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Network Assessment Tool: Interim Development Report January 2019

Electric Nation

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Glossary

Abbreviation	Term
Adjacency Model	Pathfinding, redistricting, allocation
BaU	Business as Usual
BSP	Bulk Supply Point
C#	.NET framework based object-oriented coding language
Coincidence Model	Topological overlay, intersection analysis
Convex Hull	Geometrical spatial analysis method
ERD	Entity Relationship Diagram
ESA	Energy Supply Area
EV	Electric Vehicle
EVRI	EV Readiness Index
Feeder	A circuit which feeds electrical energy from a substation
Geometric Model	Distances between points, buffers and perimeters
GIS	Geographical Information System
MPAN	Meter Point Administration Number
MSOA	Middle Layer Super Output Area
NOP	Normally Open Point
NCP	Normally Closed Point
WPD	Western Power Distribution
NAT	Network Assessment Tool
Raster Data Model	Matrix of pixels (i.e. image based)
REC	Regional Electricity Board
SQL	Structured Query Language
SSIS	SQL Server Integration Services
UI	User Interface
Vector Data Model	Data stored as co-ordinates
WMS	Web Mapping Server

1 Executive Summary

The Network Assessment Tool (working title) described in this report is being developed by EA Technology as part of the Electric Nation project. This report summarises the progress and developments to January 2019 from the previous report in October 2018. The primary focus of the past quarter has been to finalise the EV forecast analysis mechanisms to allow a user to view and probe the EV impacts to each network through from now to 2030.

In order to best achieve results system-wide, various data issues and gaps encountered are overcome using various assumptions and methods developed as part of the Network Assessment Tool (NAT) - such as using an estimated network where there is customer data but no or poor-quality asset data. An additional step has been implemented for a proportion of networks which previously caused DEBUT to fail. A substantial volume of these were found to only contain a small data issue on one feeder which would cause a substation level data failure. The additional step allows for an estimated feeder to be employed, retaining the good network data wherever possible. This work is still underway and the initial isolation to exclude the faulty feeder has been completed. To aid this, new user interface (UI) elements have also been developed to identify these lower-confidence results within the map view.

An interim EV charging profile based on early outcomes from Electric Nation trial data samples has been integrated to sense check the early works completed to ensure they are responding on the networks directly as anticipated.

Through this process, an issue with DEBUT's automatic phasing algorithm was also identified, in which the phase assignment would be re-balanced whenever a new consumer (in this case an EV) was added. This in turn was causing the network results to fluctuate from year to year in an incomparable manner. A fixed customer phasing allocation process was developed which has resolved this issue.

Due to the large volume of calculations for each network and year through to 2030, refinements have been made to the backend to optimise the tool's speed to process and calculate data. Significant improvements were found which have so far bought down the time from 1.5 days to just 5 hours to calculate each network for a single year.

Alongside the above developments, an ESA-level comparative view has been developed, so that network stresses can be analysed at this level. A new UI has been designed to better reflect these results so that the user can clearly see the wider scale of effects of increased EV uptake, and strategically perform further targeted analysis.

2 Introduction

This report details the ongoing development of the Network Assessment Tool (NAT) since the last progress report (October 2018). The tool provides LV network planners with a new platform to view and assess LV network operating conditions under future electric vehicle (EV) penetrations of differing magnitudes. Also, a module will be included to measure the potential benefit of using smart charging technology as a method to delay or avoid the need to reinforce networks overloaded by EV charging loads.

2.1 The Electric Nation Project

Electric Nation is the customer-facing brand of CarConnect, a Western Power Distribution (WPD) and Network Innovation Allowance (NIA) funded project. WPD's collaboration partners in the project are EA Technology (the authors of this report), DriveElectric, Lucy Electric GridKey and TRL.

Electric Nation, the world's largest domestic EV trial, is revolutionising domestic plug-in vehicle charging. By engaging 673 plug-in vehicle drivers in trials, the project is answering the challenge that when local electricity networks have 40% - 70% of households with EVs, it is estimated that at least 32% of these networks across Britain will require intervention.

A parallel activity as part of the project is the development of a Network Assessment Tool, this aims to enable an LV planner to assess smart charge solutions to support plug-in vehicle uptake on local electricity networks. A key outcome will be an analysis specifically tailored for highlighting plug-in vehicle related stress issues on networks and identifies the best economic solution where appropriate. This 'sliding scale' of interventions will range from doing nothing to complete smart demand control, from taking energy from vehicles and putting it back into the grid, to traditional reinforcement of the local electricity network where there is no viable smart solution.

The immediate challenge to such a tool is the prevalence of poor data quality available for LV networks in comparison to the vast and accessible datasets at HV level. As such, the tool under development will be of great interest country-wide as the next step to high visibility of LV network data at the planning stages. The outcomes of this project will be communicated to central government and the GB energy and utility communities.

This report focuses on the developments undertaken since the previous reporting cycle. This includes completion of a data run with interim EV profiles, algorithm optimisation and development of a high-level (ESA) comparative view of results.

3 Summary of Previous Progress

In the span covered by the previous report (July 2018 – October 2018), developmental focus was on incorporating EV forecast data across all WPD licence areas down to the substation level and developing an assignment functionality to reflect a realistic worst-case scenario for the network. Additionally, the user interface underwent a restyle to clearly present substation parameters and feeder operating conditions. Deployment of the Agile framework and the Microsoft Azure demonstration platform has also been effective.

The major development paths remaining from the previous report were:

- Generation of interim EV charging profiles for the DEBUT engine to use to assess networks, so that calculations could be run up to 2030.
- Refinement of the DEBUT assessment to overcome data issues such as erroneous dumb feeder assignments and to include estimated networks.
- Higher-level (ESA or licence area) comparative analysis of results.
- Implementation of a confidence metric.
- Design of the mitigation assessment module.
- Development of diversified charging profiles for EVs using Electric Nation trial data.

