SILVERSMITH Closedown Report

NIA Closedown Report

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Executive summary

The challenges faced by Distribution Network Operators (DNOs) regarding the integration of Low Carbon Technologies (LCTs) in the low voltage (LV) network are of significant interest. This report summarises our NIA funded SILVERSMITH project. The study aimed to investigate the potential compliance issues in the LV network, identify suitable solutions, and develop a strategy to address these challenges.

We identified several key challenges that DNOs are likely to encounter when customers connect LCTs. The introduction of distributed generation technologies like Photovoltaics (PV) and battery storage can lead to voltage rise constraints, while increased demand may cause thermal overloading of transformers and cables. Ensuring the security and availability of electrical networks is crucial for achieving net zero, but it requires substantial investment. Therefore, it is essential to prioritize the most significant challenges and focus on innovative network capabilities that offer substantial savings.

The study aimed to achieve the following **objectives**:

- Identify the parts of the network that require the most innovation.
- Determine the timelines for unlocking these capabilities.
- Highlight specific capabilities missing from our current toolbox, requiring further development.
- Conduct a comprehensive literature review to explore state-of-the-art technologies available in the market.

Based on the network modelling, the following **recommendations** were made:

- Innovative Solutions: Areas lacking obvious innovative solutions require additional research and innovation. In particular
  - An ability to increase cable headroom in the range of +15 to +100% for a cost below £50k would be beneficial.
  - Other requirements include the development of innovative technologies that could offer between +20% and +80% thermal transformer capacity at less than £16,000 per feeder (for underground feeders supplied by GMTs) or £7,500 per feeder (for overhead feeders supplied by PMTs) would offer significant value.

The analysis also revealed that initially, the LV network will face voltage rise challenges due to PV uptake. Subsequently, thermal overloading of transformers and cables will become a significant concern. By 2040, thermal constraints may affect approximately 40% of LV circuits, with 27% impacted on the transformer side and 13% on the cable side. This percentage is projected to increase to 60% by 2050. This directed our attention to solutions that improve voltage management and release cable and transformer thermal headroom.

To successfully integrate LCTs into the LV network and achieve net zero, it is imperative to address the challenges associated with voltage rise and thermal overloading. This requires a strategic approach, focusing on innovative solutions and improving network visibility. The findings and recommendations of this study provide valuable insights for DNOs in developing their investment and innovation plans to ensure the secure and reliable operation of the LV network.

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1. Project Background

Great Britain is undergoing a transition to renewable and distributed energy. Many energy customers are becoming more involved in the energy system, transitioning from simply being electricity consumers to electricity prosumers. This is being led through the electrification of transport (i.e. electric vehicles) and heating (i.e. heat pumps) along with the continued growth in distributed generation, most commonly solar photovoltaics (PV). Low Carbon Technologies (LCTs) such as Electric Vehicles (EVs) and heat pumps are forecast to witness vast uptake rates over the next few decades. The combined effect of these technologies will have a profound effect on the electricity network. Large numbers of these technologies will be deployed on the Low Voltage (LV) networks, which will place significant additional demand on it, in many cases beyond which the network was designed for. National Grid manage the LV network across our licence areas in the East Midlands, West Midlands, South West, and South Wales, this study aims to help increase our understanding of the challenges and opportunities for new technologies across our LV network.

As National Grid transitions towards the management of an active LV network, this must be achieved in a manner which enables customers to install LCTs at the foreseeable uptake rates. This has to be achieved while minimising costs to consumers resulting from network augmentation but continuing to provide a safe and reliable supply of electricity. Additionally, network management should be fair to all electricity consumers, regardless of whether they own LCTs or not. It is therefore important to maximise value extracted from the existing LV network to minimise network costs arising from network reinforcement.

Past innovation projects have investigated some of these technologies and developed certain use-cases against particular network problems.

- UKPN's 'FUN-LV' investigated how power electronics can enable soft open points,
- Northern Powergrid's 'Customer-Led Network Revolution' investigated on-load tap changers and,
- Electricity North West's 'QUEST' is investigating whole system voltage optimisation.

What we are missing, is an understanding of how widespread these LV issues will become, which mix of novel and BAU technologies best addresses them, and an understanding of the functional requirements needing further innovation activity to improve on new or existing practices in light of continued technology development.

2. Scope and Objectives

The project has evaluated the state-of-the-art technologies available for voltage control on the LV network, along with a study to understand where these solutions may solve real-world network challenges caused by the uptake of LCTs. Recommendations for future developments were made, along with identifying areas which were not addressed by the current range of solutions available to the DNO.

The objectives for SILVERSMITH are given in the table below. An explanation of the assessed status is given in Section 6 (Performance Compared to Original Aims, Objectives).

Table 2-1: Status of project objectives and the status of each objective at the closedown stage of the project. All objectives have been fulfilled.

Objective	Status
Understand the issues which are likely to be present on the Low Voltage (LV) network up to 2050. Business As Usual (BAU) activity does not investigate the LV network at this granularity.	✓
Document the current state-of-the-art LV voltage control options and evaluate which are likely to meet the functional requirements created in this work.	✓
Develop two design methodologies for selecting whether LV voltage control technologies can offer a benefit over conventional reinforcement strategies.	✓
Develop an understanding of which network assessment methodology is most suited for modelling issues and forecasting required investment on the LV network.	✓

3. Success Criteria

The main success criteria of this project was having a detailed understanding of the demographic of LV network constraints at several timescales leading up to a net zero power system, combined with a methodology for identifying the most cost-effective means to address these challenges. The library of project reports documents the approach taken during the project along with detailed results and analysis.

The success criteria for SILVERSMITH are given in the table below. An explanation for the assessed status is given in Section 6 (Performance Compared to Original Aims, Objectives).

Table 3-1: Status of project success criteria and the status of each criterion at the close-down stage of the project. Each success criterion has been achieved.

Success Criteria	Status
A detailed literature review is produced that captures all of the state-of-the-art LV voltage control technologies available, how they work and which DNO has implemented them.	✓
Comprehensive network studies are carried out that identify the demographic of LV compliance issues. The outputs from each approach need to explain clearly, where network compliance issues will be experienced.	✓
Each consultant produces a clear methodology, which is clear enough so DNOs can select the best LV voltage control devices based on what likely challenges are forecasted on their network.	✓
A detailed technology witnessing report is produced that explains whether the up-and-coming technologies can meet the functional requirements determined in the network study.	✓
A detailed methodology comparison report is produced that explains the strengths and weaknesses of each methodology employed by each consultant. This report clearly explains what method should be used in further analysis.	Revised during the course of the project. See section 6.

4. Details of the Work Carried Out

The SILVERSMITH project featured two phases of research, accompanied by ongoing supplier engagement summarised in the technology investigation and final recommendations report.

Phase 1 analysed the LV network with LCT connections added up to 2050 and evaluated the BAU methods for dealing with compliance and constraint issues that are predicted. EA Technology Ltd. completed the network study using both the Transform tool and a power flow study using DIgSILENT's PowerFactory software. Phase 2 evaluated the network in more detail, and considered what functional requirements are needed to combat the constraints. Supporting load flow analysis assessed the performance of novel technologies, which was used to establish the design methodology. Figure 1 shows the structure of Phase 1 deliverables, and Phase 2 deliverables alongside ongoing supplier engagement.

