Question No.	From	Proforma section	Criteria	Question	Date question asked	Date response required	Date received	Follow up to Question #	Confidential (y/n)
1	CO	n/a	b) Value for money	Selecting a single OEM will give them any unfair market advantage over their competitors for future applications. Has the advantage of engaging more than one OEM been considered?	22/08/2017	24/08/2017	23/08/2017		
2	CO	n/a	g) Robust methodology/ready to implement	For the LVDC supply option there is presently no LVDC metering available. How will the DC metering be procured? Is there agreement with Elexon regarding the registration requirements for meters of this type?	22/08/2017	24/08/2017	23/08/2017		
3	CO	n/a	g) Robust methodology/ready to implement	Have all the safety cases been developed for the use of LVDC systems in customer premises and on DNO networks?	22/08/2017	24/08/2017	23/08/2017		
4	NC		a) Enviro+consumer bens	Your submission shows the financial benefits of the proposed trial method versus conventional reinforcement. Please explain why conventional reinforcement is the most efficient method in use today. Have you considered other methods to address the problem, eg ANM or DSR. Within the Poyry report (which accompanied the Innovation Review) you contributed data to indicates 37% of the methods trialled under the LCN Fund are ready for use in business as usual and a further 41% are ready for use in the right circumstances. This would imply that there are more efficient methods available to licensees than traditional reinforcement.	24/08/2017	29/08/2017	25/08/2017		
5	NC	C5.1	g) Robust methodology/ready to implement	Please explain how the method to be trialled (a radial solution) would be applied on the lead licensee's meshed network?	24/08/2017	29/08/2017	25/08/2017		
6	NC	C5.1	g) Robust methodology/ready to implement	On page 54 you refer to figure C-9. Where is this within the submission?	24/08/2017	29/08/2017	25/08/2017		
7	NC	n/a	d) Is innovative	With specific reference to the TRL definition in the governance document please justify the stated TRLs within the submission.	31/08/2017	07/09/2017	07/09/2017		
8	EP	n/a	Multiple	Please provide information on the type of Customer you expect to request a DC link from the transformer. Within this response please outline how many requests you have received for such a link.	05/09/2017	07/09/2017	07/09/2017		
9	EP	n/a	g) Robust methodology/ready to implement	What percentage of current transformers do you believe could/ should be replaced by these solid state transformers?	05/09/2017	07/09/2017	07/09/2017		
10	EP	n/a	a) Enviro+consumer bens	We note your answer to question 4. Please provide more information on why you have not considered vacuum tap transformers to be the counter factual solution for these transformers?	05/09/2017	07/09/2017	07/09/2017		
11	EP	n/a	d) Is innovative	Has this type of transformer been successfully demonstrated within a test centre environment?	05/09/2017	07/09/2017	07/09/2017		
12	EP	n/a	a) Enviro+consumer bens	What would be the impact on the benefits proposed if the DC connection element was not part of the project?	05/09/2017	07/09/2017	07/09/2017		
13	EP	n/a	b) Value for money	Please clarify how you will ensure the tender for the transformer manufacturer provides value for money to consumers. How will you mitigate the risks of not identifying a supplier of this unproven technology for the price listed within the submission?	05/09/2017	07/09/2017	07/09/2017		
14	NC	n/a	b) Value for money	At the end of the project will the designs for the SST be open source?	12/09/2017	14/09/2017	14/09/2017		
15	EP	n/a	a) Enviro+consumer bens	Please confirm whether the Carbon Figures solely relate to CO2. If not, please list the other Greenhouse Gasses included within the figure.	12/09/2017	14/09/2017	14/09/2017		
16	EP	n/a	Mulitple	The Expert Panel would welcome a written commitment from senior management to utilise the technology/ new CBA tool created by the project if it is successful.	12/09/2017	14/09/2017	14/09/2017		
17	EP	n/a	b) Value for money	Please explain how you justify the contribution from the equipment supplier. How have you ensured this contribution provides value for money to consumers when compared to the potential benefits on offer if the technology is proven to be succesful on the network	12/09/2017	14/09/2017	14/09/2017		
18	EP	n/a	b) Value for money	What sort of learning will you share with Power Electronics UK? How can this be guaranteed before the contracts have been signed?	12/09/2017	14/09/2017	14/09/2017		
19	NC	9	Mulitple	Given the learning associated with Work Packages 2 and 3 may not be able to be fully shared and will only contribute to learning in the sense of informing the manufacturer and SP Energy Networks whether it is possible to design and manufacture a SST, please provide a justification that the proposed percentage of funding associated with this deliverable is appropriate.	14/09/2017	19/09/2017	19/09/2017		
20	NC	9	Mulitple	Given each step of project deliverable four would have to be undertaken for any new piece of equipment and it is not clear what learning will be gained from this step please provide a justification that the proposed percentage of funding associated with this deliverable is appropriate.	14/09/2017	19/09/2017	19/09/2017		
21	GS	n/a	Mulitple	With the use of solid state transformers there will be significant reduction in LV fault levels on, both radially fed and meshed, networks. Have you carried out an impact assessment of the likely implications on downstream LV protection? Which protection technologies will be used in case LV fuses are rendered inoperable? What will be the impact on LV earthing systems? Overall, how would you make sure that from protection and earthing perspective the downstream LV networks remain compliant with ESQC regulations?	21/09/2017	26/09/2017	26/09/2017		
22	EP	n/a	a) Enviro+consumer bens	You refer to the decarbonisation of electricity as a factor helping to offset the effects of the additional network losses of the method case. Please confirm that this same effect was taken into account in forecasting network losses in the counterfactual.	21/09/2017	26/09/2017	26/09/2017	15	
AQ	N/a	n/a	Mulitple	Please describe the benefits to customers by providing a future LVDC supply?	n/a	n/a	22/09/2017		
23	EP	n/a	g) Robust methodology/ready to implement	Please provide a rough estimate for the amount of time saved using this device when compared to traditional reinforcement	05/10/2017	10/10/2017	09/10/2017		
24	EP	n/a	b) Value for money	As discussed within the bilateral, please provide CBA analysis for the savings you have identified through your collaboration with UKPN's Fun-LV project.	05/10/2017	10/10/2017	09/10/2017		
25	EP	n/a	c) Generates new knowledge	In terms of capacity, please compare the power transfer for AC/ DC running over the same cable for three phrase and single phrase	05/10/2017	10/10/2017	09/10/2017		

Electricity Network Innovation Competition Full Submission

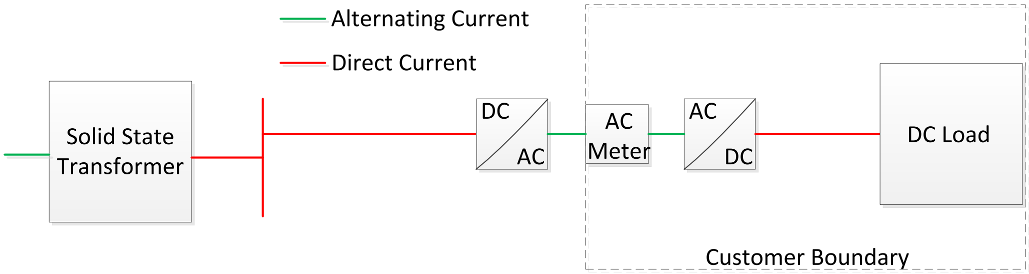
Supplementary Answer Form

Project: LV Engine

Tick if this answer has been provided verbally: ☐

Project code	SPMEN02	Question Number	Q1
Question date	22/08/2017	Answer date	24/08/2017
Submission section question relates to	N/A		
Topic	b) Value for money		
Question	Selecting a single OEM will give them any unfair market advantage over their competitors for future applications. Has the advantage of engaging more than one OEM been considered?		
Notes on question	N/A		
Answer	Yes, we are open to working with multiple manufacturers and will actively look for opportunities to promote collaboration between OEMs during the tendering process. This will ensure the project stimulates a competitive market place for Solid State Transformers within the UK. During the development of the LV Engine proposal we have engaged with 10 manufacturers and held multiple detailed discussions with each to identify those who are in a position to contribute towards the project whilst also representing best value for money. In addition, we have also distributed an "Expression of Interest (EoI)" document (Appendix Q) to allow OEMs to demonstrate their experience and capabilities and formally log their interest in the project. Within this document we specifically asked each OEM if they are willing to collaborate with other OEMs. Those who returned the EoI document have all indicated their willingness to work with others and recognise the value in doing so. During WP 2 we will carry out a fresh review of potential OEMs to ensure we identify all participants who can take part in the competitive tendering process. The funding request for the project has been designed based upon partnership with a single OEM. Consequently, if multiple OEM partners are identified it will be critical that the cost of the proposed solutions and their financial contribution represents value for money and fits within the project budget. In addition each OEM must demonstrate effective collaboration to		

	ensure that activities are not unnecessarily repeated at additional cost to the project. A detailed tendering selection criteria will be developed in the first year of project to ensure partners are chosen which best represent value for money. This criteria with clearly set out our preference to work with multiple OEMs if this can be achieved in a cost effective manner. However, if the result of the tendering process is that one OEM partner represents optimal value for money we will ensure that all critical learnings from the project are shared effectively to a wide audience so that external OEMs realise the value of developing their own SST technology independently. To do this we have developed a relationship with *PowerelectronicsUK* and intend to work with them closely to share key project learnings to a wide audience. This includes all project deliverables such as the detailed technical specifications for the SSTs and the five trial schemes in which they will be trialled. This will ensure that other OEMs can build upon the learnings of LV Engine and the project can be replicated by others efficiently. **Dr Alastair McGibbon, Director of *PowerelectonicsUK*:** *"As the main UK industry association in Power Electronics with over 70 members, we intend to work with you to promote the project and share learnings with the industry. This will help to ignite a new market place for power electronics within distribution networks in the UK and allow providers of power electronics to develop a strategic partnership with the industry."*
Attachments	N/A

Project code	SPMEN02	Question Number	Q2
Question date	22/08/2017	Answer date	24/08/2017
Submission section question relates to	N/A		
Topic	g) Robust methodology/ready to implement		
Question	For the LVDC supply option there is presently no LVDC metering available. How will the DC metering be procured? Is there agreement with Elexon regarding the registration requirements for meters of this type?		
Notes on question	N/A		
Answer	During the proposal preparation we have identified that the procurement of an approved DC meter is a risk to the delivery of the project. For this reason the chosen DC customers for schemes 4 & 5 will be metered at AC to allow standard metering procedures to be followed without the need to procure an approved DC meter. The figure below shows our intended approach to metering DC customers at AC.  **LVDC customer proposed connection methodology** During the course of the project we will consider alternative metering approaches and attempt to identify a more efficient solution that allows DC metering without impacting upon the SST design and topology, and avoiding any regulatory issues. This includes engaging with Elexon to identify a suitable DC metering arrangement which meets all registration requirements. If an approved LVDC meter becomes available we will design the schemes to include a DC meter in the place of the back to back converters shown within the figure above. It should be noted that the design illustrated above will allow us to demonstrate the principle of providing LVDC to our customers, as one of the key innovation aspects of the project, without the risks associated with procuring a suitable DC meter.		

