Energy Networks Innovation Process

Annual Project Progress Form

Notes on Completion: Please refer to the NIA Governance Document to assist in the completion of this form.
Do not use tables

Step 1 - Initial Project Details

Project Title

LCT Harmonic Limits

Project Reference

NGED_NIA_075

Nominated Project Contact(s)

jlynch@nationalgrid.co.uk

Project Start Date

05/24

Project End Date

05/25

Scope (15000 Characters max)

In 2016, National Grid Electricity Distribution (NGED), formerly Western Power Distribution (WPD), undertook a Network Innovation Allowance (NIA) project that sought to identify the 'emissions' that are generated through the charging cycle of Electric Vehicles (EVs). These emissions came in the form of generated harmonics over a range of vehicle manufacturers that were captured at the Millbrook testing facility.

Although the project led to the creation of WPD / NGED standard techniques and policy, these documents do not account for the inclusion of heat pumps and other Low Carbon Technologies (LCTs) in addition to differing geographical networks such as those seen in an urban and rural environment.

The purpose of the LCT Harmonics project is to refine and further explore this area by calculating the maximum number of electric vehicles and heat pumps that can be connected to the network before harmonic limits are exceeded. This includes both rural and urban models and will contain analysis for various proportions of LCTs and placements along the feeder of the network.

The LCT Harmonic Limits Project is building upon the findings of the Electric Vehicle Emission project, and provide maximum connection information for both EVs and Heat Pumps (HPs) combined. Specifically, the maximum number of EV and HP that can be connected on a model-rural and model-urban network will be determined, with the process exploring the sensitivity of the results to:

- Clustering of EV and HP along the feeder. As per the previous study, there will be an investigation into a random distribution and an evenly spread distribution of LCT along the feeder.
- Different proportions of EV and HP within the overall LCT penetration. This will study the effect of differing percentages of EV compared to HP to understand the network impact depending on the weighting of a certain LCT.
- Background emissions already existing on the network.
- Variation of charging diversity. Economy 7 tariffs were traditionally used in the past for EV charging but current Time of Use (ToU) tariffs offer shorter charging windows resulting in more frequent charging per week for a customer.
- The simultaneous harmonic current export from the LCT connected to the feeder based on nominated assumptions about the

Objective (15000 Characters max)

1. Comprehensive network studies are carried out that identify the maximum number of LCTs that can be connected to an urban LV network during winter and summer periods.
2. Comprehensive network studies are carried out that identify the maximum number of LCTs that can be connected to a rural LV network during winter and summer periods.
3. Capture sufficient background harmonic measurements from real life networks
4. Determine the Maximum and Minimum allowable source impedance
5. Outputs of deliverables inform and update current NGED design practices and policies.

Success Criteria (15000 Characters max)

1. Rural and Urban Models designed that are an accurate representation of those seen on NGED's network.
2. Comprehensive network studies are carried out that identify the maximum number of diversified LCTs that can be connected to an urban LV network during winter and summer periods.
3. Comprehensive network studies are carried out that identify the maximum number of diversified LCTs that can be connected to a rural LV network during winter and summer periods.
4. Maximum and Minimum source impedance identified.
5. Outputs of deliverables inform and update current NGED design practices and policies.

Step 2 - Performance Outcomes

Performance Compared to Original Project Aims, Objectives and Success Criteria

Details of how the Project is investigating/solving the issue described in the NIA Project Registration Pro-forma. Details of how the Project is performing/performed relative to its aims, objectives and success criteria. (15000 Characters max)

The following sections outline the overall performance compared to the project's aims and original objectives with detailed commentary surrounding some of the key areas that have generated learning and relevant outputs for the project.

Data Access (applicable to objective 3)

Gaining and accessing harmonic data for various LCTs was the first hurdle that the project faced. Harmonic source data was needed for several LCTs that included Electric Vehicles, Heat Pumps and Photovoltaic (PV) and Battery Energy Storage Systems (BESS) technologies).

For EVs, the harmonic data was obtained from a previous project that assessed power quality from EVs, a project that namely EV Emissions testing, formerly WPD (now National Grid Electricity Distribution).

For heat pumps, we engaged and collaborated with Scottish and Southern Energy Networks and Threepwood Consultancy as their NIA project, Low Voltage Power Quality (LVPQ) was utilising harmonic heat pump profiles for their project themselves.

Model Build (applicable to objective 1 & 2).

