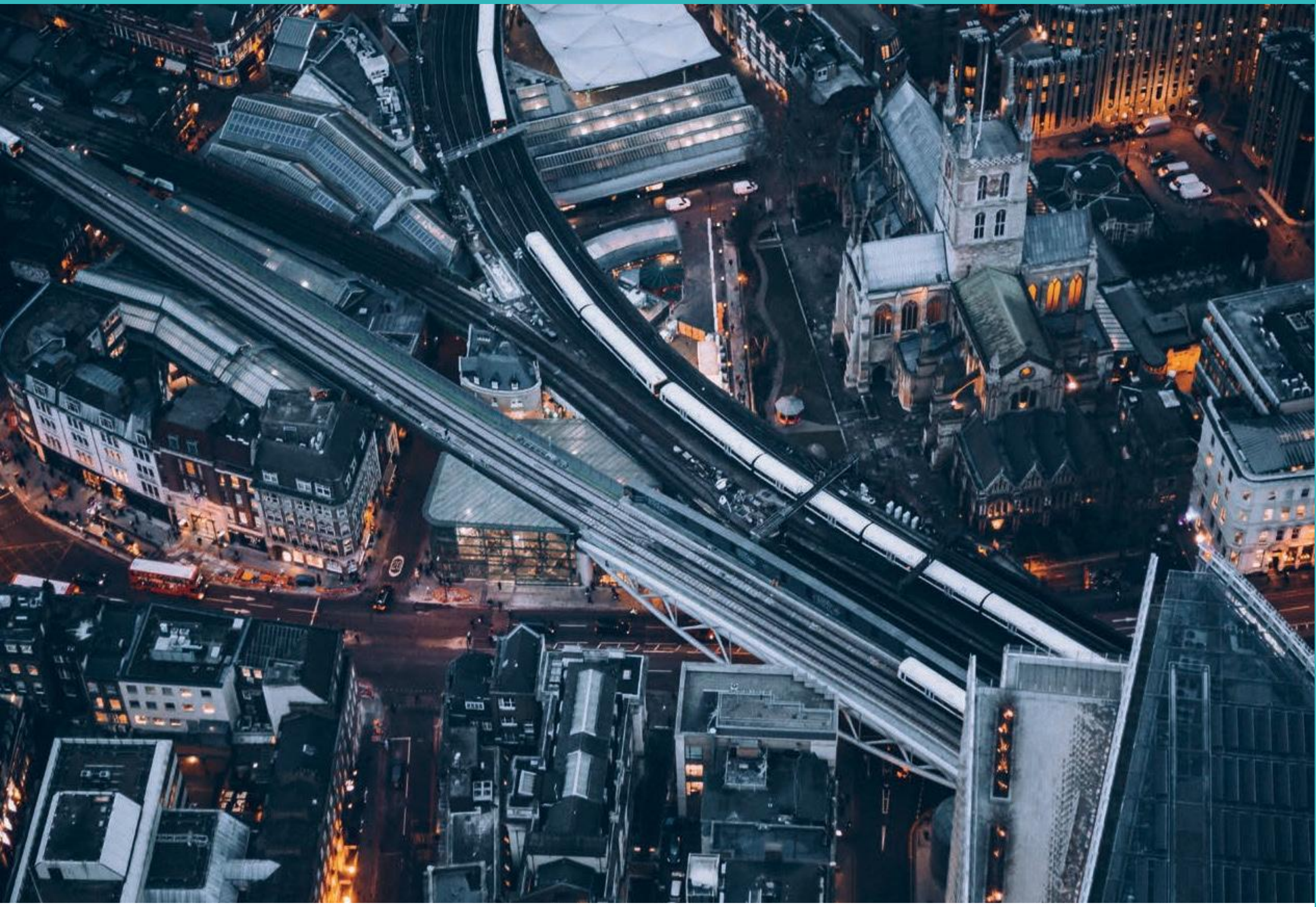

REPORT

Low Carbon Technology Harmonic Limits

Private and Confidential

Prepared for: National Grid Electricity Distribution

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technology

Classification: Commercial In Confidence

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Executive Summary

Background to the Project

The Low Carbon Technologies (LCT) Harmonics Limit project is an extension of a previous project to consider the effects of increasing penetration of Electric Vehicles (EVs) on Harmonic Distortion levels within the LV network and the SILVERSMITH project which sought to understand the capacity of the LV network to absorb EVs and other LCTs within the constraints of the permissible Low Voltage variations.

Scope and Objectives

The scope of the project is to:

- Examine the effects of increasing levels of penetration of LCTs in the LV networks with particular regard to the levels of Harmonic Distortion.

The objective is to:

- enhance understanding of the limitations of the network and where interventions may be required
- examine the effect that tariff structures which affect customer usage profiles might have on the acceptable penetration of LCTs
- inform the development of current design processes within NGED and in the wider GB distribution network operators

Key Project Learning

The studies show that the most likely issue as the penetration of Low Carbon Technologies increases within the LV network is the thermal capacity of the network. The harmonic emissions of high-capacity loads such as EV chargers and heat pumps appear to be being controlled in line with the emission limits of IEC 61000-3-12 such that they are not subject to conditional connection. This is resulting in little additional distortion being seen as penetrations increase.

The effect of these high-capacity long duration loads being encouraged to use electricity at particular times of day by the offering of advantageous tariff prices can be expected to lead to a loss of diversity between these loads which will adversely affect the network assets.

Conclusions

The main conclusions of this report are:

C1. The effect of the harmonic emissions associated with Low Carbon Technologies does not appear to be the limiting factor affecting the penetration into the Low Voltage networks before problems may be expected.

C2. Although there will be diversity between individual loads as the penetration increases it is inevitable that the maximum demand applied to the network will be significantly increased and this will affect the assets.

C3. The limiting factor in accepting the widespread deployment of these new Low Carbon Technologies will be the thermal capacity of elements of the network, whether that begins with a need to increase transformer capacity to reinforce the network or to employ demand controls.

C4. Some means may be required to balance the effects of energy tariff incentives which drive higher consumption during specific periods which may have negative impacts on network assets.

C5. As these types of LCT are typically designed so that they are not subject to conditional connection which has the beneficial effect of minimising the increasing in harmonic distortion greater visibility of the loading on individual LV feeders may be necessary to allow the necessary interventions to be planned ahead of requirement.

C6. There was an example on the rural circuit where the 37^{th} harmonic exceeded both the planning and compatibility limits in the 2040 study year. However, this condition only arose after the total load had exceeded the rating of the transformer and even more severely exceeded the rating of the first leg of the feeder from the transformer.

C7. The continued use of the limits for supply impedance described in NGED Policy Document SD5 appears to be a reasonable mitigation measure which will ameliorate some of the potential issues identified in the SILVERSMITH project and limit the harmonic effects.

Recommendations

The main recommendation of this report is:

R1. Greater visibility of loading on individual LV feeders should be considered to detect the approach of thermal capacity issues.

Contents

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Tables

1. Background and Introduction

The Low Carbon Technologies (LCT) Harmonic Limits project is an extension of a previous project to consider the effects of increasing penetration of Electric Vehicles (EVs) on Harmonic Distortion levels within the LV network and the SILVERSMITH project which sought to understand the capacity of the LV network to absorb EVs and other LCTs within the constraints of the permissible Low Voltage variations.

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1.1 Change in approach

Initial studies with what is considered the worst-case scenario of identical devices in each category with the highest level of recorded harmonic emissions showed only limited effects on the levels of harmonic voltage distortion. The studies carried out have focussed on deploying these worst-case examples of the technology in line with the deployment scenarios developed to reflect the worst-case anticipated rates of increased deployment over the period to 2050.

2. Network Models

The network models were constructed in DigSilent's PowerFactory 2023. In each model the source infeed is modelled at 11kV with a fault infeed representative of a rural and urban network respectively. Background harmonics are modelled as a voltage source at 11kV with a typical transformer capacity and impedance.

2.1 Rural Overhead LV Network

The rural overhead LV network model used an actual network as the basis of a reasonable representation of rural type circuits. The layout of this circuit is shown in Figure 1. The main spines of the feeder are modelled as 120mm^2 Aluminium Aerial Bundled Conductor, with 50mm^2 Aluminium Aerial Bundled Conductor branches and 35mm^2 service connections. The transformer in the actual circuit is a 100kVA three phase unit which would become overloaded in the early studies so for the purposes of this study this was replaced with a 315kVA three phase unit, making the limiting factor for the load capacity of the network the first leg of the overhead feeder before it splits into two branches in opposite directions through the village.

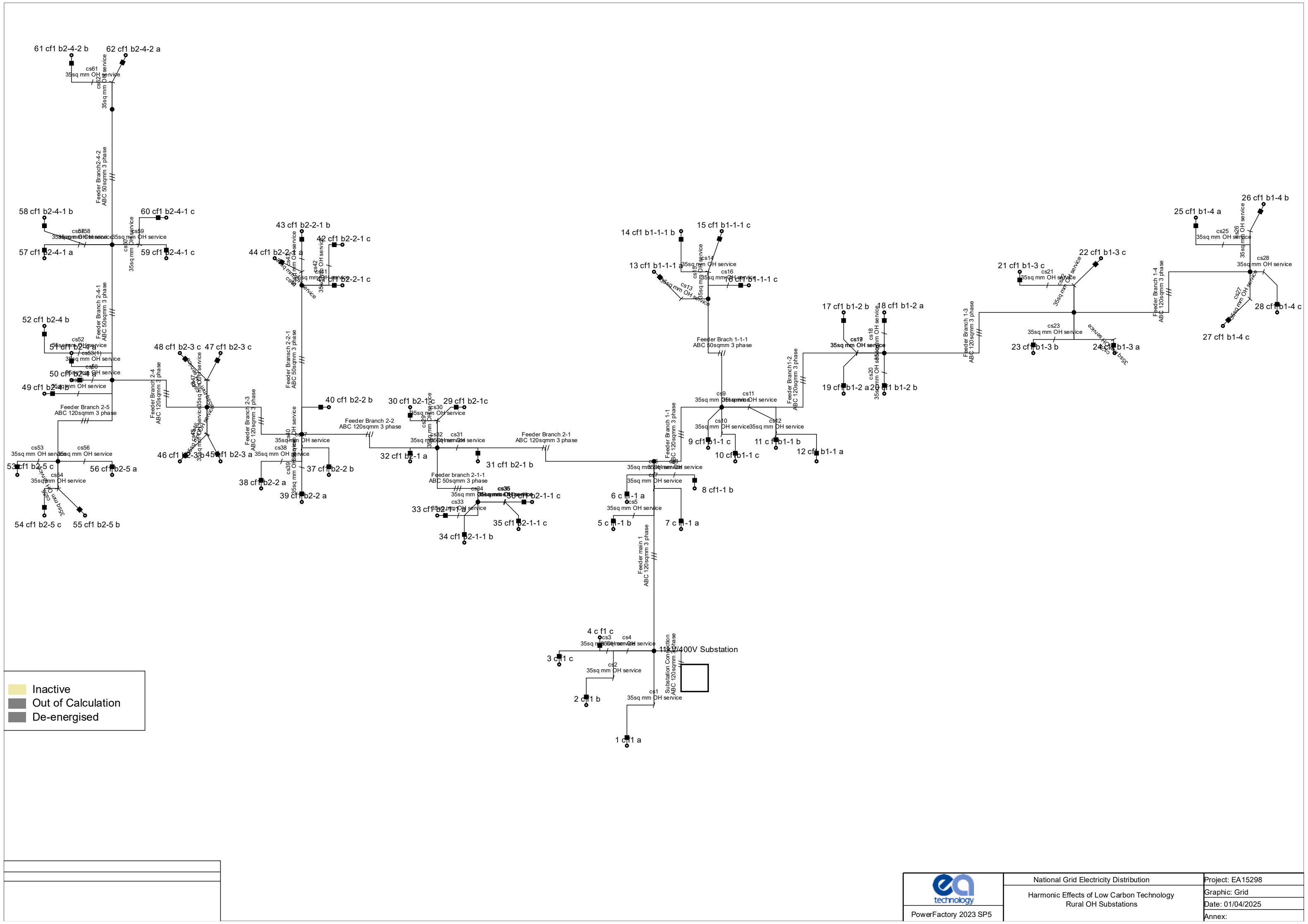

Figure 1 Rural Network Model

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2.2 Urban Underground Networks

The urban underground network model used 4 identically arranged feeders comprising a main feeder with two branches from the main cable which were used to represent four typical examples of Low Voltage networks.

- Current network designs applied to modern and future housing stock where the insulation levels are higher and therefore the electrical load required to meet the heating needs using heat pumps will be expected to be lower compared to earlier types of housing stock.
- Current network designs applied to earlier types of housing stock where the lower levels of insulation required by the building regulations of the time are expected to lead to higher levels of electrical load to deliver the necessary heat input to these properties.
- Tapered Paper Insulated Lead Covered (PILC) cable feeder.
- Tapered PILC cable feeder with half sized neutral conductors.

A fifth feeder which represented a particular example of networks where a previous main cable has been reinforced by laying a larger cable in parallel and the splitting the previous main into shorter lengths and breaching these onto the new larger capacity main cable.

By setting up the four identical feeders with the same deployments of LCTs the effects of the differences between the feeders can be seen as penetrations levels increase.

The transformer was assumed to be an 800kVA unit.

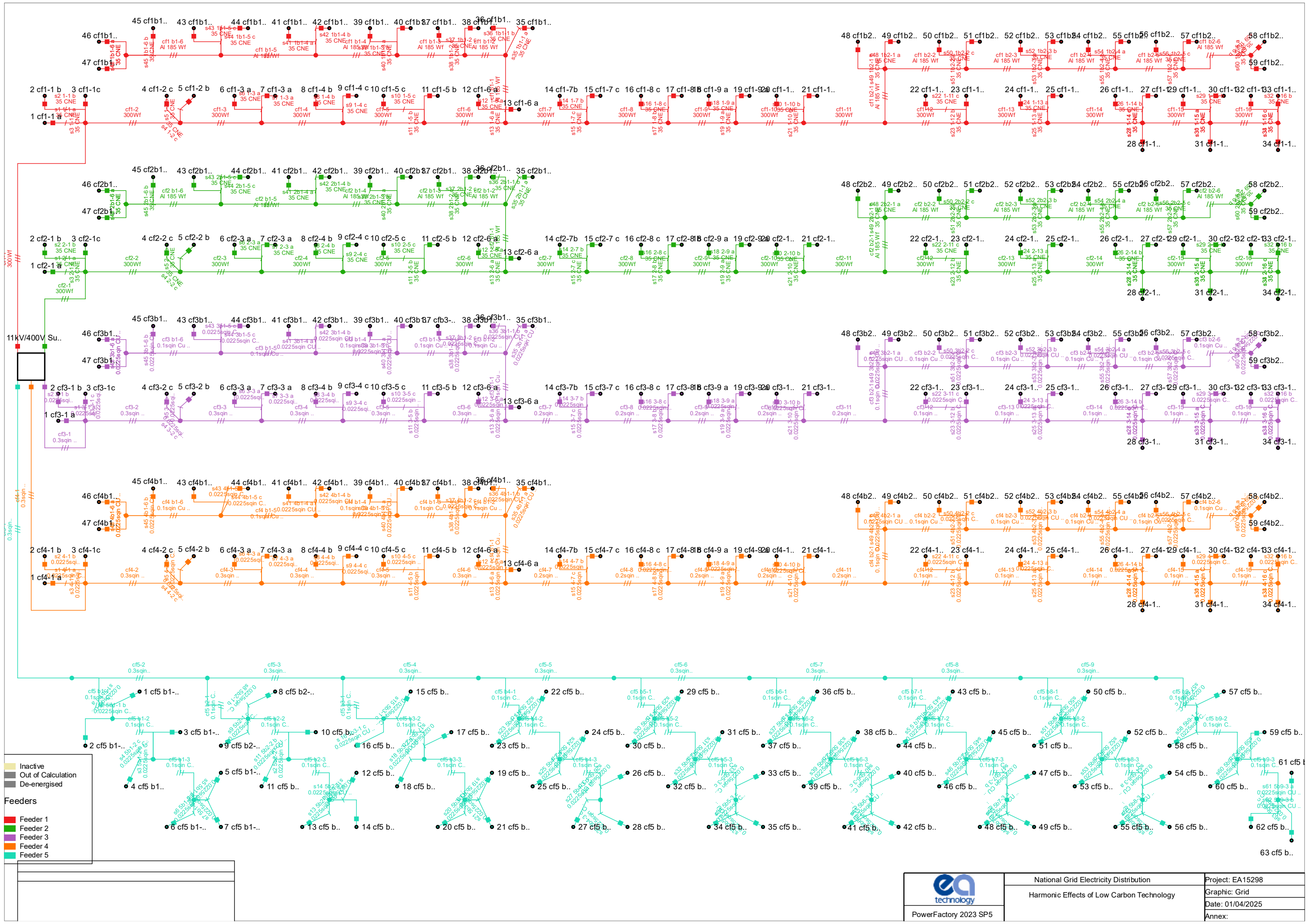

Figure 2 LV Underground Network Model

3. Harmonic and Operation Data

3.1 PV Generation

The PV Generation has been modelled using emissions data for two sizes of PV generator provided by National Grid Electricity Distribution based on 100% output and 45% output. The 45% emissions profile was used for the winter analysis. The type with the highest emissions was deployed into the model as this represented a worst-case scenario.

The time of day was not particularly considered as increasing numbers of PV installations are including battery storage so that solar generated energy can be stored for the householders use at times of greater demand within the house. Both solar energy and stored energy being supplied to the grid via an inverter the harmonic emissions will be comparable regardless of the time of day.

3.2 Heat Pump

National Grid Electricity Distribution have stated that the available evidence that they have suggests that the majority of Air Source Heat Pumps typically operate at around 50% of capacity. However, there are localised conditions which give rise to a higher level of operating current typically 70%, and it is this value that is used within NGED to undertake edge case network design studies. The conditions of concern are freezing fog which, whilst it is typically a localised event, that may not affect all of the wider network, it does occur over a wide enough area that it could be expected to affect all of the heat pumps supplied from a single HV/LV substation.

A number of different anonymised heat pump harmonic emission profiles were made available by National Grid Electricity Distribution. This data came from the Low Voltage Power Quality project a collaboration between Threepwood Consulting, Scottish and Southern Energy Networks and National Grid Electricity Distribution. The initial studies were undertaken with the profile which had the highest levels of emissions at the 5^{th} and 7^{th} which already had the highest background levels.

Operation of the heat pump was assumed to be more or less constant for winter usage where either space heating or water heating loads would be required.

3.3 Electric Vehicle Charging

For the purpose of this study, it is assumed that all future single phase EV chargers will be rated at 32A, harmonic emission data gathered in the Electric Vehicle Emissions Testing project has been used to provide a range of emissions spectra for use in the harmonic load flow studies. The studies were undertaken using the example with the highest emission levels, this represented a worst-case scenario with no diversity in manufacturers such as might be expected on a new housing development.

No restrictions on time-of-day charging were considered in the initial studies.

4. Calculation Methodology

A background level of voltage distortion was defined based on measurements at a substation with no downstream LV load. The recorded levels of voltage distortion were applied as a voltage source on the 11kV side of the distribution transformer in the model. This provided a defined level of voltage distortion against which the effect of harmonic distortion introduced by the LCT harmonic current emissions can be measured.

The effect of existing customer load was simulated with a profile based on a theoretical emission for full wave rectification 30% 3rd harmonic, 20% 5th, 14% 7th 11% 9th etc.

The harmonic load flow studies in PowerFactory cannot be run in the Quasi-dynamic study mode which only applies to load flow studies. The worst-case scenario of all of the three LCTs under consideration was considered as a first set of studies to determine if or when harmonic emissions were the driving issue limiting the capacity of the network.

5. Acceptable Harmonic Distortion Limits

The results of studies undertaken in this project have been graphed against the planning level limits contained in Engineering Recommendation G5/5. These limits represent one of the more conservative assessments of limits that could be applied. Remaining below these limits implies that there would still be capacity for other harmonic generating loads to be readily accepted on to the network.

Alternative limits which could have been applied are the compatibility levels also set down within Engineering Recommendation G5/5, the levels described in BS EN 50160 which describes the worst-case values expected across the European electricity systems, IEC 61000-2-2 describes the compatibility limits for public electricity distribution systems. The chart in Figure 3 below shows the variation in limits between the standards considered. The compatibility limits in ER G5/5 And IEC 61000-2-2 are identical, the BS EN 50160 limits do have some values which exceed these but are broadly in line with the compatibility limits. The planning limits are typically lower than the compatibility limits.

It can be seen from Figure 3 that the G5/5 Planning Limits represent the most onerous limits for this assessment, remaining within these limits implies the availability of capacity for further harmonic generating load to be accepted alongside these Low Carbon Technologies.