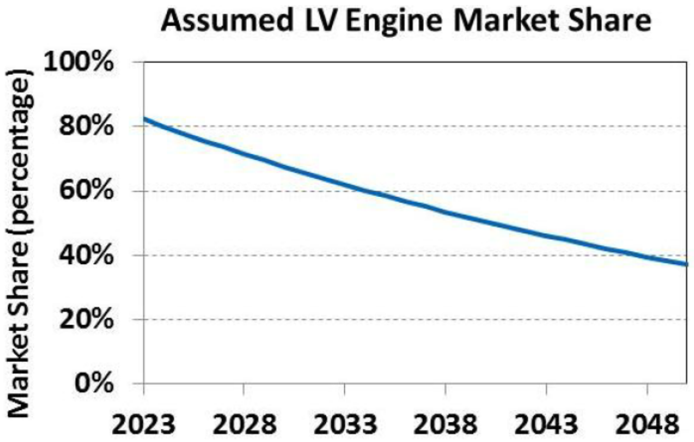
Attachments	N/A

Project code	SPMEN02	Question Number	Q3
Question date	22/08/2017	Answer date	24/08/2017
Submission section question relates to	N/A		
Topic	g) Robust methodology/ready to implement		
Question	Have all the safety cases been developed for the use of LVDC systems in customer premises and on DNO networks?		
Notes on question	N/A		
Answer	Trialling an LVDC network from a Solid State Transformer is a key element of innovation within LV Engine. The detailed technical specifications of each trial scheme including the LVDC systems will be developed during WP 1-Technical Design during the first year of the project. These specifications will include both network and customer safety requirements (voltage level, protection, earthing etc.). However, whilst preparing the LV Engine proposal we have identified relevant standards and publications that will inform the LVDC network design and specifications that will be required. We also intend to have a fresh look at on-going and previous experience in LVDC networks around the world and deploy their learnings within LV Engine. This ensures that LV Engine has a robust methodology and is ready to implement by building upon the learnings that are available from external standards and publications. Examples of the standards and publications which we have identified during the course of the proposal preparation are as follows: 1- IET Standards, Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings, 2015. 2- P. Nuutinen et al, LVDC Rules, Technical Specifications for Public LVDC Distribution Network, CIRED 2017. In addition, we are also aware of the work being carried out within IEC SG4, "Systems Evaluation Group - Low Voltage Direct Current Applications, Distribution and Safety for use in Developed and Developing Economies". We will review and consider their findings in design and implementation of LVDC network should LV Engine be awarded funding. Finally, we have included training workshops and the development of detailed installation method statements into our project delivery plan prior to the installation of each Solid State Transformer to ensure all relevant district staff is fully aware of all safety considerations and competent to		

	operate and maintain any LVDC systems. The high level risks associated with LVDC systems have been captured within our Risk Register (Appendix E) and will be reviewed in detail as a priority once the project commences.
Attachments	N/A

Project code	SPMEN02	Question Number	Q4
Question date	24/08/2017	Answer date	29/08/2017
Submission section question relates to	N/A		
Topic	a) Environmental + consumer benefits		
Question	Your submission shows the financial benefits of the proposed trial method versus conventional reinforcement. Please explain why conventional reinforcement is the most efficient method in use today. Have you considered other methods to address the problem, eg ANM or DSR. Within the Poyry report (which accompanied the Innovation Review) you contributed data to indicate 37% of the methods trialled under the LCN Fund are ready for use in business as usual and a further 41% are ready for use in the right circumstances. This would imply that there are more efficient methods available to licensees than traditional reinforcement		
Notes on question	N/A		
Answer	When constructing the Cost Benefit Analysis for LV Engine we have taken note of the guidance provided by Ofgem to ensure the financial benefits claimed are credible and accurately reflect the value of the project by considering alternative innovative reinforcement techniques. We have considered a base case which represents an average cost of BaU practices which are currently undertaken for resolving the voltage and thermal issues within LV networks. In practice there will be a range of solutions, some may involve the installation of new substations as an alternative to cable overlay, but such reinforcement is likely to be more expensive. The counterfactual is based on a traditional approach in the absence of other viable innovative solutions which offer the same range of benefits today. For instance, although time of use tariffs have been shown to provide reduction of peak loading and responsiveness to supply variations, they are not yet considered as a business as usual option. LV Engine offers a single solution for both voltage and thermal issues, whereas the same functionality may only come from the integration of multiple other solutions and such combining is not yet proven. An example is the lack of trials demonstrating the use of an 11kV/LV transformer with an on load tap changer and application of thermal monitoring to the same transformer to also increase its thermal capacity. However, we appreciate that other solutions may be proven or deployed as an alternative to LV Engine. **For this reason, within our benefit analysis we have included a generous market share for alternative innovative reinforcement approaches which may become available between 2023 and 2050.** These alternative reinforcement options include other		

techniques such as ANM, DSR, Storage, and the flexibility that could be attributed to a future Distribution System Operator (DSO). This percentage market share, as illustrated below, was multiplied by the number of opportunities calculated within our roll out methodology to acquire a reasonable estimation of the number of Solid State Transformers that will be installed across GB. In total our roll out methodology estimates that 16% of the ground mounted 11kV/0.4kV transformers will be replaced by SSTs between 2023 and 2050.



Appendix Figure C-5: Assumed market share serviced by LV Engine

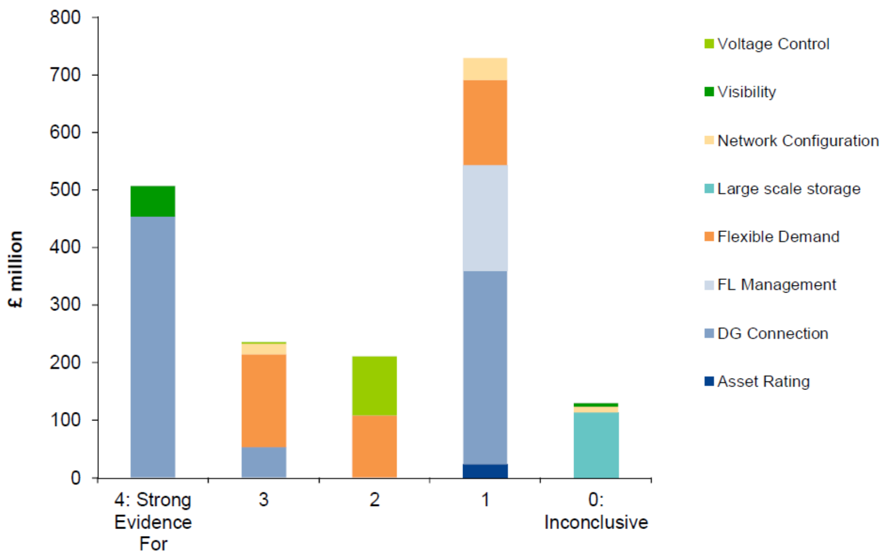
However, we believe that it is critical that DNOs develop a diverse toolbox of innovative approaches to network reinforcement that allows us to build and maintain a distribution network that remains fit for purpose and has the flexibility and adaptability to cope with the strain caused by the uptake of Low Carbon Technologies. No one solution is enough to cope with the diversity of networks and all the challenges that DNOs are expected to face.

The functionalities and benefits associated with Solid State Transformers will be an extremely valuable addition to this toolbox. To ensure this value is realised LV Engine will develop a detailed ‘Cost Benefit Analysis Tool’ which will allow Design Engineers to determined exactly when a SST delivers value over traditional and alternative reinforcement approaches. This is reflected in our decision to partner with UK Power Networks to allow us to realise the benefits associated with all LCNF projects as part of BaU where possible.

With regards to the Poyry report, it should be noted that not all of the LCN Funded projects evaluated within the report provide solutions to thermal and voltage issues within LV networks which significantly reduce the 37% and 41% figures indicated in the report. For example the ANM schemes trialled within LCN Funded projects include the control of G59 distributed generators which are mainly suitable for applications within medium voltage networks. Demand side management (DSM) solutions have been also trialled and proven for large commercial/industrial customers and these solutions is yet to be demonstrated for small residential/commercial customers within LV networks. The majority of the innovation work undertaken within LV network is in the area of monitoring and assessing the impact of different loads/generators (including LCTs) rather than providing specific solutions as is provided by LV Engine.

Figure 29 in Poyry report (which is copied below) illustrates the evidence for current BaU adoption and readiness of the different solutions trialled within Tier 1 and Tier 2 projects. The figure shows strong evidence for the BaU adoption for DG connections (which are mainly in MV networks) and network visibility, whereas the voltage control and asset rating are within low/very low evidence range.

Figure 29 – Innovation into BAU

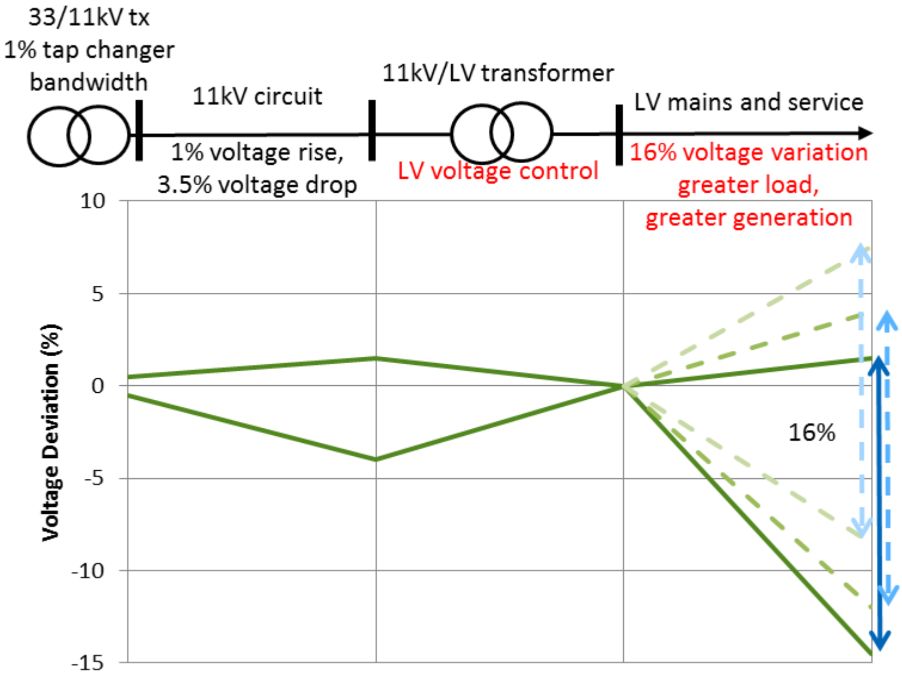


Nb. Visibility includes projects which assess innovative solutions to network monitoring
Source: GB DNOs and Pöyry / Ricardo analysis

Strong evidence for the BaU deployment of network 'visibility' in fact supports the case for LV Engine and the future deployment of Solid State Transformers (SSTs). Increased network visibility will allow Design Engineers to better identify areas of the network which would benefit from the functionality provided by an SST, thus improving the BaU roll out of the technology. Furthermore, improved network visibility will provide real-time data to SST control algorithms for the real-time described within the proposal services (voltage control and power flow).

