



LCNF Tier 1 Close Down Report

Low Voltage Network Modelling and Analysis Environment

Project ref. SSEPDT1005

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Executive Summary

Project Scope

For the first time in the history of the electricity industry there is the prospect of large amounts of data relating to the status of our low voltage networks. This data will come from Smart Meters, network embedded monitoring devices and information extrapolated using advanced modelling and forecasting tools. The existing systems, interfaces and methodologies adopted in the industry are not fit to take full advantage of this new data. Similarly the wealth of new energy sources and demands on the network are changing traditional usage profiles, again leaving the industry blind to the changing demands on the low voltage network. This project, a precursor to the New Thames Valley Vision¹ (NTVV) project, aims to source, integrate and evaluate the tools and data that will be both available and needed to face this challenge.

The project investigated the creation of a *proof of concept* 'Low Voltage Network Modelling Environment' that would enable a GB Distribution Network Operator (DNO) to carry out load flow analysis calculations without the need for significant user input. It was anticipated that this analysis would facilitate the DNO to identify where and under what conditions the electricity network would need to be reinforced in order to operate effectively under new load demands. The main driver behind this was the accelerating change towards a low carbon economy and the unknown impact this would have on a network historically designed for consumer load, with no consideration for the recent emergence of embedded generation.

SSEPD partnered with GE Digital Energy to demonstrate the capability of electrically modelling the low voltage network. The proof of concept was required to be capable of re-creating network topology from existing SSEPD information systems to avoid the need for significant user interaction to input network connectivity data. The tool was also intended to facilitate the modelling of new and emerging low carbon technologies such as solar PV, heat pumps, electric vehicles, etc.

An additional requirement of this Tier 1 project was to de-risk our Low Carbon Networks Fund (LCNF) Tier 2 project, New Thames Valley Vision¹ by laying the foundations for a fully automated Network Modelling Environment. This would provide SSEPD with a small, but representative, example low voltage network derived from the company's actual data and enable SSEPD staff to interact with the selected power analysis tool.

¹ This project has now been funded, see www.thamesvalleyvision.co.uk for further information.

Aims

- Create a prototype migration tool allowing data to be transferred from SSEPD's current Geographical Information System into the Smallworld Electric Office²
- Evaluate a number of power analysis tools and make selection on the most suitable
- Demonstrate data transfer from Smallworld Electric Office to the chosen power analysis tool
- Perform network modelling using customer associated load profiles and incorporate low carbon devices

The project was split into 3 key sections. The first concerned the transfer of network topology data from SSEPD's existing GIS (Geographical Information System) into the GE Smallworld system 'Smallworld Electric Office'. The second critical part of the project was to select an appropriate power analysis tool and integrate this with the data stored in Smallworld Electric Office. The final activity was to run various simulations using real time and mock data provided from the University of Reading for a selected trial location. The results then compared with actual live data from substation monitoring equipment.

Outcomes of the project and key learning

Integration of data from SSEPD's existing GIS with Smallworld Electric Office was completed successfully, mapping all necessary data objects and matching with a geographical referencing system 'Address Layer 2'. The completion of this activity allowed users to select a network area of interest and migrate the relevant data into Smallworld Electric Office autonomously.

The evaluation of power analysis tools resulted in selection of CYMDIST³, principally because it met the required criteria and made for simpler software integration. However it also performed well with respect to the electrical modelling capabilities and was able to handle half hourly load profiles, a feature well matched to the data expected from Smart Metering. The integration between CYMDIST and Smallworld Electric Office was completed using a manual process and performed as expected.

Modelling was completed using dynamic customer load profiles on a single feeder circuit. Data was sent from Smallworld Electric Office to the CYMDIST to perform the network modelling calculations, the results were then returned to Smallworld Electric Office. To trial the modelling tool; numerous scenarios were run with differing levels of load increases to create overload conditions - the results confirmed the outputs were in line with expectations. In addition low

² The latest version of the GE Smallworld www.gedigitalenergy.com/geospatial/catalog/smallworld_office.htm

³ Existing commercially available power analysis tool created by CYME - www.cyme.com/software/cymdist/

carbon technologies, such as distributed renewable generation, were modelled and again the results were as expected.

Conclusions and future work

The successful transfer of data from SSEPD's current GIS, through to Smallworld Electric Office and into CYMDIST, and the association of spot loads with dynamic profiles, is a proof of concept of the data flows required for the creation of the Network Modelling Environment in the NTVV Tier 2 project.

The project has proven that it is possible to provide the required functionality and has highlighted specific areas that need additional work to increase the automation, improve accuracy and has laid the foundations for the complete system. The intention is that these points will be addressed under the Tier 2 project which started in December 2011. Upon completion of the Tier 2 work, the system is expected to be rolled out across multiple areas of the distribution business. This project has shown the initial benefits of modelling and SSEPD would now place a high value on information systems with network analysis capabilities.

Intellectual property

The project made use of existing commercially available software products. It required the products to be adapted to enable integrated operation. The intellectual property (IP) developed through this activity relates to integration of a combination of systems unique to SSEPD and hence the specific integration code is unlikely to be relevant to other parties. The work completed to allow the transfer of data between the systems i.e. the data sets / data cleansing required to transfer the specific information and access to SSEPD staff know how etc. is available to other GB DNOs on request. Sharing this information will allow any other DNO to replicate the system using their existing software systems and does not constrain the DNO to using GE Smallworld or CYMDIST products.

The main benefits and knowledge delivered by the project relate to learning around the practical issues and considerations associated with integration of different systems to create a 'low voltage network modelling environment'. Details necessary to allow the project to be replicated by other GB DNOs are set out in the report. Any additional information required can be requested through jenny1.rogers@sse.com.

1 Project Background

The low carbon future will require fundamental change across the entire energy industry and its value chain. The anticipated changes in demand levels and load profiles will trigger challenges on the networks including voltage and thermal constraints. This will cause problems on the HV/low voltage network unless we can introduce solutions which are safe and able to be deployed quickly and sustainably to deliver more capacity on the network.

This tier 1 project aimed to identify, test, demonstrate and evaluate a low carbon network modelling environment for a selected small sub-set of HV/low voltage network in the UK. This project was designed to answer the following key questions relating to modelling and analysis:

- (1) What suitable Power Analysis Tools currently exist?
- (2) How can a DNO gain visibility of low carbon technologies being deployed which will affect the low voltage network?
- (3) Using Distributed Generation (DG) and Load Profiles, can an integrated geographical information system and network analysis tool identify network reinforcement requirements?
- (4) Will more accurate modelling and analysis of the network provide a sufficient assessment of the impact that DG has on the HV and low voltage networks?
- (5) Can this new modelling environment help identify optimum load-related cap-ex requirements?

In addition to providing a useful methodology to DNOs, this project also intended to provide a foundation for SSEPD's New Thames Valley Vision and provide learning to other LCNF Tier 2 submissions. The demand on the UK electricity network is expected to increase due to the anticipated installation of local embedded generation and low carbon technologies such as electric vehicles, solar arrays and heat pumps (ref: DECC Low Carbon Transition Plan).

The Local Authority in common with other councils and customers are now aiming to develop lower-carbon economies and are keen to promote and accelerate the installation of such technologies. As these technologies become increasingly mainstream, the rate of adoption is expected increase significantly. This will place additional strain on the HV and low voltage networks. At present, DNO's have little visibility of the deployment of low carbon technologies.

This Tier 1 project aimed to put in place the foundation for SSEPD's Thames Valley Vision LCNF Tier 2 project to develop a *Monitor, Model, and Manage* approach. This includes providing the opportunity to identify those Distribution substations where low voltage monitoring is or will be required and identifying the customers (by MPAN) who will most likely cause low voltage network load related reinforcement and/or demand management.

2 Scope and objectives

In order to evaluate the effect of embedded generation and low carbon devices on the HV/low voltage network, this project sought to demonstrate in a working environment a prototype capable of:

- (1) Recording and reporting on the deployment of low carbon devices;
- (2) Modelling the impact of deployed low carbon devices;
- (3) Managing multiple scenarios of low carbon low voltage networks;
- (4) Performing power analysis of these networks that includes distributed generation and load profiles. A comparison of different power analysis engines was included in this project.

3 Success criteria

The project success criteria were to analyse and report on:

- (1) The modelling and analysis capabilities of the technologies involved;
- (2) The delivered environment capabilities of analysing future scenarios, with estimated load profiles and distribution generation take-up, facilitating the identification of HV / LV substations that will most likely require reinforcement;
- (3) A low carbon network DNO reporting structure to Ofgem.

4 Details of the work carried out

4.1 Method trialled

The existing methods employed by distribution businesses across the UK to model the low voltage network are particularly time consuming, require significant user interaction and do not consider fully, new and emerging low carbon technologies. Figure 1 highlights the minimum data requirements to perform a basic network study with 6 customers connected. The user would need to obtain this information and enter it manually. It is clear that to capture the all data for a single substation with 500 customers connected would be significantly time consuming with high associated costs.