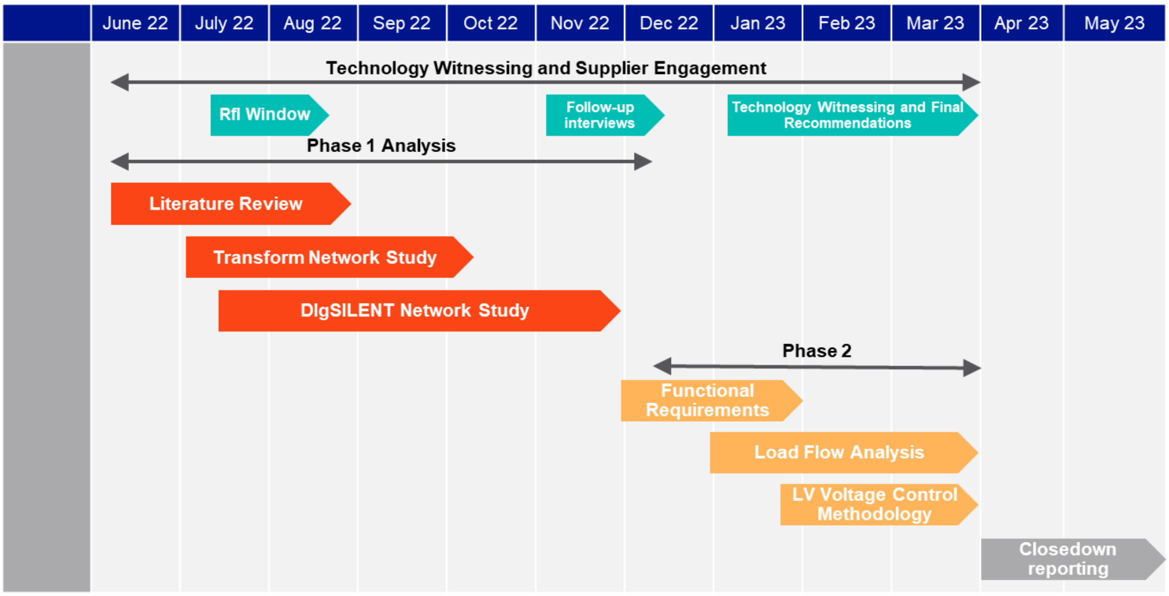

Figure 1: Project Delivery Plan

Phase 1

D1.1a: Network Study (Transform)

The Transform network study results presented an analysis that identified the types of network constraint forecast to be encountered across National Grid's licence areas. This was delivered through the use of EA Technology's Transform Model® which enables a parametric-based analysis of different LCT uptake scenarios and how they will impact the network. National Grid's existing Transform models were updated based on the scenarios in Distribution Future Energy Scenarios (DFES) 2021.

The Transform study results identified the type of network constraints encountered both at the network level and on a feeder archetype basis. It highlighted the durations, scenarios and timescales under which network constraints are met, and how this differs across archetypes.

To accurately forecast connections of new LCTs, uptake rates and demand profiles from our DFES datasets were incorporated into the Transform baseline. Each of the three DFES scenarios considered (Best View, Leading the Way, Steady Progress) have different uptake rates of LCTs and consider preferences between hydrogen and electric heat pump based solutions. This results in a natural sensitivity analysis of the uptake rate which is considered an important factor. This report highlights how we validated this data input, along with how we accounted for the natural clustering of LCTs on particular feeders. In addition, detail of the 11 LV feeder archetypes studied in Transform is provided.

Within the report, the network constraint analysis is presented in several ways. It first explains the constraint types in detail defining what is meant practically speaking. Then, it considers the scale

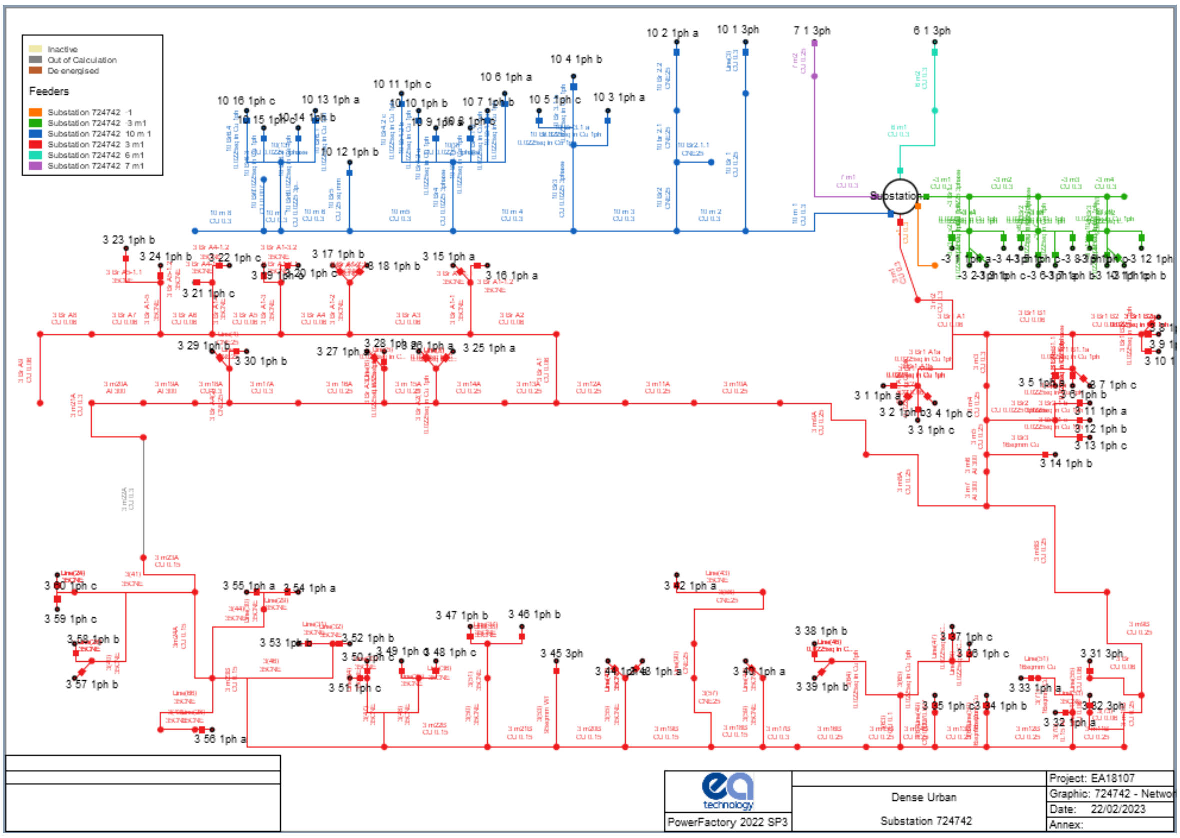

Figure 2: Dense Urban Network Model

of network-wide constraints by period, by uptake rate (using different DFES scenarios), by network archetype, and finally by comparing to a GB wide vs National Grid analysis.

D1.1b: Network Study (PowerFactory)

In parallel to the transform analysis detailed above, a separate network study was performed in DIgSILENT's PowerFactory software. This represented a more 'depth-based' approach. The report presents an analysis using PowerFactory which investigated three case studies of real-world networks (dense urban, urban and rural) in National Grid's West Midlands licence area. The constraints posed by the forecast uptake of LCTs according to the DFES scenarios were analysed in the years 2028, 2033, 2040 and 2050.