Attachments	N/A

Project code	SPMEN02	Question Number	Q5
Question date	24/08/2017	Answer date	29/08/2017
Submission section question relates to	N/A		
Topic	G) Robust methodology/ready to implement		
Question	Please explain how the method to be trialled (a radial solution) would be applied on the lead licensee's meshed network?		
Notes on question	N/A		
Answer	In total around 55% of the SPM network is designed and operated as an interconnected network, entirely interconnected at 33kV, 11kV and low voltage (LV) whilst the remaining network is designed with a non-interconnected LV and comprises radial LV feeders. It may be preferable to undertake the LV Engine trial in a radial configuration as we want to ensure that the trial results are applicable to as many parts of GB, where radial LV networks dominate, as possible. The importance of the transfer of knowledge to bring new technologies to business as usual and the widest audience as possible is well recognised. However, the LV Engine solution is applicable to both radial and meshed network types. LV Engine solution, specifically, resolves potential fault level and thermal rating issues in meshed networks. Power flow control and the decoupling of the network through back-to-back AC-DC converters can reduce fault level issues, whilst controllable load sharing between neighbouring assets can increase available capacity. Both can allow more LCTs to be connected to the network and reduces the requirement for major reinforcement. Simply put, SSTs would allow the interconnectivity of a meshed network to be maintained or extended whilst avoiding the issues experienced in these network types. Furthermore, the LVDC supply that can be made available from an SST is equally applicable in meshed network areas as in radial network areas. Detailed consideration of an appropriate trial location will include consideration of whether a radial or meshed application is most suitable for the LV Engine project bearing in mind technical, installation, operational and network configuration. Following the site selection exercise, tailored specifications will be developed for each trial scheme within Work Package 1. This includes detailed plans to determine how a Solid State Transformer would be incorporated into the SPM network and to identify any additional protection requirements that may need to be considered.		
Attachments	N/A		

Project code	SPMEN02	Question Number	Q6
Question date	24/08/2017	Answer date	29/08/2017
Submission section question relates to	N/A		
Topic	G) Robust methodology/ready to implement		
Question	On page 54 you refer to figure C-9. Where is this within the submission?		
Notes on question	N/A		
Answer	Please see figure C-9 below (labelled figure C-8 within the proposal). There is an error with the numbering of the figures in Appendix C. This will be corrected within the re-submission.  As described within the text on page 54, the figure demonstrates the additional voltage variance that can be accommodated with on-load voltage regulation as provided by a Solid State Transformer (SST).		
Attachments	N/A		

Project code	SPMEN02	Question Number	Q7
Question date	05/09/2017	Answer date	07/09/2017
Submission section question relates to	N/A		
Topic	d) Is innovative		
Question	With specific reference to the TRL definition in the governance document please justify the stated TRLs within the submission		
Notes on question	N/A		
Answer	As per the TRL definition in the NIC governance document and based on our extensive engagement with manufacturers during proposal preparation we have concluded that the TRL of the solution proposed in LV Engine to be 5. This is mainly driven by the TRL of the Solid State Transformer (SST). ***"TRL 4-6: Development activities with a more commercial application including technology validation and or demonstration in a working environment";*** The TRL of SSTs for grid applications is considered to be 5, as several prototype devices have been through laboratory trials. We have been presented the SST prototype laboratory test results by different manufacturers and academics. None of these prototypes demonstrated the hybrid AC and DC output supplies, which is a key feature of the LV Engine proposal. The technology has reached a higher level of maturity in railway traction applications, which use similar voltage levels to distribution networks. TRL of SSTs for traction applications is considered to be 8, as prototype units have been deployed and tested in field trials. "***TRL 7-8: Full scale demonstration in a working environment to test and improve technologies so they are ready for commercial deployment";*** There are still several technical and operational challenges for a SST grid application which require to be addressed before BaU adoption. This includes the final choice of topology to be adopted, the operating frequency of the HFT, and the choice of technology for the switching devices. There are additional challenges in developing control algorithms to enable smart functionalities and control (as stated in LV Engine project concept), the SST network protection design, improving efficiency and reducing losses, developing suitable modular design. In addition, it is essential to monitor the SST performance in a grid application for a period to further optimise the design, and build the confidence in the device and solution proposed by LV		

	Engine so the solution is ready for commercial deployment.
Attachments	

Project code	SPMEN02	Question Number	Q8
Question date	05/09/2017	Answer date	07/09/2017
Submission section question relates to	N/A		
Topic	Multiple		
Question	Please provide information on the type of Customer you expect to request a DC link from the transformer. Within this response please outline how many requests you have received for such a link.		
Notes on question	N/A		
Answer	The demand for DC is growing within multiple industries and as DNOs we have an obligation to provide our customers with options to enable the transition to a low carbon energy system. During proposal preparation we have held discussions with multiple interested parties who are interested in acquiring a DC supply. These include: **Glasgow City Council:** Duke street car park intends to install PV alongside battery storage and EV charging points. A DC supply could allow the technologies to be coordinated at DC and significantly reduce losses. **Liverpool City Council** have expressed their interest in acquiring a DC supply for future EV charging points across Liverpool city centre. **Eden Campus Data Centre:** At Eden campus a data centre is being built in North East Fife. Representatives have voiced their willingness to adapt their plans to accommodate a DC supply for the purpose of reducing losses if project timescales match. Since the project has not currently been awarded funding and the SST prototypes have not yet been developed we have not yet put agreements in place with any potential DC customers. In addition to the above we will also target customers with large DC appliance consumption such as commercial offices and libraries, the benefits of which have been demonstrated within other innovation projects such as “Edison Smart DC” run by WPD which retrofitted a library to provide DC directly to the computers and LED lighting with positive results. LV Engine will demonstrate how a LV DC supply could be provided to customers directly from the distribution network using a SST and lay the ground works for a future LV DC network.		
Attachments	N/A		

Project code	SPMEN02	Question Number	Q9
Question date	05/09/2017	Answer date	07/09/2017
Submission section question relates to	N/A		
Topic	g) Robust methodology/ready to implement		
Question	What percentage of current transformers do you believe could/should be replaced by these solid state transformers?		
Notes on question	N/A		
Answer	The results of our Cost Benefit Analysis (CBA) and the associated roll out methodology have concluded that **approximately 16% of GBs ground mounted secondary transformers (GMTs) could be replaced by Solid State Transformers by 2050**. We believe our estimation to be conservative and many more could be installed if LV Engine is successful in demonstrating the value of this technology within distribution networks. Our CBA has focussed in on a small selection of the functionalities that an delivered by the LV Engine method, and has not included the benefits that can be attributed to the following: • LV DC supply to reduce customer losses revolutionising the way we deliver electricity to our customers. • Modular design to allow for uprating of capacity at limited cost. • Services to the 11kV network i.e. voltage support, reactive power compensation • Fault current control • Smart hub acting as an enabler for DSO. • Benefits to other industries that would benefit from development of this technology in the future i.e. offshore wind industry We will attempt to understand and quantify the potential value of these additional benefits as an output of LV Engine to maximise the potential of the technology within GB. LV Engine method estimated roll out (GB) by year: • 2030: 7,819 (3.4% of GBs secondary GMTs) • 2040: 27,274 (12% of GBs secondary GMTs) • 2050: 36,270 (16% of GBs secondary GMTs)		
Attachments	N/A		

Project code	SPMEN02	Question Number	Q10
Question date	05/09/2017	Answer date	07/09/2017
Submission section question relates to	N/A		
Topic	a) Environmental and consumer benefits		
Question	We note your answer to question 4. Please provide more information on why you have not considered vacuum tap transformers to be the counter factual solution for these transformers?		
Notes on question	N/A		
Answer	Our counterfactual is based on proven practice which is currently undertaken by most of the DNOs including SPM and SPD. A pragmatic approach has been taken as it is recognised that in practice system planners develop bespoke solutions depending on the specific circumstances including location, equipment parameters, age, proximity to neighbouring circuits and availability of space. A potential solution could be to install new substations which would be more expensive than our counterfactual. We appreciate that Vacuum Tap Changers (VTC) can be a solution for voltage control but we have some reservations about considering VTC as a robust and fair counterfactual: **1. Additional unquantified benefits associated with the LV Engine method:** Our CBA has focussed on some of the functionalities which we could most reliably quantify the value of whilst keeping our CBA clear and transparent. However, the LV Engine method has potential to deliver additional functionalities over and above that provided by a VTC that could deliver significant value to distribution networks and our customers. An objective of LV Engine is to understand these benefits in more detail to aid the future deployment of this technology as BaU. These additional benefits include: • The availability of a low voltage DC supply which could significantly reduce customer losses. • A modular design which allows for transformer capacity to be uprated with additional "capacity banks". • Services to the 11kV network with a high penetration of SSTs along an 11kV feeder which could significantly reduce any reinforcement required on the 11kV level as the uptake of LCTs continues to grow. **2. VTCs have not been yet deployed as a BaU solution by DNOs**: We have not found enough evidence to show that VTC is considered as a proven technology by UK DNOs and it has been widely used for voltage control		

	within LV networks. Field trials and the grid performance demonstration for application in the secondary substations are not yet considered sufficient to show that this solution can be confidently adopted within LV networks. **3. VTC may not be a suitable solution for LV networks in particular where high level of LCT uptake is expected because**: • **Frequent tapping**: There are some evidences around the mechanical stress on VTCs as a result of frequent tapping in response to daily voltage variations. This can have an adverse impact on VTC life time and O&M costs. This problem will become worse in an area with high uptake of LCTs where a wide range in the daily voltage variations may be experienced as a result of diverse generation/demand scenarios. • **Step voltage control**: VTC essentially relies on the tap steps (2.5%) of the existing transformers. With this tapping granularity, the voltage control of LV feeders with different length and different LCT uptake can be challenging if even possible. This can be more challenging when different feeders supplied by the same transformer experience different voltage profiles (one high voltage and the other low voltage). ● **Phase voltage control**: VTC may not allow the voltage control on each of phases (in a 3-phase LV network) separately. This may limit the overall effectiveness of voltage control scheme, as the LCT uptake on different phase may be different. It is also unable to consider voltage readings from along the length of each feeder and calculate the optimal voltage at the LV busbar as we intend to demonstrate with the LV Engine method. Nonetheless, we appreciate that VTC can be one of the tools for voltage control within LV networks along with other innovative solutions may appear in future. Therefore we have considered a market share in our cost benefit analysis for deploying other innovative solution which will compliment with the LV Engine solution and offer system planners a range of options that can be optimally deployed to meet varied network needs We also intend to compare the voltage capability of LV Engine solution with that of the VTCs and provide recommendation on using these technologies within LV networks. We have already procured a number of VTCs as part of our innovation projects and intend to use the learnings available from these within LV Engine. These VTCs are yet to be fully installed and their performance needs to be monitored and assessed.
Attachments	

Project code	SPMEN02	Question Number	Q11
Question date	05/09/2017	Answer date	07/09/2017
Submission section question relates to	N/A		
Topic	d) Is Innovative		
Question	Has this type of transformer been successfully demonstrated within a test centre environment?		
Notes on question	N/A		
Answer	Yes. During the proposal preparation we have approached several manufacturers and academics to identify the progress and developments to date in Solid State Transformer (SST) technology. This has aided our assessment of the TRL level of the LV Engine method which we believe to be currently 5. We have been presented with evidence of SST prototypes which have been tested within laboratory/test centre environments. All these evidences are reflected within the "Expression of Interest" documents we have received from parties who wish to be involved in the project should it be awarded funding. We are happy to present these evidences in a confidential arrangement if requested by Ofgem and agreed upon by the manufacturers and academics we have held discussions with.		
Attachments			

Project code	SPMEN02	Question Number	Q12
Question date	05/09/2017	Answer date	07/09/2017
Submission section question relates to	N/A		
Topic	a) Environmental and consumer benefits		
Question	What would be the impact on the benefits proposed if the DC connection element was not part of the project?		
Notes on question			
Answer	**Impact to benefits claimed with benefits tables:** As one of the most innovative elements of LV Engine the value that can be attributed to providing a LV DC supply to our customers is difficult to quantify accurately. LV Engine intends to lay the ground works for the future adoption of LV DC supplies and demonstrate how a LV DC could be made available due to the inherent design of an SST. Consequently, within our CBA we have not claimed any direct benefits within the benefits tables from a DC connection element of the project. Therefore, there would be no impact to the figures we have published. However, we believe this element of the project could bring huge benefits to our customers if adopted in the future. For example, the losses through EV charging points due to the conversion between AC and DC could reach approx. £100M per year by 2040 across GB assuming a charging post efficiency of 92%. Allowing multiple DC appliances, DC LCT generation and DC LCT load to be coordinated together all at DC could bring huge savings to consumers through significantly lower network losses. *"We are likely to witness* ***an explosion of DC power supplied by utilities*** *in the coming years. I am often asked about the speed of change and how soon would we see a predominantly DC world. I cannot predict the future but I can safely say that in* ***about three years we will see a lot more LVDC everywhere*** *and in about twenty years, the world will have moved toward DC Distribution" - Vimal Mahendru, Convenor, SEG-4| Member, Standardization Management Board, IEC* **Impact to learnings gathered from LV Engine:** We believe the provision of a LV DC supply is one of the most innovative elements of LV Engine and could bring significant environmental and			

consumer benefits. If the LV Engine project proceeded without the DC output stage on the SST a major opportunity would be missed to demonstrate the benefits which could be provided to the consumer distribution system of the future. This reflects the rapidly changing nature of the domestic and commercial loads and renewable energy sources, which are appearing on the LV networks. Without a LV DC supply the following issues will arise:

- All Electric Vehicle supply points will need individual (or grouped) rectifier (AC to DC) units to charge the vehicle batteries
- All Electric Vehicle supply points will need individual (or grouped) inverter (DC to AC) units to allow the vehicle batteries to discharge into the LV network
- All Photovoltaics will require individual inverter (DC to AC) units to allow power to enter the LV network
- All large Data Centres will require rectifier (AC to DC) units to provide power to the computer servers
- Domestic level wind turbines will require converters (AC to DC to AC) to connect onto the LV network
- Commercial and domestic lighting systems using LEDs will require individual rectifier (AC to DC) units
- Domestic devices, such as PCs, tablets, mobile phones, etc. all require individual rectifier (AC to DC) units to charge internal batteries

By providing a single DC supply from a SST the cost and losses associated with these multiple individual converters could be avoided. However, it is recognised that all of these loads or generators will not work on a common DC voltage and in some cases DC to DC converters would be required.

