REPORT

Project SAVE- Network Modelling Tool. Report on development

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EA Technology Limited, Capenhurst Technology Park, Capenhurst, Chester, CH1 6ES;
Tel: 0151 339 4181 Fax: 0151 347 2404

http://www.eatechnology.com

Registered in England number 2566313

Executive summary

The Solent Achieving Value through Efficiency (SAVE) project is a Low Carbon Network (LCN) Fund project which is being led by Scottish and Southern Electricity Networks (SSEN).

The project aims to trial and establish to what extent energy efficiency measures can be considered as a cost effective, predictable and sustainable tool for managing peak and overall demand as an alternative to network reinforcement. The project targets domestic customers only, and the measures to be trialled will include deploying technology, offering a commercial incentive and taking an innovative approach to customer engagement.

One of the deliverables of this project will be a Network Investment Tool (NIT). The NIT will allow assessment of a network's suitability for demand reduction through energy efficiency measures and to allow informed investment choices to be made between using customer engagement and energy efficiency measures as opposed to traditional technology based measures and 'smart' solutions.

The NIT will comprise of three software models which are:

- The Customer Model, which is being developed by the University of Southampton (UoS).
- The Network Model, which is the focus of this report.
- The Pricing Model which is being developed by Scottish and Southern Energy Networks (SSEN).

This SDRC report describes the present state of development and refinement of the Network Model as a milestone towards full delivery in June 2019. This will be marked by issue of SDRC report 7.3 which will demonstrate that the functional requirements have been met in full and also demonstrate how the tool can be used by network planners within a business as usual context.

This report also discusses the software structures that are still to be developed and the questions that need to be answered between SDRC 7.2 and SDRC 7.3.

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1. Introduction

1.1 Project Background

The Solent Achieving Value through Efficiency (SAVE) project is a Low Carbon Network (LCN) Fund project which is being led by Scottish and Southern Electricity Networks (SSEN).

The project aims to trial and establish to what extent energy efficiency measures can be considered as a cost effective, predictable and sustainable tool for managing peak and overall demand as an alternative to network reinforcement. The project targets domestic customers only, and the measures to be trialled will include deploying technology, offering a commercial incentive and taking an innovative approach to customer engagement.

One of the deliverables of this project will be a Network Investment Tool (NIT). The NIT will allow assessment of a network's suitability for demand reduction through energy efficiency measures and to allow informed investment choices to be made between using customer engagement and energy efficiency measures as opposed to traditional technology based measures and 'smart' solutions.

A number of real-world customer field trials are underway as part of the SAVE project to assess the effectiveness of four energy efficiency interventions in reducing and/or time-shifting demand for electricity in a representative sample of the household population of the Solent region. The four intervention methods are:

- LED installation;
- Data-informed engagement campaign;
- DNO price signals direct to customers plus data-informed engagement; and
- Community coaching.

1.2 Report Context and Purpose

One of the deliverables within the SAVE project is the Network Investment Tool (NIT). One of the modules within the NIT is the Network Model (NM). During the bid stage of the SAVE project, Successful Delivery Reward Criteria(SDRC) were agreed with Ofgem to track progress over the overall project. SDRC's 7.1, 7.2 and 7.3 relate to the development of the Network Model.

SDRC 7.1 [1] recorded the functional specification of the NM and has already been published. SDRC 7.3 will demonstrate the final completed software and is due in June 2017.

This SDRC report describes the present state of development and refinement of the Network Model as a milestone towards full delivery in June 2019. This will be marked by issue of SDRC report 7.3 which will demonstrate the full functional requirements and demonstrate how the final development model can be used by network planners within a business as usual context.

1.3 Structure of the Report

The structure of this report is as follows:

- Section 2 provides an overview of the suite of tools that constitute the overall Network Investment Tool (NIT) that the SAVE project aims to deliver. It should be noted that this report focusses on the Network Model (NM) which is a subset of the overall NIT.

- Section 3 compares the present status of the NM against the functional specification that was published in SDRC 7.1.

- Sections 4, 5 and 6 provide a demonstration of the present capability of the Network Model (NM).

- Section 7 discusses some of the development choices facing the project and next steps.

2. Network Model Context

The SAVE project aims to produce a Network Investment Tool that will allow DNOs to assess and select the most cost-efficient methodology for managing electricity distribution network constraints. The model will consider the effectiveness of different types and degrees of energy efficiency interventions as well as more traditional techniques for network reinforcements as tools for the management of networks by DNOs.

To this aim, a set of three comprehensive models working in unison are being developed by the SAVE project to deliver an overall software tool that network planners will be able to utilise to manage distribution network challenges more effectively as an alternative to traditional reinforcement.

Figure 1 depicts an overview of the overall hierarchy of the analysis tool to be delivered by the SAVE project.

The set of models include:

(i)The **Customer Model** to represent the behaviour of trial participants in response to energy efficiency interventions. This will provide customer behaviour data to the Network Model. This model is the responsibility of the University of Southampton.

(ii) The **Network Model** which simulates the real-time operation and management of real electricity distribution networks and calculates at what point in time a network under investigation would reach the limit of its capacity across a number of different load growth scenarios and different capacity interventions. This model is the responsibility of EA Technology Ltd.

(iii) The **Network Pricing Model**, which ranks the economic investment performance of each traditional asset based solutions for network infrastructure development against non-traditional network solutions' whilst considering the technical constraints associated with the operation and management of the network. This model is the responsibility of SSEN.

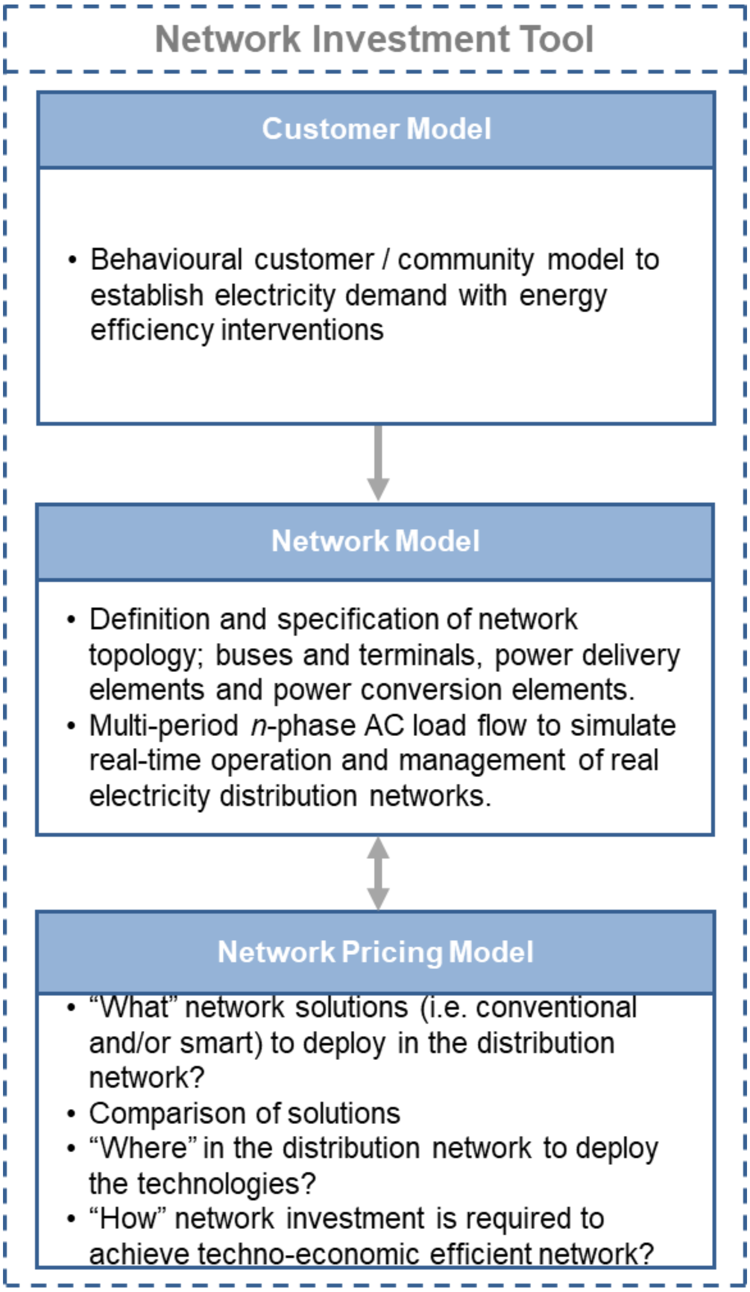


Figure 1 Conceptual overview of tool

This report discusses the state of development of the NM and its interfaces to the Customer Model and the Network Pricing Model.

3. Comparison with Functional Specification

Previous works in SDRC 7.1[1] provided a functional specification for the SAVE Network Model. The following tables provide a summary of the requirements within the functional specification and provides a summary and evidence of the functional specification being met, or provides an update on development. In all tables a colour scheme has been used to indicate the present state of development of the function specification. The convention used to allocate the colour code is summarised in Table 2.

Table 2 Colour code convention

Colour	Description
(grey)	Some initial scoping but capability development pending completion of dependant tasks
(yellow)	Significant demonstration of core capability achieved, but full capability not yet complete
(green)	Item Complete

3.1 User interface requirements

Section 3.2.1 of the functional specification [1] set out the requirements summarised in Table 3. This table provides a summary of the status and refers to sections earlier in this report where further demonstration can be found.

Table 3 User interface requirements

Requirement	Status
Run Single period (e.g. year) or multi period assessments)	Section 5.3 shows how the number of years to run can be specified in the NM. Section 6.1 shows how results from one year are presented. Section 6.2 shows how results from a multi-year analysis are presented.
Select the networks to run the assessment, from a single network, selection of network templates or a custom-built network	Section 4.2 shows how different network templates can be inputted into the NM and explains how custom-built networks can be created. This report provides evidence of how this functionality can already be delivered manually. Section 7 discusses the intention to automate this work.
Compare different energy efficiency intervention scenarios	Section 4.3.2 explains how different energy efficiency profiles can be loaded into the model. Section 5.3 explains how a new intervention profile can be selected to be run in the analysis. These results can be compared manually. Section 7 discusses next steps towards automation. The current stage of software refinement only allows one customer profile to be selected for the entire the SAVE intervention analysis. Section 7.4 discusses the intention to automate the comparison of results in the Network Pricing Model.

3.2 Network Template Requirements

Section 3.2.2 of the functional specification [1] set out the requirements summarised in Table 4. This table provides a summary of the status regarding delivery of the requirements and refers to sections later in this report where further demonstration can be found.

Table 4 Network Template Requirements

Requirement		Status
Include default templates		This text applies to all three requirements: Demonstration of the NM using network templates can be found in section 4.2. Demonstration of the template layout, including all downstream feeders can be found in 4.2. Explanation of how templates can be customised is made in 4.2. Graphical demonstration of how a template results in a model with a transformer and all downstream feeders is shown in Figure 4.
Templates will show detailed nodal representation of distribution transformers and all downstream feeders		
Network templates will be customisable		

3.3 Network Builder

Section 3.2.3 of the functional specification states a requirement to incorporate a network builder module. The network builder module is intended to allow network planners to rapidly model a specific low voltage area by defining the main assets, technical parameters and nodes of a network.

Table 5 Network Builder Requirements

Requirement		Status
Network Builder Module		Although there is no standalone module referred to as a network builder module yet, section 4.2 confirms that users can input variables through the network builder such as: • Nodes (from and to) • Asset type for cables and transformers • Asset information • Customer information

Section 7.1 discusses the next steps to be applied to this development version of the NM.

3.4 Intervention Modelling

The functional specification [1] made the requirements that are summarised in Table 6. This table provides a summary of the status and refers to sections earlier in this report where further demonstration can be found.

Table 6 Intervention Modelling Requirements

Requirement	Status
Simulate conventional solutions considering: -Cable overlays -Feeder splits -Asset replacement -Load transfer to a different feeder.	Section 4.1 demonstrates that the NM has access to a component library which facilitates network modification. Section 5.3 Further development work needs to be undertaken to allow load transfer to different feeders to be analysed. Section 6.2 shows how intervention results can be presented.
Simulate energy efficiency solutions using: -LED Lighting, -Engagement Campaigns, -TOU tariff, -Community Coaching	Section 5.3 describes how the NM can accept customer profiles which records post intervention usage patterns. Section 5.3 shows how one new customer load profile can be selected to be applied as part of the SAVE intervention. This section also discusses how load profiles reflective of the SAVE interventions can be loaded into the NM.
Allow Comparison between interventions studied	At present the development version of the NM allows users to manually compare an intervention to a base case. Section 7 discusses the next steps for this process.

3.5 Scenario Builder

The requirements for the scenario builder are described in section 3.25 of the functional requirements.

Table 7 Scenario Builder

Requirement	Status
Scenario Builder	A manual ability to load and study scenarios can already be demonstrated. The automation required for the scenario builder have been dependant on the decisions regarding the interface to the Customer Model and demonstration of the basis capability for load flow analysis. These next steps are discussed in section 7.