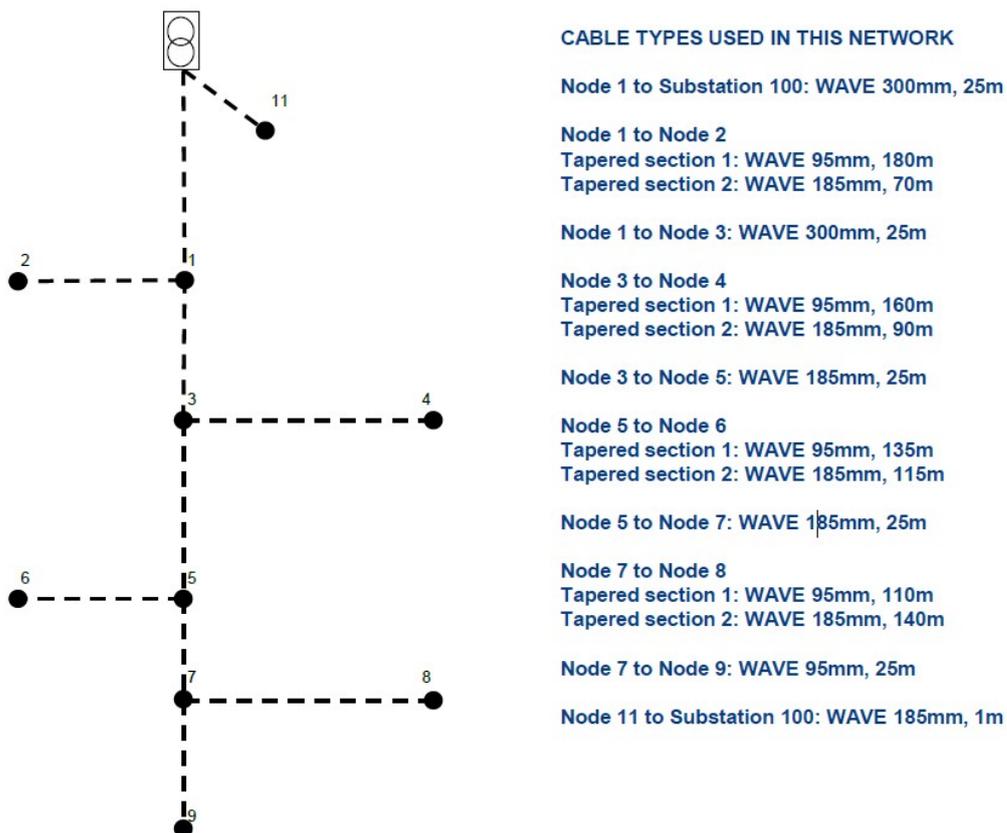


Figure 1- Existing power analysis tool data requirements

The main goal of the project was to overcome the existing issues and limitations of current network modelling methods. A critical task was to integrate the existing SSEPD information systems with Smallworld Electric Office, the CYMDIST electrical modelling package and load profile forecasts provided by the University of Reading. The intention was to create a prototype system that can complete the integration in an autonomous manner. The complete integration is referred to as the 'Low Voltage Network Modelling Environment' (NME) and is detailed in Figure 2.

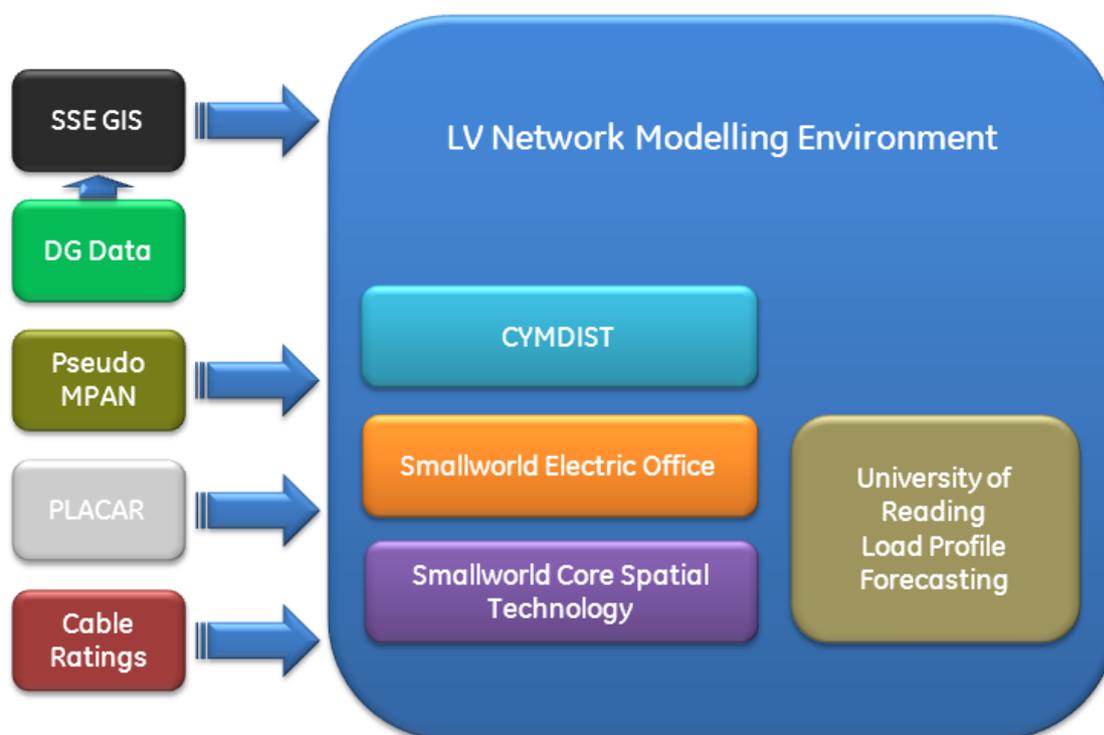


Figure 2 - Low Voltage Network Modelling Environment data sources and components

Low voltage Network Modelling Environment (NME) components

- **Smallworld Core Spatial Technology⁴** - the foundation Geographic Information System (GIS) platform
- **Smallworld Smallworld Electric Office⁵** - the Smallworld GIS application designed to manage electric network asset data, including the locations of customer supply points and Low Carbon Devices
- **CYMDIST⁶** - the specialised electrical modelling package, selected for use in the project after a rigorous evaluation process; detailed within appendix IV & V
- **University of Reading Load Profile Forecasting** – dynamic load profiles of existing and future demand on the low voltage network at customer supply points, based on the analysis of network and demographic data

NME data sources

- **SSEPD GIS** – Low voltage network connectivity data form SSEPD's existing Geographic Information System (see Appendices I and III for details of parameters of concern)
- **DG Data** - data on the locations of distributed generation devices such as PV and Wind from G83 notices (See Appendix II for a sample of the report run on generation within the trial area and the parameters of concern)
- **Pseudo MPAN** - data on the locations of customer supply points (during the course of the project the use of actual customer end point data was restricted due to our agreed data security policy) Address layer 2 TOID used as customer end point reference and location
- **PLACAR** - SSEPD's asset management system which supplied data on equipment specifications, primarily transformer ratings in kVA (see Appendix III for further detail)
- **Cable Ratings** - stored externally in spreadsheets / look up tables. The parameters of concern are cable impedance and continuous and cyclic current limits per phase (summer and winter values)

⁴ www.gedigitalenergy.com/geospatial/catalog/smallworld_core.htm

⁵ www.gedigitalenergy.com/geospatial/catalog/smallworld_office.htm

⁶ www.cyme.com/software/cymdist/

4.2 Trialling methodology

4.2.1 Overview

The main requirement of the project was to integrate the existing SSEPD GIS system autonomously with the Smallworld Smallworld Electric Office software. Upon successful completion of the integration to Smallworld Electric Office the network connectivity data had to be transferred to a suitable power analysis tool to perform required calculations. The results of the calculations e.g. load flow analysis, voltage drop etc then needed to be transferred back and displayed within the Smallworld Electric Office environment using a simple colour key to indicate network points out with limits.

The first task was to select a suitable area of the SSEPD low voltage network to perform the 'proof of concept' analysis. With the area selected the data from the existing SSEPD information systems had to be transferred in Smallworld Electric Office. The second part of the work was to select an applicable power analysis tool that performs the required electrical functions and is compatible with the Smallworld software. The chosen tool was then integrated with Smallworld Electric Office. The final task was to run some basic modelling scenarios to test and demonstrate the NME's capability to analyse load profile data to calculate and illustrate network impacts of different scenarios. This was based on customers' daily load profiles supplied from the University of Reading and also separately simulating low carbon technologies e.g. solar PV , heat pumps, electric vehicles. The profiles were then altered and increased, in order to push the voltage and thermal limits of the network in order to illustrate overload conditions.

4.3 Migration of Data to the Network Modelling Environment

4.3.1 Selection of the Trial Area

A test area of the low voltage network supplied from twenty distribution substations (11kV to 415V) in the Bracknell area was identified based on a typical mixture of domestic and light commercial customers. An initial migration of low voltage network data from SSEPD's current GIS into Smallworld Electric Office was carried out; 11kV data was also migrated to provide electrical context. Ordnance Survey MasterMap data was also loaded to provide geographical context and reference points.

For the data transfer to CYMDIST a single substation, World's End Hill, was chosen where monitoring equipment had been installed and therefore it would be possible to test the modelled network calculations of the power analysis tool against observed values.

4.3.2 Migration Approach

For the purposes of the project SSEPD provided the GE project team with a complete copy of the existing GIS database. In order to identify the extent of the low voltage network which needed to be migrated to Smallworld Electric Office; a series of network traces were run in the existing GIS from the substations in the study area. The network traces were then used to define a polygon representing the boundary of the area to be migrated. When the actual data migration was performed, the copy of the SSEPD GIS database was opened by the migration software in Smallworld Electric Office, and the entire low voltage network data inside the polygon was copied directly into the Smallworld Electric Office database. The integration methodology worked well and the time taken to perform a complete migration of the low voltage network in the project study area from the existing GIS to Smallworld Electric Office was typically no more than 20 minutes.