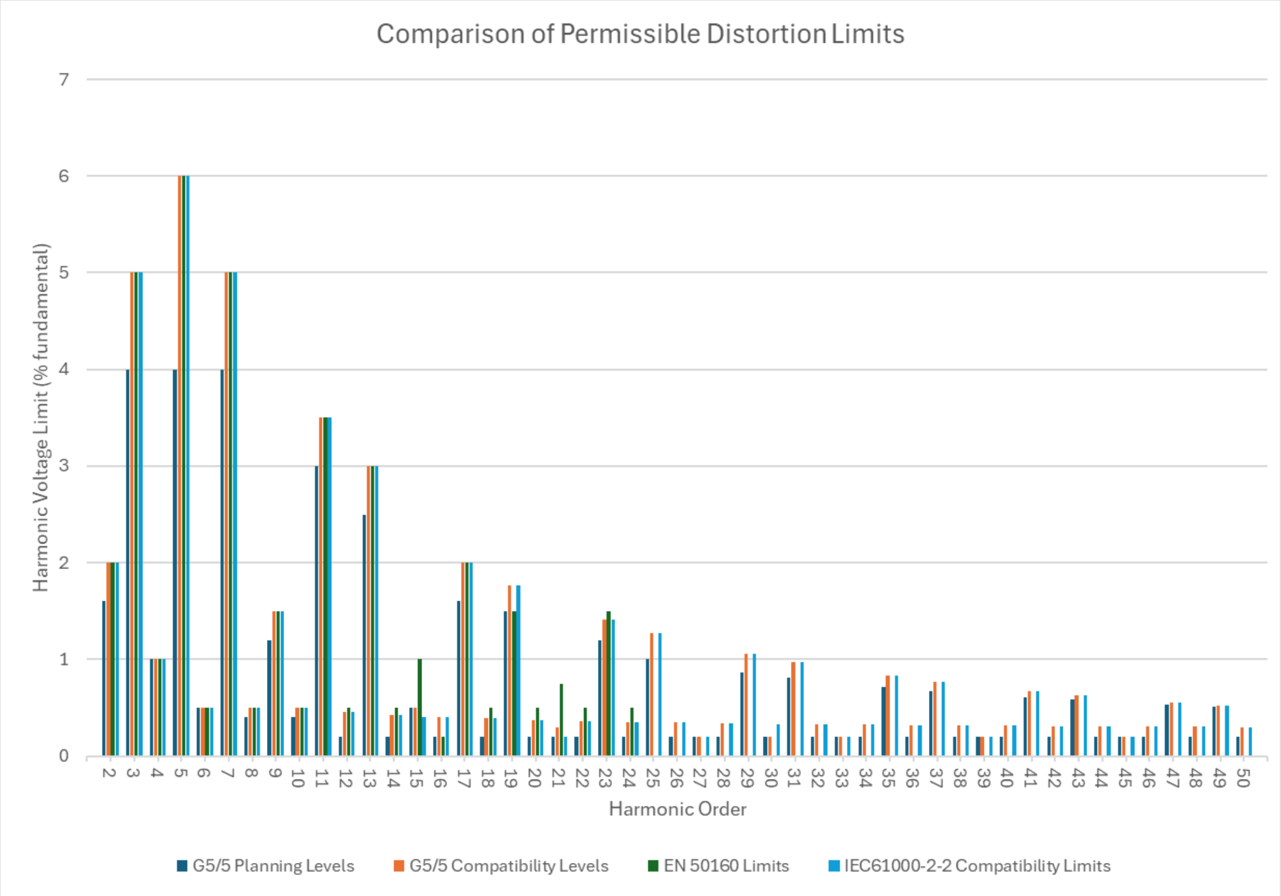

Figure 3 Comparison of Harmonic Distortion Limits

6. Future Energy Scenarios

In the SILVERSMITH project three Distribution Future Energy Scenarios were examined with varying levels of uptake of new Low Carbon Technologies across the LV distribution networks. In this project the Leading the Way scenario has been used to provide a growth pattern for the deployment of Photovoltaic Generation, Electric Vehicle Charging and Heat Pumps. This scenario represented the most optimistic view of deployment of these technologies at that time. Utilising this scenario provides a degree of continuity between this and the previous project, using the most optimistic deployment scenario maximises the effect of the new Low Carbon Technologies so that any problematic harmonic effects will be seen more quickly.

6.1 Low Carbon Technology deployment rates

The following sections describe the numbers of each technology expected to be deployed by the Leading the Way scenario in the same years used in the SILVERSMITH project.

6.1.1 Rural

The rural example circuit has 62 customers connected. Taking the percentage deployments arising from the Leading the Way Distribution Future Energy Scenario (DFES) utilised in the SILVERSMITH project leads to the numbers of each type of LCT being deployed within the network in 2028, 2033, 2040 and 2050.

Table 1 Rural example Low Carbon Technology deployment by year

LCT	Year			
	2028	2033	2040	2050
Photovoltaic	13	23	37	58
EV Charger	9	28	37	38
Heat Pump	3	6	14	19

6.1.2 Urban

The urban circuit examples have four identically arranged circuits each with 59 customers but with differing cable types between them. This allows comparisons to be made between the cable types for the same deployment conditions. The fifth circuit which represents a particular circuit arrangement which has previously been used to enhance the capacity of older Paper Insulated Lead Covered cable by laying a larger cable alongside an existing circuit and breaching sections of the previous circuit onto the new main circuit as branches. This fifth circuit has 62 customers connected to it.

Table 2 Urban example Feeders 1-4 Low Carbon Technology deployment by year

LCT	Year			
	2028	2033	2040	2050
Photovoltaic	12	22	35	55
EV Charger	8	27	35	36
Heat Pump	3	6	13	18

Table 3 Urban example feeder 5 Low Carbon Technology deployment by year

LCT	Year			
	2028	2033	2040	2050
Photovoltaic	13	22	37	59
EV Charger	9	28	37	38
Heat Pump	3	6	14	20

6.2 Deployment locations

It was decided to deploy the low carbon technologies from the end of the feeder/branches back towards the source as the penetration levels increase. This approach was taken because placing the loads at the end of the feeder is likely to maximise the level of harmonic voltage distortion and voltage drop created by the additional load on the new LCTs. It is possible that certain government decisions since then will affect the speed of uptake of some of the LCTs considered in this study, however, the results of these studies suggest that harmonics are not likely to be the driving factor limiting the ability of the networks to accept this additional load as the use of fossil fuels for heating and transport is displaced in favour of electrification of these energy demands.

6.2.1 Rural

Figure 4, Figure 5, Figure 6 and Figure 7 show the deployment locations used to study the effects in 2028, 2033 2040 and 2050 respectively using the leading the way Distribution Future Energy Scenario previously used in the SILVERSMITH project.

The initial deployment for each type of LCT has been established at the remote ends of the feeder increasing towards the source. Placing the load at the remote end maximises the effect on voltage distortion at the point of connection the current having flowed through a greater impedance, similarly voltage drop is also maximised in this way. Beginning all LCT deployments at the same point and working back to the source also reflects the expectation that early adopters of one technology are considered more likely to adopt other similar technologies.

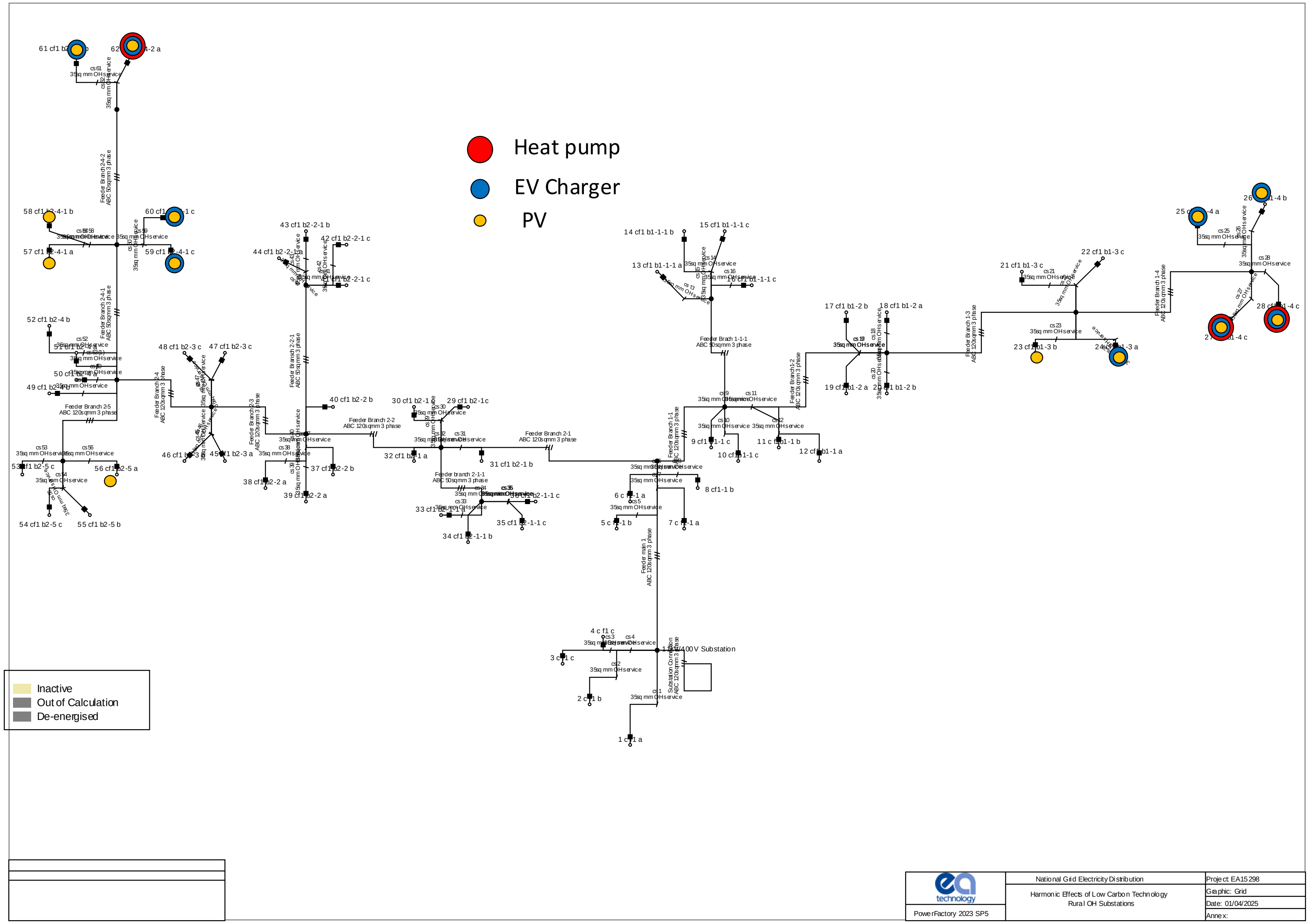

Figure 4 2028 Study Year LCT Locations

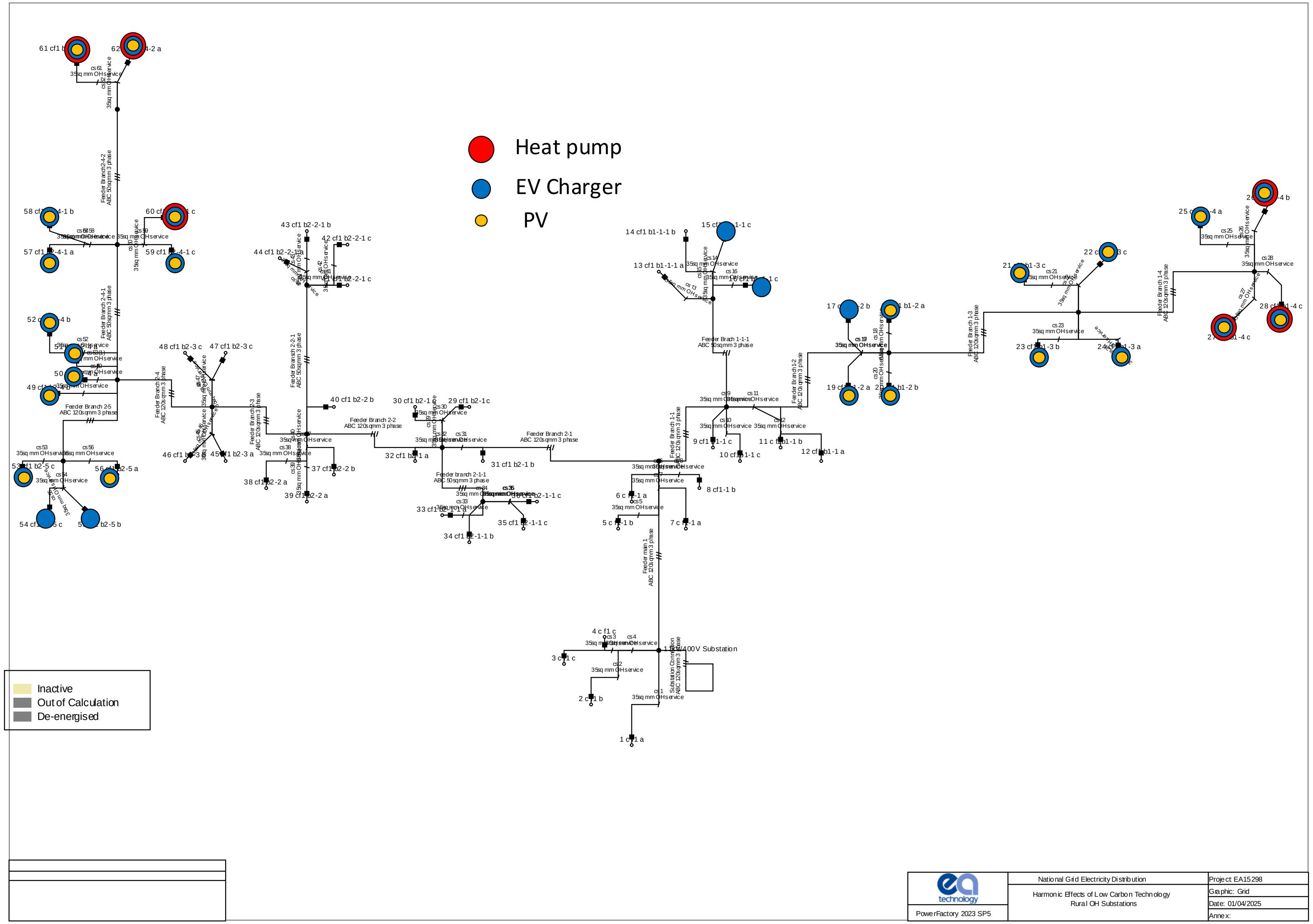

Figure 5 2033 Study Year LCT Locations

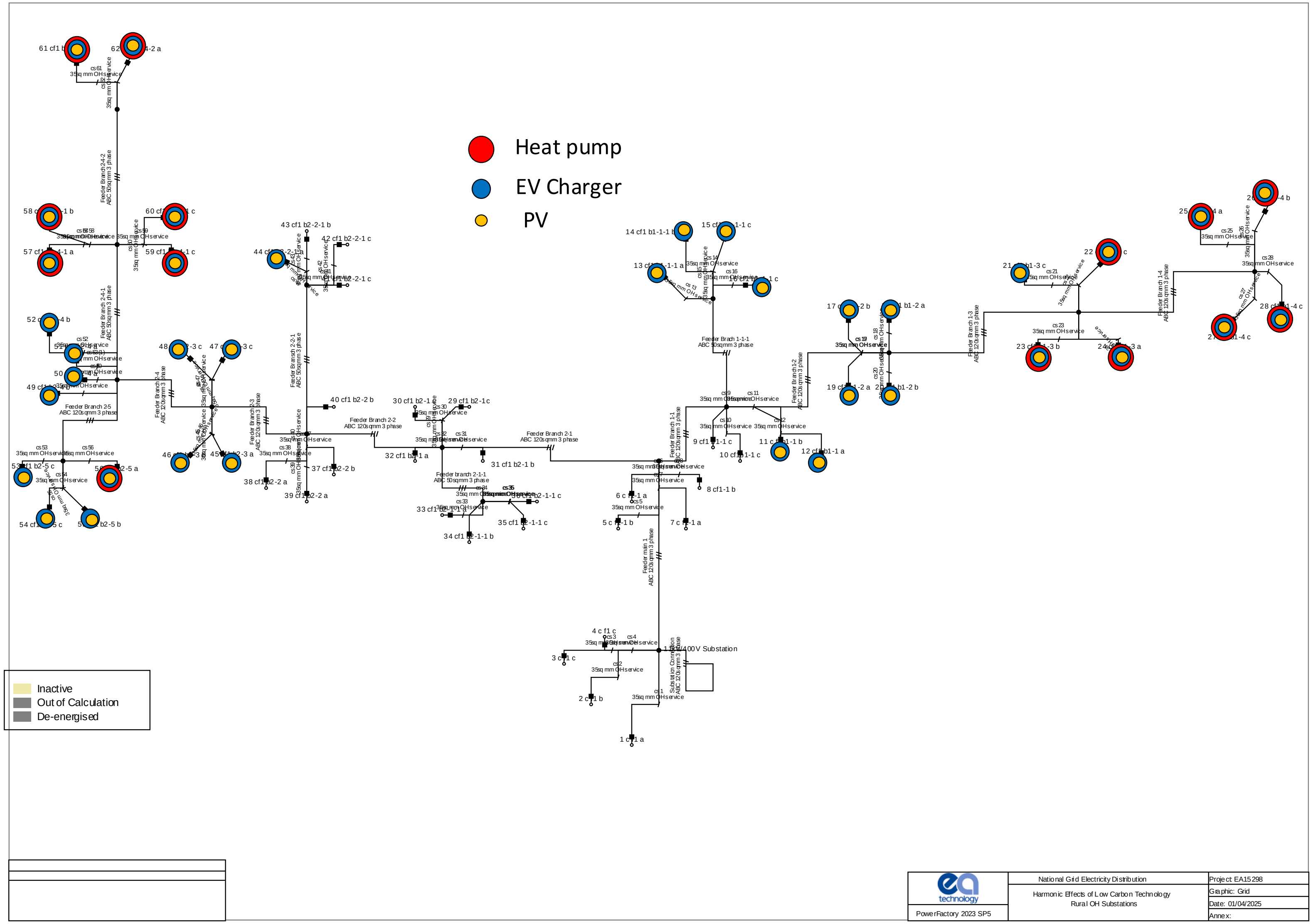

Figure 6 2040 Study Year LCT Locations

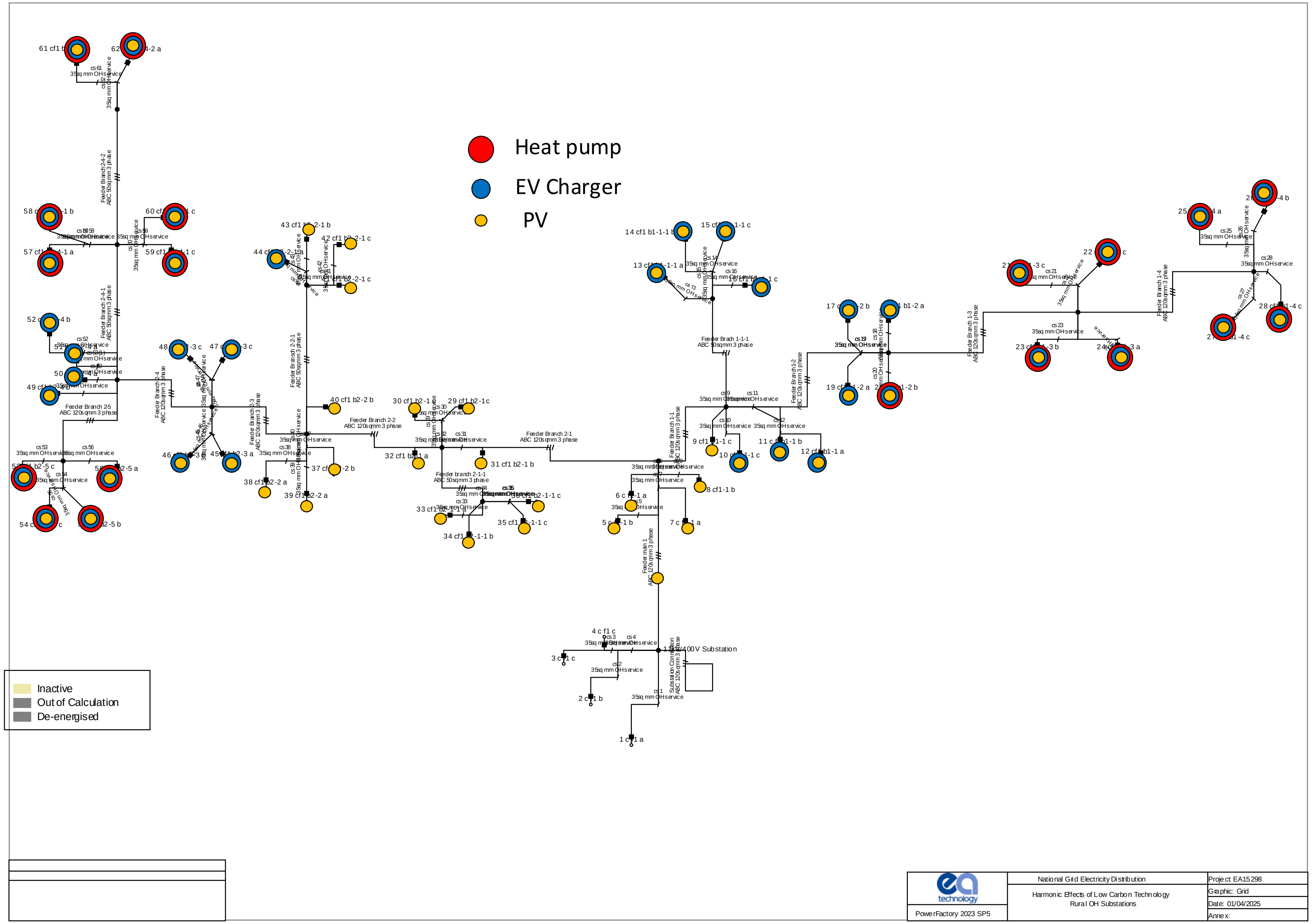

Figure 7 2050 Study Year LCT Locations

6.2.2 Urban

Figure 8, Figure 9, Figure 10 and Figure 11 below show the development of the deployment of LCTs on Feeders 1, 2, 3, 4, and 5 in years 2028, 2033, 2040 And 2050 respectively.

The deployment rate for the LV underground circuits is the same rate as for the rural circuit as described above. The deployment of LCTs in feeders 1 -4 have been started from the remote ends of the associated branches fed from the main. For feeder 5 where a number of branches have been created when the original main has been subdivided and each segment breeched onto a new main. Deployment begins at the remote end of the most remote branch and works back to the next branch and so on towards the source.