The work began by deciding upon three representative case study LV networks. One Dense-Urban, one Urban, and one Rural. Although it was understood that only using three networks would limit the extent of the modelling, it was deemed a suitable compromise between cost, time, and resources against the benefits attributed to the work. For context, across our four licence areas, we have around 60,000 ground-mounted distribution substations and 125,000 pole-mounted transformers. The three archetypes were:

- **The Dense Urban archetype** was selected to include feeders where the customers include several multi-occupancy buildings. In the case selected, there is a 15-storey tower block that has 90 individual dwellings within and some small flats/maisonettes, other properties within the model include buildings with several shops on the ground floor with residential properties above. Figure 2 shows the PowerFactory Network model for the Dens Urban archetype.
- **The Urban archetype** was selected to include a housing estate on the outskirts of a town or city. The properties in the network selected are a mixture of terraced, semi-detached, and detached properties. There are no commercial or industrial properties included within the network selected. There are 4 feeders associated with the substation and around 300 customers are associated with these 4 feeders.
- **The Rural archetype** was selected to represent a small rural village supply. The substation has a smaller capacity ground-mounted transformer fed from 11kV overhead lines. The network has a mixture of underground and overhead lines. There is a mixture of commercial and residential properties within the village.

In addition to providing details of each network, the report details the assumptions made when performing the modelling and model refinement. Similarly to the Transform study, the DFES scenarios were used to forecast the uptake of LCT devices across each network. However, to minimise resources while maximising insight, four time points were selected: 2028, 2033, 2040 and 2050. The first two coincided with Ofgem's RIIO price control periods, while the latter two were selected to capture the 'net-zero' scenario and a further intermediate step. At each study year, quasi-dynamic studies covering winter maximum demand and summer maximum generation were performed.

D1.2: Literature Review

The Literature Review identified novel technologies that could offer the potential for increasing headroom on the LV network. A Request for Information (RfI) was conducted as part of this process where providers were asked to give details about how their technologies could potentially help to increase headroom on the LV network. The Request for Information received six replies from suppliers and the relevant commercial and technical information provided was used to update the technical and commercial parameters required for modelling.

In addition to the RfI, EA Technology Ltd. summarised the relevant innovation projects which have already trialled solutions on the LV network. This knowledge informed the modelling completed by updating the benefit certain technologies have on headroom, for instance.

Phase 2

D2.1a: Functional Requirements (Transform)

The Transform Functional Requirements report was the first instance in which the project attempted to 'fix' the network compliance issues as opposed to identifying them.

Firstly, Transform was run using 'artificial' solutions. Each solution in the artificial solution set released a set quantity of a single type of headroom. For instance, '*4% Thermal Headroom*' or '*10% Voltage Rise'*. The complete list of these is provided in Appendix 3. Inspecting which artificial solutions are deployed for each archetype is a clear way to identify the Functional Requirements needed under different scenarios. Each time a network constraint is identified, Transform deploys the most cost-effective solution to resolve that constraint over the next 5-year period. This was chosen to align with the 5 year regulatory periods. However, in many instances, after those 5 years, another constraint is hit due to further deployment of LCTs, which required another intervention. This is counted as an additional constraint for this analysis since an additional solution is required to be deployed. In some cases a single feeder can be subject to three of four constraints throughout the study, requiring multiple interventions. It is possible that a one touch solution could offer longer term savings, but it would shift spending sooner and we value deferring reinforcement.

After considering the artificial functional requirements, the work identified which solutions are deployed in two instances; i) the counterfactual instance where only Business as Usual (BaU) solutions were available; and ii) with both BaU and novel technologies available. This showed the variation in technology deployment between the counterfactual and novel studies and also showed how the solutions deployed varied by network archetype.

Transform deploys solutions to minimise cost over 5-year periods, it was, therefore, important to update and validate solution costs, to establish the baseline opportunity cost which future innovation can improve upon. For this reason, all costs were validated by cross-referencing between RfI responses, available literature, and for BaU solutions - inflation-based adjustments from previous Transform Studies.

Using these costs and functional requirements, it was possible to calculate the maximal totex cost per feeder which alternative innovative solutions could offer a benefit over the more costly BAU alternatives used today. This also offers a price ceiling for flexibility directed at solving LV issues. Within the report, this was explored for the different network case studies.

Flexible solutions were excluded from network analysis. This project focuses on understanding the extent of network compliance issues and outlines how DNOs would be best suited to address them through conventional and novel technological-based solutions, establishing a pricepoint to compete against. This information can then inform ceiling price and network capability estimates for flexibility-based solutions.

Flexibility remains an important option for managing the LV network. Should flexibility solutions offer an alternative method of managing the LV network at a lower cost than the technological solutions covered in this report, then flexibility should be strongly considered as an alternative to a technological solution. As the flexibility markets develop, a clearer picture will emerge of capacity available from flexibility, the willingness of consumers to engage, and the cost of procuring flexibility services.

D2.1b: Load Flow Analysis of Novel Solutions

The PowerFactory Functional Requirements report analysed the effect of novel technologies identified in the literature review on the three case study networks. This report discussed the effect of these technologies on the network, assessing their impact on the voltage and thermal capacity of the network. Implications on fault level and harmonics were also discussed qualitatively for those technologies where parameters would be impacted.

Specifically, the 'Smart' Transformer, Statcom, On-load tap changer, and remote switching and meshing were studied across the Urban and Rural Case studies.

D2.2: LV Voltage Control Selection Methodology

The LV Voltage Control Selection Methodology report looked further into how network constraints were solved by which technologies. This report was aimed at highlighting where innovative solutions may outperform conventional means, and direct our innovation activity to the areas that are forecast to be the largest challenges in the future, and consequently offer the greatest cost-saving potential. This was done on an archetypal basis where four groups of network archetypes were considered.

The results from the Functional Requirements report were used to map constraints to solutions, then certain sensitivity studies were performed. Variation between licence areas and between scenarios was evaluated.

To visually present how the network constraints are addressed by technical solutions, in the Transform modelling, Sankey diagrams have been produced. The purpose is to visually represent how a particular technology (shown on the right-hand side) can be used to address multiple types of network constraints (shown on the left-hand side). Figure 3 below shows an example of these, displaying the technologies selected by Transform in the South Wales Licence area. The full selection of figures is available on our webpage. The interactive figures show how many sites may require intervention, given the number of instances experienced for both the constraints and solutions. Within this figure, readers are able to read how many will experience coincident constraints. For more information on this, please view the Network Study (Transform) and LV Voltage Control Selection Methodology reports.

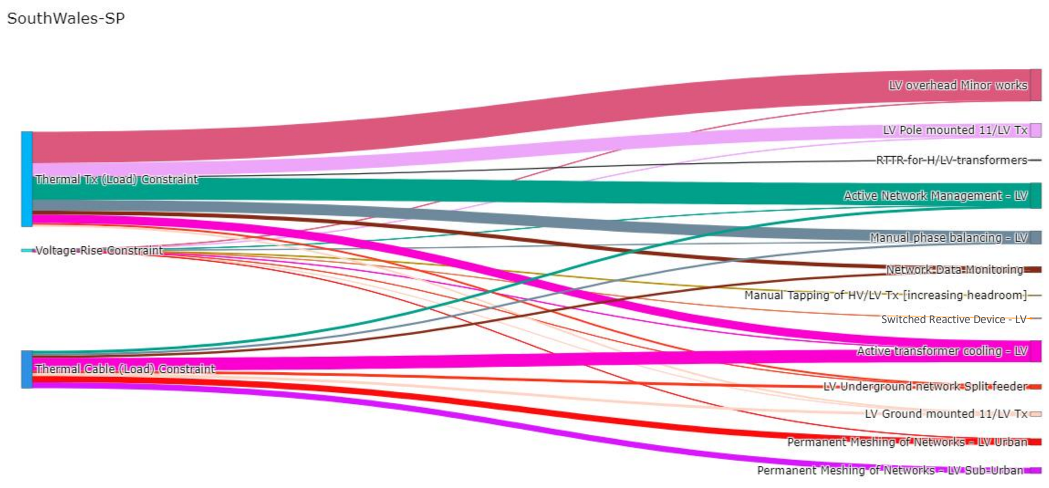

Figure 3: Sankey diagram showing how network constraints (left) are addressed by technical solutions (right) for the South Wales Licence Area Steady Progression