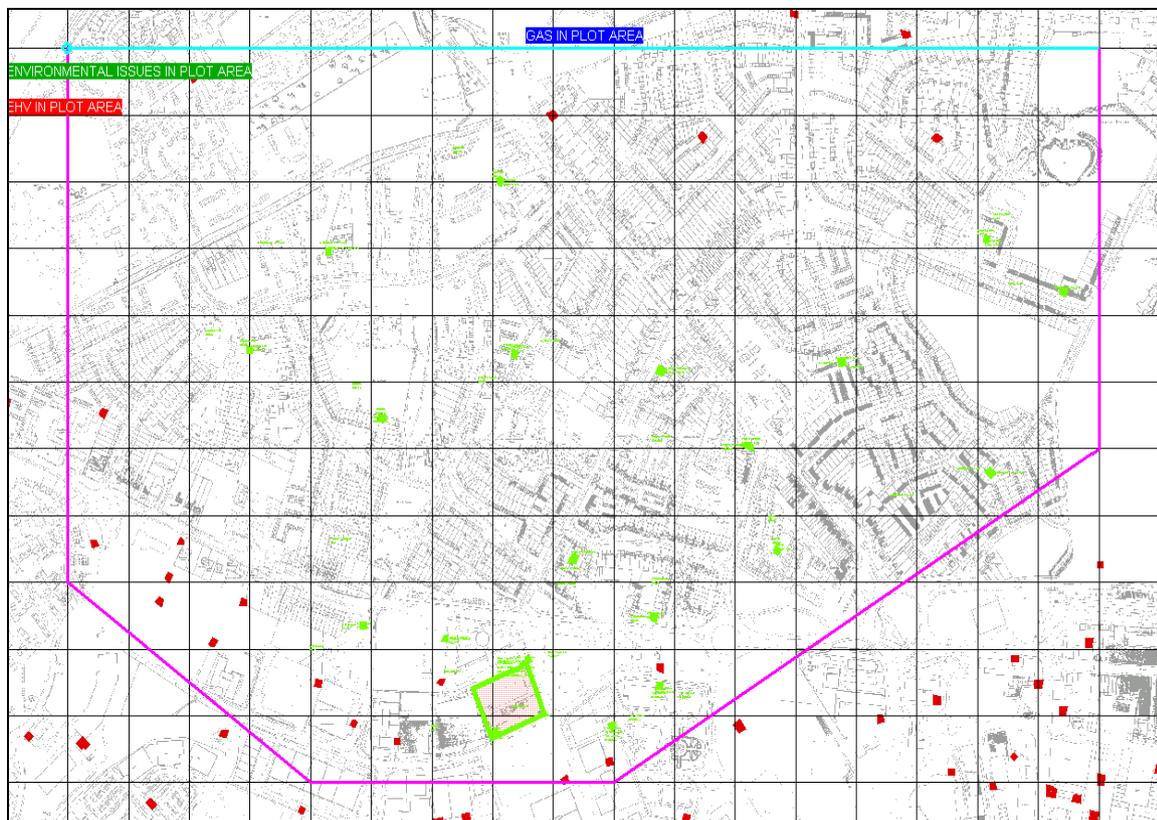


Figure 3 - Bracknell area selected for data transfer in GIS

The purple / blue line on the GIS screen shot (Fig. 3) is used to denote the selected area. The system could be used to capture all the data objects within the selection and transfer into Smallworld Electric Office for any part of SSEPD's network stored in GIS.

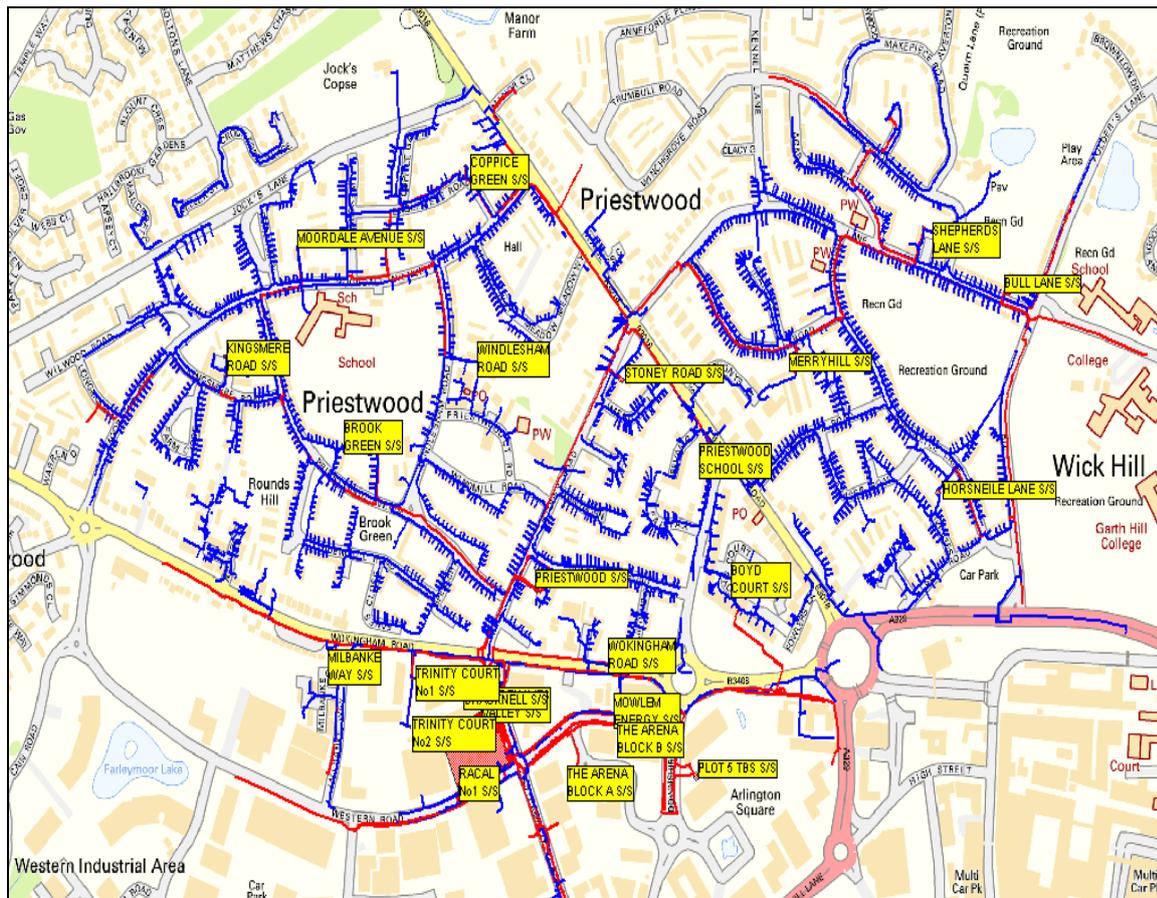


Figure 4 – Data transferred from GIS to Smallworld Electric Office

Figure 4 displays the data transferred from GIS into Electric Office; the data is referenced geographically using Ordnance survey MasterMap. The yellow boxes highlight the different distribution substations.

4.3.3 Data Mapping

The Smallworld Smallworld Electric Office low voltage network data model is substantially more complicated than in SSEPD's existing GIS: a single record in SSEPD's GIS often needed to be split across four or more records in Smallworld Electric Office. However, it was possible to map the GIS data to Smallworld Electric Office without introducing any new database tables. In general Smallworld Electric Office is a reasonably good 'fit' for SSEPD's GIS network data, in spite of having a far more sophisticated data model. Only a few small changes to fields in the Smallworld Electric Office data model were required to accommodate SSEPD's data, although in some cases data was mapped to 'notes' or 'remarks' fields as there was no obvious alternative. It is expected that the process used to perform the data migration at this stage will be refined in future developments of the system.

At present it takes approximately 20 minutes to migrate this area of 20 distribution substations and their associated low voltage feeder circuits. In this example there are approximately 5 feeders per substation, equating to 100 feeder circuits, with varying customer numbers, in total. If this were to be recreated manually in a standard modelling environment it could take up to 2 man hours per circuit, equating to 200 man hours in total if the associated network topology information was present. This begins to demonstrate the benefits of autonomously transferring data from existing information systems into a modelling environment as opposed to recreating networks manually.