Simply put, we believe a LV DC supply could act as a major enabler of LCTs in the near future.

Attachments	

Project code	SPMEN02	Question Number	Q13
Question date	05/09/2017	Answer date	07/09/2017
Submission section question relates to	N/A		
Topic	b) Value for money		
Question	Please clarify how you will ensure the tender for the transformer manufacturer provides value for money to consumers? How will you mitigate the risks of not identifying a supplier of this unproven technology for the price listed within the submission?		
Notes on question	N/A		
Answer	**Please clarify how you will ensure the tender for the transformer manufacturer provides value for money to consumers?** Whilst preparing the full proposal for LV Engine we have engaged extensively with a large number of manufacturers and discussed the LV Engine concept and the functionalities it will bring to the distribution network. During this process we released an 'Expression of Interest' document (Appendix Q) to a number of manufacturers which described the objectives of the project. We received a very positive response to this document which has demonstrated that a number of manufacturers are eager to partner with us on LV Engine. In addition, we have received direct requests to partner from manufacturers prior the full proposal submission; however we believe a competitive tendering process during project delivery will allow us to identify a partner(s) who best delivers value for money and delivers the optimal solution. It also provides us with an opportunity to put together detailed technical specifications for the SSTs and the schemes in which they will be trialled so that the responses to the tendering are fit-for-purpose and deliver the functionalities intend to demonstrate. We intend to create detailed tendering evaluation criteria and follow SP Energy Networks tendering policy for contracts of this size, which will allow us to assess the responses to our tender exercise efficiently. Cost, timescale, resources, financial contribution, track record within previous innovation projects, and previous R&D investment within power electronics and transformers will be considered essential criteria during the tendering process. We believe a competitive tendering exercise will result in the lowest cost option and highest performing solution for our consumers ensuring we identify a partner(s) who is best positioned to deliver LV Engine in partnership with SP Energy Networks and UK Power Networks.		

	How will you mitigate the risks of not identifying a supplier of this unproven technology for the price listed within the submission? Through our extensive engagement with manufacturers we have gained confidence that the project can be delivered within time and cost as described within the proposal. Within the "Expression of Interest" document we asked manufacturers to provide us with estimates of cost and timescales required to deliver the technology described within the proposal. This information was used to construct our project delivery plan (Appendix D) and the funding request for LV Engine. An average cost was chosen from the responses we received taking into account the current level of technology readiness of each response. We believe the competitive tendering may drive down these costs further as we have seen a large appetite from manufactures globally to be involved in this project. Any money saved through the tendering process and manufacturing work package will be returned to UK electricity consumers. In addition we also carried out a review of the latest research and development in the area to ascertain the TRL level (5-6) of the technology within the applications described. We have discussed this with several manufacturers, academic institutions and EU funded projects that represent the cutting edge of this technology. This has given us confidence that the project is timely and recent developments in the areas of power electronics make this the most opportune moment to begin a project of this type as described below: *"GaN and SiC are highly promising technologies that have the potential to make a disruptive impact on the Power Electronics in Energy.... This is therefore a very opportune moment to begin an SST that can tie in the extensive UK supply chain in power electronics with the energy sector"* ***Letter of Support from Dr Alastair McGibbon, Director of PowerelectronicsUK.*** *"Based upon our research and understanding of the technology we believe it is the right time to carry out a trial of SSTs for grid applications. In particular, due to the voltage levels that are applicable to power electronics and semiconductors the secondary substation level (11kV/0.4kV) is a promising point for a trial of SSTs within electricity networks"* ***Letter of Support from Prof. Dr. Johann W. Kola, Head of Power Electronic System Laboratory at ETH Zurich***
Attachments	N/A

Project code	SPMEN02	Question Number	Q14
Question date	12/09/2017	Answer date	14/09/2017
Submission section question relates to	N/A		
Topic	b) Value for money		
Question	At the end of the project will the designs for the SST be open source?		
Notes on question			
Answer	We intend to comply with default intellectual property right (IPR) arrangement set out in NIC governance document. The **relevant foreground IPR** for the LV Engine method will be fully and freely available to UK DNOs, manufacturers and academics to allow the LV Engine method to be safely rolled out on existing distribution networks. As a minimum, we aim to make the following relevant foreground IPR for SST available: • Technical specifications of the SST for procuring and deployment within secondary substations. • Functional and technical specification of the LV Engine schemes in which the SSTs will be trialled. • SST factory acceptance tests requirements and tests results. • SST network integration tests and the results. • Learning from installations and SST performance, including installation method statement, site acceptance test methodology, health and safety requirements and SST performance data in each scheme • Updated business case and road map for BaU adoption. • CBA tool, policy document, best operational practices and training material. The contracts with project partners will include the terms and conditions reflecting the NIC default IPR arrangement. We have already requested interested parties to confirm they will comply with NIC default IPR arrangement and we have received positive response from all interested parties within our LV Engine "Expression of Interest" document.			
Attachments	N/A		

Project code	SPMEN02	Question Number	Q15
Question date	12/09/2017	Answer date	14/09/2017
Submission section question relates to	N/A		
Topic	a) Environmental & Consumer Benefits		
Question	Please confirm whether the Carbon Figures solely relate to CO2. If not, please list the other Greenhouse Gasses included within the figure.		
Notes on question	N/A		
Answer	We confirm that the carbon benefits calculated are based upon **tCO2e** which includes other greenhouse gas emissions expressed in terms of CO2 and their relative global warming potential (GWP). This is in line with the greenhouse gas representations within "The Carbon Plan" published by DECC. **We would also like to take this opportunity to clarify our methodology for calculating the Carbon benefits associated with LV Engine:** The carbon benefit calculation for LV Engine includes two key factors: 1- Reduced carbon emission due to avoiding reduced civil work over the counterfactual 2- Increased carbon emission due to additional network losses The embedded civil carbon benefits outweighs the carbon associated with the additional network losses. Figure 1 below illustrates the methodology used to calculcate the carbon benefits associated with the LV Engine method.		

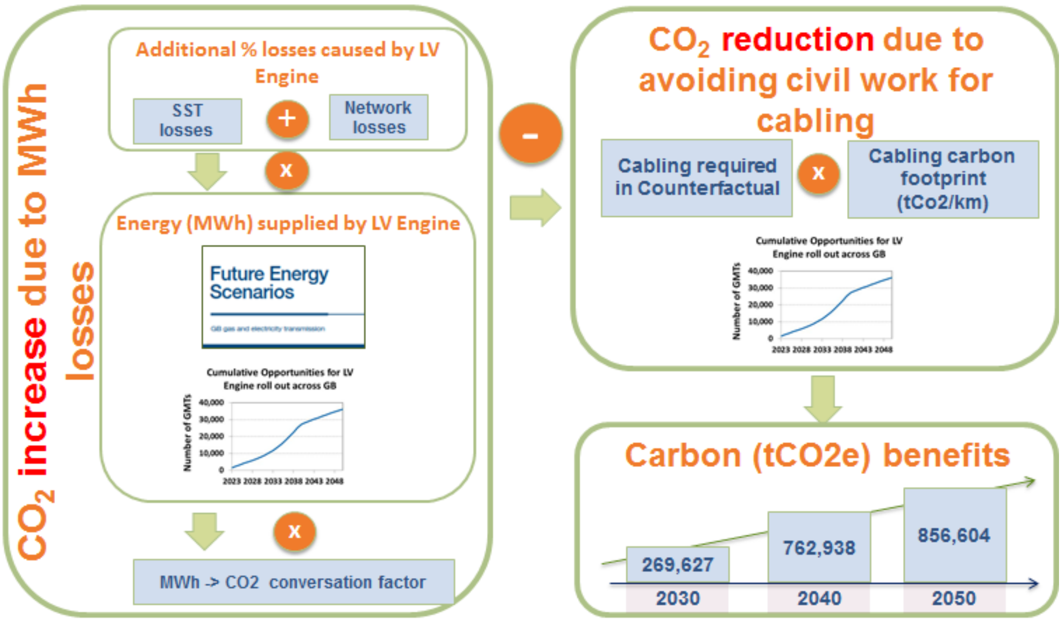


Figure 1: LV Engine carbon benefit methodology.

1. Reduced civil works of LV Engine Method vs Base Case

Each deployment of the LV Engine method will avoid LV cabling across four feeders when compared to the counterfactual. We have assumed that each km of LV cabling to be 49 tCO2e. The total Carbon benefit associated with avoided cabling is **58.8 tCO2e** per deployment. In absence of a actual carbon assessment for the SST we have conservatively assumed it to be equal to that of a conventional transformer at 6.0 tCO2e/unit.

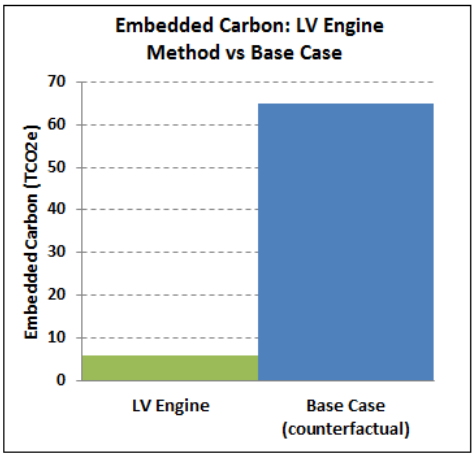


Figure 2: Embedded Carbon

Note: *The carbon footprint of LV cabling has been acquired from Capacity to Customer (C2C) Carbon Impact Assessment Trial Result conducted by Electricity North West (ENW) which states: "Summing the C2C emissions factors for cables, joints and installation, the composite emissions factor for traditional reinforcement is between 49-75 tCO2e/km.*

2. The losses associated with LV Engine Method vs Base Line.

This includes both the additional losses through the SST compared with a conventional transformer and the reduction in losses in the counterfactual due to a reduce network impedance.

<u>2A) Additional Losses through a Solid State Transformer</u>

Based upon our engagement with a number of manufacturers we concluded that an SST efficiency of at least 98% is achievable using the latest technologies. We expect this to improve as the technology continues to mature and becomes more efficient. This is reflected in Figure 3 which was used through the CBA for the new installations each year.

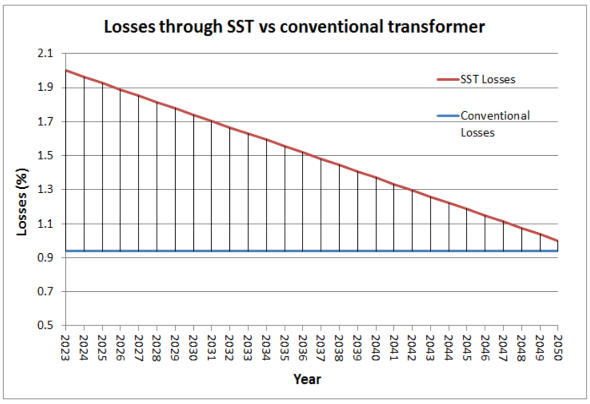


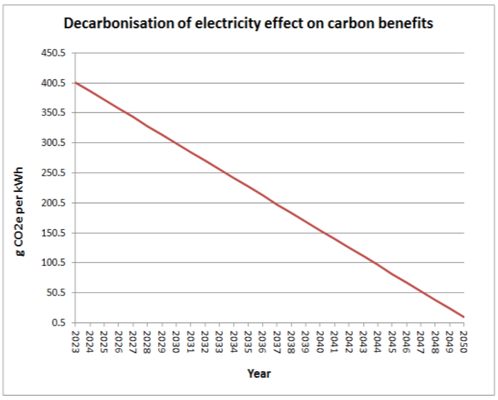
Figure 3: Losses through SST vs conventional transformer

2B) Reduction in Network losses of Base Line (Counterfactual)

The base line includes the replacement a proportion of the LV network with a larger size cable to account for network voltages out with statutory limits due to increasing levels of Low Carbon Technologies (LCTs). The installation of larger diameter cables will create a reduction in LV network losses due to lower cable impedance. Taking this into account, the LV Engine method will increase LV network losses from by 1.02% when compared to the counterfactual. This additional percentage of LV network losses is multiplied by the quantity of energy that will be supplied through each SST installed and the carbon conversion factor (g CO2e/kWh) between 2023 and 2050 to quantify the carbon impact.

