LV ENGINE

Technical guidance for the selection of LV Engine solution

About Report

Report Title	:	LV Engine Deliverable #7 - Technical guidance for the selection of LV Engine solution (Best Operational Practice)
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Contents

Report Summary & Disclaimer

This report provides recommendations and technical guidance on selection of LV Engine solution based on the learnings gathered through the project and particularly from performance analysis of LV Engine solutions in live trial which was published in LV Engine Deliverable 6. This report forms Deliverable 6 of LV Engine project in line with LV Engine project direction. This report forms deliverable 7 of LV Engine in line with project direction.

This report has been prepared as part of the LV Engine project, a globally innovative project to demonstrate the functionalities of a Smart Transformer, funded by Ofgem through the Network Innovation Competition mechanism. All learnings, outcomes, models, findings information, methodologies or processes described in this report have been presented on the information available to the project team at the time of publishing. It is at the discernment and risk of the reader to rely upon any learnings outcomes, findings, information, methodologies or processes described in this report.

1 Introduction

LV Engine provides new technology to solve voltage, thermal and imbalance constraints in LV networks. This report provides guidance on where LV Engine may be selected compared to conventional reinforcement solutions such as new substations or other emerging technologies such as voltage regulating distribution transformers (VRDT). The guidance starts by describing LV Engine use cases, applications and a selection toolkit before moving onto network reinforcement case study followed by a cost benefit analysis.

2 Use Cases

LV Engine offers several functionalities that can help enhance the efficiency, stability, and resilience of LV distribution networks. Its versatile capabilities address several critical challenges faced within distribution networks, making it a valuable addition to areas of the grid that require advanced solutions. The selection of its installation location depends on the network's specific needs and the ability of the LV Engine to address them effectively.

2.1 Addressing Undervoltage and Overvoltage Issues

One of the primary functions of the LV Engine is its ability to solve undervoltage and overvoltage issues by precisely controlling the voltage on each phase individually. This feature is particularly beneficial in areas where the network experiences voltage fluctuations due to high demand, distributed energy resource integration, or long feeder lines with significant voltage drops. Traditional solutions like tap-changing transformers often regulate voltage uniformly across all phases, which may not address voltage issues in an imbalance network. LV Engine's granular phase-specific voltage control ensures optimal voltage levels for all consumers, improving power quality of supply.

Criteria for Installation: Locations with frequent voltage compliance violations, such as rural networks with long feeders or urban areas experiencing high rooftop solar PV penetration, are ideal candidates for LV Engine deployment.

2.2 Mitigating Harmonic Distortion

Harmonic distortion, often caused by non-linear loads such as electric vehicle chargers, industrial equipment, or inverter-based generation, can degrade power quality and efficiency. LV Engine, with its advanced voltage regulation and harmonic compensation capabilities, is well-suited to mitigate such issues. By stabilising voltage and filtering harmonics, it reduces losses and prevents adverse effects on sensitive equipment.

Criteria for Installation: Areas with high penetration of harmonic-producing loads, such as commercial zones, industrial estates, or regions with extensive EV charging infrastructure, will benefit most from the LV Engine's harmonic mitigation features.

2.3 Capacity Sharing Between Substations

LV Engine facilitates capacity sharing with nearby substations through its precise voltage control capabilities. By dynamically adjusting voltages, it allows load redistribution across substations, effectively reducing stress on heavily loaded transformers and enabling underutilised infrastructure to take on additional demand. This functionality is particularly useful in areas experiencing rapid load growth or in situations where load imbalances between substations hinder efficient operation.

Criteria for Installation: Locations with thermally stressed transformers, where load-sharing can optimise overall network capacity, should be prioritised. Rapidly urbanising areas or regions where demand is expected to grow unevenly across substations are ideal. Also where neighbouring substations supply complementary load profiles e.g. residential and commercial loads

2.4 Balancing imbalanced Loads

Imbalanced loads are a common challenge in LV networks, often caused by single-phase loads distributed unevenly across three-phase systems. This imbalance can lead to inefficiencies, overheating, and reduced transformer lifespan. LV Engine's ability to make unbalanced loads appear balanced to the distribution transformer can greatly help reduce stress on the transformer. By individually controlling each phase, it redistributes power effectively, improving transformer utilisation and reducing wear and tear.

Criteria for Installation: Networks with significant single-phase load variation, such as residential areas with mixed load profiles or areas with intermittent small-scale renewable generation, are prime candidates for the LV Engine. It is particularly effective in locations where unbalanced loading frequently results in operational inefficiencies or maintenance challenges.

3 Applications

When it comes to installation of the LV Engine hardware within the LV network, there are different options based on availability of land and functions that the LV Engine is expected to perform to enhance the reliability of the network.

Different applications of the LV Engine system are described below:

Application	Description	Pre-conditions
Application A1	UPFC retrofitted into existing conventional substation on radial network (Figure 1)	Availability of space in the existing substation for the UPFC
Application A2	New LV Engine substation on radial network (Figure 1)	None
Application B1	UPFC retrofitted into existing substation on interconnected network (Figure 2)	1) Space available in the existing substation for the UPFC 2) network is interconnected or can be converted from radial to interconnected.
Application B2	New LV Engine substation on interconnected network (Figure 2)	Network is interconnected or can be converted from radial to interconnected.
Application C	New LV Engine substation on circuit (Figure 3)	None
Application D	New LV Engine substation on a circuit within an interconnected network (Figure 4)	Network is interconnected or can be converted from radial to interconnected.

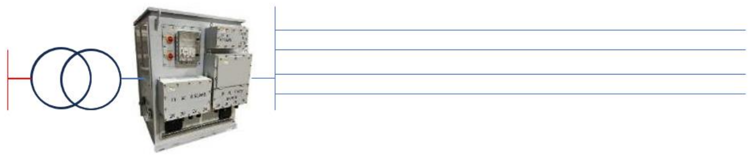

Figure 1 - LV Engine installation for Application A1 and A2

Figure 2 - LV Engine installation for Application B1 and B2

Figure 3 - LV Engine installation for Application C

Figure 4 - LV Engine installation for Application D

4 LV Engine selection toolkit

Table 1 provides LV Engine and conventional reinforcement options that should be considered for new connections (e.g. new housing) and demand increase driven investment (e.g. predicted increase in heat pumps, EV or solar PV):

	Is there going to be an increase in demand?	Is there going to be an increase in generation?
Is transformer close to thermal limit?	• Replace transformer with higher capacity • Install new conventional S/S • LV Engine Application A2 • LV Engine Application B • LV Engine Application D	
Are LV mains circuit(s) close to thermal limit?	• Replace circuit with 300mm2 Al waveform • Install new conventional S/S • LV Engine Application A2	
Are customers' supply voltages above +10%		• Replace circuit with 300mm2 Al waveform • Install new conventional S/S • Replace transformer with VRDT • LV Engine Application A
Are customers' supply voltages below -6%	• Replace mains circuit with 300mm2 Al waveform cable • New conventional S/S • LV Engine Application A	
Is there network voltage imbalance	• LV Engine Application A • Rebalance customers	• LV Engine Application A • Rebalance customers
Are voltage harmonics close to G5 limits	• LV Engine Application A	• LV Engine Application A
Are voltage fluctuations/flicker close to P28 limits?	• LV Engine Application A	• LV Engine Application A

Table 1 – Conventional and LV Engine reinforcement options

5 Network reinforcement case study

This section provides an example of network study to demonstrate the application of LV Engine solution. This example represents typical urban area where LV Engine may be used for both voltage control and thermal stress alleviation purposes. We have not chosen a worst case type network scenario, instead, an example which can be more representative of LV network.

5.1 Network Model

The base network model used for this study is depicted in Figure 5. It comprises three substations Adlington Drive, Bollington Avenue, and Northwich Girls Grammar School. The substations serve different customer groups, with 326 customers served by Bollington Avenue represented in green, 238 customers served by Adlington Drive shown in blue, and 209 customers served by Northwich Girls Grammar School marked in red, as illustrated in the figure. The locations of the substations are indicated by red squares, while the positions of the link boxes are denoted by orange circles.

The transformers at all three substations are identical and their parameters are given in Table 2. For all simulation results presented in this report, the 11kV HV voltage at all the substations is set at 1.00pu.

Parameter	Value
HV/LV Voltage Rating [kV/kV]	11/0.433
Power Rating [kVA]	500
Short-Circuit Impedance [%]	4.75
Off-load tapping range	+/-5% in steps of 2.5%
Tap setting for studies	0%

Table 2 – Transformer parameters

Three loading/generation scenarios were chosen for the study, namely Year 1, Year 2, and Year 3. The load per customer (based on ADMD) and the number of customers with rooftop PVs for the three scenarios are shown in Table 3. Each rooftop PV is assumed to have a rated capacity of 4kW, and each customer load is assumed to have the power factor of 0.98.

Parameter	Year I (2024)	Year 2 (2028)	Year 3 (2032)
Load per customer (kVA)	1	1.5	2.2
Number of Rooftop PVs	40	60	80

Table 3 – Loading and generation scenarios

For each scenario (Year 1, Year 2, and Year 3) the winter peak demand is simulated by assuming the load to be 100% and generation as 0%. Conversely, the summer minimum demand scenario is simulated by assuming the load to be 0%, and the generation as 100%.

The network model is built in the DIgSILENT PowerFactory power systems analysis tools. Load flows are carried out which determine the power flowing through the network assets and voltages at the customer's LV points of supply.