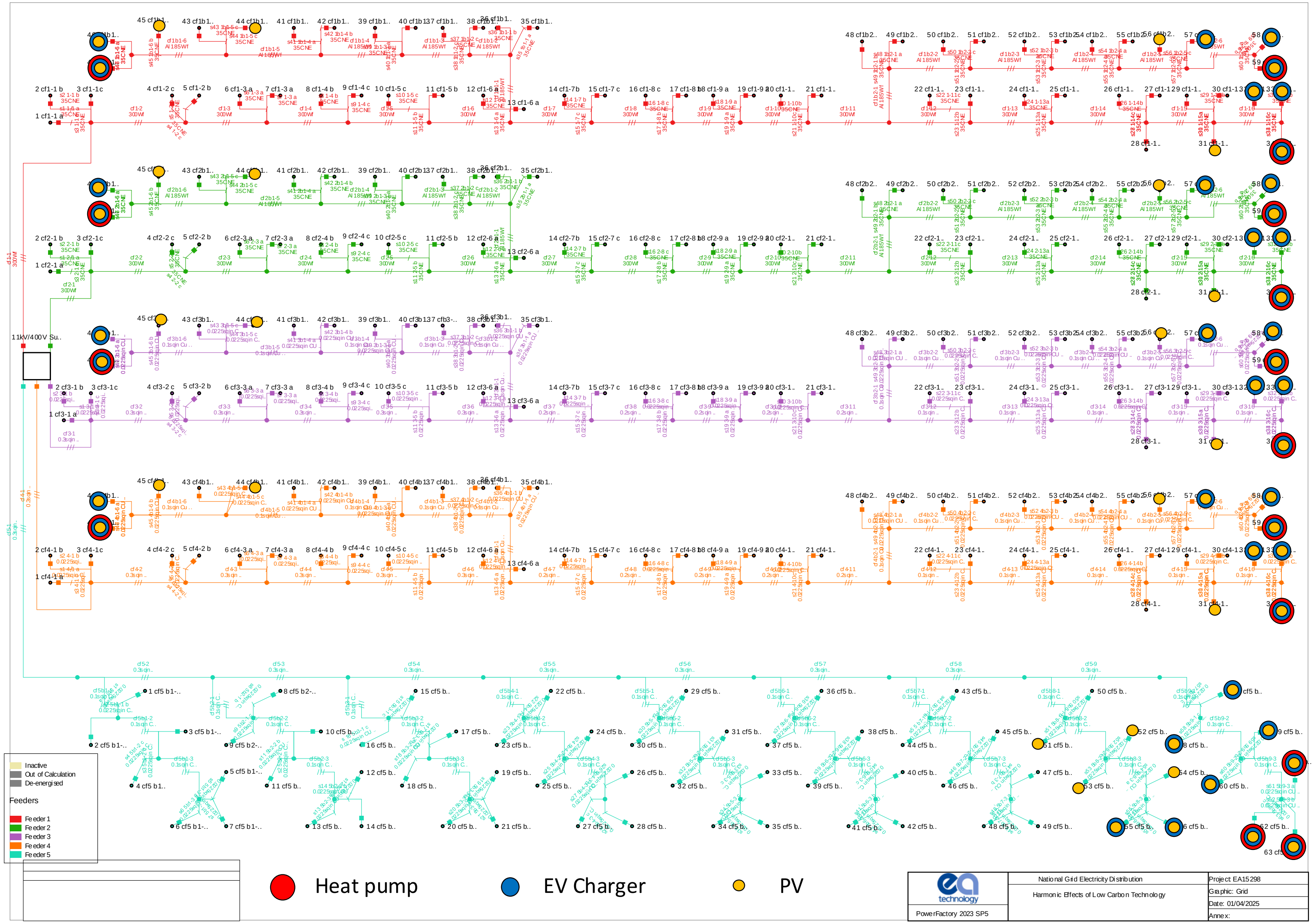

Figure 8 2028 Study Year LCT Locations

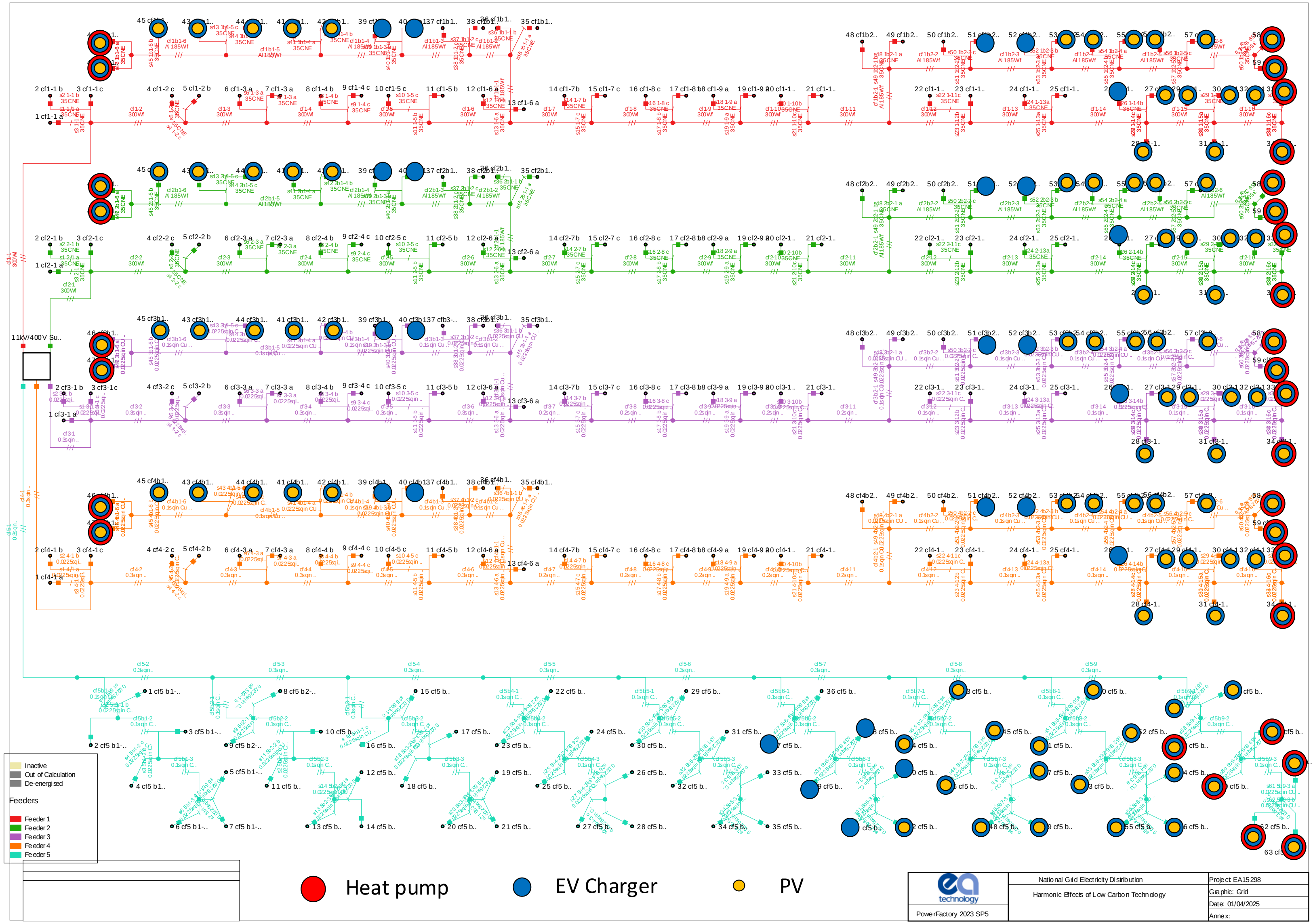

Figure 9 2033 Study Year LCT Locations

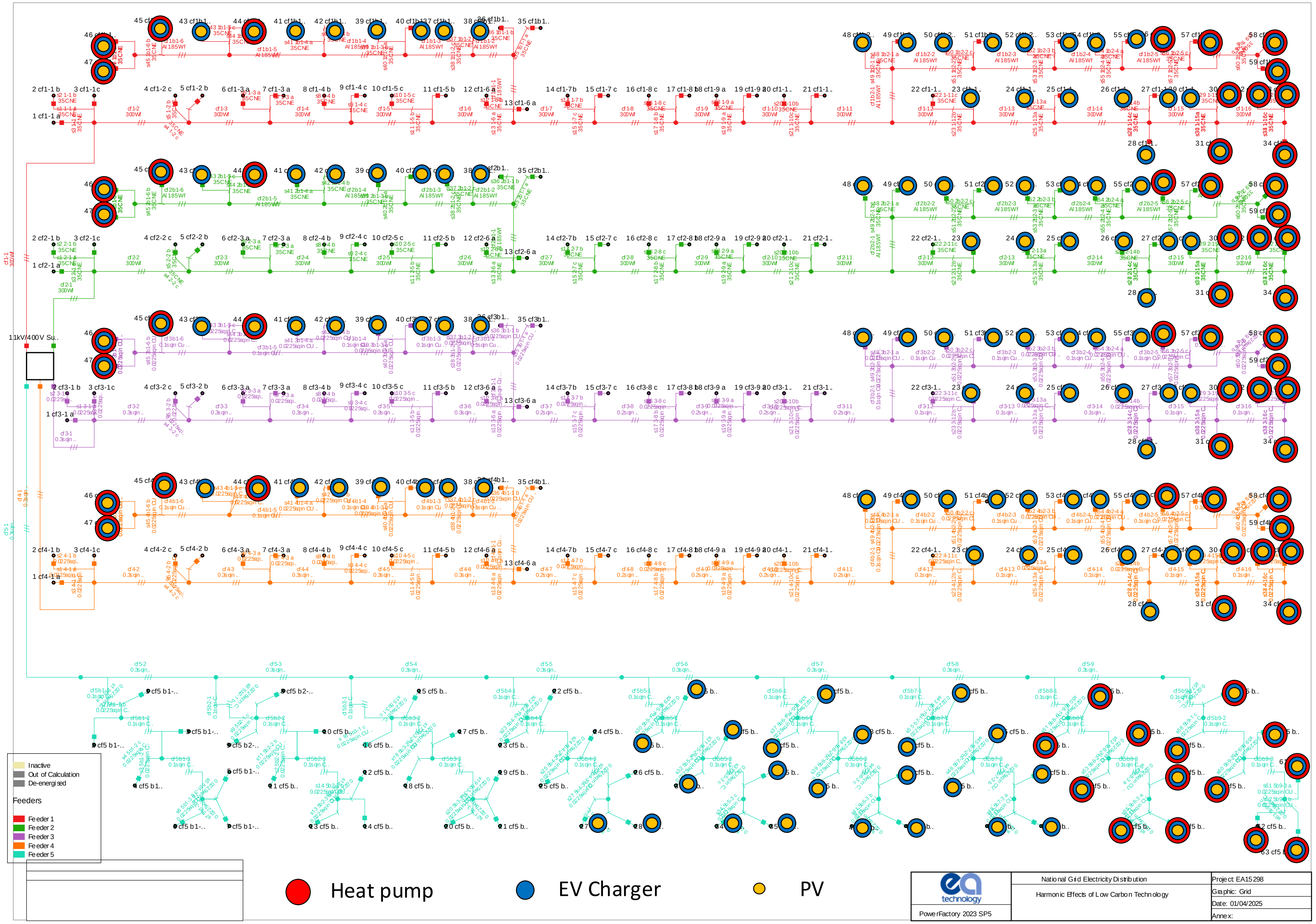

Figure 10 2040 Study Year LCT Locations

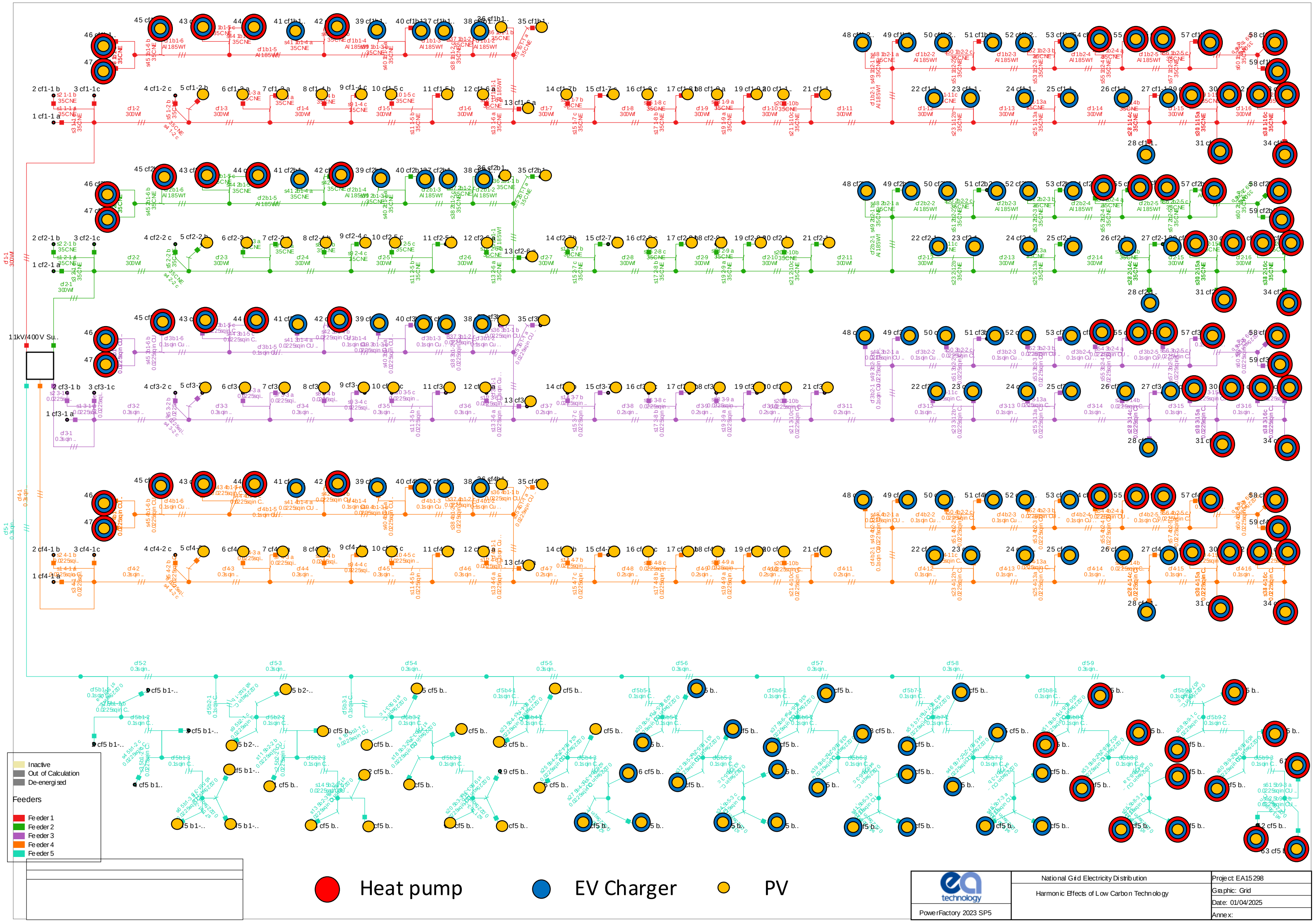

Figure 11 2050 Study Year LCT Locations

7. Harmonic Variation

Figure 12 below shows a close up of one of the graphs used to illustrate the variation in harmonic voltages across the feeders in the studies. The close up shows how the bar graphs of each customer connection point are superimposed on top of one another to show the variation between minimum and maximum values calculated for each harmonic up to the 50th harmonic.

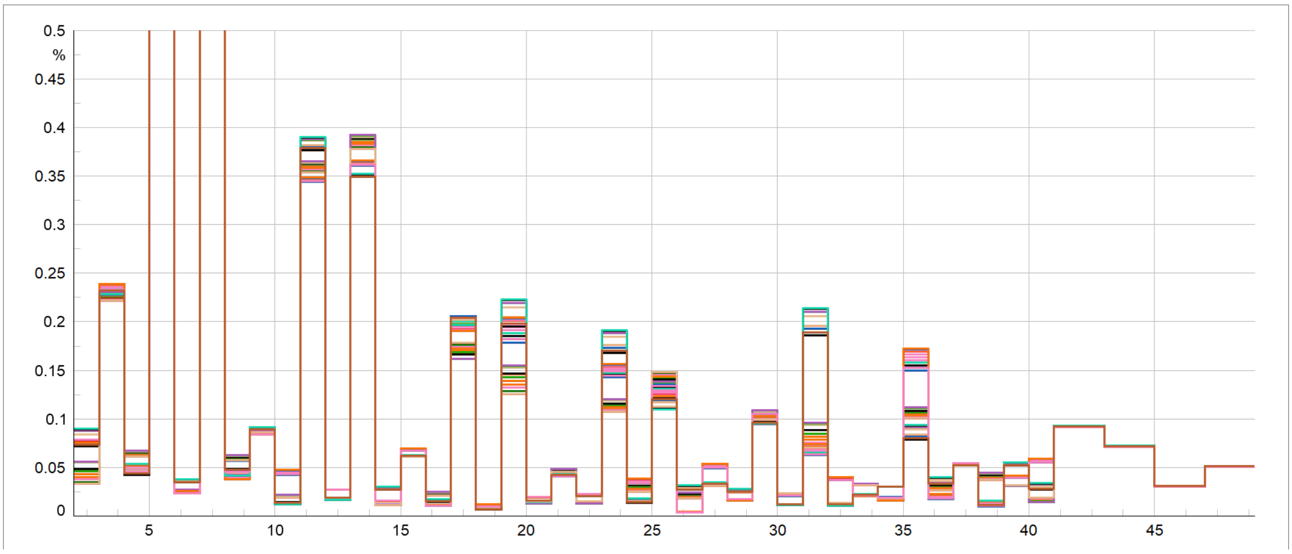

Figure 12 Close up of Harmonic Voltage Variation bar graph

8. Background Harmonic Levels

8.1 Rural

The range of background harmonic voltage levels along the feeder for the rural circuit are shown in Figure 13 below. The dominant harmonic voltage is the 5th harmonic, with a range of values over the feeder length between 2.662% and 2.718% of the fundamental voltage. The values at the remote ends of the feeder are as would be expected higher than the source values, but all well within the ER G5/5 planning levels.

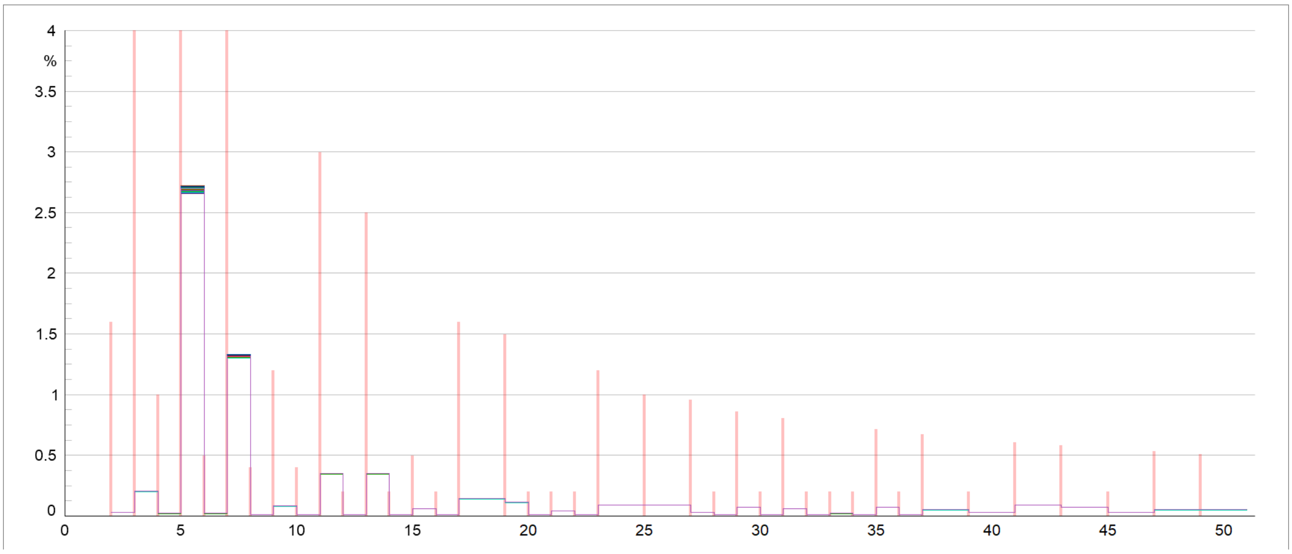

Figure 13 Background Harmonics with no LCTs plotted against planning levels

8.2 Urban

Figure 14, Figure 15, Figure 16, and Figure 17 below show the harmonic voltage spectra for the source and remote end of the main and branch circuits separately graphed by phase for feeder 1, 2, 3 and 4 respectively. Figure 18 below shows the harmonic voltage spectrum for the source and most remote branch end of the circuit for feeder 5 graphed separately by phase. As before the more remote ends of the circuit have higher values of voltage distortion than the source. The dominant harmonic values is again the 5th harmonic with ranges between 2.682% and 2.75% at the remote end of the main circuit for feeder 1, 2.683% - 2.764% for feeder 2, 2.682% - 2.755% for feeder 3, 2.682% - 2.774% for feeder 4 and 2.684 and 2.73% for feeder 5.