The following sections will detail the tasks performed in the last quarter period since the previous report. Following this is a short section to give an overview of the ongoing and anticipated next stages of development.

4 Overview of the Latest Progress

The primary development focus for the NAT during this quarter has been on designing and implementing the ESA-level comparative results analysis. Additional effort has been focused on optimising the back-end algorithms and ensuring correct allocations of phases.

Backend calculation optimisations have been implemented which have seen a substantial reduction in processing times system-wide - early indications show the total time to calculate a single year has been reduced from 1.5 days to approximately 5 hours system-wide.

A full-scale data run across all substations and years was also completed, using interim EV charging profiles in the DEBUT calculations. Addition of the custom EV penetration tool mentioned in the previous report was also completed.

A new icon was added to the UI to better identify substations with lower-confidence results. These are both substations using the estimated network, and substations in which a customer has been excluded in order to run DEBUT. It is intended that the next data run will include estimated networks for single feeders to avoid excluding customer groups.

It was also observed that the addition of EVs was causing customer phases to be incorrectly reallocated by DEBUT, which inadvertently caused fluctuating network results across calculated years. A process was developed to ensure that new EVs would not affect the original phasing and would properly represent the effects on the network.

4.1 Updated system-wide results

To enable the data to be run for all years, an interim profile to describe the EVs was required, as the data from the customer trial required to produce realistic profiles will not be available until March. This interim profile would be used in the DEBUT assessments of each substation to incorporate the effect of EVs much better than the previous incremental 'mock' results. This data run also included the estimated network substations, which the previous data run did not.

The interim profile is based on some initial EV charging profiles, so is a rough approximation of the general shape and power level that could be expected for a typical charge profile. As the data set from the customer trial is not complete, this is an imperfect profile and is not representative of the final results. It is also expected that in the end there will be several charging profiles available, representing different sizes and types of EVs.

An example result is shown in Figure 1. There are 15 EVs expected in 2030; in the DEBUT run each of these is represented by the interim profile. The results displayed no longer ascend in increments per year, but reflect the number of EVs displayed on the map.

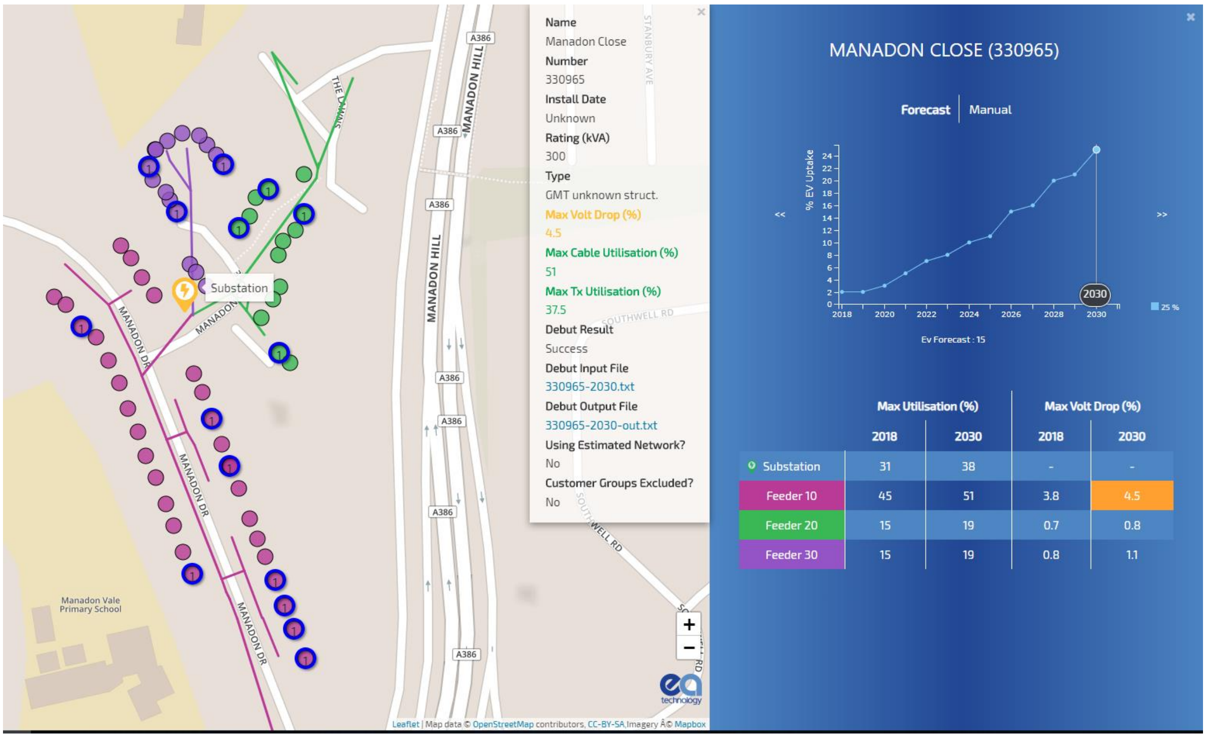

Figure 1: Example results set using interim profiles for assigned EVs

4.2 Assumed Networks and Excluded Customer Groups

A new symbol has been added to the map UI to indicate substations which have an assumption involved in obtaining their results and hence a lower confidence. This icon is a version of the substation icon, but with an 'approximately equals' symbol in the centre as opposed to a lightning bolt. An example is shown in Figure 2.