3.6 Load Flow Engine

Section 3.26 of the functional requirements stated the expectations summarised in Table 8. This table also summarises the status of present development.

Table 8 Load Flow Engine Functional Requirements

Full half hourly steady state and load flow analysis	As described in 5.4 the NM can already conduct load flow analysis at a 30-minute resolution over a period of one day, but over a series of years. Section 7 discusses next steps.
Use of ADMD style input data	As shown in section 4.3.2, customer actors are described in terms of 30-minute time series data rather than an ADMD approach. This is an improvement over an ADMD approach.
Scope of analysis to include from the distribution transformer to the feeder ends	As shown in Figure 4 and as described in section 4.2.
Based upon DEBUT and EGD[1] load flow engines	As described in section 5.1.

[1] The NM utilises two load flow engines DEBUT and EGD, these are full explained in section 5.1

3.7 Future load growth module

The future load growth module will assess the likely effects of SAVE energy efficiency interventions on the LV area against future load growth due to low carbon technology such as electric vehicles, heat pumps and domestic PV. Section 3.2.6 of the functional specification made a number of requirements which are summarised in Table 9 with an update upon the delivery status.

Table 9 **Functional requirements for future load growth module**

Requirement		Status
Make allowance for load growth for Low Carbon Technology		As shown in section 4.3.3 users can either adopt government projections (originally created by DECC and DfT) regarding Low Carbon Technology (LCT) uptake or specify their own assumptions.
Hold load profiles for common LCT's including: Heat Pumps Electric Vehicles Solar PV generation		As shown in section 4.3.4, the NM does hold load profiles for common LCT.
Perform assessment over many years from templates or customer networks		Demonstration of the use of templates has already been discussed in section 4.2.
Allow the user to time the reinforcement on to the system to understand which year reinforcement is required.		Results in section 6.2 show that present capability can understand when a network runs out of capacity and which year this occurs in. Further works are required to allow the user to time the year in which reinforcing is triggered.

3.8 Customer Model interface

The Network Model interface will take input the Customer Model. The interface is currently being agreed with the University of Southampton (UoS) who is responsible for completing the Customer Model. The NM can already accept .CSV files which express customer behaviour, but there is still work to be done to automate how the NM builds scenarios and calls customer behaviour patterns from the UoS model.

The functional requirements expressed in 3.2.8 of the functional specification [1] and progress to date is summarised in Table 10.

Table 10 Customer Model interface requirements

Requirement		Status
Semi-automated link so inputs from UoS Customer Model can be transferred into the NM		This development work is to occur in the next phase of the project and is discussed in section 7. This enables the interface with the Customer Model to be finalised before automation is developed.
Customer Model will take the form of direct links to other Microsoft excel tools using a 'CSV' file loader		NM can accept manually loaded .CSV files. Section 7 discusses the next steps towards and an automated file loader.
Aggregation layer to convert source data into a useable form by the NM		The UoS have agreed to provide data in a useable form for the NM.

3.9 Interface to Network Pricing Model

The Network Model will have an interface to the Network Pricing Model. The Network Pricing Model is a module of the Network Investment Tool, but is separate to the Network Model. The Network Model will provide the output in the required format to the Network Pricing Model. Table 11 summarises the functional requirements made of this interface.

The Network Pricing Model interface will be via a semi-automated link which will export the results from the Network Model to the Network Pricing Model. The interface will take the form of direct links using typical 'Microsoft Excel' tools and 'csv' files. Ongoing project work is developing this model as described in section 7.

Table 11 **Network Pricing Model interface functional requirements**

Requirement	Status
The Network Pricing Model interface will be via a semi-automated link for results to be ported out of the Modelling Tool	Development of these three requirements is scheduled to take place between SDRC 7.2 and 7.3. A key dependency for this work is development of the Network Pricing Model so that the interface can be fully explored.
The interface will take the form of direct links to other 'Microsoft Excel' tools, developing a 'csv' file loader for data exchange or developing an XML interface	
The specific output is still yet to be defined but expected to contain: ○ Network Key Performance Indicators ○ Utilisation ○ Voltage performance ○ Benefits of the interventions trialled ○ Lifetime benefit of the intervention	

3.10 HV and EHV Module

The functional specification of the NM required a LV and a HV/EHV module to allow the user to estimate the effect of SAVE energy efficiency interventions on upstream networks. These requirements are summarised in Table 12. Full development of this module is dependent on development of the LV modules and to a lesser extent, the Network Pricing Model but Section 7.4.1 lists some of the questions that use of this module will raise.

Table 12 HV and EHV Module

Requirement	Status
Estimate effect of interventions on upstream networks	This element of the NM module has been planned to be developed after SDRC 7.2 once the LV parts of the module are finalised.
Provide method of understanding the quantity of inventions needed to mitigate an upstream loading issue	

3.11 Load profiles

The probabilistic method used in DEBUT[2] will be employed in the Network Model. The aggregation layer will process data from the Customer Model to generate DEBUT compatible load profiles with statistical diversity factors.

This probabilistic method will however be based upon customer load profiles. The functional requirements for load profiles and current status are described in Table 13.

Table 13 Probabilistic method and load profile functional requirements

Requirement	Status
The NM will store and use half hourly load data for each Customer type	Load data can be stored for each customer type.
A method of accounting for the local variation of conventional household demand (probabilistic method), either due to the customer type or lack of diversity	The method of presenting customer data in terms of average demand per customer and the standard deviation of samples within the group will allow the NM to consider local variation in demand.
An ADMD value (a single figure, useful for speeding up assessments)	No, the NM tool is dependent on the UoS profiles which is considered to provide superior facility to ADMD without slow performance.
The effect of the SAVE interventions for the customer type; and	Providing the data has been called from the UoS model and loaded into the NM, then this functionality has been achieved.
A method of accounting for the local variation of the SAVE interventions (probabilistic method)	The NM utilises the random distribution of load readings that is expressed within the UoS intervention load profiles to account for variation in SAVE interventions.

[2] DEBUT is the loadflow engine used to calculate results and it is fully introduced in section 5.1

3.12 Overall modelling approach

Section 3.2.13 of the functional specification also set a number of general requirements, which are summarised in Table 14 along with an update of status.

Table 14 Overall modelling approach functional requirements

Requirement	Status
Consider effects on a 365 x 48 half hour basis over an entire year on a simulated network	As discussed in section 5.4 the NM at this development stage considers one day of the year over a series of years. Section 7 discusses the next steps in this process.
Consider steady state voltage and thermal issues only	Yes, this is described in section 5.4.
Tool will estimate available capacity in kW until a thermal or voltage constraint is reached	The tool at its present stage of develop shows which year capacity runs out. The next stage of development towards SDRC 7.3 will explore this.
Compare traditional reinforcement and energy efficiency reinforcements	At present the tool can study these interventions. The network Pricing Model discussed in section 7 will lead to an automated ability to compare scenarios.
Model will observe the effects of these reinforcements on the LV and higher voltage	At this present stage of development, the model demonstrates the effect on the LV system.
Analysis will consider the effect of connection phase allocation	As described in section 4.3.1, customers are allocated to phases with the aim of equalising customer numbers rather than loading. Section 7 describes the next steps here.
Analysis will consider the effect of local network topology and connection location	As shown in section 3, the model can consider the effect of local network topology and has a number of approaches to consider connection location.
The precise point of connection within a low voltage network for individual customers will not be known	As shown in section 4.3.1 customers can be allocated to general areas along a feeder and assumptions are made about location of service connections.
The NM will treat the individual energy requirements of customers independently. This shall include propensity of response to efficiency interventions independently	As described in section 4.3.1, customers can be treated completely independently when represented by a "point load approach". When customers are automatically distributed along a branch of the feeder the assumption must be made that these customers share the same annual electricity consumption and are assigned the same load profile.
The NM will estimate the range of possible effects for a defined mix of customers as informed by the Customer Model	The NM considers thermal and voltage results across the scenarios modelled.
The NM will define network performance estimates using a probabilistic function	As shown in section 4.3 the tool calculates network loading behaviour based on a probabilistic expression of customer behaviour.
The NM will compare energy efficiency interventions with more traditional techniques for reinforcements on the local low	The current development stage of the NM allows analysis of traditional reinforcement of the LV system only.

Requirement	Status
voltage network and at higher voltages	
EA Technology will define the range of traditional (capacity increasing) techniques that are used for comparison and will encode their nature and effect on network performance into the NM for automatic comparison	As shown in sections 5 the NM can consider: Feeder splitting, Feeder overlay, Transformer uprating.
A user should not be required to set-up or define these techniques but should be able to clearly understand how these techniques have been applied by the model and adjust if necessary	User understanding will be developed as part of the final manual.
The NM will enable users to configure their own network(s) therefore ensuring the model can be readily adjusted to reflect local circumstance and practice across all UK DNOs	As discussed in section 4.1, The Network Model holds a library where users can save standard component models of typical conductor types used on their network. These conductor types may then be used to help build the individual branches in the Network Model As described in section 4.2 users can upload templates, which can be configured to reflect local networks.
The network configuration parameters should encompass both the characteristics of the network under assessment as well as the nature of traditional techniques used in comparisons	As shown in section 3, networks can be represented on a node and branch representation of the network. When required, the length of the branches can be adjusted to suit network records.
The NM will be interactive to allow the user to explore any number of possible scenarios or circumstances	Under the present state of development, users can explore any number of possible scenarios by manual comparison of scenario results. Further works are discussed in section 7.
Whilst the NM and the traditional techniques used in comparisons will be based on a simulated network, the nature of results and the process by which they have been established will be transparent and readily interpretable	Demonstration of the results format and trial output can be seen in section 6.
The project will trial energy efficiency interventions on an iterative basis with the first iteration being used to refine the second iteration Prior to the first iteration, target energy efficiency	The NM can load different user profiles from the UoS Customer Model. Further work is to be undertaken on automating the scenario builder, as described in section 7.0.

Requirement	Status
messages will be defined by considering the base-case levels of performance from the Network Model In advance of this, and as an indication of the type of message to be revealed by the NM, an initial set of messages have been prepared from a highly generalised understanding of network need The NM will take inputs from the Customer Model. Depending on scale and complexity, it may be reasonable for these interactions to be via a manual (cross-typed) transfer of details (low tens of numbers) or using standardised file structures (larger exchange of details) The specification of the interface will be driven by the need for user convenience but also the iterative nature of the project's models	
The NM will provide outputs to the Network Pricing Model interface Depending on the scale and complexity, it may be reasonable for these interactions to be via a manual (cross-typed) transfer of details (low tens of numbers) or using standardised file structures (larger exchange of details) The specification of the interface will be driven by the need for user convenience but also the iterative nature of the project's models	This requirement is discussed in section 7 and will be addressed in the later stage of development.

4. Input Data

The Network Model has many user inputs, the following sections provide a discussion of these inputs.

4.1 Circuit Component Library

The Network Model holds a component library which holds data upon the following component types:

- LV cable types.
- Fuses.
- Transformers.

Users can select these component types when developing models. This library can be used when developing templates or one-off models. Calls to this library can also made when the Network Model is being used to investigate new capacity created by cable overlay schemes or transformer replacement schemes.

4.2 Network connectivity

The NM uses a representation of the network in terms of nodes and branches. In all cases, nodes and branches can be declared using the schema summarised in Table 15.

Table 15 Branch and node data format

Near Node	ID number of branch node nearest to network source. This ID number must be allocated by the user. Each node can accept more than one branch.
Far Node	ID number of node furthest from source. This ID number must be allocated by the user. Each node can accept more than one branch.
Length	Branch length in metres.
No of Phases	Number of Phases.
Cable Type	Specifies the cable type to be used on the branch. Draws data from the data library.
Number of Customers	Number of customers connected to Far node.
Customer Type	Reference to customer load profile.
Annual Consumption (kWh)	Annual consumption of customer.
Main / Service	Branch purpose i.e. LV main or service.

This format can be used to load networks into the NM via two approaches:

- By using a template recorded in a .CSV file as depicted in Figure 2.
- By manually inputting the data into an Excel tab within the NM.

As a general summary, nodes and branches are created by specifying which nodes a new branch is connected to, the length of the branch and the cable type. The NM will then use this information to populate the model with not only the new connectivity but also the impedance and rating of the branches.

In all cases the model assumes that there is one source substation that represents the transformation between the HV and the LV system. In all cases the model assumes that this substation has a single transformer, but the parameters of this transformer can be selected from the library.

The NM assumes that the voltage received at the HV terminals on the HV/LV at the transformer is fixed throughout all studies hence no allowance is made for voltage control of the HV system.