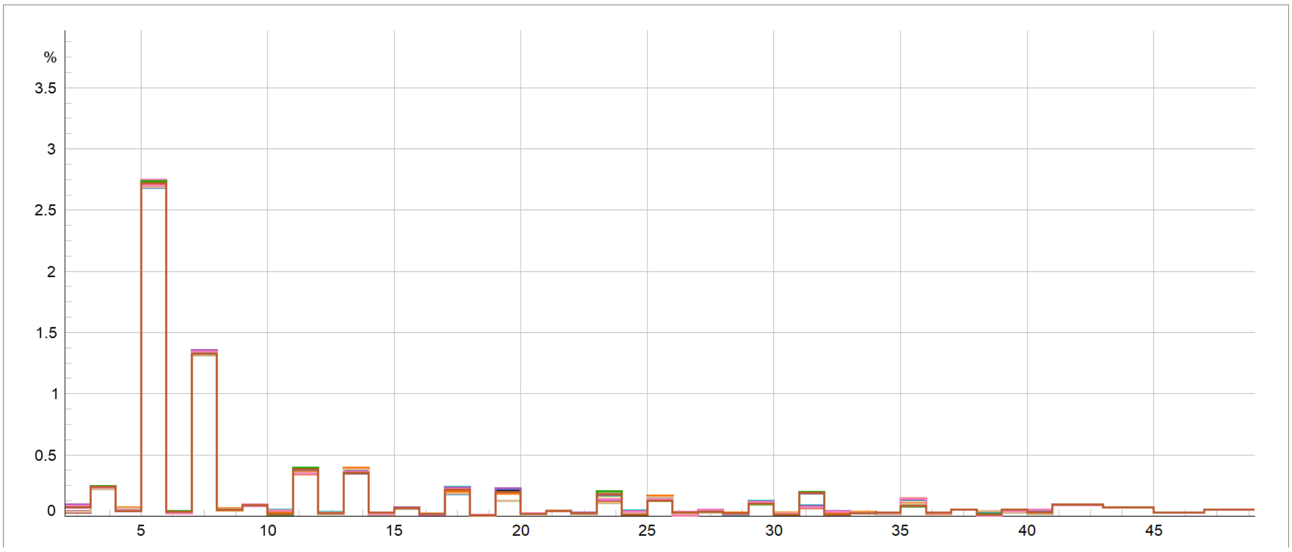

Figure 14 Feeder 1 Background Harmonics with no LCTs

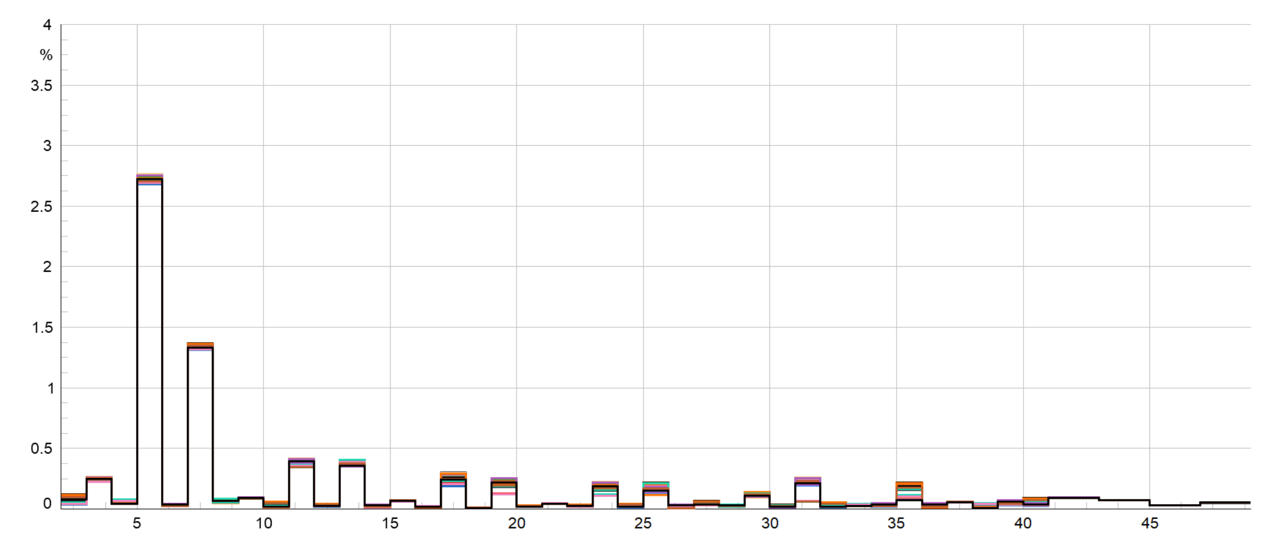

Figure 15 Feeder 2 Background Harmonics with no LCTs

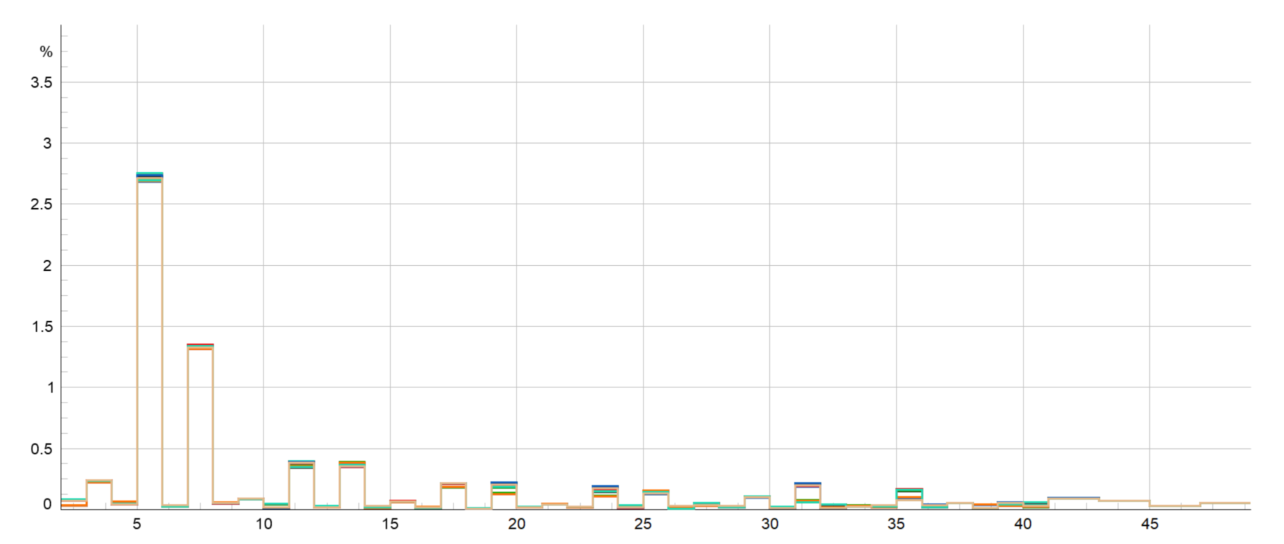

Figure 16 Feeder 3 Background Harmonics with no LCTs

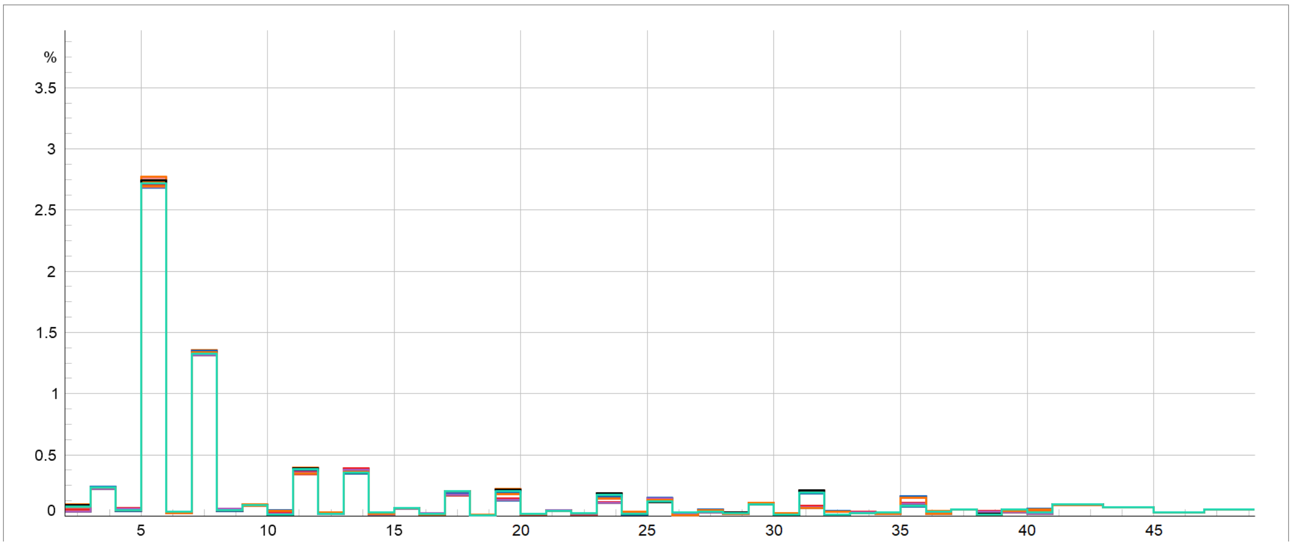

Figure 17 Feeder 4 Background Harmonics with no LCTs

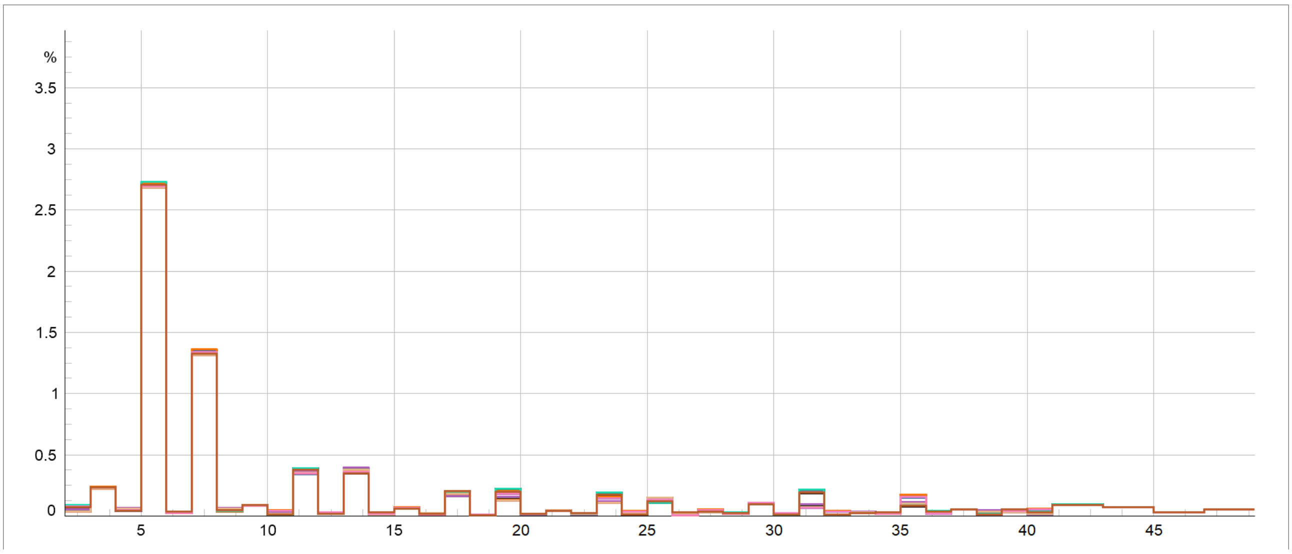

Figure 18 Feeder 5 Background Harmonics with no LCTs

9. Winter Studies

9.1 Harmonic Effects

The effects of the increasing deployment of LCTs are highlighted in the following sections. The plots shown within the body of the report illustrate the variation of each individual harmonic over each feeder for each of the study years.

9.1.1 2028

Rural

The increase in harmonics due to the initial LCT deployment on the rural circuit is shown in Figure 19 below. The dominant harmonic voltage remains the 5th harmonic, the range of 5th harmonic voltages changes to

2.677% at the first customer to 2.834% at the remote end of the feeder these remain well within the planning levels set out in G5/5.

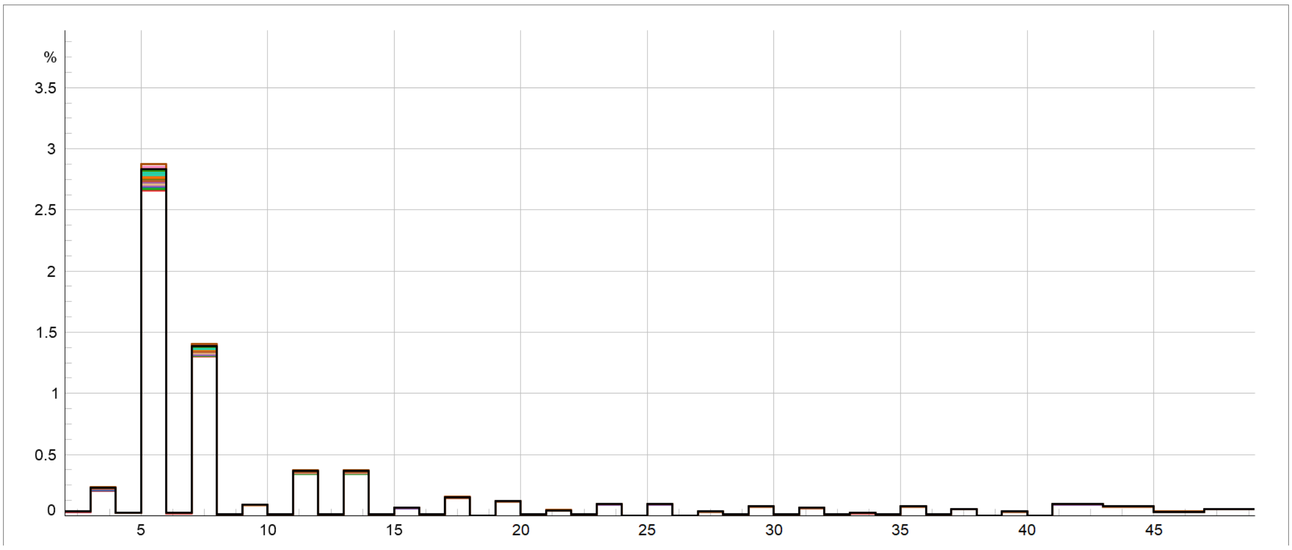

Figure 19 2028 Rural Harmonics – Harmonics Variation

Urban

Even though the number of customers per feeder is very similar between the underground feeders and the overhead feeder and consequently the penetration of LCTs has been essentially the same as shown in Tables 1-3. The effect on the increase in harmonic distortion in the underground networks is smaller than seen in the rural example, this is due to the lower impedance of the underground cables forming the mains and branches in the example underground circuits compared to the overhead circuits in the rural example. The 5th harmonic remains the dominant harmonic voltage with ranges 2.685% - 2.957% across the 5 feeders. Feeder 5 shows the highest distortion at the remote end because the deployment regime modelled has the higher concentration at the most remote end of the branched mains.

Figure 20 – 24 show the variation of each harmonic over the length of the circuit for the first study year.

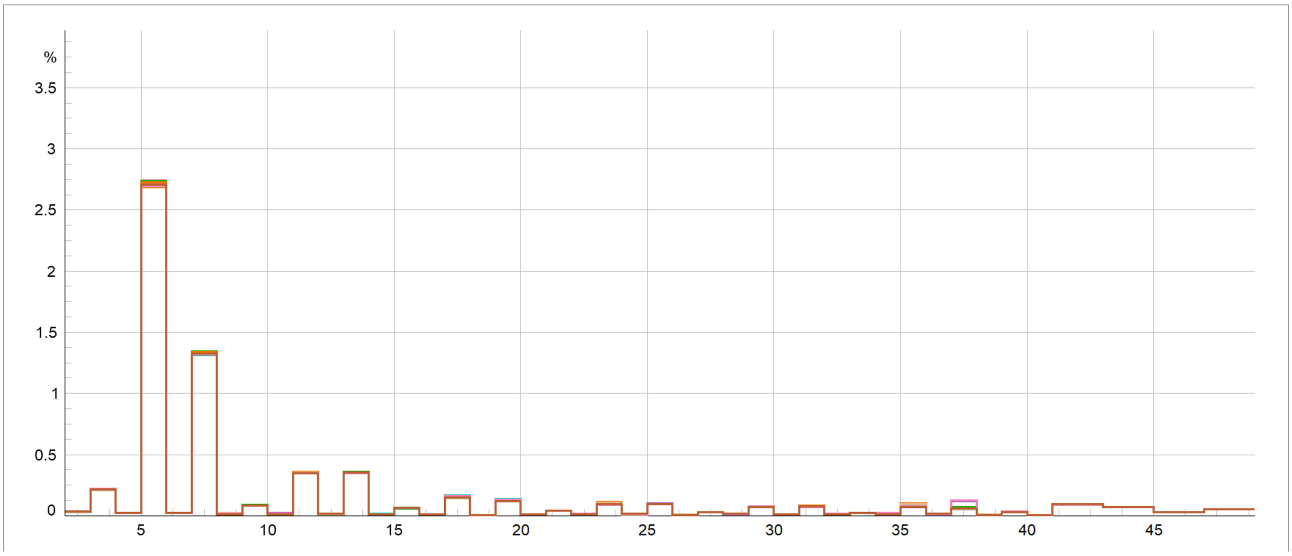

Figure 20 2028 Underground Feeder 1 Harmonics Variation

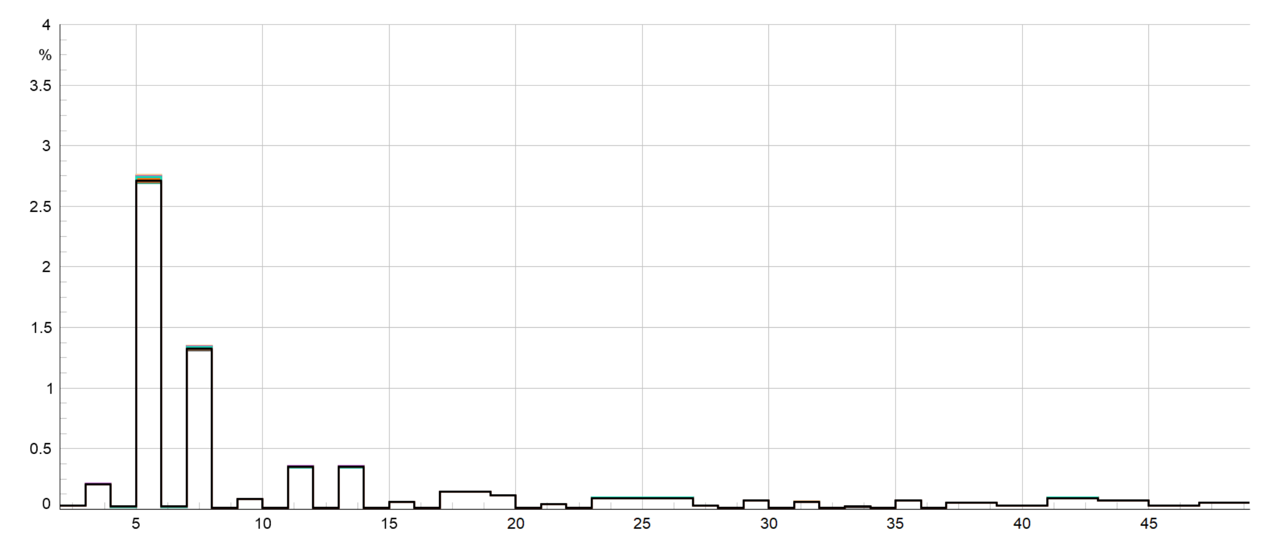

Figure 21 2028 Underground Feeder 2 Harmonics Variation

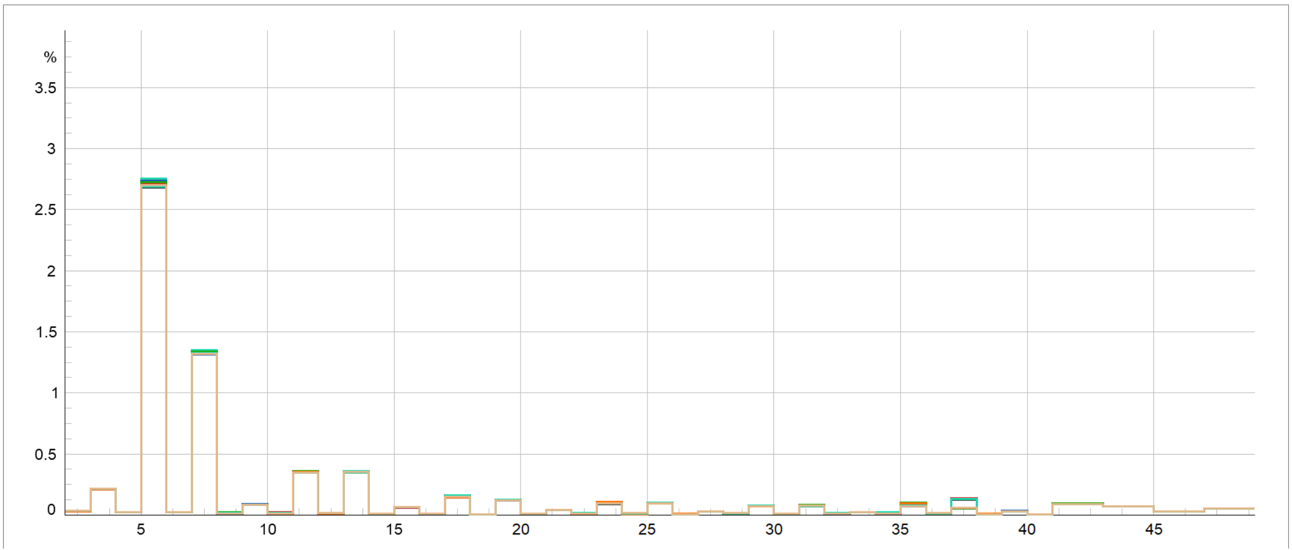

Figure 22 2028 Underground Feeder 3 Harmonics Variation

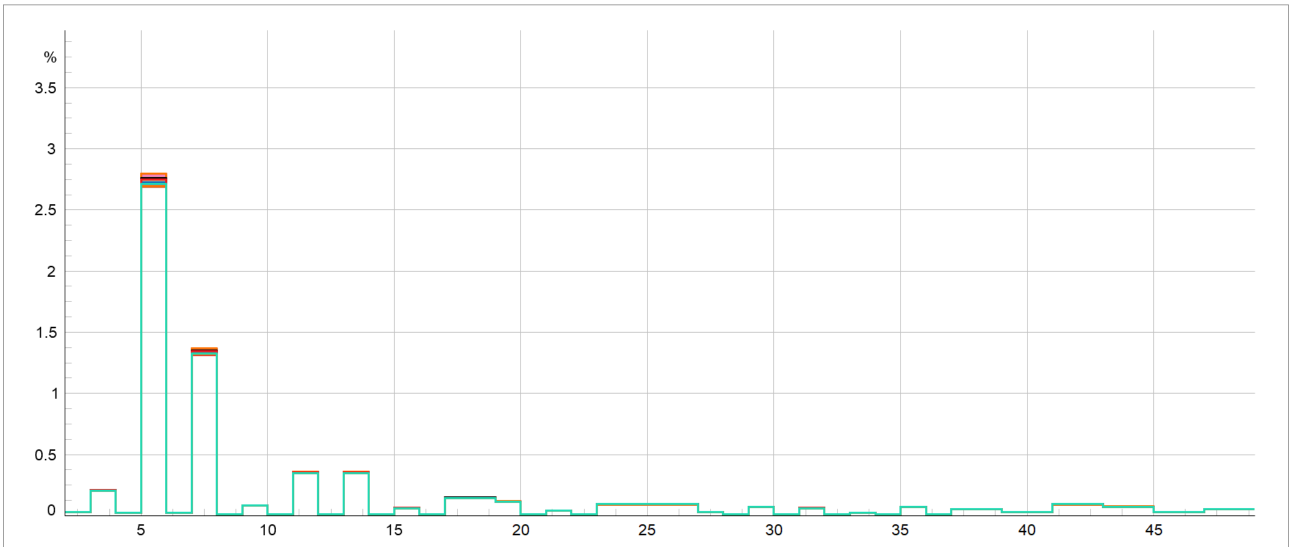

Figure 23 2028 Underground Feeder 4 Harmonics Variation

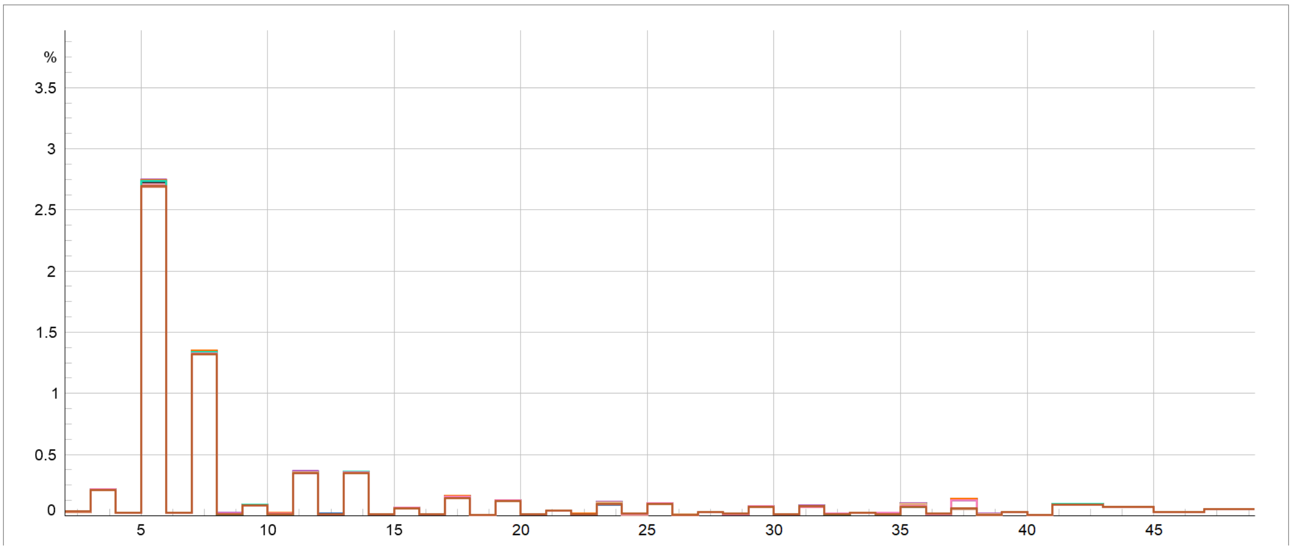

Figure 24 2028 Underground Feeder 5 Harmonics Variation

9.1.2 2033

Rural

The increased level of LCTs expected in 2033 under the scenario modelled raises the level of harmonic distortion at the remote end of the feeder, again the 5th harmonic is the dominant harmonic value ranging between 2.692% and 2.873% but this still remains well below the planning level in EREC G5/5