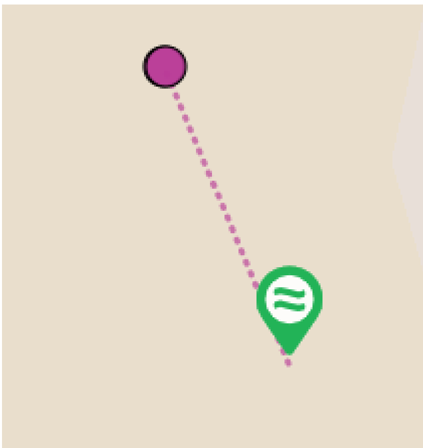

Figure 2: "Wavy" symbol for substations involving an assumption in the results.

Substations which use the estimated network are automatically given this symbol. However, this symbol is also used for substations in which a customer group has had to be excluded in order to obtain a result set. The latter issue affects a substantial proportion of substations. Excluding a problematic customer group increased the proportion of DEBUT successes by over 10% of all substations.

There are primarily two reasons why a customer group would be excluded, both corresponding to issues in the underlying data. Firstly, this could be due to an issue referenced in the previous report, in which customer(s) have been allocated to a non-existent feeder group (e.g. “999”) instead of one of the real feeder group numbers (e.g. 01, 02 or 03). This causes an ‘n+1’th customer group, when there are only ‘n’ feeders. This erroneous customer group, usually only consisting of one to a handful of premises, would be excluded.

The second reason is illustrated in Figure 3. In this example, there are five clearly-defined customer groups, but there are only four possible feeders identified from the cable layer. This means that the pink group has no assigned cables and causes DEBUT to fail the entire substation. Cases like this are not a fault of the feeder allocation algorithm; even if the “All Line Segments” layer is displayed, there are still no possible cables to assign to the pink customer group.

Figure 3: Example of “Customer Group Excluded” substation.

In cases like this, the problematic customer group is identified, excluded from the DEBUT input file, and then DEBUT is re-run for the four functional customer groups. While the results table for this will slightly underestimate the transformer utilisation, it does allow values of cable utilisation and voltage drop to be obtained for a majority of the network.

In the next full data assessment run, it is intended that an additional process will be developed for cases such as this. This process will create an estimated network for the affected feeder only (not for the working feeders), in order to get a better estimate of results for the substation. For the example in Figure 3, it would mean that an estimated feeder is created for the pink group, and the DEBUT is run for the four real feeders and one artificial feeder at the same time.

4.3 'Manual Mode' Custom EV Penetration

During the last quarterly report, the idea of custom EV penetration (Manual Mode) was introduced. This new functionality has been designed, developed and implemented into the NAT. This allows the user to manipulate the EV uptake penetration for an LV substation. Thus, for a given LV network, an LV designer will be able to test how many EVs can be introduced before some form of intervention is required, beyond the initial scope of the derived forecast. Figure 4 shows the tool, which can be located using the 'Forecast/Manual' toggle located on the side bar.

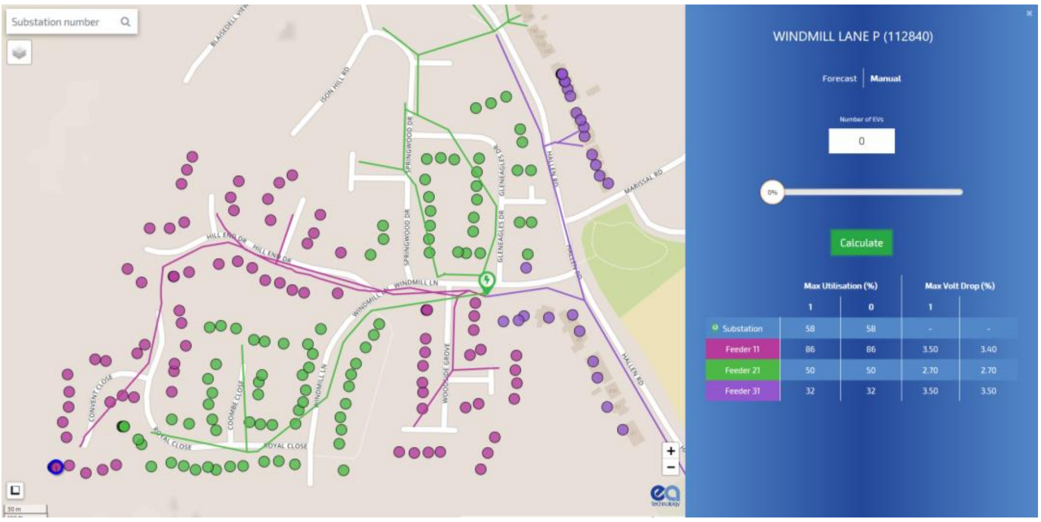

Figure 4: The Custom EV Penetration tool (Manual Mode).

The designer operates the slider to choose a penetration percentage. This percentage figure represents the proportion of customers on the network that have an EV. Therefore, 100% penetration means each consumer has been allocated an EV. The maximum allowed penetration is 200% (two EVs per consumer). Alternatively, a specific number of EVs can be introduced to the network using the input box. The EV allocation to the substation is then distributed to customers using the Three-Bucket Method (described in the previous Quarterly Report). This ensures full alignment with the deployment locations of each EV across all EV assessment methods and through time. As the user manipulates the penetration levels, the map is continually updated with EV allocations.

Once the desired percentage penetration has been selected, the user clicks 'Calculate'. The DEBUT engine then runs a one-off network calculation 'on the fly' for that network set up and returns the results in a matter of seconds.

The results table is then updated. Figures 5, 6 and 7 below show examples for a network with a penetration of 30%, 100%, and 200% respectively.