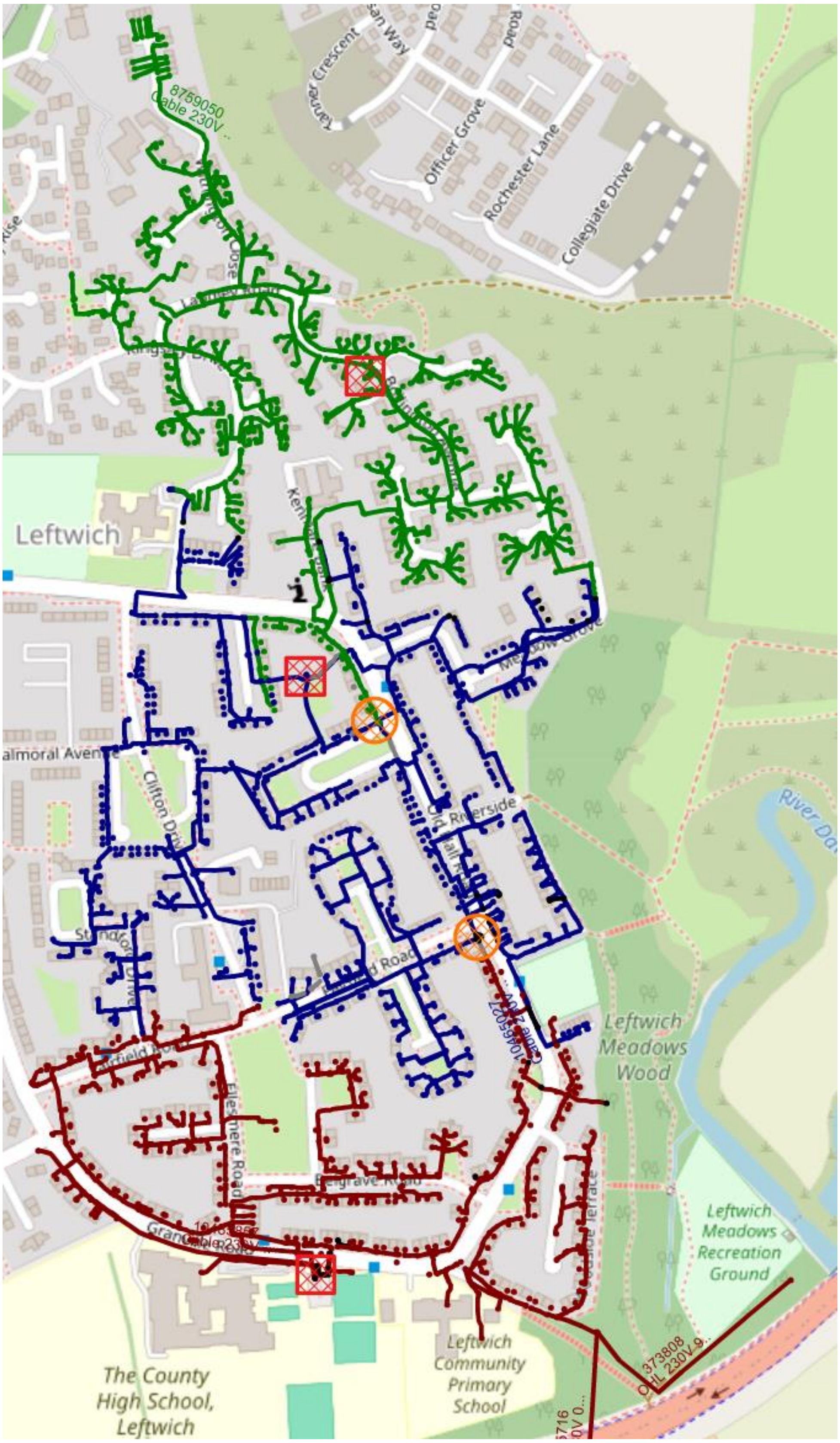

Figure 5 – Network model showing customers served by Bollington Avenue (Green), Adlington Drive (blue), and Northwich Girls Grammar School (Red)

Three reinforcement options are considered in this report to solve the potential cable overloads and point of supply over and under voltage problems as described below:

Reinforcement Option 1: Converting Adlington Drive to an LV Engine substation by installing an SST and using a seasonal LV voltage setpoint. This is LV Engine Application A2.

Reinforcement Option 2: Installing a new conventional substation at Cockington Close to supply power to loads further away from Adlington Drive substation.

Reinforcement Option 3: Installing a new conventional substation at Meadow Grove to supply power to loads further away from Adlington Drive substation.

After installation of a new substation at Cockington Close (Option 2), the customer group served by the new substation is shown in purple in Figure 6. After installation of a new substation at Meadow Grove (Option 3), the customer group served by the new substation is shown in brown in Figure 7.

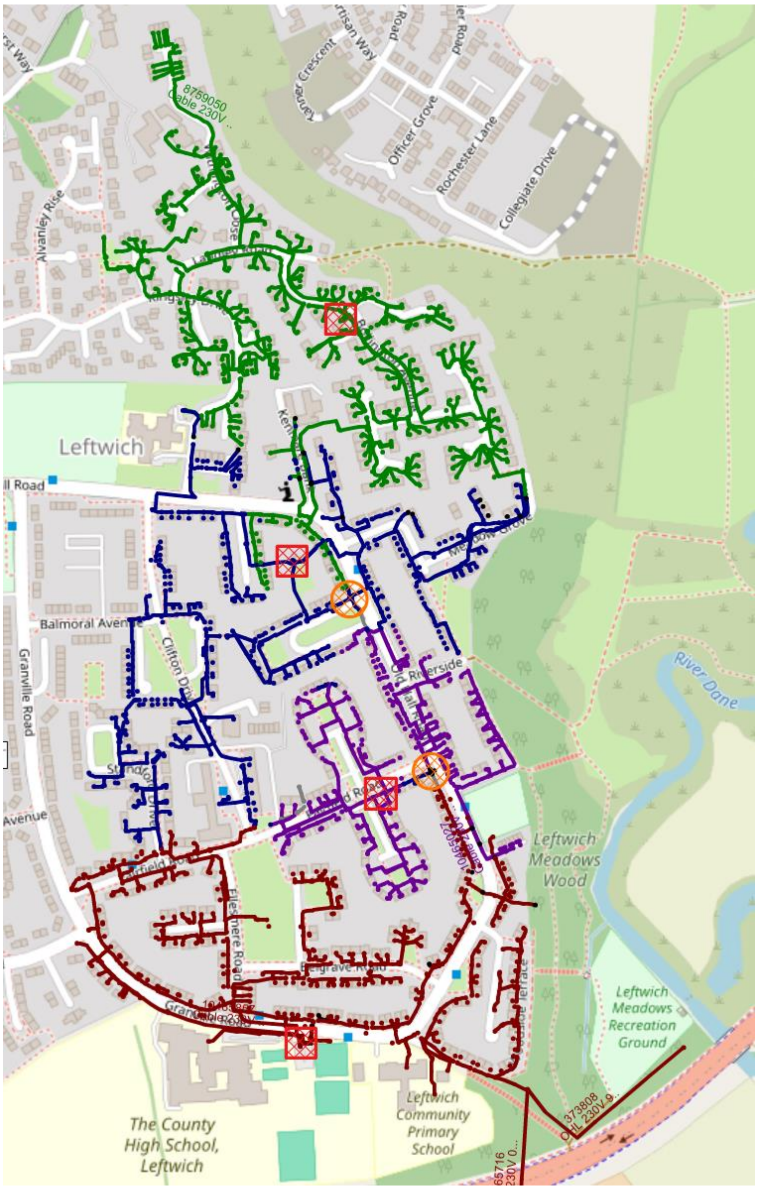

Figure 6 – Network model showing customers served by Bollington Avenue (Green), Adlington Drive (blue), Northwich Girls Grammar School (Red), and Cockington Close (Purple)