	A	B	C	D	E	F	G	H	I	J
1	SUB=1 1000									
2	2	18	5	SINGLE	AL 185	0		0	SERVICE	ON
3	3	47	20	TRIPLE	AL 185	0		0	SERVICE	ON
4	4	28	80	SINGLE	AL 185	0		0	SERVICE	ON
5	5	38	5	TRIPLE	AL 185	0		0	SERVICE	ON
6	6	42	18	SINGLE	AL 185	0		0	SERVICE	ON
7	7	28	49	TRIPLE	AL 185	0		0	MAIN	ON
8	8	47	4	TRIPLE	AL 35	0		0	MAIN	ON
9	9	7	6	TRIPLE	AL 185	0		0	MAIN	ON
10	10	39	3	TRIPLE	AL 185	0		0	MAIN	ON
11	11	40	20	SINGLE	AL 185	0	ELLCDY	3000	SERVICE	ON
12	12	23	20	SINGLE	AL 185	0		0	SERVICE	ON
13	13	21	8	TRIPLE	AL 185	0		0	SERVICE	ON
14	14	23	8	TRIPLE	AL 185	0		0	MAIN	ON
15	15	50	7	TRIPLE	AL 185	0		0	MAIN	ON
16	16	38	7	TRIPLE	AL 185	0	URMC	1000	MAIN	ON

Figure 2 **Example of a network template in a .CSV format**

Figure 2 shows an example of a network template within the .CSV format which can be loaded into the NM without the need for the user to manually input each line into the user interface. A summary in this interface is also provided which enables the user to understand the number of customers and which load profile they have been programmed to use.

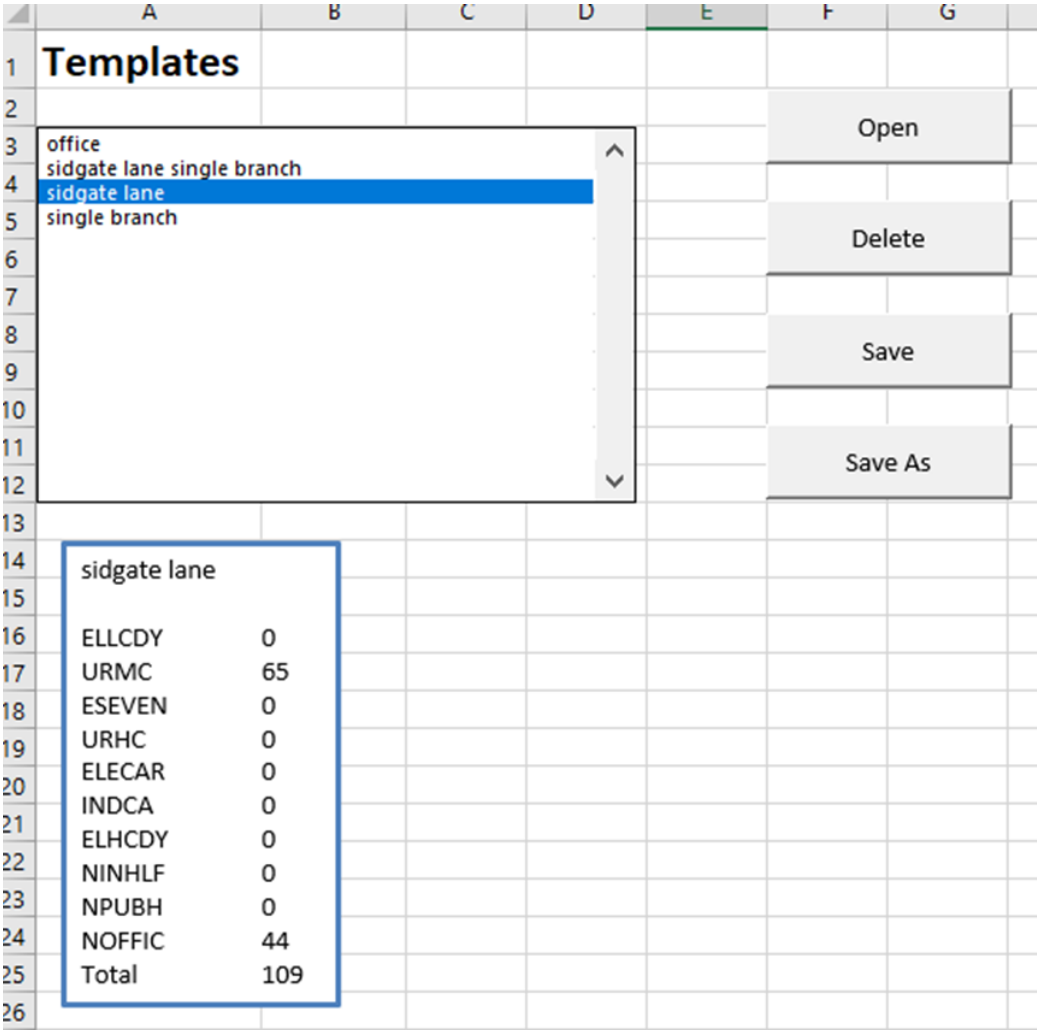


Figure 3 **Example of template selection interface**

Once the network connectivity module has been loaded into the NM it is presented in a visual format to the user to help verify the model. An example of this is shown in Figure 3.

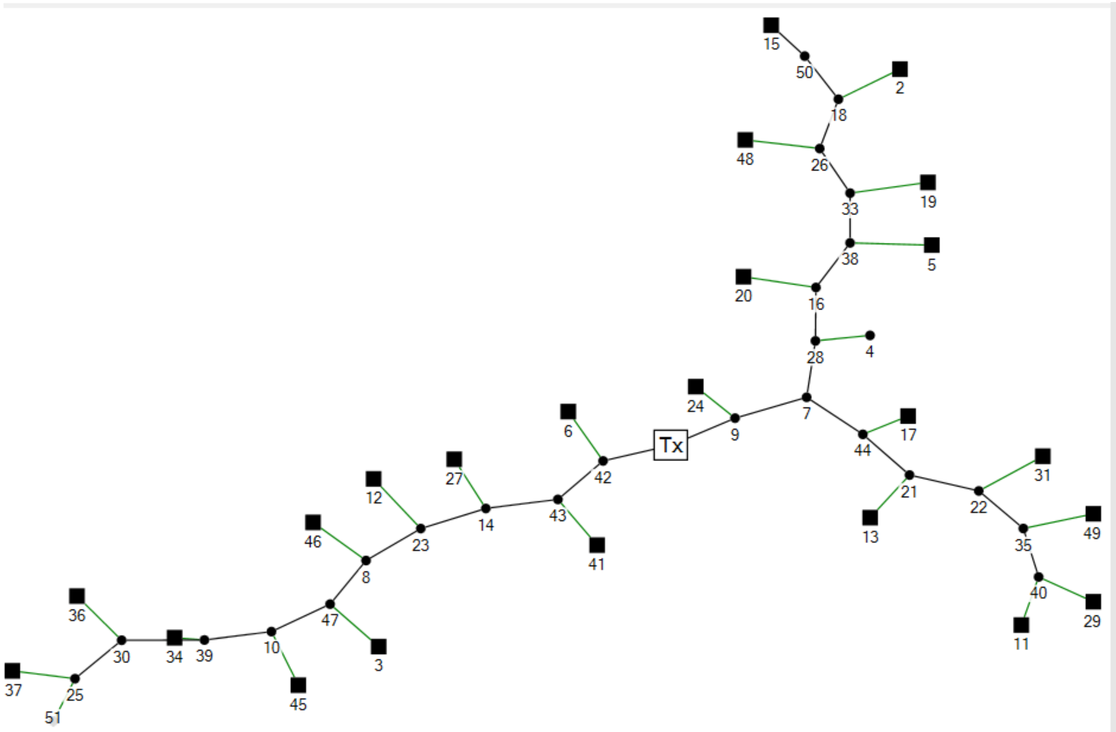


Figure 4 **Resultant Network Topography**

The location of the source transformer is depicted in the graphical network presentation as shown in Figure 4. The infinite bus[3] for the model is located above the source transformer.

To allow users to debug any connectivity which they have input into the tool, there is functionality which guides the user to any errors which may have been introduced during loading of the model. This functionality is executed when the Network Model is compiled, and it will report the location of any instances of islanded nodes. An example of such a warning is shown in Figure 5.

[3] The infinite bus is a feature common to all load flow packages. It is used to represent the source of the electricity network by providing a datum voltage and an amount of generation that is equal to the real power load and losses within the network being studied.

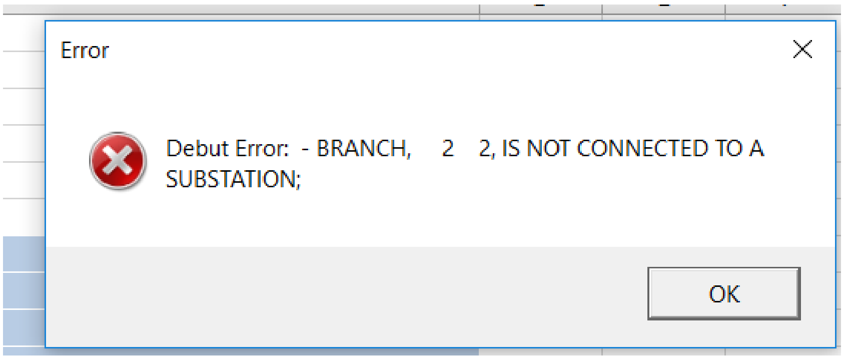


Figure 5 Islanded Node Warning

Within the data format, as summarised in Table 15 there are three fields which can be used to define customer location and behaviour, these are:

- Customer type
- Annual Consumption
- No of customers

The significance of these fields is discussed further in 4.3.1.

4.3 Customer behaviour

4.3.1 Customer Connection Points

The NM needs to be informed of where customers are connected. The NM allows the user to represent customers using two different strategies:

Customer as a point load representation

In this case, each customer is placed upon a node that has already been declared within the NM (as described in 4.2). Figure 6 shows an example of point loads being declared in the NM and the data format is explained in Table 16.

Point Load Inputs

Node	No of Consumers	Consumer Type	No of Phases	Annual Consumption (kWh)	Status
2	5	URMC	SINGLE	1000	OFF
3	2	URMC	SINGLE	1000	ON
5	6	URMC	SINGLE	1000	OFF
6	8	NOFFIC	SINGLE	1000	ON
11	4	URMC	SINGLE	1000	OFF
12	5	URMC	SINGLE	1000	ON

Figure 6 Example of point load input to the NM

Table 16 Point load data format

Attribute	Description
Near Node	ID number of the node which the load representation is to be connected to.
No of Customers	How many instances of this customer are connected to the "Near Node".
Customer Type	Refers to the load profile to be used. Load Profiles are discussed in section 3.3.2.
No of Phases	Describes whether customers are connected across Ph- N, Ph to Ph or three phases.
Annual Consumption (kWh)	Annual energy consumption of the customer being modelled.
Status	Customer on load or off load.

At present this process assigns customers to each phase with the intention of equalising customer numbers across phases. The present development status of the NM does not allow manual assignment of customers to individual phases, this capability is to be developed in the development phase between SDRC 7.2 and SDRC 7.3.

It should be noted that to each point load entry allows the user to declare multiple, but identical, users to be connected at one node. If the user wishes to declare multiple customers with different energy characteristics, then a new entry per customer would need to be declared.

The point load representation allows each customer to have a different customer profile and annual energy consumption. This is at the cost of having to declare a node and service cable for each customer.

Distributed Customer representation

In this case, identical customers can be spaced along an existing branch between existing nodes, at equal distances, without the need to first declare new nodes. This can be used to connect large quantities of customers without declaring a node for each service cable or without knowing exactly where customers are connected.

Table 16 describes the data format for creation of branches and shows that the following three parameters can be populated during branch creation:

- Customer type
- Annual Consumption
- No of customers

Use of this representation allows the user to connect a large quantity of identical customers across an existing branch. This representation makes the following assumptions:

- The customers are spaced at equal distances along the length of the branch being declared, where the spacing is the distance of the branch divided by the number of customers being distributed along the branch.
- All customers declared will use the same Customer Model (as discussed within 4.3.1).
- All the customers modelled along the branch will be assigned to have the same energy consumption.

Customers allocated to the branch in this way will be distributed across the phases in a manner that seeks to equalise customer numbers equally across the phases of the overall feeder.

4.3.2 Customer Model

As shown in Figure 1 the NM will take in load profiles which express how customers use power over the day. The University of Southampton (UoS) is responsible for the process which presents these load profiles via the Customer Model.

The outputs from the UoS Customer Model will be a set of load profiles for different customers groups or even individual customers that describe:

- Energy usage patterns under existing baseline conditions.
- Energy usage patterns following customer interventions. The Network Model also allows the user to express the percentage uptake of LCT technologies.

The rate of take up of SAVE interventions can be modelled at the template stage by the user inputting a percentage take up factor into the Network Model interface, this will then allow the appropriate number of interventions to be allowed for.

The model acknowledges that the observations of the difference in power consumption patterns between similar users will vary on a random basis. For this reason, the load profile for each customer group is defined in terms of:

- The mean average power consumption, per half hour period, across a group of similar customers.
- The standard deviation per 30-minute period across a group of similar customers.
- The annual energy consumption for the customers being modelled.