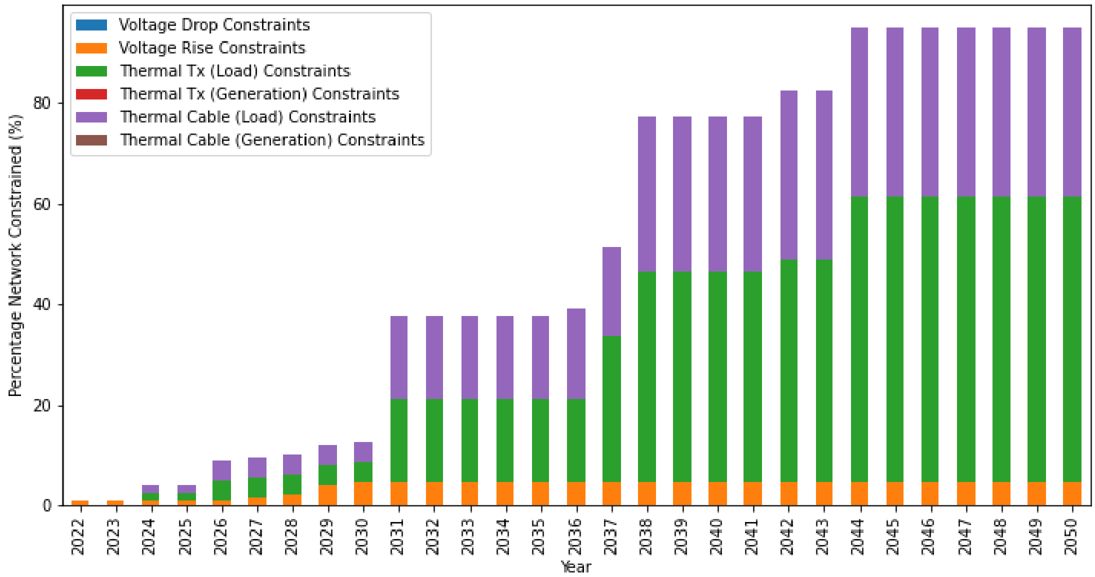

Figure 4: Solutions deployed for constraints on LV2 in East Midlands under BV scenario

To understand network requirements at a higher level than archetype by archetype, four case studies were formed from consolidating similar LV archetypes:

1. **Commercial customers** (LV1: Central Business Districts, LV3: Town Centres, LV4 Business Districts, and LV5 Retail Parks)
2. **Domestic Urban** (LV2: Dense Urban, L6: Sub-Urban Streets, LV7: New Build Housing Estates, and LV8: Terrace Streets) (as seen in Figure 4)
3. **Rural Overhead** (LV9: Rural Village Overhead, and LV11: Rural Farmsteads)
4. **Rural Underground** (LV10: Rural Village Underground)

These were each analysed and doughnut plots were produced which display the types of solution most commonly deployed to address each LV archetype's most significant constraints. In addition, to display the scale of impact faced by each archetype, cumulative plots show the proportion of each archetype which requires intervention. These figures are presented in the *'LV Voltage Control Selection Methodology'* report for each archetype.

Figure 4 shows the cumulative percentage of networks that experience an intervention caused by a particular constraint. Whenever the Transform model calculated that a given network had exceeded a particular constraint, the most significant 'driving' constraint was recorded, and the most cost-effective solution was chosen to remove constraints for 5 years. On some feeders, it was more cost-effective to implement two cheaper solutions compared to one more costly alternative. For instance, overcoming thermal overloading by installing network data monitoring and active network reconfiguration compared to overlaying with a higher capacity cable.

The report uses doughnut plots to give a clearer indication of what intervention is most commonly used for each network constraint, for each LV archetype. The doughnut plots show;

- in the inner ring, the type of network constraint encountered,
- in the outer ring, the proportion of solutions deployed to resolve the constraint type in the inner ring.

The charts show only the subset of feeders for each archetype that encounters network constraints. i.e. the proportion of uncongested feeders from the archetype are not represented.

Figure 5: Solutions deployed for constraints on LV2 in East Midlands under BV scenario

After displaying the mapping between network issues and solutions, indicative timelines were produced for each archetype. Details of how LCT clustering was considered for these timelines are included in the *'LV Voltage Control Selection Methodology'* report.

Plots are given for each archetype. The solid 'max import' and 'max export' charts show the feeder's maximum demand and maximum generation expected over the study period, based on what is connected. The dashed lines show various import and export ratings for both the cable and transformer. In Figure 6, a cable voltage rise capacity (%/kW) is breached first, initiating manual tapping of the transformer. Subsequently, demand growth triggers breaches in thermal cable ratings, thermal transformer ratings, and another voltage rise. In this case, it was more cost-effective to manage the constraint by completing a manual phase balancing, enabled by network data monitoring. Solutions are categorised as either 'Novel' or 'BaU' depending on whether they were currently used at scale within our network. These plots provide strategic direction to our innovation programme by plotting the cost and timelines of available methdology and systems. For example, Figure 6 indicates that there is an innovation gap for a system that could be deployed from the early 2030's that could address volt age issues, cable issues and transformer thermal issues, that costs less than circa £37k (i.e. the net present cost of £2,495 and £48,266 seperated by 8 years).