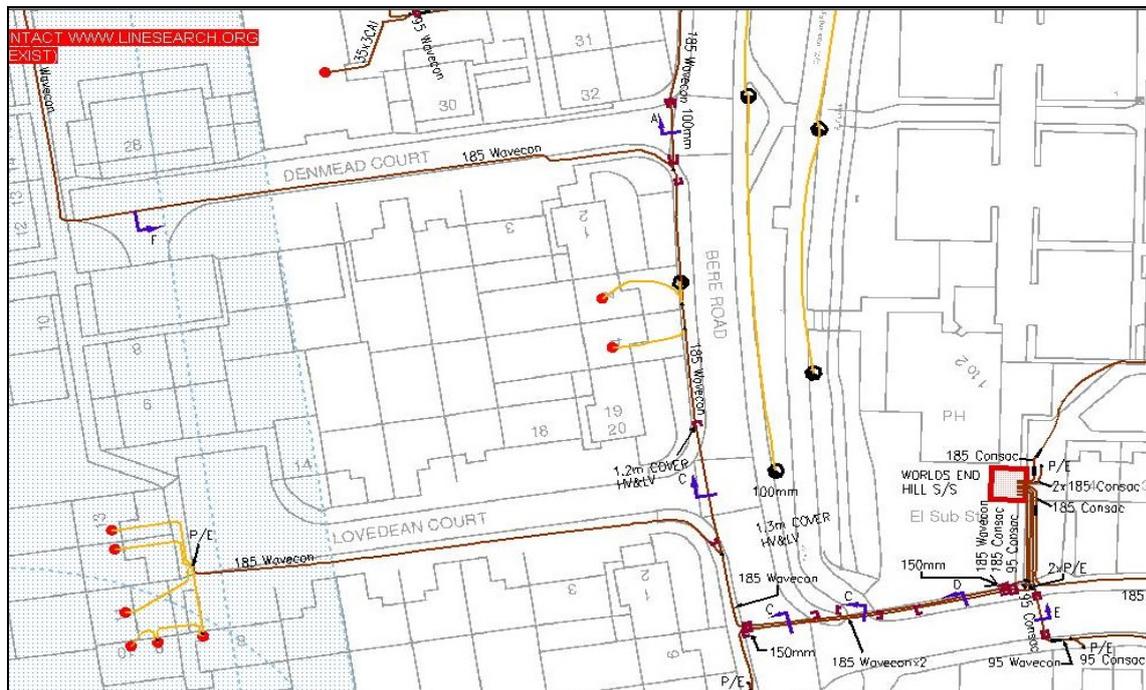


Figure 5 - Example of SSEPD's GIS system displaying a single substation, low voltage feeder cables and services

Figure 5 shows how a feeder is represented within our existing GIS – this is the view a current employee looking from cable information or wishing to investigate the low voltage network would see.

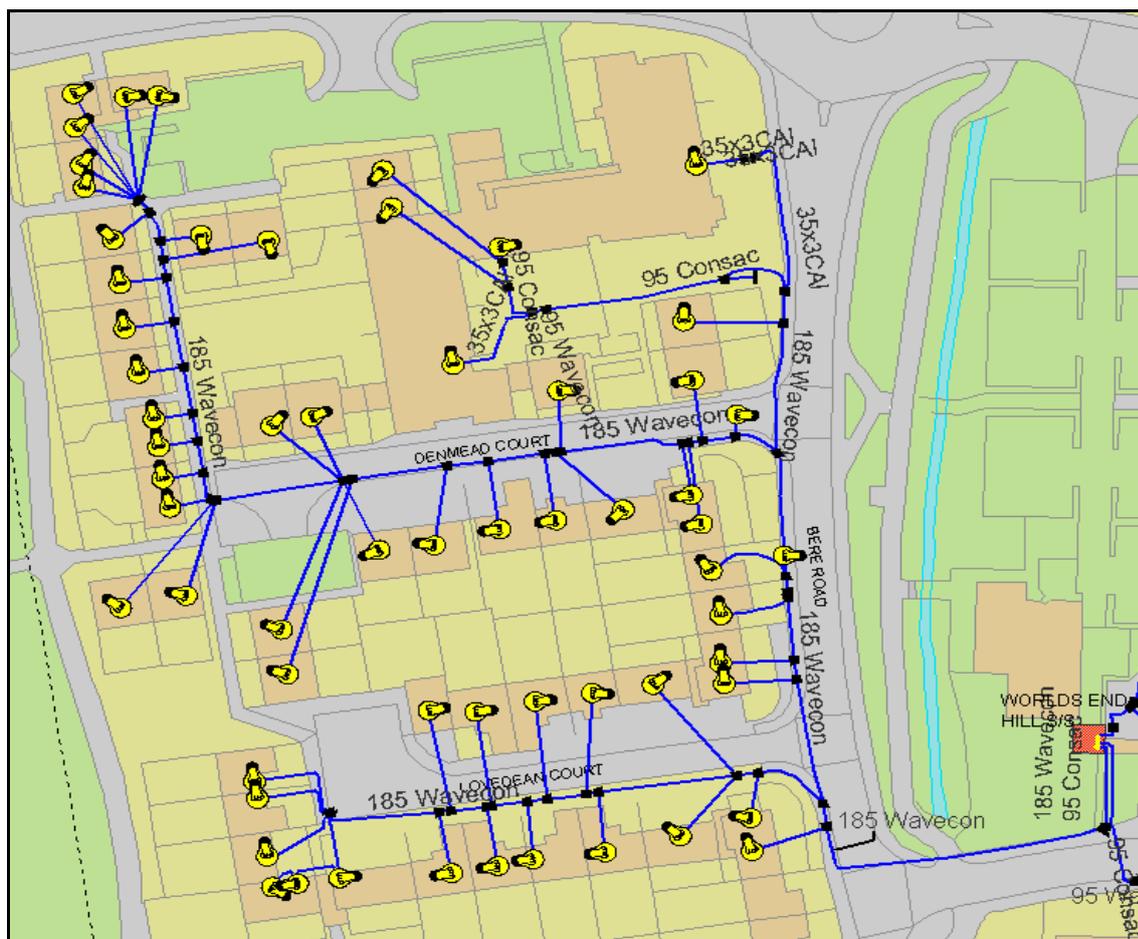


Figure 6 – The same area of SSEPD's low voltage network as shown in Fig. 5 migrated from GIS to Smallworld Electric Office

Figure 6 displays the GIS data migrated into Smallworld Electric Office –the display is very similar; however all the service cables are shown for each property. GIS only stores the known service cable information and does not link properties to each feeder circuit.

4.3.4 Data Cleansing

A critical and significant part involved in the migration was to understand the accuracy of the data being transferred. There were many parts involved in this data validation exercise – of particular importance were the cable types and subsequent current / impedance ratings. As the network has cables form the last 60 years this became a significantly larger task than anticipated. In addition to the vast number of different cables it was clear that there were errors in the cable entries e.g. consac instead of concentric cable. These errors had to be rectified before the data would be used with the modelling tool. The simplest way to do this was to do a sweep of records covering the 20 substations in Bracknell.

Cable types that appeared multiple times were considered legitimate – single records or low numbers were highlighted as suspected invalid. The complete set of cable types was validated by the particular expert within SSEPD and the invalid types altered accordingly. In cases of unknown the lowest rating was given to match that particular part of network. This style of data cleansing was repeated for multiple objects within GIS and proved successful. Although the actual data will be specific to our version of GIS – the process can be transferred to any parameters. This data is stored in spreadsheet format and will be made available on request.

To provide context for this example - the trial area which contained more than 850 underground cable records; 57 of these were unknown. This is approximately 6% that needed to have limitations applied that may have been lower than the actual cable capacity. It must be noted that this is a small sample size and may not be representative of the rest of the SEPD network.

4.4 Power Analysis Tool Evaluation

4.4.1 Evaluation Summary

The evaluation of three power analysis tools in order to select the most suitable tool to match the project requirements was carried out. A full and complete evaluation document which includes questionnaire responses from all three of the selected vendors can be found in the Appendix IV & V. A summary of this evaluation along with its main learning outcomes are detailed in the following sub-sections.

Three power analysis tools, as agreed between SSEPD and GE at the design stage of the project, went through a rigorous evaluation process during the last quarter of 2011. The three selected products and companies were: CYMDIST from CYME, Product x from Vendor x and Product y from Vendor y. The evaluation was carried out in three phases. Firstly via a questionnaire sent to each of the chosen vendors, secondly through a demonstration conducted by the vendors, and finally by a more practical test carried out by GE in conjunction with the vendors using evaluation copies of the products.

4.4.2 Questionnaire

There were 18 specific questions within the questionnaire which was broken down into in eight separate areas: Load Profiles, Embedded Generation, Batch Mode, Data Input, Data Output, Performance, GIS Linkages and Commercial Issues. These questions reflected the requirements that were deemed necessary to ensure the selected tool would support the power analysis capabilities of the Network Modelling Environment but also allow the project team to differentiate between each of the selected tools.

All three vendors provided responses to the questionnaire which were then assessed against strict evaluation criteria by three independent evaluators within GE and overseen by a representative from SSEPD. Each question was marked out of 10. In addition each question was given a weighting out of ten which reflected the relative importance of that particular question in the context of the evaluation. These were combined to give a final result.

The result of this evaluation concluded that the CYMDIST product best matched the specific requirements of the project. Vendor x ran a close second, almost matching the comprehensive functionality whilst the product from Vendor y lagged significantly behind in third place. The full evaluation can be reviewed in the Appendix IV & V.

4.4.3 Demonstration

The second phase of the evaluation was to invite all three vendors to give demonstration of their products with a focus on six specific objectives:

- Import of a circuit from an external file format
- Import of a 48 (24 hours) value dynamic load profiles for supply points
- Import of a 48 (24 hours) value generation profiles for an embedded generation location
- Demonstrate power analysis performance
- Demonstrate reporting of overloaded equipment, to an external file format
- Demonstrate an external way of driving all the above activities.

Vendor y did not respond to the invitation to demonstrate their product's ability to perform against the criteria and were therefore removed from the process at this stage. CYME and Vendor x demonstrated their products via Internet screen sharing. Each demonstration was marked out of 10 against each of the six outlined objectives. In addition to the functional objectives to be demonstrated three extra criteria were evaluated: Vendor Engagement, Product & Industry Knowledge and User Interfaces.

On completion of the demonstration evaluation process the CYMDIST product proved to meet the requirements most effectively. The areas in which it was considered to have exceeded the capabilities of Vendor x were: load / generation profile handling, external control of the power analysis tool, performance, vendor engagement and user interfaces.

It must be stated that although the CYMDIST product was the best fit for the requirements of SSEPD and the GE Smallworld Electric Office software, this does not mean that the other products for Vendors x & y could not perform the required task. It also must be noted that either of these products may be a better fit for information systems held by other GB DNOs.

