimally and efficiently.

The LV Engine projects aims to provide a fit-for-purpose Smart Transformer design and relevant control functions that can be repeated and adopted by all GB DNOs.



A Smart Transformer is a digitally controlled power electronic device otherwise known as a Solid State Transformer (SST). It is a collection of high-powered semiconductor components which can provide a high level of control to the distribution network. Smart Transformer technology can step up or step down Alternating Current (AC) voltage levels just like a traditional transformer but can also offer significant advantages, such as two way power flow, input and output of both AC and DC voltages. It can actively change power characteristics such as voltage and frequency levels. These capabilities are possible by converting the AC power to DC and conditioning the DC power before converting it back to AC for consumption by our customers.

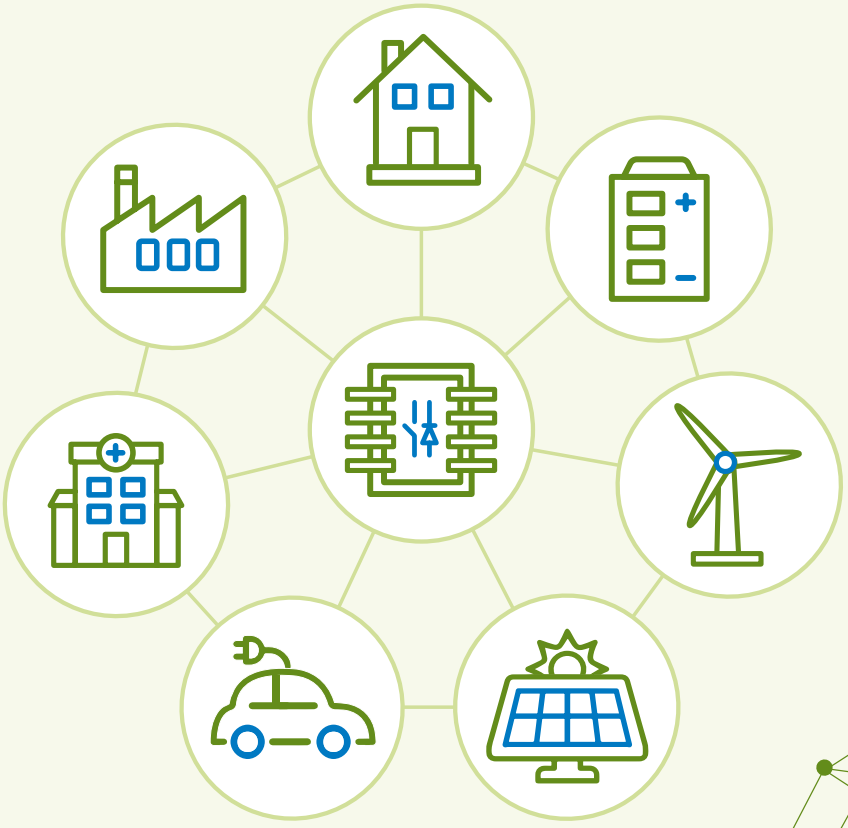



There is considerable interest in the development of Smart Transformers within academia and by manufacturers, who both see the potential for such devices within the electricity distribution of the future. Many design topologies have been proposed for Smart Transformers and our initial engagement with manufacturers has confirmed that there are a number of viable designs. We will work with our chosen manufacturing partner(s) to design a fit-for-purpose topology that can be adopted for distribution network application.

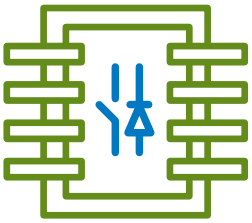
An exciting area of innovation investigated within LV Engine is the provision of a DC supply from the Smart Transformer. A DC supply has many benefits for both our customers and the electricity network. At DC customer losses and equipment costs can be significantly reduced whilst the capacity of the existing electricity network can be increased without costly reinforcement. There are many potential DC customers. These include:

- Electric Vehicles
- Heat Pumps
- Solar Panels / Photovoltaics
- Energy storage units
- Electronic DC appliances such as computers and LED lighting

# 4 | An Intelligent Grid to Power Communities



# 5 | Timescale



## 1. Technical requirements

We are creating an understanding of the technical requirements for optimum voltage regulation, power flow control and protection scheme design for the LV network. We will gain knowledge about the fit-for-purpose functionalities of a LV Smart Transformer.