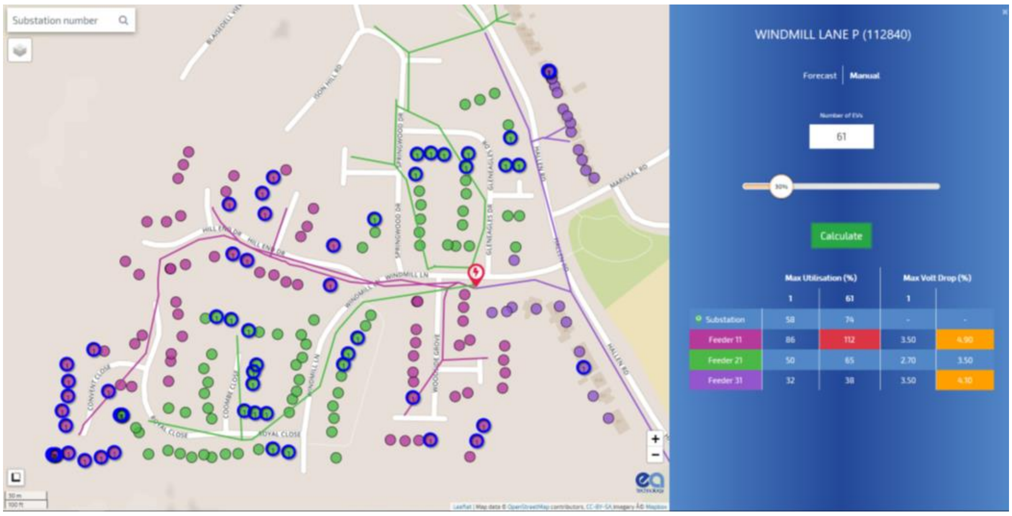

Figure 5: 30% penetration. While the transformer is still operating within limits, Feeder 11 is now over-utilised and has a volt drop approaching 5%.

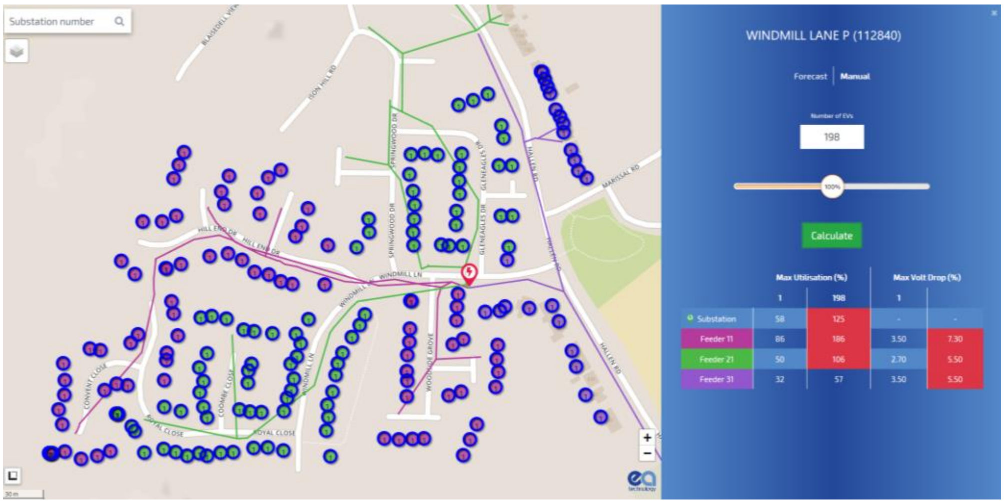

Figure 6: 100% penetration (one EV per household). The transformer is now over-utilised and Feeders 11 and 21 are over-utilised. All feeders have a maximum volt-drop over 5%.

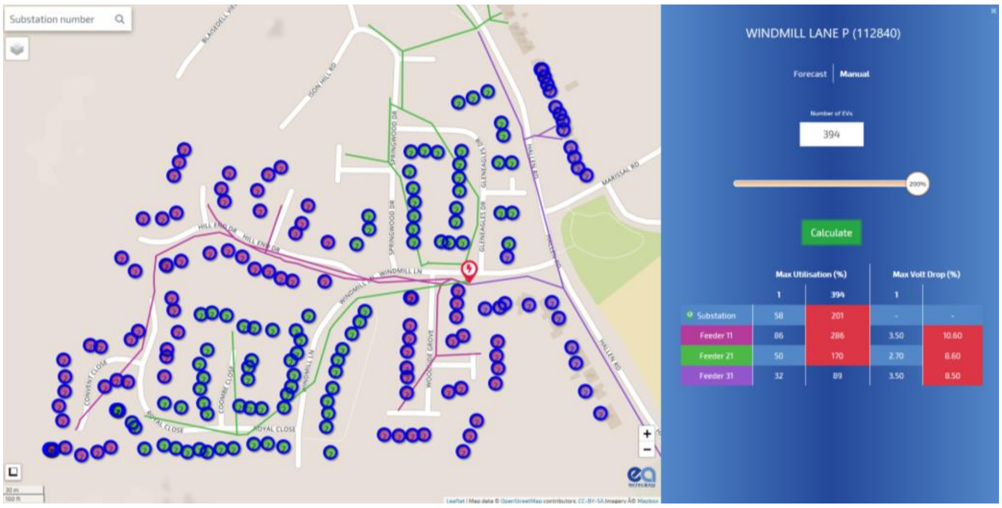

Figure 7: 200% penetration. Utilisation of the transformer and feeders is significantly increased. All feeders have a maximum volt-drop greater than 5%.

4.4 Optimisation of Backend Calculations

In parallel with the 'Manual Mode' on-the-fly network calculations, refinements have been made to the backend stack which takes the processed network data and creates a DEBUT study file, executes and saves the results. A significant drop in calculation times has been realised which has seen the overall time to complete a single calculation for every distribution substation in WPD from 1.5days to approximately 5 hours.