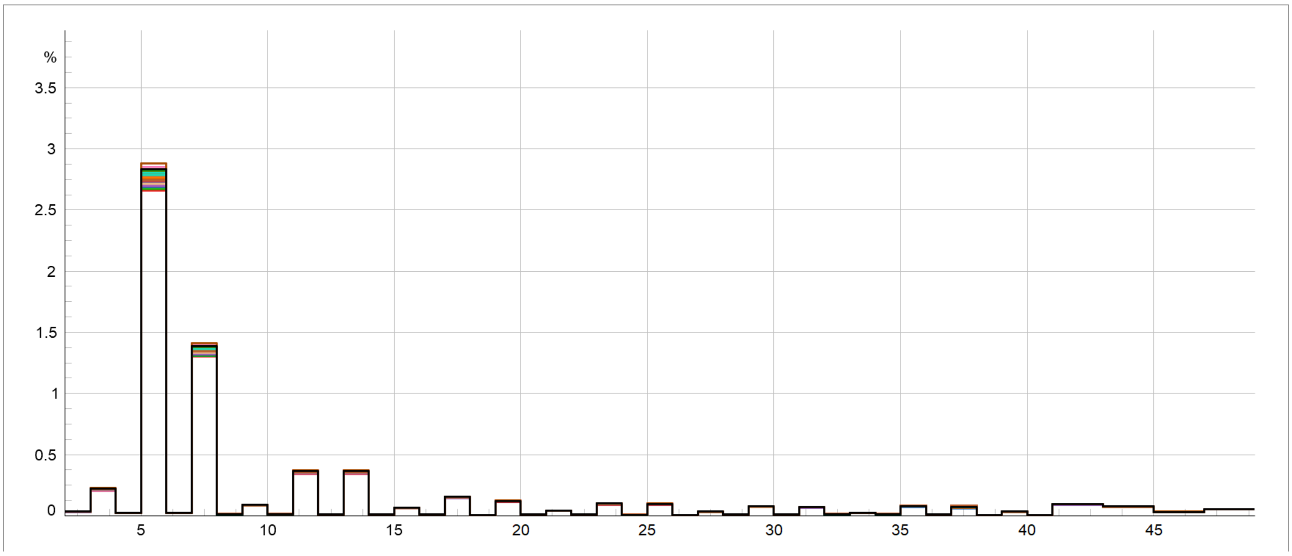

Figure 25 2033 Rural Harmonics Variation

Urban

There is a slight increase in the level of harmonic voltage distortion seen over the length of the circuit in the 2033 study year as the penetration of LCTs increases. However, the change is again not as marked as that seen in the rural example and the levels remain well below the planning levels in EREC G5/5. The range seen in feeder 3 and feeder 4 begins to expand compared to feeder 1 and 2 as the deployment increases as these circuits have slightly higher impedance cables than those modelled in feeders 1 and 2.0

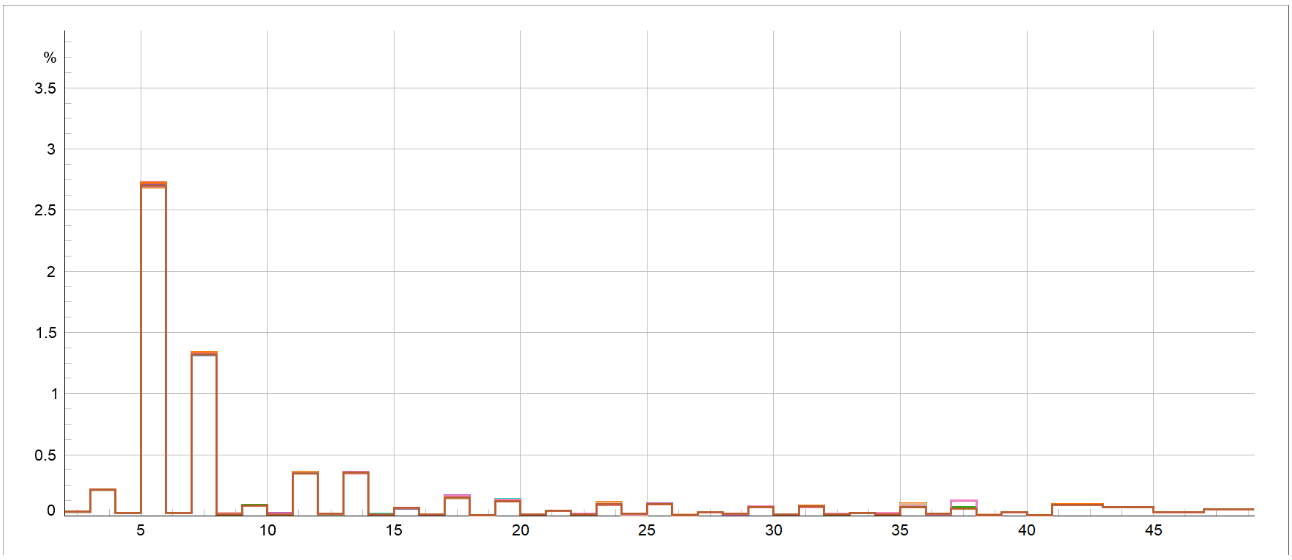

Figure 26 2033 Underground Feeder 1 Harmonics Variation

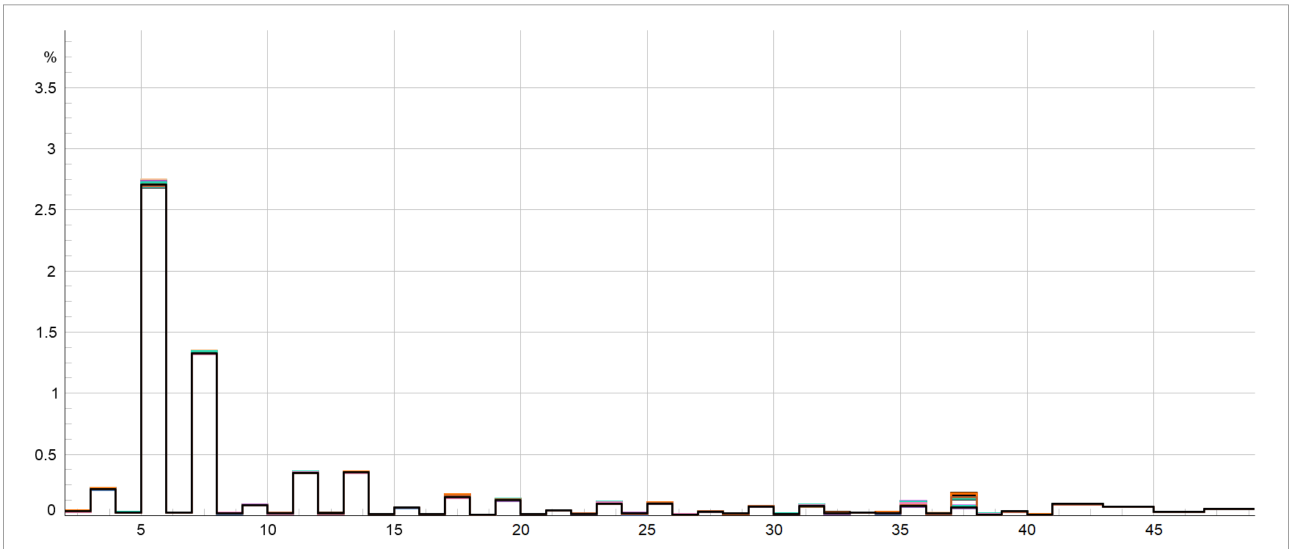

Figure 27 2033 Underground Feeder 2 Harmonics Variation

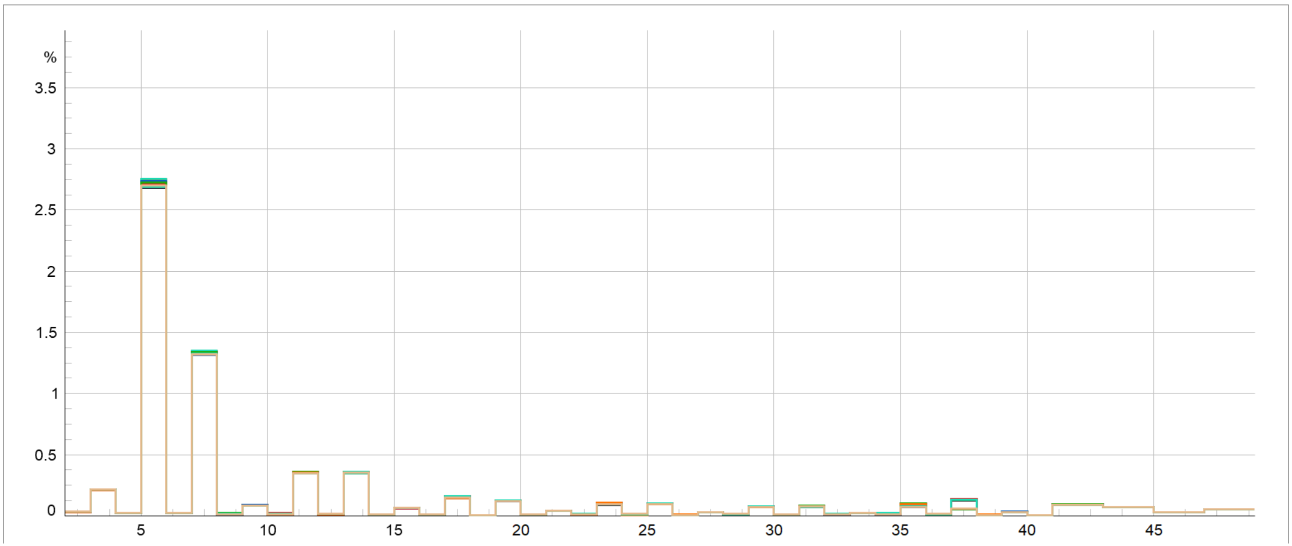

Figure 28 2033 Underground Feeder 3 Harmonics Variation

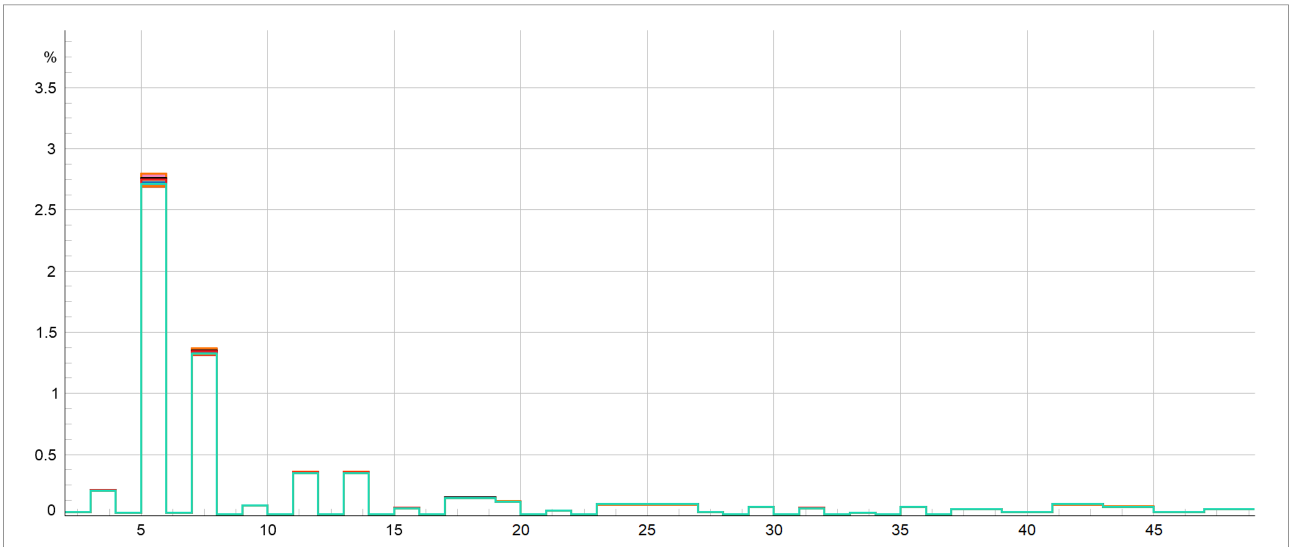

Figure 29 2033 Underground Feeder 4 Harmonics Variation

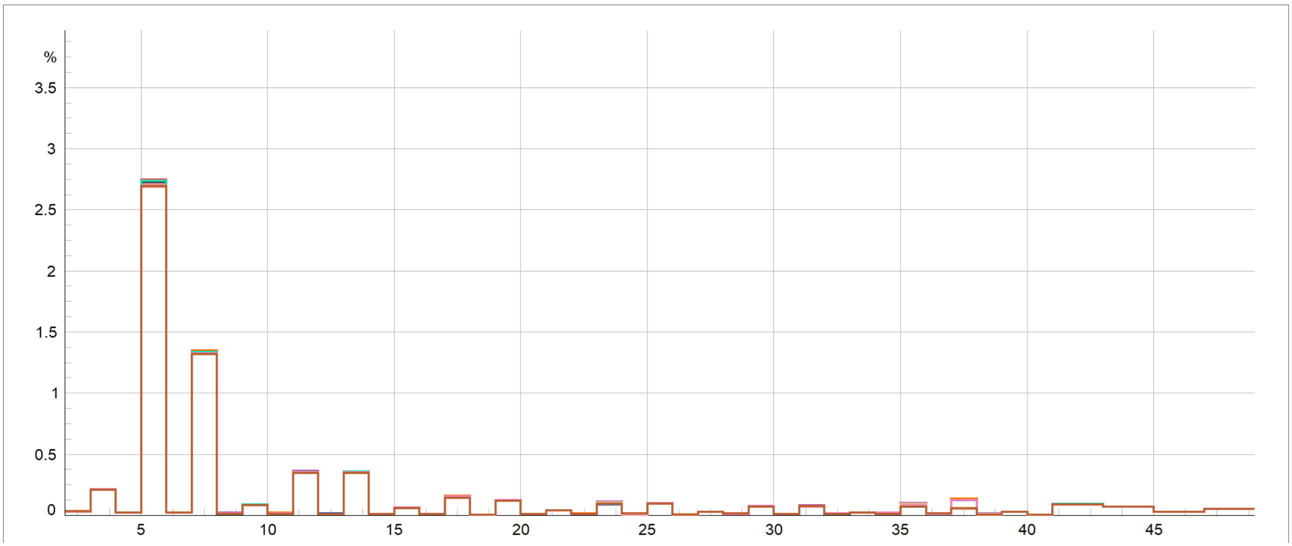

Figure 30 2033 Underground Feeder 5 Harmonics Variation

9.1.3 2040

Rural

The level of harmonic distortion increases further with the increase in penetration of the LCTs in the network, the 5th harmonic remains the dominant harmonic value, but the level is still expected to remain below the planning level in EREC G5/5. In this scenario the 37th harmonic exceeds the both the planning and compatibility levels. However, it should be noted the capacity of the circuits and the reinforced transformer deployed at the start of the studies would be exceeded before this condition would arise. The harmonic distortion studies are based on the deployed LCTs operating at maximum load which leads to the significant overload condition. This lack of diversity in load might perhaps not be considered normal although as is discussed in Section 11.1.2 where incentives drive operation at specific times the normal diversity of load may be lost.

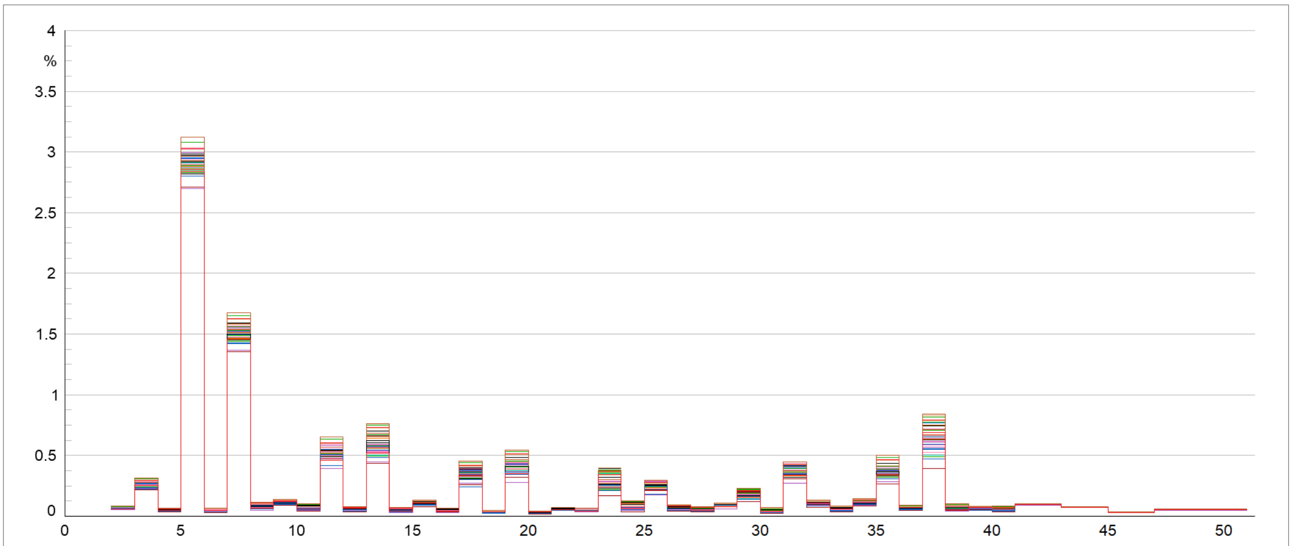

Figure 31 2040 Rural Harmonics Variation

Urban

The range of values of the harmonics for the 2040 scenario increase from the previous scenario with the increased LCT penetration. The range of values increases on feeder 4 compared to feeders 1-3 as the impedance of the half sized neutral cable is greater than the other circuit layouts. As with the rural example circuit we begin to see an increase in the 37th harmonic voltage although in the underground cable scenarios the impedance of the circuits is lower and the corresponding 37th harmonic voltages do not exceed the planning limits.