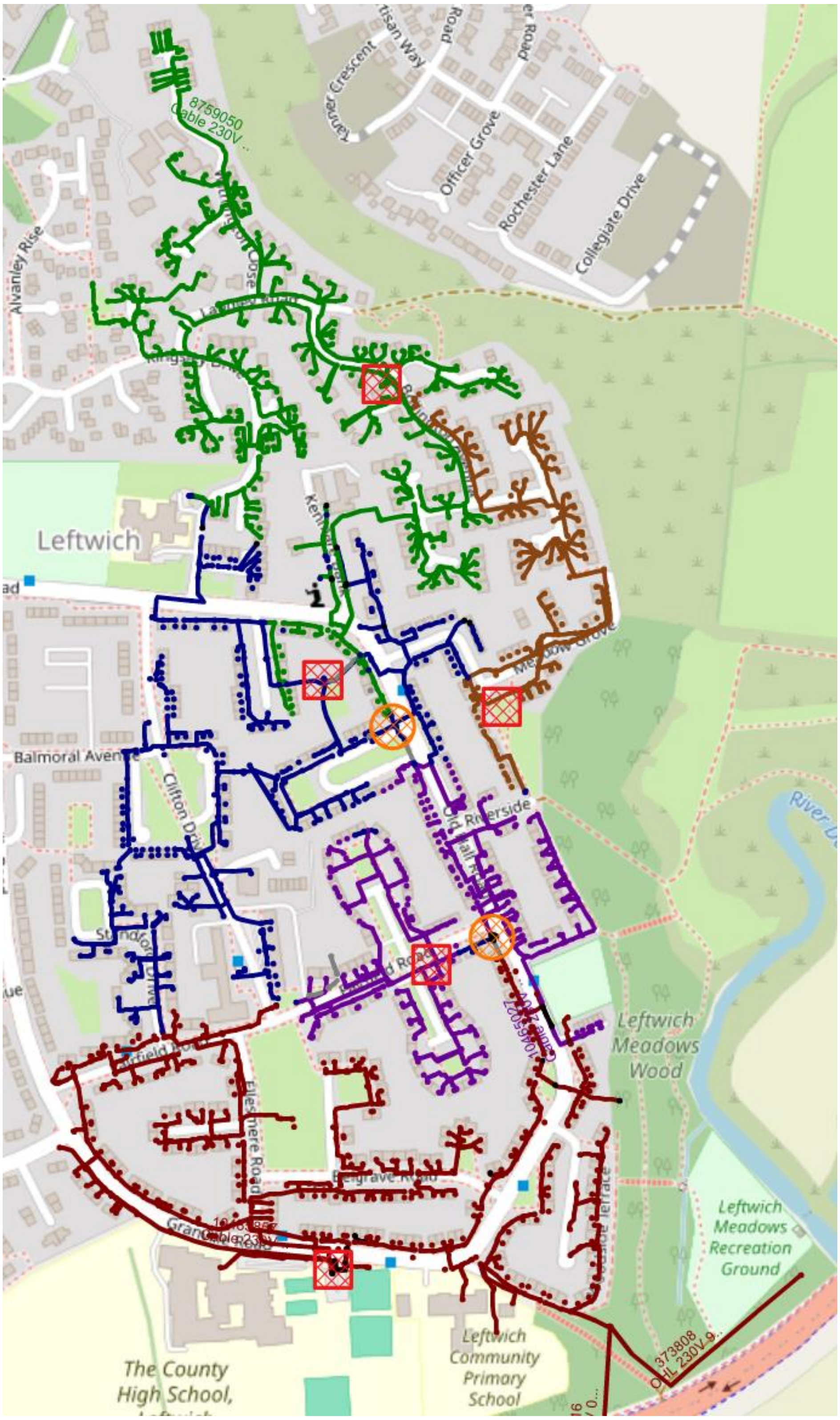

Figure 7 – Network model showing customers served by Bollington Avenue (Green), Adlington Drive (blue), Northwich Girls Grammar School (Red), Cockington Close (Purple), Meadow Grove (Brown)

5.2 Year 1 Results

The load flow results for the Year 1 winter peak demand (no generation) scenario are shown in Figure 8 and the Year 1 summer minimum demand (maximum PV generation) scenario in Figure 9. This represents the base case with the network as currently built with an assumption of 1kVA of demand per customer and 40 customers having 4kW solar PV installed on their roofs. These assumptions are made to make the network slightly stressed so that conventional versus LV Engine reinforcement options can be compared; in Figure 8 the red lines in the centre of the diagram represent overloaded cable sections of underground cable, and in Figure 9 the red dots represents points of supply where the voltage has exceeded the +10% statutory limit. The overloaded cable sections are fed from Adlington Drive substation and are overloaded by 19%. The maximum point of supply voltage is 1.14pu. The tap positions of the transformers at the three substations is set to give a no load LV busbar voltage of 1.08pu so that under peak demand conditions point of supply voltages can be maintained above the -6% statutory limit accounting for the voltage drop along all the feeders supplied by the substations. These are off load tap changers and remain at a fixed tap position through the whole year. Having the LV busbar voltage biased towards the upper end of the statutory limit causes a problem under the summer minimum demand maximum solar PV generation scenario as there is little headroom available for the voltage rise caused by the solar PV generation.

In this Y1 base case scenario the transformers at the substations are not overloaded, Table 4.

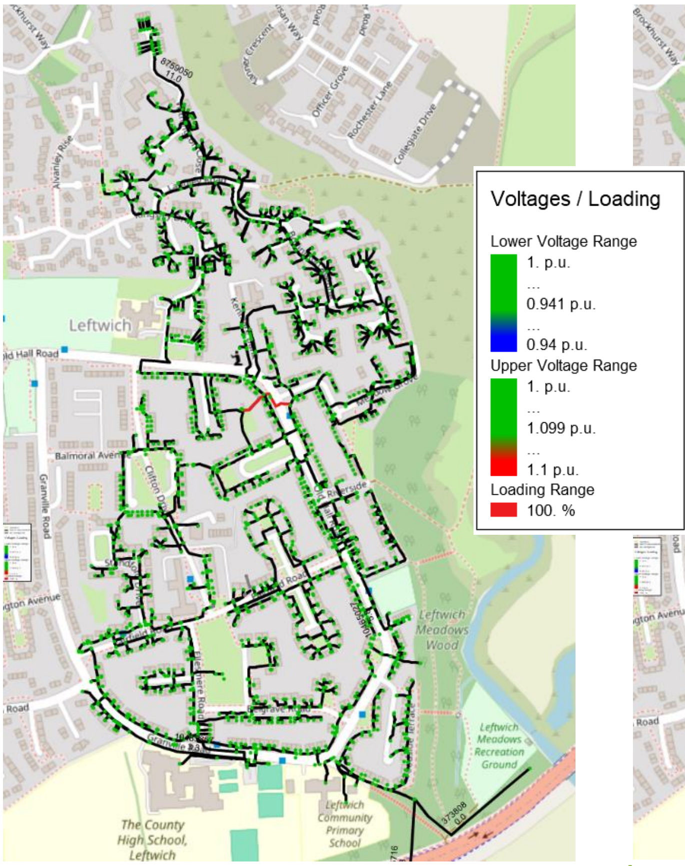

Figure 8 – Y1 winter peak demand base case

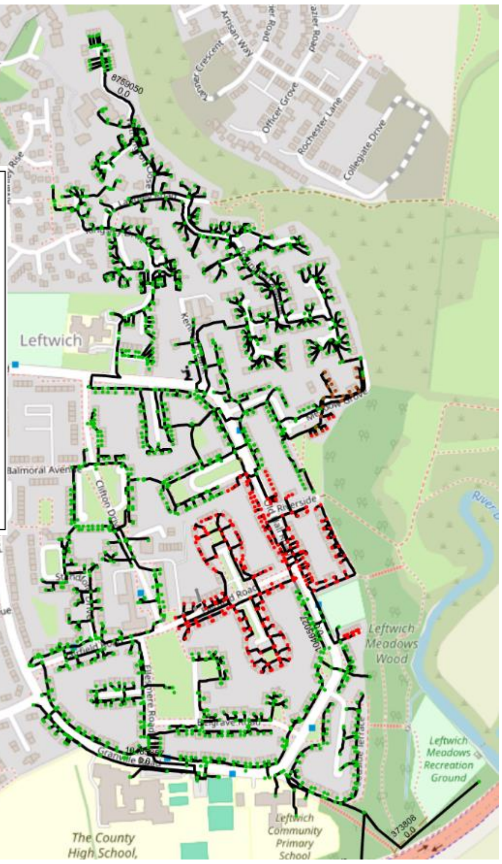

Figure 9 – Y1 summer minimum demand base case

Substation	Transformer Loading
Adlington Drive	69%
Bollington Avenue	49%
Northwich Girls Grammar School	43%

Table 4 – Transformer loading at substations during winter peak demand Y1

With Option 1 (LV Engine at Adlington Drive) a seasonal voltage setpoint or Load Drop Compensation function can be programmed to adjust the LV busbar voltage at Adlington Drive substation depending upon how much power is flowing through the transformer. At winter peak demand the LV busbar voltage can be maintained at 1.08pu but under summer minimum demand a lower setpoint of 1.05pu can be used. Whilst this does not solve the cable overload problem, Figure 10, it does solve the over voltage problem caused by the solar PV generation, Figure 11.

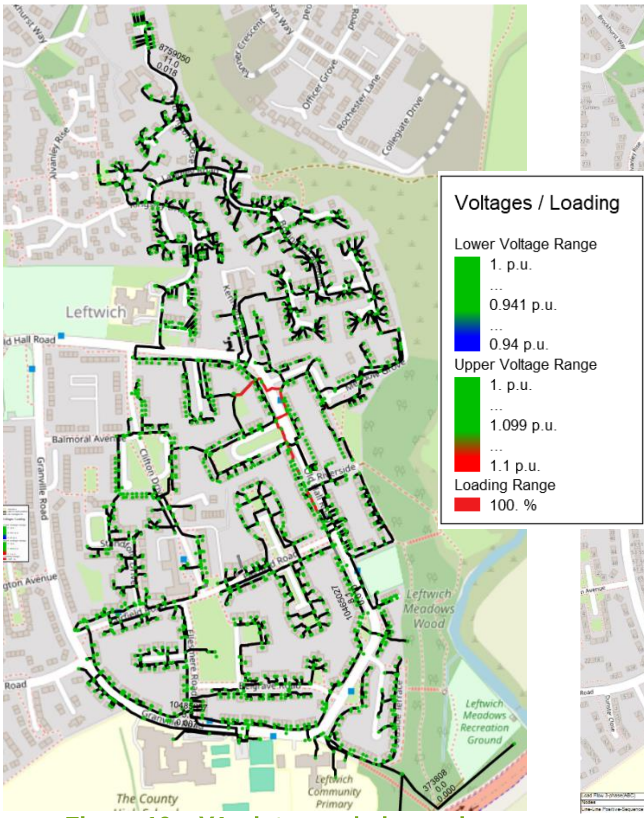

Figure 10 – Y1 winter peak demand with Option 1 reinforcement (LV Engine)