2C) Decarbonisation of electricity

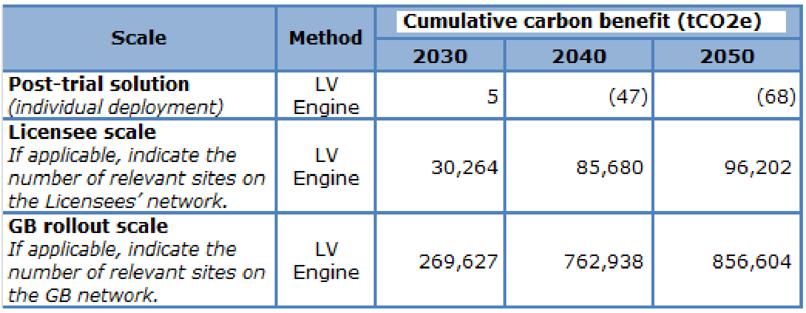
When combining the additional network losses (2A & 2B above) with the number of roll out opportunities for the LV Engine method, we took account of the decarbonisation of electricity by including an annual reduction in the conversion factor (g CO2e per kWh) used each year to quantify CO2 attributed to the additional kWh of network losses.



Summary of Carbon Calculation

As described above the carbon calculation is dominated by the reduction in civil works resulting from the LV Engine method. This gives a net reduction in carbon when compared to the counterfactual. The additional SST and network losses associated with the LV Engine method is offset by the following factors:

1. Improved SST efficiency as the technology matures.
2. The decarbonisation of electricity (CO2e per kWh) between 2023 and 2050
3. Rate of roll out. Number of deployment opportunities for LV Engine method increases towards end of 2020s as the two factors above start to become more favourable.



Scale	Method	Cumulative carbon benefit (tCO2e)		
		2030	2040	2050
Post-trial solution *(individual deployment)*	LV Engine	5	(47)	(68)
Licensee scale *If applicable, indicate the number of relevant sites on the Licensees' network.*	LV Engine	30,264	85,680	96,202
GB rollout scale *If applicable, indicate the number of relevant sites on the GB network.*	LV Engine	269,627	762,938	856,604

Potential Carbon Benefits not quantified:

- The carbon reduction associated with faster connection of LCTs which otherwise should be delayed until the network reinforcement takes place
- A future LVDC supply could potentially increase the thermal transfer capacity of existing LV AC cables which may contribute to reduction of the amount of cable reinforcement required and the associated carbon impact if a LVDC supply is adopted by DNOs.
- LVDC supply could reduce customer losses associated with the repeated conversion between AC and DC with digital loads. Demand from DC loads is increasing rapidly and two-stage DC-DC voltage conversion for different DC technologies is more efficient than three stage AC-DC-DC conversion usually used to supply DC loads.

Attachments	N/A

Project code	SPMEN02	Question Number	Q16
Question date	12/09/2017	Answer date	14/09/2017
Submission section question relates to	N/A		
Topic	Multiple		
Question	The Expert Panel would welcome a written commitment from senior management to utilise the technology/ new CBA tool created by the project if it is successful.		
Notes on question	N/A		
Answer	Please see the attached document which includes a written commitment from senior management as requested. Extracting the value of customer funded innovation projects is critical to SP Energy Networks. We are committed to adopting the learnings into our BaU processes, not only those gained through our own innovation projects but those lead by other DNOs. This is reflected by our partnership with UK Power Networks on both LV Engine and Active Response. We believe there are huge benefits to be realised by working closely together to ensure our customers see a return on the investment made in both NIA and NIC projects alike.		
Attachments	SP Energy Networks LV Engine BaU adoption_v1		

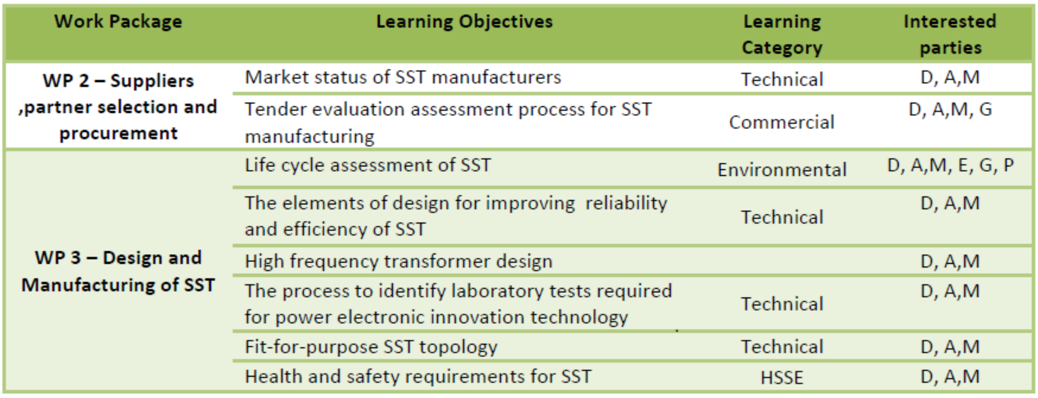
Project code	SPMEN02	Question Number	Q17
Question date	12/09/2017	Answer date	14/09/2017
Submission section question relates to	N/A		
Topic	a) Environmental & Consumer Benefits		
Question	Please explain how you justify the contribution from the equipment supplier. How have you ensured this contribution provides value for money to consumers when compared to the potential benefits on offer if the technology is proven to be successful on the network		
Notes on question	N/A		
Answer	We believe a competitive tendering to select our manufacturing partner is the best approach to deliver value for money to consumers. This approach will **drive competition between manufacturers** to ensure the project receives the most technically sound and low cost response to our tender invitation. During the process of putting together the full proposal we have engaged extensively with manufacturers and have seen a large amount of interest to take part in the project. During face to face meetings and within the "Expression of Interest" document we emphasised our intention to identify a ***project partner(s)* and not an equipment supplier**, who is willing to contribute significantly to the project and is willing to share learnings from the project publically. This was set as a **minimum** of 10% of the manufacturing costs but we emphasised that size of financial contribution will be a key factor of our selection criteria. The direct financial contribution and **investments & developments already made which can be leveraged** will both be key factors of our selection criteria when choosing our manufacturing partner(s). Any efficiencies made during this process will be returned to consumers as a project saving. As discussed during the 1st Bilateral we intend to identify a manufacturing partner(s) who is willing to contribute as much as possible towards the project and leverage previous investment made within this area. We see the partner selection work package as an area where we can find efficiencies through a tendering process. We believe that LV Engine will stimulate a strong and competitive market place for Solid State Transformers by demonstrating the benefits associated with the LV Engine Method and providing a proven and risk free business case which warrants future investment from manufacturers. Furthermore, the number of manufacturers that have engaged with us has		

	given us confidence that sufficient competition will be stimulated to drive down future costs and improve quality of the SSTs. This will ultimately provide long lasting value to our customers. In addition, we believe if the LV Engine method, part of which is the development of Solid State Transformer, is proven successful GB customers will see significant benefits in reduced network reinforcement costs and enabling the uptake of LCTs as demanded by consumers and society.
Attachments	N/A

Project code	SPMEN02	Question Number	Q18
Question date	12/09/2017	Answer date	14/09/2017
Submission section question relates to	N/A		
Topic	b) Value for money		
Question	What sort of learning will you share with Power Electronics UK? How can this be guaranteed before the contracts have been signed?		
Notes on question			
Answer	We intend to stimulate the competition for SST manufacturing and the LV Engine method by sharing the project learnings with PowerelectronicsUK. As the industry representative with over 70 members in the UK we believe this will stimulate competition and ensure suppliers design products which are tailored to the needs of GBs DNOs. We aim to share, at least, the following learnings: • Technical & functional specifications for SST that may be used by other DNOs for procuring and deploying the LV Engine method. • LV Engine scheme performance data in different network (load/generation) conditions. • Factory acceptance tests requirements for SST manufacturing. • Updated business case for SST deployment by UK DNOs and road map for BaU adoption. We believe these learnings will be adequate to raise awareness on the technical requirements for replicating the LV Engine method and demonstrates the market size for SST within Electricity Industry by providing a proven business case. The contract(s) with any manufacturing partner(s) will include the default intellectual property right (IPR) arrangement set out in NIC governance. We will ensure that the aforementioned learnings (as a minimum) will be included within the contract(s) to be freely available to the interested parties including PowerelectronicsUK and its members. **Dr Alastair McGibbon, Director of PowerelectronicsUK:** *"PowerelectronicsUK has several active dissemination routes to communicate state-of-the-art developments and opportunities to the Power electronics Community. This includes at least 4 technology-centric workshops and meetings annually, at least one of which has a strong energy industry focus. In addition, PowerelectronicsUK has a strong on-line presence including a LinkedIn group and a Basecamp forum for members. There are also regular newsletters to the wider community that can include*		

	features on technology progress. Furthermore, PowerelectronicsUK has a strong regional cluster link through Technology Scotland the enable technologies industry association in Scotland which is in the course of developing a smart energy special interest group."
Attachments	N/A

Project code	SPMEN02	Question Number	Q19
Question date	14/09/2017	Answer date	19/09/2017
Submission section question relates to	N/A		
Topic	Multiple		
Question	Given the learning associated with Work Packages 2 and 3 may not be able to be fully shared and will only contribute to learning in the sense of informing the manufacturer and SP Energy Networks whether it is possible to design and manufacture a SST, please provide a justification that the proposed percentage of funding associated with this deliverable is appropriate		
Notes on question	N/A		
Answer	By engaging with a number of manufacturers we are confident that the technology required by the LV Engine Method can be delivered within the time and cost requested within the proposal, of which work packages 2 & 3 are critical elements that directly contribute towards each of the deliverables associated with LV Engine. Based on the evidence of SST prototypes developed by manufactures and research centres, we are already confident that it is possible to design and manufacture an SST. The purpose of LV Engine is to build upon existing developments and: • Understand the value of the functionalities provided by an SST to the LV Engine Method and the distribution network. • Provide a proven risk free business case and design tools/policies to enable the future development and deployment of the technology within distribution networks. • Deliver SST design that is tailored for the specific functionalities required by GB DNOs to reduce network reinforcement and enable the uptake of LCTs. **Table 1** below shows the expected learning from WP 2 & 3 and the interested parties who will benefit from this learning: **Table 3:** Expected learning from LV Engine project (page 29 of FSP)		



Work Package	Learning Objectives	Learning Category	Interested parties
WP 2 – Suppliers ,partner selection and procurement	Market status of SST manufacturers	Technical	D, A,M
	Tender evaluation assessment process for SST manufacturing	Commercial	D, A,M, G
WP 3 – Design and Manufacturing of SST	Life cycle assessment of SST	Environmental	D, A,M, E, G, P
	The elements of design for improving reliability and efficiency of SST	Technical	D, A,M
	High frequency transformer design		D, A,M
	The process to identify laboratory tests required for power electronic innovation technology	Technical	D, A,M
	Fit-for-purpose SST topology	Technical	D, A,M
	Health and safety requirements for SST	HSSE	D, A,M

Work Package 2

We believe WP 2 is the best approach to identifying manufacturing partner(s) who represent best value for money and can deliver the most technically competent and lowest cost solution. The funding requested for this work package is based upon a number of FTE days required to adequately deliver this work package. WP 2 represents approximately 2% of the total project cost and can potentially significantly reduce the cost associated with WP 3.

