



NPADDS Prototype Functionality and Benefits Case

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Contents

1	Introduction	4
1.1	Purpose.....	5
1.2	Scope	5
2	System Overview	6
2.1	NPADDs Approach.....	6
2.2	Modules	8
2.3	Users and Workflows.....	9
2.3.1	Connections Engineers	12
2.3.2	Systems Design Engineers	12
2.3.3	Planning Engineers	13
2.4	Voltage Levels	13
3	Technical Description of the Prototype	14
3.1	Software Implementation	14
3.1.1	User Access.....	14
3.1.2	Hardware (Server)	14
3.1.3	External Software, Data Sources and Licensing.....	15
3.1.4	Software Languages.....	18
3.1.5	Software Architecture	19
3.2	User Interface.....	21
3.2.1	Main Menu	21
3.2.2	Visual Design Environment.....	29
3.3	NPADDs Database.....	33
3.3.1	Common Information Model (CIM) Data Structure	34
3.3.2	Network Components in the NPADDs Database.....	37
3.3.3	Additional Data (The Configuration Database)	49
3.3.4	Importing Northern Powergrid Networks	50
3.4	Workflows.....	58
3.4.1	Use Cases	58
3.4.2	New Assessment Setup	64
3.5	Network Headroom Engine	72

3.5.1	Load Flow Tools	75
3.5.2	Simplified HV and LV Integration.....	76
3.5.3	LV Methodology	77
3.5.4	HV Methodology.....	80
3.5.5	Outputs	83
3.5.6	Saving Results	87
3.5.7	Model Verification	88
3.6	Load and LCT Forecasting Engine	92
3.6.1	Yearly Scenario Forecasts	92
3.6.2	Threshold-constrained Solar PV Uptake.....	99
3.7	Solutions Engine.....	100
3.7.1	Solution Template Ranking.....	101
3.7.2	Detailed Solution Assessments.....	109
3.8	Thermal Properties Engine	125
3.8.1	Cable Thermal Assessment.....	126
3.8.2	Transformer Thermal Modelling Tool	127
3.9	Policy Compliance Engine	129
4	Requirements of a Business As Usual Tool	132
5	Benefits Case	133
5.1	BAU Benefits.....	133
5.2	Long-Term Benefits	136

Glossary

AC	Alternating Current
AVC	Automatic Voltage Control
BAU	Business As Usual
CBA	Cost Benefit Analysis
CIM	Common Information Model
CLNR	Customer-Led Network Revolution
DDD	Domain Driven Design
DECC	Department of Energy and Climate Change
DLL	Dynamic Link Library
DNO	Distribution Network Operator
DSR	Demand Side Response
EAVC	Enhanced Automatic Voltage Control
EES	Electrical Energy Storage
EHV	Extra High Voltage
EV	Electric Vehicle
GIS	Geographic Information System
HP	Heat Pump
HV	High Voltage
IIS	Internet Information Services
LCT	Low Carbon Technology
LV	Low Voltage
MPAN	Meter Point Administration Number
NPADDs	Network Planning and Design Decision Support tool
OLTC	On-Load Tap Changer
PC	Personal Computer
PV	Photovoltaic (Solar)
SCADA	Supervisory Control And Data Acquisition
SGF WS3	Smart Grid Forum Workstream 3
TOU	Time Of Use
URMC	Unrestricted Tariff and Medium Consumption



1 Introduction

The prototype Network Planning and Design Decision Support (NPADDs) software tool described in this report has been developed by Northern Powergrid and EA Technology as part of the Customer-Led Network Revolution (CLNR) project.

CLNR set out to trial a variety of emerging network technologies and customer propositions, evaluating how effective these alternatives to conventional reinforcement can be for the purposes of facilitating Low Carbon Technologies (LCTs) on the network. Technologies and interventions that were trialled are monitoring, enhanced voltage control, real-time thermal ratings, demand side response and energy storage.

As such propositions develop into viable ways to release network capacity, Distribution Network Operators (DNOs) will be faced with the challenge of identifying the most cost effective solution amongst a growing number of options. They will need to be able to routinely assess the effects of LCTs and demand changes over time, as well as apply any new design practices in a consistent manner. At the same time, connection request response times and design and planning resources are constraining factors in coping with the anticipated volumes of connections.

Within the CLNR project, the role of NPADDs has been to identify and demonstrate a design of a future network decision support tool that can incorporate LCTs and the CLNR technologies and learning into a DNO's Business As Usual (BAU) practices, and evaluate these alongside conventional methods within a consistent and streamlined framework. As such, a guiding principle for the software has been to deliver value for a DNO's existing design and planning activities, whilst also enabling assessments of 'smart' network technologies and LCTs. A key aim has also been to build in functionality that narrows down appropriate solutions, whether conventional or smart, to a given network constraint.

Two primary outputs have been delivered as part of the NPADDs work package:

- A prototype software tool completed to a proof-of-concept level with respect to network headroom assessment, data structures, user interface and representation of LCT and CLNR technologies; this report presents the functionality of that prototype.
- An enduring specification that describes a full list of requirements that would enable Northern Powergrid or other DNOs to tender/procure a BAU product, including functionality outside of the CLNR prototype scope; the *NPADDs Enduring Specification*¹ is published in the CLNR learning library.

NPADDs has been developed using a rapid prototyping approach, incorporating feedback from relevant stakeholders. A scope was outlined as part of an initial requirements specification work package and has guided the development along with a Functionality Matrix, built for testing purposes, produced in collaboration with Northern Powergrid in 2014. Requirements have also been

¹ CLNR-L155 - NPADDs Enduring Specification. Available in the CLNR website project library
<http://www.networkrevolution.co.uk/resources/project-library/>

captured via meetings, demonstrations and validation sessions with Northern Powergrid, and wider stakeholder audiences at conferences.

The NPADDs prototype sits at the business operational level and enables designers and planners to access several network assessment tools from one application, helping to create efficient workflows. It features a database that holds a sample of Northern Powergrid's Low Voltage (LV) and High Voltage (HV) networks, and is able to convert this data as needed in order to interface with external software packages (including IPSA2, DEBUT, and Crater Lite).

The NPADDs prototype was able to demonstrate workflows including the assessment of voltage and thermal constraints on an existing network, or following a new connection or future LCT uptake scenario. Where a headroom problem is identified, the NPADDs prototype ranks list of potential solutions and illustrates on a selected set of CLNR propositions how the user can evaluate these in detail. Assessment is also provided on thermal limits of transformers and cables.

Network headroom assessments performed by the prototype have been verified as being comparable with existing network design and planning packages used by Northern Powergrid. This has reinforced confidence in the methodologies used, and in the genuine potential to develop the prototype into a fully functional product. An indication is provided in this report of the further work that would be required, and of the benefits case to DNOs for making that investment.

1.1 Purpose

This document describes the approach, methods and functionality of the NPADDs prototype, with the aim of assisting Northern Powergrid (as a proxy for other DNOs) to make an informed decision for the integration of NPADDs as part of the future development of design and planning tools. This report documents:

- Functionality of the tool, describing how it is used and what results are obtained;
- Input data that is required from DNOs or defined within the software;
- Software methods that have been employed, including external software packages;
- Software domain design, as an overview of the software architecture and modules;
- Data storage and sources, explaining the use of databases and data formats; and
- Workflows and use cases, describing how these fit with DNO BAU activities

A brief benefits case is also presented in Section 5, which comments on the ways in which, if developed into a full product; NPADDs would support DNO businesses as part of immediate BAU activities as well as longer-term strategic aims.

1.2 Scope

Software design involves a great deal of in-depth methods, and it is not appropriate to include all such detail here. The scope of this report is to enable the reader to understand how results are obtained at a sufficient resolution to judge the extent of the functionality and the appropriateness of the methodology.



2 System Overview

2.1 NPADDs Approach

The purpose of the NPADDs software tool is to support Northern Powergrid's network planners and designers in their duties of maintaining network performance at LV and HV by identifying insufficient headroom/legroom and appropriate solutions.

Headroom is affected by new connections, load growth and, to an increasing extent, take-up rates of Low Carbon Technology (LCT) as well as general changing use of the distribution system. Meanwhile, as smart grid solutions gradually evolve into viable alternatives to conventional reinforcement methods, planners and designers will need to incorporate these into their well-established methods when identifying solutions.

NPADDs is therefore designed with a two-fold aim, to:

- **add value now, for existing BAU design and planning**
- **expand BAU to include LCT and smart grid technologies.**

In the prototype form, NPADDs enables analysis of solar photovoltaic (PV), electric vehicles (EVs) and heat pumps (HPs) on a network. It also illustrates ranking, design and analysis of example headroom solutions that were trialled by the CLNR project, within the context of the Smart Grid Forum Workstream 3 (SGF WS3) solutions.

Notably, NPADDs also trials the concept of supporting several key business functions within one software package. Its modular design can be configured to:

- **assist mass market connections by rapid yes/no network assessments**
- **provide designers with detailed modelling options of individual networks**
- **let planners assess wider network areas**

Each business function shares a detailed database of network assets and connections that can support load flow and other types of analysis going forward, which serves to streamline and future-proof DNO activities. To implement this, the NPADDs prototype:

- **represents network data in the Common Information Model (CIM) format**
- **stores data in an Oracle spatial database, with built-in geographical tool**

A key aspect of NPADDs in this sense is that analysis and results in all cases are specific to the network area under assessment – generic models are not used. NPADDs uses the spatial and asset data held for the area to perform an assessment.

The prototype features a small set of Northern Powergrid network areas that have been manually entered as a one-off for demonstration purposes. However, a key area of work required to implement NPADDs as a fully functional product will be to develop bespoke processes that feed network data from DNOs (the structure of which varies between organisations) into NPADDs on a larger scale, envisaged to be largely automated and easily repeatable in order to capture network updates on a continuous basis.



To facilitate this, NPADDs is structured to provide a clear boundary between its internal functions and input DNO data. Standardised CIM representations of network assets in the NPADDs database ensure that the core of the software is functionally independent of DNO network data sets, with a translation stage required only to convert the DNO's data into CIM.

Making use of Oracle's spatial tools, the NPADDs prototype includes a graphic interface of network assets and maps that enables designers and planners to visually confirm the features of a chosen network area, and temporarily alter it as needed. Users can:

- **identify network areas based on postcode or substation name**
- **view network layouts, currents and voltages over an OS Street View map**
- **zoom and drag the map to adjust the network view**
- **amend the properties of existing connections and assets**
- **place a new connection or asset on map, and draw new cable or line sections**

Whilst some such connection requests and headroom problems are well specified, DNOs must also handle uncertain factors such as LCT uptake and load growth. The prototype caters for this by demonstrating the use of built-in scenarios that do not require spatial input from the user. NPADDs algorithms instead alter a chosen network automatically by distributing LCTs and load growth across connected customers. Implemented features include the ability to:

- **apply % load growth on a year-by-year basis into the future**
- **allocate future LCTs on a year-by-year basis using government scenarios**
- **add amounts of PV on a feeder until a headroom constraint is reached**

These tools allow planners and designers to explore and anticipate when and where network areas may require reinforcement or other interventions.

Once a network area has been defined and/or altered, NPADDs acts as a flexible gateway to several assessment tools. It is therefore able to be more of a 'one stop shop' than traditional network analysis software, and can facilitate the sharing of results and data between those tools. At present, NPADDs links to separate load flow engines at the LV and HV levels, from which the prototype extracts thermal and voltage headroom figures and other associated parameters, and can pass the resulting load profiles to a cyclic cable rating tool and to a Transformer Thermal Modelling tool. NPADDs currently interfaces with, or encompasses:

- **DEBUT: LV thermal and voltage headroom (demand)**
- **EGD: LV thermal and voltage headroom (generation)**
- **IPSA2: HV thermal and voltage headroom (demand and generation)**
- **Crater Lite: Cyclic thermal ratings of cables**
- **Transformer Thermal Modelling Tool: Transformer temperature profiles**

When a headroom constraint is identified on the network, designers and planners face the challenge of considering an increasing number of potential solutions in the form of conventional reinforcement as well as emerging smart technologies. NPADDs addresses this with a built-in customizable pool of interventions and technologies called 'Solution Templates', and uses the network assessment results to:

- **propose solutions in order of merit, based on the TRANSFORM model**
- **enable the user to carry out a detailed assessment of such solutions**

Finally, NPADDs includes a policy compliance search engine feature, capable of making relevant policies and procedures easily available to designers and planners within the NPADDs environment when they work on an analysis task. It is based on the separation of documentation into clauses. Each clause is searchable by keyword or tag, allowing NPADDs to link clauses to particular types of assessments. The user can also carry out an independent search of such clauses in a designated area of the software.

In the prototype, the features described above have in some cases been implemented in a partial proof-of-concept fashion in order to illustrate particular functionalities. The intention is that these features can be tailored, combined, and further developed into a fully formed software product.

2.2 Modules

From the user's perspective, NPADDs functionality can be divided into seven modules. The first two – the User Interface and the NPADDs Database – look after the input, storage and display of data:

User Interface: Allows NPADDs users to make full use of the application's functionality in the most efficient and effective manner possible, through a web-based front end. The user interface defines the process flow by taking the user through a series of steps. It also presents information visually, such as network maps and assessment results. Finally, it is interactive, giving the user the ability to alter network design (e.g. by connecting new customers or cables) and change configuration parameters. The user interface is highly intuitive, which shortens the familiarisation time needed for operation of the system.

NPADDs Database: Central repository for all stored data, underpinning all assessments. It has two sections:

- The **Network Database** holds data that defines Northern Powergrid's network uploaded to NPADDs.
- The **Configuration Database** contains editable features, such as configuration parameters, temporary network data for design testing, assessment results, headroom solution properties, and generic details of customers and generators (e.g. load profiles). The overall purpose of the Configuration Database is to allow users to change configuration parameters and edit data using forms without the requirement for changes to software code.

NPADDs then features an additional five types of functions, described as 'Engines', which carry out analysis:

Network Headroom Engine: Responsible for calculating network headroom using load flow. It takes user input (in various forms, whether a new connection request, or a forecasted load growth scenario) and model input (from the NPADDs Database) and outputs a set of headroom indicators.

Load and LCT Forecasting Engine: Responsible for simulating load growth and LCT uptake scenarios, by allocating load increase and LCTs across consumers on a specific network. It takes user input as well as projections stored in the NPADDs Database, and uses algorithms to apply those scenarios to the network in question.

Solutions Engine: Responsible for proposing potential solutions by applying Solution Templates to a given network constraint. The user then has the ability to 'design in' the solution to conduct a more detailed assessment.

Thermal Properties Engine: Responsible for analysing the thermal performance of cables and transformers, based on the loading of individual pieces of equipment.

Policy Compliance Engine: Responsible for providing context specific guidance on Northern Powergrid policies, design procedures and codes of practice. It performs a keyword search on clauses in documentation that has been uploaded to NPADDs.

Each module is described in detail in this report. Additional modules would be incorporated into a BAU version of NPADDs to cater for other key activities such as fault level analysis and contingency assessments.

2.3 Users and Workflows

NPADDs has been structured to cater for a variety of activities in the connections, design and planning business processes. The three broad user classes and the functionality that these relate to in NPADDs are discussed below, in order of increasing scope:

- **Connection Engineers**
- **Systems Design Engineers**
- **Planning Engineers**

A key challenge is to make the software suitable for all these required users. At the extremes, a connections desktop estimator only needs the facility to input details of a connection request and perform a simple network assessment for a yes/no answer, whilst a planner requires a far greater level of interaction with the system and its configuration.

To account for this, the prototype doesn't have defined user classes but features a series of proof-of-concept processes and assessment engines. These 'building blocks' are intended to be adapted and rearranged in a finalised software product, to create work flows that are appropriate for different types of users. For example, a connections engineer would use only a portion of the full process that a design engineer could step through.

A set of main workflows has been implemented in the prototype, and utilise the NPADDs Engines as broadly indicated in Figure 2.1:

Existing Network Assessment: Assesses the network without the inclusion of any new connections. The results show winter and summer performance.

New Connection Request Assessment: Assesses the network when a new connection is added. The results show network performance before and after the connection was made.

This section also includes a Solar PV tool, which assesses how many consumers could install PVs on each individual feeder before a user-defined headroom constraint is reached.

Future Planning Assessment: Assesses the network when load growth and LCT uptake rates are applied annually between a start and end year, based on uptake scenarios in the NPADDS Database and built-in consumer allocation algorithms. The results show performance for each year.

Global Capacity Assessment: Assesses multiple network areas in order to obtain an overview of reinforcement requirements, effectively consolidating a set of Existing Network Assessments.

In the first three cases above, where a thermal or voltage headroom/legroom problem is encountered the user is taken to the Solutions Engine to identify an appropriate intervention. Supporting features are also available in the form of thermal assessment of individual cable segments and transformers at LV, and policy compliance search.

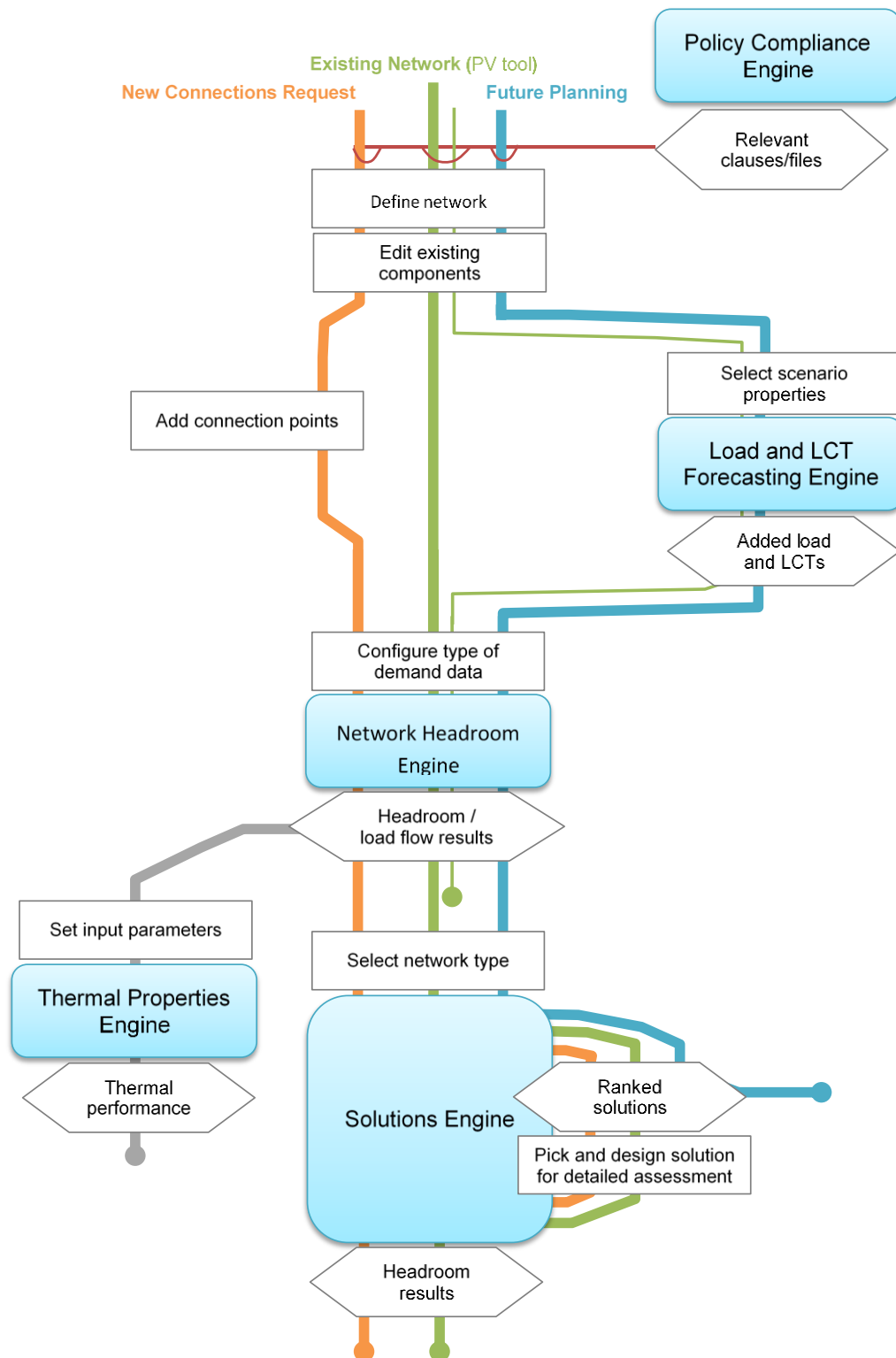


Figure 2.1 – Main workflows and their use of the NPADDs Engines

2.3.1 Connections Engineers

The connections part of the DNO business is characterised by dealing with high volume connection requests, where it is necessary to make fast but intelligent judgements on acceptability without detailed investigations. As this activity is heavily influenced by response times and associated penalties, the aim is to quickly identify the requests that do not require further assessment and that can therefore progress to quote stage without delay, versus those that require systems design input.

NPADDs provides the 'New Connections Request Assessment' feature for this purpose. The connection engineer simply adds the new consumer (temporarily) to the network at the relevant location using the intuitive drag-and-drop map interface, and then clicks a button to run a full load flow assessment. A fast yes/no answer in the form of a 'tick' or a 'cross' is then delivered by the assessment, with reference to thermal and voltage headroom limits. If the answer is a 'cross', the request would be handed over to a designer for further analysis, who can continue the analysis by assessing the impact of different solutions.

Supported by this feature, the connection engineer can quickly generate a precise answer using simple steps and the data on the connection request form. NPADDs is able to provide this functionality, as its network model at LV and HV enables full load flow analysis to be utilised by connection engineers as well as designers or planners. Load flow solutions for a network area, carried out by DEBUT/EGD (LV) and IPSA2 (HV), typically take within 30 seconds including the time taken for NPADDs to access and process the data (which will likely be possible to speed up as part of a BAU product). This is considered sufficiently fast for connection assessments across a DNO, even if several such tasks wait in a queue when requests are submitted simultaneously by different engineers. Simultaneous users is not an available functionality within the prototype, but would be developed for a final product.

2.3.2 Systems Design Engineers

Systems design activity involves a detailed assessment of a specific network area, to study the voltage and thermal headroom available across individual assets, and then identify solutions in the form of new assets or layouts that would resolve potential problems.

NPADDs caters for this by enabling the designer to use several tools to review and assess a section of network, and by providing analysis of solutions that can create additional headroom. In the prototype, the designer is currently able to use the 'Existing Network Assessment' and 'New Connections Request Assessment' features to select a network area and run load flow at LV or HV to identify thermal and voltage constraints. Using the load profiles generated by the load flow, it is also possible to assess cable cyclic ratings of individual cable segments, and run transformer thermal simulations at LV. For connection requests that would potentially result in headroom problems, the designer can perform a before/after analysis to help inform decisions regarding cost liability and apportionment.

If the network assessment identifies a breach of voltage or thermal limits, NPADDs provides one or more suggested solutions for consideration. These are based on Solution Templates following the format of the SGF WS3 output. The designer can then apply such solutions to the network and re-

run the analysis, adjusting the location or properties of a solution in order to arrive at a suitable design.

The prototype further includes a 'Future Planning Assessment' where the designer can assess likely operating conditions of a network in the future, by simulating scenarios of load growth and LCT uptake. A similar tool is available that adds solar PV to an existing network until a chosen voltage rise threshold level is reached; designers can then use this to identify a tipping point where the number of solar PV installations on a particular feeder should prompt closer monitoring or intervention.

2.3.3 Planning Engineers

The use of NPADDs for a planning engineer is to support the development of investment plans, by providing a snapshot of headroom over time and across several network areas. This allows the engineer to evaluate future requirements and to focus on the network areas most likely to be constrained.

A 'Global Capacity Assessment' developed as part of the prototype provides the planner with an overview summary of the headroom available across several HV or LV areas, and to re-assess the performance of some or all of these as needed.

For specific network areas, NPADDs runs studies across a number of years, increasing the number of LCTs connected to the area. It is then possible to form a view of when network areas are likely to become constrained. NPADDs then provides a set of proposed solutions for those areas identified as potentially requiring reinforcement with an estimate of which year the solution would be required. This is again based on Solution Templates, following the format of the SGF WS3 output.

Finally, planners can use NPADDs much in the same way a designer would. They have the ability within NPADDs to select a specific LV or HV feeder and perform a more detailed assessment of it, including the impact of reinforcement or smart grid solutions.

2.4 Voltage Levels

Finally, the scope of the NPADDs prototype is currently from, and including, the primary transformer to LV feeder ends. In order to accommodate this, the software is effectively divided into two distinct parts, handling LV and HV networks respectively. Networks are represented slightly differently within the NPADDs Database at LV versus HV. They are also assessed using their own distinct methodologies and tools in the Network Headroom Engine (DEBUT and IPSA2, respectively), and treated separately in the Solutions Engine which analyses how additional headroom can be created using appropriate equipment at each voltage level.

Samples of Northern Powergrid networks that have been included in the prototype are currently at either 400V (LV), and 11kV or 20kV (HV). In a future version of NPADDs, it would be possible to cater for other HV voltage levels as required.

3 Technical Description of the Prototype

The following section presents the technical implementation of the NPADDs prototype. Whilst the development has been guided by the initial functionality specification, the experience gained and lessons learned throughout the process have in some instances led to a change of approach. The prototyping has focused on a wide proof-of-concept demonstration, in such a way that selected features could be rearranged, adapted or more widely applied for BAU use.

3.1 Software Implementation

3.1.1 User Access

The NPADDs software is a web-based application that is run by the user from a standard web browser on a Personal Computer (PC), as shown in Figure 3.1. The PC is connected to the corporate network, and accesses centralised server-based data sources that hold all data and software that NPADDs requires in order to operate. Clients therefore simply need a network connection to the server, and no desktop applications besides the web browser.

The prototype has been developed and tested for Google Chrome, but can be extended for compatibility with other browsers.

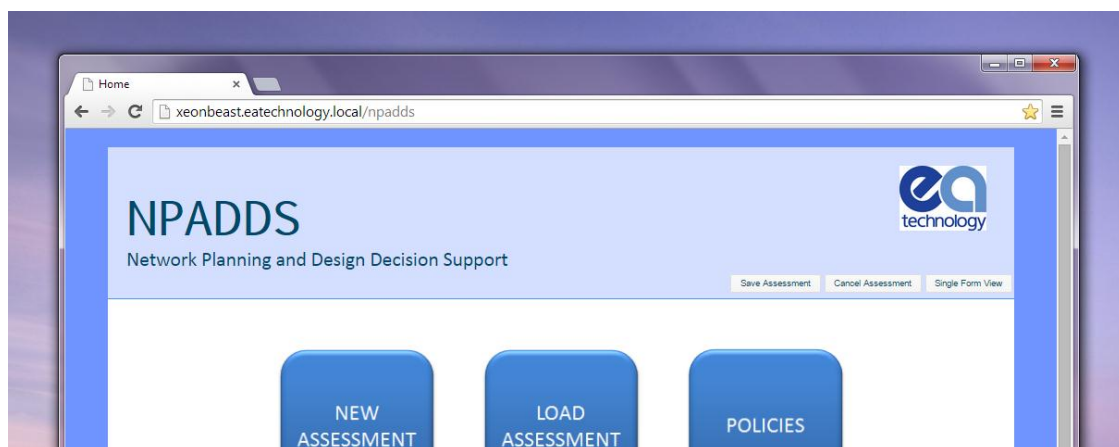


Figure 3.1 – NPADDs User Interface via web browser.

3.1.2 Hardware (Server)

The centralised data sources referred to above, that hold all data and functionality required for NPADDs, are currently hosted on a single EA Technology server and include a small selection of Northern Powergrid's network data for prototype purposes held in the NPADDs Database (Section 3.3). Development and testing has therefore been carried out without the need to access remote networks. It has also been possible to physically bring the server to meetings and conferences in order to demonstrate NPADDs to various stakeholders.

The prototype server is a Windows-based PC with the following installed:

Web application files: This refers to the application code that carries out all of NPADDs internal functions, including interactions with users and external software.

Microsoft Internet Information Services (IIS): ISS hosts the web application above.

External software: Executable and related files for external software used by NPADDs (see Section 3.1.3), including licence keys/dongles.

As a final product, NPADDs should ultimately be migrated onto servers hosted by Northern Powergrid, where it could be accessed by standard PCs with a network connection. Server specifications are likely to be different than for the prototype, in order to cater for Northern Powergrid's entire network area and to allow multiple simultaneous users. The future of NPADDs also involves these servers having direct access and deeper integration with what will become Northern Powergrid's core network data repository (Oracle eAM and Spatial), in order to keep network data up-to-date as it evolves. This is further discussed in Section 3.3.4.

3.1.3 External Software, Data Sources and Licensing

NPADDs is in part a platform that brings together existing external software tools and data sources, to allow a DNO to access its network data and carry out analysis in an efficient way. In addition, NPADDs provides its own set of novel network functions that relate to LCT and smart grid technology in particular.

External data sources

The external data sources that are used by the prototype for NPADDs functionality and assessments currently include the following, also listed in Table 3.1 along with licencing requirements.

OS Street View: An online world map free to use under an open licence, which acts as a source of street mapping tiles with coverage of the UK.

Post Code Coordinates: Set of coordinates (Eastings and Northings, as per the Ordnance Survey standard) associated with each UK post code area.

LCT uptake scenarios: Annual % uptake figures for LCT technologies across a succession of years into the future, derived from the Department of Energy and Climate Change (DECC) Carbon Budget and placed into % format by EA Technology.

LCT projections: Postcode dependent probabilities of LCT technology uptake across a range of years, capturing demographic differences in consumer behaviour, derived from a model produced by Element Energy.

Transformer Thermal Modelling tool: Calculation of transformer temperature based on equations in the BS IEC 60076-7:2005 standard on transformer loading.

External data	Provider	Licence required
OS Street View	OS Street View	No
Post Code Coordinates	Code-Point Open	No
LCT uptake scenarios	EA Technology (developed as part of SGF WS3)	Yes, covered under TRANSFORM licence
LCT projections	Element Energy	Yes
Transformer Thermal Model	BS IEC 60076-7:2005	No

Table 3.1 – External data sources used by NPADDs and their licensing requirements.

External software

External software components used by the prototype, and installed on the NPADDs server, currently include:

Oracle Spatial (11g): A RDBMS (relational database management system) database that provides geographical fields and references, as well as built-in spatial calculations and methods. It holds the NPADDs Database, which stores network data, mapping tiles, solution data, assessment results and other associated information.

Oracle Text: A SQL-based software tool provided as part of the Oracle database, which is able to index, search and analyse text and documents, based on keyword searching and other methods. NPADDs makes use of this in the policy compliance search feature to highlight relevant clauses during different stages of the network analysis, as well as to enable the user to independently search policy and guidance documents using keywords.

Oracle Map Viewer: A map rendering tool optimised for use with Oracle Spatial that enables interactive maps and spatial analysis. NPADDs applies this within the user interface, to display OS Street View maps together with DNO network data and assessment results, and to allow users to review, add or amend network components.

DEBUT: A LV design tool written in Fortran that forms part of the WinDEBUT product, which is used by many UK DNOs. DEBUT on its own is capable of assessing loads only. NPADDs runs DEBUT to assess LV headroom.

EGD: An engine taken from the WinDEBUT product to assess the effect of generation on LV circuits. This has been recreated within NPADDs (See section below).

TRANSFORM: A spreadsheet-based modelling tool developed by EA Technology as part of the DECC/Ofgem Smart Grid Forum. This has also been recreated within NPADDs (See section below).

Crater Lite: A software tool that provides ratings and thermal properties for a wide range of cable types under different conditions, including cyclic ratings.

IPSA2: A HV power flow engine in use by many UK DNOs including Northern Powergrid. NPADDs runs IPSA2 to assess HV headroom.

Python Interpreter: A Python Interpreter is a program that reads Python scripts and carries out their instructions. NPADDs uses this as an intermediary to interface with the IPSA2 software above.

These are listed in Table 3.2 below along with licence requirements.

Software	Provider	Licence required
Oracle Spatial Database (11g)	Oracle	Yes
Oracle Text	Oracle	Yes
Oracle Map Viewer	Oracle	Yes
DEBUT	EA Technology	Yes
EGD	EA Technology	Yes
TRANSFORM	EA Technology	Yes
Crater Lite	EA Technology	Yes
IPSA2	TNEI	Yes
Python Interpreter	Python Software Foundation	No

Table 3.2 – External software used by NPADDs and their licensing requirements.

Software licences are required for the use of the Oracle products (Oracle Spatial database, Oracle Text, and Oracle Map Viewer) and for the IPSA2 load flow software:

Oracle licence: An Oracle licence that covers all of the Oracle products in Table 3.2, has been procured on a development basis for the NPADDs prototype, which allows user feedback and initial testing but not BAU adoption. The licence is an ‘off-the-shelf’ database product intended for small scale implementations, however the base platform matches that of the main Oracle roll-out at Northern Powergrid. For a future NPADDs product, a different product licence will need to be arranged.

IPSA2 licence: The IPSA2 licence (unrestricted bus bar) used in the NPADDs prototype is registered to EA Technology and the terms of the licence preclude the transfer to any other party. For the chosen software architecture, and particularly the use of internet browser based access to NPADDs, IPSA2 will be installed on a server and not a local machine.

DEBUT and TRANSFORM, and Crater Lite, are EA Technology and Strategic Technology Programme (STP) products respectively, for which all GB DNOs have an in-perpetuity licence.

Finally, OS Street View and the Python Interpreter are open source software, available to use in the prototype as well as in a future commercial NPADDs product.

Re-created EA Technology software

Two EA Technology products – EGD and the TRANSFORM model – have been replicated in the programming language C#.NET and incorporated into the NPADDs software itself.

EGD is an add-on within the WinDEBUT software, which enables analysis of distributed generation and in particular the related rises in voltage. In NPADDs it is used in LV assessment in conjunction with DEBUT. It is written in Visual Basic in its original form within WinDEBUT. By replicating EGD in C#.NET, NPADDs can use it as a more flexible tool with access to all internal variables. In future development, it is possible that NPADDs could rely solely on EGD for both demand and generation assessments at LV so that DEBUT is not needed (Section 3.5.3).

TRANSFORM is a spreadsheet-based modelling tool developed by EA Technology as part of the DECC/Ofgem Smart Grid Forum. Similarly to EGD, parts of it have been replicated in

C#.NET within NPADDs. It models smart grid solutions on an existing network at a high level, and enables optimised investment decisions by ranking solutions according to headroom provided, cost, and other factors.

NPADDs-specific functions

Finally, the NPADDs prototype includes modelling facilities that are specific to this software, providing calculations and functionality internally rather than relying on an external software:

LCT uptake is modelled by NPADDs across a network area. Simulations are either driven by annual projections from government (or other) sources, or carried out as a step-wise uptake to identify when a network headroom limit would be reached. See Section 3.6.

Smart grid solutions assessment is carried out by NPADDs for a chosen technology on a specific network. Headroom assessment is in some cases based on load flow analysis by the external load flow engine at LV or HV, but for some solutions NPADDs provides a simplified built-in model of its own. See Section 3.7.

These modelling tools are in addition to the bulk of the NPADDs code, which coordinates and manipulates inputs and outputs with external software, the user interface, and DNO network data sources.

3.1.4 Software Languages

The core of the NPADDs software and functionality is written in **C#.NET**, a mainstream programming language developed and supported by Microsoft. Presentation aspects for the user interface in the web browser are written in the sister language **ASP.NET**, which is a free web framework provided by Microsoft for building web sites and services.

Other programming languages are used where appropriate to create the NPADDs interfaces with external software:

JavaScript is used for specific aspects of the interface into the Oracle Spatial database, as example code is available from Oracle which has shortened development time. It is also used for responsive browser user interface design.

Python scripting is used to integrate NPADDs with the IPSA2 load flow engine for HV assessments. Python scripting allows elements of the load flow engine in power system analysis tools such as IPSA2 to be called in the same way that a macro in Excel calls particular functions to automate processes that would require multiple step manual intervention.

These languages are well established and suitable for the scale-up of the NPADDs prototype to a full long-term product.

3.1.5 Software Architecture

The software architecture is a so-called Domain Driven Design (DDD), which is an established development methodology for basing designs on domain models and software layers. These take the form of a series of layers that perform discrete aspects of the NPADDs functionality.

Figure 3.2 below illustrates the software architecture in terms of the various software layers. Grey arrows on the diagram represent dependencies. For example, the Presentation Layer directly depends upon the Domain Model, the Tasks Layer and an instance of Oracle Map Viewer.

Client and server

The client component represents the web browser on the user's own PC. As outlined in Section 3.1.1 above, this is used to access the NPADDs functionality which is entirely hosted on the server. There is therefore no requirement for specific software, other than a standard web browser, to be installed on the client PC.

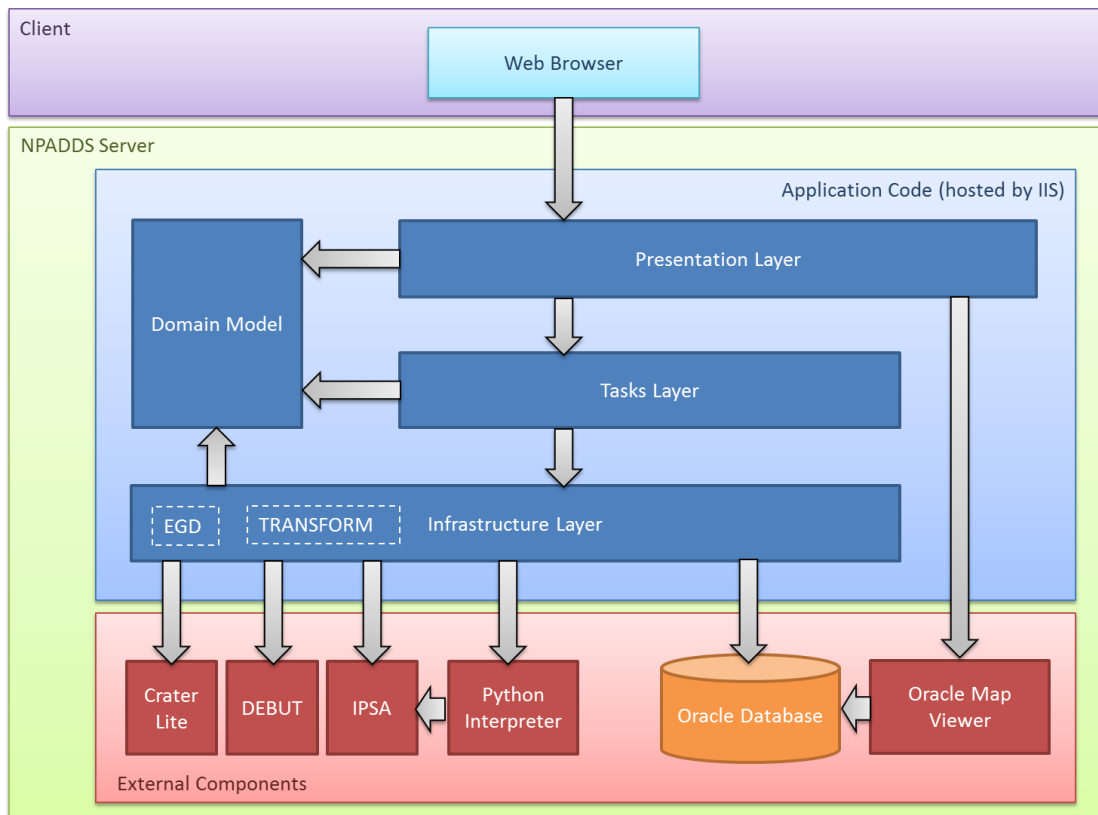


Figure 3.2 – NPADDs prototype software architecture. EGD and TRANSFORM methodologies are implemented in C# within the Infrastructure layer.

External components

External software is described in Section 3.1.3, and interacts with NPADDs application code in the following manner:

Oracle (with Oracle Spatial and Oracle Text): The Oracle database acts as a central data repository. NPADDs accesses it via C#.NET code from the Infrastructure Layer, in order to retrieve data required for tasks and assessments. 'Oracle Spatial' is a feature of Oracle which allows for modelling of geographical locations and useful related functions (such as calculating lengths and distances). 'Oracle Text' is another feature included with Oracle databases, which allows stored text or documents to be indexed and queried.

Oracle Map Viewer: Oracle Map Viewer is installed as a J2EE application server which listens for incoming map requests on a HTTP port. For the prototype version this is achieved via a standalone installation of OC4J.

DEBUT: Debut consists of an executable file and a data file with configuration information. It reads an input text file and generates an output text file. Input text files are created by the Infrastructure Layer and passed to DEBUT. Output files are similarly read in by the Infrastructure Layer.

Crater Lite: .NET DLLs (Dynamic Link Libraries) within the Infrastructure Layer are required for performing Crater assessments. These are 'wrappers' to the C and Matlab files that make up the core Crater module, and pass information between NPADDs and Crater.

IPSA2: NPADDs interfaces with IPSA2 via an intermediary Python Interpreter as described below, as well as by producing a text file that IPSA2 takes as input. IPSA2 similarly produces an output text file with results, read in by NPADDs. An IPSA2 executable must be present and accessible on the server along with a license (for example in the form of a USB IPSA Dongle).

Python Interpreter: NPADDs relies on a Python script, via C# commands, to execute IPSA2 assessments. The python script in turn relays commands to IPSA2.

Application code

The application code is the central NPADDs platform that represents the software's own internal functionality. Its role is to interact with the user, network input data, and external software, as well as to carry out data processing and modelling algorithms that are unique to NPADDs. It consists of the following parts:

Presentation Layer: Built on the Microsoft ASP.NET MVC framework, and consists of:

- Controllers for handling requests and selecting views for responses
- ASP.NET Views which generate html to respond to client requests
- JavaScript for client-side scripting and interaction with Oracle Map Viewer

Tasks Layer: Receives requests from the Presentation Layer for tasks including performing network assessments, calculating headroom solution merit scores, or communicating with the Oracle Spatial database.