4.4.4 Practical Tests

The third and final phase of the evaluation was a practical test of the data exchange functionality expected to be utilised for the NTVV Tier 2 project as this was considered a possible area of potentially high risk. A Common Interface Model extract of a small section of SSEPD network was produced from the portion of data that had been migrated from SSEPD's current GIS into Smallworld Electric Office. This was provided to each vendor with a request to load the data into their product and provide the data back to GE. Vendor y chose not to respond to this part of the evaluation. The outcome of the evaluation process was that the CYMDIST product supplied by CYME International was selected as the low voltage power analysis tool to be used on the project.

4.5 Network simulations

To prove the modelling tool operated as intended; approximately 50 different scenarios were run to simulate varying network conditions on a single feeder circuit at the chosen substation 'Worlds End Hill'. The scenarios incorporated daily load profiles for each customer connected to the network, supplied from the University of Reading⁷. The profiles were then altered and increased, in order to push the voltage and thermal limits of the network in order to illustrate overload conditions.

Demand / generation profiles were created for low carbon technologies (solar PV, electric vehicles, energy storage). These profiles were then included in simulations simply to prove the system could handle multiple profiles incorporating two way power flow e.g. at times generating more power than consuming at that particular customer connection point. The purpose was to prove the system had the required functionality to handle the half hourly profiles, not to complete analysis on the network impact of low carbon technologies.

The simulation results were then compared with actual values from low voltage monitoring equipment installed at the substation. The comparison was completed to help validate the modelling tool and hence prove that the system functioned in-line with expectations. This comparison was only made with a single point in time and did not prove the modelling was correct, it merely proved that the system had the functionality to handle the required customer profiles and model these with the network connectivity data.

⁷ The University of Reading are completing mathematical models to provide accurate estimates of customer demand.

More information www.reading.ac.uk/web/FILES/math/preprint_12_14_Haben_6Sept.pdf

5 The outcomes of the project

The outcomes of the project are defined under three main sections:

- The integration and migration of data between GIS and Smallworld Electric Office
- The integration of CYMDIST with Smallworld Electric Office
- Modelling performed with the inclusion of sample load profiles and low carbon devices to simulate varying network conditions

5.1 Data migration

5.1.1 Cable Information

The network topology (i.e. how the cables and overhead lines are connected) together with the type of conductor and its length are sourced directly from SSEPD's current GIS. Within this database cables are divided into two different type of design usage: Mains (c. 30%) and Services (c. 70%), with a further categorisation into: mains & major services; Services (minor); ancillary and unknown. An example of the information recorded for the first cable on feeder 1 of World's End Hill, the test site substation is shown below (Figure 7).

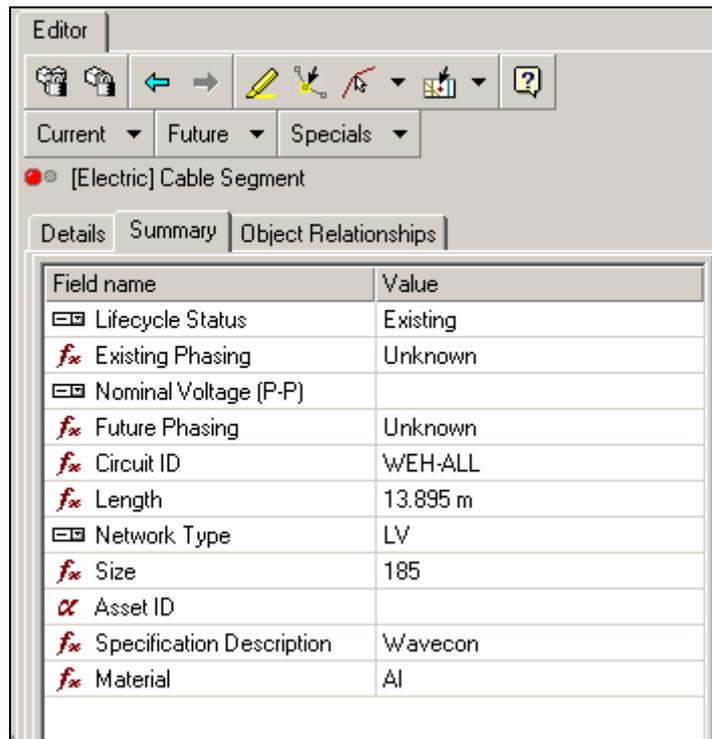
The set of screen grabs in Figures 7, 8 & 9 show data for the same piece of cable in the three information systems: SSEPD's current GIS, Smallworld Smallworld Electric Office and CYMDIST respectively. N.B. the values and parameters in these examples are test figures and may not represent the actual cable parameters.

The screenshot shows a dialog box titled "[Gis] LV Cable and Service editor". It contains the following fields and values:

Usage	[?]	mains & major services
Design Usage	[?]	Mains
Status	[?]	in use
Main Core Size	[?]	185
Number of Main Cores	[?]	3
Conductor Material	[?]	Al
Construction Type	[?]	Wavecon
Service Phase Colour	[?]	Not Applicable
Armouring	[?]	none
Tubed?	[?]	No
Number of Cables	[?]	Not Applicable
De-rating?	[?]	
Rn SI	[?]	none
Description	[v]	
Special Notes		
Calculated Length		13.89
Location	[color swatch]	[Set] [Clear]
Multi Text	[A]	[Set] [Clear] [left] [right]
Special Notes Text	[A]	[Set] [Clear] [left] [right]
Annotation	[v]	0
Assumed Routes	[v]	0
Pole/Towers	[v]	0 [Clear]
In Service?		

Figure 7 - Cable information stored in SSEPD's current GIS

The length of a cable and its specification are the two factors that determine its impedance which is essential for the load flow calculations. Within SSEPD's current GIS the length of the cable is calculated from the positional geometry stored for it, and the specification details are stored in a number of attribute fields. The Smallworld Electric Office product uses a different data model to SSEPD's current GIS, which is why the data transfer is a migration activity. This uses an installation phase asset modelling concept to separate the information specific to the electrical asset from its phase details and installation location.



Field name	Value
<input type="checkbox"/> Lifecycle Status	Existing
<i>fx</i> Existing Phasing	Unknown
<input type="checkbox"/> Nominal Voltage (P-P)	
<i>fx</i> Future Phasing	Unknown
<i>fx</i> Circuit ID	WEH-ALL
<i>fx</i> Length	13.895 m
<input type="checkbox"/> Network Type	LV
<i>fx</i> Size	185
<i>α</i> Asset ID	
<i>fx</i> Specification Description	Wavecon
<i>fx</i> Material	Al

Figure 8 - Cable Summary in Smallworld Electric Office

For this proof of concept project, data was transferred in a manual process. In future the data transfer from Smallworld Electric Office to the power analysis tool will be carried out using the Smallworld Electric Office - CYMDIST Interface. This is in the process of being extended from its current capabilities to deal with the low voltage network as part of the Smallworld Electric Office product roadmap. Smallworld Electric Office has some functionality to integrate with CYMDIST and this will be extended for future applications under the Tier 2 project. The additional work discussed here will become part of the GE Smallworld Smallworld Electric Office product and hence will be funded separately by GE themselves and not SSEPD.

Section Properties

Section ID: 51

Phase: A B C

Zone: UNDEFINED

Environment: Unknown

Devices: Add Remove

Nodes
Cable

Cable

Type: Cable

Number: 51

Status: Connected

Length: 13.895 m

Settings

Configuration

Cable Id: 185_AL_WAVECON

in parallel: 1

Nominal Rating: 320.0 Amps User defined

Summer: 320.0 Amps User defined

Winter: 356.0 Amps User defined

Summer Emergency: 100.0 Amps User defined

Winter Emergency: 405.0 Amps User defined

Equivalent Impedances

	R + jX ohms/km	G + jB μS/km
Positive Sequence:	0.195 + j0.0685	0 + j0
Zero Sequence:	0 + j0	0 + j0

Buttons: Collapse, OK, Cancel

Figure 9 - Cable information shown in CYMDIST, the power analysis tool

As shown in Figure 9 CYMDIST stores many additional cable parameters in comparison to the information systems, GIS and Smallworld Electric Office. The additional parameters are all fully configurable and are necessary to complete the network analysis. This work was completed as a manual process for each cable type within the trial migration area.

5.1.2 Equipment Ratings

The cable rating information came from SSEPD's current GIS, and SSEPD's document 'TG-PS-123', the Technical Guide for Load Ratings of Underground Cables. There is no requirement to use this information within Smallworld Electric Office, it is only required within the power analysis tool, and can be stored within the CYMDIST equipment database.

It was recognised during a project dissemination session that the cable ratings stated in TG-PS-123⁸ are quoted in Amps per phase, and that this may not be sufficient since neutral current

⁸ TG-PS-123 is an internal document to SSEPD – this information is available within the industry available document 'Engineering Recommendation P17 Current rating guide for Distribution Cables'

caused by phase imbalance may put the cable outside its thermal rating without exceeding the rating of the phases. This issue will be addressed further under the Tier 2 project.