## 3. Test in network integration facilities

The prototype Smart Transformers will be tested within a network integration testing facility to confirm that the Smart Transformer can be reliably used on the Great British (GB) Grid and help create a smarter flexible network for our customers.

January *2018*

## 2. Select manufacturing partner and technical design

We will be selecting our manufacturing partner through a competitive tender process, all project partners will work alongside the selected manufacturer to design a fit-for-purpose Smart Transformer. Health and Safety matters to us. We will be testing and manufacturing the Smart Transformer in a laboratory to ensure it meets all the health and safety requirements

## 5. Develop the best operational practice

We are going to develop the best operational practice and best policy documents which can be used as guidance for selecting the secondary transformers of the future. This will enable the development of a road map for Business as Usual (BaU) adoption of the technology throughout GB.

December *2022*

## 4. Trial in our Electricity Network

We will undertake live trails at 6 different locations within both our SP Manweb and SP Distribution licence areas. Here we will record performance data at various sites under different network conditions. We will then compare the Smart Transformers to the conventional transformers so we can complete an evaluation and identify the benefits LV Engine will bring to customers.

## 6. Dissemination

We will be effectively disseminating the lessons learnt during LV Engine to other DNO's to ensure we can create a smarter, flexible network for all customers. This will allow efficient replication of LV Engine in all locations and help GB to achieve its targets as together we make the move to a low carbon economy.

# 6 | LV Engine's Solution

The methods proposed by LV Engine will significantly enhance the flexibility of the LV network and enable an active and adaptive LV network operation paradigm. Passive LV networks can no longer provide the best value for money for our customers in a low carbon energy system. LV Engine will demonstrate that the deployment of flexible and smart secondary substations can be a superior alternative to conventional reinforcement. The design, manufacturing and proof of technology of a Smart Transformer will also create a competitive market reducing the Smart Transformer cost whilst improving quality.

## Solutions LV Engine will enable

- **Active operation of LV networks**

An active and adaptive LV network operation scheme is required to accommodate the long-term and short-term uncertainties in LV customers' demand and generation; otherwise significant network reinforcement may be required to keep the network operational.

- **Better utilisation of network assets**

The LV Engine method enables an alternative solution to conventional reinforcements, the cost of which may increase significantly during RIIO-ED2 due to growing low carbon technologies integration.

- **Facilitate the integration of Low Carbon Technologies**

The UKs low carbon emission targets depend on the successful integration of low carbon technologies within the LV network. However, the clustered integration of low carbon technology demand and generation may be delayed due to network voltage and thermal issues.

- **Support Distribution System Operator (DSO) operation transition**

LV Engine will provide the future DSO with tools and methodologies for real-time management of network constraints.

The LV Engine project is highly innovative and expected to generate significant learning to enable a more flexible and controllable distribution network.

## Opportunities unlocked through LV Engine

- The design and manufacturing of Smart Transformers with expectations to increase the Technology Readiness Level (TRL) from 5 to 8 over the period of the project.
- Increased controllability of the LV network is a major opportunity which can be achieved through use of the Smart Transformer functionalities and innovative control algorithms.
- The provision of an LV DC supply to better facilitate electric vehicle charging infrastructure and other DC customers is a major opportunity. This has is first amongst all GB DNOs so valuable learnings will be generated that can be adopted by all.
- Development of an updated methodology for designing the distribution network which considers the use of Smart Transformers alongside conventional transformers will provide a more cost effective approach to future network design.