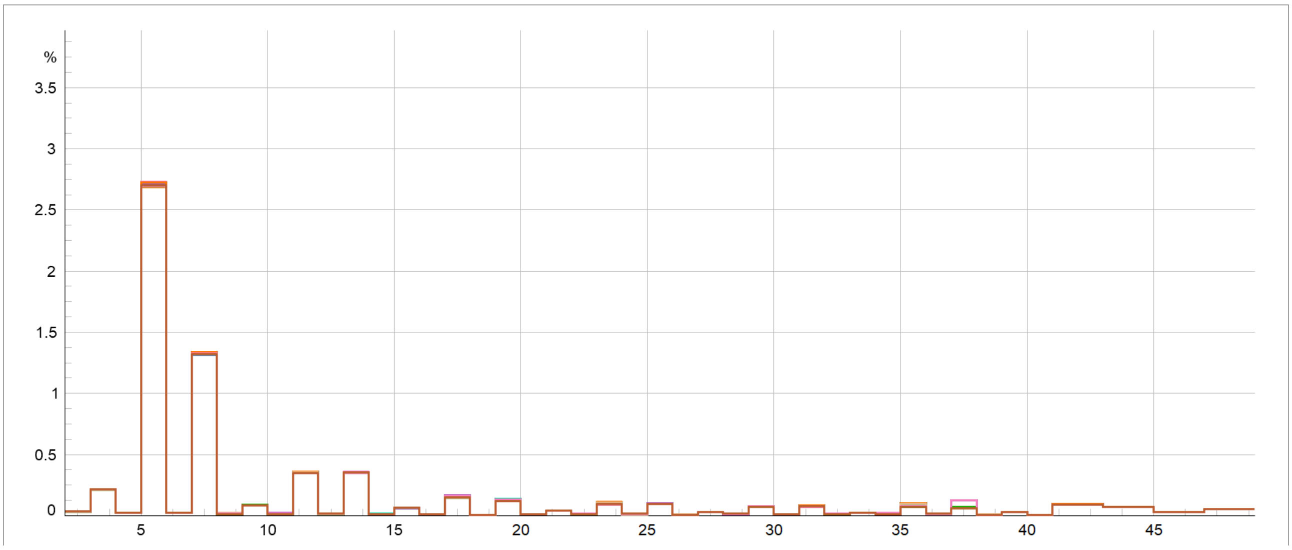

Figure 32 2040 Underground Feeder 1 Harmonics Variation

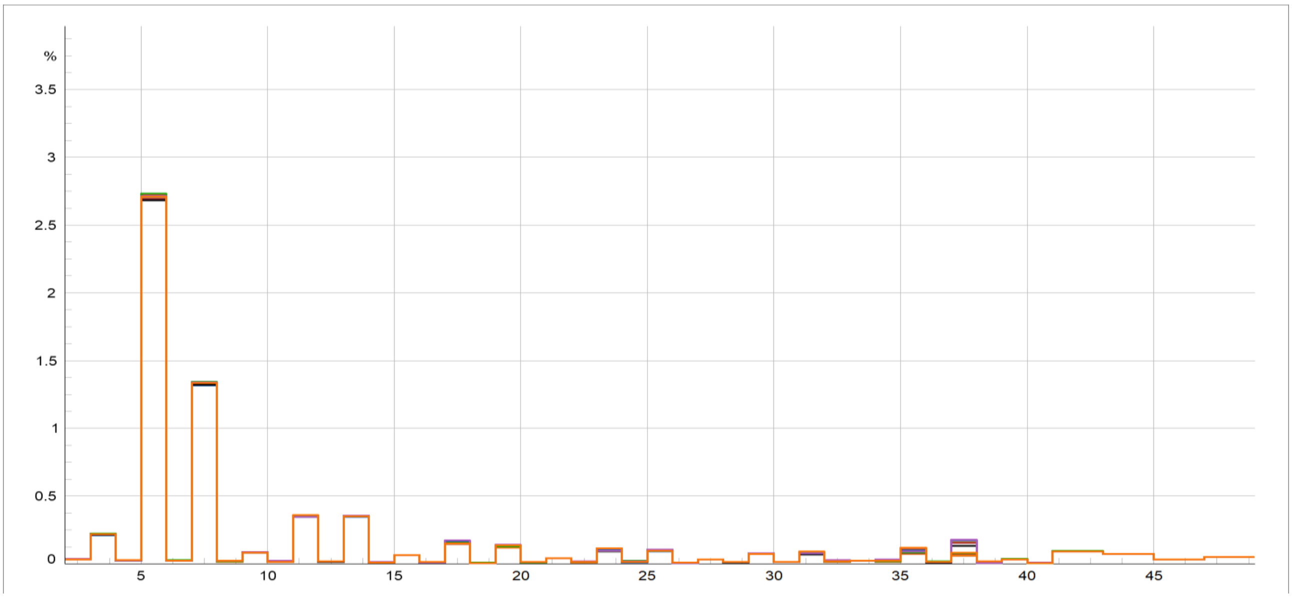

Figure 33 2040 Underground Feeder 2 Harmonics Variation

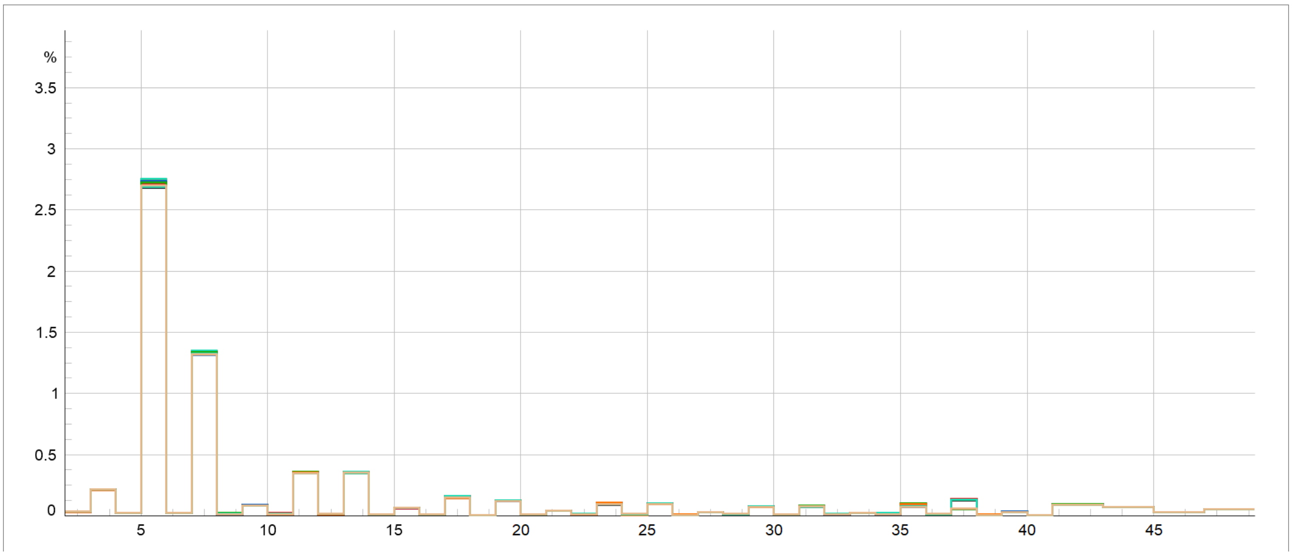

Figure 34 2040 Underground Feeder 3 Harmonics Variation

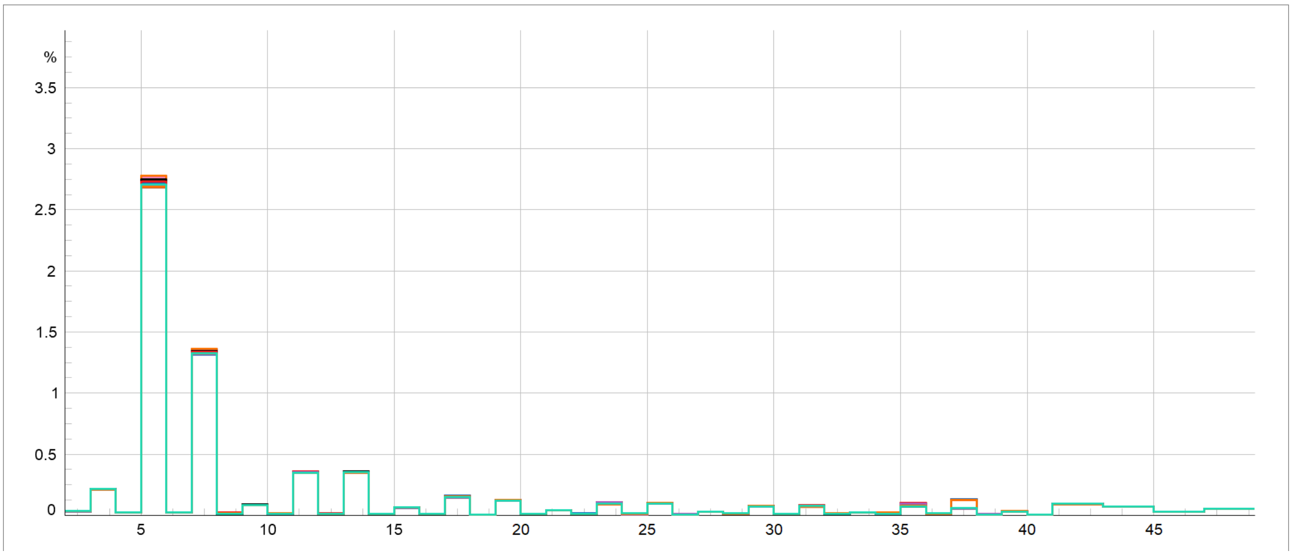

Figure 35 2040 Underground Feeder 4 Harmonics Variation

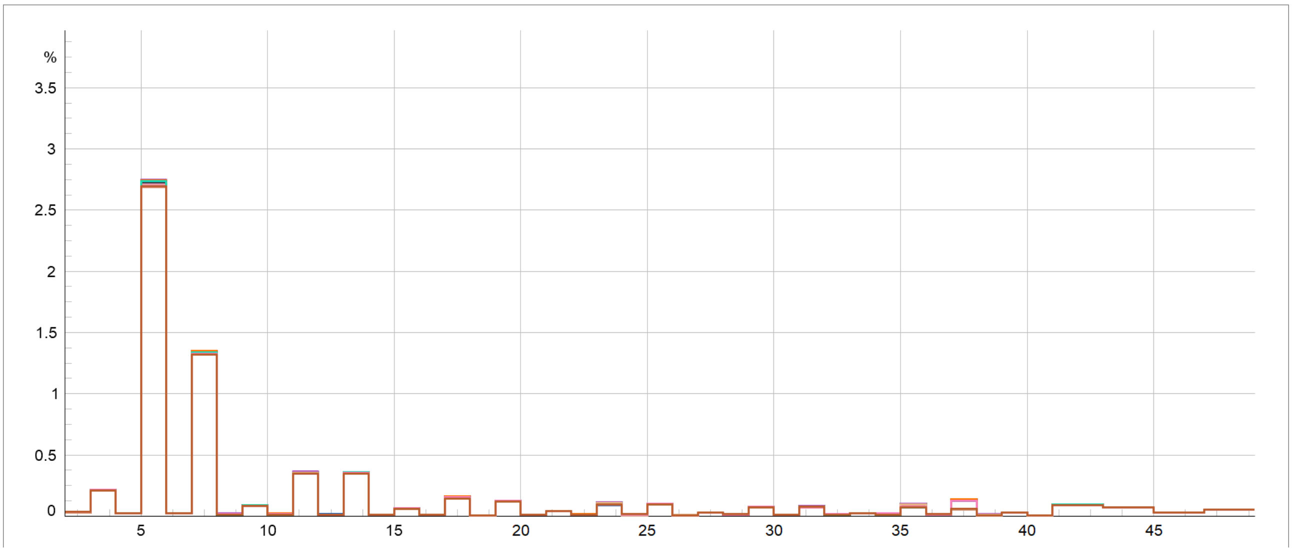

Figure 36 2040 Underground Feeder 5 Harmonics Variation

9.1.4 2050

Rural

The level of harmonic distortion remains very similar to that seen in the 2040 study year for the majority of the harmonic orders remaining well below the EREC G5/5 planning levels. The most significant difference is the 37th harmonic where the voltage harmonic returns below the planning limits. The most significant difference between the 2040 study year and the 2050 study is the deployment of PV within the network increases, even though this is a winter study, and the PV output is modelled at a reduced level the reduction in overall loading appears to have had a beneficial effect on the 37th harmonic voltage level.

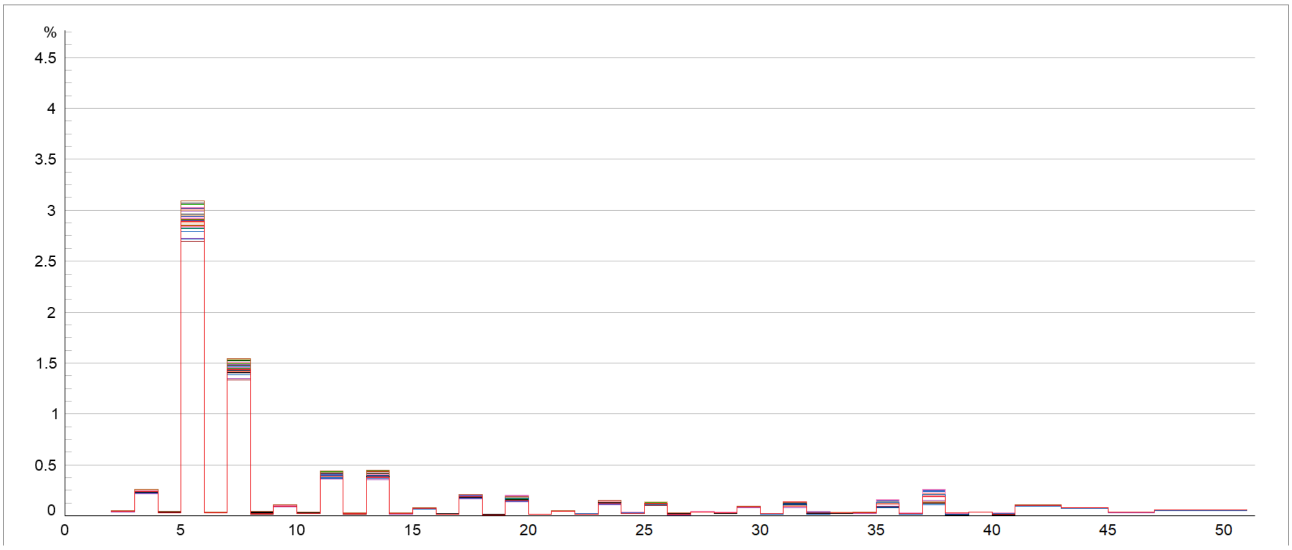

Figure 37 2050 Rural Harmonics Variation

Urban

The urban harmonic load flow studies could not be carried out because the initial load flow studies will not converge because the loading applicable under the 2050 LCT deployment scenarios significantly exceeds the capabilities of the LV network and the initial load flow studies will not converge preventing the harmonic load flow analysis from completing.

10. Summer Studies

10.1 Harmonic Effects

The effects of the increasing deployment of LCTs are highlighted in the following sections. The plots shown within the body of the report illustrate the variation of each individual harmonic over each feeder for each of the study years. The harmonics at the source and at the remote ends of the network and branches are shown in Appendix I and Appendix II for Rural and Urban results respectively.

10.1.1 2028

Rural

The increase in harmonics due to the initial deployment LCTs on the rural circuit is shown in Figure 19 below. The harmonics at the ends of the feeder increase but remain well within the planning levels set out in G5/5.

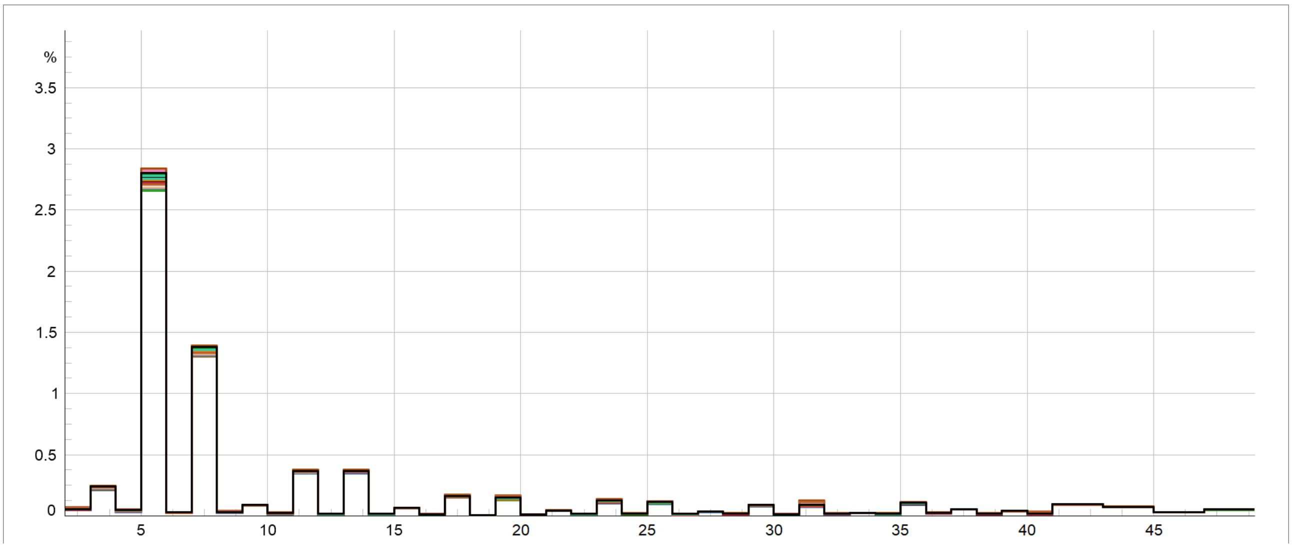

Figure 38 2028 Rural Harmonics – Harmonics Variation

Urban

Even though the number of customers per feeder is very similar between the underground feeders and the overhead feeder and consequently the penetration of LCTs has been essentially the same as shown in Tables 1-3. The effect on the increase in harmonic distortion in the underground networks is smaller than seen in the rural example, this is due to the lower impedance of the underground cables forming the mains and branches in the example underground circuits compared to the overhead circuits in the rural example.

Figure 39 – 43 show the variation of each harmonic over the length of the circuit for the first study year.