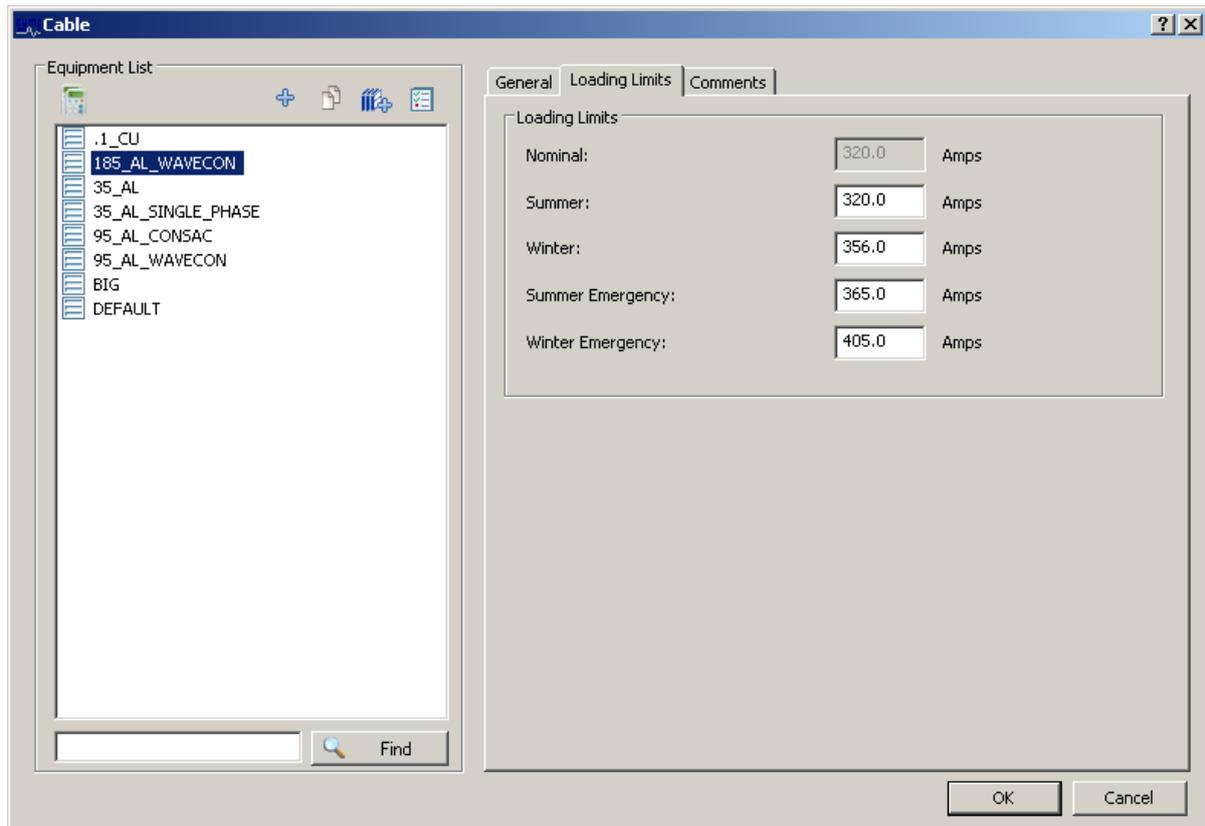


Figure 10 - The loading limits tab for a cable from the CYMDIST equipment database

As Smallworld Electric Office was used as the source of the network information for the power analysis tool a way of establishing the specification of a cable in the power analysis tool, which is part of the Smallworld Electric Office – CYMDIST Interface, was needed. Figure 10 illustrates how CYMDIST stores these parameter limits for each type of cable on the SSEPD network.

The transformer rating data comes from SSEPD's PLACAR system. The Data Migration Specification document (further details of this can be shared upon request) details the attribute level data transfer required from PLACAR to Smallworld Electric Office. Impedance data will also need to be sourced so it can be included in the CYMDIST equipment database for transformers.

Figure 11- The general tab for a two-winding transformer from the CYMDIST specification database

Figure 11 illustrates how the transformer data is stored within CYMDIST – again there are additional parameters, in comparison to our PLACAR database, required for the modelling and analysis.

5.1.3 Network End Points

The end points of the network are where the consumer load and small scale embedded generation will be modelled. It was important that these were connected to the low voltage network in order to be able to carry out the load flow analysis which was one of the main objective of the project. The supply point data in SSEPD's current GIS is split between Property, Street Furniture and Other categories, with the vast majority in the first group. The first issue was what to use as a proxy for customer end points, the second was how to connect them to the low voltage network? The phasing of loads at the end points is discussed in section 5.1.5.

5.1.4 MPAN

The Meter Point Administration Number (MPAN) data was expected to be available to the project at the design stage. This would have provided a unique reference point that could then be geo-located and connected to the low voltage network. The load profiles could then be associated

with the MPAN and be connected to the network passed from Smallworld Electric Office to the power analysis tool for the load flow calculations. Live MPAN data was not made available during the project as data protection / privacy issues were raised within SSEPD (an MPAN stores sensitive customer behaviour data with an associated address). Other options were therefore investigated, which involved examining the current data stored by SSEPD for customer and service cable locations.

It is intended that the discussed data security issues will be addressed under our Tier 2 work; the concern then is connecting the MPANs to the network as the only geographical information about an MPAN is its address. These addresses would then need to be geographically located in some way that would involve an address dataset that has a grid reference for mapping. 100% correct address matching could not be guaranteed meaning there would be either some manual intervention required to complete the matching, or a degree of unmatched data would have to be accepted. Although not currently utilising MPANs to locate meter points, the functionality has been provided to reference MPANs in this Tier 1 project to support the future work under the Tier 2 project.

5.1.4.1 Address Layer 2

The solution utilised for this proof of concept Tier 1 project was Address layer 2. Address Layer 2 is part of the Ordnance Survey (OS) MasterMap product suite, and provides geographic coordinates for addresses in Great Britain. This can be used as a proxy for the customer location and be associated with the load profiles supplied by the University of Reading that will be stored in the CYMDIST Energy Profile Manager. The Address Layer 2 data comes with a point geographical location for each address that enables them to be mapped in a GIS. This location can be connected to the network in the GIS data migration phase of the project. An alternative to Address Layer 2 would be to use the latest similar product from the OS, Address Base. SSEPD do not currently use this data but have been discussing its adoption for their mapping purposes with the OS.

5.1.5 SSEPD Service Cable Data

The service cable data in SSEPD's current GIS are for the most part assumed routes. That is the end point (a consumer address) is generally connected via a straight line to the nearest mains cable that has a known route. The split between assumed and confirmed supply points are approximately a 3:2 ratio. Looking at feeder one on World's End Hill substation the vast majority of the service cables are assumed, although there are two near the annotation of Bere Road that are not straight and are therefore not assumed (shown in Figure 6)

SSEPD are in the process of executing Positional Accuracy Improvement activities and have decided to remove all the assumed service cables; as both the mains to which they are connected at one end and the consumer end points at the other have been moved. In order for the power analysis tool to have approximate length data for the service cables they will need to be created as part of the migration process from SSEPD's current GIS into Smallworld Electric Office.

The service cable data needs to be added to the low voltage network where it does not exist in order for the customer load and generation locations to be connected and therefore included in the load flow analysis. However, it is the aggregation of the load and generation data over the whole of the network analysed and the lengths and specifications of the low voltage mains where the combined loads are flowing that is the primary focus of the analysis. Presently cable failures due to overloading are more likely to occur near the substation than near the consumer. It is these situations that the NME is expected to identify as potentially requiring reinforcement or reconfiguration to avoid forecasted overloading not the service cable level.

5.1.5.1 Phase Information

The service cables stored in SSEPD's current GIS are often assumed, and even where they are not there is no information to indicate what phase single-phase cables or consumers are on. Thus a phase allocation strategy is required as the load flow calculations are carried out on a phase by phase basis.

5.1.6 Phase Allocation Strategies

As accurate information as to which phase a customer is supplied from was not available a strategy to make assumptions was required. For the purposes of the proof of concept the balanced rotational system was employed.

Balanced Rotational - Assuming a balanced network, the consumer end points can be allocated in a strict rotation: Red, Yellow, and Blue. This simple phasing allocation strategy could be incorporated into the migration process if it is the one chosen to be applied, and would need to be done in conjunction with the service cable creation activity.

Maximum Demand Indicator Proportional - The Maximum Demand Indicator (MDI) data is available on a phase by phase basis at each distribution substation. The consumer end points can be allocated to the different phases in proportion to the MDI of each phase at the substation for all of that substation's feeders. The MDI data records the highest demand on a phase since the indicator was last reset. It does not record when this value was reached, or what the demand

on the other phases was at that time. To use this information for phase allocation the number of end users for each phase would be proportionally calculated using the ratio of the three MDI values to each other. To implement such a phase allocation strategy the MDI for each substation would be required and an allocation procedure written as part of the migration process.

The phasing of an end point is an attribute that can be stored within Smallworld Electric Office, and is available to be edited by the users. SSEPD will therefore be able to overwrite the allocated data where actual customer phasing data becomes available which it should do from the monitoring part of the Tier 2 project. Data augmented in this way will be extracted to the CYMDIST when the user carries out load flow analysis with the Network Modelling Environment.

5.2 Trialling of the Network Modelling Environment

A key focus of the project was the demonstration of the Network Modelling Environment, consisting of an integration of Smallworld Electric Office and CYMDIST. This section summarises how this integration was achieved, and describes how the NME can be used for the analysis of demand / generation on the low voltage network.

5.2.1 Network Topology

The way that Smallworld Electric Office and CYMDIST handle the topology of the electricity network is different as the two systems model the network for different purposes. Smallworld Electric Office is primarily driven by asset recording requirements, while the CYMDIST power analysis tool is focussed on electrical calculations. In Smallworld Electric Office a cable is broken into segments where the attribute characteristics of the cable change, which means that in general it stores larger sections than the power analysis tool which splits cables up wherever there is an electric connection.