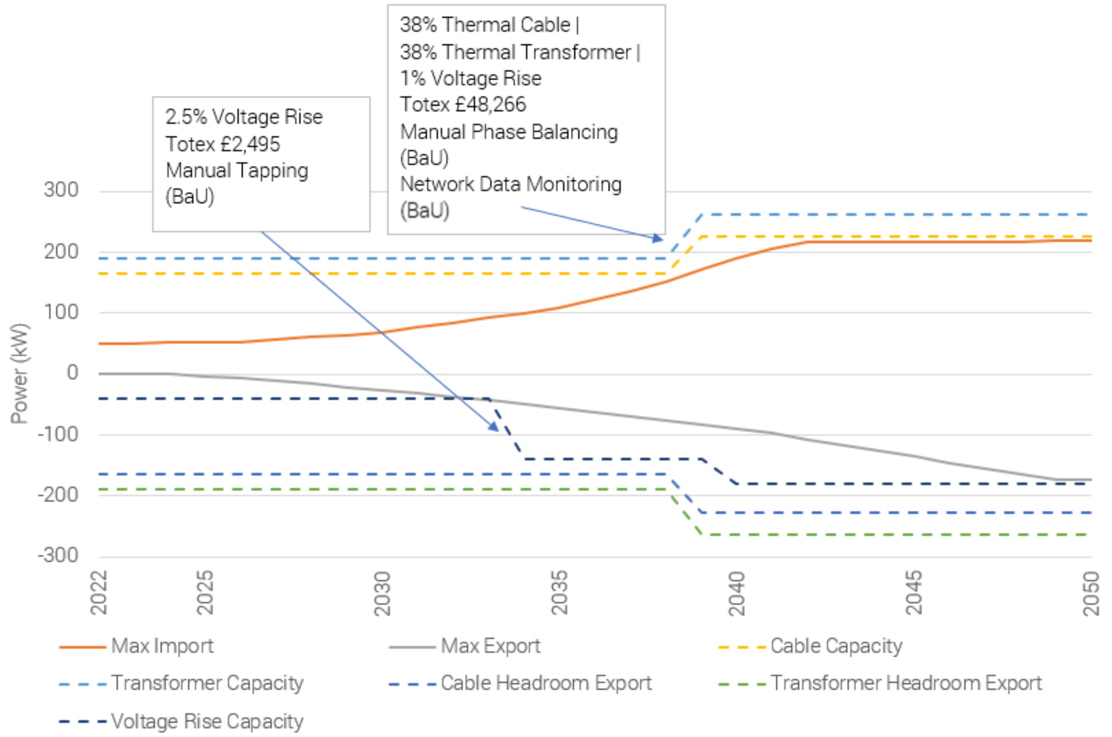

Figure 6: LV2 West Midlands Best View indicative timeline

Where increases to thermal headroom were required, we considered how flexibility could be used to manage or defer the reinforcement investment. To help describe the flexibility commitment required, we have expressed the average amount of flex per customer on particular feeders and provided timelines for when it would be needed. This will enable insights to aid flexibility market development for solving LV constraints in particular.

To defer network reinforcement for a 5-year period from time of first network constraint, between 0.7kW and 2.1kW per customer are required depending upon the network archetype. This analysis was completed based on winter peak demand.

Table 1: Table showing first interventions applied across the LV archetypes, and flexibility requirement to defer investment for 5 years

LV Archetype	Year	First Intervention(s)	Headroom Release	Totex Cost	Flexibility Required to defer for 5 years (kW)	Flexibility Required per customer to defer for 5 years (kW)
LV2	2033	▪ Manual Tapping of HV/LV Tx	▪ 2.5% Voltage Rise	£2,495	29	0.7
LV6	2033	▪ Permanent Meshing of Networks - LV Sub-Urban, ▪ Manual Tapping of HV/LV Tx, ▪ Network Data Monitoring, ▪ Active transformer cooling - LV	▪ 47% Thermal Transformer, ▪ 72% Thermal Cable, ▪ 2.5% Voltage Rise	£64,728	33	1.0
LV7	2031	▪ Network Data Monitoring, ▪ Manual Tapping ▪	▪ 15% Thermal Transformer, ▪ 15% Thermal Cable, ▪ 2.5% Voltage Rise	£9,529	33	1.1
LV8	2033	▪ Permanent Meshing, ▪ Manual Tapping, ▪ Network Data Monitoring, ▪ Active Transformer Cooling	▪ 54% Thermal Transformer, ▪ 72% Thermal Cable, ▪ 2.5% Voltage Rise	£64,728	34	0.9
LV9	2028	▪ LV Pole Mounted Tx, ▪ Network Data Monitoring	▪ 15% Thermal Cable, ▪ 107% Thermal Transformer	£14,504	31	2.1
LV10	2033	▪ LV Underground Network Split Feeder, ▪ LV Ground Mounted Tx	▪ 100% Thermal Cable, ▪ 80% Thermal Transformer	£69,867	47	1.6
LV11	2027	▪ LV Overhead Minor Works	▪ 100% Thermal Transformer, ▪ 100% Thermal Cable	£35,920	12	1.1

D3.1: Technology Witnessing and Final Recommendations

The Technology Witnessing report acts to summarise which novel technologies meet the functional requirements of our LV electricity distribution network and thus offer value to the network operator considering the forecast LCT uptake and associated network constraints. This enables us to consider which novel technologies should be progressed to trial and with what priority. It also highlights where further innovation should be focussed, by working with suppliers to develop technologies further. This includes some instances where policy, safety and design implications need to be considered for novel technologies to be deployed onto the network.

Throughout the project, engagement with technology suppliers was key to fully understanding how certain technologies operated, what their benefit to the network is, how much they cost, how to model them, and what their expected use cases might be. For this reason, following the initial responses from the RfI, follow-up interview webinars were conducted with each supplier. The Request for Information received six replies from suppliers, and the relevant commercial and technical information provided has been used to update the technical and commercial parameters required for modelling.

For **further information** on work carried out within this project please see the detailed reports which can be found on the project page on **National Grid's Innovation website**:

https://www.nationalgrid.co.uk/innovation/projects/solving-intelligent-lv-evaluating-responsive-smart-management-to-increase-total-headroom-silversmith

5. Performance Compared to Original Aims, Objectives and Success Criteria

The project has mostly satisfied its original aims objectives and success criteria.

Table 6-1: Performance compared to project objectives

Objective	Status	Performance
Understand the issues which are likely to be present on the Low Voltage (LV) network up to 2050. Business As Usual (BAU) activity does not investigate the LV network at this granularity.	✓	• Outputs of the SILVERSMITH project highlight the issues which are likely to arise on the LV network. The two network study reports explain these in detail, initially voltage rise issues due to PV uptake cause issues. However, this is quickly overtaken by thermal headroom issues due to increased loading.
Document the current state-of-the-art LV voltage control options and evaluate which are likely to meet the functional requirements created in this work.	✓	• The Literature Review has captured the state-of-the-art technologies which are available for LV voltage management. This showcases the results of our stakeholder engagement and Request for Information.
Develop two design methodologies for selecting whether LV voltage control technologies can offer a benefit over conventional reinforcement strategies.	Not achieved – change in scope	• Network modelling was performed using two separate methodologies. This led to two separate Network Study reports, and two separate evaluations of how novel solutions can be applied to manage network compliance issues. • However, it was decided during the project that the Design Methodology should be a single document using aspects of each design methodology. Further details explaining this change are documented in Section 7.
Develop an understanding of which network assessment methodology is most suited for modelling issues and forecasting required investment on the LV network.	✓	• This has been completed during the project and explained in this report in Sections 7 and 9.

Table 6-2: Status of project success criteria

Success Criteria	Achieved	Performance
A detailed literature review is produced that captures the state-of-the-art LV voltage control technologies available, explains how they work, and share which DNO has implemented them.	✓	• A detailed literature review document has been produced which explains the state-of-the-art and showcases the responses from our Request for Information.

Success Criteria	Achieved	Performance
Comprehensive network studies are carried out that identify the demographic of LV compliance issues. The outputs from each approach need to explain clearly, where network compliance issues will be experienced.	✓	• Two detailed reports explain the methodology and results from network modelling. • The demographic of network issues at future study periods has been presented in graphic means.
Each consultant produces a methodology that is enough so DNOs can select the best LV voltage control devices based on what likely challenges are forecasted on their network.	Not achieved – change in scope	• The separate methodology aspect of the project was minimised during delivery. Although modelling was completed using two separate methods (parametric model and power flow model), the results were combined into a single methodology. • Section 6 explains the reasoning, in essence, it was deemed more useful to narrow the scope of the PowerFactory modelling to understand how each novel technology operates.
A detailed technology witnessing report is produced that explains whether the up-and-coming technologies can meet the functional requirements determined in the network study.	✓	• Ongoing engagement with suppliers was key to the success of this project. • Following the initial responses to the Request for Information, follow-up interviews were made with each supplier to better understand the ability of their device to meet network needs. • Subsequent analysis in the Functional Requirement phase evaluated the suitability of each technology in dealing with the expected compliance issues, and the Technology Witnessing report explains in detail whether specific devices were selected. If they were not, it also explains why not.
A detailed methodology comparison report is produced that explains the strengths and weaknesses of each methodology employed. This report clearly explains what method should be used in further analysis.	✓	• A comparison between each methodology has been made in this report.