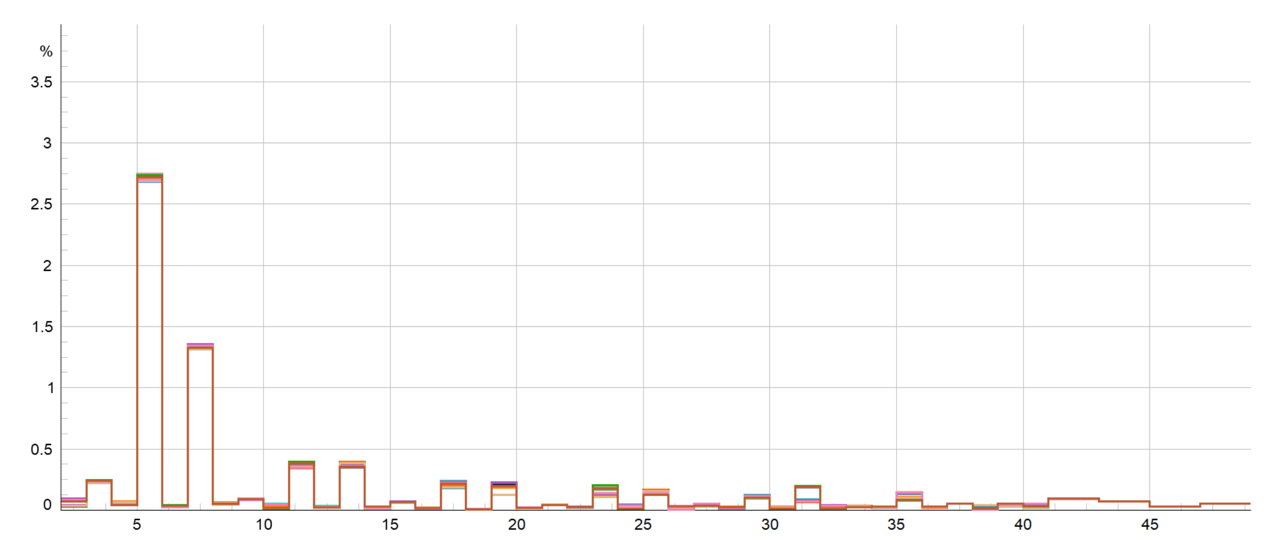

Figure 39 2028 Underground Feeder 1 Harmonics Variation

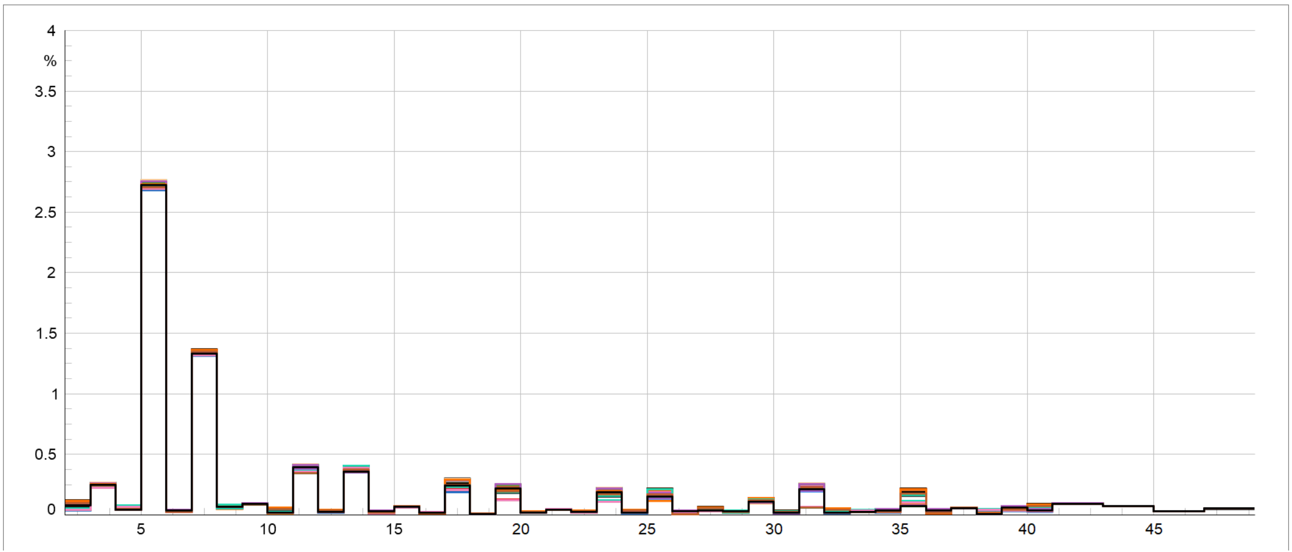

Figure 40 2028 Underground Feeder 2 Harmonics Variation

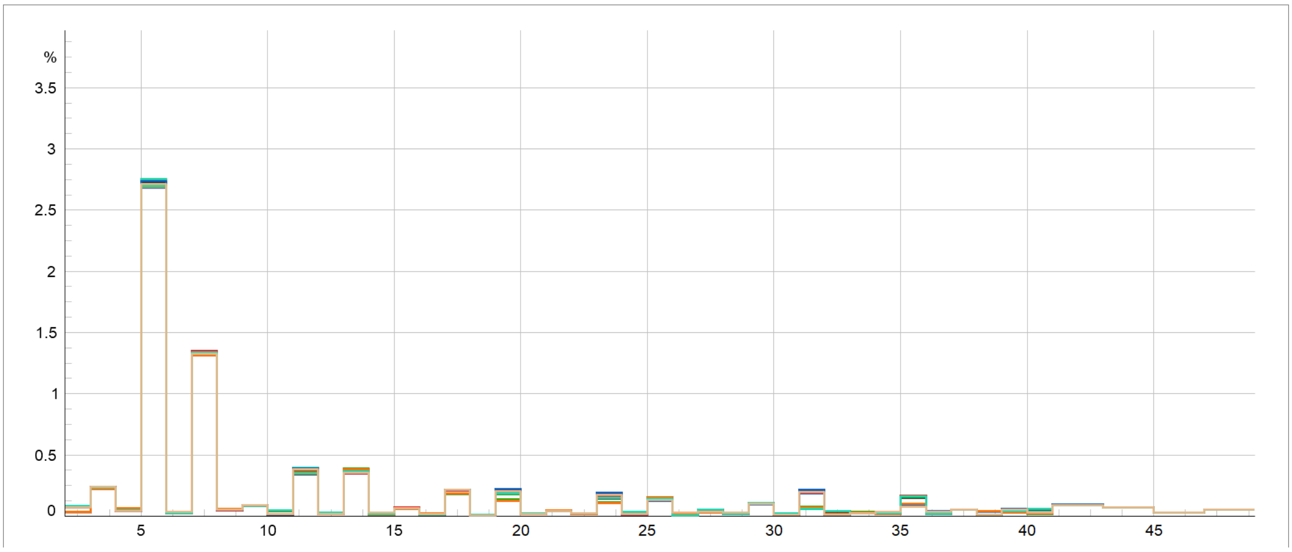

Figure 41 2028 Underground Feeder 3 Harmonics Variation

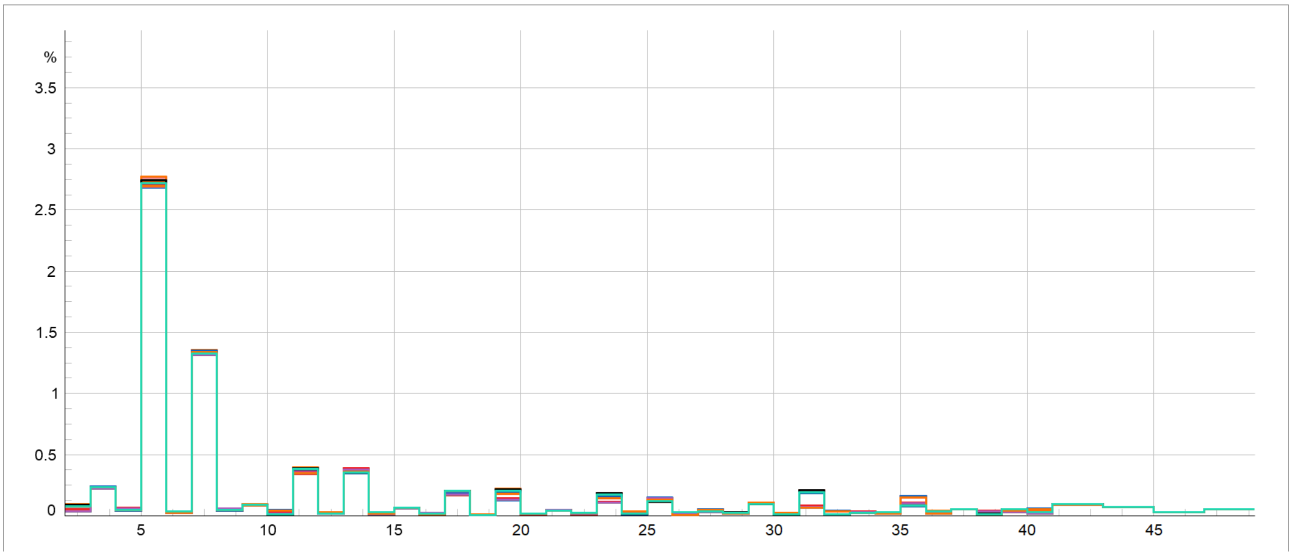

Figure 42 2028 Underground Feeder 4 Harmonics Variation

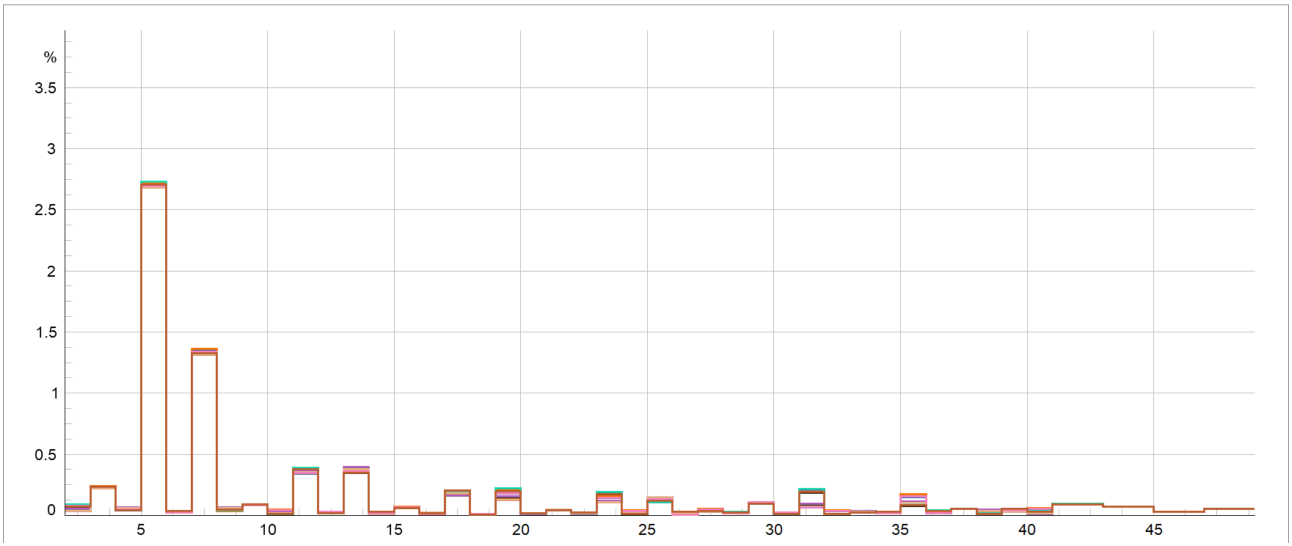

Figure 43 2028 Underground Feeder 5 Harmonics Variation

10.1.2 2033

Rural

The increased level of LCTs expected in 2033 under the scenario modelled raises the level of harmonic distortion at the remote end of the feeder, again the 5th harmonic is the dominant harmonic value but still; remains well below the planning level in EREC G5/5

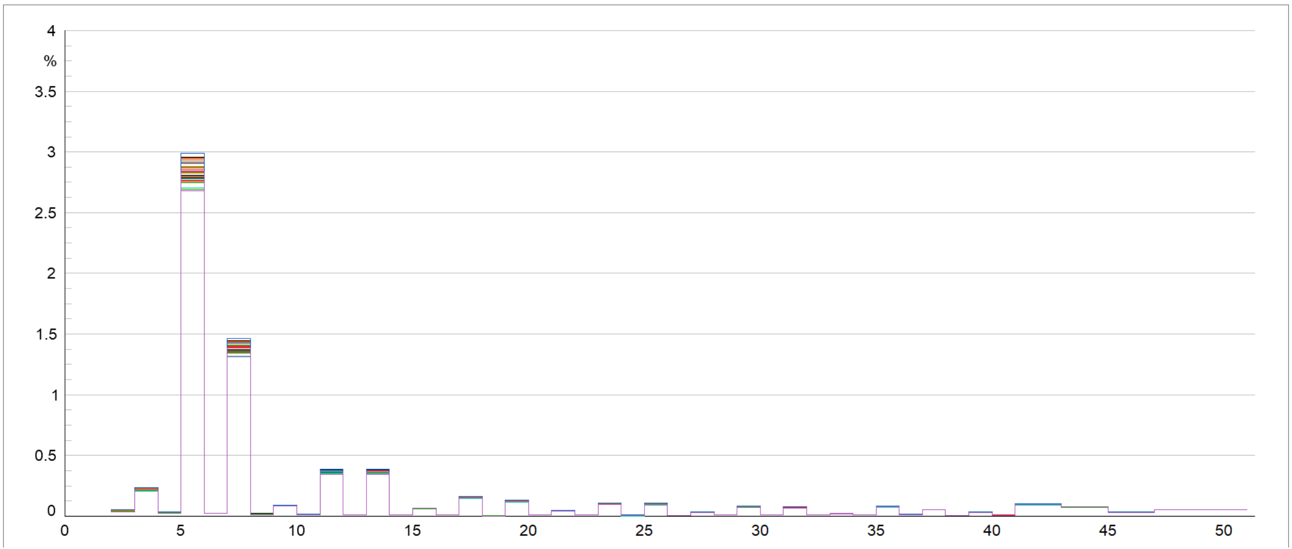

Figure 44 2033 Rural Harmonics Variation

Urban

There is a slight increase in the level of harmonic voltage distortion seen over the length of the circuit in the 2033 study year as the penetration of LCTs increases. However, the change is again not as marked as that seen in the rural example and the levels remain well below the planning levels in EREC G5/5

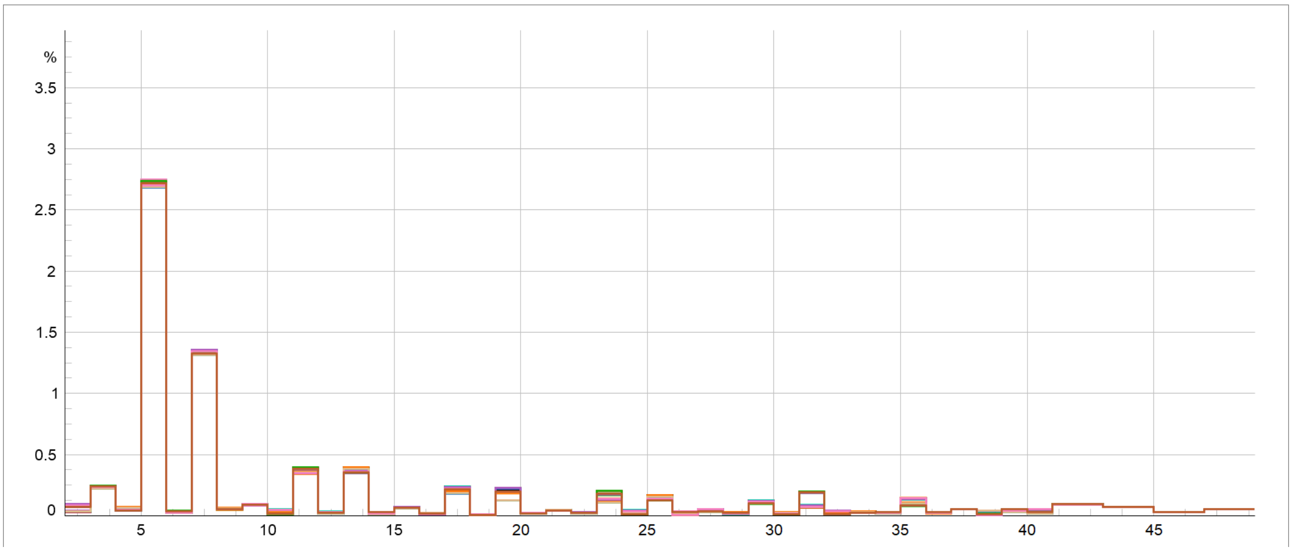

Figure 45 2033 Underground Feeder 1 Harmonics Variation

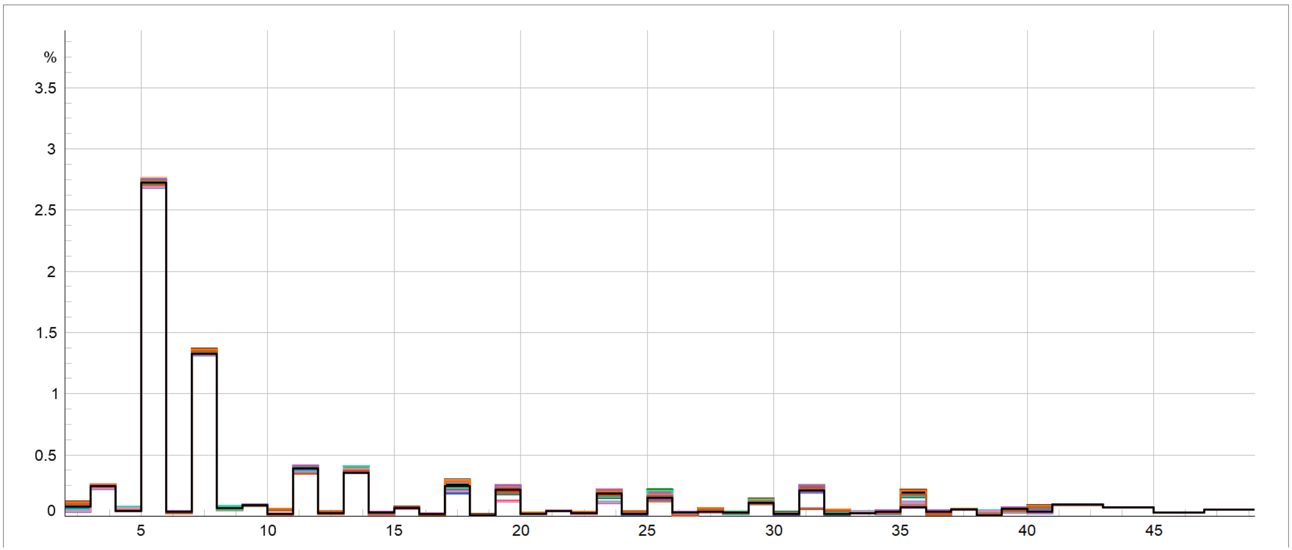

Figure 46 2033 Underground Feeder 2 Harmonics Variation

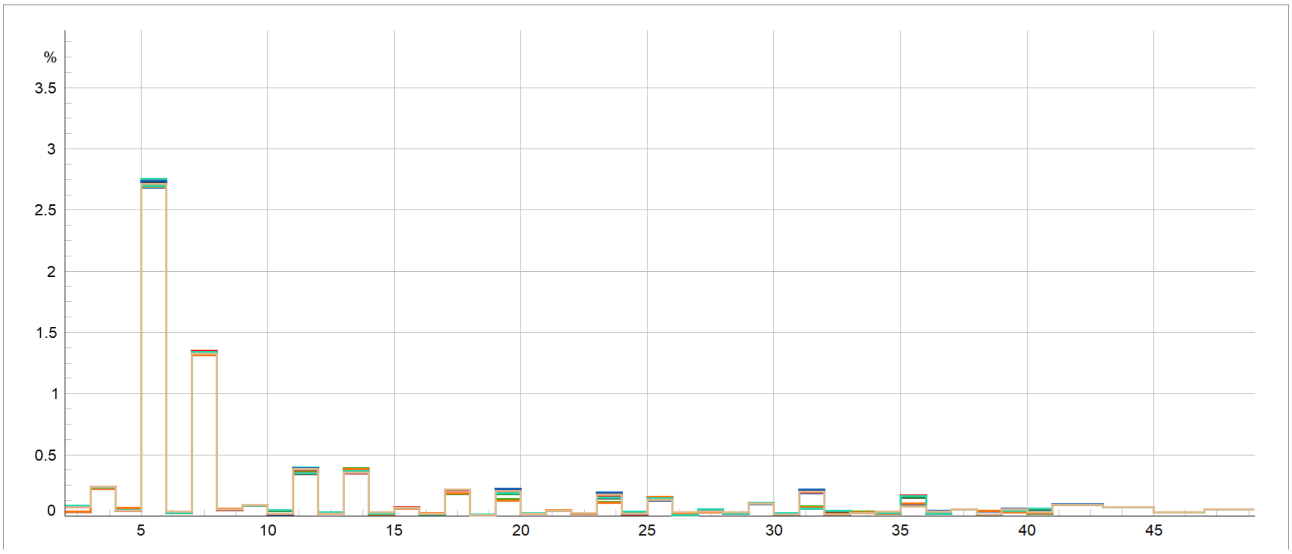

Figure 47 2033 Underground Feeder 3 Harmonics Variation

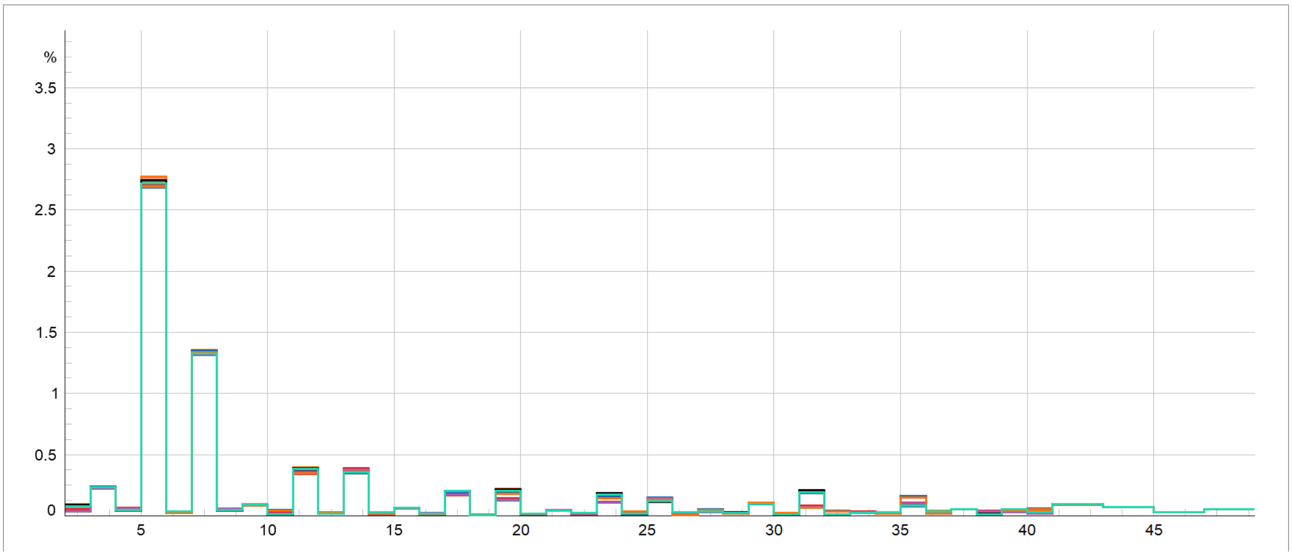

Figure 48 2033 Underground Feeder 4 Harmonics Variation

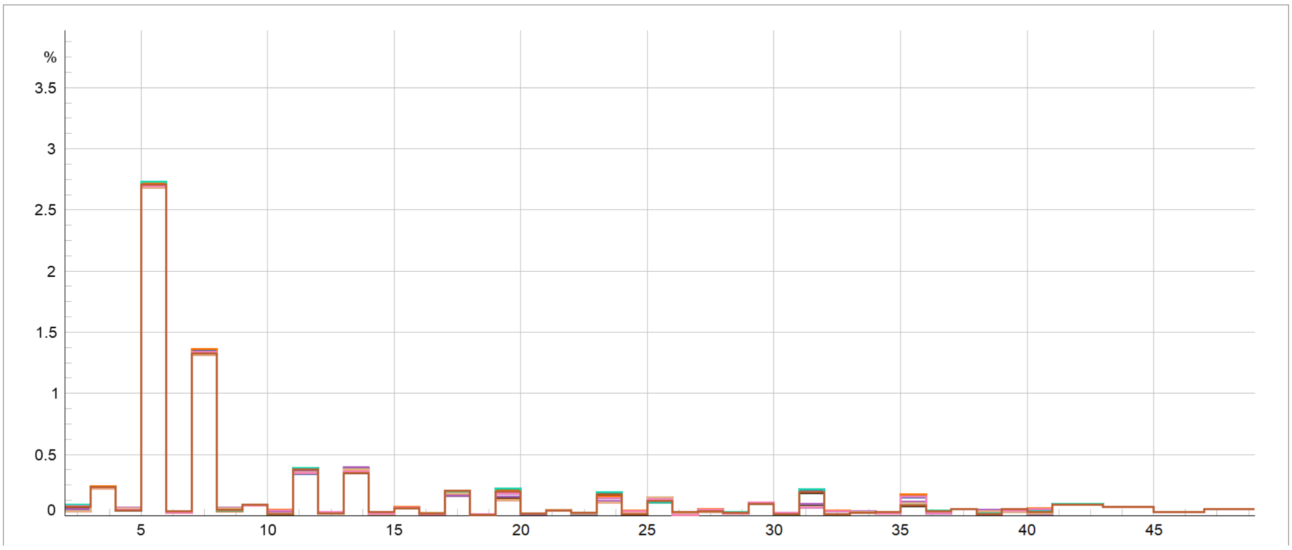

Figure 49 2033 Underground Feeder 5 Harmonics Variation

10.1.3 2040

Rural

The level of harmonic distortion increases further with the increase in penetration of the LCTs in the network, the 5th harmonic remains the dominant harmonic value, but the level is still expected to remain below the planning level in EREC G5/5. In this study scenario the output of the PV is assumed to be at the rating rather than at the reduced level seen in the winter studies, the effect of this increased output is similar to that seen in the 2050 rural winter study where the increased deployment of PV resulted in a lower level of 37th harmonic voltage.