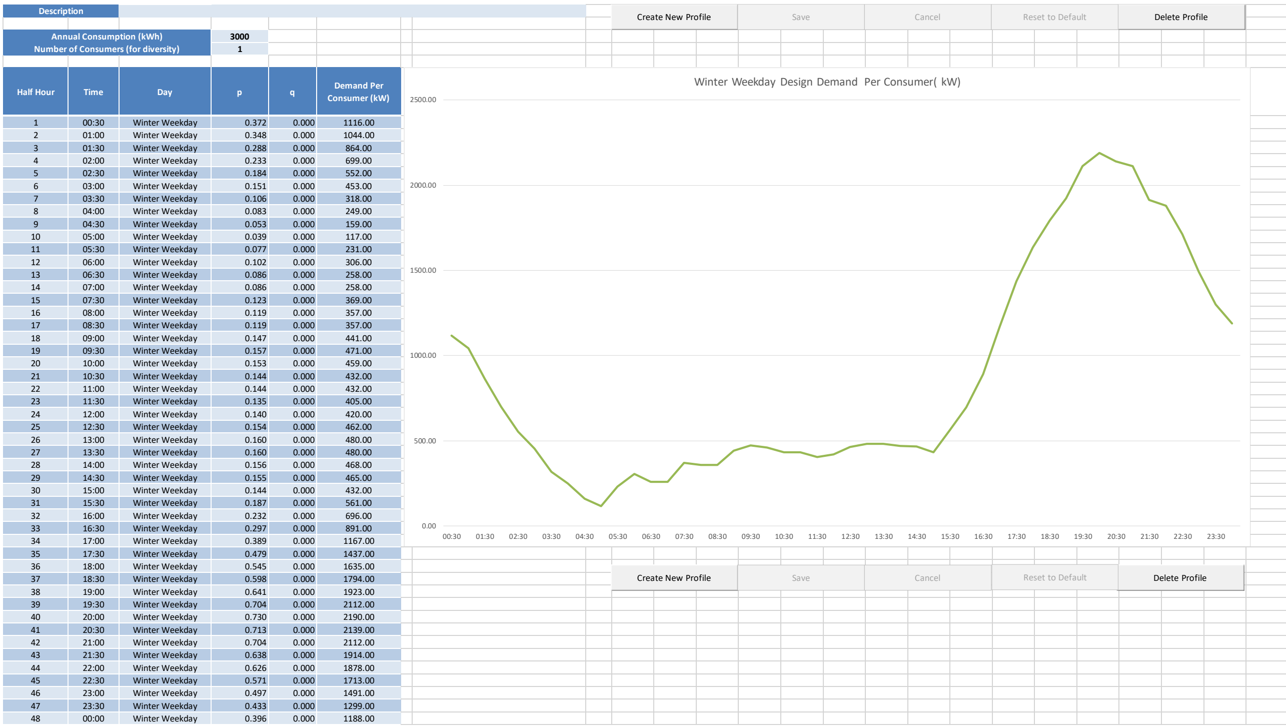
An example of how a customer profile is presented within the NM is shown in Figure 7. Customer information may be placed in to the NM either by loading a .CSV file into the NM backing store or by manually declaring a new customer and profile within the NM interface.

This approach has the benefit that it allows the DEBUT load flow engine to calculate feeder load without being reliant on fixed assumptions of feeder diversity. This feature allows the diversity between customers to vary up and down the feeder based on the number of customers connected below the point of interest.

This customer representation also allows DEBUT to forecast the feeder loading per 30-minute period on the basis on a statistical distribution. 30-minute data resolution was chosen for a number of reasons including:

- Compatibility with readings from half hourly metered customers as well as smart metered customers.
- Commensurate with the materiality tests of what duration of loading constitutes an overload.
- Represents a good compromise between model simplification and daily loading detail.

Because the Customer Model also provides data of how the observed readings from similar customers will vary within a distribution the NM can adopt a statistical view of network limits. This feature allows the DEBUT engine to calculate load flows based on the 90th percentile loading criteria which is in accordance with ACE 49 [2]. This approach is an improvement from modelling users in terms of After Diversity Maximum Demand (ADMD) as it allows diversity between users to be varied along the feeder depending upon how many users are being considered.



Description

Annual Consumption (kWh)	3000
Number of Consumers (for diversity)	1

Half Hour	Time	Day	p	q	Demand Per Consumer (kW)
1	00:30	Winter Weekday	0.372	0.000	1116.00
2	01:00	Winter Weekday	0.348	0.000	1044.00
3	01:30	Winter Weekday	0.288	0.000	864.00
4	02:00	Winter Weekday	0.233	0.000	699.00
5	02:30	Winter Weekday	0.184	0.000	552.00
6	03:00	Winter Weekday	0.151	0.000	453.00
7	03:30	Winter Weekday	0.106	0.000	318.00
8	04:00	Winter Weekday	0.083	0.000	249.00
9	04:30	Winter Weekday	0.053	0.000	159.00
10	05:00	Winter Weekday	0.039	0.000	117.00
11	05:30	Winter Weekday	0.077	0.000	231.00
12	06:00	Winter Weekday	0.102	0.000	306.00
13	06:30	Winter Weekday	0.086	0.000	258.00
14	07:00	Winter Weekday	0.086	0.000	258.00
15	07:30	Winter Weekday	0.123	0.000	369.00
16	08:00	Winter Weekday	0.119	0.000	357.00
17	08:30	Winter Weekday	0.119	0.000	357.00
18	09:00	Winter Weekday	0.147	0.000	441.00
19	09:30	Winter Weekday	0.157	0.000	471.00
20	10:00	Winter Weekday	0.153	0.000	459.00
21	10:30	Winter Weekday	0.144	0.000	432.00
22	11:00	Winter Weekday	0.144	0.000	432.00
23	11:30	Winter Weekday	0.135	0.000	405.00
24	12:00	Winter Weekday	0.140	0.000	420.00
25	12:30	Winter Weekday	0.154	0.000	462.00
26	13:00	Winter Weekday	0.160	0.000	480.00
27	13:30	Winter Weekday	0.160	0.000	480.00
28	14:00	Winter Weekday	0.156	0.000	468.00
29	14:30	Winter Weekday	0.155	0.000	465.00
30	15:00	Winter Weekday	0.144	0.000	432.00
31	15:30	Winter Weekday	0.187	0.000	561.00
32	16:00	Winter Weekday	0.232	0.000	696.00
33	16:30	Winter Weekday	0.297	0.000	891.00
34	17:00	Winter Weekday	0.389	0.000	1167.00
35	17:30	Winter Weekday	0.479	0.000	1437.00
36	18:00	Winter Weekday	0.545	0.000	1635.00
37	18:30	Winter Weekday	0.598	0.000	1794.00
38	19:00	Winter Weekday	0.641	0.000	1923.00
39	19:30	Winter Weekday	0.704	0.000	2112.00
40	20:00	Winter Weekday	0.730	0.000	2190.00
41	20:30	Winter Weekday	0.713	0.000	2139.00
42	21:00	Winter Weekday	0.704	0.000	2112.00
43	21:30	Winter Weekday	0.638	0.000	1914.00
44	22:00	Winter Weekday	0.626	0.000	1878.00
45	22:30	Winter Weekday	0.571	0.000	1713.00
46	23:00	Winter Weekday	0.497	0.000	1491.00
47	23:30	Winter Weekday	0.433	0.000	1299.00
48	00:00	Winter Weekday	0.396	0.000	1188.00

Figure 7 Example of Customer profile within the NM

Work is still ongoing to define the interface to the Customer Model and this is described in 7.1. At present the capability of the NM to interface with the UoS data is as follows:

- The tool can hold one customer pattern per customer if required, which expresses behaviour both before and after SAVE interventions.
- The NM is at a stage of development where it may only represent one 24-hour period, but on an annual basis across the breadth of the investigation period.
- The NM is at a stage of development where customer profiles must be manually loaded into the backing store. The goal of an automated loader is discussed in section 7.1.

4.3.3 Load Growth

The NM makes allowance for use of load growth scenarios so that multiyear investigations can be conducted, an example of the input tab within the NM where this controlled is shown in Figure 8.

Load Growth Rate (%)	5%
LCT Load Growth Probabilities	DECC
LCT Take Up Rate	High
LCT Distribution Weighting	Near to Sub
Start Year	2050
End Year	2050
EV Size (Annual Consumption kWh)	5000
HP Size (Annual Consumption kWh)	5000
PV Size (kW)	0
Intervention	Feeder Replacement
Select Feeder	42
New Cable Type	AL 2000

Figure 8 NM future load growth assessment tab

The user configurable options shown in Figure 8 are described as follows:

Load Growth Rate (%) – this parameter describes the annual compounded growth rate customer peak power demand.

LCT load growth probabilities – this parameter chooses which set of assumptions regarding Low Carbon Technology (LCT) load growth probabilities should be used. The user may choose to use DECC[4] appointed assumptions regarding growth in: PV generation Heat Pumps (HP) and Electric Vehicles (EV). Alternatively, users may nominate their own uptake assumptions. An example of the user configurable page where the LCT uptake probabilities can be specified is shown in Figure 9.

[4] Note, the acronym DECC refers to the former government depart who published the forecasts. This acronym is hardcoded into the NM and will be updated during further interface development.

Year	PV Low	HP Low	EV Low	PV Medium	HP Medium	EV Medium	PV High
2017	1.02%	0.21%	0.54%	1.61%	0.21%	0.69%	2.20%
2018	1.08%	0.26%	0.80%	1.80%	0.26%	1.11%	2.50%
2019	1.15%	0.73%	1.14%	2.05%	0.73%	1.70%	2.90%
2020	1.26%	1.52%	1.56%	2.37%	1.53%	2.45%	3.40%
2021	1.30%	1.64%	2.08%	2.64%	2.35%	3.40%	4.10%
2022	1.37%	1.76%	2.67%	2.94%	3.54%	4.51%	4.90%
2023	1.44%	1.88%	3.34%	3.27%	4.98%	5.78%	5.80%
2024	1.51%	2.01%	4.09%	3.64%	6.69%	7.13%	6.80%
2025	1.58%	2.15%	4.91%	4.05%	8.48%	8.64%	8.10%
2026	1.63%	2.31%	5.83%	4.50%	10.37%	10.34%	9.50%
2027	1.71%	2.46%	6.86%	5.00%	12.34%	12.25%	11.30%
2028	1.77%	2.62%	7.98%	5.56%	14.39%	14.35%	13.30%
2029	1.84%	2.79%	9.22%	6.18%	16.51%	16.67%	15.70%
2030	1.90%	2.96%	10.58%	6.83%	18.64%	19.16%	18.40%
2031	1.98%	3.15%	11.91%	7.59%	19.23%	21.50%	19.90%
2032	2.05%	3.35%	13.32%	8.35%	19.85%	23.87%	21.40%
2033	2.12%	3.57%	14.82%	9.09%	20.48%	26.29%	22.90%

Figure 9 **Example input to LCT growth assumptions tab**

LCT Take up rate. This field determines which range of take up probabilities is used i.e. low, medium or high as depicted in Figure 9.

LCT distribution weighting. This field allows users to weight where LCT technologies are connected to the LV feeder, the possible fields are:

- Near to the source substation,
- even weighting along the feeder
- or, far from sub

Start Year/End Year. Allows the user to define the time horizon over which the network analysis takes place.

EV Size (Annual consumption in kWh). This field allows the user to state one assumption for annual electrical energy consumption of Electric Vehicles.

HP Size (Annual consumption in kWh). This field allows the user to state one assumption regarding the size of heat pumps that are connected into customer premises. The volume of Heat Pumps installed within the network is decided by the choice of LCT growth assumption and by whether the High, Medium or Low range growth assumption was selected**.**

PV Size (kW). This field allows the user to state one assumption regarding the size of PV installed behind the meter in each property.

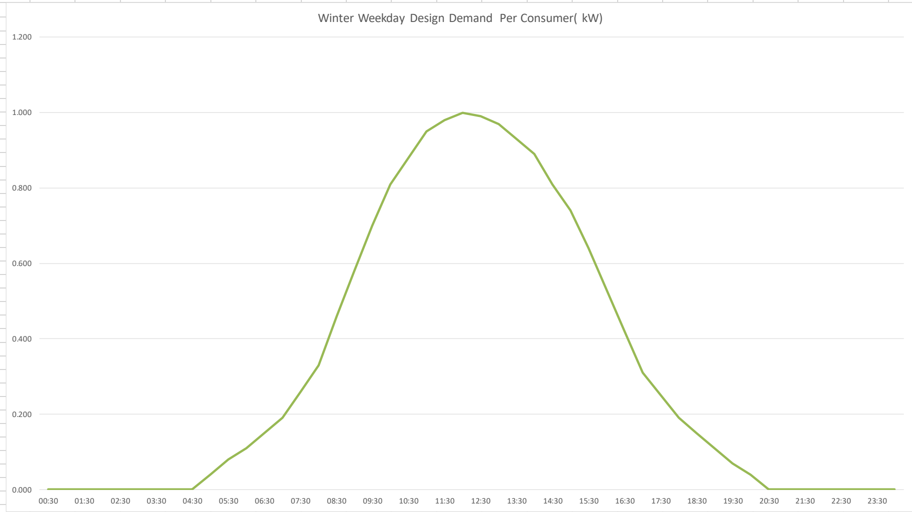
Figure 9 also has fields for initiating analysis of interventions, these are discussed in section 5.3

4.3.4 Low Carbon Technology Profiles

To allow the Low Carbon Technologies such as EV, PV generation and Heat Pumps to be modelled, the NM also holds load profiles for these technologies. Examples of the interface to these load curves are shown in Figure 10, Figure 11 and Figure 12. These graphs presently show dummy data used for development purposes rather than real load curves.