During LV Engine we will overcome several important challenges. To overcome these challenges the project has been divided into seven work packages. This gives a focus to the major activates and developments required for successful project delivery.

| | |
|---|---|
| **Work Package 1 – Technical Design**<br>**March 2018 to November 2018** | Focuses on developing the technical specifications required for the manufacturing and implementation of the Smart Transformers alongside the trial site selection methodology to identify the optimal trial sites for each LV Engine scheme. |
| **Work Package 2 – Partner Selection and Procurement**<br>**September 2018 to February 2019** | The selection of a manufacturing partner(s) through a competitive tendering process. This includes the procurement of the equipment required for each LV Engine scheme. |
| **Work Package 3 – Design and Manufacturing of Smart Transformer**<br>**February 2019 to December 2020** | Designs and manufactures fit-for-purpose Smart Transformers based on the technical requirements and functionalities developed within WP 1. |
| **Work Package 4 – Network Integration Testing**<br>**October 2019 to August 2020** | Tests the functionalities and reliability of the manufactured Smart Transformers in a network integration testing facility to obtain a network certificate prior to the live network trial. |
| **Work Package 5 – Live Network Trial**<br>**November 2019 to October 2022** | A live network trial of the manufactured Smart Transformers. This includes all activities required for site preparation, installation, commissioning and performance monitoring of the LV Engine schemes. |
| **Work Package 6 – Development of Novel Approach for Transformer Selection**<br>**November 2019 to October 2022** | A live network trial of the manufactured Smart Transformers. This includes all activities required for site preparation, installation, commissioning and performance monitoring of the LV Engine schemes. |
| **Work Package 7 – Dissemination**<br>**March 2018 to December 2022** | Disseminates the lessons learnt and the techniques implemented in LV Engine to interested parties in particular UK DNOs, academics and UK power electronics industry. |

# 7 | Benefits for our Customers

LV Engine will uncover new and innovative approaches to unlock the capacity available within our existing LV infrastructure. It will facilitate the uptake of Low Carbon Technologies (LCTs) on the scale demanded by society, whilst providing the flexibility required due to the uncertainty surrounding the nature and timing of their uptake. If rolled out across GB, LV Engine has the potential to deliver capacity for the connection of low carbon technologies, provide environmental benefits and financial benefits to customers.

The total financial benefit of

**£62m**

by 2030

and

**£528m by 2050**

in avoided network reinforcement across GB


Reduce CO2 emissions by

**418,307**

tonnes by 2030

and

**1,314,050**

tonnes by 2050

Reduce system losses and network reinforcement by facilitating a future LVDC supply for our LV customers

**One of our key areas of focus is delivering value to our customers.**

Based upon our assessment of the potential benefits that will be generated by LV Engine, we estimate the full project funding will be return to GB electricity consumers within 7 years of the start of the project. There are additional financial benefits that have not been quantified at the stage, but will be better understood as the project progresses and learnings are collated.

- Reduction in network charges through avoiding and deferring costly network reinforcements.
- Facilitate access to low cost energy by enabling more PV connections for the purposes of addressing fuel poverty.
- Providing scalability to secondary substations due to the modular nature of Smart Transformer technology, which will enable capacity of an Smart Transformer be increased at limited cost and disruption to customers by adding additional "capacity blocks" when demand increases.
- Enabling the transition to DSO by removing LV network constraints and increasing flexibility and adaptability of the LV network.

• Delivering a cost competitive, fit-for-purpose Smart Transformer design for deployment within distribution networks which can be adopted by other UK DNOs quickly to facilitate the uptake of the technology into BaU practices.

LV Engine's Smart Transformers are capable of providing the network with benefits that are not directly quantified within the financial analysis. Specific deliverables have been included within the projects work packages that will be allowing us to quantify the value of Smart Transformers more accurately.

### Deliverables

• A detailed Cost Benefit Analysis (CBA) of the LV Engine schemes post trial.

• A CBA methodology and toolset for the BaU deployment of Smart Transformers.

The tools produced within the project will allow us to better understand the network and customer benefits associated with the project. These tools will be informed by both our live network trial and the detailed Smart Transformer designs that are developed during the project.