In order to understand the impact LCTs had on our network, we firstly needed network models that could be used as a basis for analysis. The project team created a set of network models that were representative and could serve as a solid foundation to what is seen on a typical network. The modelling environment was chosen as DIgSILENT PowerFactory. The thought process was to produce both rural and urban models that incorporated numerous cable types and customer numbers. Five archetypes were designed for the urban model that represented different types of networks we usually see in a 'real' life network. These were:

- Feeder 1 – CNE Main 300sqmm – 240sqmm new development
- Feeder 2 – Tapered PILC
- Feeder 3 – Half Size Neutral PILC
- Feeder 4 – CNE Main 300sqmm – 240sqmm existing housing stock
- Feeder 5 – Overlaid CNE main picking up old main as branches.

For the rural substation we had to consider the larger end of the capacity to see changes as the penetration increases, with small customer numbers the number of combinations will be too limited. For this analysis NGED have suggested the use of a specific example substation as the source for a model Springers Hill 161806. Larger and/or older houses might be typical of these types of network tending to require a larger capacity heat pump. More affluent areas might be expected to see more rapid uptake of EVs etc. so this was considered with the DFES assumptions used. The DFES scenario and years used for modelling was "leading the way" for 2028, 2033, 2040 and 2050.

Testing

A background level of voltage distortion was defined based on measurements at a substation with no downstream LV load. The data for this was obtained from an Aberle PQ monitor, attached to an HV/LV substation with minimum loading. 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 compared against the fundamental. Harmonic profiles for the various devices to be considered were modelled as current source inputs based on their harmonic emissions. Load profiles were set to reflect the normal operation of the technology for the random allocation studies. As Quasi-dynamic studies only apply for load flow studies in our modelling environment, the worst-case scenario of all of the three LCTs 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. Results were generated by carrying out harmonic load flow calculations for each frequency a harmonic was defined.

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.

Results (applicable to objective 4 & 5)

- 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.
- 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.
- 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.
- 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.
- These types of LCT are typically designed so that they are not subject to conditional connection, which would have the beneficial effect of minimising the increasing in harmonic distortion Therefore, greater visibility of the loading on individual LV feeders may be necessary to allow the necessary interventions to be planned ahead of requirement.
- 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.
- 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.

Required Modifications to the Planned Project Approach During the Course of the Project

The Network Licensee should state any changes to its planned methodology and describe why the planned approach proved to be inappropriate. Please confirm if no changes are required. (15000 Characters max)

No modifications were required during the lifecycle of this project.

Lessons Learnt For Future Projects

Recommendations on how the learning from the Project could be exploited further. This may include recommendations on what form of trialling will be required to move the Method to the next TRL. The Network Licensee should also state if the Project discovered significant problems with the trialled Methods. The Network Licensee should comment on the likelihood that the Method will be deployed on a large scale in future. The Network Licensee should discuss the effectiveness of any Research, Development or Demonstration undertaken. (15000 Characters max)

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.

The following shows some learning from key areas of the analysis undertaken:

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.

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. However charging would not necessarily take place every day as typical usage patterns would take several days before the battery was 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.

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. This needs further investigation to ensure our modelling of future loads is reaslistic. This may require the introduction of different diversity factors at different times of day.

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.

Outcomes of the Project

When available, comprehensive details of the Project's outcomes are to be reported. Where quantitative data is available to describe these outcomes it should be included in the report. Wherever possible, the performance improvement attributable to the Project should be described. If the TRL of the Method has changed as a result of the Project this should be reported. The Network Licensee should highlight any opportunities for future Projects to develop learning further. (15000 Characters max)

Project deliverables, analysis and closedown reports can be viewed on the project page:

National Grid - LCT Harmonic Limits

Or on the ENA Smarter Networks Portal:

LCT Harmonic Limits | ENA Innovation Portal

Deliverables include details and approach around the network model structure used for analysis and the summer and winter studies that include numerous DFES projections and the harmonic effect up to the 50th order.

Step 3 - Outputs And Implementation

Data Access Level & Quality Details

A description of how any network or consumption data (anonymised where necessary) gathered in the course of the Project can be requested by interested parties. This requirement may be met by including a link to the publicly available data sharing policy. (15000 Characters max)

The only data generated throughout the project has been harmonic background data through the use of Aberle Power Quality monitors used at some of our HV/LV (11 / 0.4 kV) substations for the purpose of obtaining an understanding of the upstream harmonic component. Other data used was collected in previous projects or via collaboration on other NIA projects.

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)

Foreground IPR

A description of any foreground IPR that have been developed by the project and how this will be owned. (15000 Characters max)

The Relevant Foreground IPR is:

- All deliverable reports and documents produced during the project delivery.

The Relevant Background IPR required to produce this is:

- National Grid's network modelling data
- EV charging data from WPD_NIA_018 Electric Vehicle Emissions Testing