Infrastructure Layer: Consists of classes which manage communication with external components such as the Oracle Spatial database and the DEBUT and IPSA2 engines.

Domain Model: Contains classes and data structures for the representation of all NPADDs related data.

3.2 User Interface

The NPADDs user interface has three main roles: guiding the user through the stages of an analysis process, taking input from the user, and visualising network data and results. This section provides a brief overview of two of its key components: the user interface main menu, which acts as a starting point for any NPADDs activities, and the Visual Design Environment, which is the main way that users interact with the networks under analysis. The wide range of other features (such as displays, buttons, forms and workflows) are then demonstrated throughout this report where relevant.

3.2.1 Main Menu

When NPADDs is launched, the user is currently shown a main screen with links to four basic activities, as illustrated in Figure 3.3:

New Assessment takes the user to the main NPADDs network analysis tools.

Settings allows the user to change the underlying settings and assumptions that relate to network and solution assessments, such as acceptable voltage limits or costs associated with smart grid technologies.

Policies contains the library of policy and guidance documentation, which the user can search independently using keywords.

Tools contains independent modelling tools that are not directly linked to network assessment. In the prototype, this includes the Transformer Thermal Modelling Tool.



Figure 3.3 – NPADDs main menu.

New assessment

The NPADDs prototype user interface largely mimics the existing work flow of connection, design and planning activities and logically guides the user through the process. The work flows are described in detail in Section 3.4, but are accessed from this section of the main menu:

- Existing Network Assessment
- New Connection Request Assessment (including PV allocation tool)
- Future Planning Assessment
- Global Capacity Assessment

Workflows related to the Solutions Engine, where the user can identify and analyse viable solutions to headroom problems, are accessed via the first three cases above whenever a thermal or voltage headroom/legroom problem is encountered.

Additional assessment tools – thermal analysis of cables and transformers at LV, and policy compliance search – are also accessed via the workflows above. Apart from via the Tools menu (see below), the transformer thermal analysis is available following a ‘New Connection Request Assessment’ as an example implementation. Cable thermal assessments which include cyclic ratings are available via any of the paths above, by clicking on a cable segment within a network.

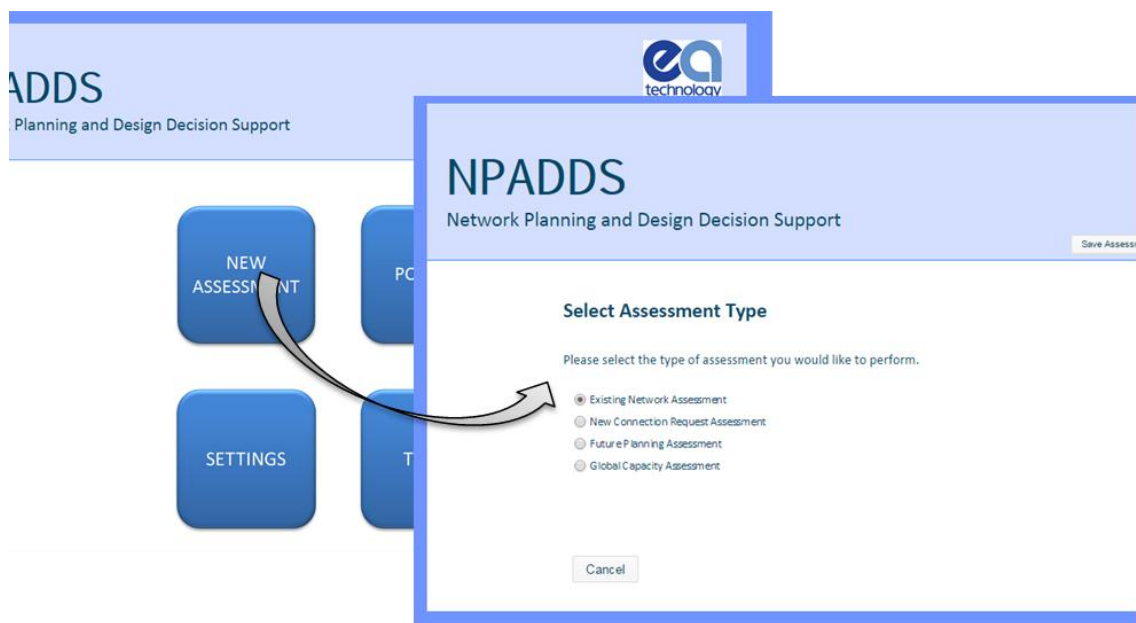


Figure 3.4 – NPADDs New Assessment section.

Settings

Under the main Settings menu, the user can adjust the assumptions that underpin network modelling and interpretation of results. The values of the settings are stored in the NPADDs Database and fed to the various network assessment tools. For a BAU product, this section will be

expanded upon to ensure users are able to view and edit any relevant settings used throughout NPADDs, as appropriate.

In the prototype a change in settings is permanently saved when a new value is entered and the “Save” button is pressed, and applied to all future simulations. In a future NPADDs product, it is likely that access to these settings would be restricted for different categories of users.

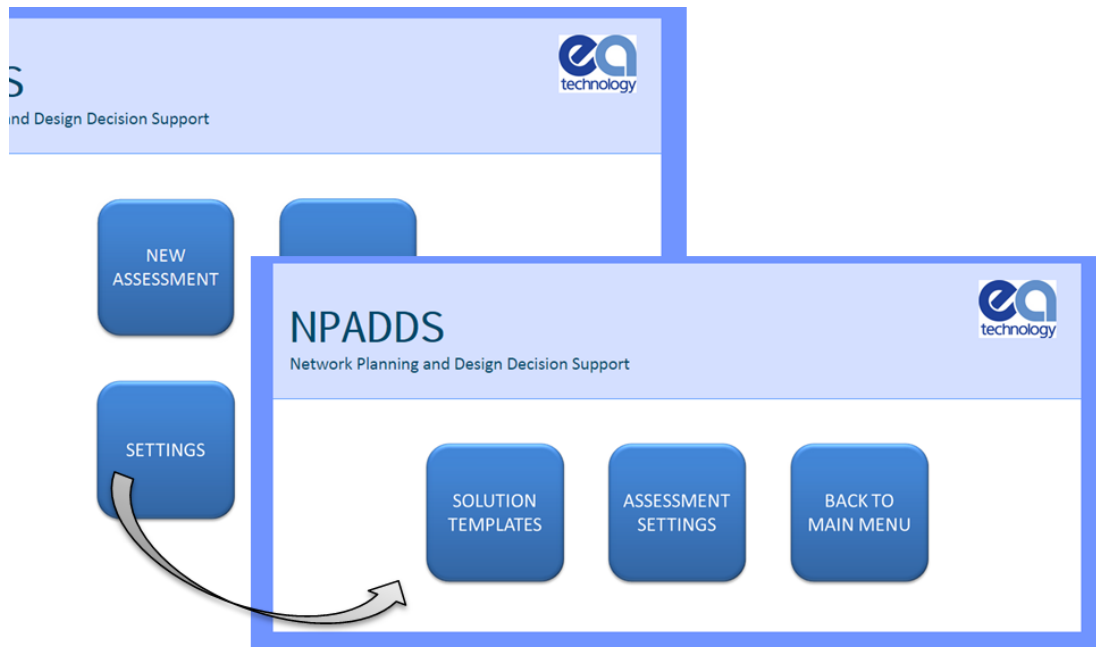


Figure 3.5 – NPADDs Settings section.

Assessment settings

Clicking on ‘Assessment Settings’ takes the user to the input form shown in Figure 3.8, where individual settings can be configured. Currently, this includes threshold settings used to identify whether network performance is within appropriate limits (Section 3.5), and solution buffer settings that determine how solutions are selected to headroom problems (Section 3.7.1).

Network performance thresholds: The evaluation of network headroom constraints is only useful if a threshold is defined to prompt further action. In the NPADDs prototype, assessment results are presented in a format similar to Figure 3.6 and Figure 3.7, with slight variations depending on the type of analysis carried out. A green tick is shown when all results are within their respective threshold settings. If any of the thresholds are breached, NPADDs instead displays a red cross.

The thresholds listed below are held in the NPADDs Database where they can be defined independently for LV and HV, and are applied to network assessment results. Statutory limits and Northern Powergrid’s policies could be used to inform these values.

‘Maximum volt drop (%)’ / ‘Maximum volt rise (%)’: Lower and upper voltage drop/rise limits. This is expressed as a % of the nominal voltage 230V at LV, and as a % of the nominal primary substation voltage at the lower side at HV.

‘Cable/Line thermal utilisation (%)’: An upper limit on cable utilisation, expressed as a percentage of its rating (the rating values used in NPADDs are described in Section 3.3.2). This is applied to all cable segments within the network that is under assessment.

‘Tx thermal utilisation (%)’: An upper limit on transformer utilisation, expressed as a percentage of its rating (the rating values used in NPADDs are described in Section 3.3.2). This is applied to all transformers within the network that is under assessment.

Using similar principles, it will be possible in future versions of NPADDs to impose thresholds on other network performance parameters. At LV, this might for example include **‘PH+N Resistance (mΩ)’** and **‘PN-N Fault Current (A)’** (fault level), both of which are already obtained via DEBUT and displayed to the user following an LV assessment.

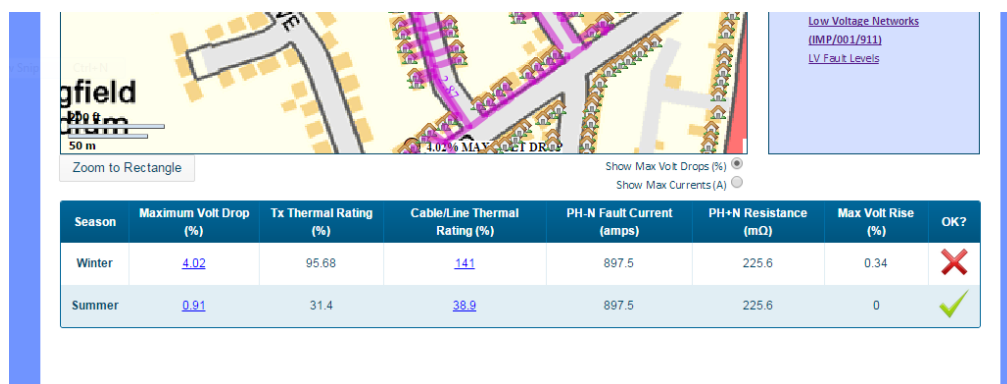


Figure 3.6 – Example format of LV headroom versus threshold results.

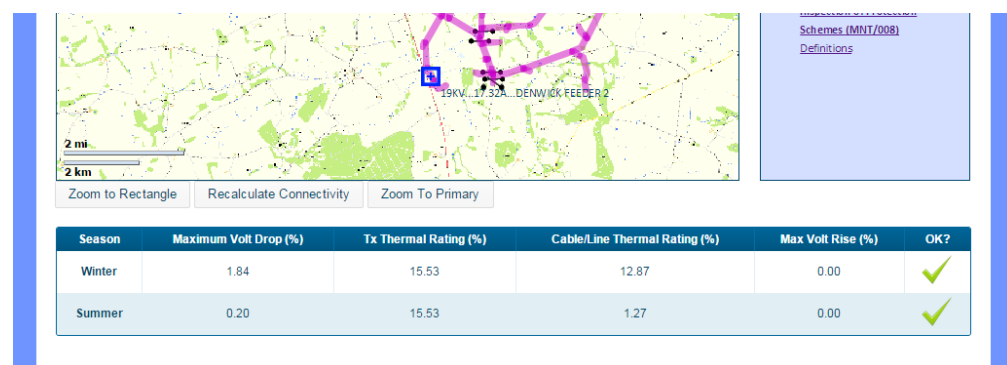


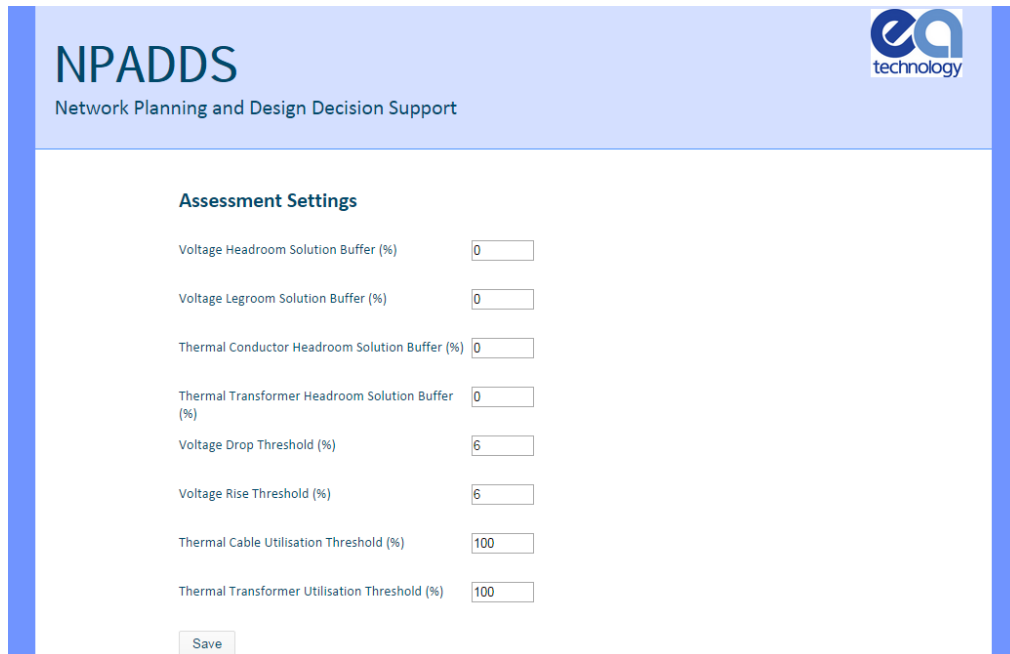
Figure 3.7 – Example format of HV headroom versus threshold results.

Solution buffers: The NPADDs Solutions Engine is capable of identifying suitable solutions to headroom problems, including those that develop during successive years in a yearly load growth

and LCT uptake assessment. To steer the outcome, the user can choose by what margin a solution should resolve the headroom problem in the current year to leave some room for further growth.

Such ‘buffers’ can be configured within this Settings section, as shown in Figure 3.8, including:

- Voltage headroom solution buffer (%)
- Voltage legroom solution buffer (%)
- Thermal conductor headroom solution buffer (%)
- Thermal transformer headroom solution buffer (%)



NPADDS
Network Planning and Design Decision Support

Assessment Settings

Voltage Headroom Solution Buffer (%)	<input type="text" value="0"/>
Voltage Legroom Solution Buffer (%)	<input type="text" value="0"/>
Thermal Conductor Headroom Solution Buffer (%)	<input type="text" value="0"/>
Thermal Transformer Headroom Solution Buffer (%)	<input type="text" value="0"/>
Voltage Drop Threshold (%)	<input type="text" value="6"/>
Voltage Rise Threshold (%)	<input type="text" value="6"/>
Thermal Cable Utilisation Threshold (%)	<input type="text" value="100"/>
Thermal Transformer Utilisation Threshold (%)	<input type="text" value="100"/>

Figure 3.8 – Assessment Settings menu.

Solution Templates

Solution Templates are descriptions of technologies that could be applied to a network to release more headroom, with associated technical impacts, costs and other properties. The use of Solution Templates in NPADDS, which is linked to the TRANSFORM model, is described in Section 3.7.1. Within the Settings section, the user is able to alter the configuration of each Solution Template.

When clicking on Solution Templates within Settings, the user is first taken to the menu shown in Figure 3.9. Several different sets of Solution Templates can be created in NPADDS: SGF WS3 “Workstream 3 Default” templates have been included as a main set, and within the prototype this has been amended into two slightly different versions for demonstration and testing purposes. Within the Settings menu shown here the user can select which set will be used within the NPADDS analysis.

Clicking “Edit” for either of these Solution Template sets takes the user to a screen shown in Figure 3.10 below, where it is possible to amend the configuration of individual templates by clicking the appropriate button. The user can adjust the way solutions are ranked in NPADDS in accordance with

its own assumptions and policies or as further data about smart grid technologies becomes available. The definitions of Solution Template properties are available in Section 3.7.1.

Similarly, further templates can be added to NPADDs by clicking “Add New Solution Template”, ensuring that NPADDs can be adapted over time. If the button “Copy from” is used, an existing set of Solution Templates can be used as a basis, avoiding the user having to re-enter all templates.

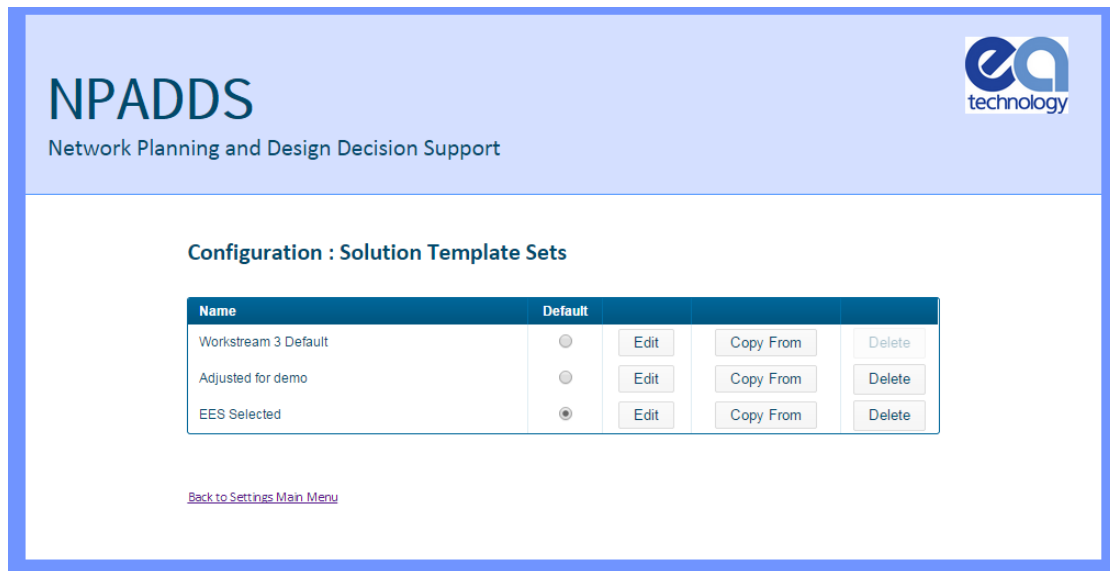


Figure 3.9 – Solution Template settings menu.

[Back to Solution Template Sets](#)

Configuration : Solution Template Set EAVC Adjusted

Solution Template Set Name

Representative Solution	Variant Solution	
Active Network Management	Active Network Management - EHV	<input type="button" value="Edit"/>
Active Network Management	Active Network Management - HV	<input type="button" value="Edit"/>
Active Network Management	Active Network Management - LV	<input type="button" value="Edit"/>
Active Network Management - Dynamic Network Reconfiguration	Active Network Management - Dynamic Network Reconfiguration - EHV	<input type="button" value="Edit"/>
Active Network Management - Dynamic Network Reconfiguration	Active Network Management - Dynamic Network Reconfiguration - HV	<input type="button" value="Edit"/>
Active Network Management - Dynamic Network Reconfiguration	Active Network Management - Dynamic Network Reconfiguration - LV	<input type="button" value="Edit"/>

Edit Solution Template : Active Network Management - LV

Representative Solution

Variant Solution

Description

Active Network Management - LV

Thermal Conductor Headroom Release (%)

Thermal Transformer Headroom Release (%)

Voltage Headroom Release (%)

Voltage Legroom Release (%)

Power Quality (%)

Figure 3.10 – Editing individual Solution Templates.

Policies

The NPADDs Policies menu takes the user to a keyword search engine, which searches policy documentation and guidance that has been previously uploaded to NPADDs (Figure 3.11). Each document has been separated into clauses. The search engine identifies and ranks individual clauses in response to the keyword provided by the user. The Policy Compliance Engine is described further in Section 3.9.

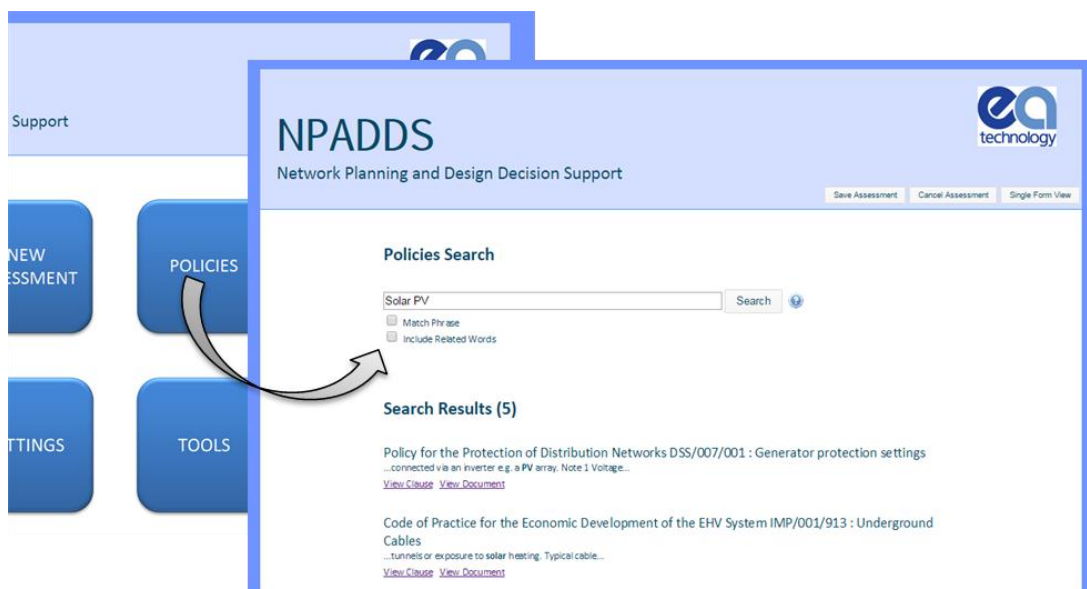


Figure 3.11 – NPADDS Policy section.

Tools

The Tools section illustrates a way that users can utilise NPADDS for additional analysis features, without entering into the main network assessments. Transformer Thermal Modelling has been implemented as an example to demonstrate this principle in the prototype (see Figure 3.13), and is accessed here as well as via buttons at certain points within the main network analysis process (Figure 3.12). Transformer Thermal Modelling is further described in Section 3.8.2.

NPADDS also includes a cable cyclic rating tool utilising Crater Lite. Although this is currently accessed only from within the network analysis process, the BAU tool could easily be adjusted to also provide an entry point from within the Tools section.

Season	Maximum Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	PH-N Fault Current (amps)	PH+N Resistance (mΩ)	Max Volt Rise (%)	OK?
Winter	19.66	104.54	104	255.9	788	3.58	✗
Summer	2.96	35.08	24.2	255.9	788	0	✓

[Go To Tx Thermal Modelling Tool](#)

Figure 3.12 – The Transformer Thermal Modelling tool can be accessed following a LV headroom assessment.

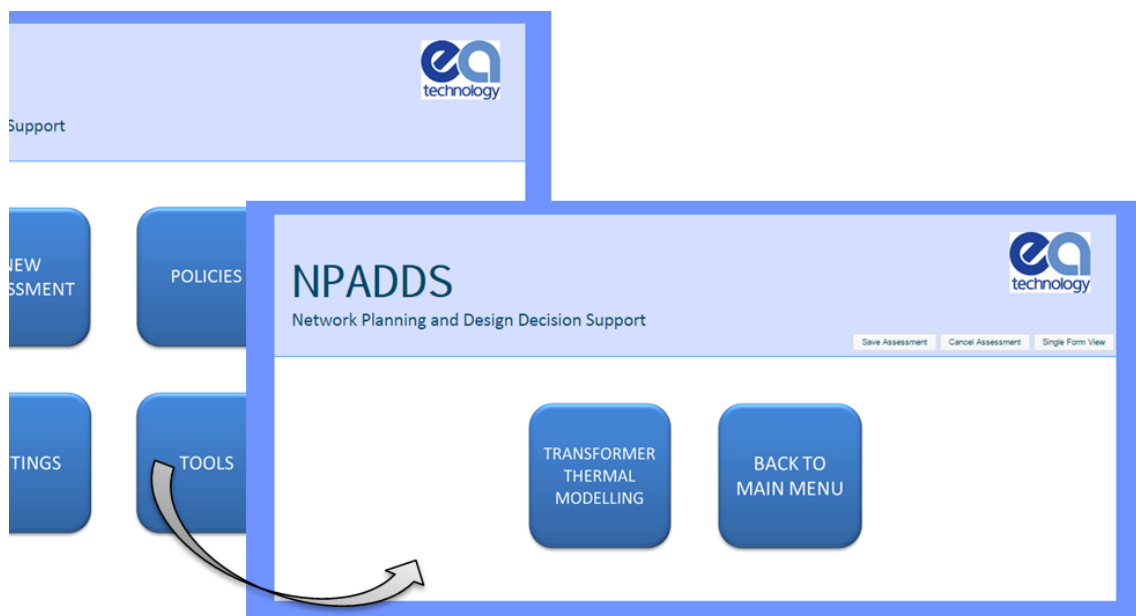


Figure 3.13 – NPADDs Tools section.

3.2.2 Visual Design Environment

The NPADDs user interface includes a Visual Design Environment, with two main parts: A map-based environment shown in Figure 3.14 which is an interactive geographic drawing of a segment of network on top of a street map, and a graph-based one shown in Figure 3.15 that acts as an interactive plot of performance parameters at each node of the network. The map design environment is the primary way that designers and planners are able to view and adapt the network data at LV and HV. In the prototype, the interactive graphs have so far been implemented within the Solutions Engine.

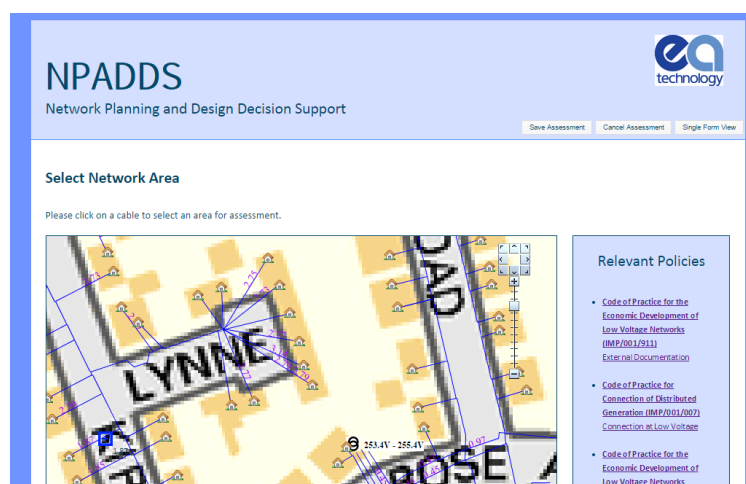


Figure 3.14 – NPADDs map-based Visual Design Environment.

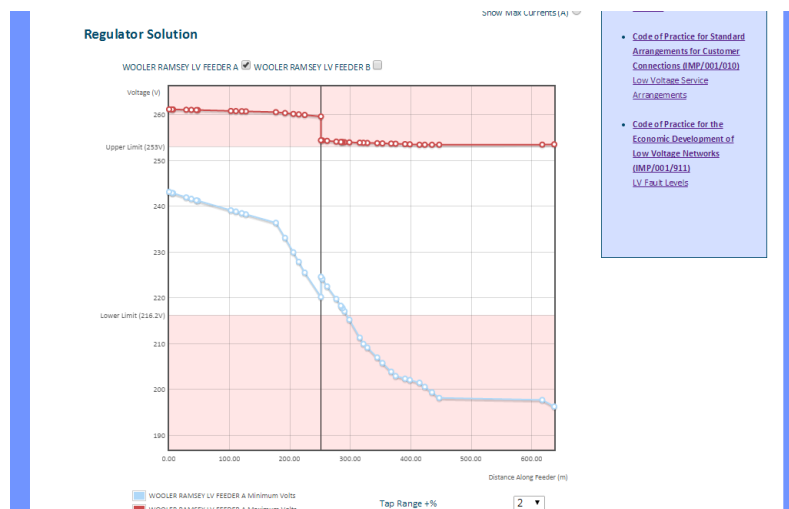


Figure 3.15 – NPADDs graph-based Visual Design Environment.

Apart from viewing data, the user is able to change the network model and add/remove components to ensure that the assessment can consider realistic impedances and customer load. The NPADDs prototype contains basic functionality in this respect for proof-of-concept. Below is a brief tour of some of the interactive features that have been implemented in the prototype.



View network assets in the area to visually verify and check the network model against a map backdrop.

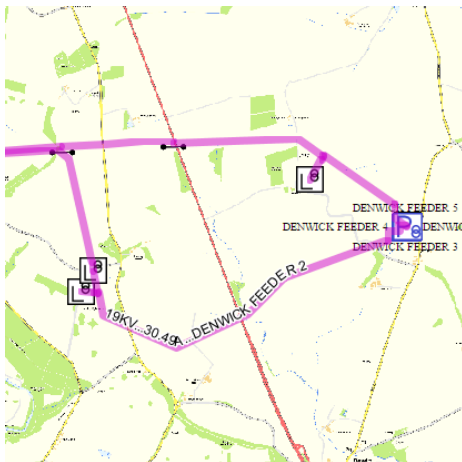
In the case of LV as shown, blue lines represent lines or cables. Icons are used to show consumers (in this case houses), generators, transformers, and switches (at HV).

In a BAU product, NPADDs could toggle between different backgrounds, including satellite images, or no background at all.



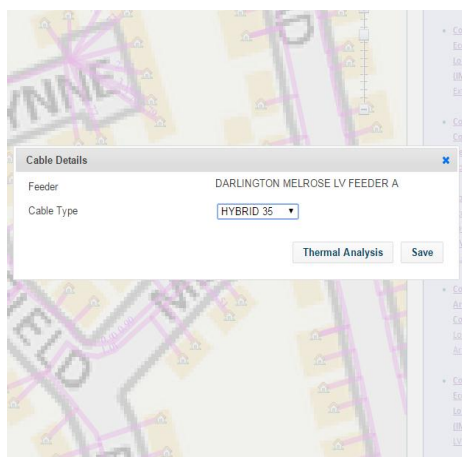
Zoom and move the map to change the view or access a particular area.

A standard directional and zooming tool is used, as shown. The user can also click anywhere on the map and drag it, or click on a button to draw a rectangle and zoom to that chosen area. In future versions, a 'zoom to primary transformer' button could also be made available at HV.



Select a network area for headroom analysis by clicking on a feeder in LV, or by clicking on a feeder in HV and then temporarily opening or closing switches to reconfigure the network to be analysed.

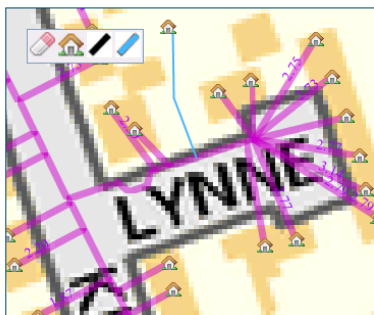
A selected network area is highlighted by thick pink lines, as shown.



Temporarily change the properties of existing network components and connection points, for example by adding PV to a consumer, or changing cable type associated with a cable segment.

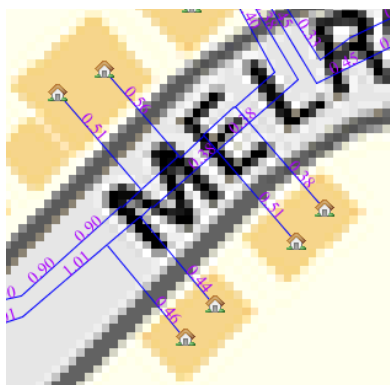
This is carried out by clicking on the component, which opens up a dialogue box as shown.

Draw Cable



Temporarily add network components and customer connection points onto the map and connect them using a range of standard cable and line types.

A drawing tool is used as shown, where clicking on the cable and new consumer opens up a dialogue box to set their properties. The process is guided by the software, such that cables are 'snapped' together and the consumer is positioned at the end of a segment.



View latest analysis results (maximum voltage drops, or maximum currents) plotted directly onto each node and feeder segment.

The data is displayed in pink numbers at LV as shown.

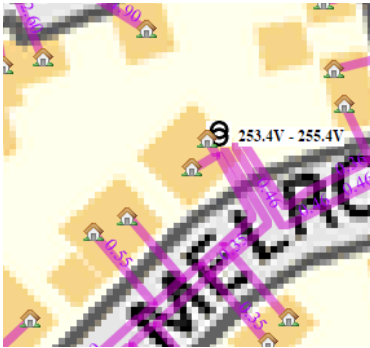


View the locations of worst-case cable headroom and voltage headroom/legroom on the map.

When such results are displayed in tabular form at the end of an assessment, the user can click on those figures to cause the map to zoom in on the associated location.



Click on a transformer to view its rating and voltages along feeders, as well as results of the latest headroom analysis within the relevant HV and LV area (voltage drops and rises, thermal headroom).

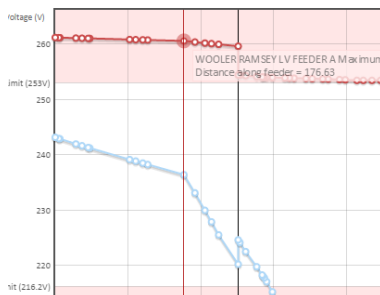


View the voltage range seen at a transformer, displayed next to the transformer icon as shown.



or Solution

WOOLER RAMSEY LV FEEDER A ☒ WOOLER RAMSEY LV FEEDER B ☐



Temporarily add a headroom solution technology, such as a voltage regulator, at a specific distance from the substation.

In the map environment, the distance can be judged by inspection, and the maximum voltage drop at a location is shown in blue letters when hovering above the cables.

In the graph environment, the distance is shown in a popup label when hovering above the nodes. Clicking on the graph places the component on the network map, at the chosen distance.

3.3 NPADDs Database

The NPADDs Database is based on an Oracle Spatial platform and acts as a central repository for all stored data, held on the server. Although it is a single database in the physical sense, it is split into two conceptual parts that store different types of data and are treated differently (Figure 3.16). The Network Database holds the data that specifically describes Northern Powergrid's network (only a subset of the network is currently represented within the prototype). The Configuration Database holds all generic data that does not relate to an individual network or customer, such as load profiles of different consumer types, as well as temporary network data, settings, configuration parameters and other properties used within the NPADDs modelling tools.

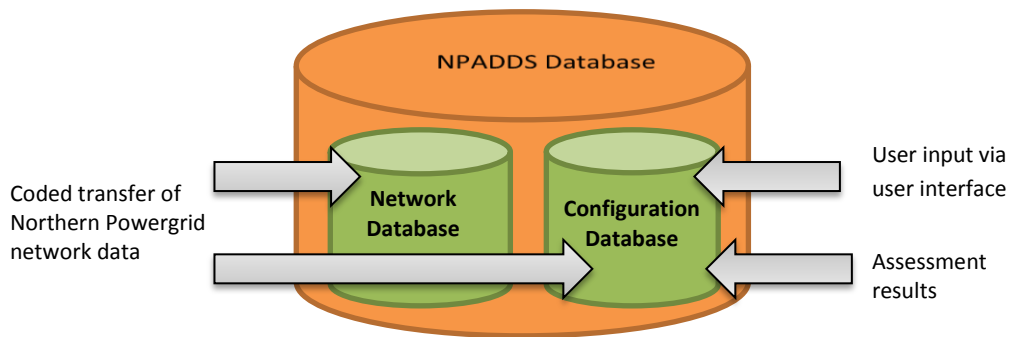


Figure 3.16 – The NPADDs Database consists of a Network Database and a Configuration Database.

Parameters that are stored in the Configuration Database could in principle be editable by the user in the web browser interface, or by NPADDs itself during run-time, and this is already the case for a subset of that data. In a final product, access to edit certain parameters should be restricted to specific users.

Conversely, network data held in the Network Database takes input only from a coded translation process, which converts Northern Powergrid’s network information into the Common Information Model (CIM) structure held in NPADDs. In future versions of NPADDs, it is envisaged that this part of the database will be populated via algorithms that import DNO network data from an external source or updates to that data at a regular interval, so that updates implemented by the DNO will also be captured by NPADDs. The user is still able to alter a network via the Visual Design Environment when running a network assessment, for example by routing a cable. However, any such alterations are only temporary and not saved back into the NPADDs Database. For a BAU NPADDs product, it would be possible to store such temporary network designs where needed.

An Oracle Spatial database was selected for NPADDs partly in lieu of the main Oracle implementation project underway in Northern Powergrid. Once complete, this synergy will simplify the transfer of network data into NPADDs.

However, due to the NPADDs development timescale having come before the elaboration phase of the main Oracle roll-out at Northern Powergrid, it was necessary to make assumptions regarding the specific way that some data was stored. Contact was maintained throughout the prototype development in an effort to ensure alignment between these two systems. As a result, NPADDs now requires less modification post-Oracle if it is to be developed into a BAU product for Northern Powergrid.

3.3.1 Common Information Model (CIM) Data Structure

Network data is stored in the database in the CIM methodology specifically designed for electrical assets. Apart from giving the development team a standard in which to design the database, it is believed that CIM will become more prolific in the future and this opens up the possibility of sharing data between stakeholders in a defined and consistent way. The initial design for NPADDs network data storage was presented to Northern Powergrid for discussion and mutually agreed.

However, it is not a requirement to use CIM within NPADDS if a future BAU product is better served by a different, bespoke format. Disadvantages of CIM include the comparatively large number of objects required to represent what is essentially a small number of parameters.

CIM background

The CIM structure is a way to describe network components and interconnections, and is simply an alternative to the way that network data is represented within software such as DEBUT, DINIS or IPSA2, or within data systems used by DNOs.

Figure 3.17 illustrates a portion of the CIM structure for unbalanced 3-phase components that has guided the development of NPADDS. In CIM, network components are described as an *Asset*, whether it is a section of cable, a fuse, a transformer, a consumer or anything else connected to the network. The *Asset* in turn belongs to a *PowerSystemResource*. This might for example be of the type *Conducting Equipment*, which is used to represent any components on the network that conduct electricity. Examples include a segment of *Conductor* (a cable or overhead line), any type of *Switch*, or an *Energy Consumer*. Generators are *Energy Sources*, although these are not shown in the diagram below.

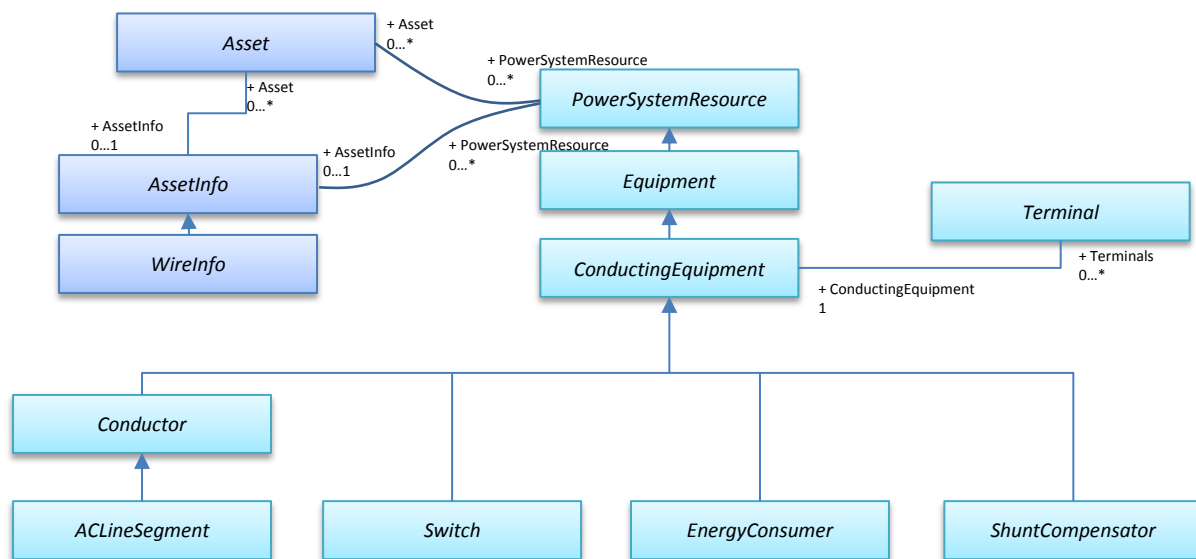


Figure 3.17 – CIM structure snapshot for unbalanced 3-phase components.

Each such piece of conducting equipment is associated with one or more *Terminals*, which are used to define interconnections to form a network. *Terminals* don't connect to each other. Instead, a *Terminal* is associated with a specific *Connectivity Node* that represents any node in a graph. Two *Terminals* associated with the same *Connectivity Node* will create a connection between the relevant *Conducting Equipment* objects.

An example piece of CIM network that connects a load (a type of *Energy Consumer*), breaker (a type of *Switch*), and an AC line segment (a type of *Conductor*) is illustrated in Figure 3.18.

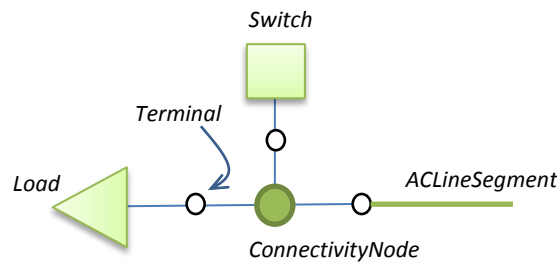


Figure 3.18 – CIM example showing *Conducting Equipment*, with *Terminals* associated with a *Connectivity Node*.