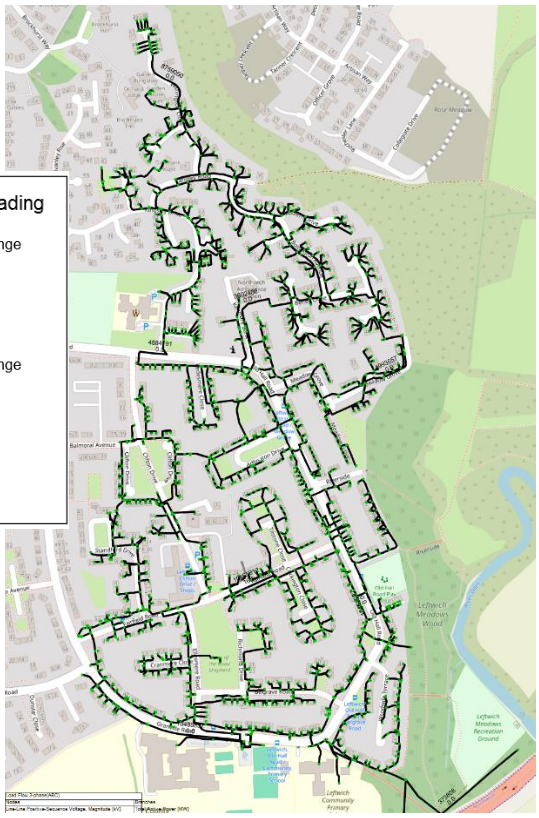

Figure 11 – Y1 summer minimum demand with Option 1 reinforcement (LV Engine)

With Option 2 (new substation at Cockington Close), both the cable overload problem is resolved, Figure 12, as well as the over voltage problem, Figure 13 .

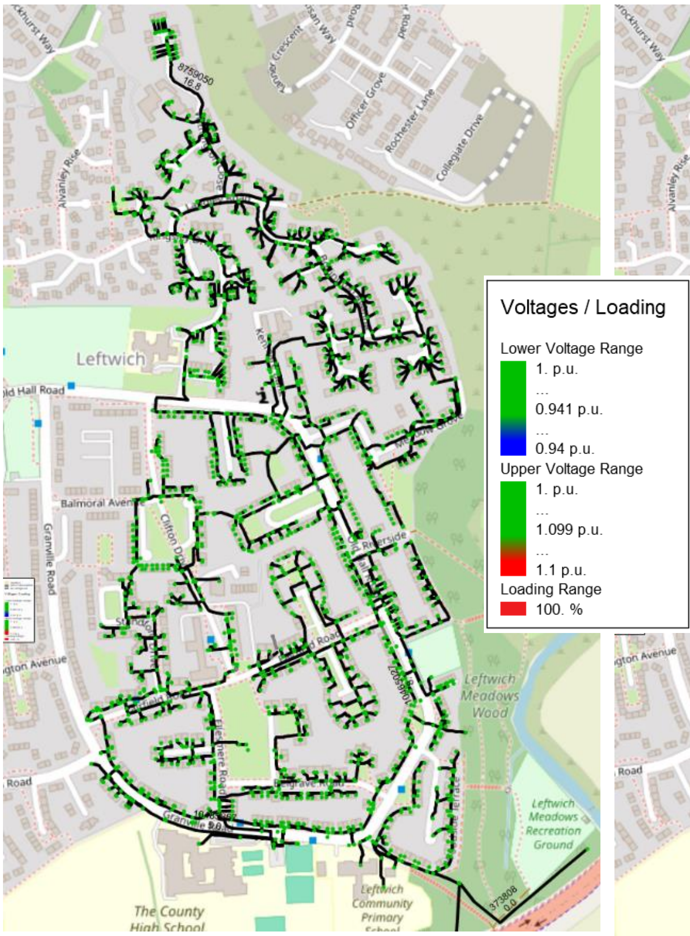

Figure 12 – Y1 winter peak demand with Option 2 reinforcement (new substation at Cockington Close)

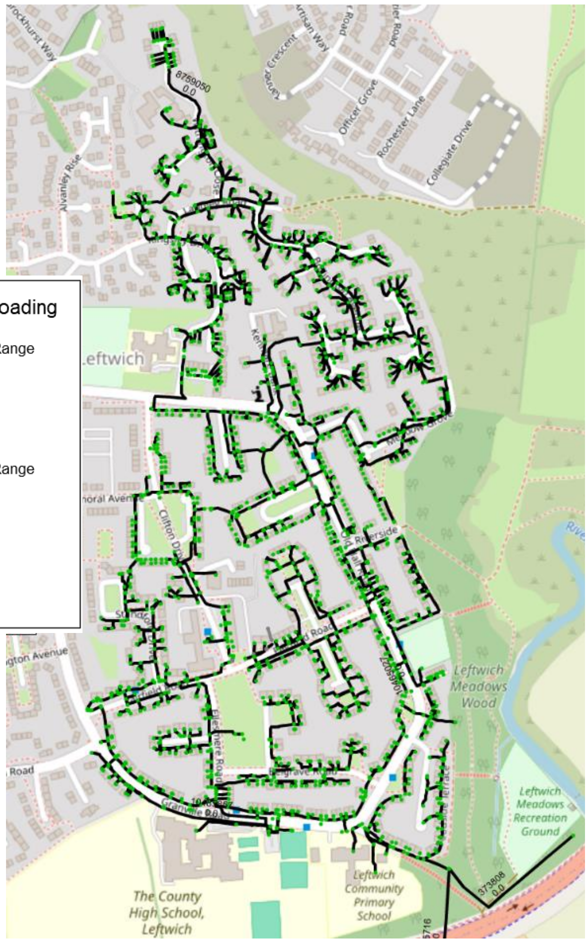

Figure 13 – Y1 summer minimum demand with Option 2 reinforcement (new substation at Cockington Close)

5.3 Year 2 Results

In Year 2 the winter peak demand loading is increased to 1.5kVA per customer (from 1kVA in Year 1) and the number of households with solar PV generation increased to 60 (from 40 in Year 1). In the base case no reinforcement from the current as-built network is considered. As well as the existing problems seen in Year 1, the following additional problems occur in the winter peak demand case:

- More sections of underground cable become overloaded in as shown by the increase in red lines in Figure 14 compared to the Y1 base case in Figure 8;
- A large area of the network has points of supply where the voltages fall below the -6% statutory limit as shown by the blue dots in Figure 14;
- The transformer at Adlington Drive substation becomes overloaded by 11%, Table 5

Under the Year 2 summer minimum demand maximum solar PV generation base case, more points of supply have voltages that exceed the +10% statutory limit under the summer minimum demand maximum solar PV generation case as shown in Figure 15 compared to Year 1 in Figure 9.

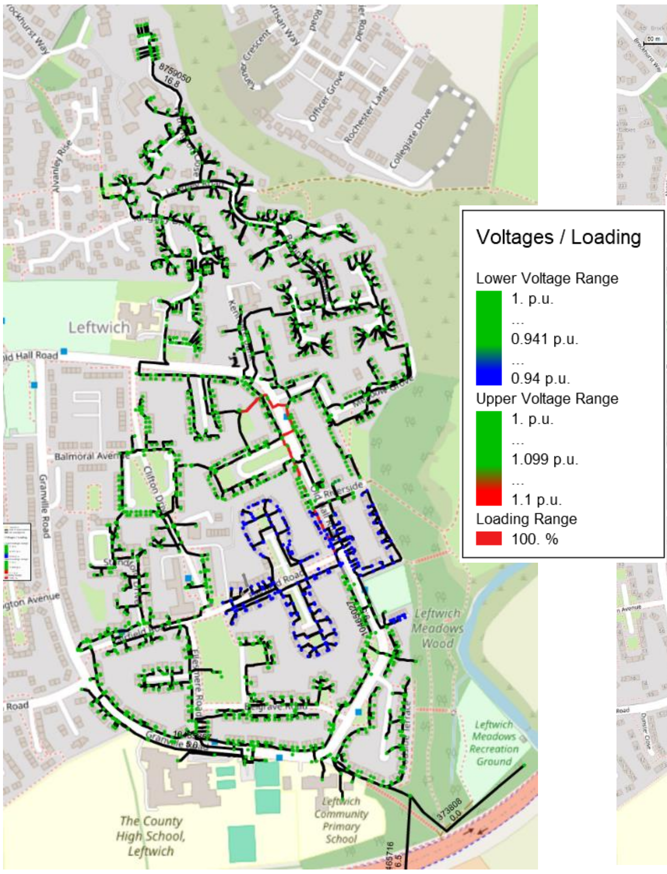

Figure 14 – Y2 winter peak demand base case

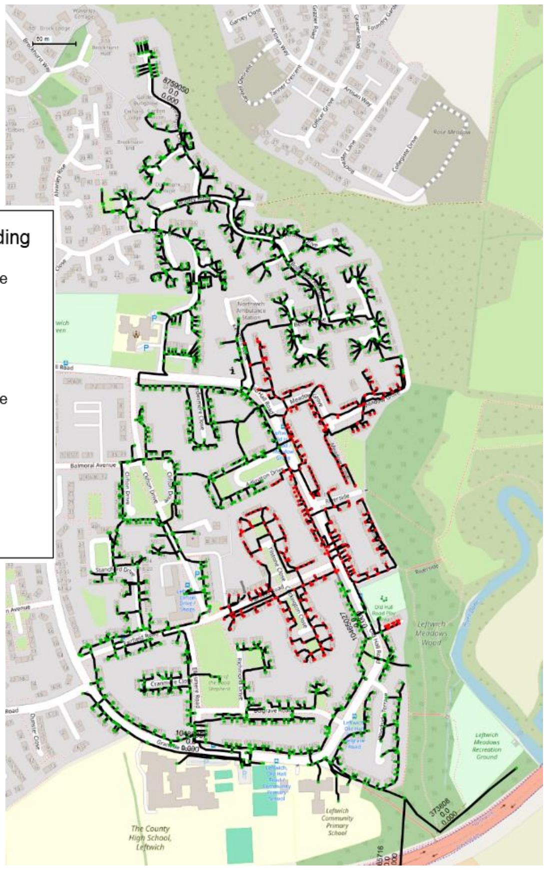

Figure 15 – Y2 summer minimum demand base case

Substation	Transformer Loading
Adlington Drive	111%
Bollington Avenue	74%
Northwich Girls Grammar School	66%