This is an ongoing task to ensure optimal processing times are reached as we add and develop additional functionalities.

4.5 Phasing

The customer phase allocations on WPD's network are unknown, therefore phases are randomly allocated using a standard '123321123..' phasing allocation algorithm. These are allocated per consumer type. However, the DEBUT engine automatically balances the three phases of an LV network when a selection of consumers is placed on said network. Therefore, when EV loads are added to LV networks as new consumers, existing loads are in some cases reallocated to different phases in order to balance the load between phases. Thus, the outputs are incomparable to the previous year as the phase loadings are not consistent, it also will not emulate cases of worsened load imbalance that could be caused by the introduction of EV loads. A method has been developed to permanently fix the phase allocations of consumers described below.

For each feeder belonging to a particular substation, the consumers are ordered by their radial distance from the substation. Phases are then allocated systematically, with the closest consumer to the substation on Phase 1, the second closest on Phase 2 and the third closest on Phase 3. The cycle then reverses, so the forth closest consumer from the substation is also allocated to Phase 3, the fifth closest to Phase 2 and the sixth closest to Phase 1. This process is repeated until all the consumers on the feeder have been allocated a phase. An example of the phase allocation cycle is given in **Figure 8:** Demonstration of the phase allocation cycleFigure 8.

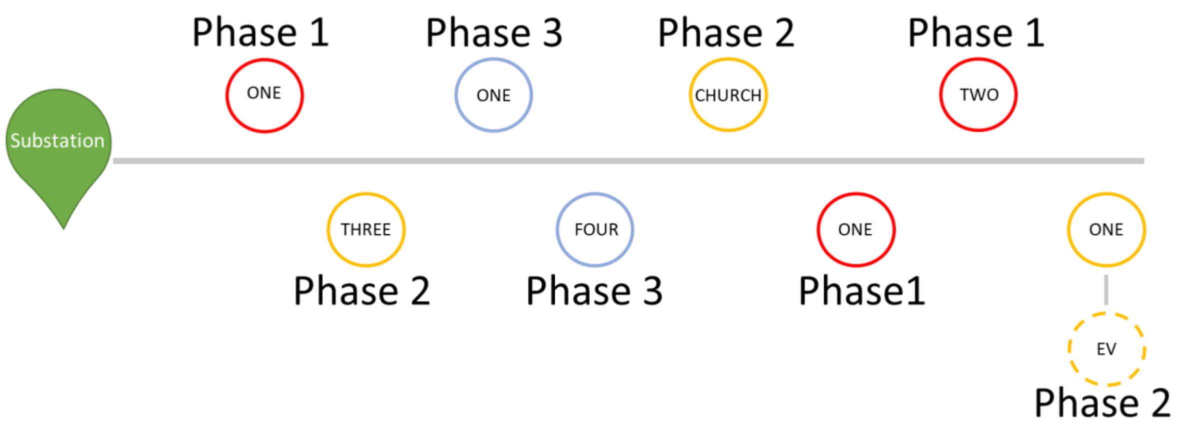

Figure 8: Demonstration of the phase allocation cycle, with a random selection of consumer types

Once each consumer has an allocated phase, additional dummy single phase branches are created. These originate from the DEBUT node on the mains cable (the DEBUT node on the mains is depicted on the NAT UI). A chain of branches is created for each phase, with a consumer positioned at the end of each branch. The calculations presented on the NAT assume that all the consumers are situated on their closest node on the mains cable. The load flow calculations do not include the analysis of the additional DEBUT branches. These additional branches are not presented on the NAT's UI, they are solely utilised to permanently fix the phase of each individual consumer. When a consumer is allocated an EV, the EV is placed on the same phase as the consumer, therefore an extra branch is daisy chained onto the chain associated with that phase. This is illustrated in Figure 9, in which the thick grey line is the mains cable with a node (visible on the UI), and the additional branches are used solely within DEBUT to ensure correct phasing allocation. Here an EV consumer has been allocate to consumer type 'One' on phase 2 (yellow).

It's important to note that the voltage drop and total impedance are reported back from the main three phase node. This ensures that the dummy branch does not add to or influence the network outputs.