Work Package 3

The funding requested for WP 3 is based upon our engagement with a number of manufacturers, academics, and FTE days mapped against each element of the work package as detailed within the Project Delivery Plan in Appendix D.

WP 3 will provide valuable learnings that can be shared with all UK DNOs including UK Power Networks who will have strategically appointed as a design authority to ensure other DNOs have access to detailed design materials developed in WP3 and have an opportunity to influence key decisions so that the developed solutions are fit-for-purpose across the UK.

WP 7 (knowledge dissemination) as seen within the project delivery plan (Appendix D) includes a number of workshops at major project milestones. The purpose of these workshops is to share key learnings with other DNOs throughout the duration of the project. This includes valuable learnings from WP 3.

For example, workshop 2 is SST design. Within this workshop we intend to share some of the design parameters of SST with other UK DNOs subject to commercial conversations and agreement with the manufacturing partner(s). These design parameters include:

- Semiconductor material type
- Number of modules
- Ratings and capacities of each module.
- Cooling system type
- Enclosure type & design
- Topology
- DC voltage levels
- Protection scheme design.

	The design parameters listed above are dependent on WP 3 and demonstrates the value of the learnings that will be acquired during this work package. In WP3, we also plan to commission a capable academic partner or consultant to carry out a detailed life cycle assessment of the SST. The results of this analysis will be shared with other UK DNOs. In addition, WP3 will also provide us with an opportunity to refine the technical specification for both the SSTs and the trial schemes which will directly benefit other GB DNOs by providing detailed and targeted specifications for procuring the LV Engine solution.
Attachments	N/A

Project code	SPMEN02	Question Number	Q20
Question date	14/09/2017	Answer date	19/09/2017
Submission section question relates to	N/A		
Topic	Multiple		
Question	Given each step of project deliverable four would have to be undertaken for any new piece of equipment and it is not clear what learning will be gained from this step please provide a justification that the proposed percentage of funding associated with this deliverable is appropriate.		
Notes on question	N/A		

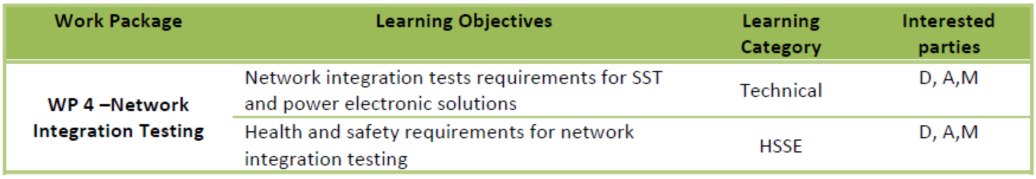
Answer

We have judged the TRL of the LV Engine method to be 5. Due to the innovative and unproven nature of the technology being trialled we believe it is in the best interest of our customers that the technology is demonstrated and proven within **a replica network** before the live network trial.

It is important to note that this deliverable is not Factory Acceptance Testing (FAT) or type testing, but network integration testing of the entire LV Engine method. This will allow the project to understand how the 5 trial schemes will perform within the network and reduce risk to customers whilst allowing us to make critical refinements before the live network trial.

Table 1 below shows some key learning that will be gained through this deliverable and WP4.

Table 1: Expected learning from LV Engine (P29 of FSP)



Work Package	Learning Objectives	Learning Category	Interested parties
WP 4 –Network Integration Testing	Network integration tests requirements for SST and power electronic solutions	Technical	D, A,M
	Health and safety requirements for network integration testing	HSSE	D, A,M

This deliverable will also:

- Demonstrate how the technology and associated protection will perform under different fault conditions;
- Demonstrate the performance of the technology under different load and harmonic distortion conditions;
- Demonstrate the various functionalities that the LV Engine method brings to the distribution network in a risk free environment;
- Demonstrating the control algorithms and comms strategies for each scheme including the LVDC supply.

The deliverable will also allow us to:

- Obtain a network integration certificate to prove the technology can

	be safely installed on the network without an unacceptable level of risk to both customer safety and supply. • Identify any unforeseen risks on a replica network without risking customer supplies. • Test any changes to SST control and algorithms during WP4 at the test centre before rolling out alterations and refinements at each trial locations. With specific reference to the 10% of funding set against this deliverable: • This deliverable is an output of work packages 1, 3 & 4 and requires learning developed within each of these work packages before this can be delivered. We believe this deliverable to be a critical step in elevating the TRL of the LV Engine method from a 5 to an 8 and giving UK DNOs the confidence that the technology can be adopted widely as BaU upon project completion. This testing is prudent to reduce risk associated with an innovative step change in how the LV network is operated. The estimated funding for this deliverable is constructed based upon our initial engagement with a Network Integration Test Centre within the UK and a reasonable personnel costs and expenses to support the relevant activities.
Attachments	N/A

Project code	SPMEN02	Question Number	Q21
Question date	21/09/2017	Answer date	26/09/2017
Submission section question relates to	N/A		
Topic	Multiple		
Question	With the use of solid state transformers there will be significant reduction in LV fault levels on, both radially fed and meshed, networks. Have you carried out an impact assessment of the likely implications on downstream LV protection? Which protection technologies will be used in case LV fuses are rendered inoperable? What will be the impact on LV earthing systems? Overall, how would you make sure that from protection and earthing perspective the downstream LV networks remain compliant with ESQC regulations?		
Notes on question	N/A		

Answer

We have already recognised that the conventional LV fuse protection may not be adequate for protection of the LV feeders supplied by a SST. Developing a smart and fit-for-purpose protection scheme for SST deployment will be one of the innovative aspects of LV Engine. Activities for developing such a scheme have been planned within work package 1 in the first year of the project and we have considered the protection design to be one of the learning outcomes of this work package, please see table below.

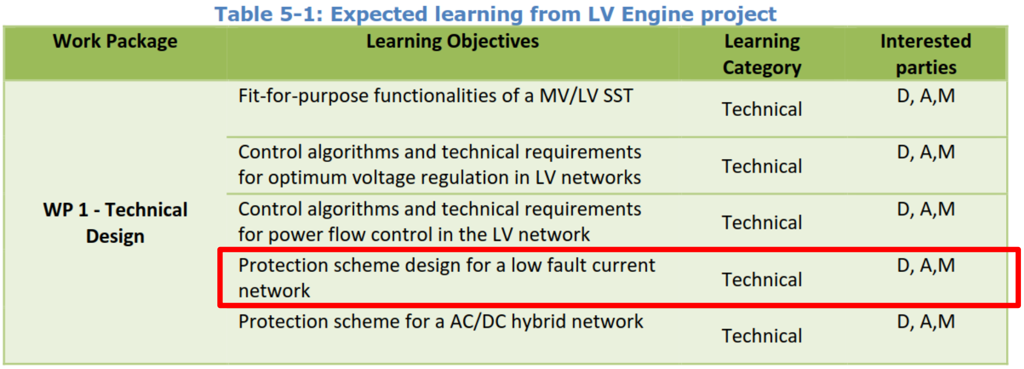


Table 5-1: Expected learning from LV Engine project

Work Package	Learning Objectives	Learning Category	Interested parties
WP 1 - Technical Design	Fit-for-purpose functionalities of a MV/LV SST	Technical	D, A,M
	Control algorithms and technical requirements for optimum voltage regulation in LV networks	Technical	D, A,M
	Control algorithms and technical requirements for power flow control in the LV network	Technical	D, A,M
	Protection scheme design for a low fault current network	Technical	D, A,M
	Protection scheme for a AC/DC hybrid network	Technical	D, A,M

Nonetheless, during the proposal preparation we have discussed the low short circuit provision issue with various experts and manufacturers to identify possible solutions, while considering the requirements specified within ESQCR. Some of the solutions that have been discussed are as follows:

1- Over rate the semiconductors: One possible solution is to consider short-term and/or long-term over-rate current for the semiconductors. In the case of any fault in LV network, the SST can provide a current level well above normal load current to provide sufficient current to identify a

	fault and allow the protection devices (even fuses) to operate on both the LVAC or LVDC systems. Such over-design will add to the overall cost and size of the SST. There should be a trade-off between the over-rating of the SST and the cost of smart protection system should be in place. For example, we may move away from fuse protection arrangement and deploy the appropriate relay and circuit breakers for clearing the faulted LV feeders. We have looked into LV protection equipment and we are confident that there are number of commercially ready products which can be deployed in LV Engine. In addition, we have been looking into learnings from UK Power Networks FUN-LV project in which the fuse protection was replaced with LV circuit breakers without adaption of the take-off chamber. **2- Using auxiliary converter on the LV side:** During proposal preparation we engaged with different manufacturers to discuss the protection issue, one solution put forward by one of the manufacturers included a topology of SST that uses a parallel auxiliary converter at the LV side. This auxiliary converter can firstly function as the LV voltage control, secondly provide additional short circuit that can be high enough to trigger the fuse protection. **3- Using DC/AC converters as fast acting circuit breaker:** Typically, the last conversion stage within an SST is a DC/AC converter. Typical topologies use two parallel DC/AC converters which are connected to a common AC busbar supplying LV feeders. One possible design includes allocating DC/AC converters to each individual feeder. In this way, if there is a fault on a feeder the DC/AC converter can act as a fast acting circuit breaker to disconnect the faulted feeder. An additional isolation switch would be also required at either side (or at least one side) of the AC/DC converter for isolation purposes. We have also discussed further solutions for detecting unbalance faults by monitoring the voltage (phase and magnitude) of earth connection. Reviewing the possible solutions has given us confidence that the earth and neutral point (for both AC and DC) can be provided in different SST topologies and we will be able to provide LV solid earthing connection in line with ESQCR requirements. These requirements are stated within our internal technical guidance and policy documents e.g. Earthing and Bonding at Secondary Substations or Secondary Substation Installation and Commissioning Specification which will be considered in the design and implementation of each LV Engine scheme. We would like to emphasise that all the aforementioned options will be reconsidered for a further evaluation and detail design in the course of project. In order to ensure that the designed protection scheme works appropriately with the final SST design, we have planned to procure the protection solution after completion of the SST design, please see appendix D our Project Delivery Plan. The technical specification of the protection scheme developed in Work Package 1 will be refined within Work Package 2 following the completion of SST within Work package 3.
Attachments	N/A

Project code	SPMEN02	Question Number	Q22
Question date	21/09/2017	Answer date	26/09/2017
Submission section question relates to	N/A		
Topic	a) Environmental and consumer benefits		
Question	You refer to the decarbonisation of electricity as a factor helping to offset the effects of the additional network losses of the method case. Please confirm that this same effect was taken into account in forecasting network losses in the counterfactual.		
Notes on question	N/A		
Answer	We confirm that the same decarbonisation of electricity factor was used for both the LV Engine Method and the counterfactual. If successful the LV Engine Method could expedite the uptake of Low Carbon Technologies (LCTs) more quickly than the counterfactual so the decarbonisation of electricity would become faster. This is an unquantified benefit of the LV Engine Method. We have chosen to take a **conservative approach and assumed the same decarbonisation rate for both cases.**		
Attachments	N/A		

Project code	SPMEN02	Question Number	Additional
Question date	From 1st Bilateral	Answer date	22/09/2017
Submission section question relates to	N/A		
Topic	Multiple		
Question	Please describe the benefits to customers by providing a future LVDC supply?		
Notes on question	N/A		
Answer	LV Engine will focus of DC trial sites which represent the biggest DC customer base in the near future and will benefit most from the learnings gathered from LV Engine. For example, it is expected that Electric Vehicles (EV) could cause a huge strain on distribution networks in the near future. LV Engine will demonstrate how a LV DC supply could act as a major enabler of the EV industry and reduce the resulting network reinforcement costs that may be required. LVDC benefits have already been demonstrated for niche applications such as data centres. Up to 10% improvement in energy efficiency, 15% savings in capital costs, 25% savings in space, and 20% savings in installations costs have been realised (ABB data centre built in 2012 in Zurich) [1]. Annual savings of 110,000MWh, £13M, and 47,000 tonnes of CO_2 have been also claimed from the potential application of existing DC technologies across London's offices [2]. For DC residential applications, the research in [3] has claimed that average energy savings up to 13% in DC houses with PV and storage can be realised. We believe, the deployment of LVDC for local power distribution by DNOs will potentially bring significant benefits with a radical improvement in energy use to customers in both rural and urban environments. It is important that DNOs provide customers with more choice particularly, to meet the rapid growth of DC loads and Low Carbon Technologies (LCTs) 1) Potential Benefits: **A) Reduced customer losses:** LVDC can potentially deliver benefits to electricity consumers through improved energy efficiency by supplying DC equipment using DC networks instead of relying upon less efficient DC/AC converters. This is because DC devices are conventionally supplied by an AC supply. These devices require a **three stage conversion process** AC-DC-device DC. A DC supply would enable a reduction in the number of conversion stages to a **two stage DC-device DC only**. This can reduce losses due to this conversion by 2.5-10%. Also, the introduction of the new USB Type-C		

standard (provides data and power up to 100W) will eliminate the need for many adapters to convert 230V AC to lower voltages and then into DC to connect electronic devices. Such new generation of technology inherently requires a LVDC supply.