Table 5 – Transformer loading at substations during winter peak demand Y2

Whilst to some extent the conversion of existing conventional substations to LV Engine substations can help to alleviate some of the voltage problems and transformer overloading (via capacity sharing) they cannot solve cable thermal overload nor the large voltage drop problems along the feeders. The same Option 2 (new substation at Cockington Close) can resolve all the Year 1 and Year 2 problems as show in Figure 16, Figure 17 and Table 6.

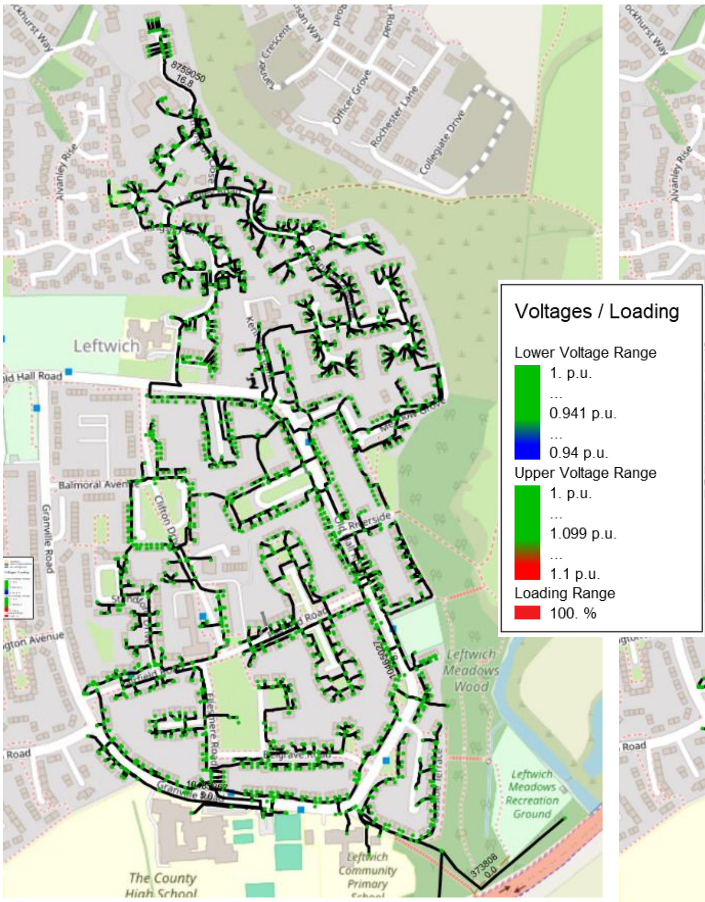

Figure 16 – Y2 winter peak demand with Option 2 reinforcement (new substation at Cockington Close)

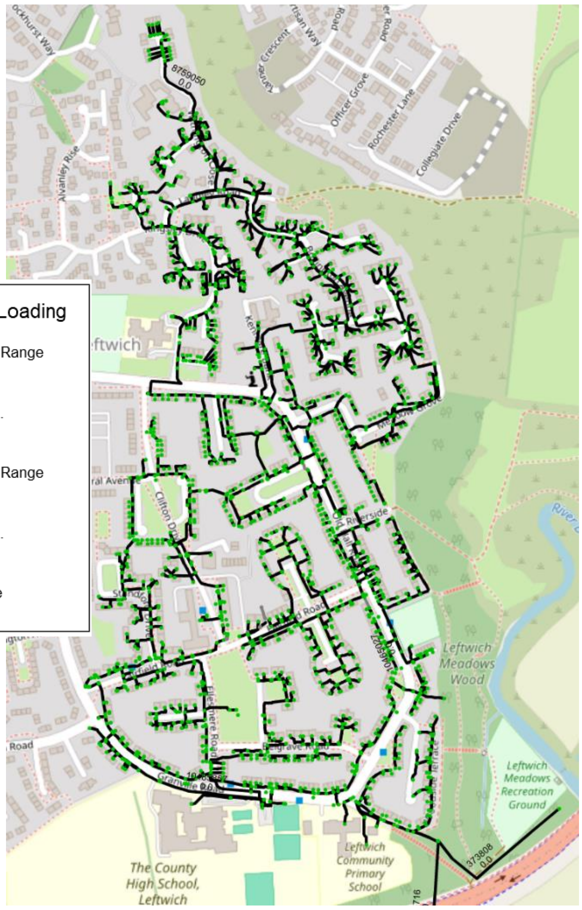

Figure 17 – Y2 summer minimum demand with Option 2 reinforcement (new substation at Cockington Close)

Substation	Transformer Loading
Adlington Drive	61%
Bollington Avenue	74%
Northwich Girls Grammar School	66%
Cockington Close	41%

Table 6 – Transformer loading Y2 winter peak demand with Option 2 (new substation at Cockington Close)

5.4 Year 3 Results

In Year 3 the winter peak demand loading is increased to 2.2kVA per customer (from 1.5kVA in Year 2) and the number of households with solar PV generation is increased to 80 (from 60 in Year 2). In the base case the new substation at Cockington Drive (Option 2 from Year 1 and 2) is considered to have been built. In Figure 18 the red lines in the centre of the diagram represent overloaded cable sections of underground cable, and in Figure 19 the red dots represent points of supply where the voltage has exceeded the +10% statutory limit. The transformer at Bollington Avenue is overloaded by 8%, Table 7. There is spare capacity at the new Cockington Close substation but because it is far away from Bollington Avenue, load sharing cannot be carried out between these two substations. Load sharing can, however, be carried out between Adlington Drive and Bollington Avenue because of their proximity.

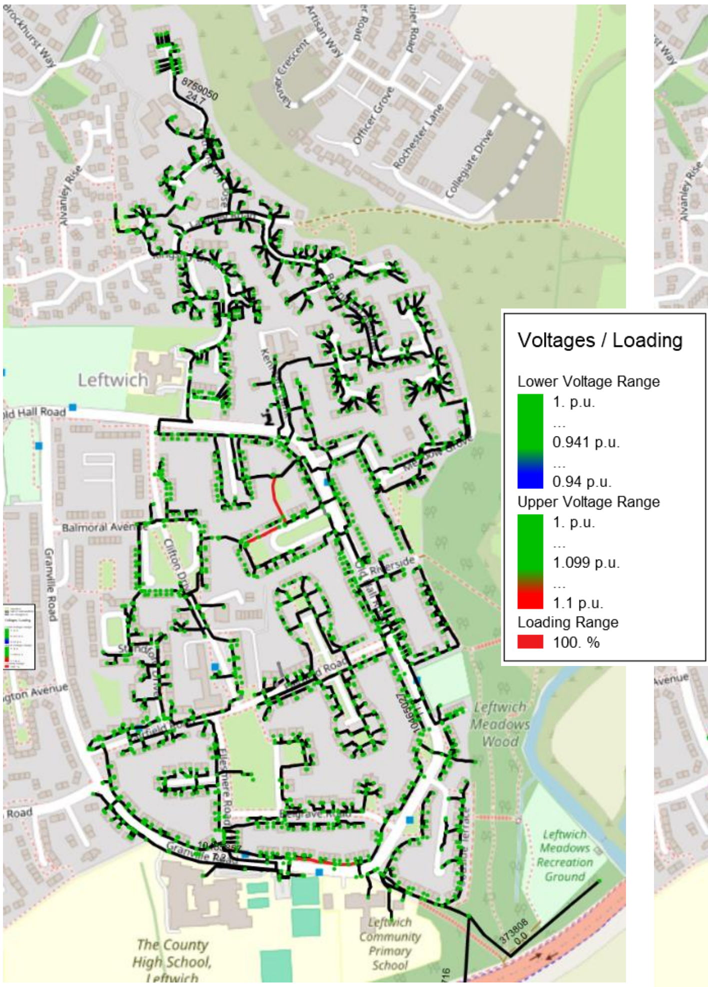

Figure 18 – Y3 winter peak demand base case Option 2 implemented (new substation at Cockington Close)