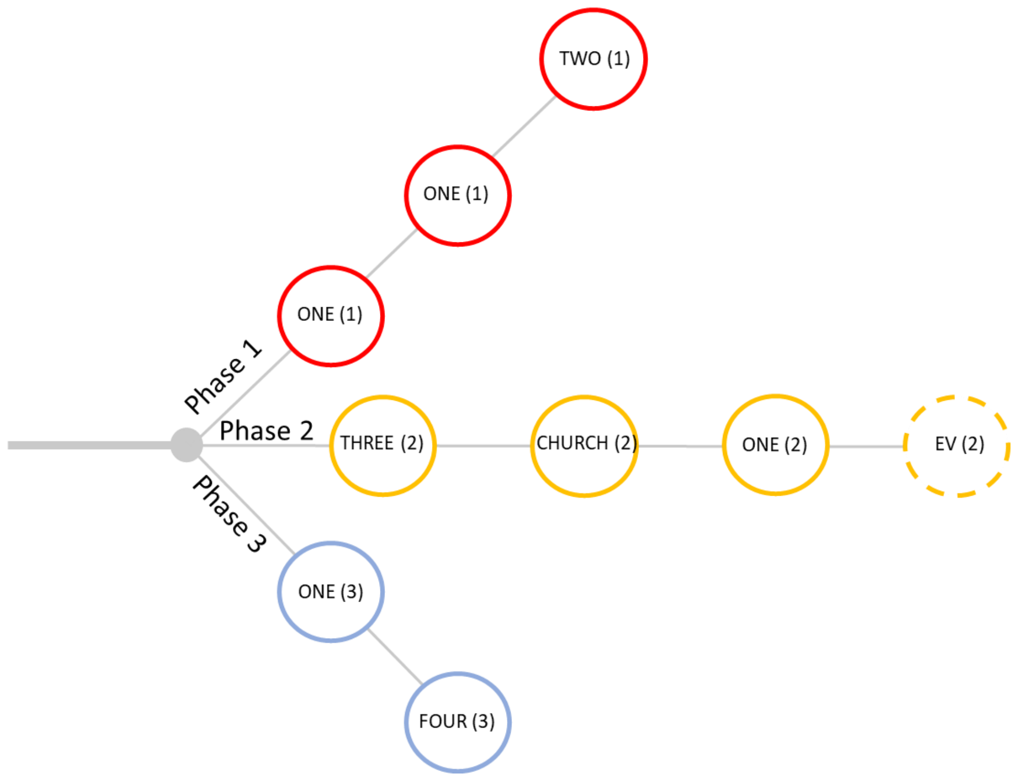

Figure 9: Demonstration of how the DEBUT engine processes consumers' phases on a node.

4.6 ESA Comparative Analysis View

The final feature which is currently in development is a view of the aggregated effects of electric vehicles across an Energy Supply Area (ESA). This view is obtainable by zooming out from the substation-level view of the map, and then selecting the area of an ESA. The area of an ESA will be highlighted red, amber, or green, in a similar way to substations.

The intended use of a view at this level is twofold. The first use, illustrated by the graphs which display automatically, is a way of illustrating the loadings and capacity system-wide (ESA-wide in this case), and how this changes as more EVs are added. If a user is more interested in digging into the detail, there is an additional graph which allows the user to identify vulnerable networks within the ESA and therefore target their investment analysis. Investment on networks is done at an ESA level.

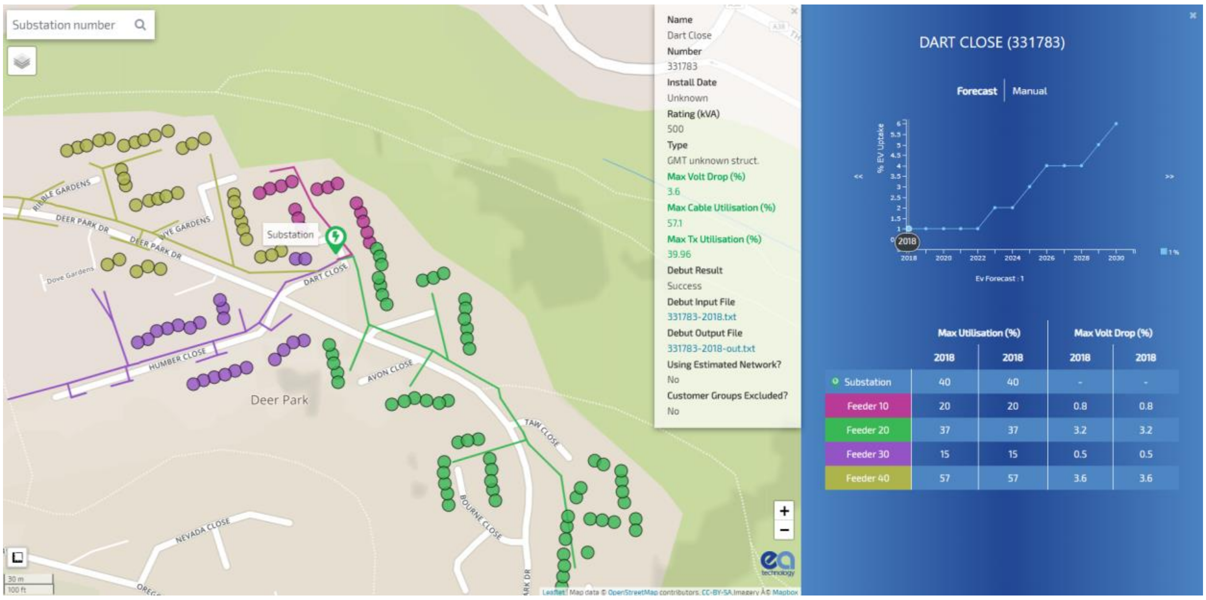

Figure 10: Illustration of the popup and sidebar at substation level. At ESA level, the sidebars will have different contents, and the network view will be replaced with the ESA map.

Overall, there are three views at ESA level: the map view (Figure 10), the white popup, and the blue sidebar, the latter two of which appear when an ESA is selected from the map view. Each shows progressively more detail. The map view shows by colour whether the ESA is fine, borderline, or bad. The white popup shows some basic statistics about the ESA for a selected year, and the blue sidebar allows the user to look at the data in detail.

There is an additional metric which has been created for this aggregation stage; the EV Readiness Index (EVRI). This is a number between 0 and 100% which indicates how well the overall network will cope with electric vehicles in a selected year. An EVRI of 100% corresponds to the entire ESA network being within the configured threshold of the constraints being measured (Thermal Transformer, Thermal Cable and Voltage). It is worth noting that most ESAs do not start with an EVRI of 100%, as there are many substations which are already over limits for either voltage drop, cable utilisation, or transformer utilisation.

This metric was created for two main reasons. Firstly, because the RAG colour system, while useful against a specific constraint or at a substation level, does not give much granularity at an ESA level. If there are e.g. five red ESAs, the EVRI metric enables the user to identify which one is worst. Secondly, the RAG analysis looks at the network at a substation level – it is based on the three failure metrics' maxima for the substation, regardless of how many of the substation's feeders are overloaded. A single overloaded feeder causes the entire substation to be labelled red. The EVRI takes the number of feeders into account as well, which better reflects the health of urban networks in particular.