CIM used in NPADDs

In practice, the use of CIM in NPADDs manifests as a set of SQL data tables within the Oracle Spatial database. A data table characterises a particular CIM object, with a column for each of that object's properties. Rows then represent individual instances of such an object. Figure 3.19 illustrates this for *Terminal* objects.

	IDENTIFIEDOBJECTID	SEQUENCENUMBER	CONDUCTINGEQUIPMENTID	CONNECTIVITYNODEID	CONNECTED	SITEID
109	85963167	2	85963160	85840576	1	85640542
110	85963168	1	85963169	85840599	1	85640542
111	85963176	2	85963169	85840577	1	85640542
112	85963177	1	85963178	85840578	1	85640542
113	85963185	2	85963178	85840599	1	85640542
114	85963186	1	85963187	85840598	1	85640542
115	85963194	2	85963187	85840578	1	85640542
116	85963195	1	85963196	85840605	1	85640542
117	85963203	2	85963196	85840673	1	85640542
118	85963204	1	85963205	85840603	1	85640542
119	85963212	2	85963205	85840605	1	85640542
120	85963222	1	85963223	85840580	1	85640542

Figure 3.19 – Example of CIM object definitions in the NPADDs Database (*Terminal* objects).

It is necessary to convert network data between CIM and other formats, where NPADDs interfaces with external inputs or software:

Network input: Importing portions of Northern Powergrid's network into NPADDs involves translating that data into the appropriate CIM objects. As is described below, in the prototype development portions of this translation work were manual processes as opposed to fully automated.

External software interfaces: Similarly, each time NPADDs sends a piece of network to an external software tool such as DEBUT or IPSA2, it fetches information stored as CIM objects within the NPADDs Database and converts it to the particular format that is required by the load flow engine.

Within NPADDs itself, CIM objects are used directly with no translation needed. The application code, written in C#, essentially fetches CIM objects from the NPADDs Database and creates equivalent versions in C# in order to access data and carry out tasks.

The prototype does not utilise the full set of objects defined by CIM. So far it includes a subset that is directly relevant for the functionality that has been implemented, as listed in Table 3.3 below. With the CIM framework in place, object classes can then be added to suit further development of NPADDs. A full product version is likely to be required to represent for example LV link boxes and fuses; the structure to implement this already exists, alongside the methodology to do it.

Conversely, the NPADDs Database only makes use of the CIM format where relevant. This keeps the software fit for purpose rather than shoehorned into a particular representation. Data such as assessment results and consumer type definitions are stored in bespoke tables, for instance.

Finally, CIM allows for flexibility in the extension of object definitions. This feature has been used in NPADDs in order to, for example, ensure that cable segments can be displayed to the user in the Visual Design Environment as belonging to a particular feeder.

Data stored in the prototype NPADDs Database are described below.

Connectivity and supporting structures	Network components
<ul style="list-style-type: none"> • <i>Connectivity Node</i> • <i>Terminal</i> • <i>Measurement</i> • <i>Analog</i> • <i>Discrete</i> • <i>Location</i> • <i>PositionPoint</i> • <i>Length</i> • <i>PowerSystemResource</i> • <i>Equipment</i> • <i>ConductingEquipment</i> • <i>Asset</i> • <i>AssetInfo</i> • <i>WireInfo</i> 	<ul style="list-style-type: none"> • <i>Conductor</i> • <i>ACLineSegment</i> • <i>NPADDsACLineSegment</i> (extension of <i>ACLineSegment</i>) • <i>Switch</i> • <i>EnergyConsumer</i> • <i>PowerTransformer</i> • <i>PowerTransformerEnd</i> • <i>TransformerEnd</i> • <i>TapChanger</i> • <i>RatioTapChanger</i> • <i>Reactance</i> • <i>Resistance</i> • <i>Susceptance</i> • <i>EnergySource</i>

Table 3.3 – CIM object classes used in NPADDs.

3.3.2 Network Components in the NPADDs Database

This section describes how a network is represented within NPADDs at LV and HV, and hence what input data is required from DNOs in order to carry out assessments. Data is structured differently at LV and HV levels, reflecting differences in network design as well as in load flow practices within the DEBUT/EGD and IPSA2 tools.

Cables

NPADDs cables are defined on the basis of a set of standard types, in a similar manner to both DEBUT and DINIS. A cable object that is specific to the individual network is stored in the Network Database with a set of properties that describe its place within the network, and is then defined as being of a 'type'. Definitions of those cable types – such as conductor material or impedance – is generic information and instead stored in the Configuration Database (in the case of HV), where they could be made available to edit by the user if desired.

Together, this information is used to generate input information for load flow engines, and is primarily captured through the main properties shown in Figure 3.20:

NPADDS Cables

- Coordinates of the cable start and end point
- Association with CIM *ConnectivityNodes* at each end, defining a connection with other components at those nodes
- A length, which NPADDs calculates based on the coordinates
- ID/name of the feeder and substation site that the cable belongs to
- Standard 'type' of the cable

Figure 3.20 – Main properties of NPADDs cables.

Cable types and properties

LV LV cable types refer to a list of cable descriptions listed in a ‘data file’ text file that DEBUT reads in as an input, shown in Figure 3.21, resulting in a straightforward interface for load flow assessments. The standard DEBUT list of cable types is used as a starting point by NPADDS, and was extended to include additional Northern Powergrid cable definitions.

In the prototype, the list of cable types in the DEBUT 'data file' was amended manually. In a BAU version, however, it would be possible to allow the user to add or edit cable types within the user interface, and for NPADDS to then reconfigure the file automatically.

HV At HV, NPADDs defines cable types in a format that mimics DINIS, shown in Figure 3.22, and stores the cable type definitions in the Configuration Database. This suits the interface with the external IPSA2 engine used for HV load flow, which takes as input the particular impedance value for the full length each branch. NPADDs calculates and stores these impedance values, based on the length of the individual cable and its cable type, and passes them to IPSA2 when running an HV assessment.

In the case of both LV and HV, cable types are defined using static ratings and those values are used for load flow assessments. At LV, NPADDs is also capable of assessing an individual cable segment's cyclic rating and comparing this against its daily loading (Section 3.8.1).

CABLES									
! TYPE	SIZE	COST (P)	RATING (AMPS)	OPERATING RESISTANCE		FAULT RESISTANCE		FAULT REACTANCE	
				PHASE (MILLIOHMS/M)	NEUTRAL (MILLIOHMS/M)	PHASE (MILLIOHMS/M)	NEUTRAL (MILLIOHMS/M)	PHASE (MILLIOHMS/M)	NEUTRAL (MILLIOHMS/M)
AL	0.0225	1	84	2.0672	2.0672	2.5633	2.5633	0.0750	0.0750
AL	0.025	1	88	1.8605	1.8605	2.3070	2.3070	0.0750	0.0750
AL	0.04	1	112	1.1628	1.1628	1.4419	1.4419	0.0750	0.0750
AL	0.05	1	125	0.9302	0.9302	1.1535	1.1535	0.0750	0.0750
AL	0.06	1	135	0.767	0.767	0.952	0.952	0.075	0.075
AL	0.08	1	158	0.5814	0.5814	0.7209	0.7209	0.0750	0.0750
AL	0.1	2	185	0.456	0.456	0.596	0.569	0.073	0.073

Figure 3.21 – Format of DEBUT cable type definitions, used by NPADDs.

LINECODEID	NAME	R	X	B	ZR	ZX	ZB	NOMKV	NORMAL	HOT	COLD	AVAILABLE
2375414	95mm_cu_ug_oil_66kv	0.00432200015	0.00243599996	0.00400000006	0.0000100000005	0.0000100000005	0	66	295	295	295	1
2375415	95mm_cu_66kv_ip_3c	0.00420419991	0.00534950018	0.00382999986	0.00100000001	0.00100000001	0	66	275	275	275	1
2375416	120mm_cu_ug_of_66kv	0.00351200014	0.00220200002	0.00476000011	0.0000100000005	0.0000100000005	0	66	330	330	330	1
2375417	120mm_cu_66kv_ip_sc	0.00316199988	0.00404350013	0.00437999994	0.00100000001	0.00100000001	0	66	350	350	350	1
2375418	150mm_cu_ug_66kv_sc	0.00280000001	0.00219999999	0.00680999994	0.0000100000005	0.0000100000005	0	66	400	400	400	1
2375419	150mm_cu_ug_66kv_3c	0.00284700006	0.00208900005	0.00547999978	0.0000100000005	0.0000100000005	0	66	370	370	370	1
2375420	150mm_cu_66_sc_XLPE	0.00606100023	0.00505100012	0.00205300003	0.0000100000005	0.0000100000005	0	66	335	335	335	1
2375421	185mm_cu_ug_66kv_sc	0.00223000005	0.00215000004	0.00698000014	0.00100000001	0.00100000001	0	66	450	450	450	1
2375422	185mm_cu_66_sc_XLPE	0.00293847561	0.00314508736	0.00218999997	0.00100000001	0.00100000001	0	66	430	430	430	1
2375423	185mm_cu_ug_of_66kv	0.00227500007	0.00199000001	0.00612999976	0.0000100000005	0.0000100000005	0	66	415	415	415	1
2375424	240mm_cu_ug_66kv_sc	0.00170000002	0.00209000006	0.00768000007	0.00100000001	0.00100000001	0	66	510	510	510	1
2375425	240mm_cu_ug_of_66kv	0.00173099995	0.001919	0.00680999994	0.0000100000005	0.0000100000005	0	66	480	480	480	1

Figure 3.22 – Format of HV cable type definitions, mimicking DINIS.

Cable references to feeders and substations

Neither feeders nor substations technically exist in the NPADDs prototype. That is, feeders exist purely in the sense that NPADDs can group together cables that are associated with the same feeder ID/name, for example to plot voltages along the length of a feeder in the Network Headroom Engine. The cable CIM objects in NPADDs have been extended in order to accommodate such references.

- LV The prototype assumes that LV networks are radial, such that each cable segment belongs to a single feeder and substation in a straightforward manner.
- HV At HV, software such as DINIS do not specify a cable as belonging to a certain HV substation, as the network configurations can change when switches are opened or closed. NPADDs on the other hand does identify HV cables as belonging to a specific feeder and substation site. The former is achieved using a dynamic algorithm that identifies separate feeder branches within a particular network configuration, as given by opened and closed switches. This is implemented by the software traversing HV feeders, and ‘collecting’ cable segments that belong to a particular feeder until an open point or a substation bus bar is reached. If a user operates a switch to change the network configuration for an assessment, NPADDs responds by recalculating the new feeder designations.

Transformers and substations

NPADDs focuses on representing individual electrical assets such as transformers, rather than built units such as a substation. Components within a substation are represented as follows at each voltage level, as illustrated in Figure 3.23.

- LV NPADDs assumes one LV transformer per substation, with a simple set of properties.
- HV Substations at HV are represented as individually defined transformers, bus bars, and in-and out feeds, as in DINIS; NPADDs represents the latter two as cables. EHV (Extra High Voltage) supply points are not represented as CIM objects in NPADDs, but are simply handled as a default slack bus when running an IPSA2 assessment.

Transformers are defined in the same way at HV and LV, as individual objects in the Network Database without references to standard ‘types’ and with the main properties listed in Figure 3.24.

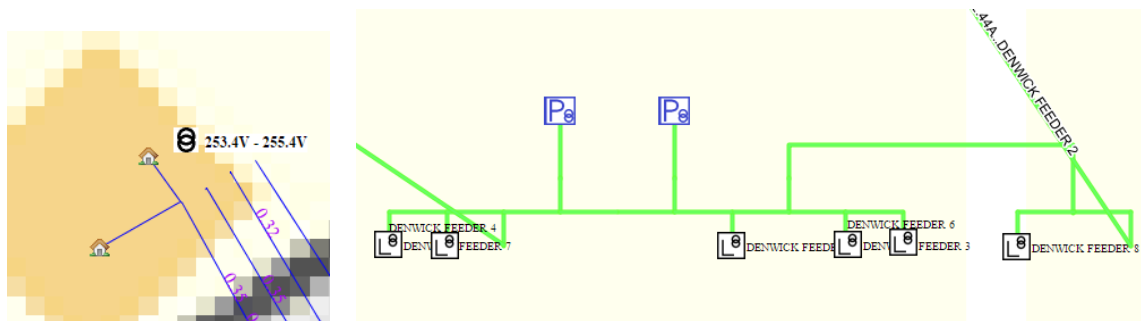


Figure 3.23 – NPADDs representations of substations at LV (left) and HV (right). At LV, feeders lead up to a single transformer. At HV, several transformers shown as blue P symbols are modelled along with the bus bar and HV feeders. (LV transformer symbols are also present at the HV substation; these represent HV feeders that have not been fully incorporated into the NPADDs prototype and are therefore modelled as arbitrary loads.)

NPADDs Transformers

- Coordinates of the transformer location
- Association with a CIM *ConnectivityNode*, defining a connection with other components at those nodes (typically several outgoing cables at LV, or a cable connecting to a busbar at HV)
- Transformer rating
- Tap changing ratio

Figure 3.24 – Main properties of NPADDs transformers.

Transformer properties

Transformers at both LV and HV are defined using static ratings, and those values are used for load flow assessments. At LV, NPADDs is also capable of assessing an individual transformer's winding temperature profile that results from its daily loading (Section 3.8.2), as modelled by NPADDs.

LV A rating has been assigned to all LV transformers in the NPADDs prototype. DEBUT currently uses the rating property solely to calculate the utilisation of the asset.

A default tap ratio has similarly been assigned to all LV transformers. NPADDs utilises the transformer tap changing ratio to modify the LV side voltage level of the transformer that is given to DEBUT as an input. When a HV assessment has been previously carried out and saved, the voltage at the HV side of the secondary transformer is always used as a starting point and reduced by the tap changing ratio. Where no such assessments are available, DEBUT simply uses a default value for the LV side voltage. The impact of this can be seen at the transformer voltage levels in plots such as Figure 3.48.

HV At HV, all transformers have individual ratings as given by data from Northern Powergrid. NPADDs uses this value, along with the power flow at the transformer given by the IPSA2 load flow assessment, to assess the transformer's utilisation level.

Switches

NPADDs currently defines switches for use in HV only, and stores these object definitions in the Network Database with the main properties shown in Figure 3.25:

NPADDs Switches

- Coordinates of the switch location
- Association with a single CIM *ConnectivityNode*, defining a connection with other components (typically cables) at those nodes
- An opened/closed state

Figure 3.25 – Main properties of NPADDs switches (HV only).

The user is able to temporarily alter the state of a switch in order to simulate an n-1 case or to reconfigure a network area to include only certain parts in an analysis. Such alterations are stored in run-time memory, and are currently discarded at the end of that particular assessment. (See Section 3.5.6 on the ability in NPADDs to save network reconfigurations and assessment results).

Consumers

NPADDs stores consumers as CIM objects with a number of properties, in an Oracle-based format that provides the flexibility and opportunity to extend consumer definitions to incorporate modern approaches to customer classification. As evidence and data sources become available, properties can be added that define demographics and behaviour with respect to consumption patterns and LCT uptake in particular.

As a starting point within the NPADDs prototype, consumers have been defined using somewhat different methods at LV and HV:

- LV Consumers at LV are defined with reference to a set of standard consumer types, in a similar manner to DEBUT. A consumer object that is specific to the individual network is stored in the database with unique properties that define its location in the network, and described as being of a particular ‘type’. Definitions of consumer types is, in turn, generic information and instead stored in the Configuration Database, where they could be made available to edit by the user if desired.

Together, this information is used to generate input information for load flow engines, and is primarily captured through the main properties shown in Figure 3.26.

NPADDs Consumers - LV

- Coordinates of the consumer's location
- Association with a CIM *ConnectivityNode*, defining a connection with other components at those nodes (typically a service cable)
- Standard 'type' of the consumer

Figure 3.26 – Main properties of NPADDs consumers at LV.

HV At HV on the other hand, consumers are defined as individual objects each with their own demand properties stored in the Network Database, with no reference to standard types. This is more in line with how loads are represented in software such as DINIS, and includes the main properties shown in Figure 3.27. For a BAU product, it may be desirable to implement standard consumer types at HV, primarily for the purpose of categorising HV consumers into different activity classes.

NPADDs Consumers - HV

- Coordinates of the consumer's location
- Association with a CIM *ConnectivityNode*, defining a connection with other components at those nodes (for loads representing LV substations, this may be several feeders)
- Single demand figures that represent "rating", "thermal demand indicator" value, and "actual load"

Figure 3.27 – Main properties of NPADDs consumers at HV.

The specifics of these arrangements are described below, followed by a discussion of future implementation of demographic properties.

Consumer types and profiles

NPADDs features Time of Use (TOU) network assessments at both LV and HV, on a half-hourly basis (see Section 3.5 for further details). At HV, worst-case assessments have also been implemented. Both winter and summer days are considered in most assessments, motivated in particular by the ability to analyse voltage rise in the summer as a result of solar PV generators.

LV Standard LV consumer types are defined in a format that encompasses that used by DEBUT (Figure 3.29) with a few adjustments, which results in a straightforward interface for load flow assessments.

NPADDs uses DEBUT's regular list of consumer types as a starting point, which consists of a customer code associated with a TOU daily half-hourly profile shape. When carrying out the load flow analysis DEBUT scales the profile shape by a consumption factor, given for each individual consumer and effectively treated as an annual demand. This produces an actual

power demand at each half-hourly interval (which DEBUT then scales further to account for diversity, see Section 3.5.3). In the NPADDs prototype, the consumption factor is currently a property of the consumer type, which means all consumers of the same DEBUT consumer type will present the exact same consumption pattern. The type has also been fleshed out with a written description, for improved user friendliness within the user interface. Thus, an NPADDs consumer type is defined by the main properties shown in Figure 3.28:

NPADDs Consumer types - LV

- DEBUT consumer code
- Consumer category description
- Winter and summer weekday half-hourly profile shapes
- Winter and summer consumption factors

Figure 3.28 – Main properties of NPADDs consumer types at LV.

NPADDs currently makes use of winter weekday profiles provided within DEBUT. There are placeholders for several other values, such as Sunday lunchtime, which can be readily incorporated if such data is available.

Summer profiles are however not used by DEBUT. When the NPADDs prototype runs a summer assessment, each consumer is simply redefined as the ‘summer’ version of its type. Summer profiles have been specifically created for the two domestic consumer categories that are currently in use – URM (Unrestricted Tariff and Medium Consumption) and Economy7 (which offers a cheaper tariff at night) – by adding new consumer type definitions within the ‘data file’ text file that DEBUT takes as input.

The use of summer profiles illustrates how NPADDs is able to use DEBUT and EGD with the flexibility of extended or updated consumer information. Adjusted load profiles that represent Demand Side Response (DSR) have been implemented in a similar manner to facilitate the analysis of that headroom solution, as described in Section 3.7.2. Another example of such functionality is the adding of ‘consumer types’ that represent individual LCT loads (described below), as a way of incorporating future consumer behaviour.

Presently, the DEBUT ‘data file’ has been manually updated with such new profiles. However profile shapes are also stored in the Configuration Database. In a BAU version, it would be possible to enable users to edit or create a profile via a user interface, whereupon NPADDs would automatically reconfigure the DEBUT ‘data file’. As a result, as output from LO1 and LO2 gives a greater understanding of how customer load is changing, for example, any new profiles could be uploaded, allowing the user to run assessments based on the likely load in future years.

URLC									
0.102	0.238	0.065	0.202	0.048	0.153	0.039	0.156	0.037	0.140
0.035	0.136	0.038	0.131	0.039	0.136	0.041	0.137	0.047	0.145
0.062	0.241	0.073	0.231	0.096	0.235	0.132	0.264	0.172	0.275
0.211	0.329	0.234	0.371	0.221	0.339	0.234	0.344	0.212	0.342
0.202	0.354	0.181	0.308	0.178	0.307	0.179	0.303	0.189	0.309
0.176	0.298	0.164	0.271	0.155	0.253	0.156	0.258	0.154	0.280
0.161	0.285	0.174	0.318	0.211	0.314	0.245	0.330	0.323	0.388
0.356	0.489	0.377	0.388	0.361	0.338	0.346	0.352	0.329	0.325
0.330	0.319	0.337	0.343	0.337	0.336	0.322	0.360	0.297	0.359
0.250	0.333	0.213	0.344	0.157	0.297	0.331	0.402	0.329	0.460
0.282	0.446	0.239	0.394	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 3.29 – Example of DEBUT consumer type definition.

HV A different structure is used to represent consumer types at HV. This is mostly due to design practices at HV. An individual value for each load is used rather than just a class or a type. Similarly, as opposed to DEBUT, the IPSA2 power flow software takes a single power consumption value as input for a consumer node, with no reference to categories of consumer types or temporal profiles.

On this basis, NPADDs defines each HV consumer object with its own specific load size, stored in the database. Two values for the load size can be stored, with corresponding fields in DINIS:

- “Rating”: The rated capacity at the load connection
- “Thermal demand indicator”: The highest demand measured for a consumer

These are illustrated in Figure 3.30. For the purposes of BAU, an “Actual load” field has also been added, as in DINIS, to allow this to be populated with measured data.

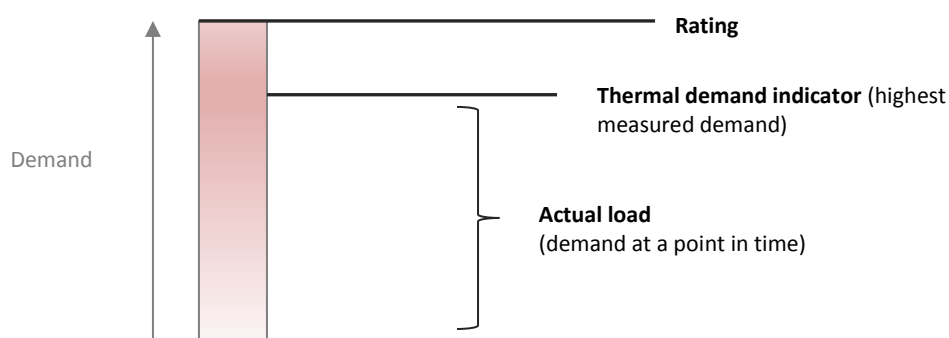


Figure 3.30 – Relationship between “Rating”, “Thermal demand indicator” and “Actual load”.

During the process of running a network assessment, two additional ways are available to define a HV load size:

- NPADDs provides the option of a built-in HV load allocation algorithm, which apportions a load chosen by the user (e.g. SCADA data) across the consumer nodes with reference to the load sizes above.
- By clicking on a specific load, the user can also provide a user-specified demand value that is used within that one assessment but not stored permanently in the NPADDs Database.

NPADDs provides the user with the choice of which of these inputs to use for a network assessment. For a 'worst case' study, the individual values are used on their own. For TOU analysis, the selected load value is replicated across each of the half-hourly intervals. Section 3.5.4 describes all these features further.

Summer load at HV is represented in the prototype simply by taking a certain percentage of the selected load value above. The percentage is currently set at 10%, but would be made user configurable in a BAU NPADDs version. The scaling procedure is performed at the time of passing load data to the IPSA2 load flow engine, rather than storing the summer demand levels in the NPADDs Database.

Finally, LV substations are a specific type of load at the HV level, and currently represent the only genuine TOU demand data within a HV assessment. LV substations exist as a HV consumer object, with demand size properties as above. However, they may also include TOU load profiles for winter and summer, taken from the most recent LV network assessment that is stored in the NPADDs Database, if available, as well as the corresponding worst-case values. NPADDs is thus able to link LV and HV analysis, as discussed further in Section 3.5.2.

LCT loads (LV)

NPADDs includes the ability to assess how LCT loads impact on network headroom at the LV level. Electric Vehicles (EVs) and Heat Pumps (HPs) are represented in the prototype as proof-of-concept of the methodology:

- LV LCTs are represented in NPADDs as consumer objects described above, connected at the same node as the regular consumer who owns the technology. An EV and a HP have been added to the list of standard DEBUT consumer types, with associated half hourly consumption shapes. Individual LCT consumer objects are then given a consumption factor, with which DEBUT scales the profile shape. Profiles of household base load and LCTs can therefore be kept separate, offering a flexible modular approach that builds up demand at each node from distinct components of demand. This enables potential future functionality, such as analysing sources of load on the network.

Half-hourly consumption profile shapes and consumption factors for EVs and HPs (such as Figure 3.31) are in use in NPADDs, in the same format as LV consumers described above.

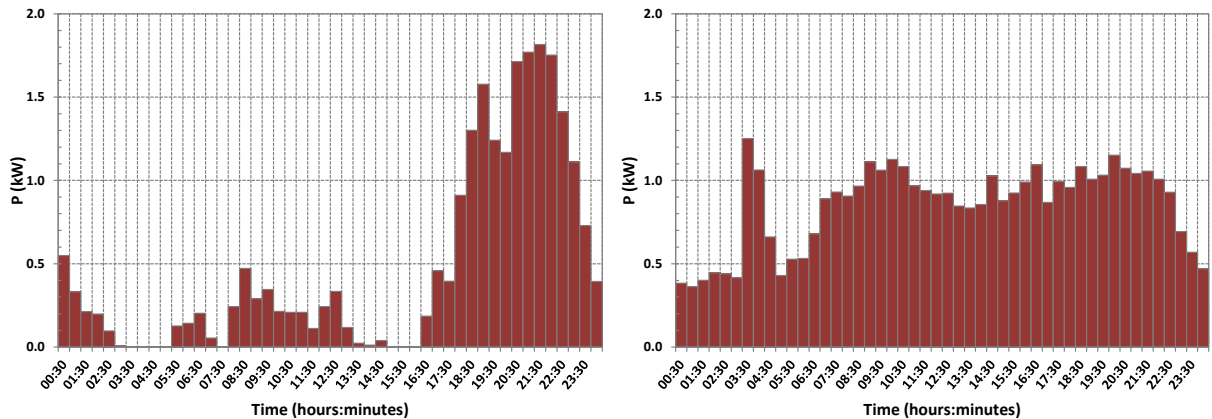


Figure 3.31 – CLNR EV (left) and HP (right) consumption profiles in winter.

Consumer phase connection

Individual consumers stored in the database are defined in terms of their location and connections within the network as described above. Phase connections are then handled as follows:

- LV DEBUT is designed to generate its own phase allocation of loads on the network in order to carry out a 3-phase unbalanced load flow assessment, using an algorithm that can distribute connection points evenly between phases.
- HV At HV, all loads in the prototype are currently described as balanced 3-phase loads, with no phase details required.

Consumer demographics

Consumer types could be revised or added in future versions of NPADDs based on a greater demographic granularity (provided that a data set is made available that classifies consumers in this manner) with the ability to carry out TOU analysis at both LV and HV. There is also sufficient proof-of-concept within the prototype to illustrate the potential to create industrial and commercial TOU demand profiles at the HV level, if such input data is accessible. Overall, this provides a level of confidence that it will be possible to adjust NPADDs to support future revisions to the ACE49 standard.

The Oracle Spatial database that makes up the NPADDs Database also comes with the flexibility to add fields and functions. CIM object definitions can be expanded upon within certain guidelines to suit the software needs. NPADDs can therefore be considered to include placeholders for additional customer information for future years, to represent demographics and consumer behaviour. These could be developed for a BAU product.

Recent work on the prototype has begun the process to include such demographics properties. Element Energy has completed work as part of a separate project to look into demographic and geographic factors that have an impact on load and generation. NPADDs provides a link to this work when estimating LCT uptake. Findings by Element Energy include probabilities of LCT ownership on the basis of location using postcodes, which NPADDs accesses via the postcode coordinate dataset

that has been stored in the Configuration Database. A consumer's coordinate location can be used to place it within a certain postcode, so that their LCT uptake behaviour can be tuned by the properties of that area. The LCT uptake algorithms in Section 3.6 are capable of taking this as input.

Generators

NPADDS generators are defined primarily as individual objects in the Network Database, with a partial reference to standard types at LV. Once again, the NPADDS Oracle-based format provides the flexibility to add properties and related functions; in the future this could be utilised to develop a more sophisticated supply model, for example adjusting solar PV output profiles on the basis of geographic location provided a suitable input data set is accessible, or creating a more formal set of generator types. Thus far in the prototype, generators are described by the main properties in Figure 3.32.

NPADDS Generators

- Coordinates of the generator' location
- Association with a CIM *ConnectivityNode*, defining a connection with other components at those nodes (typically a consumer or service cable)
- Generator capacity

Figure 3.32 – Main properties of NPADDS generators.

Generator properties and profiles

NPADDS features TOU network assessments at both LV and HV, on a half-hourly basis (see Section 3.5 for further details). At HV, worst-case assessments have also been implemented. Both winter and summer days are considered in NPADDS network assessments, motivated in particular by the ability to analyse voltage rise in the summer as a result of solar PV generators.

Generator output power levels are treated similarly to demand levels of consumers, with a somewhat different methodology at LV and HV which reflects the use of different load flow engines:

- LV Generation at LV is analysed using EGD rather than DEBUT. Similarly to DEBUT, generators are defined in EGD as having a rating, in addition to a type with corresponding profile shapes for winter and summer. EGD scales the profile shapes by the rating when running an assessment, to produce an actual power level generated at each half-hourly interval.

Thus far only solar PV generators have been implemented at LV in the NPADDS prototype; the software therefore makes the assumption that all generators are of the type solar PV, with a code and profiles as shown in Figure 3.33. For a BAU product, it is likely that generator types will be implemented more formally as for consumers, and that types beyond than solar PV will also be represented (for example microCHP).

NPADDs Generators types - LV

- EGD generator code
- Winter and summer weekday half-hourly profile shapes

Figure 3.33 – Main properties of NPADDs generator types at LV.

Solar PV standard profile shapes for winter and summer days are shown in Figure 3.34. Passing such profile information to EGD is more straightforward than to DEBUT, as EGD has been reproduced in C#.NET and incorporated into the NPADDs software. The profiles are stored in the NPADDs Database, and simply passed as code to EGD in order to run an assessment without the need for an intermediary text file. As for consumers, a future BAU version of NPADDs may enable the user to edit generator profiles via the user interface, so that updated profiles can be incorporated when relevant.

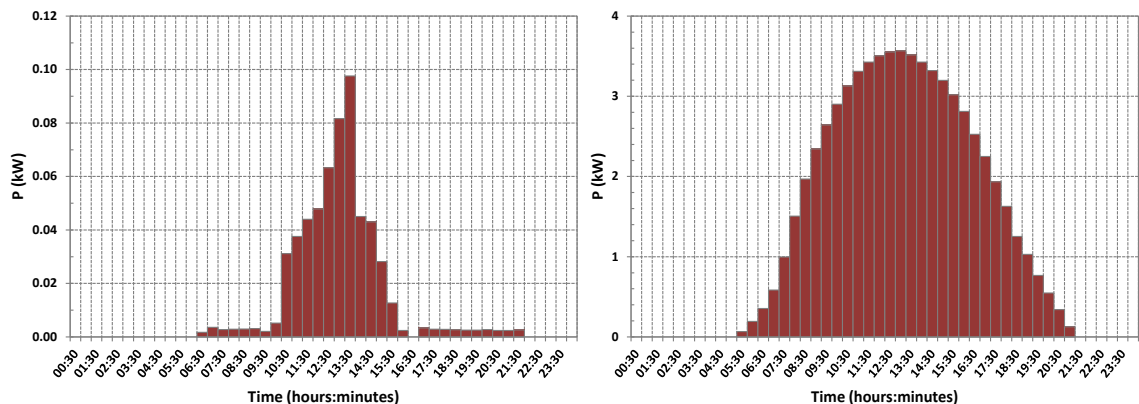


Figure 3.34 – CLNR solar PV output profile during winter (left) and summer (right).

HV As in the case of consumers, IPSA2 takes as input a single value that specifies power injected at a generator node, with no reference to categories of generator types. NPADDs generators at HV are similarly defined with a single rating value rather than a type, which is also assumed to be its power output. During a TOU assessment, as in the case of consumers, the generator rating is replicated across each of the 48 time intervals. Generators are assumed to have the same output in winter and summer; in a BAU product it would be desirable to enable these to be different, in a way that is configurable by the user.

Any HV generators analysed in the NPADDs prototype are those that a user has added temporarily within the “New Connections Request Assessment”. Under those circumstances, NPADDs asks for a generator rating to be used as above.

Generator phase connections

As in the case of consumers, while the generator location is given by the properties listed above, the phase connection is handled separately as follows:

- LV EGD is designed as an add-on to DEBUT, and is designed to inherit DEBUT's phase allocation. When an assessment is complete, DEBUT produces a text file with input data for EGD, which includes the phase allocation of each consumer in the network. NPADDs reads in and passes the contents of this file to pass its internal version of EGD and, knowing which consumer a LV generator belongs to, ensures to give the generator the same phase allocation as the consumer.
- HV At HV, all generators in the prototype are currently described as 3-phase generators, with no phase details required.

3.3.3 Additional Data (The Configuration Database)

The Configuration Database also holds additional data that supports the various assessment functions. The key categories of such data are:

Previous assessment results: NPADDs currently stores results from all previous network headroom assessments. Data stored includes voltages and currents across the network at the smallest granularity that the assessment was carried out at, i.e. TOU values are stored following a TOU assessment. In a BAU product, it is likely that a more discriminating procedure will determine which results will be saved.

Assessment settings: Threshold settings that determine acceptable limits on voltage levels and thermal headroom, discussed in Section 3.2.1, are stored here. When such settings become editable by the user in a BAU version of NPADDs, any changes made by the user would get saved by overwriting the stored values.

Transformer Thermal Modelling properties: The Transformer Thermal Modelling tool described in Section 3.8.2 requires a set of input data for each transformer in the network. A default input data set has been stored in the Configuration Database. Each transformer also has an entry within this section of the database (in anticipation of the creation of standard transformer types in the NPADDs transformer object structure) with its own unique set of input values, which are saved each time the user amends them when running an assessment. The user can choose to return these to the default values.

Cable modelling in Crater Lite: NPADDs stores a table in the Configuration Database that links standard LV cable types used for DEBUT load flow assessments to the specific set of cable types used by the Crater Lite software (Section 3.8.1). The structure of the table exists, although for the purposes of the prototype all DEBUT cable types point to the same Crater cable.

Solutions templates and TRANSFORM data: The Configuration Database stores the parameters associated with each of the 'Solution Templates', as well as additional data associated with the TRANSFORM model. When the user edits a Solution Template (Section 3.2.1), the new value is saved permanently here.

OS Street View data: The map tiles that are used to display street maps in the NPADDs Visual Design Environment have been downloaded and stored within the Configuration

Database, where they are accessed by Oracle Map Viewer. A new download could be carried out in future in order to incorporate updated street data into NPADDs.

DECC and Element Energy forecasts: LCT uptake figures derived from DECC scenarios and Element Energy's load model are stored here, and accessed by the NPADDs Load and LCT Forecasting Engine when carrying out simulations.

Postcode coordinates: A dataset that links each UK postcode to a coordinate has been downloaded into the NPADDs Database. It is accessed here by for example the network area search where the user enters a postcode to bring up a certain area of the UK map.

Policy clauses: As part of the CLNR project a set of Northern Powergrid policy documents have been broken down into separate clauses. These clauses are stored as text within the Configuration Database, alongside references to the file name of the original document and its location on the NPADDs server. The NPADDs Policy Compliance Engine bases its search on this input data.

3.3.4 Importing Northern Powergrid Networks

A set of samples of Northern Powergrid's network areas have been incorporated into the NPADDs prototype, and are currently available to be analysed for the purposes of software development and demonstration. The prototype therefore does not provide automated input of network details from existing DNO network databases, which would be required in a BAU version. That constitutes a substantial and challenging development task, as the data sources are typically bespoke for the specific applications that use them and do not conform to accepted or modern standards.

Data sources for the sample network areas include LV Design (LV), DINIS (HV), and GIS files (LV) as described below. For BAU, it is expected that NPADDs would instead take data direct from Northern Powergrid's implementation of Oracle Spatial/eAM, which is likely to present a different situation and require somewhat different methods.

Still, the processes to incorporate networks into the prototype have provided important learning. The steps and methods offer an indication the types of procedures that need to be automated, and issues that need to be resolved, depending on the format of the input data at LV and HV. They are therefore described in some detail below, for illustration purposes.

Manual intervention required to edit and verify these conversions, before an assessment is possible, has consequences for NPADDs ability to automatically import up-to-date network models. However, the methods below provide a degree of confidence that it would be possible to develop solutions and methodologies as part of NPADDs to handle automated updates.

The sample networks are 'test cells' within the CLNR project and belong to four classifications of data formats: LV North, HV North, LV Yorkshire, and HV Yorkshire. All of Northern Powergrid's networks from the northern licence area were successfully incorporated into the NPADDs prototype, however it is only possible to run assessments on the CLNR test cells, as these network areas have had manual intervention (e.g. data cleansing) to allow them to be assessed.

HV and LV networks areas shown in Table 3.4 have been partly or entirely incorporated into the NPADDs prototype:

<i>Licence area</i>	<i>HV test cells</i>	<i>LV network areas</i>
North	Denwick	Wooler Bridge Wooler Ramsey Wooler St Mary
	Rise Carr	Darlington Melrose Harrowgate Hill High Northgate
	High Barmston	(n/a)
	(n/a)	Sidgate Lane
Yorkshire	(n/a)	Maltby

Table 3.4 – HV test cells and associated LV network areas incorporated into NPADDs prototype.

LV North: LV Design data

A design package called LV Design is used in the northern licence area, with source data from a variety of databases. When running an assessment, LV Design exports the network data to a DEBUT Fortran engine using a text file export routine.

NPADDs does not make use of LV Design, and interacts with DEBUT directly. As part of the prototype development, the semi-automated method below has been developed to convert the LV Design network data, which was provided as .CSV files, into CIM objects held within the NPADDs Database. To carry out a DEBUT assessment NPADDs then translates that data directly into the appropriate input text file format.

Translation of LV Design data was carried out using SQL database scripts, by reading in .CSV files and re-creating the listed cables, consumers and generators in those files as a CIM object in the NPADDs Database.

Cables

Cable data was provided in a tabular format with fields and example values as listed in Table 3.5. The data set describes two key features: network layout and type of cable used within each segment of the network.

Field	Example data
Substation Asset ID	6506
Substation Full Name	FERRYHILL RAMSAY
Feeder ID	154344
Feeder Name	WYNYARD VILLAGE LV FEEDER C
Cable Section ID	2685852
Cable Section Number	-
Cable Section Usage	SERVICE
Point Order	1

X (Coordinate)	433806.565
Y (Coordinate)	527154.727
Cable Type	185_AL_PILC
Conductor	ALUMINIUM
CSA	185MM
Number of Cores	4
Phasing	RYB
Length of Type	11.4

Table 3.5 – LV North cable input data format.

Cable types and properties: The standard DEBUT list of cable types is used as a starting point in NPADDS. However, not all of Northern Powergrid’s cable designations can be directly matched to these pre-existing types. In these cases the approach was taken to alter the DEBUT list by adding a new cable type with associated properties. This process was partly manual, as the properties of a new DEBUT-style cable had to be investigated and created, but is a one-off task.

For some service cables within the Northern Powergrid data no cable type had been specified. In this case the NPADDS prototype allocates a default type (HYBRID 35).

Connectivity: Connectivity in CIM format is described in terms of each end of a cable being associated with a *Connectivity Node*, which effectively represents a node in the network graph. In the LV Design cable data, on the other hand, the intersection between mains cables and service cables is not specifically accounted for; a cable of type ‘MAINS’ is described as going from coordinates A to C, even if there is a cable of type ‘SERVICE’ that has a starting coordinate B halfway along that mains cable. Here, the NPADDS import methodology therefore includes code that identifies coordinates where a service cable intersects a main cable. It then splits that mains cable into two segments at a *Connectivity Node*, as shown in Figure 3.35. Other connectivity information is then mapped in a straightforward manner into the NPADDS Database, such as which substation and feeder each cable belongs to.

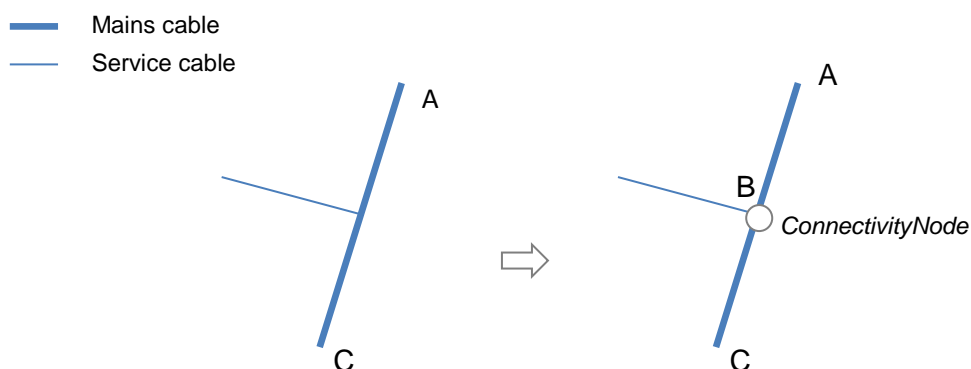


Figure 3.35 – Completing connectivity between service and mains LV cables.

Inconsistencies were found within the LV Design connectivity data, where some service cables did not quite connect up to the mains cables (with differences often of the order of

just a few centimetres). This required a degree of manual data manipulation and completion that would be very difficult to automate, taking 1-2 hours per LV service area. Once Northern Powergrid's Oracle rollout is complete, however, these types of problems likely would not be encountered by NPADDs.

Substations and transformers

No LV substation or transformer data from Northern Powergrid was used as input into the NPADDs prototype, apart from the Substation Asset ID and Substation Full Name properties available from the cable data.