• Voltage support and reactive power contribution to the 11kV network

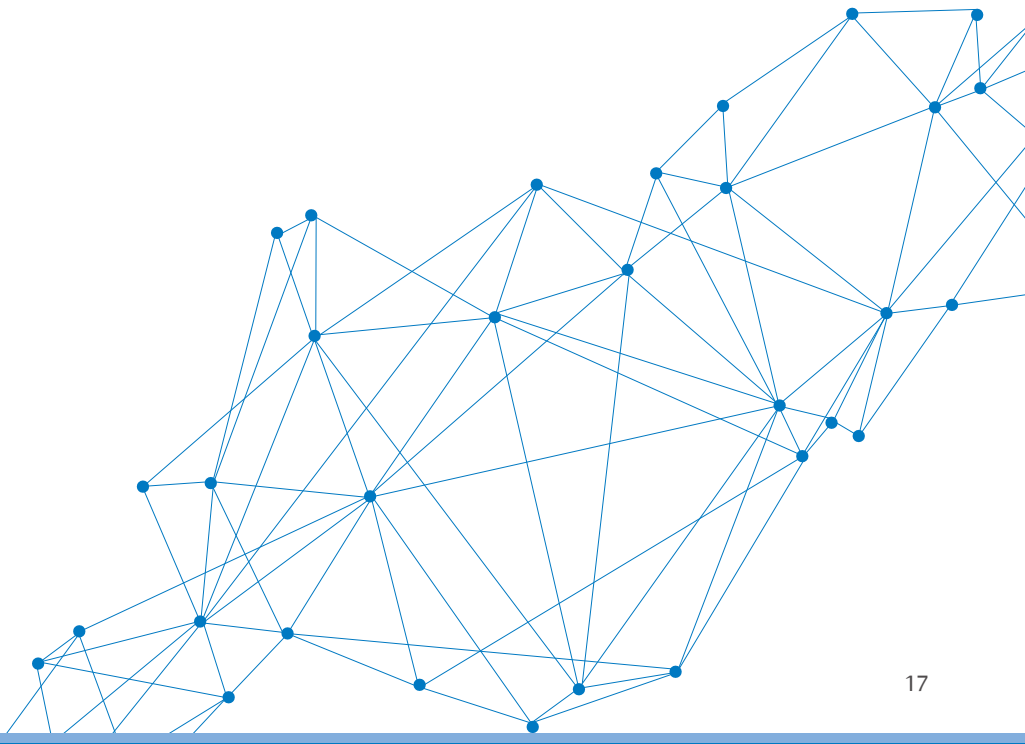
• The value of a low voltage DC supply to electricity customers

• Capacity increase of Smart Transformer with modular "capacity banks"

• Power quality improvement by operating Smart Transformers as active harmonic filters

• Value of any reduction in substation footprint

• Peak shaving by exercising conservation voltage reduction



# 8 | Funding

**LV Engine is a flagship innovation project funding through Ofgem's Network Innovation Competition (NIC) fund, Network licence compulsory distribution and external funding.**

| | |
|---|---|
| • NIC fund | £7,290,060 |
| • Network licence compulsory distribution | **£824,160** |
| • External funding | £53,690 |
| • Total funding | **£8,295,280** |

# 9 | More information

LV Engine will be delivered with the collaboration of various industrial and academic parties. UK Power Networks is another network operator within Great Britain who have partnered with us to deliver this project. This collaboration will ensure the LV Engine solution can be replicable by other GB DNOs. We have also brought in experience from academia including University of Kiel in Germany and the University of Strathclyde. These universities are bringing significant experience in Smart Transformers and LV DC design and applications. Additionally we have WSP acting as our lead technical consultant.

**Project Supporters**

- Glasgow City Council
- Liverpool City Council
- British Standards Institute (BSI)
- The Institute of Engineering and Technology (IET)
- International Electrotechnical Commission (IEC)
- BRE
- PowerElectronicsUK
- Chargemaster
- Franklin Energy

**Project Partners**

- SP Energy Networks
- UK Power Networks
- WSP
- University of Kiel
- University of Strathclyde

# 10 | Glossary of Terms

| Abbreviation | Definition |
|---|---|
| **AC** | Alternating Current |
| BaU | **Business as Usual** |
| **CBA** | Cost Benefit Analysis |
| DC | **Direct Current** |
| **DNO** | Distribution Network Operator |
| DSO | **Distribution System Operator** |
| **LCTs** | Low Carbon Technologies |
| LVDC | **Low Voltage Direct Current** |
| **LV** | Low Voltage |
| NIC | **Ofgem's Network Innovation Competition** |
| **OLTC** | On-Load-Tap-Changers |
| TRL | **Technology Readiness Level** |

SP ENERGY NETWORKS

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