To calculate the EVRI:

EVRI = 100%*(1 - x_1 - x_2)

where x_1 is the maximum of:

(the fraction of all feeders which have volt drops of over 5%,
the fraction of all feeders which have cable utilisations of over 100%,
the fraction of all substations which have transformer utilisations of over 100%)

where x_2 is 0.5* the maximum of:

(the fraction of all feeders which have volt drops of between 4% and 5%,
the fraction of all feeders which have cable utilisations of between 90% and 100%,
the fraction of all substations which have transformer utilisations of between 90% and 100%)

4.6.1 Analysis Bar – Ancillary White Popup

The white popup is very similar in design to the version which appears at the substation level. This popup is designed to be an at-a-glance display of a few key attributes for the selected year and ESA. It will display a variety of static descriptors:

- Number of constituent substations and feeders
- Number of domestic customers (those likely to gain EVs)
- Percentage of substations which use the estimated network, or fail Debut entirely
- Average confidence metric across the ESA.

There will also be displayed a number of statistics for the ESA for the selected year, which will change value if the selected year is changed:

- EV Readiness Index
- Average maximum voltage drop, cable utilisation and transformer utilisation
- Percentage of constituent substations which are red, and amber

4.6.2 Analysis Sidebar – EV Uptake graph

The first graph displayed on the sidebar will show the expected percentage uptake of EVs with time, aggregated from all the constituent substations. On an additional y-axis, the EVRI will be plotted, so the relationship between the two quantities is easily visible. Underneath the graph, the percentage forecast for the selected year will be displayed. This is illustrated in Figure 11.

Above this graph is a slider which allows the user to select the year of interest. This differs slightly from the currently implemented NAT design, in which the year selector is a part of the EV uptake graph. This design was changed in order to make the UI cleaner, as there are more data series on the graph at this level. It is expected that this design change will be subsequently applied to the substation-level sidebar to maintain consistency.

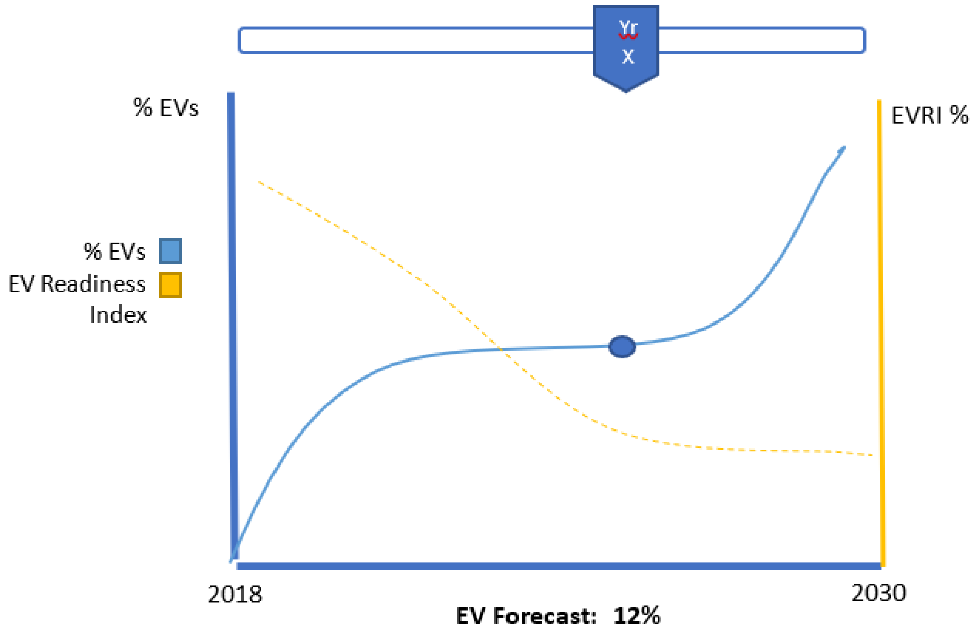

Figure 11: Concept design for the EV uptake graph and year slider

4.6.3 Analysis Sidebar – Breakdown graph

Underneath the EV uptake graph will be a stacked area graph indicating the progressive change in the number of substations which fail by each of the three metrics. This is illustrated in Figure 12.