Transformer properties: LV transformers were created as placeholder objects and given, in addition to location, a set of default properties with respect to rating and tap ratio.

Connectivity: Although not explicitly given in the cable data, the location of the LV substations (transformers) could be inferred from the pattern of cables congregating in a central location. In the NPADDs prototype, the transformer location was therefore defined manually via a visual inspection of the connected cables plotted on a map. Specific substation locations were given in the Generator data (below) but only for a small number of sites; these were therefore not used.

Other LV components

The LV Design network data includes components such as link boxes, fuses and circuit breakers. NPADDs currently does not represent these. However, they are defined much in the same way as cables, consumers and generators, and can in the future be included using a similar methodology and represented as CIM objects within the NPADDs Database.

Consumers

Consumer data was provided as tabular fields with example values as listed in Table 3.6:

Field	Example data
Substation Asset ID	6506
Substation Full Name	FERRYHILL RAMSAY
Feeder ID	154344
Feeder Name	WYNYARD VILLAGE LV FEEDER C
Cable Section ID	2685852
X (Coordinate)	433806.565
Y (Coordinate)	527154.727
MPAN Profile Class	Domestic Unrestricted

Table 3.6 – LV North consumer input data format.

Consumer types and properties: In the LV Design data, the consumer type is defined purely by an MPAN (Meter Point Administration Number) Profile Class. Each such class in the data set was successfully mapped to a standard DEBUT consumer type, in a process that required manual checking and confirmation; if no match had been found, a new consumer type could have been created in NPADDs. Where a customer type was specified as 'Not available', the

NPADDs prototype arbitrarily allocates a commercial consumer type (INDHLF), an assumption that can be altered if needed. Each consumer was given a default annual consumption factor as defined within NPADDs for each DEBUT consumer type.

Connectivity: In the LV Design data, a consumer has an associated ID of the mains cable segment they are connected to. No reference to the intermediary service cable is given. For the NPADDs Database, however, it is necessary to pinpoint the exact *Connectivity Node* at the end of the service cable where the consumer is connected. To achieve this, a method is implemented in the prototype that matches the customer coordinates with the end coordinates of a service cable.

Generators

Generator data was provided in a tabular format with fields and example values as listed in Table 3.7, for a fairly small number of units that included wind, solar PV, CHP and other forms of generation. The capability to import these into the NPADDs Database was demonstrated. However, within the particular sample LV North networks that was ultimately kept within the prototype, there were no generators connected.

Field	Example data
Generator Type	GENERATION - PHOTOVOLTAIC
Rating Info	12 amp
Premises X	447574900
Premises Y	515821700
Feeder ID	124492
LV Feeder Name	RIDGEWAY (YOR) LV FEEDER C
Substation Site ID	4601
Substation Name	BOOTHAM STRAY
Substation X	447680402
Substation Y	386347045

Table 3.7 – LV North generator input data format.

Generator properties: A generator is defined in the LV Design data by a type and a rating. The type is not yet used by NPADDs, in the sense that only solar PV was encountered and used. The rating was translated in a straight forward manner directly into the NPADDs generator object, with a conversion into kW where necessary.

Connectivity: The LV Design data includes coordinates of the premises where the generator is connected, allowing the NPADDs prototype to identify and associate the generator with the *Connectivity Node* that has already been created for the relevant consumer.

HV North: DINIS data

The source data for HV networks in the northern licence area was provided as text files, in the format used by the DINIS load flow engine. Two files are used: a description of network components and their interconnections, and a description of the cable types (DINIS “line code”).

With the exception of the line code, extracting network data in the DINIS format is more complex than the case of LV North. Rather than plain columns of data, DINIS text files contain groups of

different types of network components with varying and fairly complex data formats separated by “|” symbols. NPADDs code that carries out this translation was therefore written in C#.NET rather than as SQL database scripts. The DINIS network text file format is not described in detail here as it requires substantial explanations. Field definitions and examples can instead be found in DINIS documentation.

Once the input text files have been parsed, however, the HV North network data is more straightforward to incorporate into NPADDs. Every node is represented, providing start and end points of different components to implement as CIM object *Connectivity Nodes*.

For the purposes of prototype development a subset of the HV feeders within each network area was implemented. Feeders not modelled in detail are represented by an arbitrary load at the substation.

Cables

DINIS line code was provided in as tabular fields with example values as listed in Table 3.8:

Field	Example data
Type	.025_cu_oh_11kv
R	1.51110992
X	1.08611
B	0
ZR	0.709000015
ZX	4.38
ZB	0
NomkV	11
Normal	191
Hot	165
Cold	206

Table 3.8 – HV North cable input data format (DINIS line code).

Information about individual cable segments was then provided within the network text files, where they are represented as “line records” with reference to a cable type in the line code file. An example line segment is shown below in Figure 3.36. Additionally, the “node records” in the DINIS format (Figure 3.37) provide the nodes, or *Connectivity Nodes*, that link cables into a network. Together, this was used to generate NPADDs cable objects.

An example of a line record for a multi-segment line:

```
LN132|2|2||0|0|||||||0|0|||442.7|1.0|0|EDSE0050HS|1|1|0|0|0|0...
...|0.0|0.0|0.0|2|438.7|0|0|524837864|16504582|525276579...
...|165045842|524837864|165045842|525276579|165045842...
...|438.7|11_cables|EDSE0050HT|4.0|11_cables|EDSE0050HU|0.0|0.0|
```

Figure 3.36 – HV North data format (DINIS line record).

If a DINIS symbol called Ld_Gen is defined to consist of a load and a generator the following would be a valid layout for a node record:

```
[ND108|423190000|563620000|0|0|LD_GEN|||62950|305|...  
BB RYB|433|||LD77| load fields |GN129| generator fields...  
|TX118| text fields |TX118| text fields |
```

Figure 3.37 – HV North data format (DINIS node record).

Cable types and properties: DINIS cable types listed in the line code were translated using a straight-forward mapping process into NPADDs CIM cable types, with similar impedance and rating data fields. A DINIS cable segment that referred to a particular cable type in the DINIS line code would therefore refer to the same type of cable type in NPADDs expressed as a CIM object instead.

Connectivity: DINIS line records were directly translated into cables and *Connectivity Nodes* in NPADDs, with location given by the coordinates. As in DINIS, an NPADDs CIM cable object can consist of several ‘twists and turns’ before reaching its end point.

Substations and transformers

Substation data – in the form of individual transformers, bus bars, in-feeds and EHV grid supply – is represented in the DINIS network text files within “node records” and “line records” respectively, similar to those shown in Figure 3.36 and Figure 3.37. This was used to generate NPADDs transformer objects as below, as well as cable objects for bus bars and in-feeds in a similar way as described in the section above.

Transformer properties: Transformer ratings were translated in a straight-forward manner into the corresponding property of the NPADDs CIM transformer object. Tap ratio data was also available and could be imported in a similar fashion in a BAU product, as required, but is currently not used within the prototype.

Connectivity: Locations and connectivity of individual transformer objects in NPADDs were taken directly from the coordinates of the relevant node record, and by associating the transformer with the relevant *Connectivity Node*.

Switches

Switches are represented in the network text files within “node records”, similar to that shown in Figure 3.37.

Switch properties: Switches are defined as opened or closed in the DINIS data. This setting was mapped directly across to the NPADDs switch object.

Connectivity: Locations of switch objects in NPADDs were taken directly from the coordinates of the relevant node record, and by associating the switch with a *Connectivity Node* at that location.

Consumers

Consumers are represented in the network text files within “node records”, similar to that shown in Figure 3.37.

Consumer properties: DINIS consumer characteristics are defined by fixed measures of the load size. Two of the types of load sizes in DINIS are also represented within NPADDs, and so are mapped directly across to the NPADDs CIM consumer object: “thermal demand indicator”, and “rating”.

Connectivity: Locations of consumer objects in NPADDs were taken directly from the coordinates of the relevant node record, and by associating the consumer with a *Connectivity Node* at that location.

LV substations are also represented as consumers. As NPADDs has implemented a link between LV and HV analysis (Section 3.5.2) it was necessary to map the HV load representation of each LV substation to its representation at the LV level. This was a manual process in the prototype, where the names of substation loads in DINIS were matched with the relevant transformer objects at LV based on the LV substation site names. A BAU product will most likely require this process to be automated.

Generators

No generators were present at HV in the Northern Powergrid sample networks. Had they been present, however, they would have been represented in the network text files within “node records”, similar to that shown in Figure 3.37. NPADDs would be able to use similar processes to those above to translate such generator definitions into NPADDs CIM generator objects.

LV Yorkshire: GIS (Graphic Information System) data

One Yorkshire LV network area has been re-created within the prototype. The Yorkshire LV area serves to demonstrate the concept of translating GIS data into NPADDs, and highlights how this task differs depending on network data format received from a DNO.

The GIS data was provided as three types of text files, with data relating to cables, usage (classifying cables as service or mains), and addresses (consumers) respectively. Work was required primarily to parse the complex formatting of these text files, with different formats required for each set of data. Once that work had been carried out, it was straight forward to use cable coordinates and type definitions to create corresponding NPADDs cables. The address (consumer) file however contained only consumer locations, with no reference to consumer types or consumption levels. NPADDs therefore had to assign an assumed type (URMC) to all consumers.

HV Yorkshire: DINIS data

Data for the Yorkshire licence area HV network was obtained from an export of data sources used by DINIS. This mimicked the HV North data set.

3.4 Workflows

The following section describes the NPADDs workflows that have been implemented as part of the prototype, demonstrating how the user is guided through the process of carrying out assessments on the Northern Powergrid sample networks. Use cases are presented along with the steps the user must, or can, take within the user interface when setting up such assessments.

Details of the analysis carried out by each type of Engine, including outputs and any related workflow steps, are described in each of the relevant Engine sections in the remainder of this report.

3.4.1 Use Cases

Figures below illustrate the use cases that form the core of the NPADDs prototype workflows:

- Existing Network Assessment, including new connections Solar PV tool (Figure 3.38);
- New Connection Request Assessment (Figure 3.39);
- Future Planning Assessment (Figure 3.40);
- Global Capacity Assessment (Figure 3.41)
- Thermal Properties Assessments of cables and transformers (Figure 3.42); and
- Policy Compliance Search (Figure 3.43).

NPADDs does not have user profiles within the software that require user specific logins; instead, the prototype user interface gives a clear steer as to the functionality of each part of the system. Should NPADDs be further modified after the CLNR project it would be advisable to implement user roles so the look and feel of the system would reflect the type of activity.



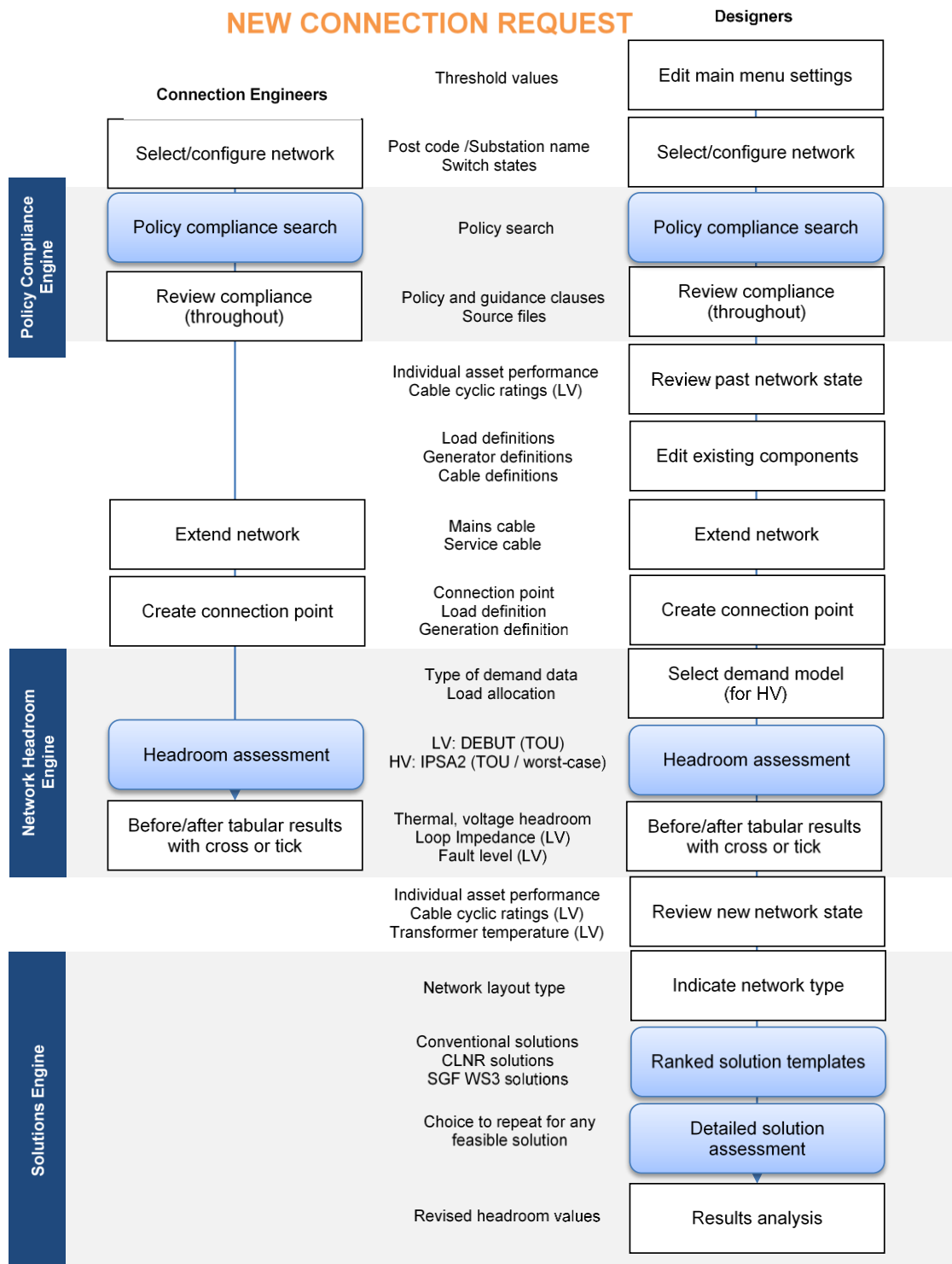


Figure 3.39 – Use cases for New Connection Request Assessments.

FUTURE PLANNING

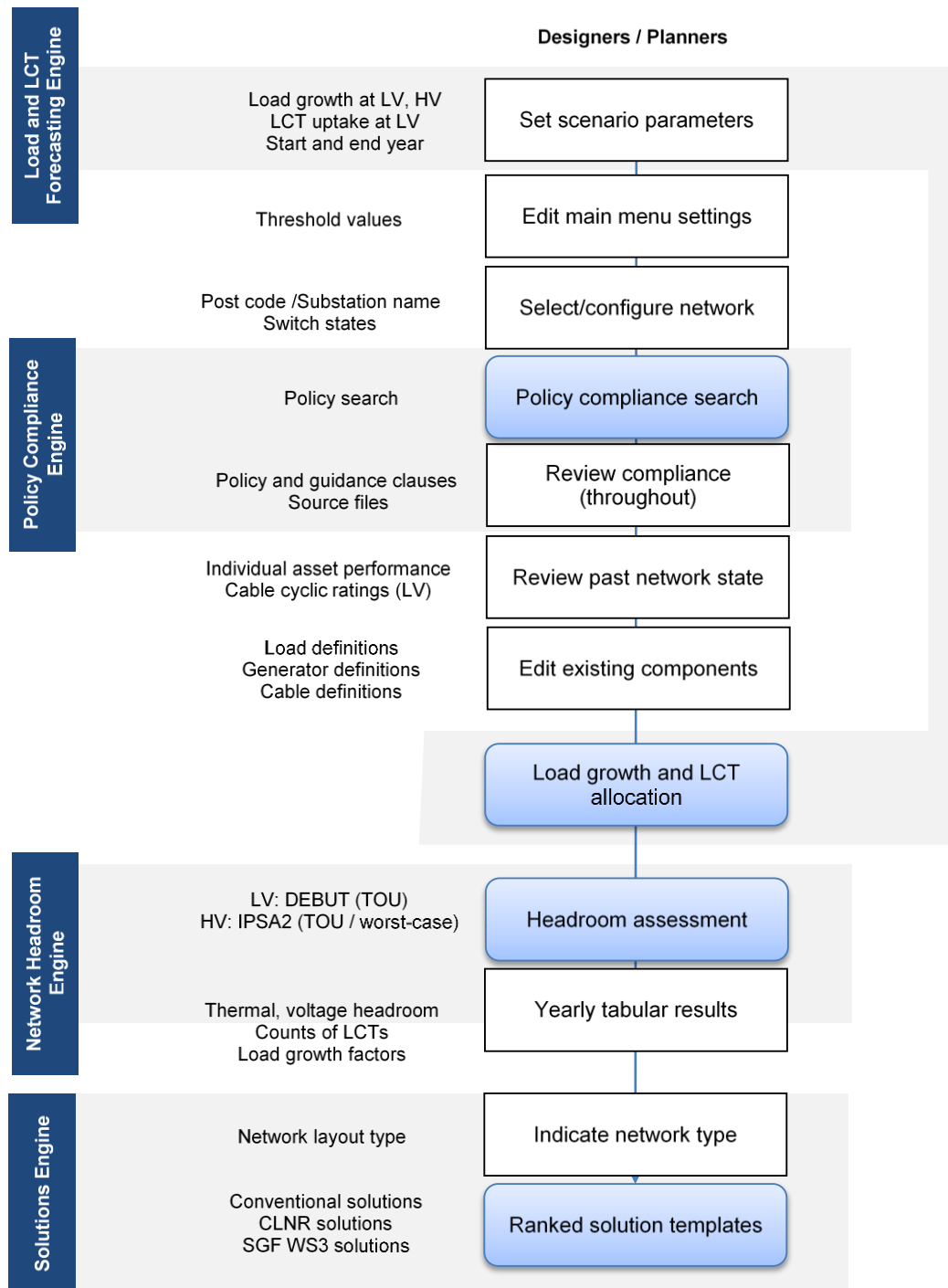


Figure 3.40 – Use case for Future Planning Assessments.

GLOBAL CAPACITY ASSESSMENT

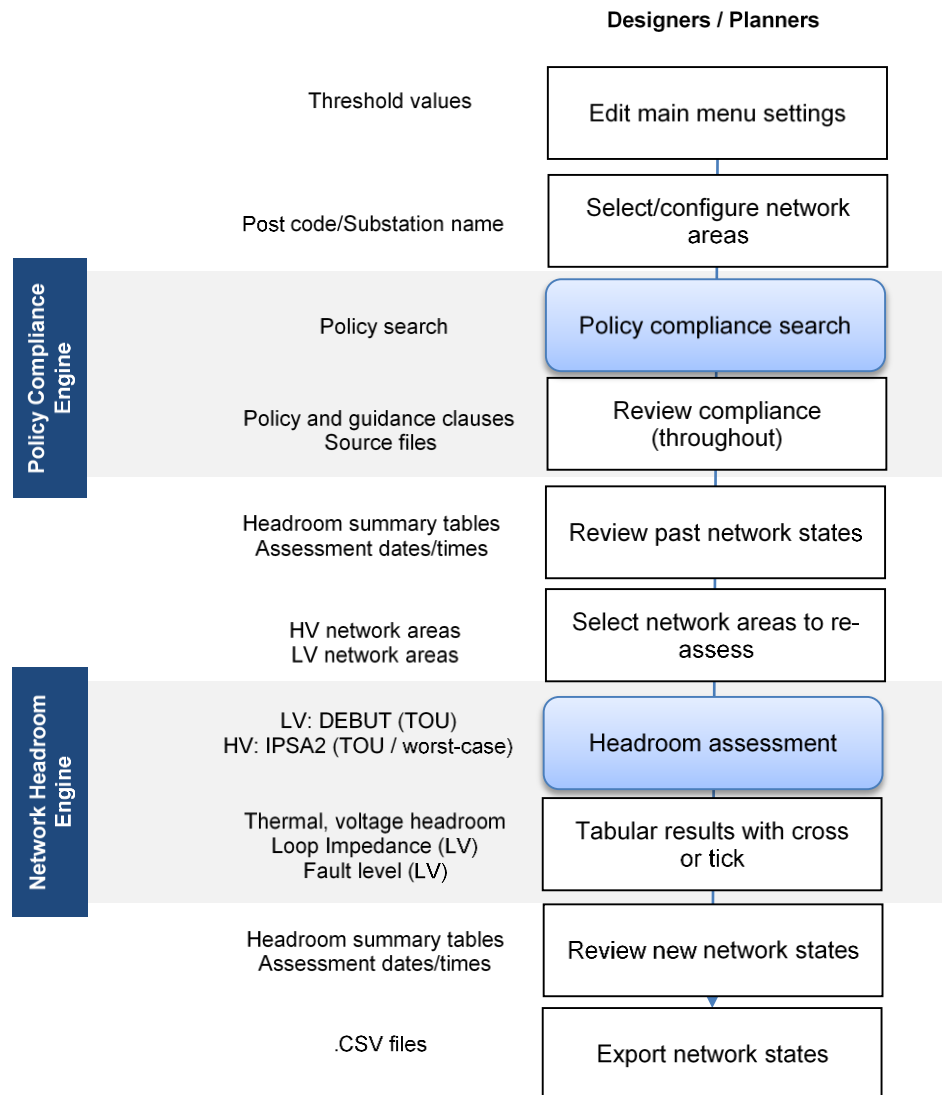
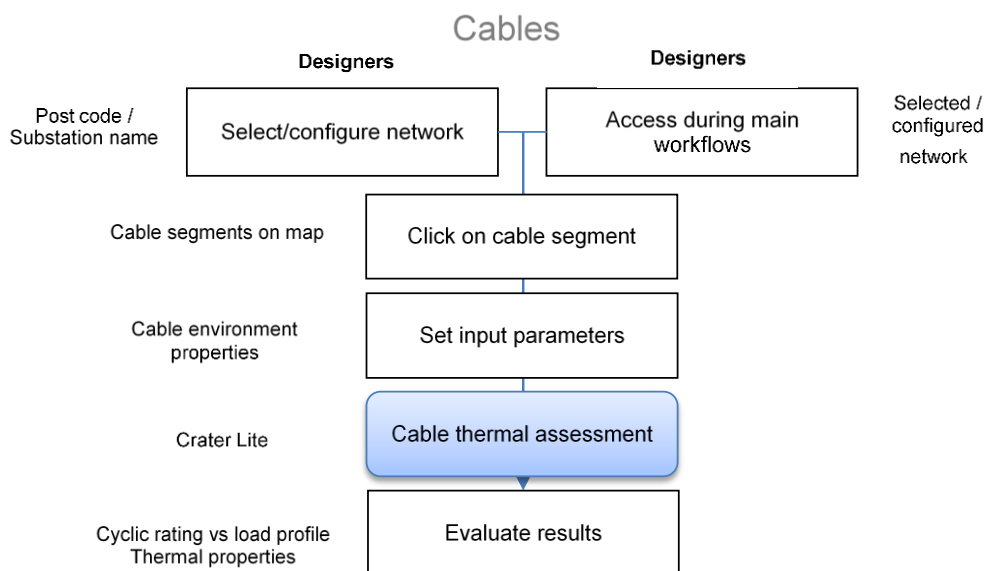


Figure 3.41 – Use case for Global Capacity Assessment.

THERMAL PROPERTIES (LV)



Transformers

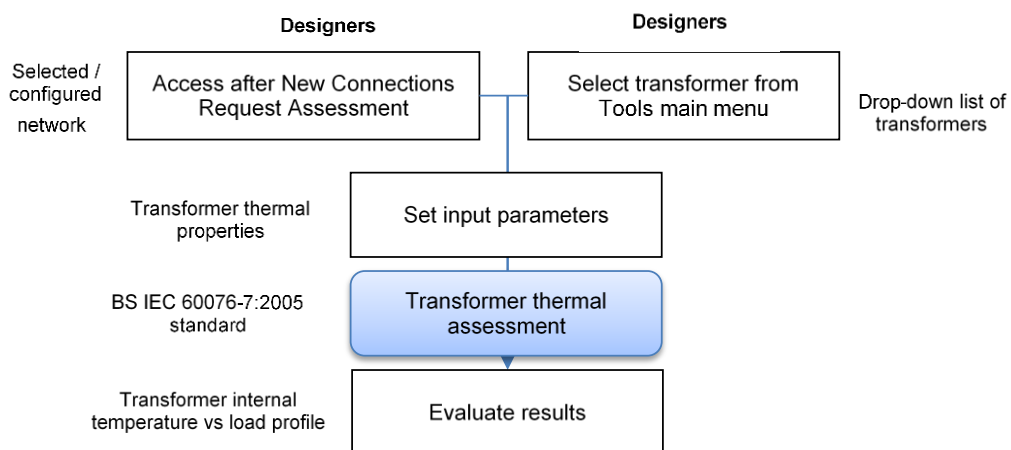


Figure 3.42 – Use cases for assessment of cable and transformer thermal properties.

POLICY COMPLIANCE

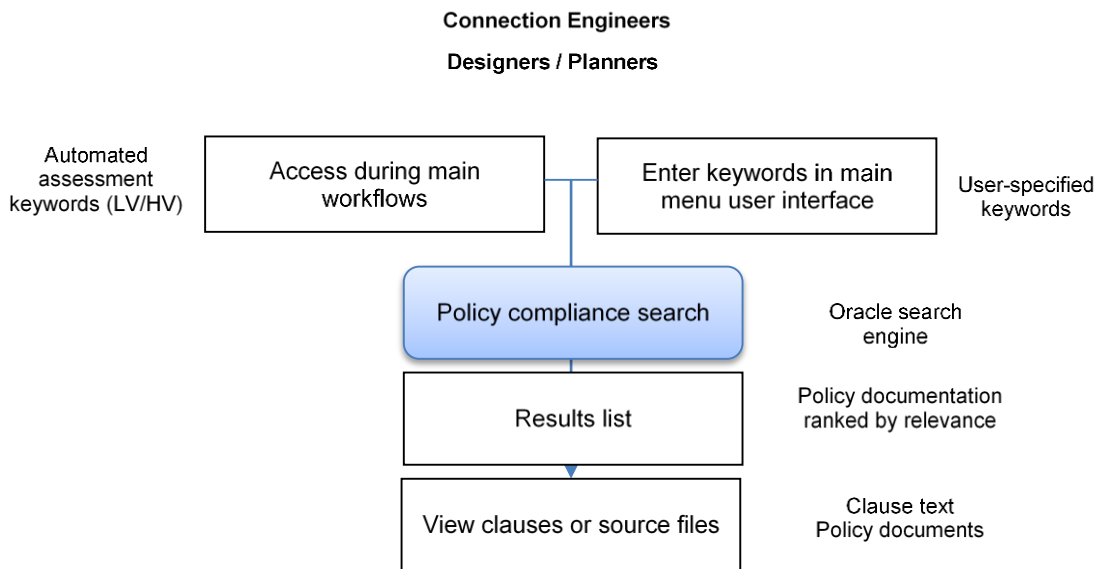


Figure 3.43 – Use cases for policy compliance search.

3.4.2 New Assessment Setup

An important aspect of each assessment workflow is the way in which the user can interact with network data at the start of the process, in order to pick out a relevant network, view information about it, and manipulate it for the purposes of the analysis. Brief descriptions are provided below of the set-up steps that the user is able to take ahead of each assessment, as indicated in the use cases above.

Currently, the prototype provides a range of basic functionality for any assessment, such as selecting network areas and viewing past performance data. The ability to modify the network then depends on the workflow; particular alterations are currently available only as part of particular assessments, such as adding a new connection.

It may be desirable to provide designers with a flexible 'sandbox' area outside of the assessment tool where any types of alterations can be made to design and connections. The NPADDs prototype already demonstrates how several adjustments can be made in sequence as outlined below.

'Existing Network', 'New Connection Request' and 'Future Planning' assessments

Adjust settings

Ahead of carrying out an assessment, the user can access the Settings part of the user interface main menu in order to configure properties such as headroom/legroom threshold values and Solution Template characteristics (Section 3.2.1).

Select and configure network area

Setup of a network assessment requires the user to select which network area is to be analysed. The starting point for any assessment in the NPADDs prototype is an existing network stored in the NPADDs Database. Users can access this as in the example shown in Figure 3.44, by:

- 1) Selecting HV or LV voltage levels for analysis
- 2) Picking a network area by substation name or alternatively by searching for a postcode (the NPADDs prototype utilises a dataset that links each postcode to a set of Easting/Northings coordinates).

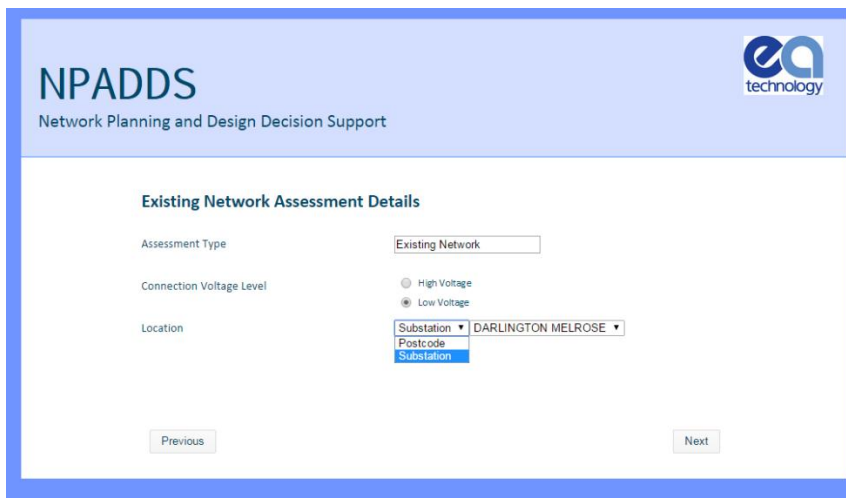


Figure 3.44 – Selecting an existing network area by substation name or postcode search.

The Visual Design Environment map will then move to display that local area. At this point, the user selects a specific network area by clicking on a cable segment within it, which highlights connected feeders and associated substation.

HV At HV, the user must also define the network topology under which the assessment should be run as there are switches present that could be either opened or closed. The NPADDs Database contains network switches at HV, with a default position for normal operation. These switches can be temporarily configured by the user (Figure 3.45) for example to cut off a particular segment of network from the analysis, or to simulate an abnormal operating condition (e.g. n-1). It is also possible to switch HV cable segments in and out by clicking on the cable itself. The new, temporary network area connectivity is recalculated in response to each of these actions, and thus the network area to be assessed is adjusted, using the traversing method outlined in Section 3.3.2.

In addition, the prototype currently contains only isolated HV network areas, with no connection between them. When considering network data that covers entire licence areas, some neighbouring HV network areas will be interconnected in such a way that connection points could be fed by more than one primary substation. A BAU product should ensure that network areas can be appropriately selected for assessment under such circumstances.

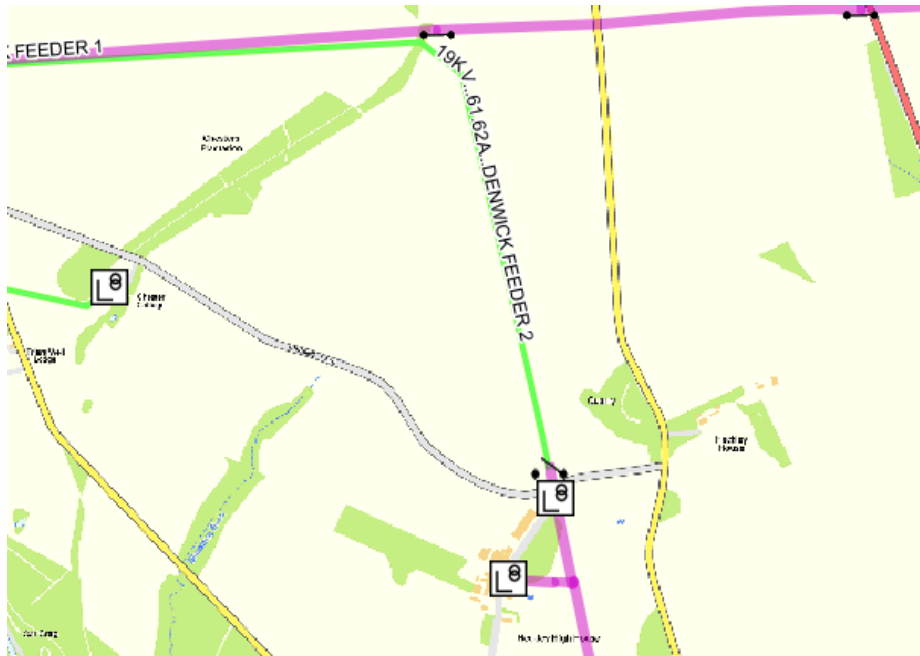


Figure 3.45 – Opening and closing switches at HV to reconfigure the network.

Review policy compliance

Upon entering a network assessment workflow, the NPADDs prototype presents the user with relevant policy clauses and links to the source documentation to the right on the screen (Figure 3.46). This list remains accessible throughout the assessment, enabling the user to click on them in turn as needed in order to read either the clause or the source file, as further described in Section 3.9, to ensure that assessments and decisions are in line with the DNO's procedures.

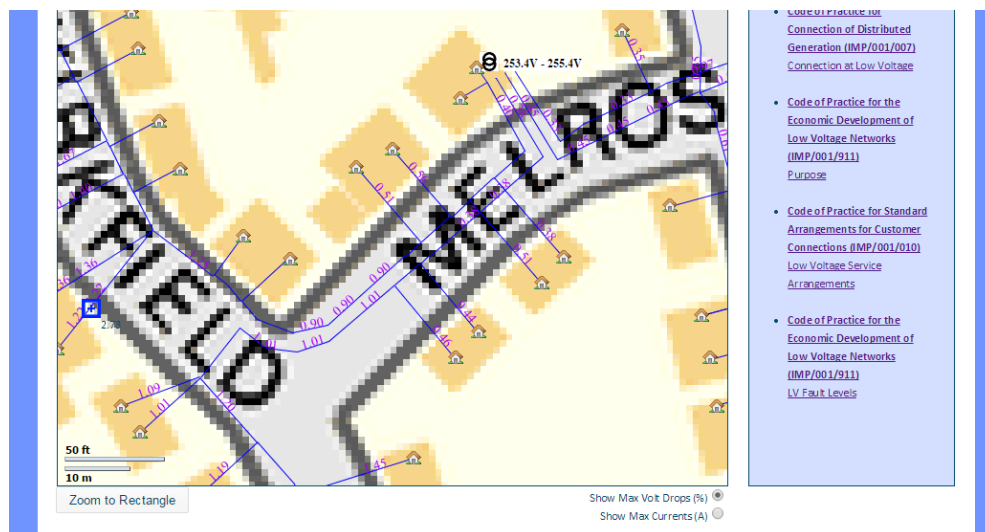


Figure 3.46 – Relevant policies are shown in the right-hand column during assessments.

Review past network states

At this stage, ahead of carrying out an assessment, the user is able to view the chosen network area and access stored results from the most recent previous analysis performed on it. This provides an opportunity to review that past state of the network. Information and functionality that the NPADDs prototype makes available at this point includes, as suggested in Section 3.2.2:

- Worst-case percentage voltage drops (LV)/voltages (HV) and current in cables (Figure 3.47)
- Location markers showing the nodes within the network with the worst voltage drop and thermal headroom
- Maximum and minimum voltages seen at transformers
- Clicking on a transformer to view a plot of voltages along feeders and other performance data (Figure 3.48)
- Clicking on a cable segment to perform a thermal cyclic rating assessment based on the previously found load profile at that cable (Section 3.8.1).



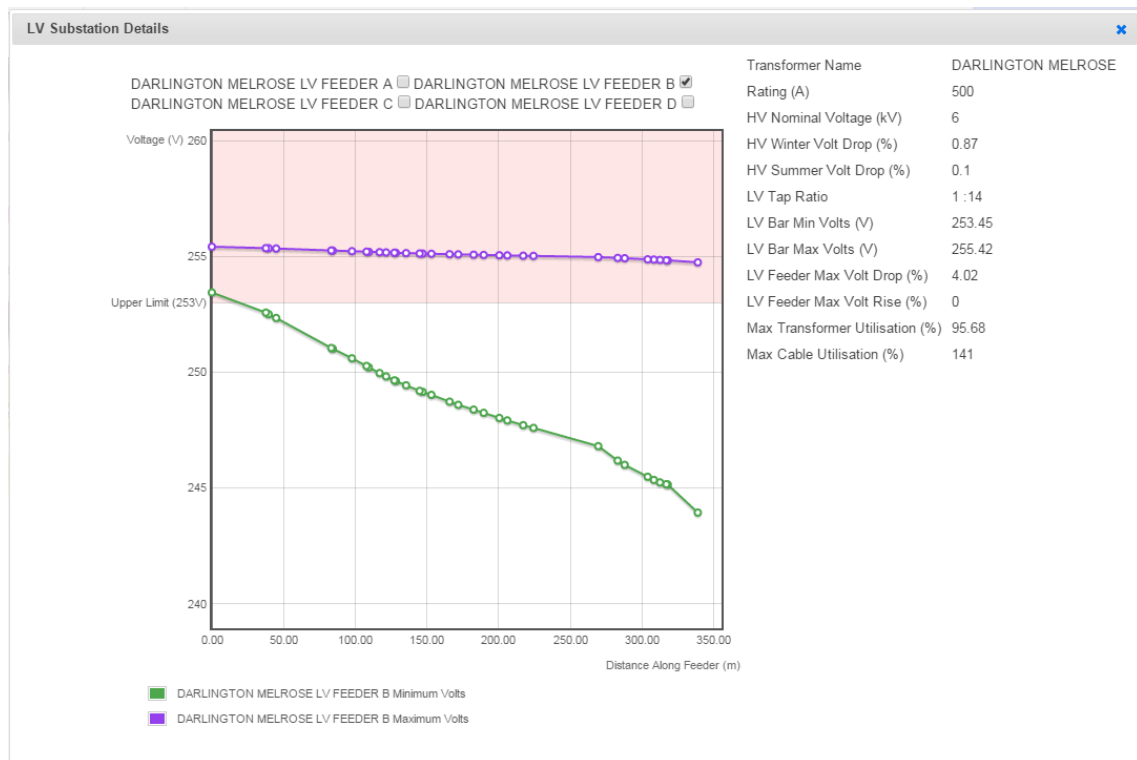


Figure 3.48 – Viewing individual asset minimum and maximum voltages (V) at LV by distance from the substation, obtained by clicking on an LV transformer. Similar results are shown at HV, without the data table on the right. When a default voltage is used at the transformer, this shows up as the minimum and maximum voltages sitting at that same default level at the start of the feeder.

Edit existing components

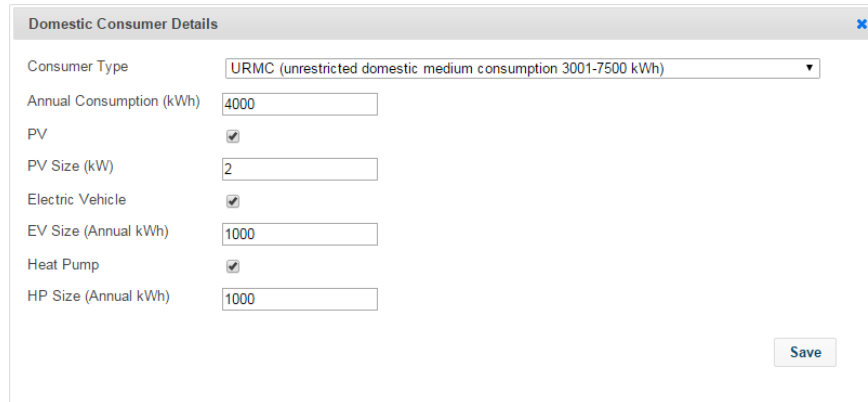
With a network area selected, users can temporarily alter existing assets and connection points, such that the assessment will effectively consider a ‘what if’ analysis.

LV At LV, NPADDs allows the user to click on existing consumers to specify an individual annual consumption in kWh, adjust the standardised consumer type, or add an LCT (PV, EV and EHP) as shown in Figure 3.49. LCTs at LV are defined by the user as:

- PV: Size as capacity (kW)
- EV: Size as annual consumption (kWh)
- EHP: Size as annual consumption (kWh)

HV At HV, the user can click on a load in order to change the type of demand information from the NPADDs Database that is used within the load flow algorithm, or alternatively enter a temporary User Specified Value in kVA. This is illustrated in Figure 3.50 below.

The user can similarly click on a cable segment to change its type (Figure 3.51). At LV, this also provides the option to perform thermal analysis on that particular cable segment (see Section 3.8.1).



Domestic Consumer Details

Consumer Type: URM (unrestricted domestic medium consumption 3001-7500 kWh)

Annual Consumption (kWh): 4000

PV: ☒

PV Size (kW): 2

Electric Vehicle: ☒

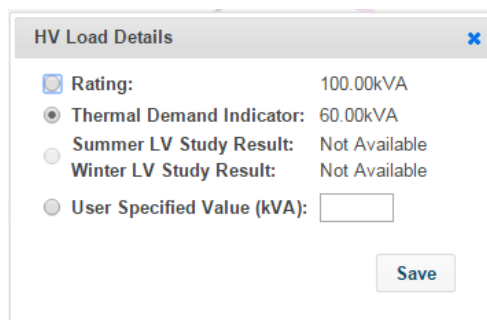
EV Size (Annual kWh): 1000

Heat Pump: ☒

HP Size (Annual kWh): 1000

Save

Figure 3.49 – Editing individual LV consumer properties.