An **optimised standardised DC voltage output** from the SST could increase this loss saving further. For example, considering DC Electric Vehicle charging, and if the DC voltage level of LVDC distribution systems or SST output voltage is optimised to charge EVs directly, the need for additional conversion stage could be removed altogether.

B) Improved LCTs connections and control

Most micro-generation and energy storage devices generate DC outputs. These devices can be connected directly or by more efficient DC/DC converters to LVDC networks. As an example, the cumulative energy losses of the DC-AC-DC conversion when powering DC appliances through local PV systems is in the range of 5-7% [4]. The inverter and PV module weights have reduced over the last ten years from 12kg/W to 2kg/W [5], and further reductions in size and cost will be realised through the use of LVDC infrastructure.

C) Improved flexibility & safety at Extra Low Voltage DC

The DC-DC converters can provide Extra LVDC (ELVDC) (i.e. <120Vdc ripple free) for directly powering electronic devices run on low power DC. This would allow the use of USB-C and Power over Ethernet (PoE) cables to deliver low DC power with improved monitoring and controls of DC devices (such as intelligent LED lighting) within a safer environment (5-48Vdc). This is particularly important for commercial buildings where a large portion of loads are IT and lights. For <30Vdc and in normal dry condition for <60Vdc basic protection is not required for DC SELV and PELV systems [6].

D) Reduced network reinforcement:

An LVDC distribution system can offer a higher power carrying capacity than the 400 VAC systems. This **higher power transfer capacity** can be achieved by using DC voltages that are within the insulation withstand capability of the conventional LV cable circuits. For example bipolar system at higher voltage up to ±750 is used. Most of existing LV cables are rated within the range of 450V-1kV, and LVD 2006/95/EC allows the use of LVDC voltages up to 1500V. University of Manchester provides evidences that by deploying (or converting) conventional 4 core and 3 core AC LV cables for DC operation the power transfer capacity can be increased up to around 4 times while running these cables at the same thermal limits as LV AC networks [7][8].

The additional transfer capacity can be unlocked considering **a better (stable) voltage profile** which can be provided by LV DC as the inductances effects on voltage profiles will be very limited. Using LVDC with higher voltages will deliver the same AC power with reduced thermal losses and limited voltage drops in the cables.

This could potentially lead to much **lower investment required within the LV cable infrastructure** to cope with thermal load growth across the LV network due to the uptake of Electric Vehicles if existing AC networks were converted to DC. Alternatively, a smaller cable cross sectional area could be used in new developments to satisfy the same demand at a lower cost with reduced disruptive street-works

DC network does not have the same issue as imbalance phases in AC networks. Imbalance LV network may trigger significant network reinforcement [9][10]or require costly exercise of changing the phase connection of the customers. Higher network losses is another issue of imbalance AC networks. SSEN estimated that imbalance network loading can contribute up to 12% of the LV network losses.

Better voltage profile and higher power transfer capacity offered by LV DC network suggests LV DC circuits can **supply more customers connected to a longer feeder length**. Therefore, the total number of substations and transformers required to distribute electricity to customers can be reduced, allowing DNOs to deliver electricity to customers through a smaller asset base and at lower cost. This is also a benefit when land for additional substations is at a premium at the expense of electricity consumers.

E) Improved security of supply:

Higher LVDC transmission capacity can reduce the number of lateral 11kV line sections meaning the network shortens and the number of protection zones increase. Therefore, the number and duration of interruptions reduce. LVDC distribution power systems have been proposed to replace some of the Korea Electric Power Corporation (KEPCO) existing AC rural MV distribution networks (used for supplying light loads) in South Korea in order to save up to 5% of the total operating cost [11].

Also LVDC will allow faster connection of renewables by allowing customers to connect new generators without significant constraints such as synchronisations and stability issues. Furthermore, connection of local generation and storage to DC bus can enable a DC system to operate in island mode and reduce vulnerability to major blackouts.

2) Potential LVDC voltage levels:

Within WP 1 & 3 will intend to identify an optimal standardised LVDC voltage for the SST DC output, which is targeted to reduce network losses. This standardised DC voltage will be optimised based upon the key DC customers identified and most efficient option in terms of wider network losses.

However, initial research has been carried as part of preparation of this document has indicated a few potential voltage levels that could be used are:

- +/- 750 VDC
- 1500V unipolar
- 380Vdc (+/-190)

- 350Vdc

We appreciate that LV DC application to bring this into BaU there are some technical, commercial and regulatory issues that should be tackled. Nonetheless, there are numerous research and working groups suggesting that LV DC is emerging and there is a growing need for it. LV Engine aims to demonstrate an LV DC network operation and produce learning to tackle some of the technical challenges such as protection and earthing issues. The actual performance of the DC circuit will be also available as part of learnings for further developments in DC networks.

3) Example future LVDC Network Concept:

An example future DC network diagram with DC voltage optimised for electric vehicle fast charging to maximise the reduction in network losses, and encourage future development of smart houses and wide spread use of DGs at LVDC distribution systems.

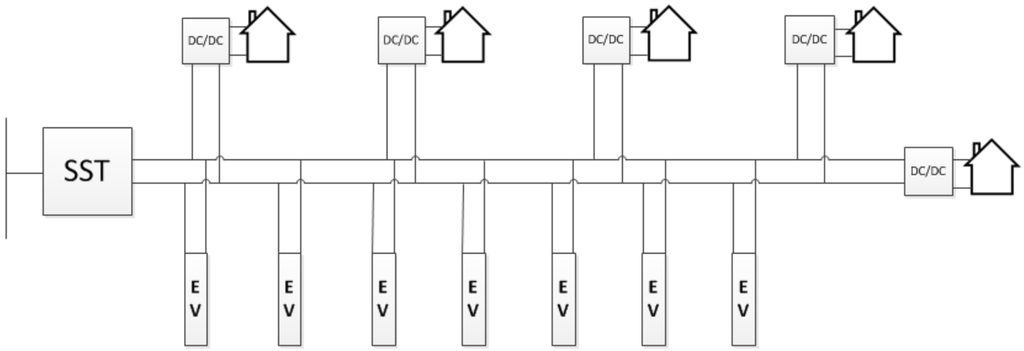


Figure 4: Future LV DC Network Concept

The unknown risk of LVDC and its associated components can only be mitigated with controlled field trials of LVDC in low power applications, where component failures have limited consequences. These low risk deployments of LVDC will help to formulate the necessary standards and product supply chain for more complex DC distribution networks.

A promising area of investigation, which offers a staged progression from some of the existing LVDC deployments in commercial buildings and warehouses, is the use of LVDC to facilitate the implementation of electric vehicle charging infrastructure. This may be applied to both Low Power Charging (LPC) applications and High Power Charging (HPC) microgrids. At the low power level, LVDC can be used to increase the power carrying capacity of existing street lighting cables to enable EV charging on the curb side for the 9.2 million households in the UK that do not have access to off-street parking [12]. Furthermore, from field trials in the Netherlands, LVDC is noted to increase the energy efficiency of street lighting networks due to the native DC properties of new LED lighting modules [13],[14],[15]. To the best of our knowledge the performance benefits (installation costs and energy savings) of integrated EV charging and LED street lighting on a LVDC network have yet to be fully quantified.

At the high power level, EV charging infrastructure manufacturers are moving from the 50kW rapid DC charger up to 350kW DC chargers that can charge an EV in under 15 minutes [13]. At these power levels, network connection challenges are likely to arise but these may be mitigate with the integration of stationary energy storage, that may charge at a low power level over time and supply a rapid discharge to an EV when required. Furthermore, the stationary battery may play in ancillary markets and provide further support functions to the DNO.

References:

[1]. Efficient DC power supply for data centres, available at: https://www.electricalreview.co.uk/features/9475-efficient-dc-power-supply-for-data-centres+&cd=3&hl=en&ct=clnk&gl=uk

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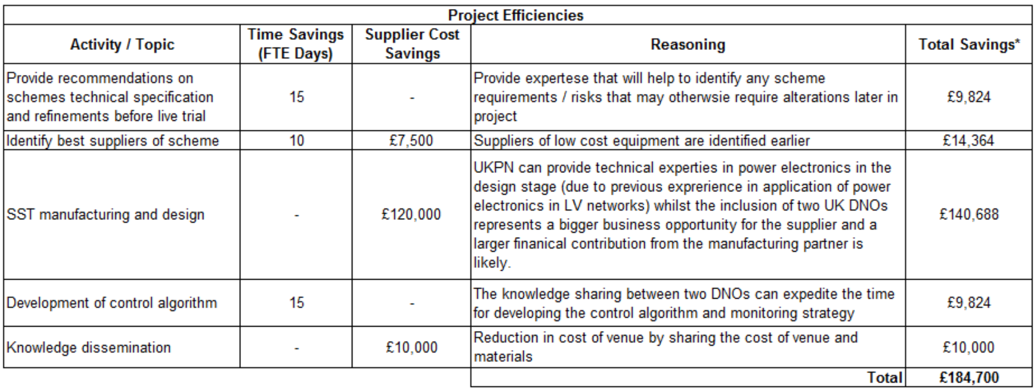
Attachments	N/A

Project code	SPMEN02	Question Number	23
Question date	05/10/2017	Answer date	10/10/2017
Submission section question relates to	N/A		
Topic	g) Robust methodology / ready to implement		
Question	Please provide a rough estimate for the amount of time saved using this device when compared to traditional reinforcement		
Notes on question			
Answer	Below is a summary of the time to plan and deliver the reinforcement of LV cable network between two substations. In practice the operational time and cost can vary depending on the specific characteristics on the reinforcement example i.e. city centre cobbled pavement vs country lane. • Design and Approval: 4-6 weeks • Tendering of cable work: 4-12 weeks • Road closure notices and traffic management: 12 weeks in advance • Replacement of cable: 5 weeks (200-250 meters per week) • Testing and Commissioning: 2 weeks Dependent on the specific scenario, the LV Engine Method may reduce the time to reinforce by **approximately 15-18 weeks** by avoiding the need to carry out LV cabling, road closure, and a reduction in the extent of design work required to select an appropriate LV cable route. This will allow the capacity provided by the LV Engine method to be provided quicker than the counterfactual, expediting the uptake of Electric Vehicles and other Low Carbon Technologies.		
Attachments	N/A		