Generator Type	PV		
Half Hou	Time	Day	p
1	00:30	Winter Weekday	0.000
2	01:00	Winter Weekday	0.000
3	01:30	Winter Weekday	0.000
4	02:00	Winter Weekday	0.000
5	02:30	Winter Weekday	0.000
6	03:00	Winter Weekday	0.000
7	03:30	Winter Weekday	0.000
8	04:00	Winter Weekday	0.000
9	04:30	Winter Weekday	0.000
10	05:00	Winter Weekday	0.040
11	05:30	Winter Weekday	0.080
12	06:00	Winter Weekday	0.110
13	06:30	Winter Weekday	0.150
14	07:00	Winter Weekday	0.190
15	07:30	Winter Weekday	0.260
16	08:00	Winter Weekday	0.330
17	08:30	Winter Weekday	0.460
18	09:00	Winter Weekday	0.580
19	09:30	Winter Weekday	0.700
20	10:00	Winter Weekday	0.810
21	10:30	Winter Weekday	0.880
22	11:00	Winter Weekday	0.950
23	11:30	Winter Weekday	0.980
24	12:00	Winter Weekday	1.000
25	12:30	Winter Weekday	0.990
26	13:00	Winter Weekday	0.970
27	13:30	Winter Weekday	0.930
28	14:00	Winter Weekday	0.890
29	14:30	Winter Weekday	0.810
30	15:00	Winter Weekday	0.740
31	15:30	Winter Weekday	0.640
32	16:00	Winter Weekday	0.530
33	16:30	Winter Weekday	0.420
34	17:00	Winter Weekday	0.310
35	17:30	Winter Weekday	0.250
36	18:00	Winter Weekday	0.190
37	18:30	Winter Weekday	0.150
38	19:00	Winter Weekday	0.110
39	19:30	Winter Weekday	0.070
40	20:00	Winter Weekday	0.040
41	20:30	Winter Weekday	0.000
42	21:00	Winter Weekday	0.000
43	21:30	Winter Weekday	0.000
44	22:00	Winter Weekday	0.000
45	22:30	Winter Weekday	0.000
46	23:00	Winter Weekday	0.000
47	23:30	Winter Weekday	0.000
48	00:00	Winter Weekday	0.000

Save Cancel Reset to Default



Save Cancel Reset to Default

Figure 10 Examples of Solar PV Generator load curves used within the NM

View/Edit Profile

Consumer Type	EVSUMW
Description	
Annual Consumption (kWh)	3000
Number of Consumers (for diversity)	1

Create New Profile Save Cancel Re

Half Hour	Time	Day	p	q	Demand Per Consumer (kW)
1	00:30	Winter Weekday	0.372	0.000	1116.00
2	01:00	Winter Weekday	0.348	0.000	1044.00
3	01:30	Winter Weekday	0.288	0.000	864.00
4	02:00	Winter Weekday	0.233	0.000	699.00
5	02:30	Winter Weekday	0.184	0.000	552.00
6	03:00	Winter Weekday	0.151	0.000	453.00
7	03:30	Winter Weekday	0.106	0.000	318.00
8	04:00	Winter Weekday	0.083	0.000	249.00
9	04:30	Winter Weekday	0.053	0.000	159.00
10	05:00	Winter Weekday	0.039	0.000	117.00
11	05:30	Winter Weekday	0.077	0.000	231.00
12	06:00	Winter Weekday	0.102	0.000	306.00
13	06:30	Winter Weekday	0.086	0.000	258.00
14	07:00	Winter Weekday	0.086	0.000	258.00
15	07:30	Winter Weekday	0.123	0.000	369.00
16	08:00	Winter Weekday	0.119	0.000	357.00
17	08:30	Winter Weekday	0.119	0.000	357.00
18	09:00	Winter Weekday	0.147	0.000	441.00
19	09:30	Winter Weekday	0.157	0.000	471.00
20	10:00	Winter Weekday	0.153	0.000	459.00
21	10:30	Winter Weekday	0.144	0.000	432.00
22	11:00	Winter Weekday	0.144	0.000	432.00
23	11:30	Winter Weekday	0.135	0.000	405.00
24	12:00	Winter Weekday	0.140	0.000	420.00
25	12:30	Winter Weekday	0.154	0.000	462.00
26	13:00	Winter Weekday	0.160	0.000	480.00
27	13:30	Winter Weekday	0.160	0.000	480.00
28	14:00	Winter Weekday	0.156	0.000	468.00
29	14:30	Winter Weekday	0.155	0.000	465.00
30	15:00	Winter Weekday	0.144	0.000	432.00
31	15:30	Winter Weekday	0.187	0.000	561.00
32	16:00	Winter Weekday	0.232	0.000	696.00
33	16:30	Winter Weekday	0.297	0.000	891.00
34	17:00	Winter Weekday	0.389	0.000	1167.00
35	17:30	Winter Weekday	0.479	0.000	1437.00
36	18:00	Winter Weekday	0.545	0.000	1635.00

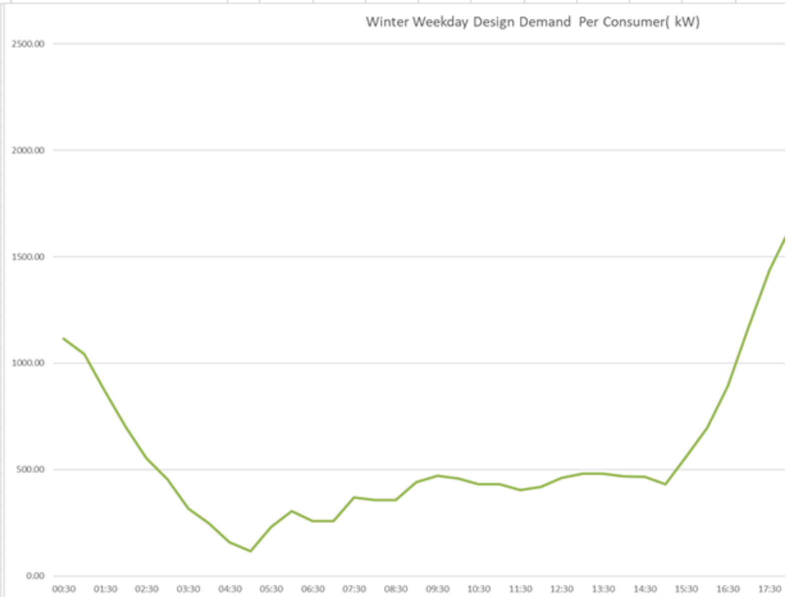
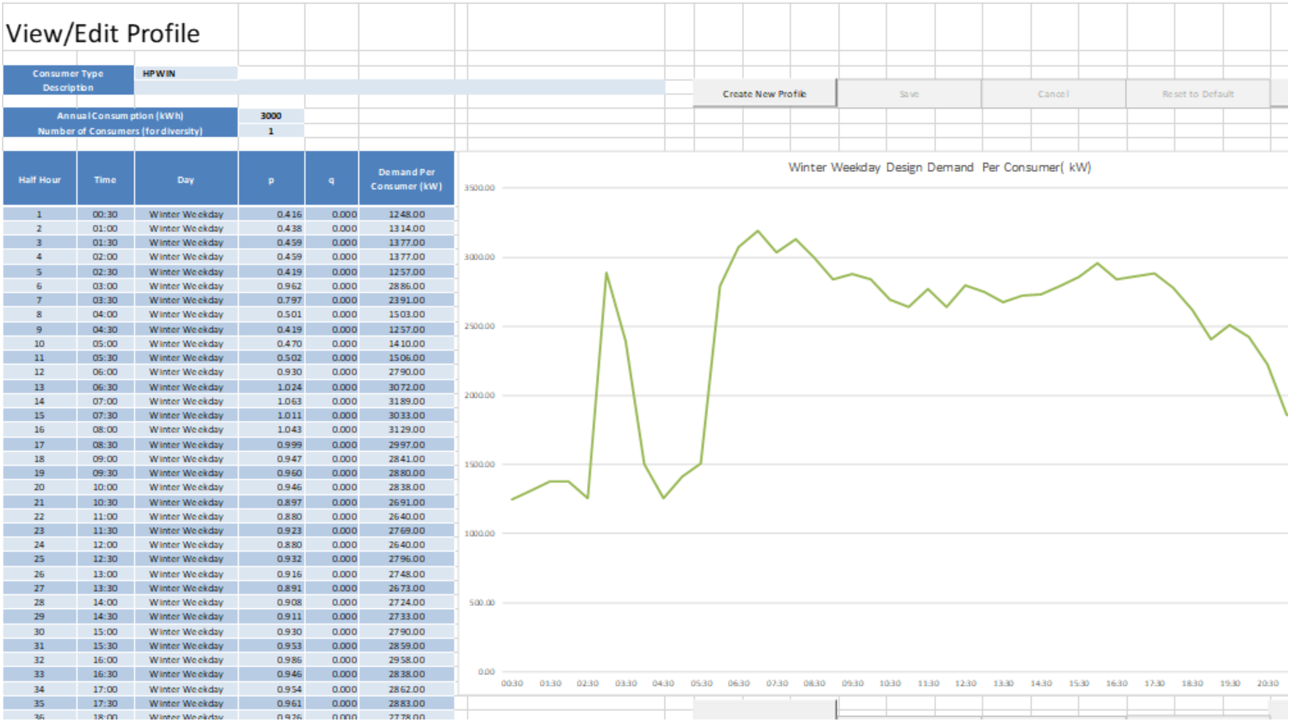


Figure 11 Example of EV load profile used within NM



Half Hour	Time	Day	p	q	Demand Per Consumer (kW)
1	00:30	Winter Weekday	0.416	0.000	1248.00
2	01:00	Winter Weekday	0.438	0.000	1314.00
3	01:30	Winter Weekday	0.459	0.000	1377.00
4	02:00	Winter Weekday	0.459	0.000	1377.00
5	02:30	Winter Weekday	0.419	0.000	1257.00
6	03:00	Winter Weekday	0.962	0.000	2886.00
7	03:30	Winter Weekday	0.797	0.000	2391.00
8	04:00	Winter Weekday	0.501	0.000	1503.00
9	04:30	Winter Weekday	0.419	0.000	1257.00
10	05:00	Winter Weekday	0.470	0.000	1410.00
11	05:30	Winter Weekday	0.502	0.000	1506.00
12	06:00	Winter Weekday	0.930	0.000	2790.00
13	06:30	Winter Weekday	1.024	0.000	3072.00
14	07:00	Winter Weekday	1.063	0.000	3189.00
15	07:30	Winter Weekday	1.011	0.000	3033.00
16	08:00	Winter Weekday	1.043	0.000	3129.00
17	08:30	Winter Weekday	0.999	0.000	2997.00
18	09:00	Winter Weekday	0.947	0.000	2841.00
19	09:30	Winter Weekday	0.960	0.000	2880.00
20	10:00	Winter Weekday	0.946	0.000	2838.00
21	10:30	Winter Weekday	0.897	0.000	2691.00
22	11:00	Winter Weekday	0.880	0.000	2640.00
23	11:30	Winter Weekday	0.923	0.000	2769.00
24	12:00	Winter Weekday	0.880	0.000	2640.00
25	12:30	Winter Weekday	0.932	0.000	2796.00
26	13:00	Winter Weekday	0.916	0.000	2748.00
27	13:30	Winter Weekday	0.891	0.000	2673.00
28	14:00	Winter Weekday	0.908	0.000	2724.00
29	14:30	Winter Weekday	0.911	0.000	2733.00
30	15:00	Winter Weekday	0.930	0.000	2790.00
31	15:30	Winter Weekday	0.953	0.000	2859.00
32	16:00	Winter Weekday	0.986	0.000	2958.00
33	16:30	Winter Weekday	0.946	0.000	2838.00
34	17:00	Winter Weekday	0.954	0.000	2862.00
35	17:30	Winter Weekday	0.961	0.000	2883.00
36	18:00	Winter Weekday	0.926	0.000	2778.00

Figure 12 Example of Heat Pump load curve used within NM

During scenario analysis, the NM will allocate LCT to be connected at locations along the feeder. The NM will decide the quantity and location of LCT in a manner that is decided by the assumptions that are selected with the load growth assumptions tab as discussed in section 4.3.3.