HV Load Details

☒ Rating: 100.00kVA

☒ Thermal Demand Indicator: 60.00kVA

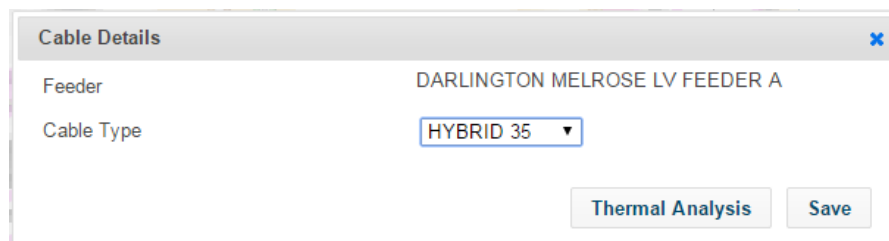
☐ Summer LV Study Result: Not Available

☐ Winter LV Study Result: Not Available

☐ User Specified Value (kVA):

Save

Figure 3.50 – Editing properties of an individual HV consumer connection point.



Cable Details

Feeder: DARLINGTON MELROSE LV FEEDER A

Cable Type: HYBRID 35

Thermal Analysis Save

Figure 3.51 – Editing individual cable properties.

Alter network further (workflow dependent)

Each type of network assessment uses an existing network as the basis, as shown in Figure 3.52. Following the steps above, the chosen network can be adjusted by reconfiguring HV switches and editing properties of existing assets and connection points. From that point onwards, the network can be edited further depending on the workflow:

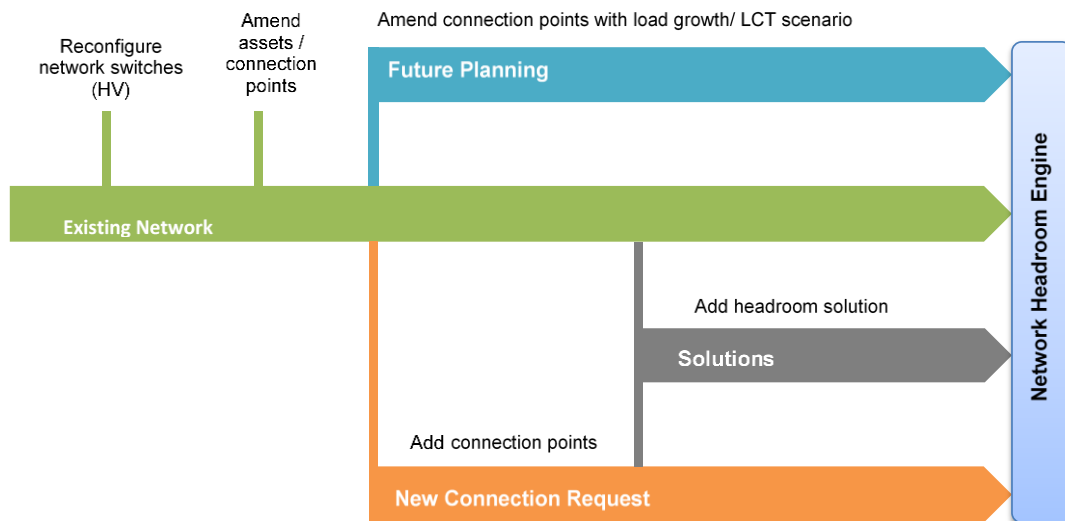


Figure 3.52 – Altering an existing network for different forms of assessments.

Existing Network Assessment: No further amendments are made to the network.

New Connection Request Assessment: Adding new connection points forms the basis of the 'New Connections Request Assessments' feature. At LV, the user can add a consumer with or without LCTs. At HV, it's possible to add a consumer or a separate generator. Any number of these can be temporarily added during an assessment. Illustrations are provided in Figure 3.53.

The user:

- selects the cable drawing tool and draws any new mains and services cables, guided by the user interface which 'snaps to' available feeder segments to link up to. NPADDs finds the chosen cable segment in the NPADDs Database, and (temporarily) splits it in half to create a junction for the new cable connection. NPADDs also displays the length of each new cable, as it is added;
- picks a standard cable type from a drop down list, as in Figure 3.51;
- selects the consumer or generator drawing tool and clicks on a new service cable to attach a connection point at the cable end; and
- defines the consumer at LV as shown in Figure 3.49, or provides a user-specified value at HV for a consumer load in kVA (Figure 3.54) or similarly a generator output in kW.

Forecast scenarios (Solar PV tool, and Future Planning Assessment): The existing network is also temporarily altered when the Load and LCT Forecasting Engine creates a scenario for analysis; the user does not manually make changes in the Visual Design Environment, but enters parameters for the scenario algorithm as input as shown in Figure 3.68 and Figure 3.70.

Solutions Assessment: Finally, if the workflow results in a headroom problem being identified so that the Solutions Engine is deployed to identify and analyse a design intervention, the network may be edited further to reflect this by the addition of network solution components. See Section 3.7.2.

Once the user has selected and amended the network as required, a load flow network headroom assessment can be undertaken using the Network Headroom Engine as dictated by the workflows. All remaining set-up processes, methodologies, and results are described within each relevant Engine section below.

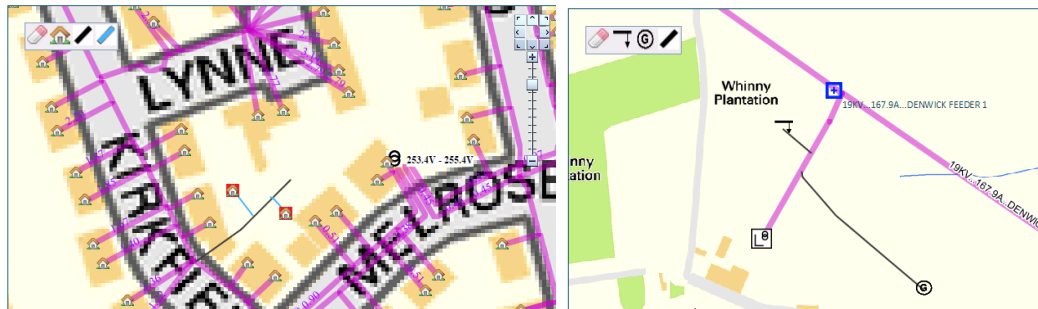


Figure 3.53 – Creating new connection points at LV (left) and HV (right).

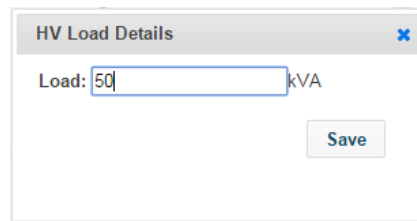


Figure 3.54 – Adding a new HV consumer.

‘Global Capacity Assessment’

The Global Capacity Assessment that is being developed for the prototype allows the user to gain a quick overview of the state of multiple networks at LV or HV. A table is displayed, containing one row for each network area, along with a number of useful indicators, such as maximum volt drop and maximum cable utilisation. These indicators will be obtained from the most recent assessment carried out on each network, excluding assessments where modifications of any type were made by the user (as also explained in Section 3.5.6). In other words, only results from assessments of networks in their existing state are displayed. Date and time of the assessment from which results are taken are also displayed. The table can be sorted by any of its indicator columns.

User can elect to re-run an assessment on an individual network from this page, to refresh its results to reflect the current data for that network. Assessments can also be re-run for all network areas at LV or HV, or for a subset of them.

3.5 Network Headroom Engine

The Network Headroom Engine is a key module within the NPADDs prototype, and is utilised by several types of assessments as shown on the left in Figure 3.55. It is based on separate tools and methodologies dedicated to LV (DEBUT and EGD) and HV (IPSA2) analysis. Both perform assessments on sections of the network to deliver three key sets of data, whose use is also illustrated in Figure 3.55:

- 1) Worst-case headroom in network area
- 2) Worst-case values across all individual assets
- 3) TOU load flow patterns at individual assets

Whilst used for different purposes, all three sets are the output of a load flow analysis. Load flow analysis uses a network model and a single snapshot of load on each node, to calculate corresponding conditions such as currents and voltage drops within each part of the network. The load allocation and calculations can be performed iteratively, for example for each half hour, to provide daily profiles of loads and network conditions.

Heuristics assessments, which are simpler sets of rules or arithmetic, were originally considered in the prototype specification for certain types of headroom assessments. However it was found that full load flow analysis could be carried out with sufficient ease to form the basis of all headroom assessments.

The three sets of load flow data are generated as follows:

- LV** The Network Headroom Engine always carries out a Time of Use (TOU) load flow assessment at LV, for winter as well as summer. “TOU load patterns at individual assets” (3, above) alongside voltage profiles are therefore effectively the raw analysis output. NPADDs examines this detailed information to obtain the maximum and minimum values seen at each asset (2, above), and then processes this further to obtain the most extreme values across the network area as a whole for the “Worst-case headroom in network area” (1, above). This process is illustrated in Figure 3.56.

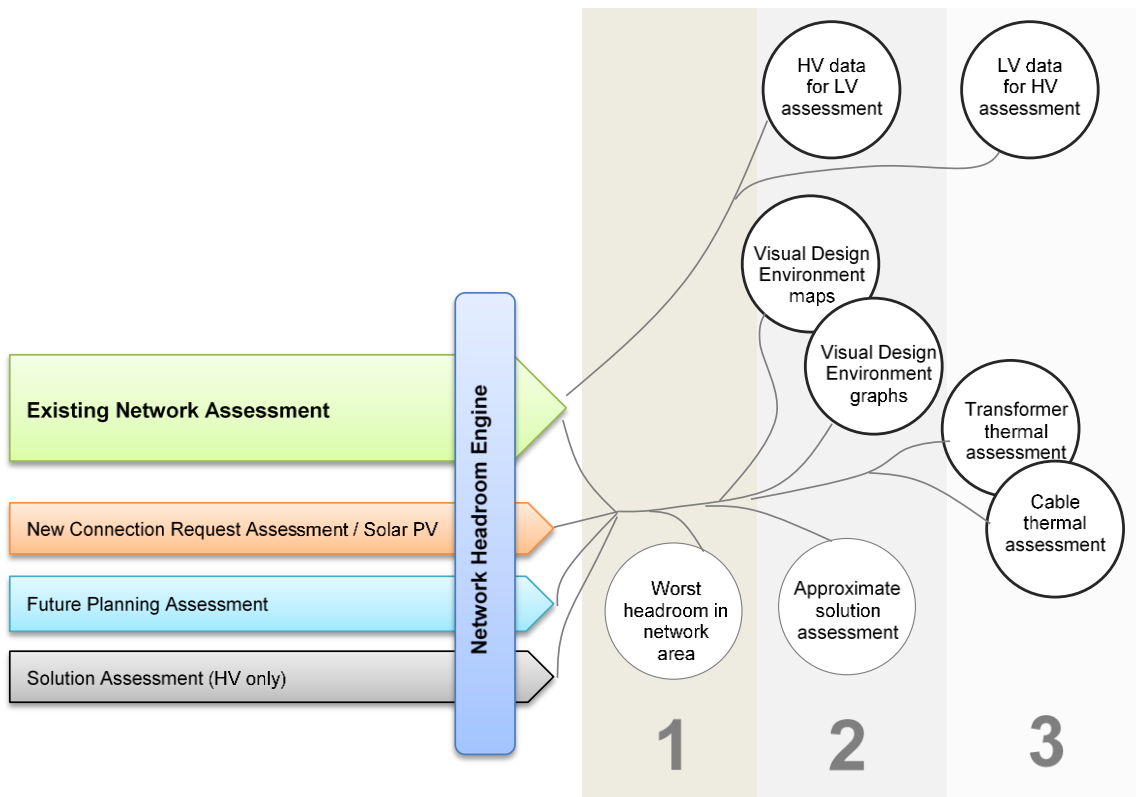


Figure 3.55 – Uses of the Network Headroom Engine, and the data output as (1) Worst-case headroom in network area, (2) Worst-case across all individual assets, and (3) TOU load flow patterns at individual assets. The most recent results from Existing Network Assessments that are indicated by thick circle borders can be re-accessed when a network area is revisited.

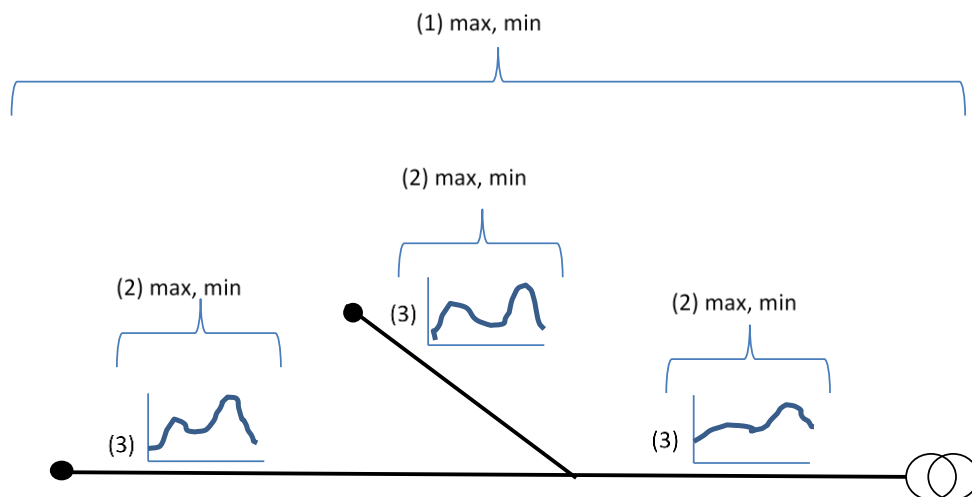


Figure 3.56 – Processing of TOU load flow data (3) into worst-case at each asset (2), and worst-case headroom in the network area (1).

HV At HV, the user has an option of running a TOU or worst-case load flow assessment. In the latter case, load patterns (3, above) is not available. Instead, the load flow analysis is carried

out only twice – once for a winter load, and once for a summer load – such that the “Worst-case values across all individual assets” becomes the raw output of the analysis. NPADDs then processes this as above to obtain the “Worst-case headroom in network area”.

The type of data available within each set is briefly outlined below, along with an indication of where and how they are utilised within the NPADDs model:

Worst-case headroom in network area: These overview results form the core of the network headroom feature, and provide connection engineers, designers and planners with the largest voltage deviations and highest loaded assets within the network under analysis (Table 3.9). These key parameters are displayed at the end of a network assessment, in a format that varies with the type of analysis carried out. See Figure 3.59 for an example.

Across the network area

Max voltage drop (%)
Max voltage rise (%)
Max cable thermal headroom (%)
Max transformer thermal headroom (%)
Max loop impedance (mΩ) – LV only
Min fault level (A) – LV only

Table 3.9 – 1) Worst-case headroom in network area.

Worst-case values across all individual assets: For a more detailed view, NPADDs users are able to view worst-case assessment results for each individual cable segment and transformer in the network area (Table 3.10). Following an assessment these can be viewed within the Visual Design Environment, displayed on the map or plotted along feeders when clicking on an individual transformer (See Figure 3.47 and Figure 3.48 for examples.) Such results can also be viewed without carrying out a network assessment, in which case they are based on the most recent analysis of the existing network without any alterations stored in the NPADDs Database.

For each individual asset

Max voltage drop/rise (%)
Max and min voltage (V, kV)
Max cable load (A)
Max transformer load (A, kW)

Table 3.10 – Worst-case values across all individual assets.

TOU load patterns at individual assets: Finally, when the Network Headroom Engine carries out a TOU assessment, it produces half-hourly load patterns as seen at cables and transformers (Table 3.11). Apart from providing the raw data for the sets of results above, the load patterns are passed to other assessments by NPADDs.

For example, when a user runs a Crater Lite analysis to obtain the cyclic rating of a cable (Section 3.8.1), this is based on the current profile seen in that cable as provided by the Network Headroom Engine. Similarly, the load profile seen at an LV transformer can also be passed as input to the HV network analysis (Section 3.5.2). These passed-on load patterns

are also always based on the most recent analysis of the existing network without any alterations, stored in the NPADDs Database.

For each individual asset

Half-hourly cable load profile (A)
Half-hourly transformer load profile (kW)

Table 3.11 – TOU load flow patterns at individual assets.

Load flow tools used to generate these results are described in the following sections.

3.5.1 Load Flow Tools

Existing Northern Powergrid assessment/load flow tools are IPSA2 (EHV), DINIS (HV), DEBUT (LV) and spreadsheet macros (LV). Estimating or directly calculating volt drops and current flow given a network topology and customer connection information therefore presents little challenge – established tools are available to achieve this.

For the NPADDs Network Headroom Engine, DEBUT with an EGD add-on was selected for LV analysis, and IPSA2 for HV analysis. The main constraints in implementing a load flow engine into software such as NPADDs are the speed of load flow calculations, and the ability to present the network in a suitable format. From experience, using DEBUT and EGD for this type of assessment is very fast for LV network areas. IPSA2 is a more complex and capable solution engine for HV networks, but provides fast and robust analysis.

In both cases, the functionality of using C#.NET means that NPADDs can easily interface with the load flow engines using text files as a means to transmit input data and results (with an intermediary Python script in the case of IPSA2.) The add-on EGD module for analysis of distributed generation on LV networks was re-created in C#.NET within NPADDs, removing the need for a software interface.

NPADDs thus illustrates the ability to link to different types of software and processes, by manipulating data into whatever format is required. For example, DEBUT is based on built-in databases of cable types and consumer types, whereas IPSA2 take the raw electrical power system values as input. Both can be handled in the prototype due to the flexibility of the NPADDs Database and the C#.NET code around it.

Load flow as a service

NPADDs provides direct access to DEBUT and EGD for LV, and IPSA2 for HV, meaning that the load flow engines are used as a service and are largely blind to the user. It does this by converting the network model, held as CIM objects in the NPADDs Database, to a format suitable for import to DEBUT and IPSA2, uses commands to run these load flow engines, and then the similarly converts the analysis results back into a consistent format within NPADDs.

This provides a clear delineation between NPADDs and the load flow engines, allowing them to be separated should the need arise to use a different tool in the future. The use of CIM also enables an agnostic approach to selecting the load flow engines to be used in the future; it provides a stable and well documented platform to integrate.

3.5.2 Simplified HV and LV Integration

Current practices for design of distribution networks separate the assessment of LV and HV network areas. A set of design rules, held in policy and guidance documents, are used to allow the network voltage level areas to be assessed independently without encroaching on design constraints. A typical example of a design rule that allows this separation is limiting the permitted voltage drop on an LV feeder so that the HV network voltage does not need to be considered for LV connections, and vice versa.

Although this approach simplifies the assessment process and allows faster and easier assessment of mass market connections, it is believed that significant additional capacity is 'locked' into the network through conservative design. This could be released by considering upstream network voltages using more detailed analysis, but full TOU HV assessment that also performs a study of all LV feeders would be a considerable burden on central resources like the Oracle server. It may be possible to run as routine overnight, but is unlikely to be practical as part of daily work practices.

In order to link the LV and HV network levels whilst keeping the software practical, the NPADDs prototype instead enables a simplified exchange of data:

LV results used at HV: Analysis of HV network areas in the prototype provides the user with an option to use saved LV assessment results as input at distribution substations. Provided that a network assessment has been previously carried out on a given LV network, the resulting load profile at that substation will have been saved and is available to be passed to the HV assessment.

HV results used at LV: When carrying out an LV assessment, NPADDs uses the results of previous HV analysis (where available) to set the voltage level at the secondary substation; the HV voltage found at that node is stepped down based on the transformer's tap ratio property and used as input to the LV network assessment.

The prototype illustrates how flexibility could be built in to allow the user to choose whether or not to link the voltage levels: in the worst-case HV headroom assessment, the user can choose from several types of demand figures for loads that represents LV substations, including but not limited to demand data stored from previous LV assessments (Figure 3.50)

Finally, if the processes above are carried out in succession, the LV and HV links will create a feedback loop that progressively makes the load flow assessments more accurate, as illustrated in Figure 3.57. In a BAU implementation, it may for example be suitable to carry out an automatic, weekly assessment of existing networks on an overnight basis, linking HV and LV analysis as shown.

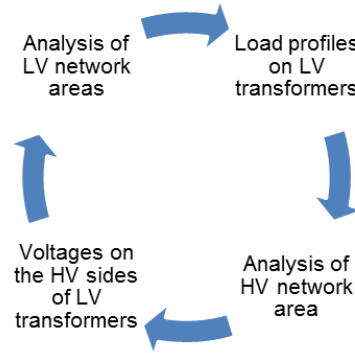


Figure 3.57 – Feedback loop of data transfer between LV and HV assessments.

3.5.3 LV Methodology

Similar to WinDEBUT, NPADDs utilises both DEBUT and its add-on EGD whenever assessing an LV network. A DEBUT assessment is run first, containing all loads but no generators; it was not designed to analyse distributed generation. DEBUT then passes its results to EGD, where generators are added and an updated set of results are produced.

DEBUT versus EGD

Both DEBUT and EGD are able to perform unbalanced 3-phase load flow calculations, with a separate analysis for each phase. They also both carry out TOU assessments, such that each load or generator is associated with a half hourly load profile; the load flow engine iterates through each half hour in a 24h period to calculate the resulting performance at each time interval.

However, DEBUT and EGD differ in the granularity of their load flow outputs. This is primarily because EGD has been recreated in C#.NET within NPADDs, making all internal variables available. Whilst DEBUT carries out a detailed load flow analysis internally, it outputs only the worst case voltage drops and asset utilisation at each node, by nature of its design. By contrast, NPADDs is able to access the full detail of the current and voltage TOU load flow assessment results within EGD, at each time stamp, which enables a wider range of functionality.

EGD is therefore a more flexible LV load flow assessment tool for the purposes of NPADDs. In fact, DEBUT results are used only to generate the cable/transformer utilisations at the end of a Network Headroom Engine assessment, as shown in Table 3.12. It is the output of the corresponding EGD assessment which, apart from providing the worst case voltage drop and rise in that same table, forms the basis for all load flow assessment results stored in the NPADDs Database. It is those saved EGD results that are displayed within the Visual Design Environment (e.g. Figure 3.14) and passed to other analysis tools such as the TOU load profiles in cables that forms the input to the Crater Lite analysis (Section 3.8.1).

In future versions, NPADDs may rely solely on EGD for load flow analysis. The primary reasons why this has not yet been implemented are that:

- DEBUT includes a phase allocation algorithm, which places each LV consumer on one of the three phases. That phase allocation is passed on from DEBUT to EGD. It would be possible to implement a similar phase allocation internally in NPADDs and pass that to EGD instead.
- DEBUT accounts for demand diversity by scaling demand profiles on a network using the ACE49 statistical process based on the number of consumers. EGD does not feature a similar methodology, as load data is fed from DEBUT and generators are added in EGD without diversity considerations. It may be possible for NPADDs to carry out a similar process such that EGD can be used in isolation for all load flow, although this is non-trivial. For a BAU product, it would also be desirable to ensure that generator diversity is accounted for in EGD in a similar manner.

DEBUT does however provide analysis tools beyond regular load flow – in particular, phase loop impedance and fault current calculations. NPADDs currently makes use of these features and is likely to continue to do so in future.

Finally, it should be noted that DEBUT cannot analyse meshed LV networks. It presents an error when such an attempt is made. If meshed LV network assessments are a requirement of a future BAU product, it is likely that a replacement tool must be used for load flow purposes (such as EGD, with sufficient development as briefly outlined above).

Process

The Network Headroom Engine carries out an LV assessment through the process described below. The process begins only after the network that is to be assessed has been defined, as described in Section 3.4.2:

Converting NPADDs network data into DEBUT format: At the start of the assessment, NPADDs takes network data stored in the Network Database along with any temporary changes made, and converts this into a ‘study file’ text file input for DEBUT, excluding any generators. Cables and consumers are already defined in terms of standard DEBUT types, and the CIM object definitions contain detailed connectivity information to convert into DEBUT branch data.

Only LV transformers require data manipulation; the voltage level at the lower side of the transformer is produced by NPADDs either by stepping down the HV side voltage from a previous HV assessment on the basis of the transformer tap ratio – representing the link in NPADDs between HV and LV analysis – or by reverting to a default voltage level (Section 3.3.2). The user can see whether a default value was used in the most recent assessment, by clicking on a transformer within the Visual Design Environment to bring up the window shown in Figure 3.48.

The ‘data file’ text file input that NPADDs provides to DEBUT, with definitions of cable and transformer types, has been manually amended as a one-off process as part of the prototype implementation as described in Section 3.3.2.

DEBUT phase allocation: Having read in the ‘study file’ and ‘data file’ inputs, DEBUT runs an internal algorithm to allocate each consumer to one of the three phases.

DEBUT load flow: DEBUT then carries out a load flow calculation for each of the three phases, running a separate assessment for each of the 48 time intervals within the half-hourly profiles. In order to set up the load flow analysis, DEBUT also carries out internal manipulations, such as obtaining the power level at each consumer node by scaling the relevant consumer type profile shape by the 'annual consumption', and calculating the impedance of each branch by finding the branch length and unit impedance of the relevant cable type.

DEBUT results and EGD input: The load flow results are presented in an output text file, where the worst case % voltage drop and the worst case cable and transformer utilisation is listed for each node. DEBUT also produces an input file for EGD, containing the loading level at each node in the network as a result of the consumers, as well as the phase that each consumer was allocated to.

Collecting DEBUT results: NPADDs reads in the DEBUT output text file, and finds the worst case voltage and thermal headroom figures for display at the end of the assessment. The same process is applied to the loop impedance and fault level current.

Passing information from DEBUT to EGD: NPADDs also reads in the text file that DEBUT produces for EGD. It uses this input data to create the 'study file' input data for the NPADDs version of EGD, although no text file as such is needed; as EGD has been recreated in C#.NET, the data is simply delivered as part of the code. Alongside the output from DEBUT, NPADDs adds generator definitions in the suitable EGD format, which again is a straight forward process as NPADDs generators have been defined using the standard EGD format. The LV generators are placed at the relevant nodes, and given a phase allocation that matches the consumer they belong to.

NPADDs also provides EGD with its equivalent version of a 'data file', which includes generator type profile shapes.

EGD load flow: EGD then runs its own load flow process, one for each of the three phases, and repeating the process for each of the 48 half-hourly time intervals. Like DEBUT, it processes the input data by obtaining actual generator power outputs at each node by scaling the standard profile shape by the generator capacity.

Collecting EGD results: NPADDs is able to access the EGD results and variables directly, within the code itself. TOU currents and voltages at each node are obtained and saved in the Configuration Database for further use in future assessments or for display in the Visual Design Environment. Results are also analysed for the worst case voltage rise and displayed in the network assessment output, as described below.

Repeating the process for summer assessment: The above process represents a winter assessment. Once complete, it is repeated with summer input data. This is achieved by NPADDs during run-time, by temporarily redefining each unique consumer and generator to be of a different, summer version of their original type. When DEBUT and EGD run their assessments, this results in summer profile shapes being used and scaled.

3.5.4 HV Methodology

NPADDs uses IPSA2 for all HV load assessments, for worst-case as well as TOU analysis. IPSA2 documentation is available from TNEI that describes its methodologies and capabilities. The prototype has put in place the basic API interface to IPSA2, which could be expanded to incorporate additional analysis features by providing the appropriate sets of input data and run commands.

Worst-case vs TOU analysis

Contrary to DEBUT and EGD, IPSA2 is set up to analyse a single snapshot in time of a network, with a particular load level and power production at each node with a consumer or generator. NPADDs is therefore able to run IPSA2 in two different ways: a worst-case assessment, which represents such a single snapshot, or a TOU analysis where the IPSA2 software is called repeatedly for each of the 48 half-hourly intervals.

In worst-case assessments no account is taken of the level of simultaneity of loads as would be apparent from daily load profiles. The purpose is to identify how the network would behave if load and generation lined up in the most extreme fashion in terms of network headroom.

A TOU analysis, which is a more granular approach, may indicate additional headroom compared with worst case assessments where customer peak loads are not coincident, but at the price of higher computational time and burden. Particularly for large network areas this type of assessment will have a high computation load; using the IPSA2 engine through modern higher level programming languages introduces complexity which reduces task speeds.

TOU assessments are particularly computationally challenging as they also require that TOU information is available for the loads and generators within the network area. As many loads on the HV network are LV substations, the half-hourly loads seen at these nodes must first be obtained by TOU assessments at the LV levels. Given the time consuming nature of each such assessment, NPADDs is designed such that those LV networks must have been analysed previously, with the results stored in the NPADDs Database. HV TOU analysis can then call upon those load profiles as an input, which represents the link between LV and HV implemented in NPADDs.

Worst-case and TOU inputs into HV headroom assessments are handled in NPADDs as described below.

Defining demand data

The process of setting up a headroom assessment in NPADDs is more complex at HV than at LV, as the type of load data to use must be chosen once the network area has been chosen as in Section 3.4.2. Whether a worst-case or TOU analysis is carried out, the NPADDs user is able to select any of the following definitions of the load sizes of HV loads as shown in Figure 3.50:

User-defined load: By clicking on a HV load, whether a LV substation or a large individual consumer, the user is able to enter a single load value.

LV study results: This represents TOU load profiles at LV substations that have been saved from previous LV assessments, and which can also be turned into single values for worst case assessments.

Thermal Demand Indicator and Rating: Each of these are single load values that are stored as consumer properties within the NPADDs Database, and will have been populated where available when the DNO's network data was imported into NPADDs.

The user can click on each HV load and manually select either of those options. Whenever this is not done, the following order of priority is used (and could be altered, as needed) where if one type of data is not available, the next one down the list will be utilised instead:

- 1) User-defined load
- 2) LV study results
- 3) Thermal demand indicator
- 4) Rating

(Generators use only a single output value, similarly to that illustrated for a new consumer in Figure 3.54.)

As an alternative, NPADDs features an additional 'load allocation' option during worst-case HV assessments, which enables the user to set the feeder load at the primary source. NPADDs then scales the downstream loads to match this figure, which could for example be based on monitoring data. As Figure 3.58 shows, the user can set real (P) and reactive (Q) values for maximum (winter) and minimum (summer) worst-case conditions. The process is referred to as the NPADDs 'Load Allocation' algorithm, and is implemented as follows:

Load Allocation: For each feeder at HV, the user can specify a particular feeder load level at the primary, for example on the basis of monitored data. The HV Load Allocation algorithm spreads that load across the individual consumer nodes as follows.

First, the total load on the feeder is estimated using the load's saved Thermal demand indicator (where available) or Rating value, with a "gearing factor" to provide an improved estimate. The gearing factor represents the percentage of the Rating that is assumed to typically be the actual load – e.g. a gearing factor of 0.5 means that the actual load is assumed to be half of the rated value. A ratio ("scaling factor") is then calculated, which represents the difference between the modelled load and desired load level. This ratio is applied to each consumer load in order to adjust it. Any loads that are defined by Rating values are also further adjusted by the gearing factor, which is a way of accounting for the fact that such loads are likely to be lower in reality. As a result, the total modelled feeder load has been manipulated to equal the desired level. Generator sizes are independent and not accounted for or modified as part of the load allocation algorithm.

As part of a BAU product, it would be possible to implement a similar method based around load allocated at the feeder mid-point, and to extend a similar feature to LV networks.

Feeder Data

Feeder ID	Feeder Name	Data Model	Max Load (kW, kVAR)	Min Load (kW, kVAR)
1	DENWICK FEEDER 1	<input type="radio"/> Raw Model Data <input checked="" type="radio"/> Load Allocation	p 5000 q 1000	p 643 q 128.6
2	DENWICK FEEDER 2	<input checked="" type="radio"/> Raw Model Data <input type="radio"/> Load Allocation		
16	DENWICK FEEDER 3	<input type="radio"/> Raw Model Data <input checked="" type="radio"/> Load Allocation	p 7250 q 1450	p 225 q 45
17	DENWICK FEEDER 4	<input checked="" type="radio"/> Raw Model Data <input type="radio"/> Load Allocation		
18	DENWICK FEEDER 5	<input type="radio"/> Raw Model Data <input checked="" type="radio"/> Load Allocation	p 9500 q 1900	p 525 q 105
19	DENWICK FEEDER 6	<input checked="" type="radio"/> Raw Model Data <input type="radio"/> Load Allocation		
20	DENWICK FEEDER 7	<input checked="" type="radio"/> Raw Model Data <input type="radio"/> Load Allocation		
21	DENWICK FEEDER 8	<input checked="" type="radio"/> Raw Model Data <input type="radio"/> Load Allocation		

Figure 3.58 – Electing to apply the HV Load Allocation for each individual feeder at HV, where “Raw Model Data” refers to demand definitions shown in Figure 3.50. P and Q values for each feeder are entered individually and saved between assessments in the NPADDs Database.

Once the sources of demand data have been set, these are passed to IPSA2 to carry out either worst-case or TOU assessments:

Worst-case assessments: A winter and a summer condition is analysed. Winter loads are assumed to be the single values identified above, while summer loads are taken to be a percentage of those winter values as described in Section 3.3.2. In the case of LV substations where TOU assessments have been selected or defaulted to the demand value, the peak of the winter day load, and the minimum of the summer day load, is used for each individual node even if these occur at different times during the day.

TOU assessments: TOU data at HV is available only at LV substations where assessments at LV have been carried out previously, where both a winter day and a summer day are available and used to assess winter and summer conditions. Any other loads and generators, which have a single demand or supply figure, are simply taken as a constant demand or supply, with the level replicated across each of the 48 data points. This provides proof-of-concept of TOU assessments at the HV level. In future versions of NPADDs, HV consumers and generators could potentially be given TOU profiles as and when data becomes available.

Process

The Network Headroom Engine carries out an HV assessment through following process, once the network that is to be assessed has been defined as in Section 3.4.2.

Converting NPADDs network data into IPSA2 format: At the start of the assessment, NPADDs takes network data stored in the NPADDs Database along with any temporary changes made, and converts this into a text file input for IPSA2. Cables and consumers are already defined in terms of load levels and impedances, and the CIM object definitions

contain detailed connectivity information to convert into IPSA2 branch data. HV transformers are not used as input; NPADDs currently passes the HV level nominal voltage as an input (as 1p.u.) without reference to an EHV voltage, alongside zero values for MW and MVar inputs at EHV grid infeeds for slack bus bar purposes. Once the input file has been generated, NPADDs runs a Python script which in turn feeds commands to IPSA2.

For a worst-case analysis, NPADDs will have a single set of demand and generator power levels and runs an IPSA2 assessment only once with that data. For TOU analysis, IPSA2 is run 48 separate times with the demand and generator power levels being changed each time to represent the levels at each of the half hourly intervals:

IPSA2 load flow: IPSA2 carries out a single balanced load flow calculation. NPADDs assesses the transformer utilisation based on the load on connected feeders.

Collecting IPSA2 results: NPADDs reads in the IPSA2 output text file, and stores currents and voltages, which are available on a branch and bus-bar basis at each point in the network, in the NPADDs Database assigned to the particular worst-case set or TOU time stamp that was analysed.

Interpreting IPSA2 results: Once the worst case or set of TOU assessments are carried out, NPADDs analyses the saved currents and voltage values across the network area, along with cable and transformer capacities stored in the NPADDs Database, to obtain the worst case voltage and thermal headroom figures for display at the end of the assessment. Raw TOU results are also stored in the NPADDs Database, where they can be used as voltage level input for LV analysis, thus indirectly linking the voltage levels.

Repeating the process for summer assessment: The above process represents a winter assessment. Once complete, it is repeated with summer input data. This is achieved by NPADDs during run-time, by temporarily scaling the consumer power levels by a percentage (currently set at 10%, see Section 3.3.2) when converting the network data into the IPSA2 input file.

IPSA2 load flow assessments are more time consuming than those carried out by DEBUT/EGD at LV. A single load flow solution is typically obtained in around 5 seconds, depending on the size of the network area. Around 10 seconds are therefore required for a worst-case assessment that covers both winter and summer. A half-hourly TOU assessment, which requires 48x2 runs for a winter and summer day, takes substantially longer and is in the order of 10 minutes. NPADDs overheads surrounding the IPSA2 process, such as accessing and presenting data, also adds some time but can be optimised as in the case of LV described above.

3.5.5 Outputs

Network Headroom Engine outputs at LV consists of headroom figures, load flow data, fault current and loop resistance. As briefly described at the start of Section 3.5, these results are used for three distinct purposes. The following section describes in more detail how such results are derived.

Worst-case headroom in network area

Results that are presented to the user immediately after an assessment fall into this first category. The output identifies the peak values of different parameters found across the entire network area under study and across all time points (whether worst-case or TOU). In each case the output is derived from the calculations in Table 3.12 (DEBUT and EGD, at LV) and Table 3.13 (IPSA2, at HV):

Parameter	Display name	Engine	Obtained by
Max % voltage drop	“Maximum Volt Drop (%)”	EGD	Maximum voltage drop found across the network from the EGD output, expressed as a % of the nominal voltage at the LV substation side
Max % voltage rise	“Maximum Volt Rise (%)”	EGD	Maximum voltage rise found across the network from the EGD output, expressed as a % of the nominal voltage at the LV substation side
Max % thermal headroom - cables	“Cable/Line Thermal Rating (%)”	DEBUT	DEBUT output value for the maximum % thermal utilisation found on any cable
Max % thermal headroom - transformers	“Tx Thermal Rating (%)”	DEBUT	Maximum load on any substation from the DEBUT output, versus the transformer capacity
Max loop impedance	“PH+N Resistance (mΩ)”	DEBUT	Maximum DEBUT output value for the loop impedance found across the network
Max fault level	“PH-N Fault Current (A)”	DEBUT	Maximum DEBUT output value for the fault current found across the network

Table 3.12 – Derivation of results presented to the user at the end of LV network assessments.

Parameter	Display name	Engine	Obtained by
Max % voltage drop	“Maximum Volt Drop (%)”	IPSA2	Maximum voltage drop found across the network from the IPSA2 output, expressed as a % of the HV nominal voltage level
Max % voltage rise	“Maximum Volt Rise (%)”	IPSA2	Maximum voltage drop found across the network from the IPSA2 output, expressed as a % of the HV nominal voltage level
Max % thermal headroom - cables	“Cable/Line Thermal Rating (%)”	IPSA2	Maximum load on any cable from the IPSA2 output, versus the cable segment’s capacity
Max % thermal headroom - transformers	“Tx Thermal Rating (%)”	IPSA2	Maximum load on any transformer from the IPSA2 output, versus the transformer capacity

Table 3.13 – Derivation of results presented to the user at the end of HV network assessments.

NPADDs can be designed to display these results in whatever way is most user friendly, to suit the needs of a particular type of assessment – for example, in a BAU product the highest three cable utilisations could be displayed rather than just the top one. The following workflows currently utilise the Network Headroom Assessment Engine:

Existing Network Assessments: Figure 3.59 (LV) and Figure 3.60 (HV) are results shown following an assessment of an existing network, where the data from Table 3.12 and Table 3.13 is analysed and displayed separately for winter and summer.

New Connection Request Assessments: In Figure 3.61 and Figure 3.62, a new connection has been assessed, and the results are instead shown as before and after. Here, only winter results are considered for all but the maximum % voltage rise, where summer results are instead utilised.

In the solar PV workflow (see Figure 3.71), outputs from the headroom assessment are utilised but not directly displayed to the user.

Future Planning Assessments: Figure 3.63 shows the results displayed after scenarios of load growth and LCT uptake at LV have been applied on a yearly basis to a selected network. Winter and summer results are shown separately for each year as per Table 3.12, alongside figures that describe the load growth and, for LV, number of consumers and number of LCTs. HV results are similarly shown in Figure 3.64, based on load growth only.

Solution Assessments: The NPADDs Network Headroom Engine can also be utilised for detailed analysis of certain Solution Templates as part of the Solutions Engine. An example before/after output is shown in Figure 3.65.

Season	Maximum Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	PH-N Fault Current (amps)	PH+N Resistance (mΩ)	Max Volt Rise (%)	OK?
Winter	19.66	104.54	104	255.9	788	3.58	✗
Summer	2.96	35.08	24.2	255.9	788	0	✓

Figure 3.59 – Existing Network Assessment results at LV.

Season	Maximum Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	Max Volt Rise (%)	OK?
Winter	14.58	16.09	55.93	0.00	✗
Summer	1.07	15.52	4.55	0.00	✓

Figure 3.60 – Existing Network Assessment results at HV.

Scenario	Max Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	PH-N Fault Current (amps)	PH+N Resistance (mΩ)	Max Volt Rise (%)	OK?
Before New Connection	4.02	95.68	141	897.5	225.6	0	✓
After New Connection	4.02	96	141	897.5	225.6	0.08	✓

Figure 3.61 – New Connections Request Assessment results at LV.

Scenario	Max Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	Max Volt Rise (%)	OK?
Before New Connection	14.58	4.02	55.93	0.00	✗
After New Connection	14.73	4.03	56.51	0.00	✗

Figure 3.62 – New Connections Request Assessment results at HV.

Winter

Year	Season	Load Growth Factor	Consumers Count	PV Count	EV Count	HP Count	Max Volt Drop (%)	Max Volt Rise (%)	Max Cable Thermal (%)	Transformer Thermal (%)
2014	Winter	1.03	34	0	0	0	2.22	0.00	68.1	66.25
2015	Winter	1.06	34	0	0	0	2.22	0.00	68.1	66.25
2016	Winter	1.09	34	0	0	0	2.22	0.00	68.1	66.25
2017	Winter	1.13	34	0	0	0	2.22	0.00	68.1	66.25
2018	Winter	1.16	34	0	0	0	2.22	0.00	68.1	66.25
2019	Winter	1.19	34	0	0	0	2.22	0.00	68.1	66.25
2020	Winter	1.23	34	1	1	0	2.23	0.00	68.1	66.38

Summer

Year	Season	Load Growth Factor	Consumers Count	PV Count	EV Count	HP Count	Max Volt Drop (%)	Max Volt Rise (%)	Max Cable Thermal (%)	Transformer Thermal (%)
2014	Summer	1.03	34	0	0	0	0.45	1.20	12	11.14
2015	Summer	1.06	34	0	0	0	0.45	1.20	12	11.14
2016	Summer	1.09	34	0	0	0	0.45	1.20	12	11.14
2017	Summer	1.13	34	0	0	0	0.45	1.20	12	11.14
2018	Summer	1.16	34	0	0	0	0.45	1.20	12	11.14
2019	Summer	1.19	34	0	0	0	0.45	1.20	12	11.14
2020	Summer	1.23	34	1	1	0	0.46	1.12	12	11.33

Figure 3.63 – Future Planning Assessment results at LV.