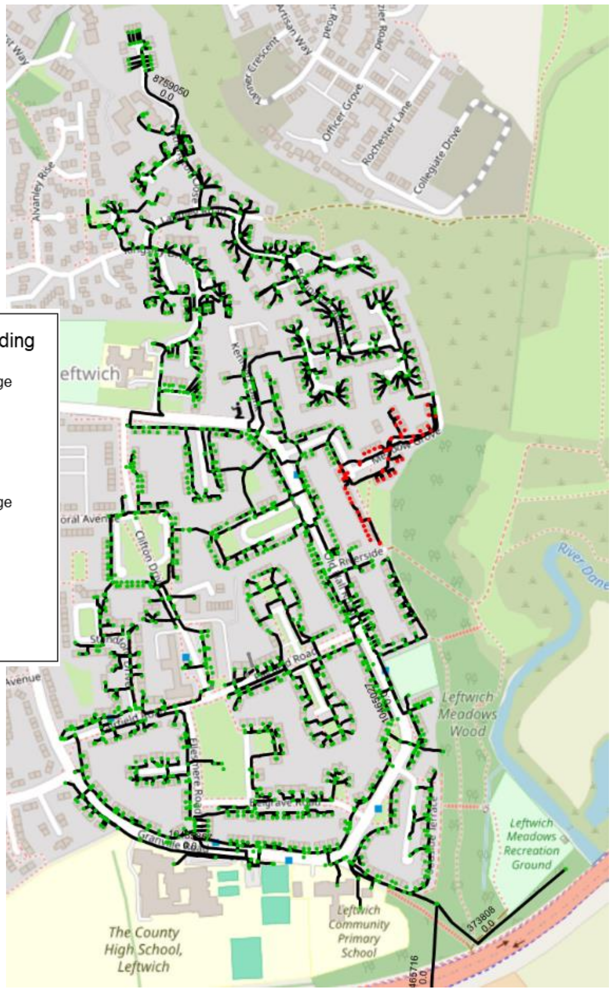

Figure 19 – Y3 summer minimum demand base case Option 2 implemented (new substation at Cockington Close)

Substation	Transformer Loading
Adlington Drive	89%
Bollington Avenue	108%
Northwich Girls Grammar School	96%
Cockington Close	59%

Table 7 - Transformer loading Y3 winter peak demand base case Option 2 implemented (new substation at Cockington Close)

Load sharing can be carried out by converting Adlington Drive from a conventional to an LV Engine substation and paralleling Adlington Drive to Bollington Avenue substation. Whilst this resolves the over voltage and transformer overloading problems, it does not resolve the cable overload problems. The network is re-enforced by replacing the overloaded 0.1in^2 Cu mains cables (rating 240A) with 300mm2 Al waveform cables (rating 430A). Figure 18, Figure 19 and Table 8 show that these interventions resolve the problems. Note, that the LV Engine substation at Adlington Drive has its LV busbar voltage set to 1.06pu to provide headroom for the solar PV generation. Using LV Engine to reduce the LV busbar voltage may also help relieve loading on the cables as it was found during the performance analysis of Conservation Voltage Reduction test that 4% reduction in voltage leads to approximately 4% reduction in demand.

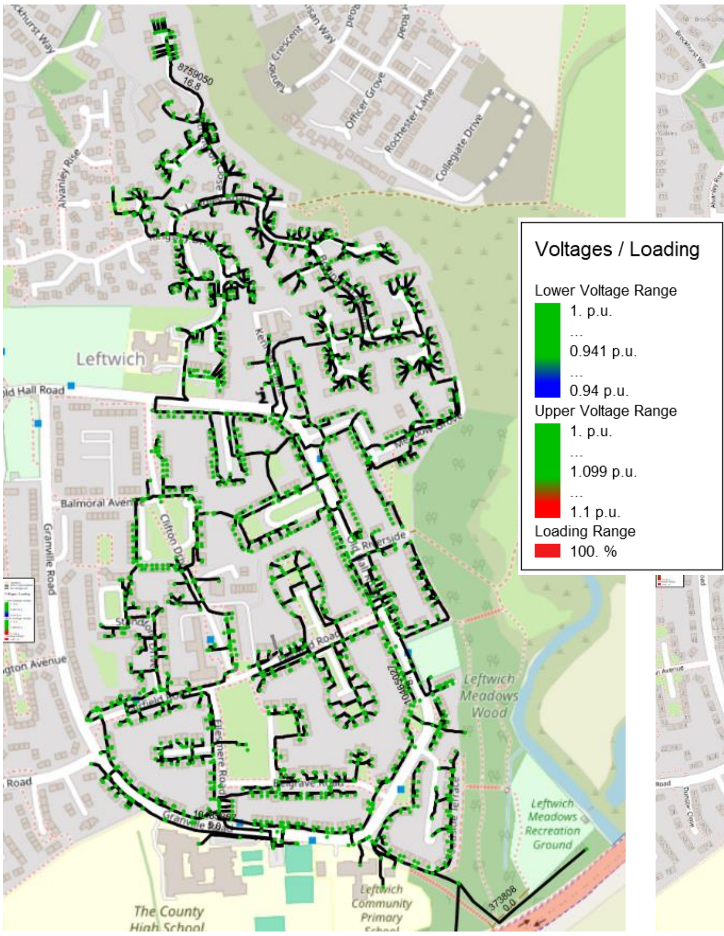

Figure 20 – Y3 winter peak demand with Option 1 (LV engine substation at Adlington Drive), Option 2 (new substation at Cockington Close) and mains cable reinforcement implemented

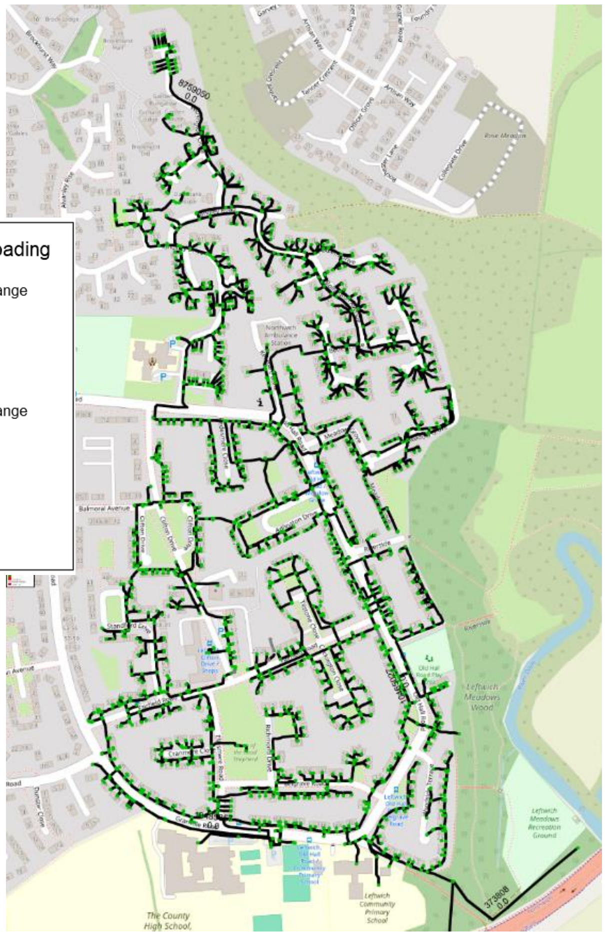

Figure 21 – Y3 summer minimum demand With Option 1 (LV engine substation at Adlington Drive), Option 2 (new substation at Cockington Close) and mains cable reinforcement implemented

Substation	Transformer Loading
Adlington Drive	99.7%
Bollington Avenue	98.7%

Table 8 – Transformer loading with Option 1 (LV engine substation at Adlington Drive), Option 2 (new substation at Cockington Close) and mains cable reinforcement implemented

Overvoltage issues during the summer minimum demand and overloading of the transformer at Bollington Avenue substation can also be solved by installing an additional new substation near Meadow Grove (Option 3). The location of this new substation and the connected customers are shown in Figure 7. The voltage at all nodes within the network after implementation of Option 3 instead of Option 1 are shown for winter and summer in Figure 22 and Figure 23 respectively, and the transformer loading in this case is shown in Table 9. The results show that installation of an additional substation at Meadow Grove also solves the overvoltage and transformer overloading issues