6. Required Modifications to the Planned Approach during the Course of the Project

Change of supplier

Initially, the project was scoped to achieve a comprehensive analysis of the network using two separate, but parallel approaches. One depth-based analysis using PowerFactory and Connect LV, and one breadth-based approach using the Transform Tool. However, during the start of the project, a key supplier became unexpectedly unavailable, which resulted in a change of delivery team. As per our project governance, we instigated actions from our risk and issue control framework to contain the impact. This change meant that the PowerFactory-based approach, which was to be delivered by a separate consultant, was given to EA Technology Ltd. Despite the mitigation measures put in place to contain the impact, the change had a limited effect on the project.

Revised scope for D2.1b: Functional Requirements (PowerFactory)

The scope of work for the Phase 2 deliverable *'D2.1b: Functional Requirements (PowerFactory)'* was tailored to suit the project during delivery. Initially, the report was designed to be performed in parallel to the *'D2.1a: Functional Requirements (Transform)'* report and offered a contrasting methodology. However, during the course of the project, two factors influenced a change in approach from this. The altered report focused more on investigating the impact of each novel technology on the Distribution Network, investigating its performance in managing the LV network and highlighting any significant issues which arise.

The first factor which influenced this change was the outputs of the Network Study. During work on *'D1.1b: Network Study (PowerFactory)'* it was found that the severity of network compliance issues was relatively limited. This shows the importance of being able to model clusters of LCT uptake being unevenly distributed, as the uptake is not evenly spread across feeders. Another reason for the relatively small number of compliance issues, was because the cabled selected for study were relatively high capacity. Their low impedance meant that voltage issues were less likely, and could accommodate higher loading. This, however, is not representative of our entire network.

Some compliance issues were experienced in the later years, under the more aggressive uptake scenarios however the majority of the networks in the three case studies remained largely unaffected by the increased LCT uptake. It was proposed that this was likely due to the sites having high-capacity LV mains cables already installed, which with their relatively low impedance could cater for the additional current at peak demand without a significant impact on voltage. Rather than artificially breaking the network to test how to fix it, or alter the models to change conductor type, it was proposed that subsequent power flow studies should investigate the impact of each novel solution.

The second factor which influenced our decision to focus specifically on the novel technologies was the suitability of the PowerFactory software in identifying the needs of the network on a macro scale. The project did not have the resources or budget to perform power flow studies at the scale required to obtain a macro view of the network's functional requirements. In fact, due to incomplete LV network records, constructing and testing the three relatively simple case studies took significantly longer than initially expected. It would be wise to say that any future work to construct power flow models for large parts of the LV network should be cautious in their time budgeting.

Due to the comparative ease in conducting macro-scale analysis using Transform, and acknowledging that the strength of PowerFactory lies more in the detail, the scope of *'D2.1b: Functional Requirements (PowerFactory)'* was revised to focus on evaluating each of the technologies which were the focus of the Request for Information.

7. Project Costs

During the course of the project, the only variance between the budget and actual spending was an increase in spending for National Grid time and resources.

Table 8-1: Project Spending and Variances

	Budget (£)	Actual (£)	Variance(£)
National Grid	24,912.00	31,230.03	6,318.03
EA Technology Ltd.	280,588.00	280,588.00	0.00
Contingency	30,550.00	(6,318.03 – this is included in the overspend in National Grid Cost)	-24,231.97
Total	**336,050.00**	**311,818.03**	-24,231.97

Comments around variance

Use of contingency budget for additional National Grid Project Management time and resources. This change was a result of extending the project duration but did not exceed the contingency attributed to the project.

8. Lessons Learnt for Future Projects and Outcomes

The learning from the SILVERSMITH project has been captured and shared on the SILVERSMITH website.

Table 8-1. Learning from SILVERSMITH

Topic	Learning detail	Related Document
State-of-the-art LV Voltage Control devices	• As part of the literature review, a range of solutions have been considered that have the potential to provide either additional voltage or thermal capacity to the network. These solutions range from retrofit devices, physical network interventions, market solutions (encouraging consumer engagement) and policy solutions. • The Literature Review documents the operating parameters of different LV voltage control devices.	• Literature Review
Modelling LCT uptake using DFES scenarios	• Currently, no commercial heat pump profile exists. Within this project, this limited the insights and results obtained for LV feeders, which had more commercial customers connected. • It was recommended that an understanding of commercial heat pump profile(s) should be developed such that the effect of commercial heat pumps can be included in future network modelling.	• Network Study Results • Functional Requirements • Design Methodology
Power flow models	• During the PowerFactory network modelling, several delays were caused by a lack of model convergence. LV network studies are not currently performed as a business-as-usual activity, as such the electrical diagrams are often incomplete or missing detail. Where information was missing, approximations and assumptions were made, which often caused a lack of convergence until improvements were made incrementally. • In future work, it is recommended to err on the side of caution when planning detailed network modelling using LV records. It is also recommended that to improve this process, systematic improvements to the LV records should be made. • The networks modelled in the PowerFactory work at the project's outset were limited in their ability to evaluate novel solutions. D1.1 showed that very few issues were expected to arise looking out to 2050. When it came to assessing the functional requirements of the novel options, solutions were limited to improving areas of the network that didn't experience significant issues. In particular, remote switching/meshing was only possible to be modelled on one area of the urban model. • One of the main objectives was to understand how often LCT loads would require certain proactive measures to be taken on the LV network. For instance, we wanted to understand how increased LCT loading and export at different times throughout the day may require multiple interventions throughout the day to manage the voltage. By only investigating three scenarios, we were not able to	• PowerFactory Network Study Results

	accurately model the impact of this across the network and understand where this may be needed at scale.	
The demographic of network issues	• Feeder types dominated by commercial customers are forecast to witness primarily voltage rise constraints. This is due to an uptake of PV. • Transformer load-related constraints are consistently the most significant issue across all licence areas. • In 2028, on average across all National Grid's licence areas approximately 6% of feeders require intervention for thermal constraints under net import (approximately 4.5% transformer and 1.5% cable), and 2% of feeders require intervention for voltage rise constraints. • By 2040, thermal constraints will affect 40% of feeders. 27% Transformer, 13% thermal. This increases to 60% by 2050. • While commonly a single network constraint is encountered, it is also common that multiple types of network constraints are encountered at the same time. When multiple network constraints are encountered, these are sometimes on distinct feeders, but regularly also on the same feeder. A common example would be thermal transformer and thermal cable constraints being witnessed simultaneously on a feeder.	• Network Study Results
	• The network results showed that the Dense Urban network is more likely to experience breaches in thermal capacity significantly before statutory voltage limits are breached. This may mean that solutions which may become necessary for the Dense Urban network will favour those which can reduce circuit loading, particularly during the winter evening peak periods. Flexibility may be a strong solution in Dense Urban networks, which are estimated to require around 1.0 kW of demand turn-down per customer. • In the Urban Network, higher levels of PV generation and longer feeders, when compared tothe Dense Urban network, show that statutory upper voltage limits (+10%) could begin to be breached from 2033. It was also found that thermal loading begins to become overloaded during winter peak from 2033 (Leading the Way) and 2040 (Best View) at which point some intervention would be necessary. For the Urban Network, interventions which reduce the thermal loading during the winter whilst also improving voltage management in the summer will be necessary. • For the Rural Network, some customers will experience high voltages breaching the upper statutory voltage limits during peak PV export from 2040 onwards. Although circuit loadings remain well below their 100% rating the total loading on the supply transformer will begin to be exceeded for the highest LCT uptake scenarios (Leading the Way). In some situations, circuit loading remains within thermal limits but in Rural networks, voltage issues may begin to occur at different points along the feeder.	• PowerFactory Network Study Results