5. Running the Model

Analysis can be undertaken using two approaches:

- Single year assessment using the existing network without considering any interventions as discussed in section 5.2.

- Multiple year assessment which considers both the existing network and one intervention as discussed in section 5.3. Both approaches are dependent on the load flow engines which are discussed beneath.

5.1 Load Flow Engines

To calculate current flows and voltage drops, the Network Model uses two load flow engines, DEBUT and EGD. As an overview:

- DEBUT is a familiar, trusted and very well understood piece of software that provides voltage drops and asset utilisations from customer load models. Developed by EA Technology, it is implemented in Fortran and, unlike most load flow tools, DEBUT uses a unique calculation process to take account of diversity following the ACE49 design method. This method is not easily replicated in iterative load flow methods (e.g. Newton Raphson[5]).

- EGD (Embedded Generation for Distribution) was originally developed by EA Technology to allow the assessment of generation in the DEBUT software, again familiar to all DNOs. The EGD module is a traditional load flow engine utilising the common Newton Raphson iterative method. The main reason for including it in this proposal is that the code is readily adaptable for alternative uses, such as advanced probabilistic methods, and it allows us to model generation on LV circuits.

The inclusion of both engines allows the NM to verify the outputs of the tool against DEBUT which is well proven and trusted. DEBUT can be used for the assessment of circuits where it is expected that generation connected to the circuit would have minimal effect (e.g. peak winter) and where the interventions can be adequately modelled using the specific methods defined in ACE49. EGD is to be used to develop alternative probabilistic methods and to assess networks where it is expected that generation would feature (e.g. summer assessment with Solar PV) as DEBUT lacks the ability to model generation.

5.2 Single assessment

There are many fields where the user can control parameters which influence how the model is run. Figure 13 shows an example of the fields on the NM settings tab which allow the size of the source transformer to be specified and where the DEBUT files are to be saved. There is also an option to control or tidy up old files.

[5] The Newton Raphson methodology is a interactive approach to solving the equations used to calculate how the current and voltage will propagate across complex networks.

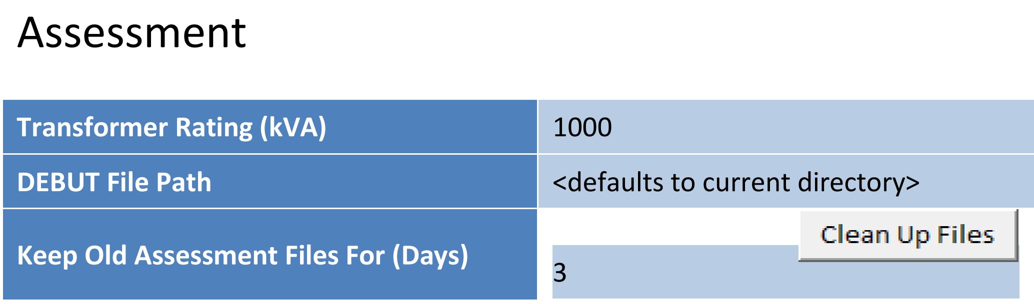


Figure 13 **NM Settings Tab**

To run a single assessment, the user need only initiate the assessment from the single assessment tab, an example of which is shown in Figure 17.

5.3 Multiple assessment

To consider a multiple year horizon or start considering the effect of different interventions the multiple assessment tool must be used.

This tool is partially driven by the network load growth tab as shown in Figure 8 and section 3.3.3. This tab is particularly important as it allows the user to specify the time horizon which is to be studied.

The future load growth tab of the NM is partially depicted in Figure 14. This figure shows where the user may specify which intervention shall be studied in addition to the base case. It should be noted that at the present stage of development, the NM assumes that the intervention is made at the start of the year that the user has declared to be the start of the analysis period.

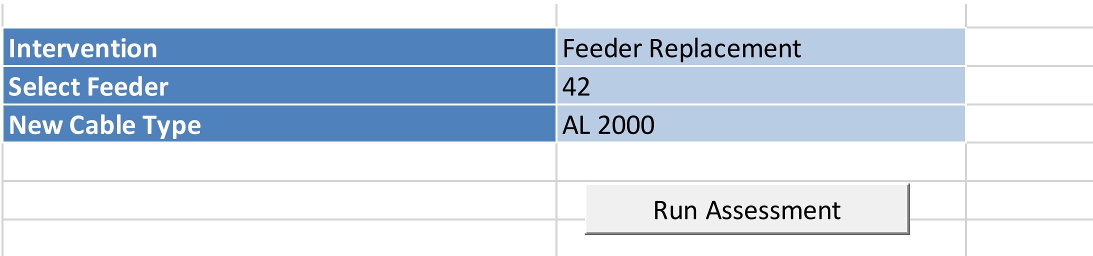


Figure 14 **Future Load Growth Assessment Tab**

Figure 15 shows the drop-down menu which appears when the interventions are selected.

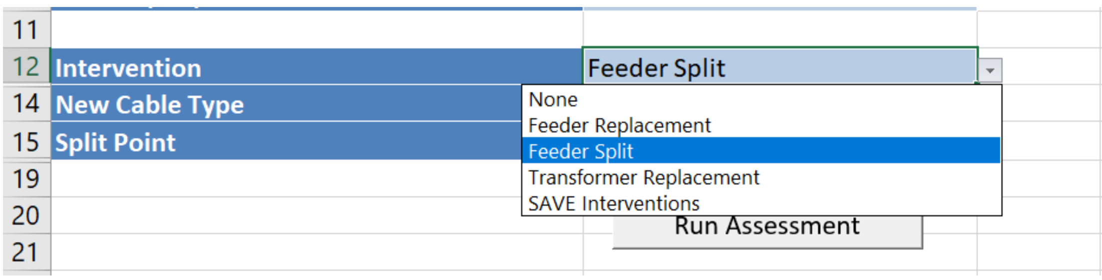


Figure 15 **Selection of intervention to be studied**

Depending on which option is selected, the NM will ask for further information that is relevant to the intervention that is being studied.

- If the **"Feeder Replacement"** intervention is to be studied, the NM will request a preference for the new cable type and which feeder is to be replaced. One feeder can be investigated at a time, rather than applying the approach to the whole substation.
- If the **"Feeder Split"** intervention is selected, then the NM will request the number of split points to be studied and the size of the new cable that will create the new feeder.
- If the **"New Transformer"** intervention is selected, then the NM will request the user to specify the size of the new transformer. This will reference into the NM data library.
- If the **"SAVE Interventions"** choice is taken, then the user will be requested to select a SAVE customer profile from the profile library. This profile will relate to one of the SAVE energy efficiency interventions. The user will also be required to specify an assumed value of intervention take up percentage within the customers.

If the user seeks to programme assumptions into the intervention that are inconsistent with data loaded in to the backing store of the NM, then warning notices are provided in a pop up box, as shown in Figure 16.

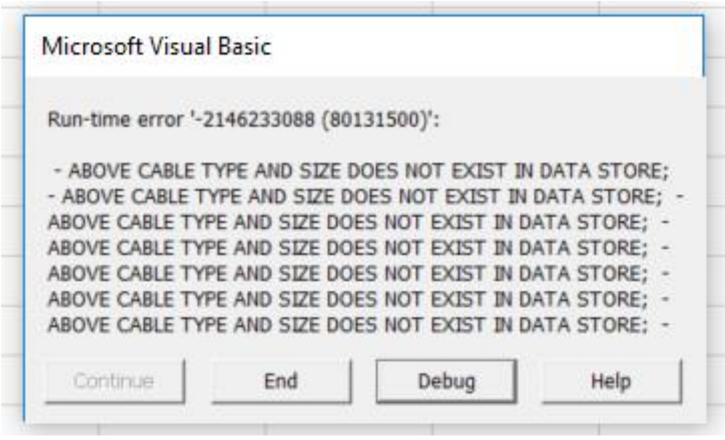


Figure 16 **Example of warning output during network building**

At present there is no option to study LV load transfers by re-arranging normal open points on the LV main. The requirement for this is presently under review as it is considered that over time it will result in the same outcome as the Feeder split.

5.4 Analysis capability

The NM will conduct a load flow (i.e. current and voltage) analysis in 30-minute steps as per the load profile data. The NM considers the network under system intact conditions only and does not investigate any form of circuit outage.

Development of the NM already allows it to consider one 24-hour period and the analysis may be executed over one single year or over a multi-year period. The results format from this output is discussed in section 6.

Clearly, a modelling tool which only considered one day of a year would not allow the DNO to make judgements based on the whole year. It has always been an intention of this project to have 365-day analysis and section 7.2 discusses the next steps towards a 365-day analysis tool.

6. Network Model Format of results

The output from the NM is presented via a selection of different reports. This section describes the present format state of development for the NM results output. In the longer run these reports will form an interface into the Network Pricing Model

6.1 Single Assessment, no Interventions

The NM may conduct a single year assessment. The summary format from a single analysis is shown in Figure 17.

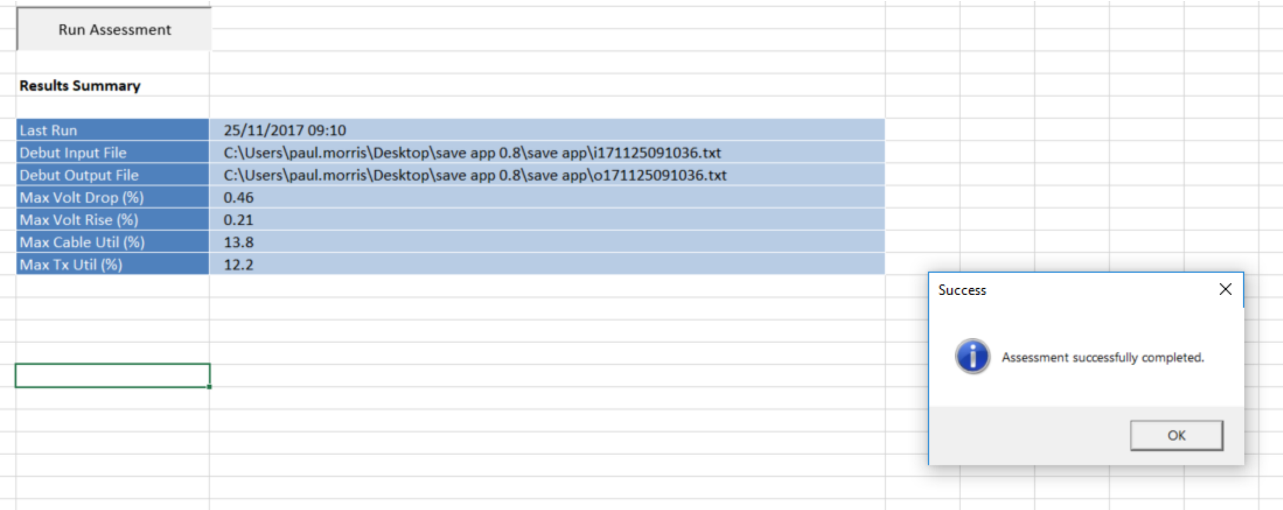


Figure 17 Results from single assessment

Figure 17 shows that a pop up box will confirm whether the analysis was ran satisfactorily. The report will also provide a summary of the:

- The Maximum voltage drop or rise in percent.
- The maximum cable utilisation (based on the most heavily loaded phase).
- The maximum transformer utilisation.

Following single analysis, the NM also provides further reports that describe the substation loading, as shown in Figure 18 and branch loading in Figure 19.