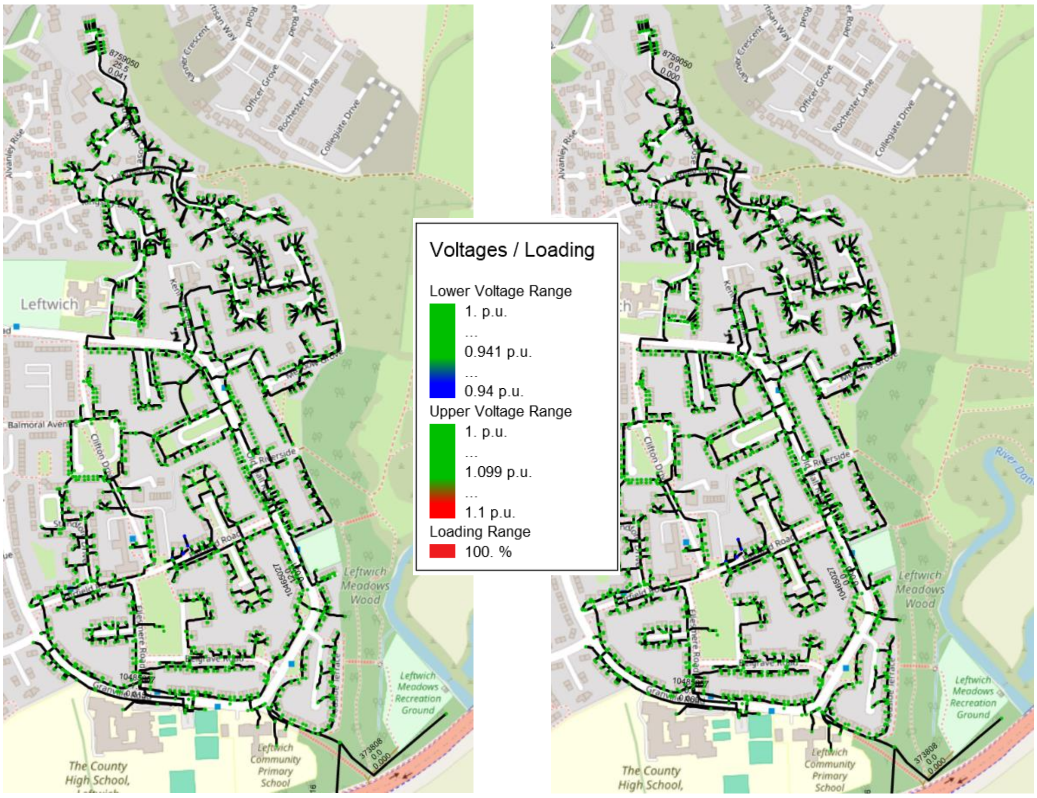

Figure 22 – Y3 winter peak demand with Option 3 (new substation at Meadow Grove), Option 2 (new substation at Cockington Close) and mains cable reinforcement implemented

Figure 23 – Y3 summer minimum demand With Option 3 (new substation at Meadow Grove), Option 2 (new substation at Cockington Close) and mains cable reinforcement implemented

Substation	Transformer Loading
Adlington Drive	76%
Bollington Avenue	99 %
Northwich Girls Grammar School	98%
Cockington Close	60%
Meadow Grove	36%

Table 9 - Transformer loading during Y3 winter peak demand with Option 2 (new substation at Cockington Close) and Option 3 (new substation at Meadow Grove) implemented

5.5 Summary of Year 1, Year 2 and Year 3 load increase

In Year 1 there is:

- overloading of up to 184% on some sections of the cable network during winter peak demand; and,
- over voltages of up to 1.15pu of the points of supply during summer minimum demand.

Converting Adlington Drive substation to an LV Engine substation resolves the over voltage conditions but does not resolve the cable overloading because the overloading mainly happens on the outgoing feeders from the substation so no action taken at the substation can resolve the overloading. Installing a new conventional non-LV Engine substation at Cockington Close resolves both the cable overloading and point of supply over voltage problems because a) approximately half of the load from Adlington Drive is shifted to the new substation and the outgoing feeders from the substation are no longer overloaded and b) the power infeed from rooftop PVs now has to travel much shorter distance to the substation, resolving the overvoltage issue.

In Year 2 prior to any interventions considered in Year 1, the Year 1 problems become more severe and two new problems arise there is:

- overloading of up to 186% in some sections of the cable network during winter peak demand;
- over voltage at 1.16pu of the points of supply during summer minimum demand;
- under voltage at 0.93pu. of the points of supply during winter peak demand; and
- overloading of the transformer at Adlington Drive.

As with Year 1, it is not possible to resolve all these problems by converting an existing substation to an LV Engine substation. However, all four problems can be resolved by installing a new conventional substation at Cockington Close.

In Year 3, with the new substation at Cockington Close there is:

- overloading of transformers at Adlington Drive and Bollington Avenue substations during winter peak demand;
- overloading of up to 292% on some sections the cable network during winter peak demand

The conversion of Adlington Drive substation to an LV Engine substation with network reconfiguration or installation of a new conventional substation at Meadow Drive can solve the can solve the transformer overloading problem. Upgrades to the cable network are required in both cases.

To summarise:

- An LV Engine substation can resolve over voltage problems due to solar PV generation. This is because conventional substations run with a fixed LV busbar voltage at the upper end of statutory limits to account for voltage drop under winter peak demand. However, under summer minimum demand with solar PV generation an LV Engine substation can lower this LV busbar voltage to create headroom on the network for solar PV generation.
- An LV Engine substation can alleviate some transformer overloading situations by allowing capacity sharing.
- Undervoltages are typically caused by the voltage drop on the network under peak winter demand and conventional reinforcement (upgrading the cable network) is required to resolve this.
- Overloading of cable network sections due to increase in winter peak demand requires conventional reinforcement (upgrading the cable network).

In the load growth and solar PV increase scenarios we have investigated for this part of the network in Northwich all areas of the network are stressed: cable thermal limits become exceeded, transformer capacities are exceeded, and over and under voltages occur. It is possible to solve some but not all these problems by migrating conventional substations to LV Engine substations.

5.6 Consideration of Load Imbalance

The analysis so far assumes that as customer load and rooftop PV uptake rise, they still remain more or less equally distributed across the three phases. This may, however, not accurately reflect reality as the distribution of customers across the three phases may be unbalanced, and the analysis would be incomplete without accounting for this possibility.

In order to simulate a worst-case scenario, the customers have been distributed across the three phases in such a way that 50% of the customers are connected to Phase A, 25% to Phase B, and 25% to Phase C. The results for customers connected to the Adlington Drive substation under Year 3 loading conditions are shown for winter and summer season in Figure 24 and Figure 25 respectively.

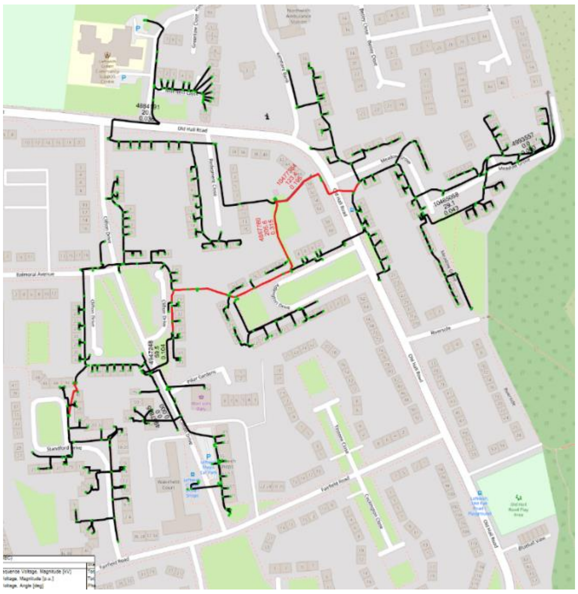

Figure 24 – Snapshot of Adlington Drive network for Y3 winter peak loading with unbalanced load

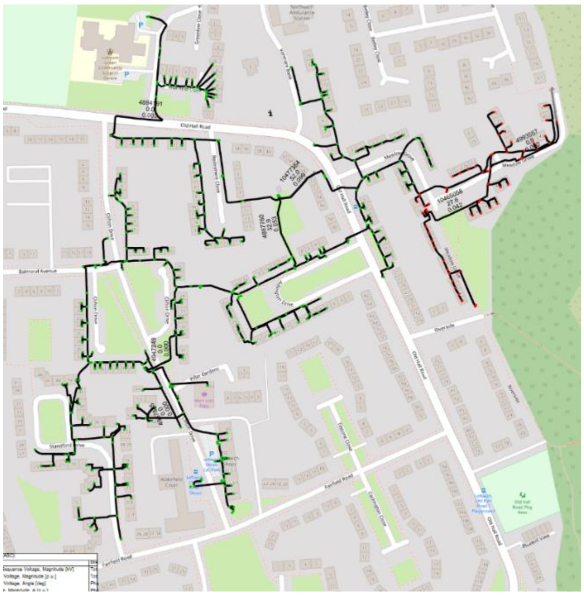

Figure 25 - Snapshot of Adlington Drive network for Y3 summer loading with unbalanced load

The results for winter season (Figure 24) do not show any voltage issues but for summer season (Figure 25), several customers are found to have overvoltage issues due to the rooftop PVs generating maximum power. Moreover, the instances of overvoltage in this scenario are taking place on Phase A due to a disproportionate number of customers on this phase.

The voltage at the LV busbar at Adlington Drive substation and some of the customers at the end of the feeders is shown in Table 10. This shows that although voltage on Phase B and Phase C is very close to the upper limit of 1.10pu, the limit is exceeded only for Phase A.

The results after installation of LV Engine solution at Adlington Drive and selectively lowering the voltage on Phase A to 1.05 are shown in Table 11. This does have any impact on the voltages on Phase B and Phase C but the Phase A voltage is now under the upper limit of 1.10pu.

The results show that LV Engine is a viable solution for solving overvoltage issues as the uptake of rooftop PVs rises and the customer connections are not perfectly distributed across the three phases.