Project code	SPMEN02	Question Number	24
Question date	05/10/2017	Answer date	10/10/2017
Submission section question relates to	N/A		
Topic	b) Value for money		
Question	As discussed within the bilateral, please provide CBA analysis for the savings you have identified through your collaboration with UKPN's Fun-LV project?		
Notes on question	We have considered all savings that can be made by working with UKPN and not just those attributed to learnings from FUN-LV.		
Answer	We are delighted that UK Power Networks are a partner of LV Engine and believe their inclusion in the project will deliver clear benefits to UK electricity consumers both during the project and when adopting project learnings into DNO BaU processes. In total UK Power Networks have committed to 172 days (FTE) of contribution during LV Engine of which they have agreed to contribute 50% as in kind support. We believe their contribution will be invaluable in expediting the uptake of the LV Engine method as BaU amongst the DNO community. This will ultimately quicken the payback period for the project, and spark more investment by manufacturers as they will see it as a bigger business opportunity. However, partnership with UKPN will also provide direct efficiencies during project delivery that could reduce the total cost of the project. Table 1 shows the estimated savings that could be achieved due to UKPN’s involvement in LV Engine. We are confident that this efficiency can be made by working with UK Power Networks and have consequently decided to reduce the project costs and the associated funding request within the resubmission of the LV Engine proposal to reflect this amount. **Table 2: LV Engine potential savings due to partnership with UK Power Networks.**			



Project Efficiencies				
Activity / Topic	**Time Savings (FTE Days)**	**Supplier Cost Savings**	**Reasoning**	**Total Savings***
Provide recommendations on schemes technical specification and refinements before live trial	15	-	Provide expertese that will help to identify any scheme requirements / risks that may otherwsie require alterations later in project	£9,824
Identify best suppliers of scheme	10	£7,500	Suppliers of low cost equipment are identified earlier	£14,364
SST manufacturing and design	-	£120,000	UKPN can provide technical experties in power electronics in the design stage (due to previous exprerience in application of power electronics in LV networks) whilst the inclusion of two UK DNOs represents a bigger business opportunity for the supplier and a larger finanical contribution from the manufacturing partner is likely.	£140,688
Development of control algorithm	15	-	The knowledge sharing between two DNOs can expedite the time for developing the control algorithm and monitoring strategy	£9,824
Knowledge dissemination	-	£10,000	Reduction in cost of venue by sharing the cost of venue and materials	£10,000
			Total	**£184,700**

Attachments	N/A

Project code	SPMEN02	Question Number	25
Question date	05/10/2017	Answer date	10/10/2017
Submission section question relates to	N/A		
Topic	c) Generates new knowledge		
Question	In terms of capacity, please compare the power transfer for AC/DC running over the same cable for three phrase and single phrase?		
Notes on question	N/A		
Answer	LV Engine will **allow us to understand the ability of LVDC to reduce network reinforcement by understanding the additional capacity that can be attained at different DC voltages** whilst considering all safety and operational requirements. Replacing the LV cable network can be very costly, disruptive to the public and has a negative environmental impact. The cost alone can average £77,500/km, but may be significantly higher in busy city centres. By 2040 the cost to reinforce the network due to the EVs will be in the order of many of billions of pounds so finding an innovative approach to reducing this reinforcement cost should be a priority. If existing low voltage AC circuits are converted to DC the transfer capacity, which is determined by both the thermal constraints of cable and the allowable network voltage drop can be significantly increased. This will allow a higher penetration of Electric Vehicles before the network requires costly reinforcement. **Transfer capacity of AC vs DC within thermal constraints of cable:** The chosen DC voltage level and LVDC cable configuration (bipolar 3-wire vs unipolar 2-wire) will determine the additional capacity that can be attained at DC vs AC. The existing 3 phase LVAC underground network consists of either 4-core or 3-core cables as shown in Figure 1. Equation (1) to Equation (4) show the calculation for power transfer in 3-phase AC, 1-phase AC, DC unipolar and DC bipolar systems.		

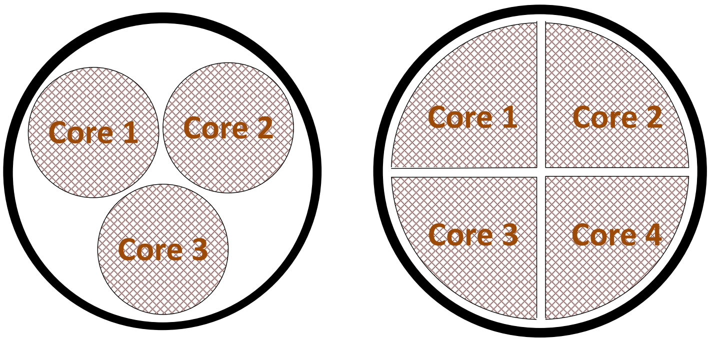


Figure 1: Typical arrangement for the existing 4 core and 3 core cables.

Equation (1): $P_{AC-3ph} = \sqrt{3}.V_{AC}.I\,.PF$ $\quad PF = power\ factor, V_{AC} = 400\ V$

Equation (2): $P_{AC-1ph} = V_{AC}.I\,.PF$ $\quad PF = power\ factor, V_{AC} = 230\ V$

Equation (3): $P_{DC-unipolar} = V_{DC}.\ I$

Equation (4): $P_{DC-bipolar} = 2.V_{DC}.\ I$

The maximum LVDC voltage which has been trialled in other projects is 1500V (or ±750V). This voltage level is within the insulation capability of most of existing LV cables. Table 1 shows the additional capacity can be transferred through unipolar and bipolar DC networks compared to a 3-phase AC network. For calculations given in Table 1, we have assumed i) the same thermal rating (or current I) for the cables operating at AC and DC, ii) a power factor of 0.95 in the LV AC network.

Table 1: The additional capacity can be released by operating at DC compared to AC

		Core 1	Core2	Core 3	Core 4	Additional capacity
3 core	**Unipolar**	+400	0	0		-39%
		+500	0	0		-24%
		+750	0	0		14%
	Bipolar	+400	-400	0		22%
		+500	-500	0		52%
		+750	-750	0		128%
4 core	**Unipolar**	+400	0	+400	0	22%
		+500	0	+500	0	52%
		+750	0	+750	0	128%
	Bipolar	+400	-400	+400	-400	143%
		+500	-500	+500	-500	204%
		+750	-750	+750	-750	356%

For a similar comparison with a single phase AC supply, we consider a 2 core cable or 3 core cable is used for AC operation as shown in Figure 2. Using Equation (2) to Equation (4) we can calculate the additional capacity that can be attributed to converting single phase AC to DC operation as shown in Table 2.

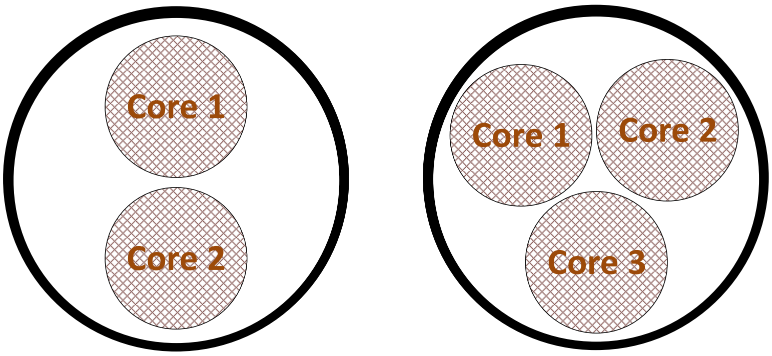


Figure 2: Typical arrangement for the existing 2 core and 3 core cables for single phase AC operation.

Table 2: The additional capacity can be released by operating at DC compared to single-phase AC

		Core 1	Core2	Core 3	Additional capacity
2 core	Unipolar	+230	0		5%
		+400	0		82%
		+500	0		128%
3 core	Unipolar	+230	0	0	5%
		+400	0	0	82%
		+500	0	0	128%
	Bipolar	+230	+230	0	110%
		+400	+400	0	265%
		+500	+500	0	356%

University of Manchester have also presented a similar capacity release calculation [1]. Please note the choice of voltage levels in Table 1 and Table 2 is only for the purposes of capacity released demonstration although all of aforementioned voltages are within the LV DC voltage level definition (<1500V). It should be noted that the voltage levels given in Table 1 & 2 may need to be reduced to at the customer connection point using DC-DC converters. The level of reduction depends on customer needs and safety requirements which recommend no more than 200V for 2-wire systems and 200V for 3-wire systems).

If the driver for DC is to reduce customer losses then a low voltage can be used which is closer to the voltage level of the end consumer and within the recommended safety margins. Contrastingly, a higher voltage output (i.e. ±750V) would allow for a **356% higher transfer capacity in a 4-wire system** for EV charging as shown in table 1, while DC/DC converters at the each charging post could provide a voltage suitable for rapid EV charging.

Transfer capacity of AC vs DC due to reduced voltage drop

The transfer capacity within LV DC network is higher than LV AC networks considering a better (stable) and controllable voltage profile offered by LV DC. In a DC network, the inductances effects on voltage profiles will be very limited. In addition, the reactive power in a DC network does not exist, hence, the impact of reactive power supply on the voltage profile can be eliminated resulting in less voltage drop compared to AC.

The less voltage drop in LVDC networks over LVAC networks allows for longer feeders before voltage drop becomes an issue. This can reduce the number of substations that are required in an area to supply customers. Figure 3 shows the study conducted by University of Strathclyde to compare the increased power transfer capability over distance of a DC network at +/-200V DC vs a conventional 230V AC supply whilst staying within a voltage drop of 3% [2].

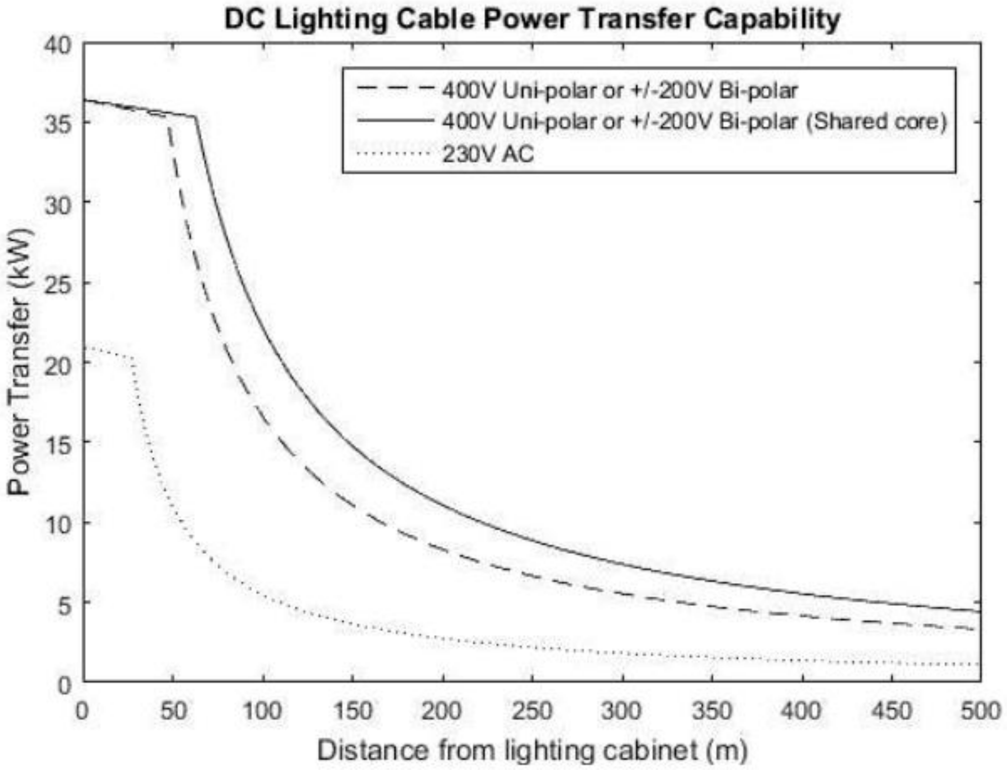


Figure 5: Power transfer capabilities of AC vs DC from [2]

[1] D. Antoniou, A. Tzimas and S. M. Rowland, "Transition from alternating current to direct current low voltage distribution networks," in *IET Generation, Transmission & Distribution*, vol. 9, no. 12, pp. 1391-1401, 2015.

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Attachments	N/A