Winter

Year	Season	Load Growth Factor	Max Volt Drop(%)	Max Volt Rise(%)	Max Cable Thermal(%)	Primary Thermal(%)
2014	Winter	1.03	15.12	0.00	57.89	16.15
2015	Winter	1.06	15.67	0.00	59.94	16.20
2016	Winter	1.09	16.26	0.00	62.07	16.27
2017	Winter	1.13	16.88	0.00	64.30	16.34
2018	Winter	1.16	17.52	0.00	66.63	16.42

Summer

Year	Season	Load Growth Factor	Max Volt Drop(%)	Max Volt Rise(%)	Max Cable Thermal(%)	Primary Thermal(%)
2014	Summer	1.03	1.10	0.00	4.68	15.52
2015	Summer	1.06	1.13	0.00	4.83	15.52
2016	Summer	1.09	1.17	0.00	4.97	15.52
2017	Summer	1.13	1.20	0.00	5.12	15.52
2018	Summer	1.16	1.24	0.00	5.28	15.52

Figure 3.64 – Future Planning Assessment results at HV.

	Maximum Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	Max Volt Rise (%)	OK?
Without Capacitor	<u>14.58</u>	16.09	55.93	0.00	✗
With Capacitor	12.38	15.70	52.82	1.35	✗

Figure 3.65 – Solutions Assessment (switched capacitor) results at HV.

Worst-case values across all individual assets

These results are used for example to display worst-case voltages and currents at a cable segment (Figure 3.47), and voltages along a feeder (Figure 3.48). LV results are also used as input at distribution transformers during worst-case HV assessments, while HV results are used as input at distribution transformers during LV assessments (Section 3.5.2).

LV At LV, all such results are based on EGD output, where the results of the load flow are interrogated at each node and TOU time point.

HV HV results are always produced by IPSA2, and at each node may be taken directly from a winter and summer worst-case assessment, or involve the evaluation of each TOU time point.

Winter days are typically used for all worst-case data apart from the maximum voltage rise values where summer day results are used. As above, it may be desired to ensure that a BAU NPADDs product always looks at both winter and summer results, to capture circumstances where technologies such as air conditioning lead to peak loads occurring in summer, and that the user is able to view a summary of both the winter and summer results.

TOU load flow patterns at individual assets

Finally, Figure 3.97 and Figure 3.99 show load profiles found at an LV cable and an LV transformer respectively, and provide examples of how the high resolution ‘raw’ TOU data from the LV Network Headroom Engine is used across NPADDs. Following an assessment, EGD results are available for each location in the network for both summer and winter days. Whether a summer or a winter day is used is specified by each such application; for example, cyclic rating assessments of cables use a winter day as input.

3.5.6 Saving Results

The NPADDs prototype enables load flow results to be saved in two ways: all raw outputs from Network Headroom Engine assessment are currently saved in the NPADDs Database and, during a Global Capacity Assessment, the results table can also be exported to .CSV file format for presentation and manipulation in other applications such as MS Excel.

When results are stored in the NPADDs Database it is the highest resolution of data that is kept, which always means TOU data at LV and TOU or worst-case at HV. NPADDs also keeps track of whether the network under assessment had been amended. Only the latest assessment of an existing non-altered network will be passed to other functionalities within NPADDs, such as cable

and transformer thermal tools, or displayed on the Visual Design Environment maps. If an assessment is carried out on an altered network, the results themselves are saved, but the network alteration itself is not.

3.5.7 Model Verification

EA Technology visited the Northern Powergrid offices at Shiremoor in order to compare load flow results generated by the NPADDs prototype Network Headroom Engine with the corresponding results produced by Northern Powergrid's BAU load flow tools. The purpose of this exercise was to verify the correctness of results produced by NPADDs. Two separate visits took place, the first for HV assessment results verification, and the second for LV.

As briefly outlined below, the tests performed to date indicate that the NPADDs prototype has been successful in terms of producing assessment results that are sufficiently similar to those provided by the DNO's BAU methods.

HV verification

All HV verification tests were performed on the Denwick network area, as this network was known to be large, complex and comprehensively modelled compared to networks at the other two modelled HV areas Rise Carr and High Barmston. Three separate load flow assessments were performed. In each case NPADDs and DINIS (Northern Powergrid's BAU HV tool) were set up to assess the same feeders and load allocations.

The descriptions below refer to Feeders 1 and 2 at Denwick. These names were assigned during the initial data import into NPADDs, and describe the feeders indicated in Figure 3.66:

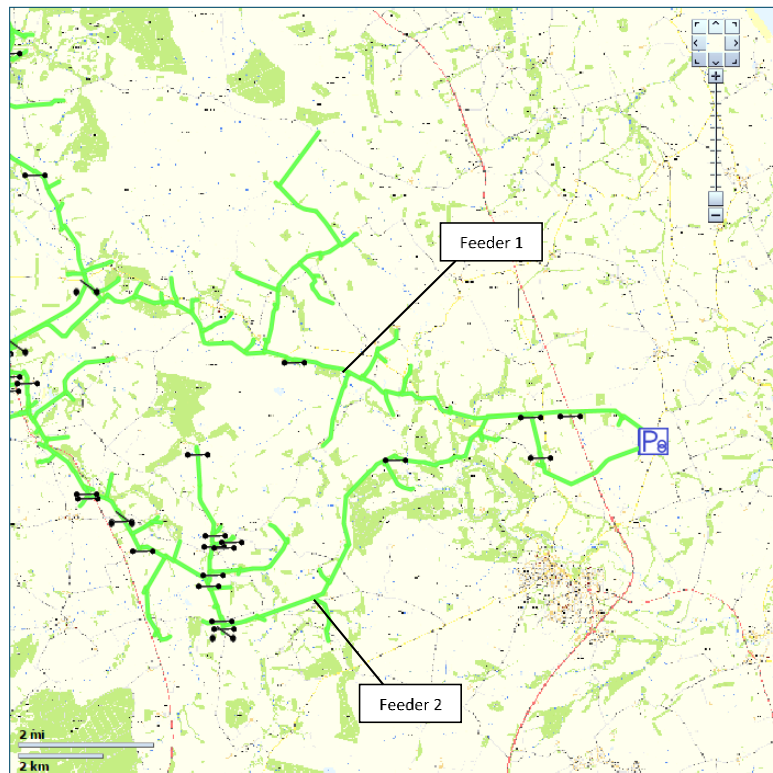


Figure 3.66 – Denwick Feeder 1 and Feeder 2 considered during HV load flow verification.

Three tests were carried out with the configurations shown in Table 3.14-Table 3.16. In each test the load allocation values were suggested by a Northern Powergrid representative, based on current network information but allowing for some variation (i.e. on Feeder 1 between HV Test 1 and 2).

Results were found to be broadly comparable, with the differences in maximum volt drop ranging from 0.2% in HV Test 2, to 0.6% in HV Test 3, and the location of the maximum volt drop being consistent between the two systems in each test. It was concluded that the difference in maximum volt drop could be explained by the two systems using a different load flow engine (NPADDS uses IPSA2), and fundamentally different load allocation algorithms. NPADDS allocates load prior to the load flow assessment, whereas DINIS iteratively modifies the allocated loads during its load flow assessment. Furthermore, NPADDS implements a unique approach to weighting in order to scale down those loads derived from transformer ratings, compared to those derived from Thermal demand indicators.

HV Test 1	
Network Area	Denwick
Configuration	Feeders 1 and 2 both switched in
Feeder 1 Load Allocation	P = 2678kVA Q = 880kVAR
Feeder 2 Load Allocation	P = 2282kVA Q = 750kVAR
NPADDS Max Volt Drop (%)	8.73
DINIS Max Volt Drop (%)	8.1
Max Volt Drop Locations	Identical

Table 3.14 – HV verification results (HV Test 1).

HV Test 2	
Network Area	Denwick
Configuration	Feeder 1 only (Feeder 2 switched out)
Feeder 1 Load Allocation	P = 4960kVA Q = 1630kVAR
Feeder 2 Load Allocation	n/a
NPADDs Max Volt Drop (%)	13.62
DINIS Max Volt Drop (%)	13.4
Max Volt Drop Locations	Identical

Table 3.15 – HV verification results (HV Test 2).

HV Test 3	
Network Area	Denwick
Configuration	Feeder 2 only (Feeder 1 switched out)
Feeder 1 Load Allocation	n/a
Feeder 2 Load Allocation	P = 2282kVA Q = 750kVAR
NPADDs Max Volt Drop (%)	8.39
DINIS Max Volt Drop (%)	7.7
Max Volt Drop Locations	Identical

Table 3.16 – HV verification results (HV Test 3).

LV verification

At LV, tests were performed across three LV network areas: Darlington Melrose, Sidgate Lane and Wooler Ramsey. A total of four tests were carried out, configured as shown in Table 3.17-Table 3.20, including one ‘New Connection Request Assessment’ at Sidgate Lane. The BAU tool used by Northern Powergrid for LV load flow is LV Design which, like NPADDs, uses DEBUT as its load flow engine.

The verification exercise at LV differed considerably from that at HV in two notable respects. Firstly, both NPADDs and LV Design use DEBUT for load flow analysis, and therefore it might be expected that results would be more comparable than at HV. Secondly, no LV consumption data was available to incorporate into the NPADDs prototype, as outlined in Section 3.3.4, and therefore consumption values were set to defaults according to the MPAN meter class of each consumer. LV Design on the other hand has an individual consumption value for each consumer, based on a meter reading taken at some time in the past. In this respect, it might be expected that results at LV would vary more than those at HV.

Ultimately the difference in maximum volt drop between NPADDs and LV Design was found to be very small (less than 0.1%) in the first three tests LV Test 1-3, but very large in LV Test 4 on the Wooler Ramsey network area (approximately 11% difference). This difference was discussed with a designer at Northern Powergrid, who was satisfied that it was a result of the different consumption values used by NPADDs and LV Design on this network area. Wooler Ramsey is unique in that it contains 15 consumers who are classed as Economy7 consumers, but who in fact do not exhibit

typical Economy7 behaviour. During the NPADDs data import, these consumers were assigned an annual consumption of 5,500kWh, resulting in a high volt drop at 1am. In LV Design, these consumers have a much lower consumption figure, which is not split between day and night in the same manner as in NPADDs. The result is a much lower maximum volt drop in LV Design, at a more typical evening peak time.

LV Test 1

Network Area	Darlington Melrose
Configuration	Normal
NPADDs Max Volt Drop (%)	4.02
LV Design Max Volt Drop (%)	4.1
Max Volt Drop Locations	Identical

Table 3.17 – LV verification results (LV Test 1).

LV Test 2

Network Area	Sidgate Lane
Configuration	Normal
NPADDs Max Volt Drop (%)	1.92
LV Design Max Volt Drop (%)	1.9
Max Volt Drop Locations	Identical

Table 3.18 – LV verification results (LV Test 2).

LV Test 3

Network Area	Sidgate Lane
Configuration	New connection near end of feeder: Economy7 consumer with annual consumption of 10000kWh (Figure 3.67)
NPADDs Max Volt Drop (%)	3.92
LV Design Max Volt Drop (%)	3.2
Max Volt Drop Locations	Identical

Table 3.19 – LV verification results (LV Test 3).

LV Test 4

Network Area	Wooler Ramsey
Configuration	Normal
NPADDs Max Volt Drop (%)	19.66
LV Design Max Volt Drop (%)	8
Max Volt Drop Locations	Identical

Table 3.20 – LV verification results (LV Test 4).

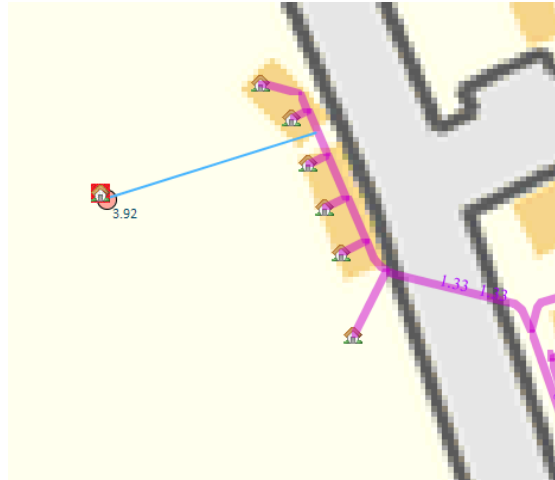


Figure 3.67 – New connection allocated as part of LV Test 3.

3.6 Load and LCT Forecasting Engine

A major challenge for network design and planning lies in incorporating the effect of changing customer behaviour and new technologies on the network. The ability to describe load growth and LCT take up rates to perform analyses on network sections is therefore a key facet of NPADDs.

Scenario analysis and uncertainty are at the core of this type of assessment. Whereas the user can analyse a known situation by adjusting the size of a particular load or adding a LCT such as an EV or HP at an individual node (as in Section 3.4.2), such manual alterations of network connections are not a viable way to forecast behaviour on a wider scale across a network area or over time. For that purpose, NPADDs instead features built-in algorithms that alter the network with allocations of load growth and LCTs. Such alterations are only temporary and do not affect the DNO network model in the NPADDs Database.

Two different processes have been implemented within the prototype, in order to illustrate how NPADDs can support designers and planners – one that applies load growth and LCT uptake over a series of years to illustrate the change in network impact, and another that identifies how much solar PV could be added to a network before a voltage threshold is reached. Both are based on the same core LCT allocation algorithm.

3.6.1 Yearly Scenario Forecasts

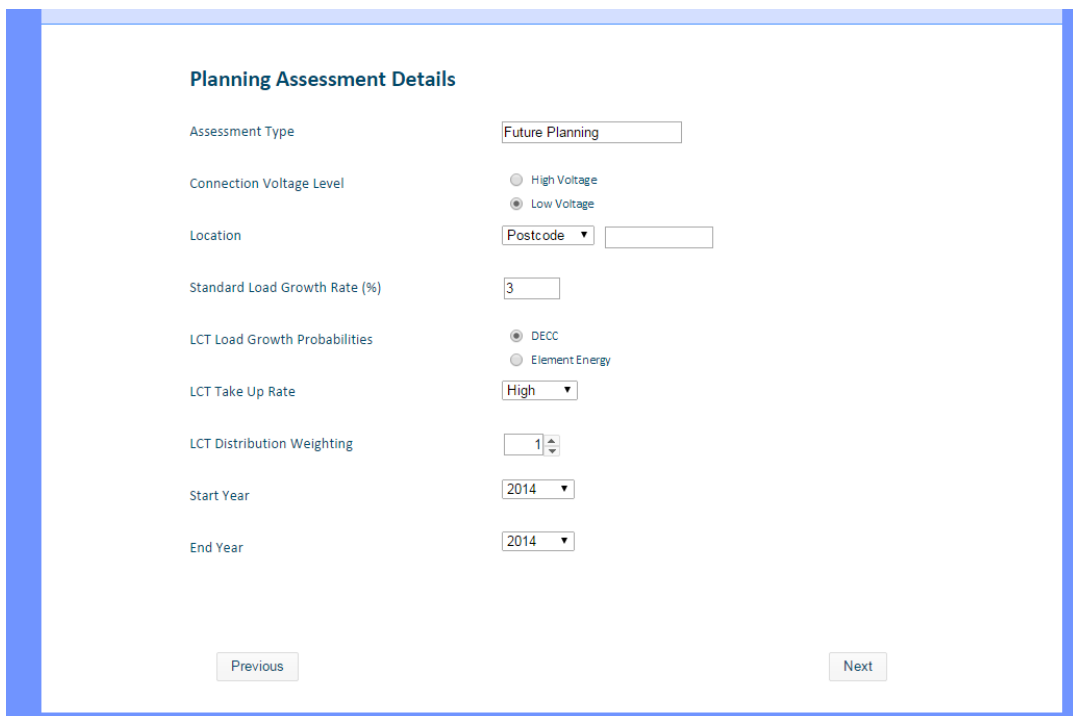
The yearly scenario forecast feature in NPADDs is shown in Figure 3.68. Once the network area to analyse has been selected – as per Section 3.4.2 – the user can create an assessment by setting three types of input:

Load growth: “Standard Load Growth Rate (%)” represents a percentage load growth that NPADDs will apply annually to the ‘base load’ already present on the network. This represents the gradual change in all electrical demand apart from specific LCT loads (EVs and HPs) that are treated separately in the LCT uptake section below.

LCT uptake (LV only): The LCT uptake accounts for the adoption amongst consumers of particular emerging supply and demand technologies, and has been implemented at LV only

for proof-of-concept. Implementation in the prototype has so far focused on three key technologies of concern for DNOs: solar PVs, EVs, and HPs. “LCT Load Growth Probabilities” is a setting that allows the user to choose which input data set (with annual percentage uptakes of these technologies) the analysis will be based on. “LCT Take Up Rate” then defines whether a low, medium or high LCT uptake scenario will be used from the chosen input data set. Finally, the “LCT Distribution Weighting” is an NPADDs parameter that adjusts the spatial allocation of LCTs amongst consumers on the network.

Time period: “Start year” and “End year” set the start and end point for the scenario analysis. NPADDs will apply the scenario progression of load growth and LCT uptake to every year within the given range.



The screenshot shows a web form titled "Planning Assessment Details". It contains the following fields and options:

- Assessment Type:** A text box containing "Future Planning".
- Connection Voltage Level:** Two radio buttons: "High Voltage" (unselected) and "Low Voltage" (selected).
- Location:** A dropdown menu showing "Postcode" and an adjacent empty text box.
- Standard Load Growth Rate (%):** A text box containing the number "3".
- LCT Load Growth Probabilities:** Two radio buttons: "DECC" (selected) and "Element Energy" (unselected).
- LCT Take Up Rate:** A dropdown menu showing "High".
- LCT Distribution Weighting:** A spinner box showing the value "1".
- Start Year:** A dropdown menu showing "2014".
- End Year:** A dropdown menu showing "2014".

At the bottom of the form are two buttons: "Previous" on the left and "Next" on the right.

Figure 3.68 – User specified input parameters for yearly scenario forecasts.

Once the parameters for the forecast analysis have been set, NPADDs alters the network according to the methodologies described below and then performs an assessment using the Network Headroom Engine for both winter and summer cases using the LCT half-hourly profiles stored in the NPADDs Database, repeating this process for each year within the time period.

LV LV analysis is always carried out on a TOU basis, via DEBUT.

HV In the prototype, HV analysis of load growth is carried out on a worst-case basis only.

As an output, NPADDs generates tabular results for each year within the chosen time period as shown in Figure 3.63. In addition to the voltage and thermal headroom calculated by the Network Headroom Engine, the user is also able to view the load growth factor applied to each year, and the total count of EVs, HPs, and solar PVs found on the network.

Methodologies

Both the load growth and LCT uptake features in NPADDs must rely on assumptions about the extent to which a consumer's demand will change between one year and the next. Methodologies implemented in the prototype are described below, demonstrating two different approaches for growth rates:

- Load growth scenarios are generated by a single percentage figure set by the user, which enables flexibility and sensitivity analysis.
- LCT uptake is generated from fixed sets of annual uptake rates, based on input data that is underpinned by research and/or endorsed by the regulator.

Similarly, two different approaches are illustrated with respect to the spatial distribution of the consumers whose demand is changing:

- Load growth is applied evenly across all consumer nodes on the network.
- LCT uptake can be spatially varied by distance to the substation using a weighting factor.

In all cases, load and LCTs are added only to existing customer nodes within the network, which means that the network area's layout and connections remain the same. No new consumers or connection points are created.

Currently, scenario assessment results are not stored in the NPADDs Database, but this could be implemented in a BAU product. This would enable the user to click on an individual consumer node and review the changing daily power flow pattern at that node as the years progress.

Load growth allocation

NPADDs applies the percentage of annual load growth that has been entered by the user (via the "Standard Load Growth Rate (%)" input) evenly to every customer load on the network, for both summer and winter load figures.

For example, if the annual load growth is set to 3% and the analysis is set to start at 2014, each individual consumer load will grow by a factor of 1.03 by one year later in 2015, and a compounded factor two years later in 2016 (i.e. 1.061). If the analysis was set to start at 2016, this year would still show the 1.061 load growth figure. That is, the current year is always used as a starting point; the "start year" and "end year" inputs are therefore primarily a means to study only a portion of the annual forecasts rather than having to view and analyse all years since 2014, as a way of saving time and processing power.

The percentage load growth factor is applied somewhat differently at the LV and HV voltage levels:

- LV At LV, where NPADDs runs load flow assessments via DEBUT, the growth in a consumer load is achieved by multiplying the winter and summer annual consumptions by the percentage growth factor. DEBUT then scales the consumer's standard half-hourly load profile by the increased annual consumption (see Section 3.3.2), resulting in a higher load curve.
- HV HV loads are represented in the NPADDs Database by a single demand figure that can be based on several different definitions, such as the Thermal Demand Indicator or rating.

Exceptions are LV substations with saved TOU assessments, although these also have a single (maximum) demand figure associated with them for both winter and summer. For the HV load growth assessment, which is carried out on a worst-case basis rather than TOU, the load growth percentage is simply applied to the single demand figure that has been selected for use within the Network Headroom Engine. By default, this is the LV assessment maximum demand result for secondary substations and the Thermal Demand Indicator for other HV loads.

At this stage of the prototype development, the situation doesn't arise where LCT technologies such as EVs are also already present on the network, connected at the same node as the consumer that 'owns' them (as described in Section 3.3.2). However, if such loads did exist, the algorithm would not apply the load growth factor to them.

LCT uptake allocation

NPADDs allocates LCT technologies on an annual basis amongst consumer nodes on the network using a step-wise process. First, the % uptake of each specific technology for a specific year is identified, and used to calculate how many units of that technology will be added to the network. Next, the "LCT Distribution Weighting" factor and distances to the substation are used to determine where on the network the technology will appear or, put a different way, which individual consumers will be allocated the technology.

Scenario input data: As one of the options in the prototype, scenarios for LCT ownership provided by DECC have been used to derive uptake percentages. Table 3.21 illustrates the DECC data, with probabilities of ownership of each technology up until 2050 for a scenario with "high" uptake. Percentages for each technology and year have been stored within the Configuration Database. Additional data sets can be imported and used; NPADDs can also use uptake probabilities derived from Northern Powergrid's load model produced by Element Energy, where the behaviour varies by post code area.

Probabilities			
Year	PV	HP	EV
2012			
2013	1.1%	0.1%	0.0%
2014	1.3%	0.1%	0.2%
2015	1.6%	0.1%	0.4%
2016	1.9%	0.2%	0.8%
2017	2.2%	0.2%	1.3%
2018	2.5%	0.3%	2.0%
2019	2.9%	0.7%	2.8%

2020	3.4%	1.5%	3.8%
2021	4.1%	2.3%	5.2%
2022	4.9%	3.3%	6.8%
2023	5.8%	4.8%	8.6%
2024	6.8%	6.9%	10.6%
2025	8.1%	9.2%	12.8%
2026	9.5%	11.8%	15.3%
2027	11.3%	14.6%	17.8%
2028	13.3%	17.4%	20.6%
2029	15.7%	20.3%	23.6%
2030	18.4%	23.1%	26.8%
2031	19.9%	23.8%	29.6%
2032	21.4%	24.6%	32.3%
2033	22.9%	25.4%	34.8%
2034	24.4%	26.2%	37.3%
2035	25.8%	27.0%	39.9%
2036	27.3%	27.8%	42.7%
2037	29.2%	28.7%	45.8%
2038	31.1%	29.7%	49.4%
2039	33.3%	30.6%	53.6%
2040	35.5%	31.6%	58.8%
2041	38.0%	32.6%	63.9%
2042	40.6%	33.7%	68.8%
2043	43.3%	34.8%	73.6%
2044	46.3%	35.9%	78.0%
2045	49.5%	37.1%	82.1%
2046	52.9%	38.3%	85.7%
2047	56.5%	39.5%	88.7%

2048	60.3%	40.8%	90.9%
2049	64.5%	42.2%	92.2%
2050	68.9%	43.6%	92.3%

Table 3.21 – Probabilities of LCT uptake over time based on DECC LCT ownership scenarios.

Allocation of LCTs amongst consumers: The impact of LCTs on a network area depends in part on how far from the substation they are located. NPADDs therefore features an allocation algorithm that enables several scenarios to be studied with respect to this characteristic. Consumer points in the network area are divided into three spatial groups – near, mid-distance, and far from the substation. NPADDs defines these groups by calculating the set of straight-line distances to the substation, and categorising these such that there is an equal or nearly equal number of consumers in each group.

Distances ‘as the crow flies’ are used, rather than tracing the actual cable length between a consumer and the substation, in order to avoid all technologies being allocated to a single particularly long feeder. A more even spread across the network area is considered more realistic and useful for modelling purposes.

Once the spatial groups have been defined, users can set the “LCT Distribution Weighting” factor W_{LCT} between 0 and 2 to influence the relative allocation of LCTs between them. This is achieved by distributing the probabilities of LCT ownership (Figure 3.69) unevenly; the mid-distance group maintains the original probability, while the near and far groups will take on more or less of the technologies as per:

Near:	original probability x $(2 - W_{LCT})$
Mid-distance:	original probability
Far:	original probability x W_{LCT}

Hence, for a “LCT Distribution Weighting” factor of 1 (default in the prototype), the original probability is applied to all spatial groups, whilst for a factor of 0 no LCTs are allocated to the far away consumers.

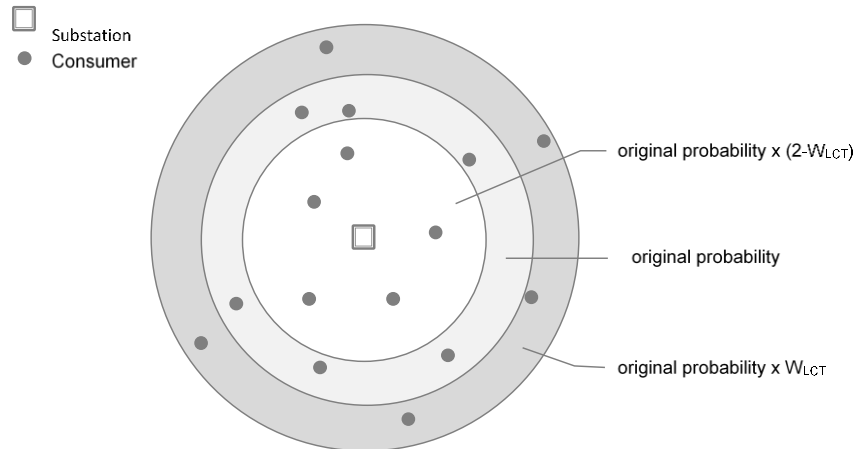


Figure 3.69 – LCT allocation where a weighting factor W_{LCT} adjusts the allocation based on the distance of consumers from the substation.

Given the total number of consumers in the spatial group, and the percentage uptake figures calculated as above, NPADDs assesses how many instances of each technology should be added within each group that year. These numbers are rounded down to integers, resulting in a count of EVs, HPs, and solar PVs to be distributed. Finally, these LCT units are allocated to particular consumers by their individual distances to the substation, starting with those farthest away.

In the NPADDs models, these LCTs are implemented by the creation of individual consumer objects (for EVs and HPs) or generators (PVs) that are temporarily connected at the same node as the original consumer. As described in Section 3.3.2, the LCTs have standard profile shapes in NPADDs for use within DEBUT, and are scaled by a consumption factor or generator capacity respectively. In the prototype, consumption factors and capacity values are currently hardcoded into the software, but represent yet another example of parameters that could be made editable by the user in future.

Each year in the assessment represents an independent analysis. LCTs allocated in one year are discarded during the next year's analysis, when a different probability uptake figure is applied.

In the current version of the prototype, LCTs already present on the network have not yet been encountered or accounted for in the context of LCT uptake scenario analysis. LCTs within consumer premises on the LV network were not present in the network data provided by Northern Powergrid for the samples of networks used within the prototype, and no other generators or LCT loads were represented as independent nodes. (Similarly, no HV generators were present within the Northern Powergrid sample set of networks.)

Incorporating demographics

Forecasting of load growth and LCT uptake is an area where modern approaches to consumer classification could provide DNOs with more refined insights into the likely developments on

individual segments of network. Factors such as demographics, geography, or building types will impact on the likelihood of demand changes and LCT penetration. The NPADDs Database has been designed in such a way that additional consumer properties can be added to account for these types of variations.

A recent development of the NPADDs prototype is the addition of a new input data set for LCT uptake figures provided by Element Energy, as an alternative to the DECC derived data described above. The Element Energy data defines the percentage penetration of technologies on a post code basis, rather than as a single national figure. NPADDs has the ability to map consumers to a post code by matching their location coordinates against those of post code areas held in the Configuration Database (Section 3.1.3), and therefore can define consumers on the basis of uptake rates in their particular area. The allocation process above then distributes the specific amount of LCT capacity or load that is relevant for a particular network area.

3.6.2 Threshold-constrained Solar PV Uptake

The threshold-constrained solar PV tool in NPADDs, which is implemented at LV only, differs from the annual scenarios above in the nature of the question that it answers: it lets the designer or planner obtain an upper figure for the amount of LCT (solar PV, in this case) that a particular network area can accommodate before breaching a chosen headroom margin, without reference to annual levels of growth. On this basis, DNOs would be able to quickly assess the impact of G83 Stage 2 (e.g. multiple PV) connection requests.

Figure 3.70 shows the assessment user interface. Once a network area to analyse has been selected – as per Section 3.4.2 – the user can create an assessment by setting three types of input:

PV size: The “Average PV Size” determines the size of solar PV systems that will be gradually added to the network area until the chosen threshold is reached.

Spatial allocation: The “Distribution Weighting” fills the same role as the “LCT Distribution Weighting” factor described in the annual LCT uptake forecast described above, and allows the user to adjust the spatial allocation of the solar PV units amongst consumers on the network.

Voltage and threshold: “Maximum voltage” is a threshold level set by the user; solar PV units will be added to the network area until any node reaches a voltage level that exceeds this threshold. Voltage levels are calculated by the Network Headroom Engine, which in turn requires a starting point for the voltage at the secondary substation. This starting point is given by the “Bar voltage” and thus adjustable by the user, rather than taken from previous HV assessments or a hardcoded default value as is the case in regular network headroom assessments.

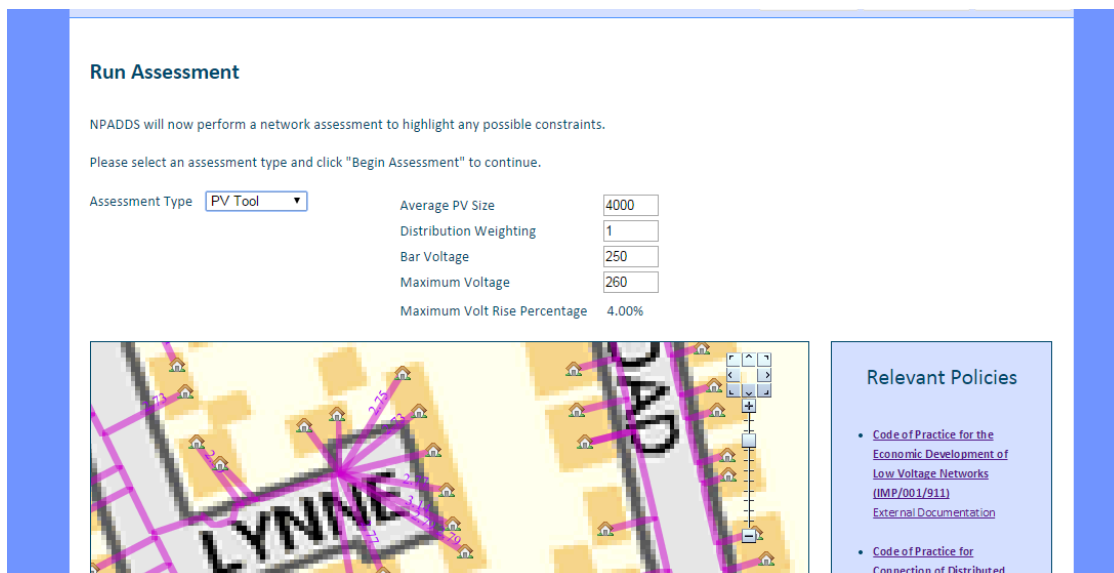


Figure 3.70 – Threshold-constrained Solar PV uptake assessment.

Once the parameters for the solar PV assessment have been set, NPADDs alters the network by adding a solar PV unit of a capacity given by the input “Average PV Size”. Voltage headroom is then calculated by the Network Headroom Engine using a TOU assessment, utilising the typical solar PV daily profile stored in the NPADDs Database and considering a summer weekday only as PV impact is most significant during the sunnier half of the year. This process is repeated until the threshold is exceeded.

As an output, NPADDs generates tabular results for each feeder within the network area, as shown in Figure 3.71. These show the amount of solar PV that could be installed *before* the threshold was reached, both in terms of the number of installations and the total generating capacity (W). Users are also able to view this within the context of the total number of consumers on the feeder.

Feeder Id	Feeder Name	Number of Consumers	Number of Permitted PV	Total Permitted Generation (W)
142490	DARLINGTON MELROSE LV FEEDER A	60	6	24000
142491	DARLINGTON MELROSE LV FEEDER B	68	29	116000
142492	DARLINGTON MELROSE LV FEEDER C	85	85	340000
142493	DARLINGTON MELROSE LV FEEDER D	80	58	232000

Figure 3.71 – Output from threshold-constrained solar PV assessment.

Methodology and algorithms are largely shared with the LCT uptake assessments described in Section 3.6.1. The total count of solar PV installations to install accumulates by 1 with each iteration of the process, with the size of each installation chosen by the user (rather than by any annual projections.) Beyond that, however, the process is the same. The solar PV units are distributed between consumers in the network area based on three groups of consumers – near, mid-distance and far from the substation – at proportions driven by the “Distribution Weighting” user input.

3.7 Solutions Engine

The sections above have described how the NPADDs prototype is capable of identifying headroom problems on networks. In today’s operational circumstances, designers can quickly select solutions

to such problems from experience as the range of appropriate solutions for a particular constraint is modest. As smarter solutions become mainstream, however, the number of potential solutions will increase and manually assessing all technologies and all combinations of technologies would be infeasible. Also, many of the solutions are only applicable for particular asset types and voltage levels.

A core aspect of NPADDs is therefore the ability to guide the decisions of designers and planners in response to a headroom problem found on the network, by proposing solutions in the form of network reinforcement or other mitigating actions and enabling detailed assessment of these. This functionality is provided by the NPADDs Solutions Engine, through two features:

Solution Template ranking: Providing a ranked list of solutions using the methodology of the TRANSFORM tool, which narrows the list of options to consider for a designer or planner based on a high level assessment of factors such as technical feasibility, expected headroom released, and costs.

Detailed solution assessments: Enabling users to then analyse individual solutions in detail on a specific network, where each solution has its own specific assessment methodology depending on its design and network impact, and may for example use the NPADDs Network Headroom Engine.

A Cost-Benefit Analysis (CBA) feature has been developed that presents the user with a summary of the detailed solution modelling results, including multiple solutions, in a single table. Its purpose is to allow a quick and easy comparison of solutions, to help determine which are the most suitable for a given constraint. As a solution is modelled by the user, its corresponding row in the CBA table is updated, and retained while the user investigates other suggested solutions. Columns in the CBA table include information from Solution Templates, such as costs, as well as indications of how the solution affected the network in terms of voltage and thermal headroom.

The prototype NPADDs Solutions Engine allows some future proofing with respect to emerging smart solutions by introducing a framework within which they can be accommodated, and provides a demonstration of the decision support concept. In a BAU product, designers may not feel the benefit in the short term.

3.7.1 Solution Template Ranking

A template for each solution type is held in the NPADDs Database, containing generic details of the expected effect on the network area and type of network for which it is appropriate. Using this approach, solutions can be ranked according to their overall merit on the basis of deterministic ranking, without the need to iteratively model the inclusion of all potential solutions on the network. Solution Templates can also serve to track and keep abreast of advances in performance and cost as technologies develop.

NPADDs applies this methodology to two distinct cases, as described below:

- A single fixed assessment, where a solution to a particular headroom problem is being analysed at a fixed point in time ('Existing Network Assessment', 'New Connections Request Assessment');

- A yearly scenario assessment, where headroom problems are being analysed and resolved over the course of several years ('Future Planning Assessment').

In each case, NPADDs utilises the TRANSFORM methodology to propose solutions. Yearly scenario assessments represent the same type of long-term planning perspective that TRANSFORM was originally designed for. However, in NPADDs the methodology is also adapted as a novel way to provide guidance to designers in the process of narrowing down appropriate solutions to existing or near-term headroom problems on specific networks.

Solutions for a fixed headroom problem

Figure 3.72 illustrates the step in the NPADDs prototype user interface where the Solutions Engine can be launched, following a headroom problem identified by the Network Headroom Engine that is presented to the user as a red cross. In this particular HV case, the maximum voltage drop has been identified as 14.58%, which is 8.58% higher than the chosen threshold setting of 6%.

Season	Maximum Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	Max Volt Rise (%)	OK?
Winter	14.58	16.09	55.93	0.00	✗
Summer	1.07	15.52	4.55	0.00	✓

In order for NPADDs to suggest suitable solutions, please select a network type.

Figure 3.72 – Example step in NPADDs to identify solutions to a single fixed headroom problem.

Solution Requirements

Voltage Headroom	Voltage Legroom	Thermal Conductor Headroom	Thermal Transformer Headroom
0%	8.58%	0%	0%

Suggested Solutions

Rank	Solution(s)	Enabler(s)	Total Totex	Total Merit Cost	Voltage Release (%)	Thermal Headroom Release (%)	Relevant Policies
1	Double Solution: Optimize primary voltage setpoint (£550) Switched capacitors - HV (£40358.66)	N/A Communications to and from devices - LAST MILE ONLY (£5488.13) HV Circuit Monitoring (along feeder) (£38784.52)	£85181.31 ?	£1211.08 ?	Headroom: 9 Legroom: 9	Conductor: 50 Tx: 0	<ul style="list-style-type: none"> Code of Practice for Standard Arrangements for Customer Connections (IMP/001/010) High Voltage Points of Supply Code of Practice for Connection of Distributed Generation (IMP/001/007) Connection at High Voltage Code of Practice for Standard Arrangements for Customer Connections (IMP/001/010) High Voltage Standard Connection Arrangements Code of Practice for the Economic Development of Low Voltage Networks (IMP/001/911) Voltage Policy for Maintenance and Inspection of Protection Schemes (MNT/008) Definitions
2	Double Solution: EAVC - HV circuit voltage regulators (£42126.67) Optimize primary voltage setpoint (£550)	Communications to and from devices - LAST MILE ONLY (£5488.13) HV Circuit Monitoring (along feeder) (£38784.52) HV/LV Tx Monitoring (£969.61) N/A	£87918.93 ?	£1696.36 ?	Headroom: 9 Legroom: 9	Conductor: 0 Tx: 0	
3	Double Solution: EAVC - HV circuit voltage regulators (£42126.67)	Communications to and from devices - LAST MILE ONLY (£5488.13) HV Circuit Monitoring (along feeder) (£38784.52)	£127727.59 ?	£2882.99 ?	Headroom: 12 Legroom: 12	Conductor: 50 Tx: 0	

Figure 3.73 – Example NPADDs solutions ranking to specific headroom problem.

The user can elect to find an appropriate solution, by entering the type of network that the assessment refers to from a drop-down list (see Figure 3.72), in order to ensure the Solutions Engine will consider eligible Solution Templates.

Once a network type is provided, NPADDs presents the user with a list of eligible Solution Templates in their order of merit, as shown in Figure 3.73, where some suggestions may be combinations of two or more Solution Templates in order to achieve the optimal effect.

In the interest of transparency, the user can click on 'Total Totex' or 'Total Merit Cost' (as marked by '?' symbols) in order to explore the methodology and specifics of a particular option's performance. The information then presented by NPADDs is shown in Figure 3.74 and Figure 3.75.

A list of 'enablers' is provided next to each solution, indicating infrastructure systems such as monitoring or communication that would need to be in place to facilitate the solution's operation. Costs of such enabling systems are incorporated into the merit calculations that determine the ranking of solutions, but are not directly available to model in detail in the NPADDs prototype due to the complexity of such a task.

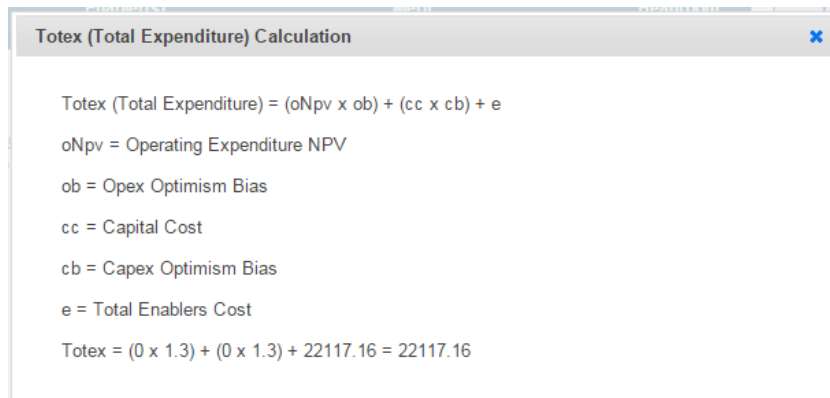


Figure 3.74 – Example NPADDS solution Totex calculation.