5.2.2 Smallworld Electric Office – CYMDIST Integration

CYMDIST uses a flexible database structure with the ability to keep the three different types of data, Network, Equipment specifications and Load Profiles, in separate databases. As the NME is expected to store large amounts of load profile forecasts from the University of Reading then a scalable database was utilised. The static equipment specification data can be held separately from the network data so just a shared single copy can be used in conjunction with the individual network databases that are created for analysis purposes.

5.3 Load Flow Analysis

The primary objective of the Network Modelling environment is to analyse the performance of the low voltage network under various operating conditions. Apart from changing the configuration of

the network, or the characteristics of the equipment and conductors, the user may wish to investigate any forecasted change in demand or generation. In order to do this the Energy Profile Manager provides a variety of options within CYMDIST to carry out load flow analysis:

1. Single Time

This option allows the user to specify a particular time, on a particular day either in the past, present or future and perform the study using the load and generation profiles stored for that moment. Invoking this option causes one study to be run.

2. Peak Demand

This option allows the user to specify a time range, a study is then run at the point in time when the network experiences peak demand.

3. Time Range

The user specifies a time range that can span multiple days, and a study is run every 30 or 60 minutes for the duration of this period. This results in multiple studies being performed, and a report being produced that documents the performance of the network over the specified time period.

5.3.1 Management of Multiple Network Scenarios

A user may wish to reconfigure the network in order to create a future network state on which to carry out load flow analysis on. Both Smallworld Electric Office and CYMDIST have facilities for modifying the network which are discussed below:

Designs in Smallworld Electric Office

Smallworld Electric Office allows users with the appropriate access rights to create designs within which they can make changes to the network. These changes are unique to that design, and do not affect the as-built view of the network. The user can also create alternate designs that could be used to investigate the feasibility of different approaches to deliver the same service. The user can choose which version of the network to send to CYMDIST by navigating to the appropriate design and choosing the portion of the network they wish to be included in the analysis. The use of designs to store different configurations of the low voltage network allows users to compare these different approaches and establish which is the most resilient or cost effective. Once the preferred approach has been decided the changes in the design can be incorporated into the as-built record of the network, at which point the contents of the design become visible to

other users of the system. Alternatively if the design is not going to be constructed then it can be deleted without the contents being introduced into the as-built record.

Study Files in CYMDIST

CYMDIST adopts a similar approach to the designs used in Smallworld Electric Office by providing the user with the ability to make local changes that do not affect the original version of the network. CYMDIST allows the implementer to separate the data into logical partitions. It is anticipated that the electrical characteristics of conductors and equipment will reside in the equipment database. This data is relatively static, and only needs to be updated once new equipment becomes available. Once a portion of low voltage network is sent to CYMDIST for analysis the topology of the network and location of equipment will be stored temporarily in the network database. If the user were to interact through the CYMDIST user interface they would be able to modify the network, and save these changes as a study file without affecting the original version in the Network database. Similarly the user can update the Network database with these changes if required.

5.3.2 Results Presentation and Thematic Mapping

Through the CYMDIST user interface one can:

- Select a section of network and investigate the results of the study using the Results Box, which can be configured to display any of the electrical characteristics available in the product
- Colour code the network according to characteristics of the network (e.g. cable type, loading level of the conductor etc.)
- Display tags that appear relative to the network element describing some user-defined aspect of the element
- Produce tabular reports and charts

The primary parameters modelled for in this project were current (% of maximum rating, by cable section) and voltage (at any given point on LV network).

5.3.3 User Interaction Summary

Through the experience gained with Smallworld Electric Office and CYMDIST and the ways in which they can be integrated, the expected user interaction process within the NME is:

- 1) The user chooses a circuit on which to conduct load flow analysis. Optionally they can also choose to reconfigure the low voltage network in Smallworld Electric Office. This is

the manual editing of the infrastructure, e.g. opening/closing switches, changing equipment specifications, connection of new load and/or generation locations to the network. Smallworld Electric Office will then create circuits from the new network configuration

- 2) The user chooses a date / time for the analysis. As the University of Reading load profile forecast work for the Tier 2 project develops then the user will also be able to choose from different forecasting scenarios that will be provided
- 3) The network data of the circuit of interest is passed to CYMDIST using the GE Smallworld Smallworld Electric Office – CYMDIST Interface product. This network data will have the equipment specification identifiers within it that will allow CYMDIST to use its equipment database to establish the loading limits that the network is capable of handling
- 4) A load flow analysis is carried out using load and generation profiles which are stored in the CYMDIST Energy Profile Manager, the load profiles are linked to the spot loads on the CYMDIST representation of the low voltage network by a shared reference number
- 5) CYMDIST will create a report on any abnormal conditions identified by the load flow analysis. This information can be returned to Smallworld Electric Office and a thematic map displayed to the user. The current thinking for this is that a simple “traffic light” map be produced showing the user green network where the load on the network is forecast to be within the equipment’s capabilities, red where it is not, and amber where there is a possible issue
- 6) The user may then wish to repeat the process for the same section of network or another one, returning to step 1

5.4 Trialling of the Modelling of Low Carbon Devices

This section discusses how the Network Modelling Environment has modelled low carbon devices in order to integrate them into power analysis with associated load / generation profile data.

5.4.1 Geographical Modelling

DNOs must be notified of new generation equipment connected to the electricity network (although in some cases this process is not always followed). Generation is covered by the documentation of Engineering Recommendation G83/1, and the information sent to the DNO by the householder or their installer - usually known as a G83 notice. SSEPD currently store such notifications in our Supply Interruption Management System (SIMS), but the quality of this data is understood to be low, both in terms of coverage and accuracy of recording. Appendix II illustrates the SIMS interface for storing generation data and also a sample of the report run for the substations within the trial area.

Moving forward the intention is to modify the current GIS to store the generation data so this can be included in the data migration to Smallworld Electric Office, and therefore in subsequent data transfers to CYMDIST for inclusion in the load flow analysis.

5.4.2 Power Analysis Modelling

Within CYMDIST low carbon devices can be modelled in two ways. Firstly, generic generator objects can have a generation profile attached, or secondly there are individual objects e.g. Photo-Voltaic and Wind Turbine objects which are designed to model specific characteristics of these devices. This functionality allows the user to very quickly add a generation profile to a single meter point or a larger array. This would theoretically allow the system user to quantify the effects of solar generation on, for instance, 50% of the properties on a particular feeder.

CYMDIST has a module called the Energy Profile Manager (EPM) which is described as “a planning tool that allows users to perform time range analysis based on a combination of historical consumption patterns and real-time monitoring”. Profiles can be stored for: Customer Types, Metered Loads, Generators, Metered Demands and Network Demands, of which the first three of these are of most interest. Generically these profiles can be stored at intervals of 5, 10, 15, 30 or 60 minute intervals, or there is the facility for lower levels of granularity to be used and for different months or seasons to have particular daily profiles. The EPM has functionality for displaying the load profiles by date for a specific day as a graph, or a chosen month in a calendar format. The actual values can also be inspected and edited. This calendar functionality of the EPM is designed for storing historical data, but it can also be used to store forecasts of future loads.

5.5 Load Profiles

The spot loads at the customer end points where loads will be attached to the network can have load profiles related to them in two ways. A spot load within CYMDIST has its own unique ID which can be associated with a unique profile, but it can also have a Customer Type and so be associated with a profile shared with other spot loads of that type. This provides flexibility in the way that the University of Reading will be able to provide forecasts, although it is currently expected that their forecasts will be at the individual level, it may be that forecasts are made for categories, and that multiple spot loads belong to a category. The upcoming rollout of smart meters is expected to greatly increase the level of consumption information that is available to DNOs, and therefore the ability to carry out accurate analysis with that data.

A load profile for a day is shown in the screenshot in Figure 12. This example has 24 hourly values, but the Energy Profile Manager can go down to a periodicity of 15 minutes, however the

data provided moving forward will be 30 minute averages, as this is what will be available from the UK smart meter rollout. The example shown is for a category called “RESIDENTIAL”, so this is in the Customer Type Profiles group on the left of the screenshot. As many other categories as required can be added here. The group below this, Metered Load Profiles, is where the individual spot load IDs would have their profiles stored, and below this is Generator Profiles which are discussed in the next section.