Substation Results

Half Hour	Time	Day	kW
1	00:30	Winter Weekday	21.4
2	01:00	Winter Weekday	24.2
3	01:30	Winter Weekday	24.4
4	02:00	Winter Weekday	24.3
5	02:30	Winter Weekday	24.1
6	03:00	Winter Weekday	23.1
7	03:30	Winter Weekday	22
8	04:00	Winter Weekday	20.6
9	04:30	Winter Weekday	19.3
10	05:00	Winter Weekday	17.8
11	05:30	Winter Weekday	16.5
12	06:00	Winter Weekday	15.9
13	06:30	Winter Weekday	15.1
14	07:00	Winter Weekday	15.5
15	07:30	Winter Weekday	8.1
16	08:00	Winter Weekday	9.3
17	08:30	Winter Weekday	10.4
18	09:00	Winter Weekday	11.1
19	09:30	Winter Weekday	14.9
20	10:00	Winter Weekday	16.7
21	10:30	Winter Weekday	17.4
22	11:00	Winter Weekday	16.7
23	11:30	Winter Weekday	16.1
24	12:00	Winter Weekday	16.2
25	12:30	Winter Weekday	16.9
26	13:00	Winter Weekday	16.4
27	13:30	Winter Weekday	16.1
28	14:00	Winter Weekday	15.5
29	14:30	Winter Weekday	15
30	15:00	Winter Weekday	15.2
31	15:30	Winter Weekday	15.5
32	16:00	Winter Weekday	14.8
33	16:30	Winter Weekday	16
34	17:00	Winter Weekday	17.1
35	17:30	Winter Weekday	15.7
36	18:00	Winter Weekday	14.7
37	18:30	Winter Weekday	13.9
38	19:00	Winter Weekday	12.7

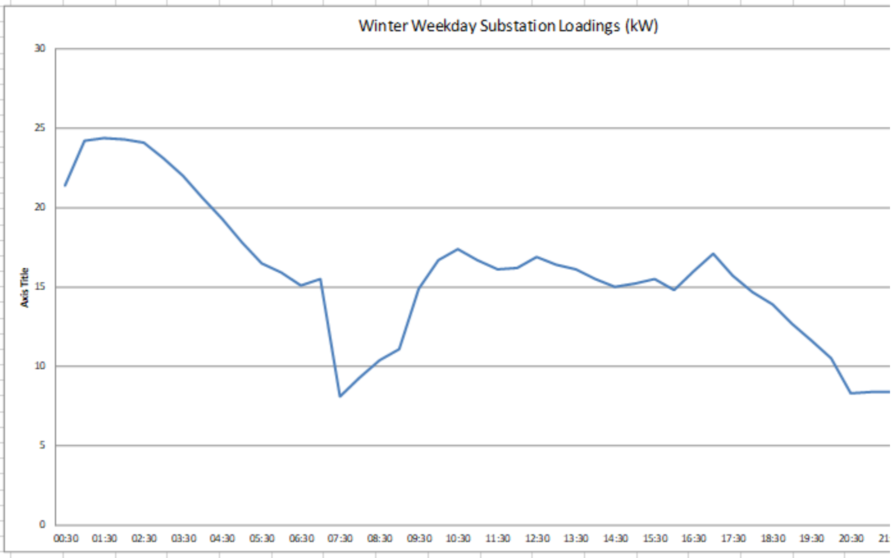


Figure 18 Example of substation loading report for single analysis

The substation loading report provides a load versus time graph of the load upon the substation. The report also provides the results in tabular form. Because the report is published in excel, users may apply conditional formatting to the results table to highlight results.

Branch Results

						Phasing						Max Current			Branch Load						Far Node Max Volt Drop		
Feeder Number	Near Node	Far Node	Length	No of Consumers	Consumer Type	Red	Yellow	Blue	Number of Phases	Cable Type	Rating (Amps)	Value (Amps)	MC Time	MC Day	Percent Load	Max Demand (kW)	MD Time	MD Day	Far Node Ph-N Fault (Amps)	Far Node Ph+N Resistance (mOhm)	Value (%)	MVD Time	MVD Day
1	47	3	20	0		0	0	0	TRIPLE	AL185	330	4.32	17:30	WeekDay	1.3	0			3140	58.64	0.39	01:00	WeekDay
1	42	6	18	0		0			SINGLE	AL185	330	43.27	02:00	WeekDay	13.1	0			14128	10.72	0.14	01:30	WeekDay
1	8	47	4	0		0	0	0	TRIPLE	AL35	130	12.89	01:00	WeekDay	9.9	0			3520	52.08	0.39	01:00	WeekDay
1	10	39	3	0		0	0	0	TRIPLE	AL185	330	10.96	17:30	WeekDay	3.3	0			3192	57.65	0.39	01:00	WeekDay
1	23	12	20	0		0			SINGLE	AL185	330	9.35	17:30	WeekDay	2.8	0			6817	25.81	0.19	01:30	WeekDay
1	14	23	8	0		0	0	0	TRIPLE	AL185	330	24.06	01:00	WeekDay	7.3	0			8843	19.25	0.19	01:30	WeekDay
1	23	8	98	0		0	0	0	TRIPLE	AL185	330	24.06	01:00	WeekDay	7.3	0			3572	51.39	0.39	01:00	WeekDay
1	25	51	32	0		0	0	0	TRIPLE	AL50	156	0	03:00	Friday	0	0			2476	73.96	0.39	01:00	WeekDay
1	14	27	7	0		0	0	0	TRIPLE	AL185	330	2.49	17:30	WeekDay	0.8	0			8975	18.92	0.19	01:30	WeekDay
1	30	25	21	0		0	0	0	TRIPLE	AL185	330	6.05	17:30	WeekDay	1.8	0			2641	70.12	0.39	01:00	WeekDay
1	39	34	1	0		0	0	0	TRIPLE	AL185	330	10.96	17:30	WeekDay	3.3	0			3175	57.98	0.39	01:00	WeekDay
1	1	42	8	0		0	0	0	TRIPLE	AL185	330	45.63	01:30	WeekDay	13.8	0			22418	4.81	0.04	01:00	WeekDay
1	30	36	22	0		0	0	0	TRIPLE	AL185	330	4.32	17:30	WeekDay	1.3	0			2629	70.44	0.39	01:00	WeekDay
1	25	37	21	0				0	SINGLE	AL185	330	6.05	17:30	WeekDay	1.8	0			2411	77	0.4	01:00	WeekDay
1	39	30	17	0		0	0	0	TRIPLE	AL185	330	6.05	17:30	WeekDay	1.8	0			2920	63.23	0.39	01:00	WeekDay
1	43	41	2	0		0	0	0	TRIPLE	AL185	330	28.07	01:30	WeekDay	8.5	0			9855	16.95	0.19	01:30	WeekDay
1	42	43	35	0		0	0	0	TRIPLE	AL185	330	38.88	01:30	WeekDay	11.8	0			10185	16.29	0.19	01:30	WeekDay
1	43	14	1	0		0	0	0	TRIPLE	AL185	330	24.06	01:00	WeekDay	7.3	0			10017	16.62	0.19	01:30	WeekDay
1	10	45	6	0		0	0	0	TRIPLE	AL185	330	12.37	01:30	WeekDay	3.7	0			3140	58.64	0.39	01:00	WeekDay
1	8	46	23	0		0	0	0	TRIPLE	AL185	330	22.92	01:30	WeekDay	6.9	0			3130	58.93	0.46	01:00	WeekDay
1	47	10	14	0		0	0	0	TRIPLE	AL185	330	12.89	01:00	WeekDay	3.9	0			3245	56.67	0.39	01:00	WeekDay

Figure 19 Example of Branch loading report from single analysis

The prototype branch loading report makes a one row report for each branch in the model. The first 12 columns of the branch loading report confirm the construction details for each branch. The second 12 columns of the report confirm the load flow results for each branch as follows:

- The value of maximum current load and the time and day upon which it occurred.
- The value of maximum power load and the time and day upon which it occurred.
- The largest voltage drop, relative to the source LV bus bars and the time and day upon which it occurred.

Because these results are presented in an excel format, the user may utilise the spreadsheet tools that are available in this package for conditional formatting and data sorting.

6.2 Multi Assessments

As described in section 5.3 the user may conduct a multiple analysis that will:

- Conduct load flow analysis over the time horizon specified (example shown in Figure 8).
- Within the time horizon, conduct load flows upon the existing network and then re-run the analysis with one chosen intervention in accordance with the desired load growth parameters as discussed in 4.3.3.

When such an analysis is performed the user is currently presented with two reports. The first report records the performance of the network with no intervention. The second report records the performance of the network with a selected intervention.

An example of the non-intervention, multiyear, report is shown in Appendix I. For each year within the assessment horizon the report records:

- The largest voltage drop per branch, at which node it occurs and at what time of day it occurred.
- The largest voltage rise per branch, at which node it occurs and at what time of day it occurred.
- The highest cable loading per branch, upon which branch it occurs and at what time of day it occurred.
- The highest transformer loading at the secondary substation and at what time of day it occurred.

Appendix II shows an example output for a post intervention analysis over the same study period, in this case the chosen intervention was a transformer replacement.

As can be seen, the results format is the same as the non-intervention solution, but the calculated transformer utilisation is significantly reduced due to the reinforcement. Despite the reinforcement, the results predict that the transformer will again be outside of capacity by 2025 when maximum utilisation is 103%. Similar results can be shown for the other interventions.

As acknowledged in section 5.4 and 7.2 this development version of the NM was only intended to consider one day of the year as a development milestone. It is expected that refinements prior to the final version to be delivered within SDRC 7.3 will be compatible with a full 365 days per year scope.

7. Next development stages

As acknowledged throughout the report, the NM and its interfaces are under development. This is commensurate with the requirement for the Network Model to be complete by SDRC 7.3 in June 2019. The follow sections provide a summary of the key next steps and intentions.

7.1 Interface to Network Builder and interface to Customer Model

Further works are now to be undertaken which will develop the semi-automated link so that customer and network inputs can be automatically loaded into the NM.

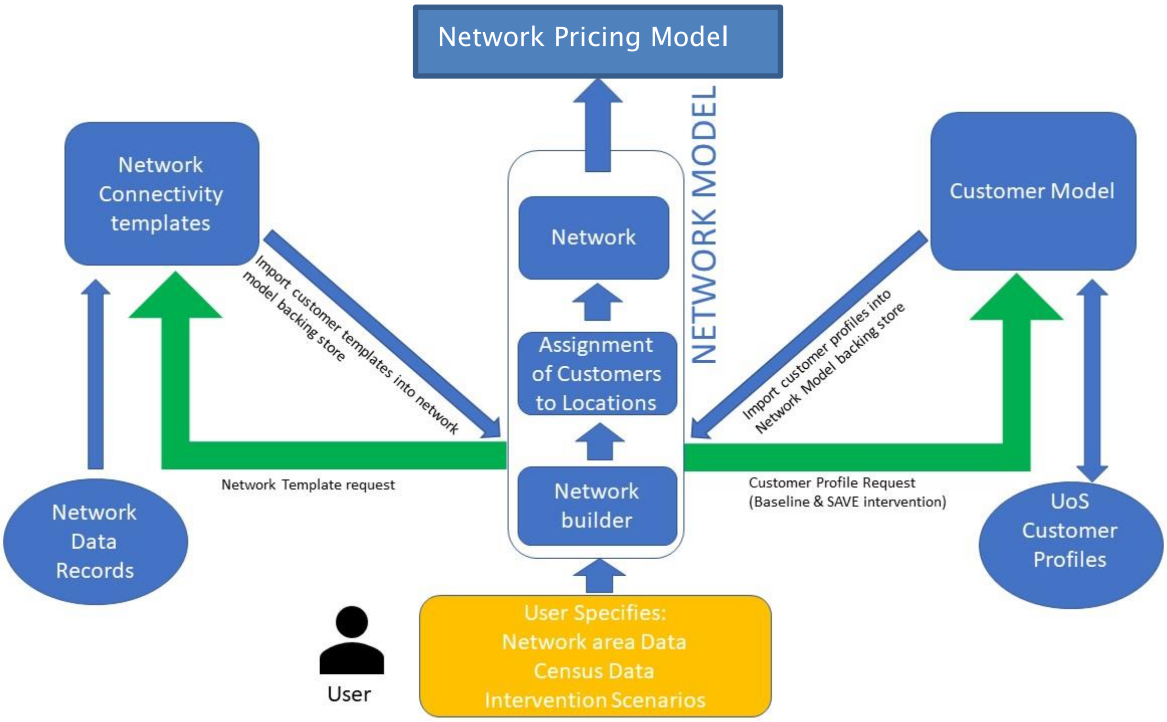


Figure 20 **Customer Model interface**

Development choices are still being considered by SSEN about their preferences for the user interaction with this automation. The present design intention is depicted in Figure 20. This diagram shows a summary of the interface across the Network Model to the network connectivity database and the Customer Model.

The present working assumption is that users of the overall Network Investment Tool will load some initial parameters into the Network Model interface. These parameters are likely to be:

- Network parameters to describe the network to be studied. These parameters could possibly be postcodes or NRN numbers.
- Demographic parameters to link the network being studied to the expected customer make up. These parameters could potentially be census data.
- A list of the intervention scenarios to be considered.
- Data to be entered in the format that will be provided by the UoS Customer Models.
- Approaches to be taken which can either model individual users or can model large groups of similar users.
- Network data to be loaded into the NM using templates in a .CSV format.

The network builder element within the NM would then make calls to gather files from across the following two interfaces:

- To the Customer Model to gather the customer energy usage profiles required to populate the model. This call would be informed by the customer demographic parameters as to which customer profiles would need to be loaded into the NM backing store. This will have required not only the base case customer profiles to be loaded, but also the customer profiles reflecting behaviour after an energy efficiency intervention to be loaded.

- To the network data store to gather in a network template which expresses the ratings and connectivity of the network to be considered.

This report has already shown how the model has the functionality to accept such files, but the next part of the project will automate the request and loading of these files.

7.1.1 Customer representation interface

Figure 20 shows that part of the network builder element within the NM will be the function to assign customers to locations. To design this interface consideration has had to be made regarding how the UoS Customer Model describes different customers. The options that have been considered with the UoS and SSEN are as follows:

1. **Use of an average customer per feeder concept**
   This concept would require the Customer Model to aggregate the demographic of customers that are connected to a feeder into one profile that was applied to each customer connection location. This approach would simplify the automation within the Network Model but would increase the complexity on the Customer Model side of the interface. Because this approach proposed to use a normalised view of a customer it would also undermine the model of the calculation of the current flow and voltage profile along a feeder by the NM. For these reasons this approach was not progressed.