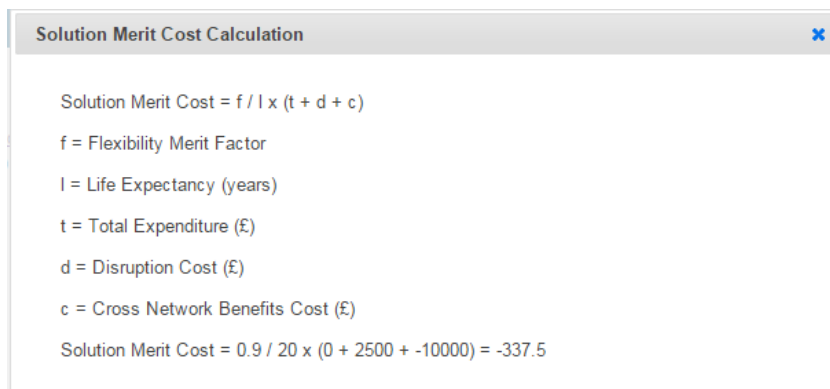


Figure 3.75 – Example NPADDS solution Total Merit Cost calculation.

Finally, at this point, the user can click on the name of a solution within the list shown in Figure 3.73, in order to model it in detail on the specific network. A limited set of solutions have been implemented in the prototype for this type of detailed assessment.

Solutions for yearly scenario headroom problems

Ranking of solutions for the purposes of annual scenario assessments differs from the case above in two important respects. Firstly, solutions are proposed and ranked as a series of investments over time, in such a way that headroom problems over the course of several years are resolved when needed. Secondly, no individual solutions are available to model in detail on the specific network; the purpose of scenario assessments is simply to provide an overview of the likely role of different types of headroom solutions across the DNO's licence area, so that plans and strategies can be put in place accordingly.

Figure 3.76 illustrates the step in the NPADDS prototype user interface where the Solutions Engine can be launched, following a 'Future Planning Assessment' with a load growth and/or LCT uptake scenario forecast projecting future headroom problems. In this particular case, the maximum cable thermal headroom has been found to be 140% in 2014, and increasing steadily up to 216% at the end of the assessment in 2026.

Winter

Year	Season	Load Growth Factor	Consumers Count	PV Count	EV Count	HP Count	Max Volt Drop (%)	Max Volt Rise (%)	Max Cable Thermal (%)	Transformer Thermal (%)
2014	Winter	1.03	293	3	0	0	4.04	0.28	140	98.32
2015	Winter	1.06	293	4	1	0	4.21	0.25	144	101.04
2016	Winter	1.09	293	5	2	0	4.34	0.30	155	103.84
2017	Winter	1.13	293	6	3	0	4.48	0.49	159	106.72
2018	Winter	1.16	293	7	5	0	4.77	0.62	164	109.7
2019	Winter	1.19	293	8	8	2	4.65	0.62	169	112.76
2020	Winter	1.23	293	10	11	4	4.8	0.60	160	115.92
2021	Winter	1.27	293	12	14	6	4.95	0.58	165	119.18
2022	Winter	1.30	293	14	19	9	5.31	0.54	178	122.52
2023	Winter	1.34	293	16	25	13	5.07	0.32	182	125.98
2024	Winter	1.38	293	19	31	19	5.38	0.19	188	129.52
2025	Winter	1.43	293	23	38	26	5.71	0.42	193	134.98
2026	Winter	1.47	293	27	45	34	5.7	1.06	216	142.84

In order for NPADDs to suggest suitable solutions, please select a network type.

LV6 Suburban street (3 4 bed semi detached or detached houses) ▼

Previous

Next

Figure 3.76 – Example step in NPADDs to identify solutions to a progression of annual scenario headroom problems.

The user can elect to find appropriate solutions, again by entering the type of network that the assessment refers to from a drop-down list. NPADDs then presents the user with the Solution Template of the highest merit, as shown in Figure 3.77, where the required year and season of implementation is also shown. NPADDs accounts for the fact that implementing a particular solution in 2014 to resolve an existing headroom problem will be sufficient until 2016, when a new solution is needed to facilitate the growing load.

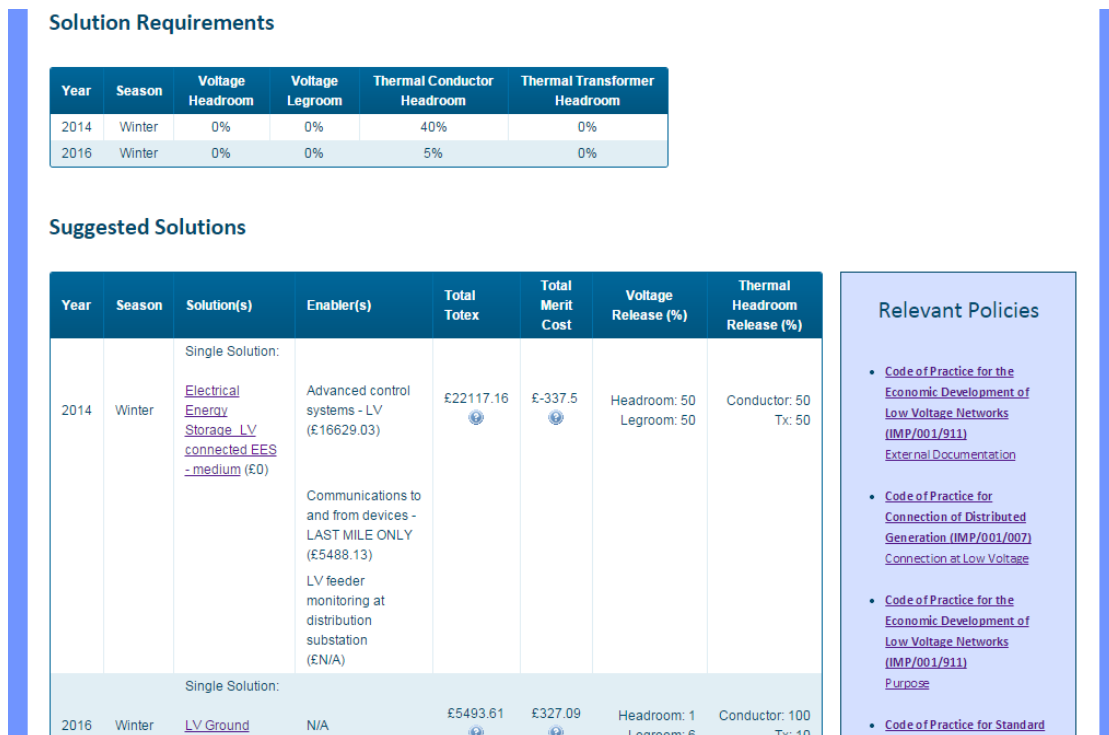


Figure 3.77 – Example of solutions suggested by NPADDs to resolve headroom problems that occur by specific years during a multi-year scenario.

Ranking methodology

NPADDs applies the logic of the TRANSFORM model, recreated in C#.NET, to assess the relative merit of each solution. Methodology descriptions can be accessed via the TRANSFORM documentation. Refinement is likely to be required for a BAU product, in order to provide a degree of sense checking that ensures proposed solutions are feasible for the situation and aligned with Northern Powergrid’s policies.

Briefly, each Solution Template holds properties as those shown for the case of the “EAVC – HV/LV Transformer Voltage Control” Solution Template in Figure 3.78 (where EAVC stands for Enhanced Automatic Voltage Control) including:

- Headroom Release (Thermal, Voltage);
- Percentage change of power quality;
- Percentage of fault level headroom released;
- Cost (Capex, Opex, Net Present Value of Opex, Solution Life Expectancy);
- Operational (Disruption Factors, Flexibility of Solution, Cross Network Benefits);
- Impacts (Losses, Quality of Supply);
- Availability (Year)

The user can hover over the field labels in Figure 3.78 in order to obtain more details on the meaning of each field.

EAVC - HV/LV Transformer Voltage Control	
Representative Solution	EAVC
Thermal Conductor Headroom Release (%)	0
Thermal Transformer Headroom Release (%)	0
Voltage Headroom Release (%)	15
Voltage Legroom Release (%)	15
Power Quality (%)	0
Fault Level (%)	0
Capital Cost (£)	0
Operational Expenditure (£)	0
Cost Curve Type	2
Life Expectancy (years)	40
Disruption Factor (0-5)	3
Disruption Cost (£)	10000
Flexibility (0-5)	2
Flexibility Merit Factor	0.95
Cross Networks Benefit Factor	1
Cross Network Benefits Cost (£)	-5000
Impact on Fixed Losses (%)	2
Impact on Variable Losses (%)	0
Impact on Quality of Supply (%)	0
Year Available	2014
Is Smart Solution?	<input checked="" type="checkbox"/>
Model this Solution	

Figure 3.78 – Example Solution Template.

Each Solution Template also has a set of additional properties specifying constraints and requirements for its implementation, including:

Types of eligible networks: The types of networks where a particular technology can be deployed are specified at LV and HV, and includes up to 20 pre-specified categories at the LV voltage level as shown in Figure 3.79.

Compatibility and synergy with other solutions: This is expressed as a matrix that states whether or not a pair of solutions can be deployed in combination.

Additional ‘enabling’ technology required: These are technologies or systems that would need to be in place in order to facilitate the solution’s operation. Costs of such enablers are incorporated into the merit calculation above, in such a way that the cost is accounted for only once when required for several solutions that are implemented as a combination or in subsequent years from each other.

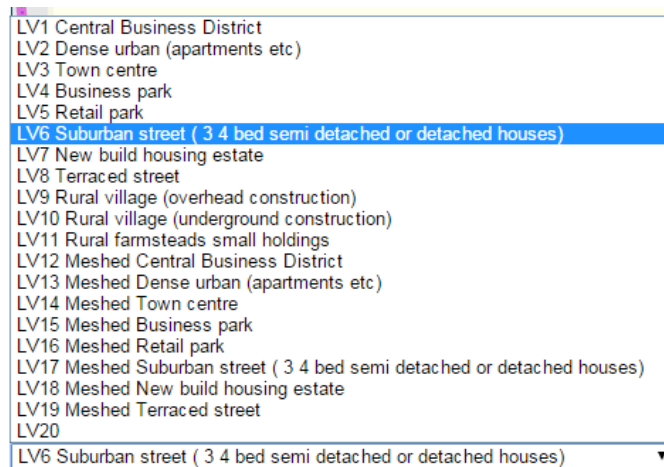


Figure 3.79 – Types of LV networks, each of which is defined as eligible or not eligible for every Solution Template.

Solution Templates are ranked on the basis of this input information, constrained by the type of network under assessment (as specified by the user), and by achieving the headroom release that is required on the specific network; in the case illustrated in Figure 3.73, this is the need to increase voltage headroom by 8.58% whilst there is no need to release voltage legroom and equipment thermal headroom. Given such a target, the TRANSFORM logic identifies an eligible set of solutions and combinations of solutions, calculates a merit cost for that subset, and finally lists the eligible solutions in the order of rising merit cost. A headroom margin is applied to ensure proposed solutions give more headroom than is immediately required to cater for some future load growth.

For scenario assessments, solutions are applied in succession; NPADDs selects the most appropriate solution from the merit list to resolve the first headroom problem to occur, with the required buffer specified by the user with the Settings main menu. Headroom figures for subsequent years are adjusted to account for the release provided by this initial solution. The ranking algorithm will then repeat this process in any following years when headroom problems once again arise.

Sets of Solution Templates

NPADDs applies the ranking process to the set of Solution Templates that has been selected and defined within the user interface Settings main menu. An original SGF WS3 ‘Workstream 3 default’ set replicates the comprehensive database of Solution Templates that was generated as part of the original development of TRANSFORM under the SGF WS3 work. Additional, modified versions of this set have been included in the prototype for demonstration and testing purposes.

Template solutions that are part of the ‘Workstream 3 default’ SGF WS3 set, which encompass CLNR technologies, include both smart and conventional reinforcement methods. The NPADDs prototype is capable of modelling several such solutions in detail on a specific network, as proof-of-concept.

Smart and CLNR technologies: All technologies and propositions trialled as part of CLNR are accounted for as Solution Templates within the NPADDs prototype.

Conventional reinforcement options: Conventional reinforcement options are an important part of the solutions set. The emergence of novel or smart technology in the power sector does not make conventional reinforcement approaches redundant. In many cases the most

appropriate headroom solutions will be in line with incumbent practices, and NPADDs therefore considers these solutions seamlessly in line with smart solutions.

Conventional reinforcement templates are currently based on the WS3 work, but details of these should be brought into line with Northern Powergrid's operational experience for a BAU product.

Reconfiguration of the network is often used to avoid replacement of assets, defined here as moving load from a heavily loaded feeder to one with lighter loading. It was not included in the original WS3 TRANSFORM work aimed at policy guidance, but is a relevant solution for design activities when resolving individual headroom problems as applied within NPADDs. For BAU application, it is suggested that a Solution Template for network configuration is defined in consultation with Northern Powergrid in order to prompt designers to consider this option as part of the design process.

Having several sets also means that the user can revert back to the multi-party approved DNO-generic SGF WS3 version if required. This would allow comparison of the solution sets between this standard model and the Northern Powergrid / CLNR flavoured version.

Finally, users can add custom Solution Templates to a set, provided that properties can be supplied in the format required (similar to Figure 3.78.) Such a solution will then be ranked in order of merit along with the others in that set. However, it cannot be assessed in detail on the network without an NPADDs software upgrade that incorporates the appropriate assessment methodologies for that specific solution.

3.7.2 Detailed Solution Assessments

Once a list of solutions is proposed from the templates, the designer can choose to assess an individual solution in more detail on the network in question, so that the effect of the proposal can be understood. This includes tuning the design of the solution, such as its location and parameters, as well as obtaining an actual network headroom assessment following the introduction of the technology on the specific network.

Detailed solution assessments have been developed as a proof-of-concept of how such analysis can be approached, in particular where simple heuristic assessments can be applied versus making use of the Network Headroom Engine. The following are available in the prototype and described below:

- Transformer Voltage Set Points
- Voltage Regulators
- Switched Capacitors (HV only)
- Demand Side Response (DSR)
- Electrical Energy Storage (EES)

A BAU product would need to be expanded to also model conventional reinforcement and potentially other smart solutions in more detail.

Transformer voltage set points

Transformer voltage set points at LV and HV represent the assessment of On-Load Tap Changer (OLTC) transformers installed at distribution or primary substations.

When electing to model this solution, the user is taken to the interface shown in Figure 3.80. The graph shows the existing minimum and maximum voltage drop along each feeder that is connected to the substation, taken from the worst-case summer and winter load flow results (respectively) from the preceding Network Headroom Engine assessment. These are shown against the set voltage limits shaded in red, referred to within the Settings in Section 3.2.1. Alternate minimum and maximum voltage drops are also shown, where the new OLTC setting has been applied and the voltage adjusted accordingly.

A single user-defined design parameter determines the OLTC impact:

- Voltage set point

Given this central setpoint, NPADDs calculates the voltage change required to bring both the minimum and the maximum voltage at the start of the feeder to that level. The identified voltage change is then simply applied to shift the minimum and maximum voltage along the feeder, up and down respectively, making the simplified assumption that an increase or reduction in voltage at the top of the feeder will carry through all the way to the end. Therefore no new load flow assessment by the Network Headroom Engine is used.

NPADDs also obtains the required +/-% tap ratio that the OLTC must feature, by calculating the largest voltage change as a percentage of the original starting voltage (maximum or minimum voltage), and displays this to the user.

Online Tap Changer

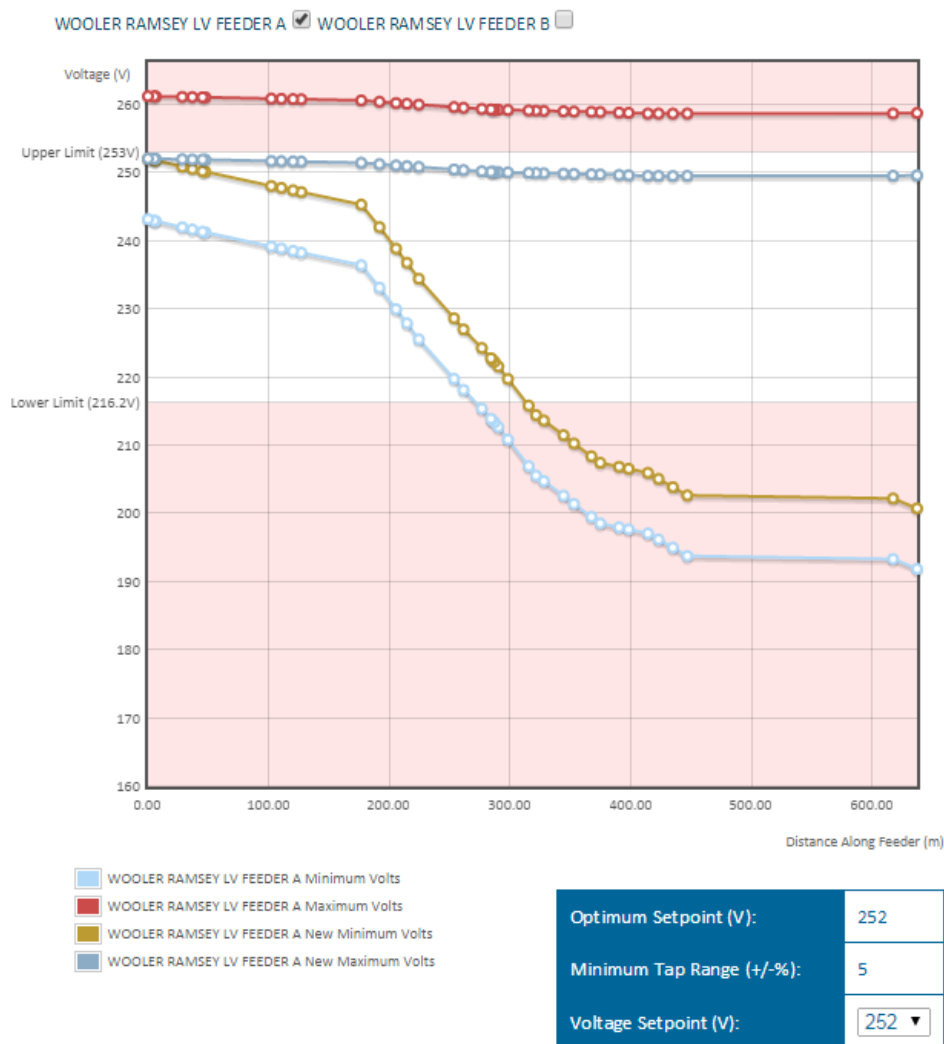


Figure 3.80 – Transformer voltage set point solution modelling at LV.

An “Optimum Setpoint (V)” shown in Figure 3.80 is calculated by NPADDs, providing an estimate of a likely appropriate voltage set point given the conditions on the worst performing feeder, shown on the graph as default. It is identified by looping through potential voltage set points (in multiples of 1V at LV, and 500V at HV) across a range that encompasses the upper and lower voltage thresholds, and selecting the one where the margins from the set point to the existing minimum and maximum voltages are the most similar.

Effect on LV Voltage

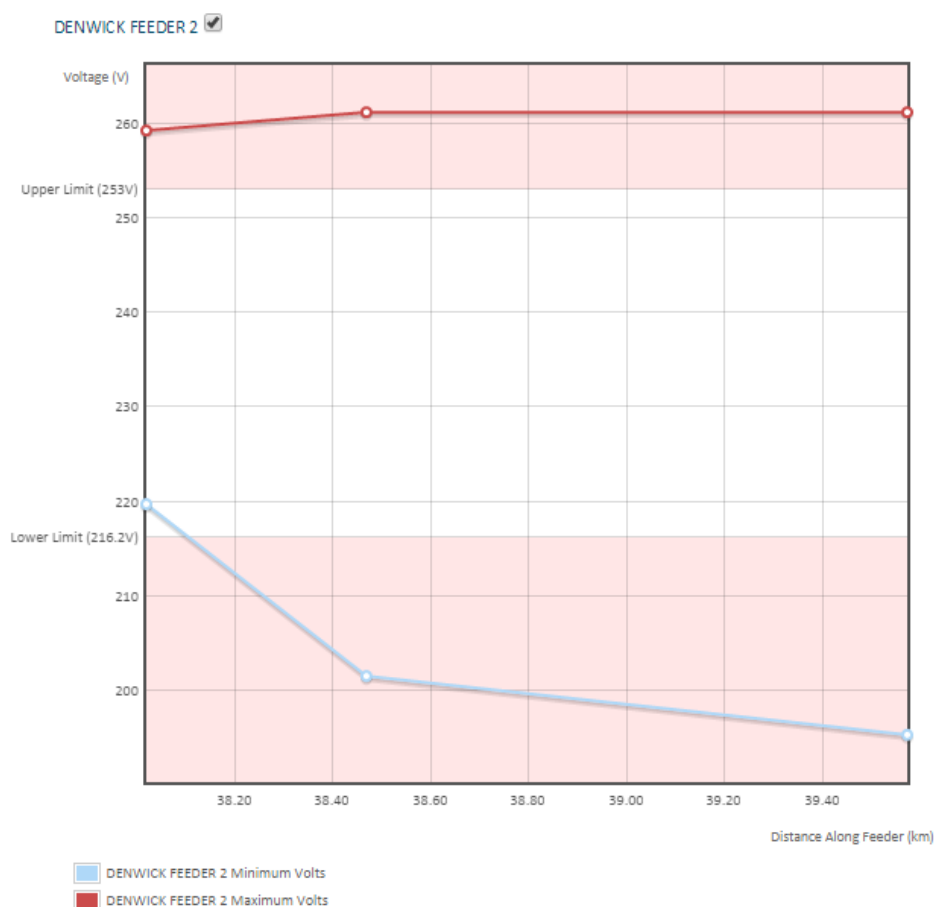


Figure 3.81 – Transformer voltage set point solution modelling at HV showing the impact on LV feeder voltages.

By inspecting the graph, the user can then assess whether changing the AVC (Automatic Voltage Control) set point can bring the voltage back within permissible levels using different design parameters, not only on the feeder with the most exacerbated voltage problem but on all feeders at the substation by ticking the appropriate check boxes.

HV At HV, the model also considers the effect of the primary transformer voltage set point on the connected LV networks, as shown in Figure 3.81. Currently, the summer and winter worst case voltage levels along the LV feeders are also simply shifted (where results have been saved from previous network headroom assessments), by the same percentage that the HV side of the distribution transformer is shifted compared with its previous level.

Voltage regulators

Voltage regulators at LV and HV represent the placement of regulators along feeders.

When electing to model this solution, the user is taken to the interface shown in Figure 3.82. As in the case of the transformer voltage set point solutions, the graph shows the existing minimum and maximum voltage drop along each feeder that is connected to the substation, taken from the worst-case summer and winter load flow results (respectively) from the preceding Network Headroom Engine assessment. These are again shown with reference to the voltage limits, shaded in red and

defined in the Settings main menu. The map, meanwhile, shows the network layout against a street map, providing the user with a spatial context for the location of any regulators to be placed along the feeder.

Placing the regulator within the network is done by either clicking on a location on the feeder on the map, or by clicking along the graph, where the x-axis represents the distance along the feeder from the substation. On the graph, the distance is indicated to the user so that an informed choice can be made. NPADDs uses an algorithm to dynamically calculate the feeder distance from the substation each time the graph is plotted, in order to account for any reconfigurations of the network carried out by the opening or closing of switches.

An icon appears on the map when the regulator is placed and, as shown in Figure 3.83, the minimum and maximum voltages are adjusted up and down (respectively) from its point of installation to the end of the feeder.

Three user-defined parameters determine the regulator impact on network voltage, representing desired design parameters that are implemented by NPADDs as far possible:

- Voltage set point
- Tap Range -%
- Tap Range +%

Tap Range values are expressed as percentages of the existing summer (minimum) and winter (maximum) worst-case voltages at the regulator. These voltages are then shifted as follows. If they are above the Voltage set point, they are stepped down by an amount that depends on whether the maximum downward shift facilitated by the Tap Range -% parameter is sufficient to reach the Voltage set point:

- If yes, the voltage is reduced by the amount required to reach the Voltage set point
- If no, the voltage is reduced by the maximum downward shift.

The maximum and minimum voltages are similarly shifted up on the basis of the Tap range +% parameter, if they are below the Voltage set point.

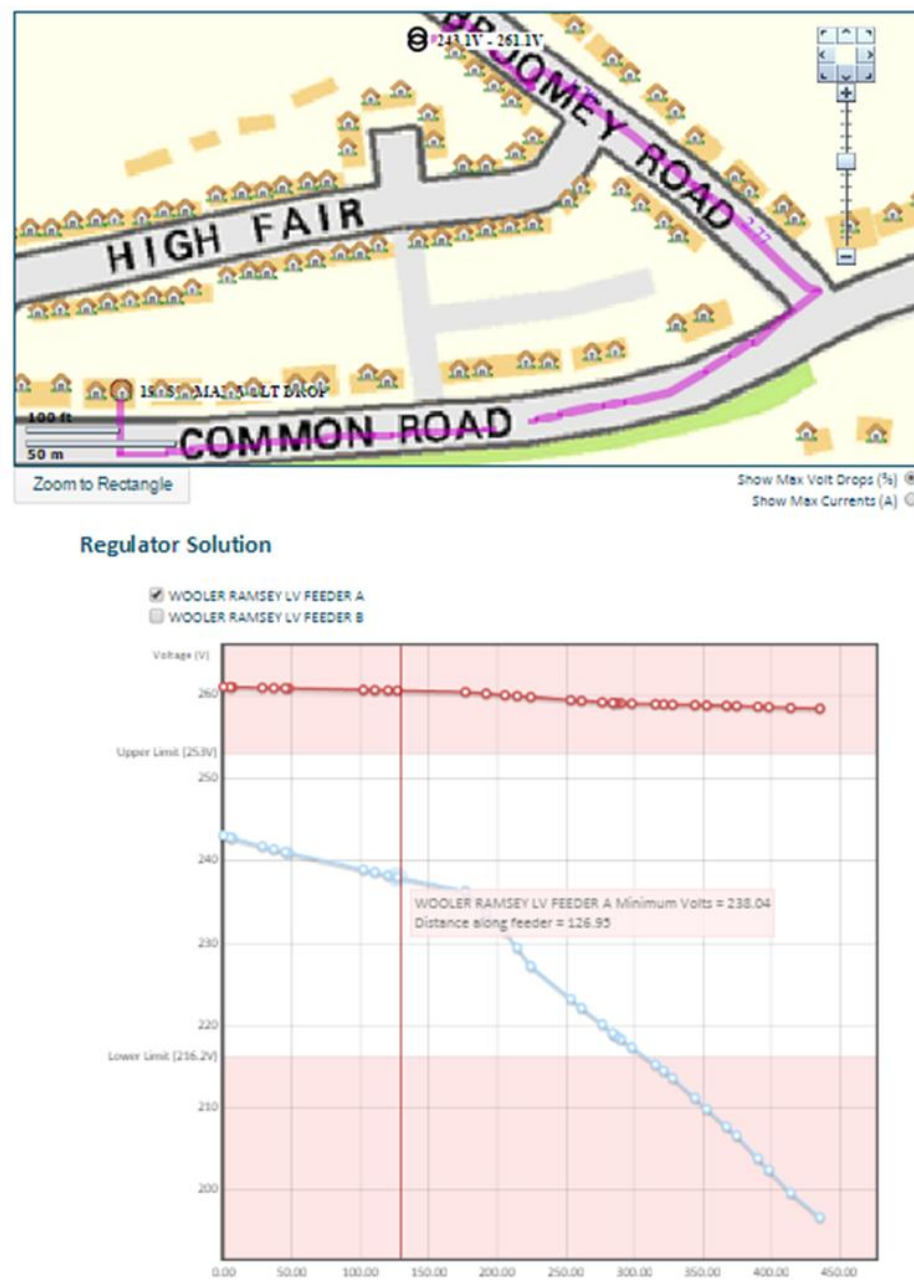


Figure 3.82 – Regulator solution modelling at LV, without regulator.

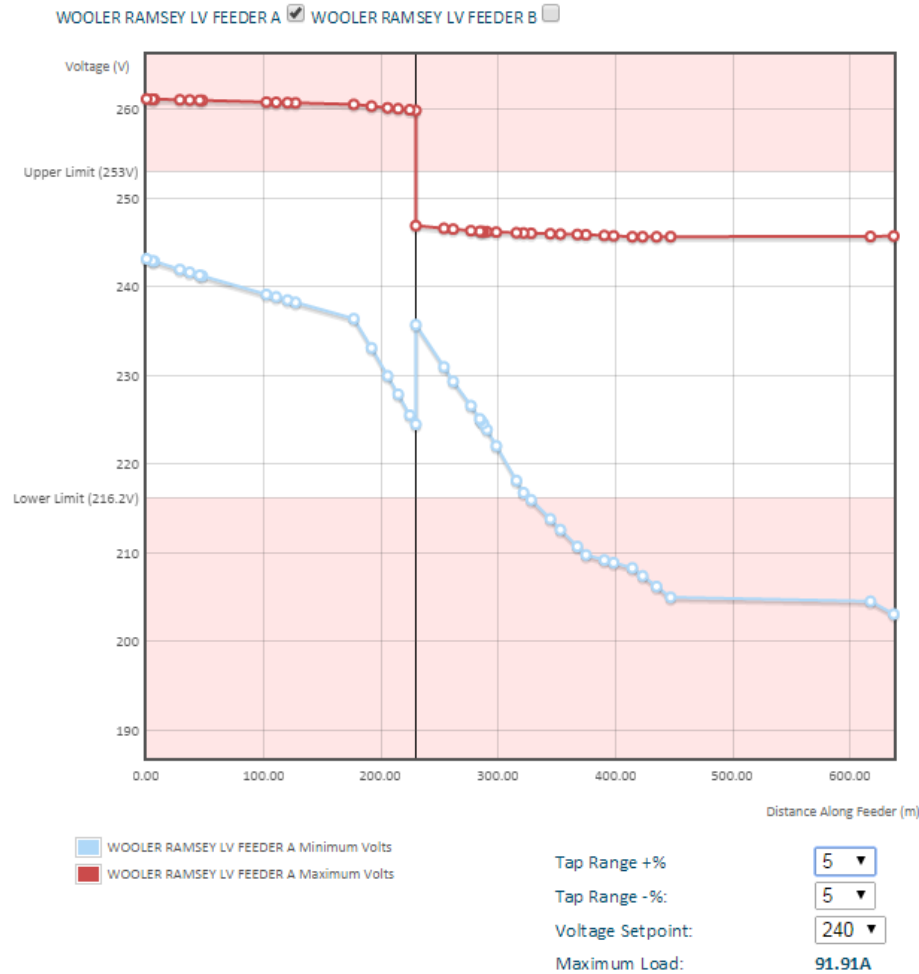


Figure 3.83 – Regulator solution modelling at LV, with regulator.

As in the case of the transformer voltage set points above, the identified voltage change is then simply applied to shift the minimum and maximum voltage long the feeder, up and down respectively – but only downstream from the point where the regulator is installed – making the simplified assumption that an increase or reduction in voltage at the top of the feeder will carry through all the way to the end. Therefore no new load flow assessment by the Network Headroom Engine is used.

Once again, the user can inspect the graph to assess the ability of the solution to bring the voltage back within permissible levels using different settings.

Finally, NPADDs displays to the user a Maximum Load value, which represents the peak load at the point where the regulator has been placed. This indicates to the designer what rating the regulator will require, which could potentially provide another design constraint.

Switched capacitors (HV)

Switched capacitors represent the placement of a capacitor along a HV feeder. When electing to model this solution, the user is taken to the interface shown in Figure 3.84, which mirrors that

described for the voltage regulator solutions above all the way up to the placement of the capacitor either on the map or within the graph.

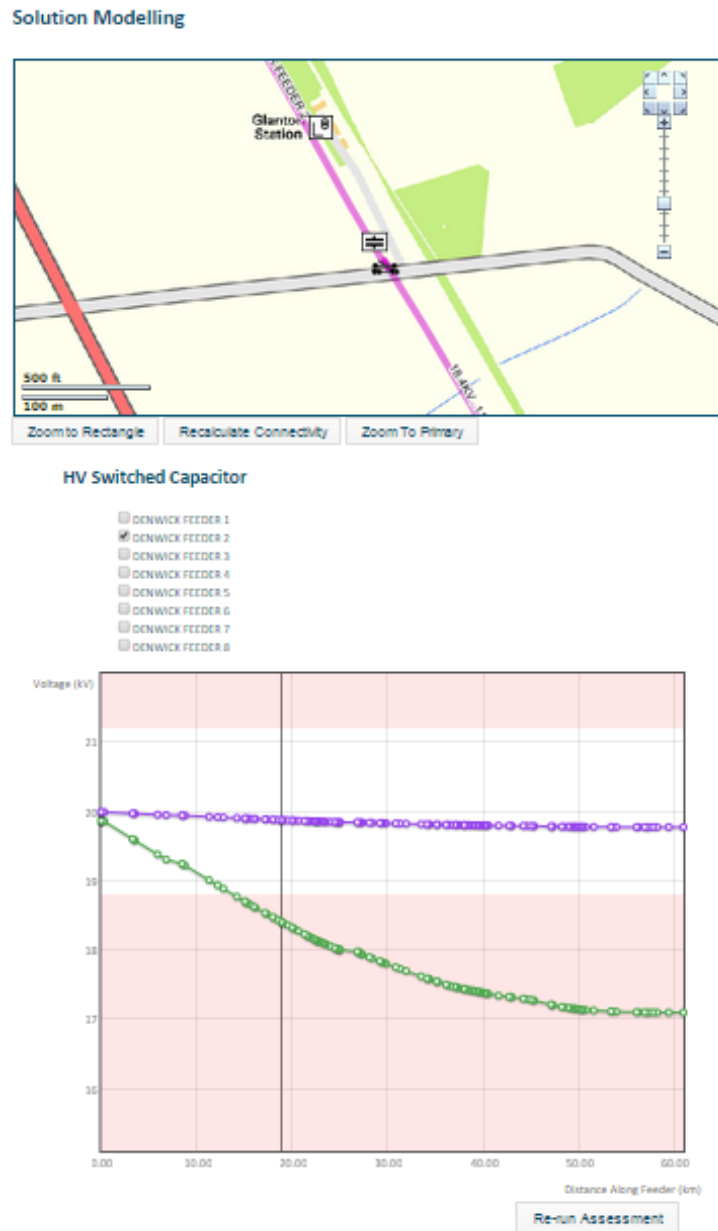
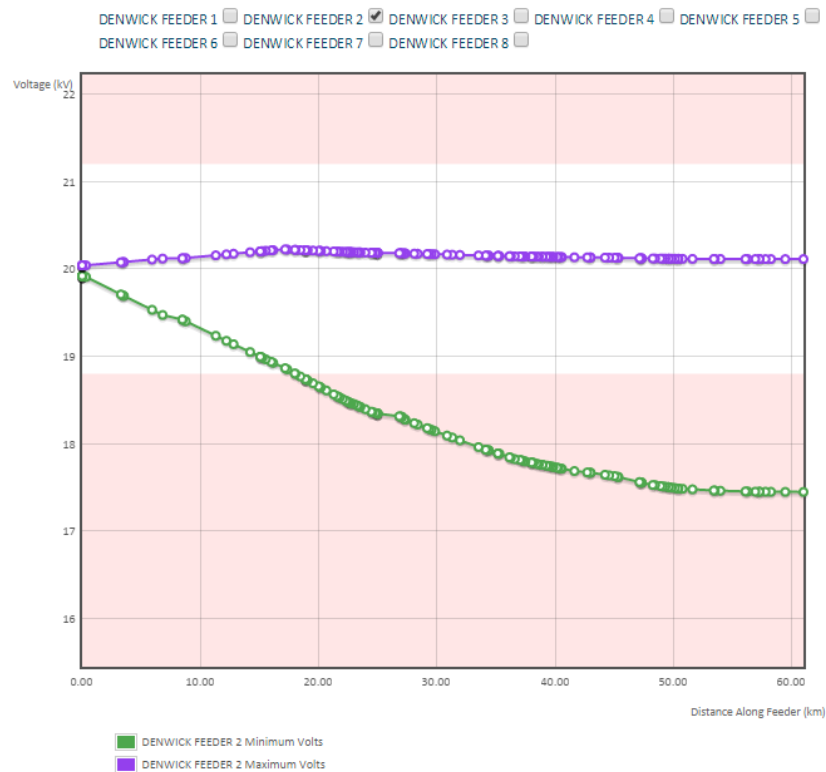


Figure 3.84 – Switched capacitor solution modelling at HV, with a capacitor in place but impact not yet assessed.

At that point, in order to assess the impact of a capacitor on the network, NPADDs re-runs an assessment using the Network Headroom Engine. Results are plotted on a new graph, as shown in Figure 3.85, as well as presented to the user in tabular format with respect to the both thermal and voltage thresholds as shown alongside a red cross or green tick to indicate whether all headroom problems are resolved for the network area as a whole.

HV Switched Capacitor



Rerun Assessment

	Maximum Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	Max Volt Rise (%)	OK?
Without Capacitor	14.58	16.09	55.93	0.00	✗
With Capacitor	12.75	15.70	52.85	1.11	✗

Figure 3.85 – Switched capacitor solution impact at HV, following deployment.

Demand Side Response (DSR)

DSR for the purposes of this report refers to the adjustment of consumer profiles in order to shift load. It has been implemented somewhat differently at LV and HV, to account for the ways that consumer demand is treated at each voltage level within the NPADDs prototype.

DSR at LV

The low voltage solution has the user interface shown in Figure 3.86, and is implemented per consumer type. Thus, for a network which serves a variety of consumer types, the user can select which of those types will be updated to model the impact of DSR. In the Configuration database, each consumer profile can be associated with one or more corresponding DSR profiles. For example, the URM C consumer type might be associated with a set of additional altered profiles URM C DSR1,

URMCDSR2 and URMCDR3, allowing the user to update a proportion of URM consumers on the network to be characterised by one of these subtypes instead.

As Figure 3.86 shows, for each consumer type the user chooses a percentage of consumers to update to the specified DSR type. Given this input and the number of relevant consumers within the network area under study, NPADDs selects a subset of consumers to modify in this way. Consumers are selected according to the algorithm used for LCT uptake allocation, as described in Section 3.6.1.

DSR Settings

Consumer Type	Count	DSR Type	Percentage
URMC	181	URDSRA ▼	70 ▼
ESEVEN	15	ESDSRB ▼	0 ▼

Re-run Assessment

Figure 3.86 – LV DSR input parameters.

With DSR deployed, NPADDs re-runs an assessment using the Network Headroom Engine. Results are reported in the form of voltage graphs for each feeder (Figure 3.87), as well as a TOU load profile at the substation along with tabular headroom results before and after DSR was deployed (Figure 3.88).

Voltage Profile

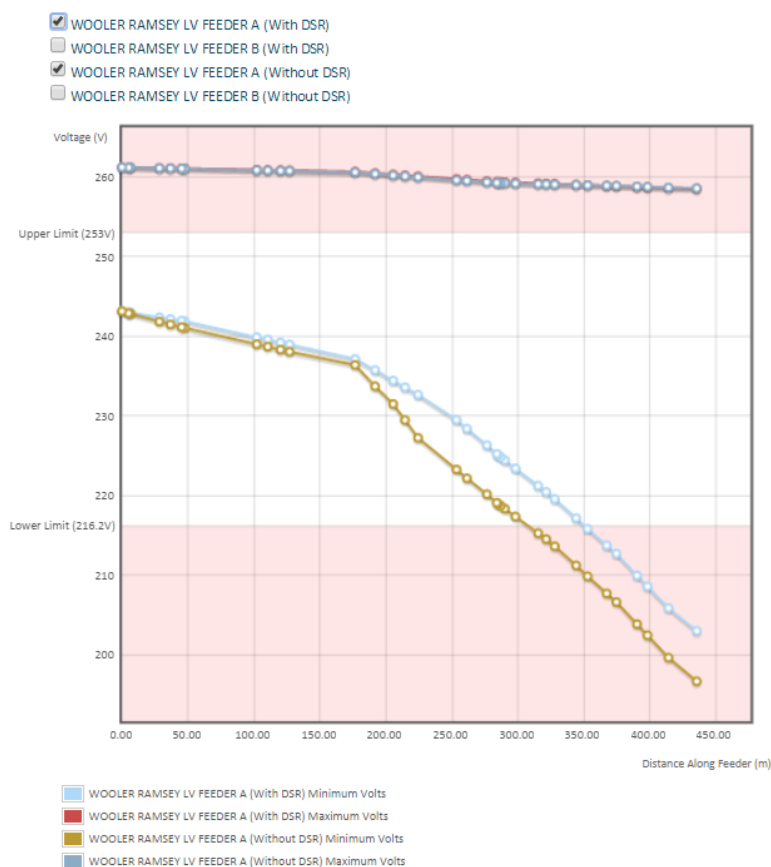
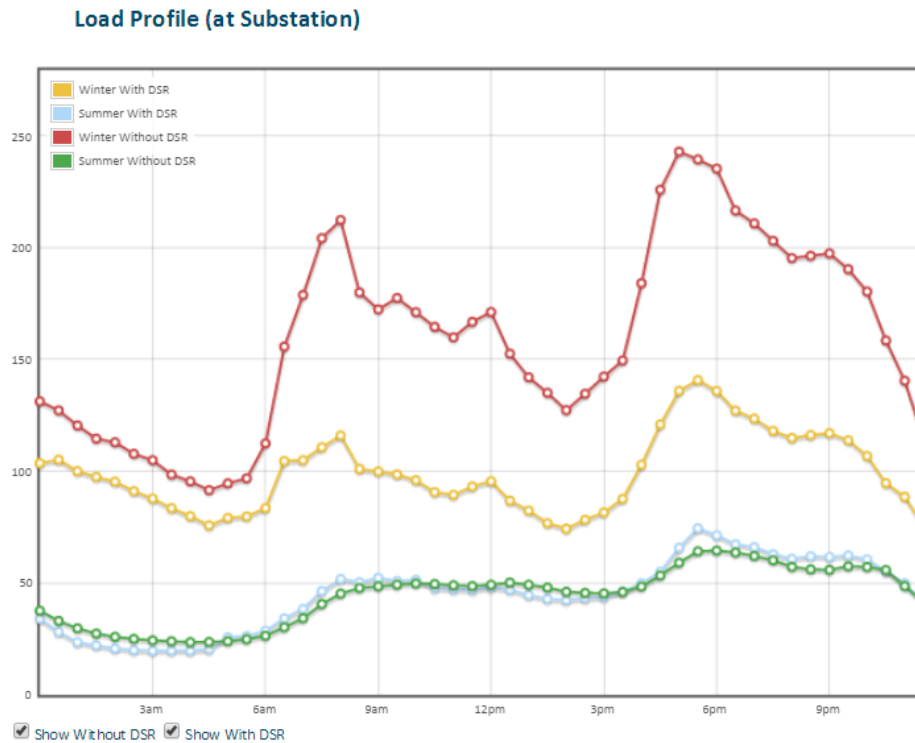


Figure 3.87 – LV DSR voltage graph results.