Performance of Novel LV Voltage Control Devices	• To use a STATCOM successfully, remote monitoring of the network is needed. This is to feed into an algorithm which triggers when the STATCOM needs to be operated. Failing to do so would increase losses and consume capacity. • Ideally, a STATCOM would only resolve voltage issues during the middle of the day when the voltage rise is highest due to PV. At other times of the day, it was found to consume too much of the network's capacity due to the additional reactive power flow. • Harmonic filtering and phase balancing offer benefits which primarily apply to the transformer and the HV network upstream of the connection point. On the LV network, harmonic currents will still exist as the active injection to cancel the harmonics will only benefit the network upstream of the filter.	• Load Flow Analysis of Novel Solutions
Most commonly used technologies	• The novel solutions most commonly deployed across National Grid's LV network and therefore offering value over business-as-usual solutions are: – Network data monitoring – Active network management (dynamic control of the network by controlling, for example, normally open points) – Active transformer cooling – Real-Time Thermal Ratings for HV/LV Transformers • If the ENA140 Consultation which is considering whether to widen voltage tolerances is passed, manual tapping to increase headroom could be accommodated on networks where previously it would not be deployable due to voltages dropping below the statutory voltage minimum limit.	• LV Voltage Control Selection Methodology
Sensitivity studies	• Similar solutions are selected to be deployed across all four of National Grid's electricity distribution licence areas. The proportion of solution deployment is sensitive to the LCT uptake rates on each licence's area feeder set. Any solutions deployed should be based on the network constraint type and extent of constraint witnessed on the specific feeder. • The number and types of distinct solutions required across National's Grid network are independent of the scenario. Regardless of the actual LCT uptake rate, the distinct solutions will be utilised for particular feeders due to the variability in the clustering of LCT deployments. Network Operators do not need to be concerned about the uptake rate of LCT across the system, instead, they should focus on the constraint type and extent caused by LCTs on each feeder.	• LV Voltage Control Selection Methodology
Consideration of flexibility	• The use of domestic flexibility (technology agnostic) was considered as part of the Selection Methodology. The average amount of flexibility per feeder and per customer on that feeder was calculated to i) defer the initial reinforcement by 5 years, and ii) remove the need for the second wave of reinforcement. Based on these studies, to defer network reinforcement for 5 years from the time of the first network constraint, a change in demand at system peak of between 0.7kW and 2.1kW per customer is required depending upon the network archetype.	• LV Voltage Control Selection Methodology

	• The cost and duration of this flexibility was beyond the scope of this work, but is being considered in our NIC project EQUINOX which this learning has supported. • As further trials investigating domestic flexibility are conducted, more accurate information will be available to estimate the amount of demand side response available to shift demand away from peak times, and the expected cost which DSOs would be willing to pay.	
Opportunity for future innovation	• It was estimated that solutions offering cable headroom increase between 15% and 100%, for less than £50,000, would have significant value. Where a network experiences a cable headroom requirement of between 15% and 50% headroom uplift, Transform would pick network meshing. However, for practical reasons, it is unlikely that retrofitting classic Network Meshing would be achievable at scale which leaves a significant opportunity. In cases where network meshing is not possible, the next logical solution is splitting the feeder at a totex cost of £53,880. Therefore solutions that can release greater than 15% thermal cable capacity with less cost and technical challenge than that of permanent network meshing would offer significant value. • Innovative technologies that could offer between 20% and 80% thermal transformer capacity at less than approximately £16,000 per feeder (for feeders supplied by GMTs) or £7,500 per feeder (for feeders supplied by PMTs) would provide significant value to the network operator. Innovation activity could investigate solutions able to fill this gap. Appendix 2 provides detail of each network archetype including the average number of feeders per archetype, which varies between 1 and 5. • The available solution set has a gap between cheaper minor improvements and costly major improvements. Where solutions offering minor improvements don't address the network issues, we are forced to deploy far more costly solutions. Intermediate solutions would offer significant savings.	• LV Voltage Control Selection Methodology • Technology Witnessing and Final Recommendations
Recommended technology developments	• Of the available technologies, active transformer cooling was widely selected and recommended for a trial by the late 2020s. • By the early 2030s, trial Real-Time Thermal Ratings for HV/LV Transformers across a sample of National Grid's pole-mounted transformers are forecast to become thermally constrained. Trials should focus on how to install equipment necessary for RTTR on PMTs and on quantifying the benefit of RTTR on thermal PMT capacity. • By the mid-2030s trial active network management across a section of National Grid's LV network and quantify the thermal and voltage headroom release achieved. • Trial new use cases of network data monitoring. This includes real time flexibility forecasting, real time thermal ratings, and temporary ratings to inrease the utilisation of existing assets.	• LV Voltage Control Selection Methodology

9. The Outcomes of the Project

The outcomes of the project are as follows:

- A detailed literature review which documents the state-of-the-art technologies which are being developed by suppliers.
- A breadth-based Network Study which uses the economic model Transform to estimate the demographic of future network constraints witnessed on the LV network from now up until 2050. Different DFES scenarios consider the impact of the LCT uptake rate on network constraints.
- A depth-based Network Study using DIgSILENT's PowerFactory software to evaluate three case study networks. After connecting LCTs according to the three DFES scenarios, analysis was performed in study years: 2028, 2033, 2040, and 2050.
- A report detailing the Functional Requirements expected to be needed by each archetype was produced. This details the range of BAU technologies which would be used today, and also where novel technologies are used in place of BAU approaches, detailing the financial savings which could be possible.
- A power-flow-based study evaluated each of the novel technologies considered in our project. This study evaluated the relative strengths and weaknesses of the technologies.
- A comprehensive LV Voltage Control Selection Methodology was produced, which clearly explained the types of technologies that should be considered for addressing network compliance issues in different case studies. It also highlighted the scale of customer flexibility which would be required to defer and avoid BAU reinforcement.
- A summary report, that gives an overview of how each technology is applied to our network in the study, and reasons why some of the novel technologies were not selected.
- The information contained within the SILVERSMITH reports provides benefit to our customers, by allowing us to direct our innovation to the most critical parts of our network requirements. It focuses the effort for future innovation, and provides a stimulus for supply chain engagement.

10. Data Access Details

All reports and supporting work are published on the National Grid – SILVERSMITH project page. Additional data can be requested by contacting us directly.

NGED data can be requested via the National Grid Connected Data Portal (https://connecteddata.nationalgrid.co.uk/).

(/www.nationalgrid.co.uk/innovation/contact-us-and-more)

11. Foreground IPR

New foreground IPR has been created in the project reports. These are published and freely available on the NGED Innovation website.

12. Planned Implementation

This project is a piece of research which will direct our innovation efforts towards the areas that have the greatest impact on maintaining a secure and cost-effective network.