Phase	Busbar Voltage [p.u.]				
	Substation LV	11959239	11959219	12009386	11963163
Phase A	1.08	1.12	1.13	1.12	1.12
Phase B	1.08	1.09	1.09	1.09	1.09
Phase C	1.08	1.09	1.09	1.09	1.09

Table 10 – Voltage at substation LV busbar and end of feeders during summer without LV Engine

Phase	Busbar Voltage [p.u.]				
	Substation LV		Substation LV		Substation LV
Phase A	1.05	Phase A	1.05	Phase A	1.05
Phase B	1.08	Phase B	1.08	Phase B	1.08
Phase C	1.08	Phase C	1.08	Phase C	1.08

Table 11 - Voltage at substation LV busbar and end of feeders during summer after installation of LV Engine

Load on each phase of the transformer on the LV side during the winter peak is shown in Table 12. The transformer is rated at 500kVA which corresponds to current rating of 667A for each LV winding. Table 12 shows that the current through the Phase A winding is 922A which results in it being overloaded to 138%. On the other hand, Phase B and Phase C windings are loaded at only 67% and 64% respectively leaving a significant unutilised headroom. LV Engine has the capability to make unbalanced load appear as balanced load to the transformer. Results for the same scenario after installation of LV Engine and enabling its load balancing feature are shown in Table 13. This shows that after the load is evenly distributed across the three phases by LV Engine, each winding is loaded at 94%, preventing any overloading.

Phase	Rated Current [A]	Simulated Current [A]	Loading [%]
Phase A	667	922	138%
Phase B	667	449	67%
Phase C	667	426	64%

Table 12 – Transformer loading during Y3 winter peak without imbalance load correction by LV Engine

Phase	Rated Current [A]	Simulated Current [A]	Loading [%]
Phase A	667	629	94%
Phase B	667	629	94%
Phase C	667	629	94%

Table 13 - Transformer loading of Adlington Drive during Y3 winter peak with imbalance load correction by LV Engine

6 Cost benefit analysis for the case study

Cost benefit analysis has been carried out between two reinforcement scenarios as shown in Table 14. The baseline scenario considers only installation of new substations as reinforcement options. One the other hand, LV Engine implementation scenario considers retrofitting LV Engine at an existing substation in Year 1 and deferring installation of a new substation to Year 2.

Based on the cost saved by implementation of LV Engine and deferring the installation of new substations, the Net Present Value (NPV) based on different payback periods is shown in Table 15. Because installation of a new substation is more expensive than retrofitting LV Engine into an existing substation, Table 15 shows positive values for NPV for all payback periods leading to the conclusion that LV Engine can help defer implementation of expensive network reinforcements and save costs.

As a reminder the reinforcement options are:

Reinforcement Option 1: Converting Adlington Drive to an LV Engine substation by installing an SST and using a seasonal LV voltage setpoint. This is LV Engine Application A2.

Reinforcement Option 2: Installing a new conventional substation at Cockington Close to supply power to loads further away from Adlington Drive substation.

Reinforcement Option 3: Installing a new conventional substation at Meadow Grove to supply power to loads further away from Adlington Drive substation.

Scenario	Year 1	Year 2	Year 3
Baseline Scenario (Without LV Engine)	Implement Reinforcement Option 2	No Action	Implement Reinforcement Option 3
LV Engine Implementation	Implement Reinforcement Option 1	Implement Reinforcement Option 2	No Action

Table 14 – Cost benefit analysis scenarios

Scenario	NPV based on payback periods				
	10 years	20 years	30 years	45 years	Whole Life
LV Engine Implementation	£520	£6,820	£10,680	£8,570	£8,310

Table 15 – NPV based on payback periods

7 Comparison between LV Engine and voltage regulating distribution transformer (VRDT)

A VRDT is a distribution transformer (11kV/0.4kV) fitted with On-load Tap Changer (OLTC).

Figure 26 illustrates the voltage control improvement concept by deploying VRDT.

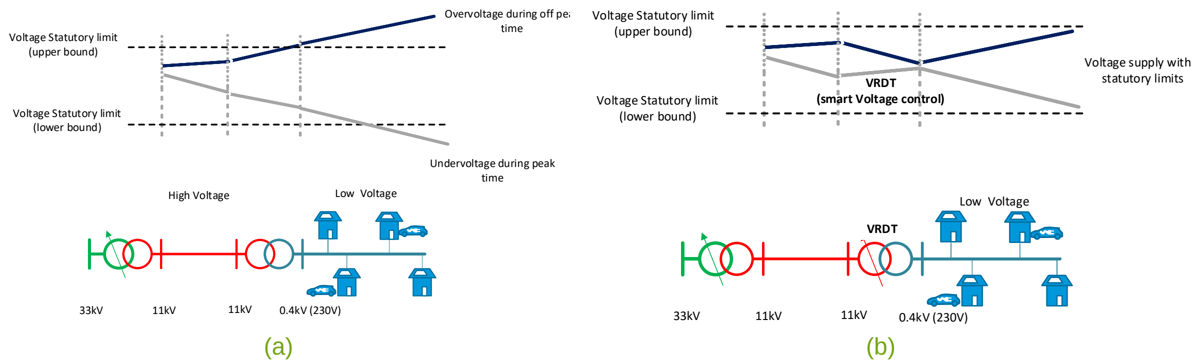

Figure 26 – Conventional voltage control vs VRDT application

(a) Conventional arrangement that may result in overvoltage or undervoltage at LV
(b) Smarter voltage control arrangement using VRDT

Deployment of a VRDT can provide the following benefits:

- Provide a flexible voltage control at secondary substations
  - Independent LV voltage control from voltage variations on the HV network
  - Adjust the target voltage as required at LV without the need to de-energise the distribution transformer
- A faster and less expensive solution compared to conventional solutions such as cable circuit upgrades and installing a new substation which otherwise are used for alleviating voltage issues.
- Potential reduction in customer's energy bills by allowing operation at a lower voltage at LV.

Figure 27 summarises the benefits of using a VRDT solution.

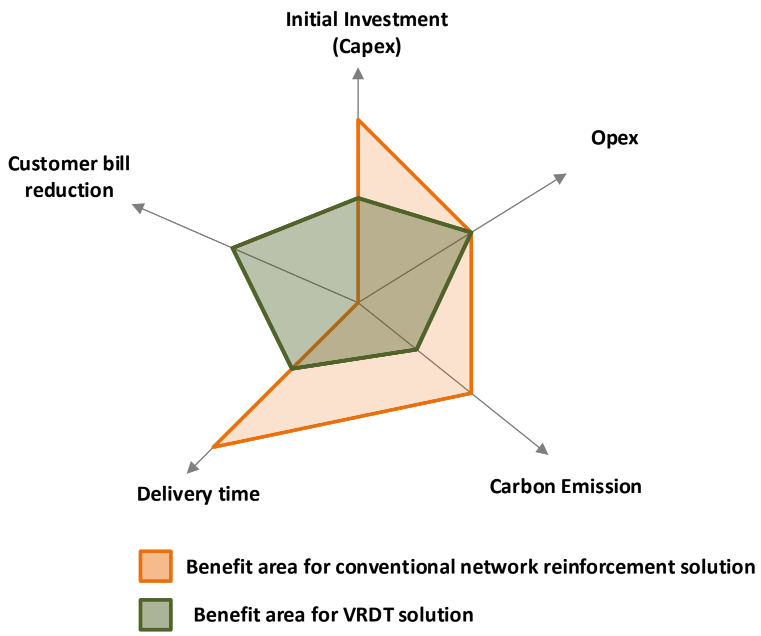

Figure 27 – A summary of comparing benefits from conventional reinforcement with a VRDT solution

LV Engine offers further advantages over VRDTs in terms of voltage regulation and load management. Unlike VRDTs, which operate with discrete steps for voltage adjustment, LV Engine provides highly granular control, enabling precise voltage tuning. This capability extends to individual phase adjustments, a feature not possible with conventional VRDTs, which regulate voltage uniformly across all phases. By allowing phase-specific voltage and current, LV Engine control can make unbalanced loads appear as balanced to the distribution transformer, enhancing overall system stability. Furthermore, the granular voltage control facilitates precise load sharing between substations helping prevent any thermal overloading in the system.

Table 16 – Comparison between LV Engine and VRDTs

Features	LV Engine	VRDT
Voltage regulation range	+/-8%	+/- 5%
Power rating	500kVA (trialled)	1MVA (approved), 500kVA (trialled)
Voltage regulation for each phase	Yes	No
Voltage regulation tuning	Fine	Coarse
Power factor correction	Yes	No
Operation in a meshed network	Controlled power	No control
Can be used within circuit	Yes – for voltage control and cancelling imbalanced load	No
Harmonic compensation	Yes	No
Monitoring and local analytics	Yes	Yes (but limited)
Connection method	Cable connected to existing transformer	Replacing the transformer
Cost	Almost two times a conventional transformer	Almost two times a conventional transformer

8 Conclusions

This reports provides use cases, applications and a toolkit for selecting LV Engine to solve network reinforcement requirements. The following use cases may consider for LV Engine applications:

- Application within secondary substations or within LV circuits to provide voltage regulation, imbalance load cancellation and load sharing among neighbouring substations within an interconnected network.
- Area with high penetration of PVs or EVs are most likely benefit from this technology. Also, for a just transition to a low carbon future, LV Engine can be used initially in deprive areas to optimise the voltage for reducing the customer consumption and consequently reducing customer's annual energy bill.
- Neighbouring substations with interconnected network may LV Engine within interconnecting circuit or in the substation to conduct capacity sharing during peak time.
- LV Engine competes with voltage regulating distribution transformer in terms of voltage control benefits, however, LV Engine provides wider services compared to only voltage control. That makes LV Engine more superior multi functional solution compared to VRDT. VRT has reached now to volume manufacturing that helps brining down the unit cost, whereas LV Engine is just at the very early stage for next generation production and picking up volume manufacturing orders.
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