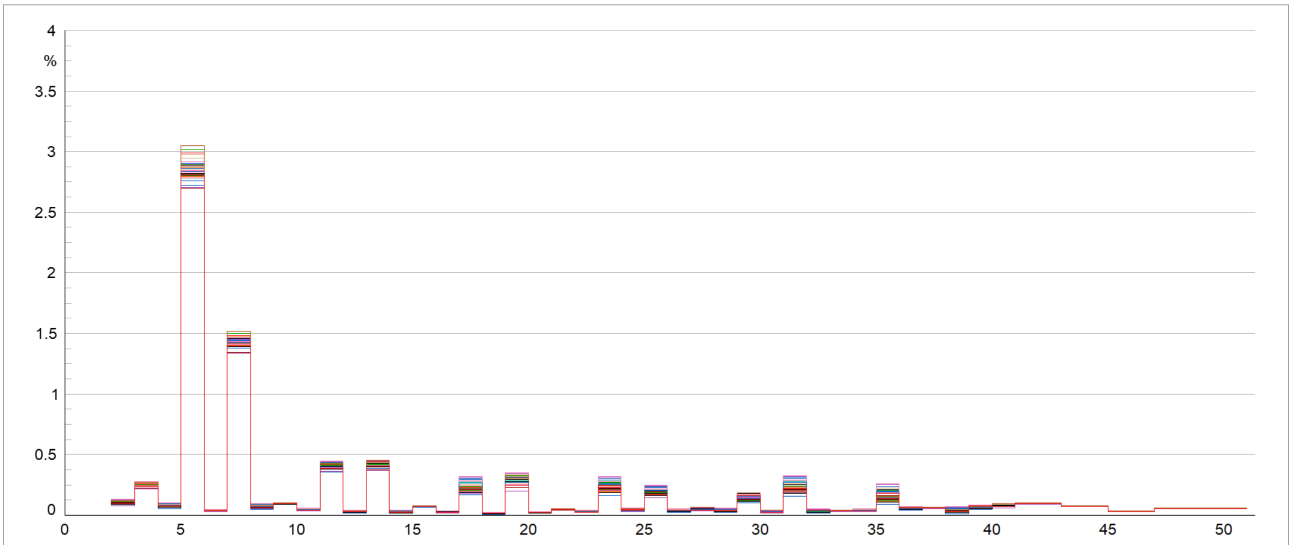

Figure 50 2040 Rural Harmonics Variation

Urban

The range of values of the harmonics for the 2040 scenario increase from the previous scenario with the increased LCT penetration. The range of values increases on feeder 4 compared to feeders 1-3 as the impedance of the half sized neutral cable is greater than the other circuit layouts.

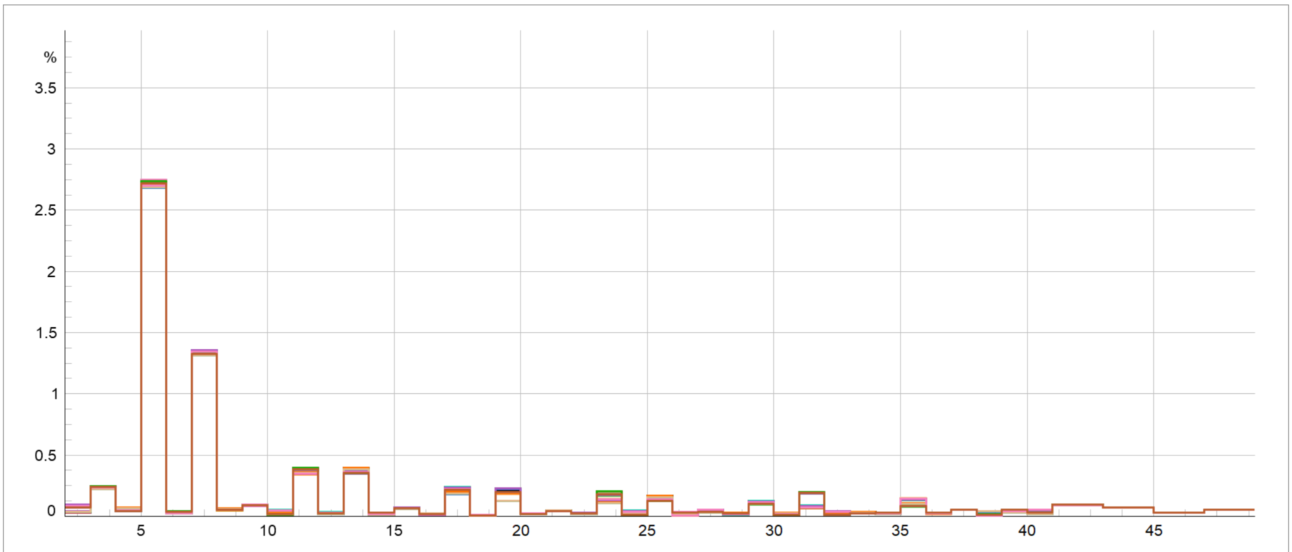

Figure 51 2040 Underground Feeder 1 Harmonics Variation

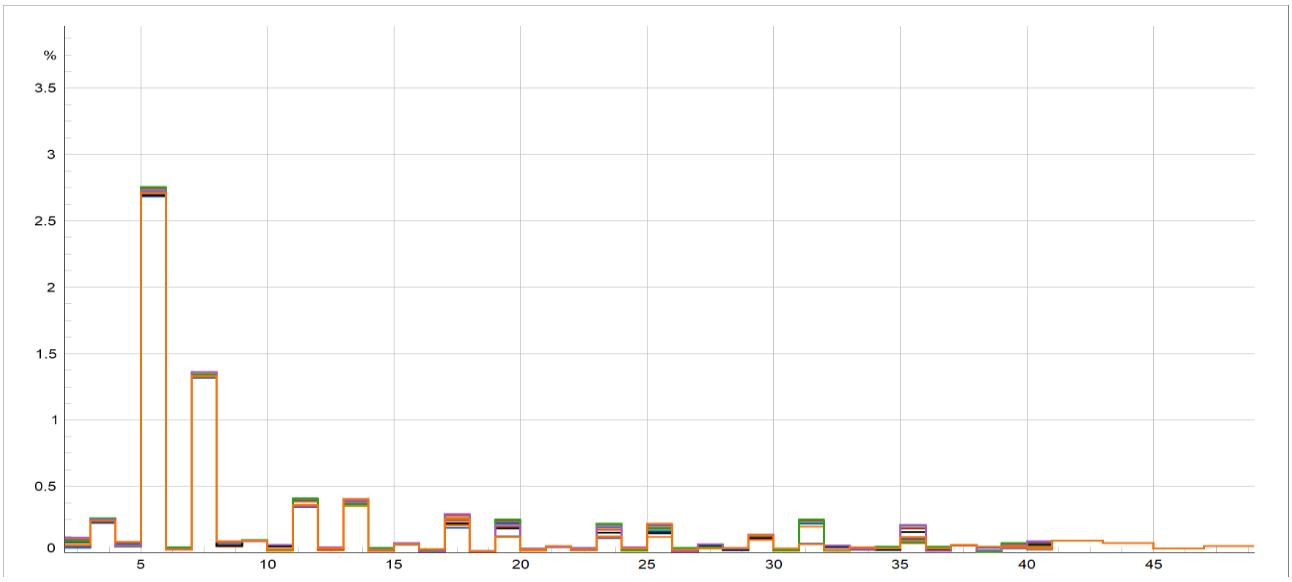

Figure 52 2040 Underground Feeder 2 Harmonics Variation

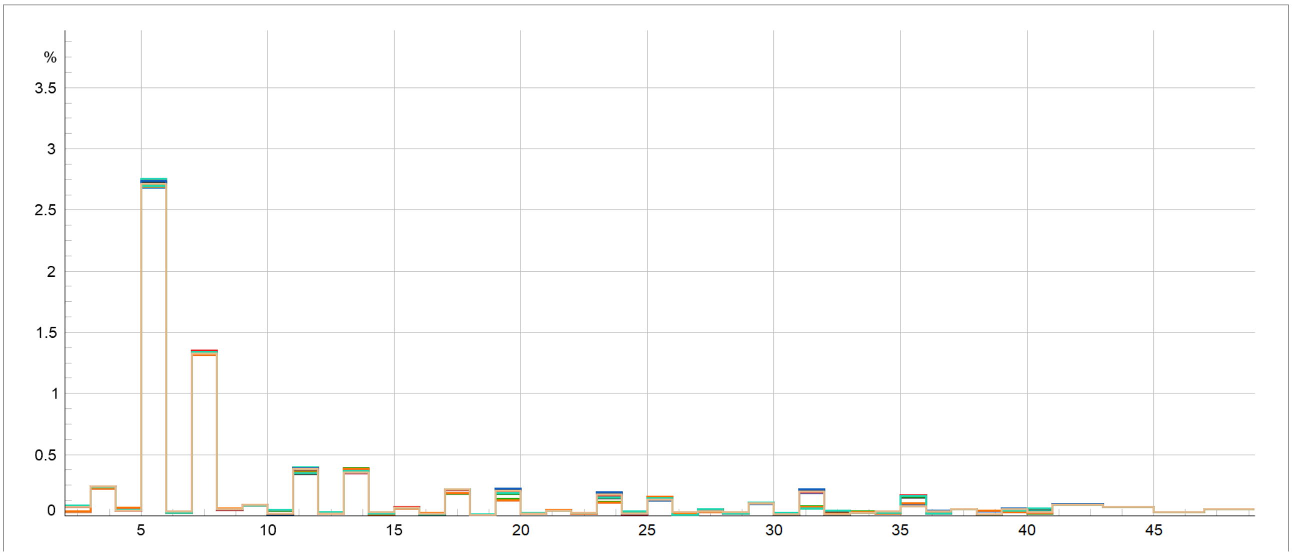

Figure 53 2040 Underground Feeder 3 Harmonics Variation

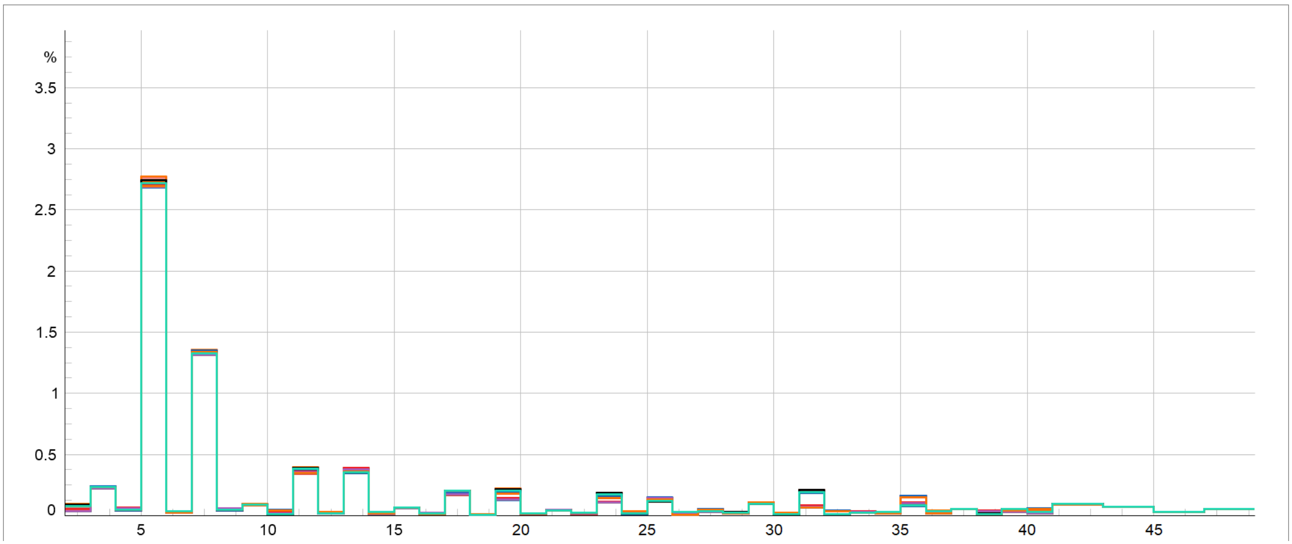

Figure 54 2040 Underground Feeder 4 Harmonics Variation

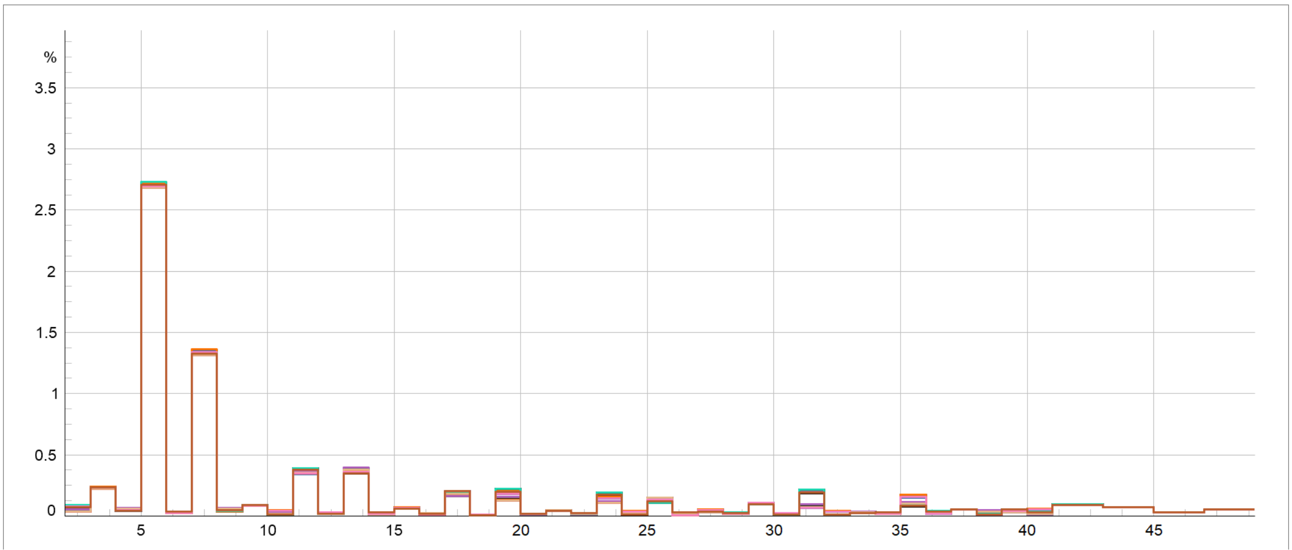

Figure 55 2040 Underground Feeder 5 Harmonics Variation

10.1.4 2050

Rural

The level of harmonic distortion remains very similar to that seen in the 2040 study year remaining well below the EREC G5/5 planning levels. The range of individual harmonic values increases compared to the 2040 LCT deployment scenarios, the maximum value of each harmonic is below the planning limits in ER G5/5.

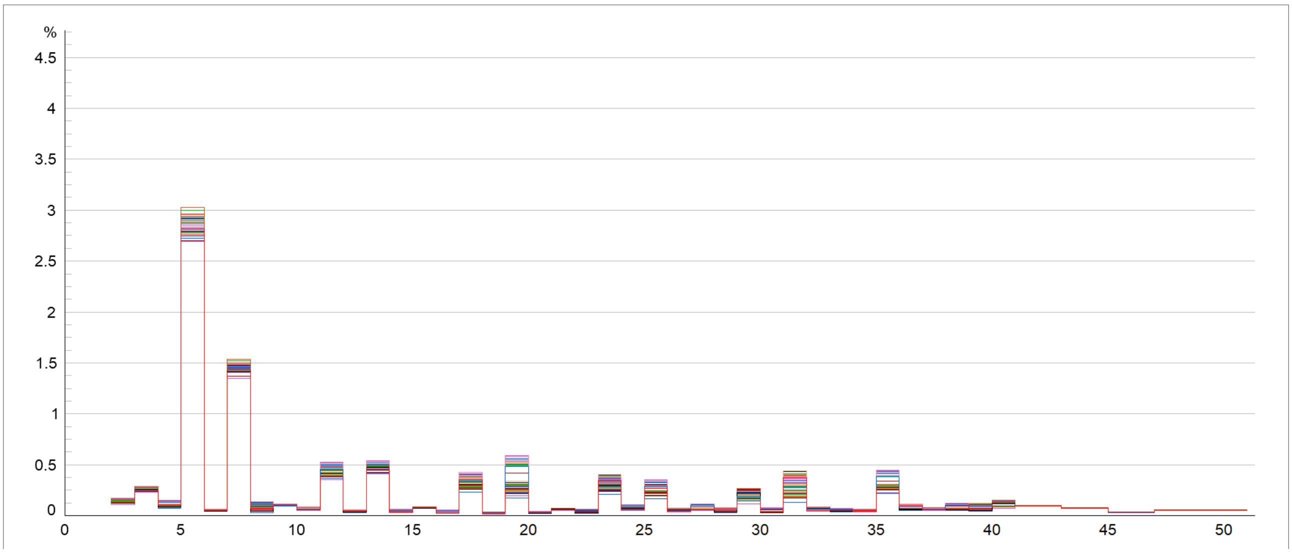

Figure 56 2050 Rural Harmonics Variation

Urban

The urban harmonic load flow studies could not be carried out because the initial load flow studies will not converge because the loading applicable under the 2050 LCT deployment scenarios significantly exceeds the capabilities of the LV network.

11. Implications of increased LCT penetration

11.1 Loading effects

The typical LV domestic network is designed using a value of demand for each connected customer known as the After Diversity Maximum Demand (ADMD) with total demand expected usually calculated as nA +P where n is the number of connected customers, A is the ADMD value and P an addition to allow for loss of diversity when n is low. Typical values for A and P are 2.5kW and 8kW respectively. The new LCT loads will in normal operation exhibit some natural diversity of their own. However, these additional loads still represent a significant increase in electrical demand compared to the previous value used to initially design the networks and to consider any additions/changes made since their initial installation. The nature of these loads is such that they tend to be at their peak demand for longer periods when compared to other high load devices in the domestic setting such as electric showers and cooking appliances.

The studies have shown that the increase in harmonic distortion arising from the increased penetration of the LCTs does not appear to be the limiting factor for the capacity of the network to absorb this additional load. Rather the thermal capacity of the network is reached before the individual and aggregate levels of harmonic voltage distortion will typically be exceeded. In many ways this is a reflection on the success of the electromagnetic compatibility standards in controlling the emissions of harmonic generating equipment. The market acceptance of these LCTs is in part affected by the ease of connection, were the emissions to be of such a level that the LCT would fall into the conditional connection category the additional work required to assess each new connection would be a considerable burden on the network operators and result in longer times to get connected.

The rate of penetration and the number of customers connected to a circuit will affect the time at which reinforcement or other mitigation may be required and additional monitoring applied to each LV circuit may need to be considered to identify when the thermal capacity of the individual networks is being compromised.

11.1.1 Uncontrolled usage

In a completely uncontrolled scenario, the charging patterns for EVs might be expected to be similar in that customers will most likely connect their car to the charger when they return home at the end of the day although not necessarily every day as typical usage patterns would not require daily charging as the battery would not be close to fully discharged. In this way some natural diversity is achieved between individual users and a diverse value can be used to assess the likely demand placed on the network.

However, even allowing for diversity it must be expected that network demand will significantly increase, average miles per year of 10,000 and around 3.5 mile per kWh would suggest that for a single EV a household demand would increase by around 2800 kWh almost doubling, similarly heat pump demand with a coefficient of performance of 4 would add another 2500kWh for the typical property.

11.1.2 Effect of Tariffs

A number of suppliers are offering tariffs which incentivise use at particular times of the day when demand might otherwise be expected to be lower than the available supply. The effects of these tariffs must inevitably reduce the level of diversity that would otherwise be expected across the customers. Tariffs which encourage the use of load types which typically have a higher magnitude and a longer expected duration than other types of loads in the domestic environment will reduce the level of diversity that can be applied to them during such periods and would be expected to lead to higher levels of maximum demand.

11.2 Existing Policy

Based on the outcomes of previous projects NGED have already put in place a design policy for all new domestic networks that the customers supply loop impedance will not exceed 0.144Ω for entirely underground circuits and 0.245Ω for circuit including overhead conductors. These values which are lower than the typical maximum previously assumed across the industry will ameliorate the feeder voltage rise conditions anticipated when PV output is at its highest with little local load to utilise the exported energy as well as reducing the voltage drop effects under maximum load conditions which may be expected when the penetration of EV charging, and Heat Pumps increases. Having a limit on the impedance for the customer connection will also necessarily further limit the impact of harmonics on the network as it must result in either a reduction in circuit length and therefore the number of customers that can be served along the route or an increase in the size of the of the main circuit conductors.

Given the potential advantages offered and the expectation that thermal capacity will likely be the limiting factor in the future with increased deployment of LCTs the continued use of this policy appears to be reasonable.

12. Conclusions

The main conclusions of the report are:

C1. The effect of the harmonic emissions associated with Low Carbon Technologies does not appear to be the limiting factor affecting the penetration into the Low Voltage networks before problems may be expected.

C2. Although there will be diversity between individual loads as the penetration increases it is inevitable that the maximum demand applied to the network will be significantly increased and this will affect the assets.

C3. The limiting factor in accepting the widespread deployment of these new Low Carbon Technologies will be the thermal capacity of elements of the network, whether that begins with a need to increase transformer capacity to reinforce the network or to employ demand controls.

C4. Some means may be required to balance the effects of energy tariff incentives which drive higher consumption during specific periods which may have negative impacts on network assets.

C5. As these types of LCT are typically designed so that they are not subject to conditional connection which has the beneficial effect of minimising the increasing in harmonic distortion greater visibility of the loading on individual LV feeders may be necessary to allow the necessary interventions to be planned ahead of requirement.

C6. There was an example on the rural circuit where the 37th harmonic exceeded both the planning and compatibility limits in the 2040 study year. However, this condition only arose after the total load had exceeded the rating of the transformer and even more severely exceeded the rating of the first leg of the feeder from the transformer.

C7. The continued use of the limits for supply impedance described in NGED Policy Document SD5 appears to be a reasonable mitigation measure which will ameliorate some of the potential issues identified in the SILVERSMITH project and limit the harmonic effects.

13. Recommendations

The main recommendation of this report is:

R1. Greater visibility of loading on individual LV feeders should be considered to detect the approach of thermal capacity issues.

14. References

BS EN 50160 – Voltage characteristics of electricity supplied by public electricity networks

IEC 61000-2-2 – Electromagnetic Compatibility (EMC) Part 2-2: Environment – Compatibility levels for low frequency conducted disturbances and signalling in public low-voltage power supply systems

Energy Networks Association Engineering Recommendation G5/5 – Harmonic voltage distortion and the connection of harmonic sources and/or resonant plant to transmission systems and distribution networks in the United Kingdom

SILVERSMITH project report EA16143 TR3 – PowerFactory network study results

SILVERSMITH project report EA 16143 TR5 – Load flow analysis of novel solutions

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