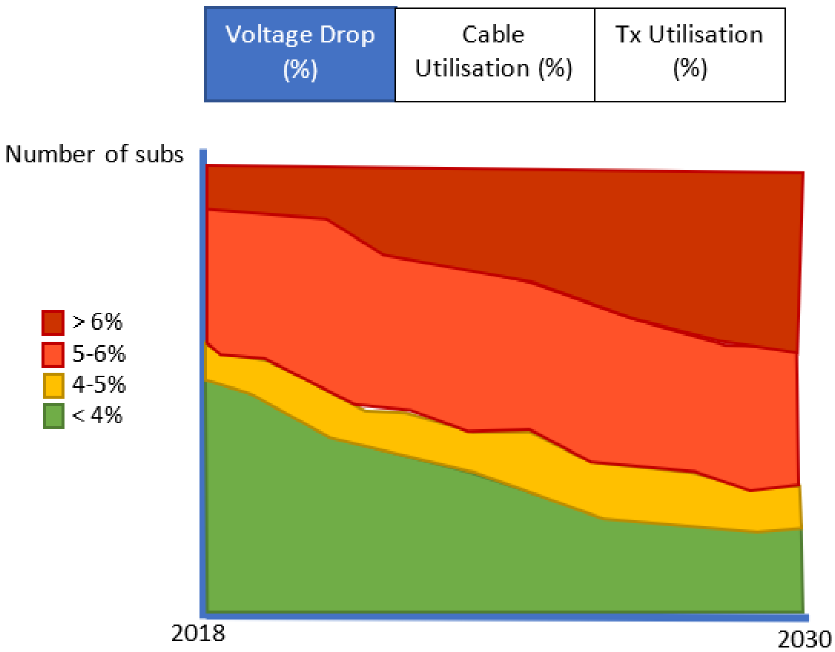

Figure 12: Concept design for the breakdown graph

The user will select one of the three failure metrics – voltage drop, cable utilisation or transformer utilisation. The metrics are broken down into four categories; green, amber, red, and dark red, representing the network being fine, borderline under-limit, borderline over-limit, and highly over-limit respectively. The graph reflects how many substations are in each category and how this changes with time. This view allows the user to easily see what proportion of the network is in danger of breaching limits, and how this is likely to change as the number of EVs increases.

The four categories on the graph are currently defined for voltage drop as: <4%, 4-5%, 5-6%, and >7%. The overload point is defined here as 5% as most of the networks do not include service cables, so a proportion of the statutory voltage drop limit is left for this. The corresponding groups for the two utilisation metrics are: <90%, 90-100%, 100-110%, and >110%.

4.6.4 Analysis Sidebar – Detailed Breakdown graph

The stacked area graph can be swapped for a more detailed graph, shown in Figure 13, while keeping the view of the uptake graph and year slider above. This graph will display data only for the selected year.

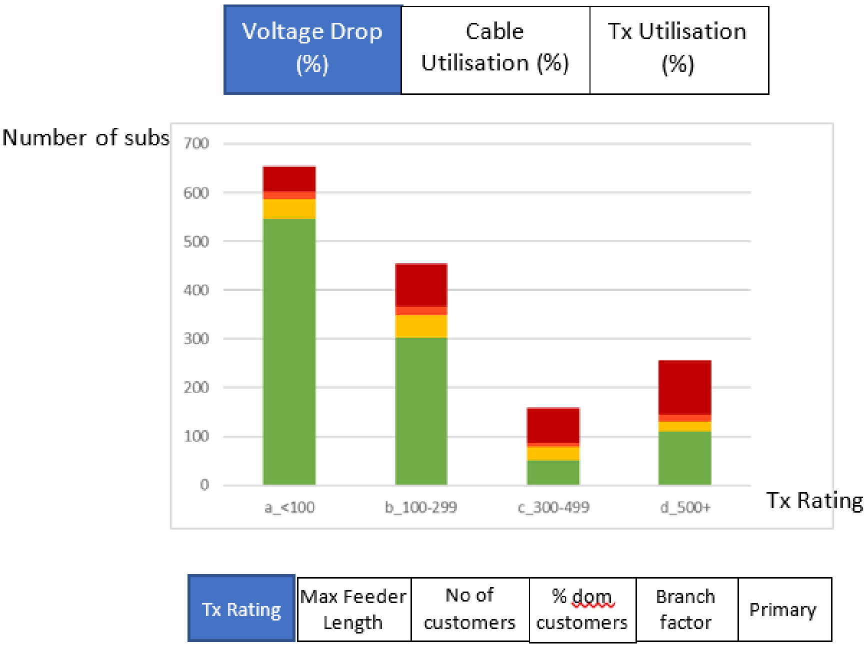

Figure 13: Concept design for the detailed breakdown graph. (The letter prefix labelling of the x-axis will not be present in the end design.)

The detailed breakdown graph is a histogram in which the data is broken down by a substation-level characteristic. This allows the user to identify features of networks within the ESA which are vulnerable to the presence of EVs. It also allows the user to perform more targeted analysis of the planned investment within an ESA.

As with the previous graph, the buttons above the bar graph allow the user to select which failure metric is to be studied. The buttons below the graph select the units of the x-axis. There are six categories by which the data can be broken down:

- Transformer rating
- Maximum feeder length of substation
- Number of customers per substation
- Percentage of a substation’s customers that are domestic

- Branching factor (an artificial number indicative of how much the network is prone to branching, calculated per substation)
- Primary: some ESAs cover the scope of more than one primary substation – this allows it to be known if the problem is limited to the scope of one primary, or across all, in order to target investment

To calculate branching factor for a substation:

- For each feeder, count how many nodes have more than two cables (i.e. when one cable splits into more than one at a joint).
- If the node branches into two, count once. If the node branches into three, count twice, etc.
- Divide this total count by the number of feeders

4.6.5 Data Export

The sidebar will also include an "Export Data" button which will download a subset of the database for the selected ESA and year, so that the user is able to examine the effects in greater detail if they so wish.

An extra page to this sidebar will be added at a later date, to show the aggregated effects of solutions across the ESA.

5 Ongoing Development Path

The following immediate development paths are in progress or awaiting a pre-requisite task before development can progress:

- The mitigation assessment module will be defined and designed – which will enable assessment of smart charging as a mitigation method (vs reinforcement) for networks overloaded by forecasted EV loads. This work stream is in the early stages of development. It is expected that the tool will have the ability to give results for differing uptake of charge management.
- Research will continue to obtain diversified charging profiles for EVs with different charging rates and battery sizes, using the data gathered from the Electric Nation trial. The DEBUT engine requires profiles made up of mean consumption for every half hour period of the day and the standard deviation of consumption for every half hour period. In addition, the total annual consumption of the EV is required. The different EV types can then be placed into the DEBUT engine in much the same way as domestic properties are.
- Completion of a data run in which a substation with an excluded customer group is analysed with an estimated feeder.
- Developing an algorithm to deal with the data issue in which multiple feeder start cables are connected at a normally-open joint. This would allow many substations which currently using the estimated network to instead use the WPD cable data.