2. **Bespoke model per customer**
   This concept would require the Customer Model to provide one bespoke model for each customer that was connected to a feeder. This approach presented significant challenges to the Network Model as two nodes and one service branch would have to be declared per customer.

   Work by the UoS also demonstrated that significant customer differences could often be explained by only a small number of demographic features. This conclusion led to a view that the complexity of a bespoke model might not be warranted.

3. **Grouped Customer Model**
   The UoS demonstrated that the variance in customer behaviour could be demonstrated by a small number of key demographics. This fact allows large numbers of customers to be grouped into a small number of representative groups that have similar load profiles and census data.

The UoS, SSEN and EA technology all elected to use approach three to describe customers. This will have the following benefits on the design of the interface to the Customer Model:

- It will allow the Network Model to utilise its distributed customer (as described in 4.3.1) approach to populating the model.
- It will optimise the number of customer load profiles that need to be called from the UoS Customer Model and allocated to a position on the feeder.
- Because customers who share the key demographics are likely to have similar load profiles, this approach is likely to optimise Network Model accuracy when compared to the other two options. This approach will also lend itself to scale, as it will streamline development of Customer Models.

7.2 Year-round analysis

This report has shown that the NM can already conduct analysis on one day of the year over a series of years.

The next step in development will be to allow analysis over 365 days a year over a series of years and update the reporting format to reflect this.

7.3 Customer phase allocation

As discussed in this report the present development version of the NM assumes that customers are allocated across phases in a manner that equalises customer number rather than demand.

Further project steering conversations are planned with SSEN to decide whether this functionality is sufficient or whether additional phasing sensitivity tests are justified and practical within the analysis. These conversations are expected to consider what evidence exists regarding typical levels of asymmetry as an input to modelling assumptions.

7.4 Interface to Network Pricing Model.

This report has shown that at present the NM can already compare the base case to one intervention. SSEN are presently developing their initial steps on the Network Pricing Model.

Examples of the output from the Network Model that could be passed over the interface and into the Network Pricing Model are shown in Figure 17, Figure 18, Figure 19 and also appendices I and ii All of these examples were based upon data within the development version of the Network Model.

The next development steps will focus on the requirements stated in section 3.2.4 and 3.2.5 of the functional specification and finalise the parameters of the interface.

The present working concept for how the interface to the Network Pricing Model is summarised in Figure 21. This diagram shows the same Network Model functionality as Figure 20 but the interface to the Customer Model and the network data is simplified.

As discussed in section 6 the NM can already run either single studies or comparative studies that include one intervention. During the next stage of development, automation will be introduced that runs the number and scope of intervention studies that are required by the user. The results files from these interventions will then be passed to SSEN's Network Pricing Model for comparison of the technical and financial performance. The exact format of these interface reports will be decided following completion of the Network Pricing Model.

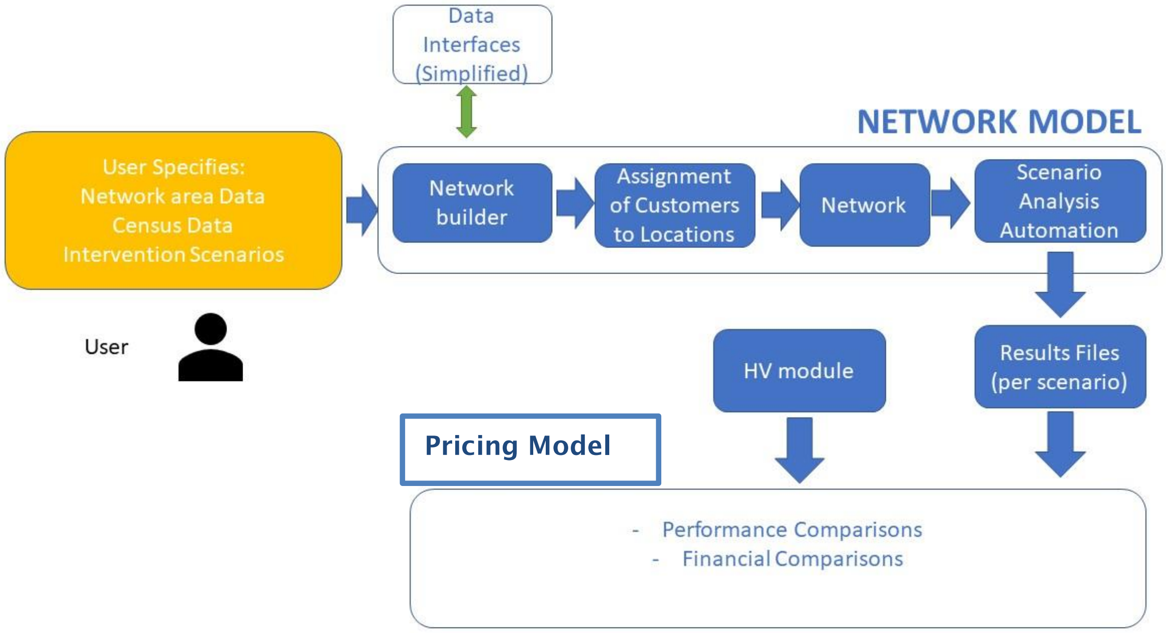


Figure 21 Interface to Network Pricing Model

7.4.1 HV/EHV module

The functional requirements of the Network Model make requirements that are recorded in in section 3.10 and summarised beneath.

- Provide a method of aggregating the effects of the SAVE interventions based on multiple LV network areas.
- Provide an understanding of the quantity of interventions needed to achieve a desired level of demand reduction.

To date, development activity has been placed upon reaching the first internal milestone of delivering capability to study the Low Voltage (LV) network. The next development stage will consider the how these requirements should be delivered. Before freezing the design intent for the HV and EHV module the following questions will be explored with SSEN:

- Would it be most advantages for the HV/EHV module to interface directly with the network Pricing Model or should this be a sub-module within the Network Model?
- What is the best way to ensure that the HV/EHV captures the network capacity limits that will have been calculated by the DNO's HV and EHV planning engineers?
- How should this HV/EHV module allow for any export constraints that are active on upstream systems. For example, is it appropriate to allow for demand reduction at LV when it would exacerbate an upstream export constraint?
- What is the most effective way for the HV/EHV module to understand the extent and composition of the LV networks that will be effective upon an upstream loading problem?
- What should be the format of output from the HV/EHV module to its interface (which will be either the Network Model or the Network Pricing Model)?

8. References

[1] SDRC 7.1: Initial Network Model, Castro, Potter & Mukherjee *Et Al*, EA Technology Ltd, 05/12/14

[2] ACE 49; ENA, 1981. "Report on Statistical Method for Calculating Demands and Voltage Regulations on LV Radial Distributions Systems", Energy Networks Association, 1981

Appendix I Example of results, Multi Year Report without intervention

This appendix shows an example of a multiple year analysis without any interventions being made.

Branch Results

						Phasing						Max Current			Branch Load						Far Node Max Volt Drop		
Feeder Number	Near Node	Far Node	Length	No of Consumers	Consumer Type	Red	Yellow	Blue	Number of Phases	Cable Type	Rating (Amps)	Value (Amps)	MC Time	MC Day	Percent Load	Max Demand (kW)	MD Time	MD Day	Far Node Ph-N Fault (Amps)	Far Node Ph+N Resistance (mOhm)	Value (%)	MVD Time	MVD Day
1	47	3	20	0		0	0	0	TRIPLE	AL185	330	4.32	17:30	WeekDay	1.3	0			3140	58.64	0.39	01:00	WeekDay
1	42	6	18	0		0			SINGLE	AL185	330	43.27	02:00	WeekDay	13.1	0			14128	10.72	0.14	01:30	WeekDay
1	8	47	4	0		0	0	0	TRIPLE	AL35	130	12.89	01:00	WeekDay	9.9	0			3520	52.08	0.39	01:00	WeekDay
1	10	39	3	0		0	0	0	TRIPLE	AL185	330	10.96	17:30	WeekDay	3.3	0			3192	57.65	0.39	01:00	WeekDay
1	23	12	20	0		0			SINGLE	AL185	330	9.35	17:30	WeekDay	2.8	0			6817	25.81	0.19	01:30	WeekDay
1	14	23	8	0		0	0	0	TRIPLE	AL185	330	24.06	01:00	WeekDay	7.3	0			8843	19.25	0.19	01:30	WeekDay
1	23	8	98	0		0	0	0	TRIPLE	AL185	330	24.06	01:00	WeekDay	7.3	0			3572	51.39	0.39	01:00	WeekDay
1	25	51	32	0		0	0	0	TRIPLE	AL50	156	0	03:00	Friday	0	0			2476	73.96	0.39	01:00	WeekDay
1	14	27	7	0		0	0	0	TRIPLE	AL185	330	2.49	17:30	WeekDay	0.8	0			8975	18.92	0.19	01:30	WeekDay
1	30	25	21	0		0	0	0	TRIPLE	AL185	330	6.05	17:30	WeekDay	1.8	0			2641	70.12	0.39	01:00	WeekDay
1	39	34	1	0		0	0	0	TRIPLE	AL185	330	10.96	17:30	WeekDay	3.3	0			3175	57.98	0.39	01:00	WeekDay
1	1	42	8	0		0	0	0	TRIPLE	AL185	330	45.63	01:30	WeekDay	13.8	0			22418	4.81	0.04	01:00	WeekDay
1	30	36	22	0		0	0	0	TRIPLE	AL185	330	4.32	17:30	WeekDay	1.3	0			2629	70.44	0.39	01:00	WeekDay
1	25	37	21	0				0	SINGLE	AL185	330	6.05	17:30	WeekDay	1.8	0			2411	77	0.4	01:00	WeekDay
1	39	30	17	0		0	0	0	TRIPLE	AL185	330	6.05	17:30	WeekDay	1.8	0			2920	63.23	0.39	01:00	WeekDay
1	43	41	2	0		0	0	0	TRIPLE	AL185	330	28.07	01:30	WeekDay	8.5	0			9855	16.95	0.19	01:30	WeekDay
1	42	43	35	0		0	0	0	TRIPLE	AL185	330	38.88	01:30	WeekDay	11.8	0			10185	16.29	0.19	01:30	WeekDay
1	43	14	1	0		0	0	0	TRIPLE	AL185	330	24.06	01:00	WeekDay	7.3	0			10017	16.62	0.19	01:30	WeekDay
1	10	45	6	0		0	0	0	TRIPLE	AL185	330	12.37	01:30	WeekDay	3.7	0			3140	58.64	0.39	01:00	WeekDay
1	8	46	23	0		0	0	0	TRIPLE	AL185	330	22.92	01:30	WeekDay	6.9	0			3130	58.93	0.46	01:00	WeekDay
1	47	10	14	0		0	0	0	TRIPLE	AL185	330	12.89	01:00	WeekDay	3.9	0			3245	56.67	0.39	01:00	WeekDay

Appendix II Example of Example of results, Multi Year Report with intervention

This analysis shows an example of results from a multi-year analysis with the impact of an intervention being studied.

Future Assessment Results (Transformer Replacement)

	Voltage						Thermal					
	Max Volt Drop			Max Volt Rise			Max Cable Utilisation				Max Transformer Utilisation	
Year	Volt Drop (%)	Volt Drop Node	Volt Drop Time	Volt Rise (%)	Volt Rise Node	Volt Rise Time	Max Utilisation (%)	Near Node	Far Node	Cable Utilisation Time	Max Tx Utilisation (%)	Tx Utilisation Time
2020	9.75	15	02:00:00	5.67	48	02:00:00	315	18	50	01:30:00	77.74	01:30:00
2021	10.2	15	02:00:00	5.97	48	02:00:00	331	18	50	01:30:00	82.04	01:30:00
2022	10.67	15	02:00:00	6.45	48	02:00:00	348	18	50	01:30:00	86.71	01:30:00
2023	12.06	15	02:00:00	7.21	15	02:00:00	365	18	50	01:30:00	91.88	01:30:00
2024	12.59	15	02:00:00	7.34	15	02:00:00	383	18	50	01:30:00	97.54	01:30:00
2025	12.6	48	03:00:00	7.43	48	02:00:00	402	18	50	01:30:00	103.45	01:30:00
2026	13.6	48	03:00:00	7.88	48	02:00:00	422	18	50	01:30:00	109.73	01:30:00
2027	14.39	15	02:00:00	8.13	49	02:00:00	444	18	50	01:30:00	116.55	01:30:00
2028	15	15	02:00:00	8.65	49	02:00:00	466	18	50	01:30:00	123.64	01:30:00
2029	15.72	15	01:30:00	9.03	49	02:00:00	489	18	50	01:30:00	131.53	03:00:00
2030	17.73	48	03:00:00	9.95	48	02:00:00	514	18	50	01:30:00	139.96	03:00:00

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EA Technology, Capenhurst Technology Park,
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