	Max Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	Max Volt Rise (%)	OK?
Without DSR	19.08	77.1	105	0	✗
With DSR	16.48	44.68	75.2	0.17	✗

Figure 3.88 – LV DSR substation profile and summary results.

DSR at HV

At HV, DSR is modelled as generation on the network that effectively offsets demand by major HV consumers. The user is guided towards adding one or more generators to the network in the usual way (i.e. by first drawing cables to connect to the network as described in 3.2.2), with the resulting implementation shown in Figure 3.89 below.

In the prototype all HV loads are displayed using the same icon. In reality, the DSR modelled here would only be implemented at those loads which represent an industrial customer, and not at those that represent HV/LV distribution substations. In a BAU tool it would be useful to display HV commercial customers using a different icon, to guide the user towards placing generators in appropriate locations.

With generation applied, NPADDS re-runs an assessment using the Network Headroom Engine. Results are then presented in the form of voltage graphs (Figure 3.90) and a standard HV load flow summary results table, before and after adding DSR.

Solution Modelling

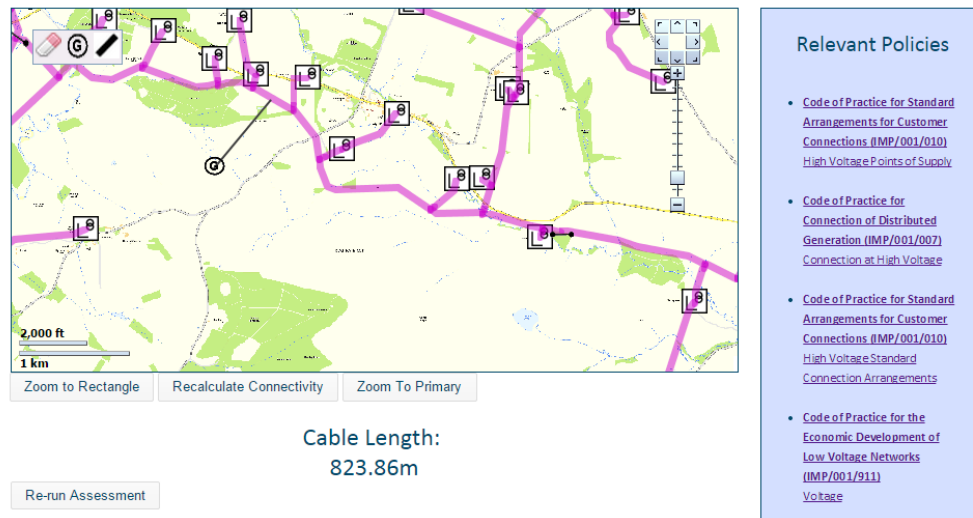


Figure 3.89 – Placement of generator to simulate DSR at HV.

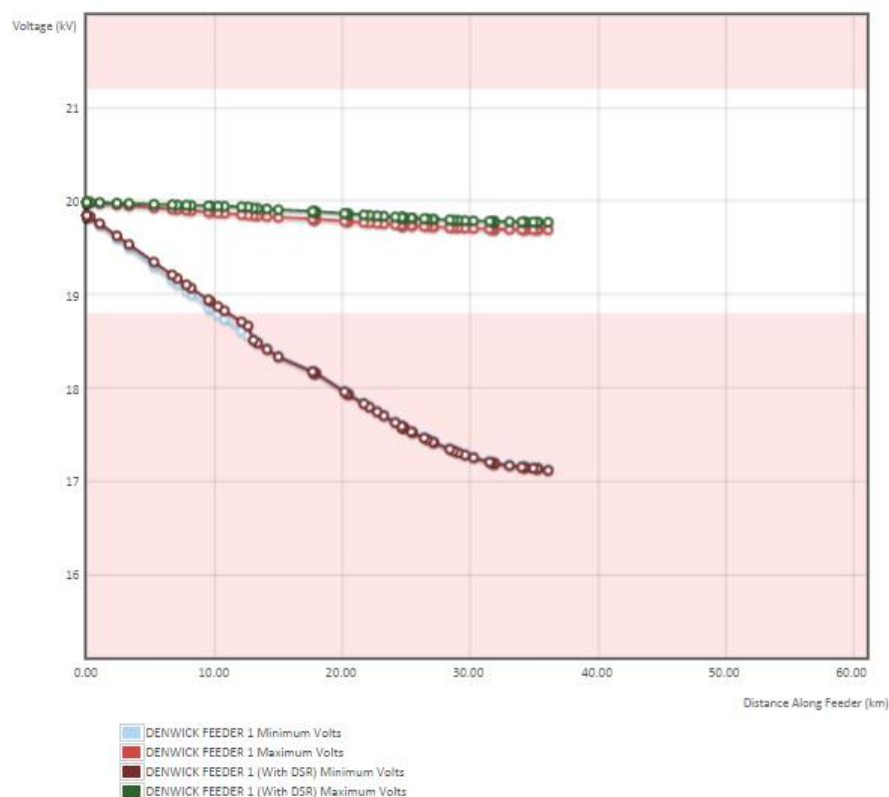


Figure 3.90 – HV DSR voltage graph results.

Electrical Energy Storage (EES)

Electrical Energy Storage (EES) represents a Solution Template where a storage component is placed within the network to extract/inject energy as per a certain capacity. Like DSR, EES has been implemented somewhat differently at LV and HV, to account for the ways that consumer demand is treated at each voltage level within the NPADDs prototype.

EES at LV

At LV, the user is taken to the interface shown in Figure 3.91. The user can place the storage unit on the map anywhere on the network area under study, as well as select a size in kW. EES on the network is then modelled as a TOU load and a generator at the same point, using the same load flow approach to model these new components as for a 'New Connection Request Assessment'. The magnitude of the load and generator are derived from the user-defined EES size.

Solution Modelling



Figure 3.91 – Placement of LV EES on the network.

Following a new headroom assessment by the Network Headroom Engine, EES results are presented before and after the deployment in the form of a voltage graph for each feeder (Figure 3.92), and a TOU load profile at the relevant substation alongside a results summary table (Figure 3.93).

Voltage Profile

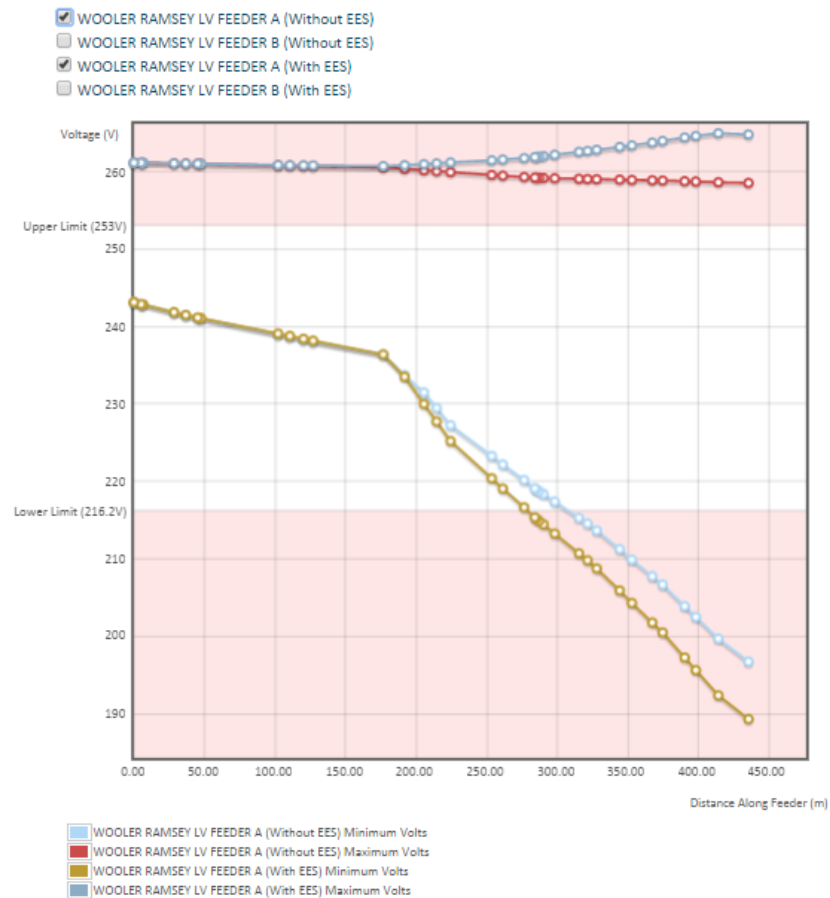


Figure 3.92 – LV EES voltage graph results.



Figure 3.93 – LV EES substation profile and results summary table.

EES at HV

As at LV, EES at HV can be placed anywhere on the network under assessment within the interface shown in Figure 3.94. The storage unit is modelled as a generator during the winter assessment and as load during the summer assessment, whose sizes are entered by the user as maximum real and reactive power indicated in Figure 3.94.

NPADDs then once again re-runs a Network Headroom Engine assessment, and reports results before and after the addition of the EES unit in the form of voltage graphs for each feeder (Figure 3.96) alongside a results summary table (Figure 3.95).

Solution Modelling

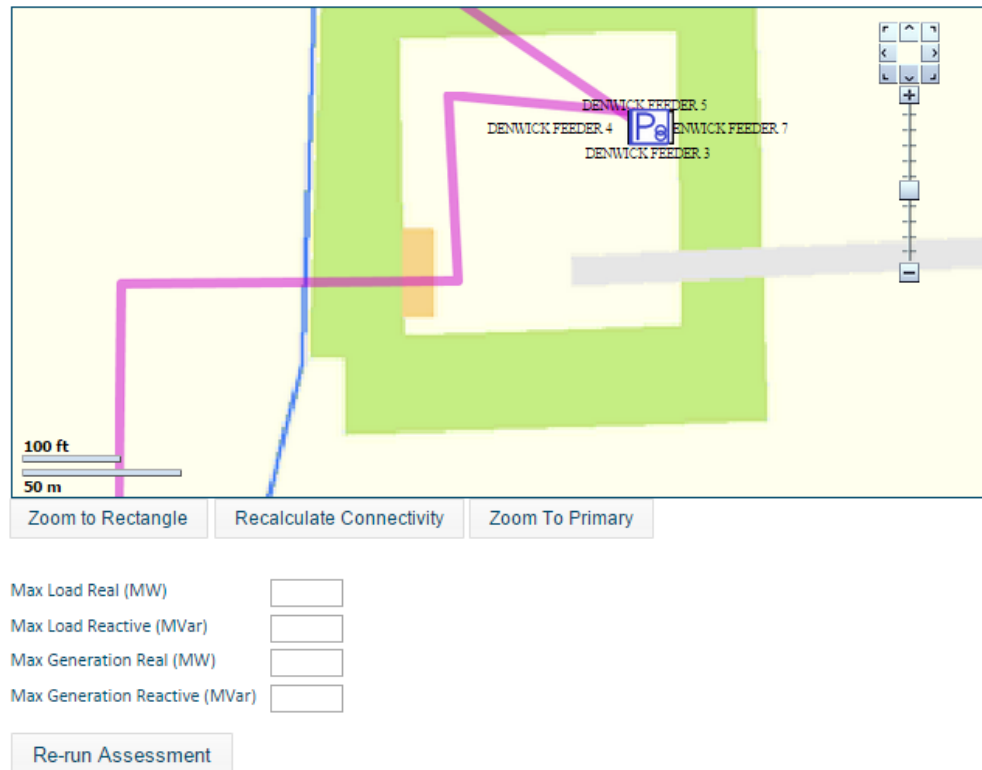


Figure 3.94 – HV EES input parameters.

	Max Volt Drop (%)	Tx Thermal Rating (%)	Cable/Line Thermal Rating (%)	Max Volt Rise (%)	OK?
Without EES	14.23	33.41	70.87	0	✗
With EES	11.35	26.56	66.58	0	✗

Figure 3.95 – HV EES results summary table.

HV EES

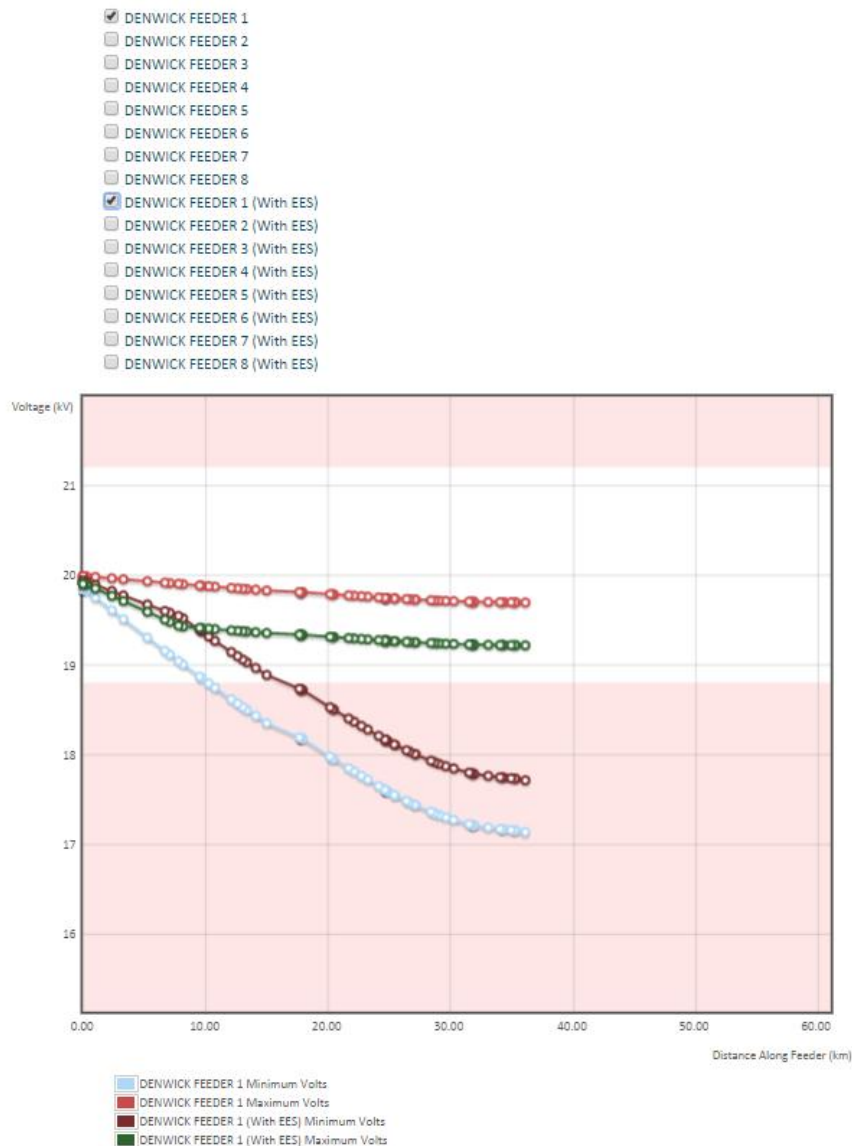


Figure 3.96 – HV EES voltage graph results.

3.8 Thermal Properties Engine

Two separate modelling tools are currently available in NPADDs to assess thermal performance, in cables and transformers respectively. A key benefit is that NPADDs enables the user to access such assessments within a single software tool. Apart from removing the inconvenience for the user of having to switch between different software packages, this means that NPADDs is able to utilise power flow results from the Network Headroom Engine as inputs to the thermal assessment tools.

In future versions of NPADDs, additional analysis tools could be linked to in a similar fashion where network data stored in the NPADDs Database could serve as input.

3.8.1 Cable Thermal Assessment

NPADDs provides thermal assessments of cables through a link to the Crater Lite software, which models the cyclic rating, loss properties, and temperature of a cable segment.

Clicking on a cable within the Visual Design Environment brings up the initial dialogue box shown in Figure 3.97, where the user can select 'Thermal Analysis' of that specific cable segment in order to launch the Crater Lite assessment.

In order to then run the analysis, NPADDs provides two sets of inputs to Crater Lite. The first is the daily load profile experienced by that specific cable segment, obtained from the latest load flow assessment saved within the NPADDs Database. Winter assessment results are currently used for this purpose, as a worst case study. The LV load flow assessment results from DEBUT are stored in NPADDs as currents seen at a cable section.

The second input comprises the type of cable as well as information about the environment where it is installed. Each LV cable type stored in the NPADDs Database has been mapped, for this purpose, via a relational table in the database to one of the standard cable types in Crater Lite. For a BAU version of NPADDs, these would be mapped to distinct types as needed by manually altering the code or, alternatively, the user interface could be developed further to allow the user to edit cable types interactively.

The remaining inputs required by Crater Lite are shown in the second dialogue box in Figure 3.97, and are available for the user to edit in order to tailor the analysis. A default set of values is saved in NPADDs and loaded up for any type of cable as a starting points. Again, defaults could be made editable within for example the Settings section of the NPADDs user interface.

NPADDs displays the outputs from Crater Lite, without modification, in a tabular form as shown in the last window in Figure 3.97. The software is then able to add further value to users by plotting the cable's load profile against its cyclic rating, so that its loading can be immediately visualised and the results put into context.

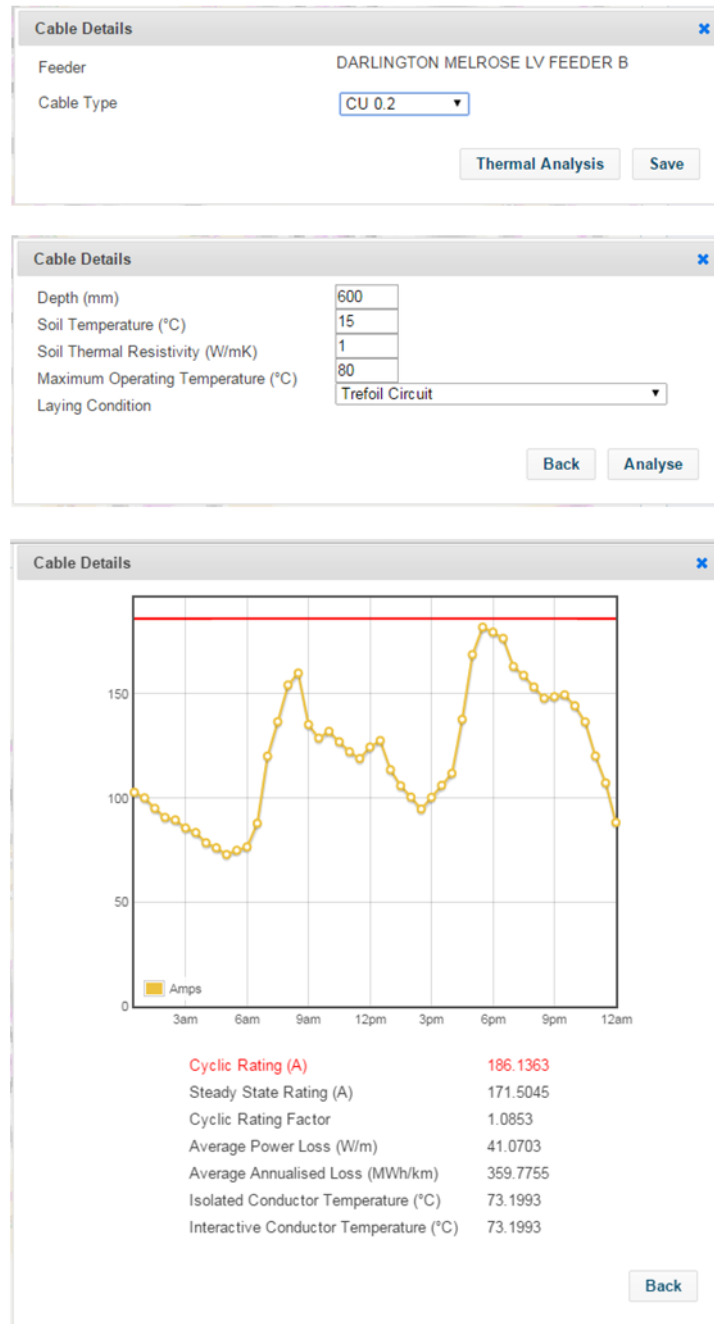


Figure 3.97 – Example input and output of the NPADDS analysis of cable thermal performance.

3.8.2 Transformer Thermal Modelling Tool

The Transformer Thermal Modelling Tool in NPADDS, is based on the calculation of winding temperature given in BS IEC 60076-7:2005 Loading Guide for Oil Immersed Transformers (Figure 3.98). A transformer TOU load profile is applied to the dynamic equations given in the IEC standard to estimate the winding temperature over a 24 hour period.

The temperature increase to a level corresponding to a load factor of K is given by:

$$\theta_h(t) = \theta_a + \Delta\theta_{oi} + \left\{ \Delta\theta_{or} \times \left[\frac{1 + R \times K^2}{1 + R} \right]^x - \Delta\theta_{oi} \right\} \times f_1(t) + \Delta\theta_{hi} + \{ Hg_r K^y - \Delta\theta_{hi} \} \times f_2(t) \quad (5)$$

Correspondingly, temperature decrease to a level corresponding to a load factor of K , is given by:

$$\theta_h(t) = \theta_a + \Delta\theta_{or} \times \left[\frac{1 + R \times K^2}{1 + R} \right]^x + \left\{ \Delta\theta_{oi} - \Delta\theta_{or} \times \left[\frac{1 + R \times K^2}{1 + R} \right]^x \right\} \times f_3(t) + Hg_r K^y \quad (6)$$

Figure 3.98 – Transformer temperature calculations implemented in NPADDs from BS IEC 60076-7:2005.

As the NPADDs Network Headroom Engine is able to produce a TOU load profile at the transformer, this is fed into the Transformer Thermal Modelling Tool to provide the daily temperature profile shown in Figure 3.99. Presently, it is the latest saved assessment of the winter daily load on a transformer that is used as input. In addition to a load and temperature curves, the maximum load and temperature are displayed directly to the user and indicated on the graph.

Additional model input parameters are shown on the left hand side. They can be inspected by hovering over each label with the mouse, and include factors such as hot spot factor and average oil time constant. An individual LV transformer can be selected from a drop-down menu, bringing up relevant input values for that device. Values previously used for each individual transformer, including its rating, have been stored in the Configuration Database and are loaded as a starting point. The user can then edit these (resulting in a new set of values stored in the database) or elect to return to a predefined set of default parameters.

In the prototype, the sample set of LV transformers incorporated into the software are used for demonstration purposes, each assigned the default metrics in addition to their own individual capacity. For BAU use, rather than editing each individual transformer manually, it may be preferable to implement standard transformer types in a similar way to the use of cable types (Section 3.3.2). Individual transformers can then be set to map to a transformer type where a specific set of parameters applies.

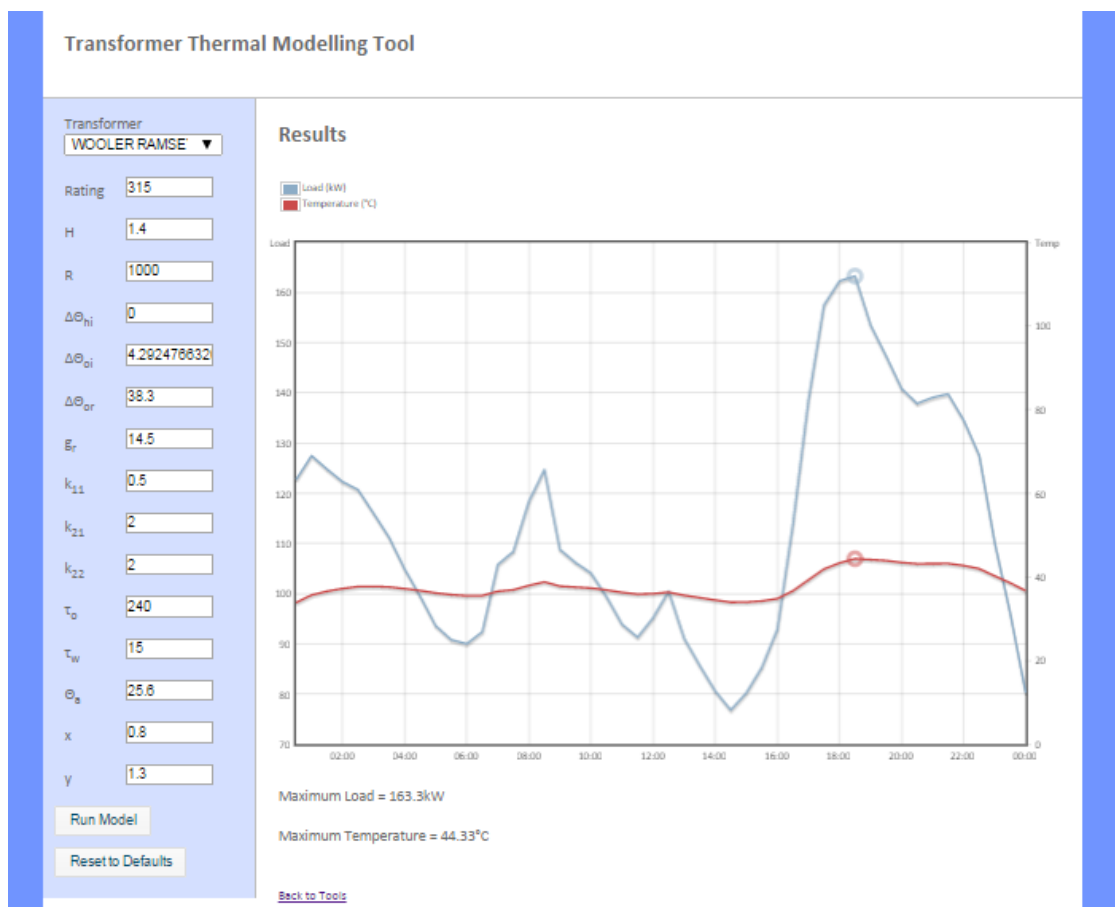


Figure 3.99 – Example input and output of the Transformer Thermal Modelling Tool.

3.9 Policy Compliance Engine

The Policy Compliance Engine constitutes a keyword search of policy documentation that has been linked to NPADDS. Planners and designers can either search this database independently within the Policies main menu section (Section 3.2.1), or browse the set of policies that NPADDS has identified as relevant and presented as part of the network assessment user interface.

The documentation consists of various policies, guidance notes and specifications. Clauses within the documents have been disaggregated into separate segments of text (Figure 3.100), and stored within the NPADDS Database alongside the file name and location on the server of the full document. In future, clauses may be derived from any number of relevant sources that can be stored on the NPADDS server. However, the process to extract clauses was a manual one and would most likely need to be automated depending on the volume of documentation required for BAU.

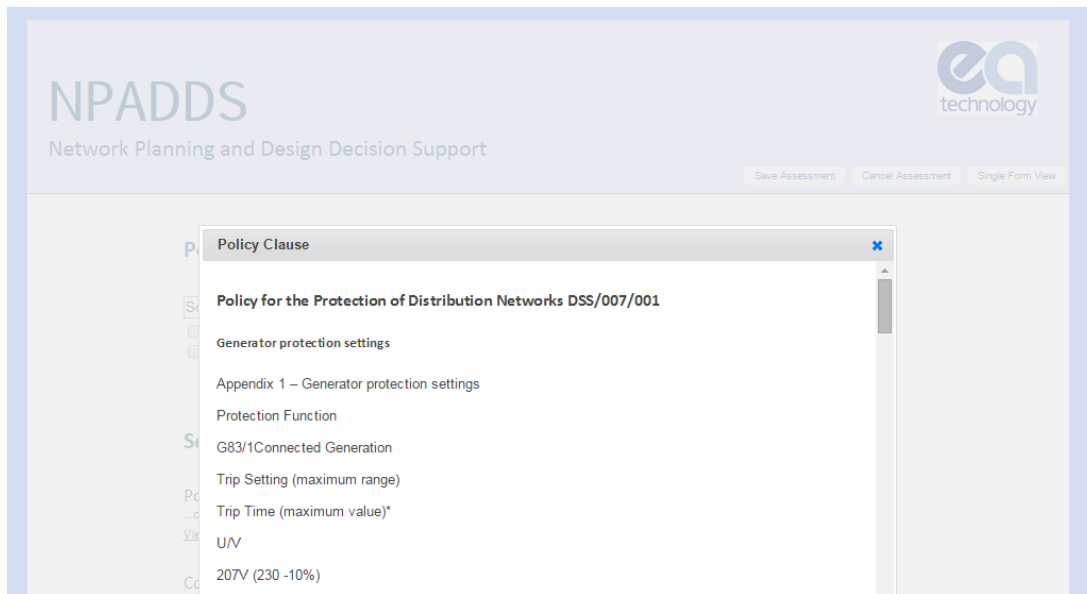


Figure 3.100 – Viewing a clause within the NPADDs policy search tool.

Once clauses and documentation have been uploaded into NPADDs, the prototype uses the Oracle Text search engine to search the clause texts for any keyword. It would also be possible to associate a set of tags (“metadata”) to each clause, where some obvious examples would be:

- Asset specifics, e.g. cable or overhead line
- Voltage level
- Load or generator specifics, e.g. G83 for a PV installation

Within the Policies main menu section the user enters any keywords of their choice – similar to well-known search engines such as Google – with options that include exact matches, and is presented with a search result list (Figure 3.101). They can then choose to view the full clause text as in Figure 3.100, or open the full document itself which is stored on the NPADDs server.

Within the network assessment processes, NPADDs itself has carried out the search on the user’s behalf, in order to present the user with a single display of relevant information specific to the design job (Figure 3.102). In the example of a housing development design, for example, keywords may be defined to present documentation for voltage control, LV design guidance and underground cables. Again, the user can then view either the individual clause, or open up the source document.



Figure 3.101 – NPADDS Policy main menu section search results.

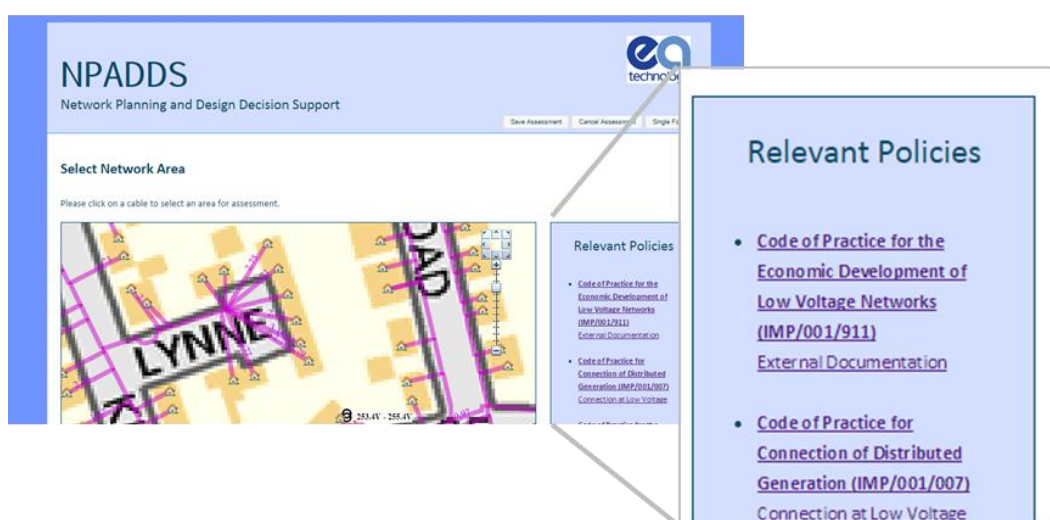


Figure 3.102 – NPADDS Policy section within a network assessment.



4 Requirements of a Business As Usual Tool

The NPADDs prototype is functionally capable of performing network assessments and assessing solutions, with a software framework that provides proof-of-concept of data handling and many forms of analysis. Populating this structure with refined and additional functions will be necessary to deliver a product that meets BAU requirements.

The additional requirements for a BAU tool are described in a separate document *NPADDs Enduring Specification*.



5 Benefits Case

A BAU version of the NPADDs tool is expected to benefit DNO business activities by supporting improvements to the performance of the network and of regulatory parameters whilst reducing the requirements on staff time. This section briefly outlines the principles of why to invest in such a BAU decision support tool, considering immediate and long-term impacts on connection, design, and planning activities.

5.1 BAU Benefits

NPADDs has been designed on the principle that it should add value to existing BAU activities within DNO businesses. DNOs are likely to see benefits within the following key areas, by utilising NPADDs in their present work flows and by incorporating the additional features that the software offers into their practices.

Regulatory targets

NPADDs is capable of providing DNOs with practical means to manage and assess certain parameters that form part of targets under the upcoming RIIO-ED1 regulatory framework. These include:

Connection request handling: User workflows in NPADDs will provide an efficient and thorough tool for evaluating high volumes of new connection requests, supporting the DNO's ability to meet processing time scales and avoid related penalties. Connection engineers will be able to perform a fast initial evaluation based on the relevant types of network assessments, which can then be accessed and elaborated upon by designers where needed.

Customer service levels and staff time

NPADDs provides the opportunity to reduce requirements on staff time in connections, design, and planning activities. Sitting at the business operational level, the software effectively acts as an integrated, centralised 'one stop shop'. It is able to streamline tasks and processes, and incorporate new types of analysis into the work flow. This is achieved by interconnecting a single robust database of the DNO's network assets (the NPADDs Database) with multiple users and several types of network assessment tools, as well as by providing an automated connection between these such that results can be passed between users and assessment tools.

This has the potential to significantly reduce the response time to provide connection request quotations whilst improving the quality of the network checks that are carried out. Many functions which are currently undertaken by trained engineers, with a software tool applying a methodology consistent with policy, can also be passed to lower skilled staff, leaving trained engineers for the exceptional cases.

On the basis of these principles, NPADDs is expected to reduce DNO staff time specifically by:

A single tool for several activities: Reducing the time that designers and planners spend on accessing different tools or dealing with separate input databases, by instead operating from a single network database and moving seamlessly between different types of assessments. For example, the user will be able to click a simple sequence of buttons in order to first assess LV thermal and voltage headroom, and then examine the suitability of LV fuse values on the same network.

Efficient workflow for new connections: Reducing the time that connection engineers spend accessing different tools or applying different guides, by offering a single semi-automated work flow. The user will be able to enter a brief set of properties about the connection and then click a simple sequence of buttons in order to carry out (as needed) network headroom assessment, fault level assessment, disturbing load assessment, and cost book and apportionment rule assessment, and then be presented with relevant consequences and decisions in a transparent manner.

Standardising work practices: Standardising and optimising practices and work flows across the DNO's licence area, by guiding users to move from one assessment to another through the process-based user interface. For example, after identifying a headroom problem during a headroom assessment, the user is taken to the solutions engine where headroom solutions are presented in order of likely relevance and are available to be assessed one by one.

Automatic transfer of data: Removing the need to carry out manual transfers of input data or results between different tools, and removing the potential for human error, by providing an automated process. For example, within NPADDs the transformer thermal assessments and cable cyclic rating assessments can take load profile data directly from the output of the headroom assessment tool.

Sharing of connection cases between staff: Decreasing process times and duplication of work when cases are passed from connection engineers to designers, where a new connection requires a more detailed assessment of network performance and potential mitigating actions. NPADDs will be capable of storing the initial assessment carried out by a connection engineer, and allowing this to be emailed (or similar) to a design engineer, who will be able to quickly access the same assessment and continue work from that point. In addition, by enabling connection engineers to apply full load flow assessments rather than rely on basic rules, the number of cases that are passed on to designers for re-assessment could be reduced.

Access to policies and guidance: Improving access to planning policies, guidance and other documentation and thus reducing the risk of issues being missed or requiring rework, by highlighting relevant clauses within each type of network assessment and enabling the user to instantly access the original documents.

Offering a ranked list of likely headroom solutions: Facilitating an efficient decision making process for staff who need to solve a headroom problem on a specific network, by providing a list of potential solutions ranked by their likely appropriateness. This ensures that designers and planners are able to consider headroom solutions in an appropriate order.

New tools: Automating new processes such as LCT uptake forecasts applied to specific network areas, which may otherwise require manual analysis or the resources to develop in-house spreadsheet models.

Network cost effectiveness

Tools available within NPADDs could support DNOs to achieve more cost-effective network designs or planning choices. In particular, the software is designed to simplify access to improved modelling methodologies, and to assist in the optimisation of network reinforcement investments or smart grid interventions. Examples of specific areas where DNOs could implement improvements include:

Additional planning principles: Integrating additional planning principles into the DNO's BAU processes, which provide a firmer basis on which to make risk-based design decisions. For example, NPADDs simplifies the integration of cyclic ratings by enabling the user to click on a cable within the user interface to assess its cyclic rating via the Crater Lite tool, and thus make revised decisions about reinforcement needs.

Refined view of network conditions: Obtaining a more refined view of network conditions of existing assets and whether these genuinely require reinforcement, by the use of tuned methodologies for network headroom modelling. For example, NPADDs:

- provides a connection between LV and HV assessments, by automatically passing data from one voltage level assessment to the other, such that the accuracy of assessments can be refined from the current baseline of planning assumptions.
- enables a choice of different demand data at HV loads, including user-specified load magnitudes and the ability to represent loads across a feeder on the basis of an actual metered level at the top or mid-point.

Range of headroom solutions: Considering and assessing an expanded range of headroom solutions as part of BAU practice, potentially identifying options that are more cost-effective than conventional reinforcement. NPADDs could serve to promote the consideration of such solutions more widely when the TRANSFORM-based solution ranking methodology presents them as suitable options to the user.

LCT uptake and load growth scenarios: Accounting for forecasted levels of LCT uptakes and general load growth on specific networks, such that decision making procedures employed by designers and planners can account for the expected impact on network headroom, fault levels, power quality etc. NPADDs enables the user to apply and assess LCT and load growth scenarios within specific network areas over a chosen range of years, and has a structure that allows such assessments to become demographics-specific rather than generic.

Automatic regular network assessments: Identifying network areas that may require attention in the form of reinforcement or other mitigating steps through an automated regular process, such that those issues can be dealt with and accounted for by designers and planners at an early stage and in an integrated manner.

5.2 Long-Term Benefits

Long-term benefits of NPADDs to the business activities of DNOs are by nature more difficult to specify. However there are evident themes where NPADDs is likely to offer an advantage by future-proofing DNO tools and methodologies.

Smart grid / low carbon readiness

As LCTs become more common-place and smart grid technologies emerge as viable BAU propositions, DNOs will require the ability to integrate these into their connection, design and planning activities. CLNR outputs including the NPADDs prototype have illustrated elements of how this could be achieved. Although the majority of methodologies and data sets will require further development before they are sufficiently mature for BAU applications, DNOs will benefit from a BAU version of NPADDs which has been designed with a structure and approach that will enable integration of relevant smart grid and low carbon applications in the future. For example, CIM representation of networks, consumers and generators within the NPADDs Database offers flexibility to incorporate 'new' components, while the use of flexible Solution Templates offer a similar degree of future proofing with respect to smart grid technologies.

Database capabilities

DNO network data is often stored across bespoke asset databases and other data repositories, at times with incomplete or erroneous information in particular at the LV level. Whilst this has been perhaps fit for purpose, it is becoming clear that DNOs are likely to benefit from (or even require) more modern data storage facilities in the future, with the capabilities that this will bring for sophisticated analysis of issues such as network operation and performance of distributed intelligent assets across the infrastructure. Whilst such analysis is still some years away, the need to understand the impact of LCTs on distribution networks is already pointing towards more detailed assessments of LV networks than what is currently standard practice.

The NPADDs Database provides a structure capable of facilitating such assessments in the near and medium-term future, and of holding network data relating to any form of analysis required. Implementation of NPADDs offers DNOs the opportunity to organise network data into a format where connectivity information and other asset details can be completed and corrected. Such efforts will serve to future-proof the DNOs planning and design activities, embedding a system that is capable of supporting the evolution of such activities going forward.

Flexible framework

Finally, as NPADDs acts as an interface with several network assessment tools, and hosts a detailed database of DNO network information, this forms a flexible framework that could be expanded in future to support a range of new applications. DNOs are likely to be able to attain and roll out additional tools relatively rapidly, achieved by commissioning an NPADDs software upgrade and appropriate interface that would be available to users across the business, as an alternative to



implementing a further stand-alone database or procedure that would then be distributed and maintained.



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