13. Contact

Further details on this project can be made available from the following points of contact:

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14. Glossary

Abbreviation	Term
BaU	Business as Usual
BESS	Battery Energy Storage System
BV	Best View
CBD	Central Business District
DFES	Distribution Future Energy Scenarios
EV	Electric Vehicle
GB	Great Britain
GMT	Ground Mounted Transformer
HV	High Voltage
LCT	Low Carbon Technology
LtW	Leading the Way
LV	Low Voltage
OLTC	On-load Tap Changer
PMT	Pole Mounted Transformer
PV	Photovoltaics
RfI	Request for Information
RIIO-ED2	Revenue = Incentives + Innovation + Outputs – Electricity Distribution 2
RTTR	Real-Time Thermal Rating
SP	Steady Progress
Tx	Transformer

Appendix 1: LV Feeder Archetypes

Number	Network Archetype Name	Description
LV1	Central Business District	Radial underground central business district feeders supplying only commercial customers. Typically found in town and city centres.
LV2	Dense Urban (Apartments etc.)	Radial underground feeders are typical of those found in areas with dense populations in cities (such as where there are many apartments in close proximity). Feeder supplies a range of residential property types.
LV3	Town Centres	Radial underground feeders typical of those found in town centres. These feeders supply primarily commercial customers but also have a small number of domestic customers.
LV4	Business Park	Radial underground feeder with only commercial customers representative of a typical business park.
LV5	Retail Park	Radial underground feeder with only commercial customers representative of a typical retail park.
LV6	Suburban Street (3 4 Bed Semi-detached or Detached Houses)	Radial underground feeder representative of a typical suburban area. This feeder supplies detached and semi-detached residential properties.
LV7	New Build Housing Estate	Radial underground feeder representative of a typical new build housing estate.
LV8	Terraced Street	Radial underground feeder representative of a typical feeder supplying a row of terraced houses.
LV9	Rural Village (Overhead Construction)	Radial overhead feeders supplying mostly domestic customers, typical of that found in rural villages.
LV10	Rural Village (Underground Construction)	Radial underground feeders supplying mostly domestic customers, typical of that found in rural villages.
LV11	Rural Farmsteads Small Holdings	Radial overhead feeders typically used to supply small groups of houses or small farms.

Appendix 2: Network Details

LV Network	Substation Capacity (kW)	Thermal Conductor (kW)	Number of feeders	Planning Voltage Upper Headroom Limit (%)	Planning Voltage Lower Limit (%)	kW/%	Number of Networks			
							East Midlands	West Midlands	South Wales	South West
LV1 Central Business District	238	231	4	1%	15%	40	1275	1305	484	869
LV2 Dense urban (apartments etc.)	190	164	4	1%	15%	40	4288	4389	1630	2922
LV3 Town centre	190	179	5	1%	15%	40	2876	3093	1124	1949
LV4 Business park	238	184	4	1%	15%	40	4999	5920	2235	2975
LV5 Retail park	238	184	4	1%	15%	40	2517	2248	1056	1369
LV6 Suburban street (3-4 bed semi-detached or detached houses)	119	111	4	1%	15%	40	18590	17547	7937	9990
LV7 New build housing estate	119	164	4	1%	15%	40	9506	7060	3752	4631
LV8 Terraced street	119	111	4	1%	15%	40	17033	17209	6488	11227
LV9 Rural village (overhead construction)	48	131	2	1%	15%	40	12339	16317	13346	16146
LV10 Rural village (underground construction)	100	113	3	1%	15%	40	6413	7142	2773	6883
LV11 Rural farmsteads small holdings	48	56	1	1%	15%	40	14716	20860	17693	21544

Appendix 3: Artificial Solutions

Solution	Thermal Transformer Capacity Release (%)	Thermal Cable Capacity Release (%)	Voltage Headroom Capacity Release (%)	Voltage Legroom Capacity Release (%)
Thermal Transformer 1	5%	0%	0%	0%
Thermal Transformer 2	10%	0%	0%	0%
Thermal Transformer 3	15%	0%	0%	0%
Thermal Transformer 4	20%	0%	0%	0%
Thermal Transformer 5	25%	0%	0%	0%
Thermal Transformer 6	30%	0%	0%	0%
Thermal Transformer 7	35%	0%	0%	0%
Thermal Transformer 8	40%	0%	0%	0%
Thermal Transformer 9	45%	0%	0%	0%
Thermal Transformer 10	50%	0%	0%	0%
Thermal Transformer 11	55%	0%	0%	0%
Thermal Transformer 12	60%	0%	0%	0%
Thermal Transformer 13	65%	0%	0%	0%
Thermal Transformer 14	70%	0%	0%	0%
Thermal Transformer 15	75%	0%	0%	0%
Thermal Transformer 16	80%	0%	0%	0%
Thermal Transformer 17	85%	0%	0%	0%
Thermal Transformer 18	0%	0%	0%	0%
Thermal Transformer 19	100%	0%	0%	0%
Thermal Transformer 20	500%	0%	0%	0%
Thermal Cable 1	0%	5%	0%	0%
Thermal Cable 2	0%	10%	0%	0%
Thermal Cable 3	0%	15%	0%	0%
Thermal Cable 4	0%	20%	0%	0%
Thermal Cable 5	0%	25%	0%	0%
Thermal Cable 6	0%	30%	0%	0%
Thermal Cable 7	0%	35%	0%	0%
Thermal Cable 8	0%	40%	0%	0%

Thermal Cable 9	0%	45%	0%	0%
Thermal Cable 10	0%	50%	0%	0%
Thermal Cable 11	0%	55%	0%	0%
Thermal Cable 12	0%	60%	0%	0%
Thermal Cable 13	0%	65%	0%	0%
Thermal Cable 14	0%	70%	0%	0%
Thermal Cable 15	0%	75%	0%	0%
Thermal Cable 16	0%	80%	0%	0%
Thermal Cable 17	0%	85%	0%	0%
Thermal Cable 18	0%	0%	0%	0%
Thermal Cable 19	0%	100%	0%	0%
Thermal Cable 20	0%	500%	0%	0%
Voltage Headroom 1	0%	0%	1%	0%
Voltage Headroom 2	0%	0%	2%	0%
Voltage Headroom 3	0%	0%	3%	0%
Voltage Headroom 4	0%	0%	4%	0%
Voltage Headroom 5	0%	0%	5%	0%
Voltage Headroom 6	0%	0%	6%	0%
Voltage Headroom 7	0%	0%	7%	0%
Voltage Headroom 8	0%	0%	8%	0%
Voltage Headroom 9	0%	0%	9%	0%
Voltage Headroom 10	0%	0%	10%	0%
Voltage Legroom 1	0%	0%	0%	1%
Voltage Legroom 2	0%	0%	0%	2%
Voltage Legroom 3	0%	0%	0%	3%
Voltage Legroom 4	0%	0%	0%	4%
Voltage Legroom 5	0%	0%	0%	5%
Voltage Legroom 6	0%	0%	0%	6%
Voltage Legroom 7	0%	0%	0%	7%
Voltage Legroom 8	0%	0%	0%	8%
Voltage Headroom 1	5%	0%	0%	0%
Voltage Headroom 2	10%	0%	0%	0%

Voltage Headroom 3	15%	0%	0%	0%
Voltage Headroom 4	20%	0%	0%	0%
Voltage Headroom 5	25%	0%	0%	0%
Voltage Legroom 6	30%	0%	0%	0%
Voltage Legroom 7	35%	0%	0%	0%
Voltage Legroom 8	40%	0%	0%	0%
Emergency Solution	5000000%	5000000%	5000000%	5000000%

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