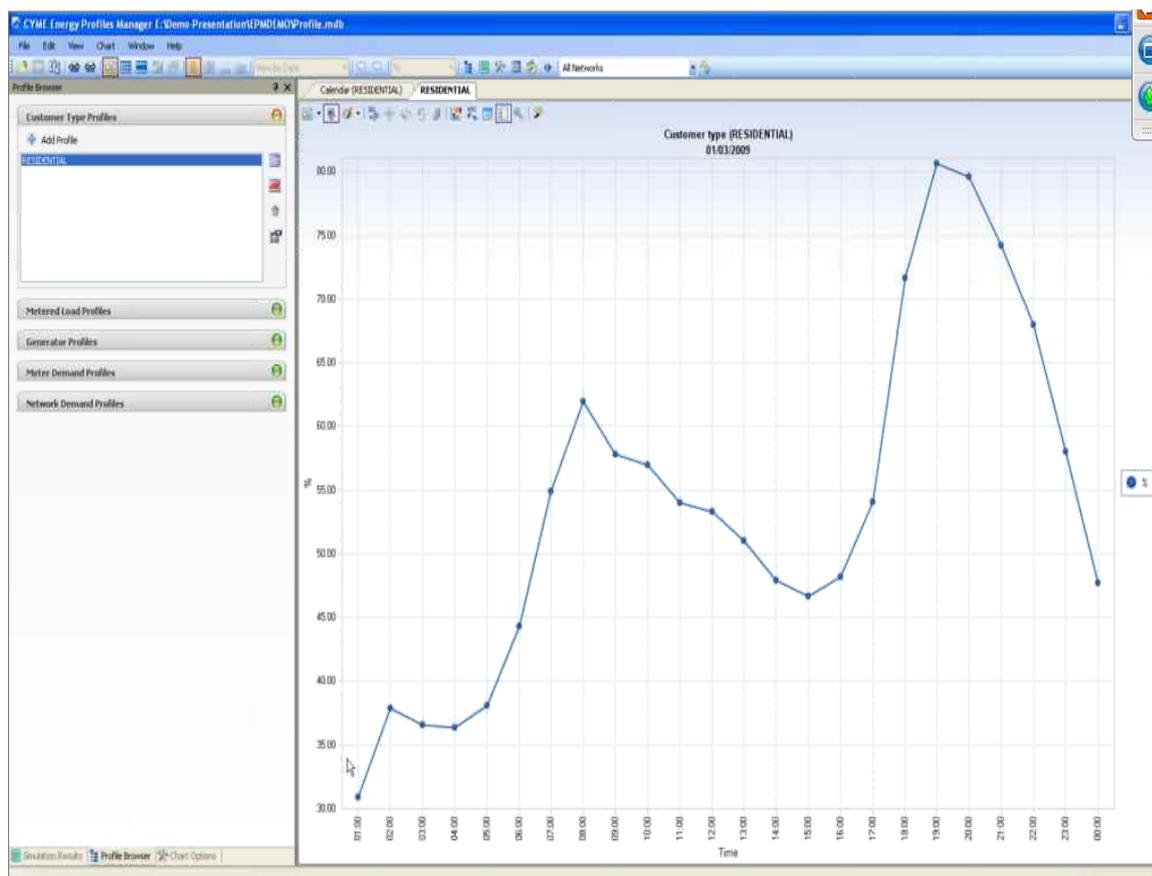


Figure 12 -CYMDIST – Energy Profile Manager – 24 Hour Profile load profile

The calendar tab allows a month of profiles to be viewed (Fig. 13).

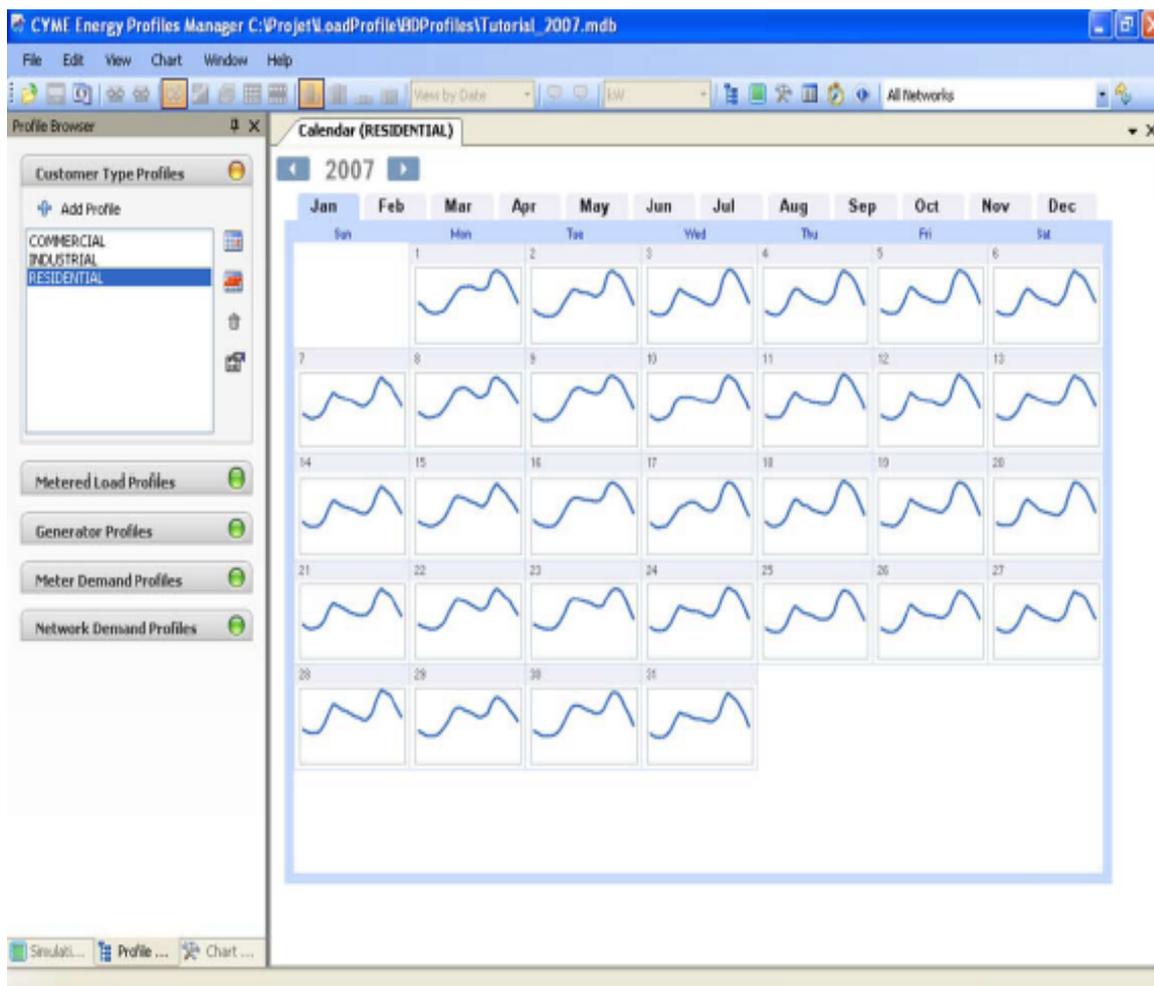


Figure 13 - CYMDIST – Energy Profile Manager – Calendar View

In order for the load flow analysis to be carried out using profiles, the spot loads that are created in CYMDIST, to represent the customer connections, need to have a common identifier provided by the University of Reading and stored in CYMDIST. In the proof of concept this was done using the Address Layer 2 Topographic Identifier (TOID).

5.5.1 Generation Profiles

Generation profiles in CYMDIST are handled in a similar way to load profiles. Generation devices such as PV or wind turbines can be modelled as Electrically Coupled Generators and each will have a unique ID that can be associated with a generation profile stored in the CYMDIST Energy Profile Manager database. The output of the generation device will then be taken into account when the load flow analysis is run. A single customer supply point could potentially have several different generation profiles associated with multiple generation devices. Generation profiles can have negative values. This would indicate that the device is actually drawing from the network

rather than adding to it, for instance energy storage devices such as batteries which both generate and absorb energy.

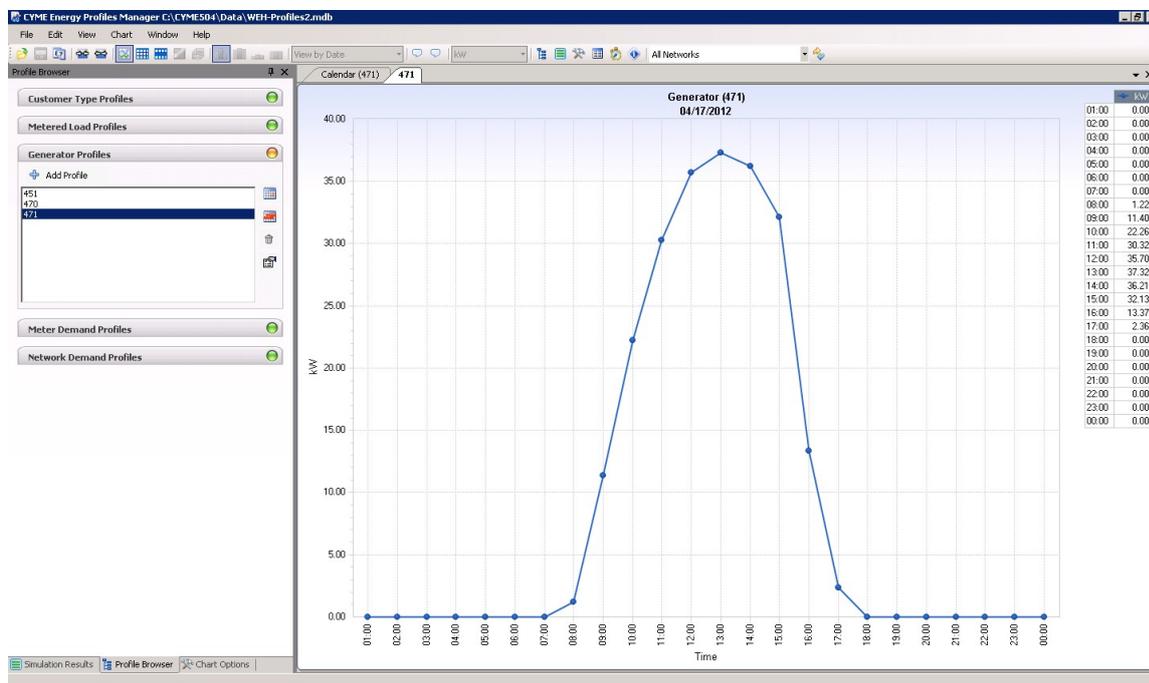


Figure 14 - Solar generation profile stored in CYMDIST

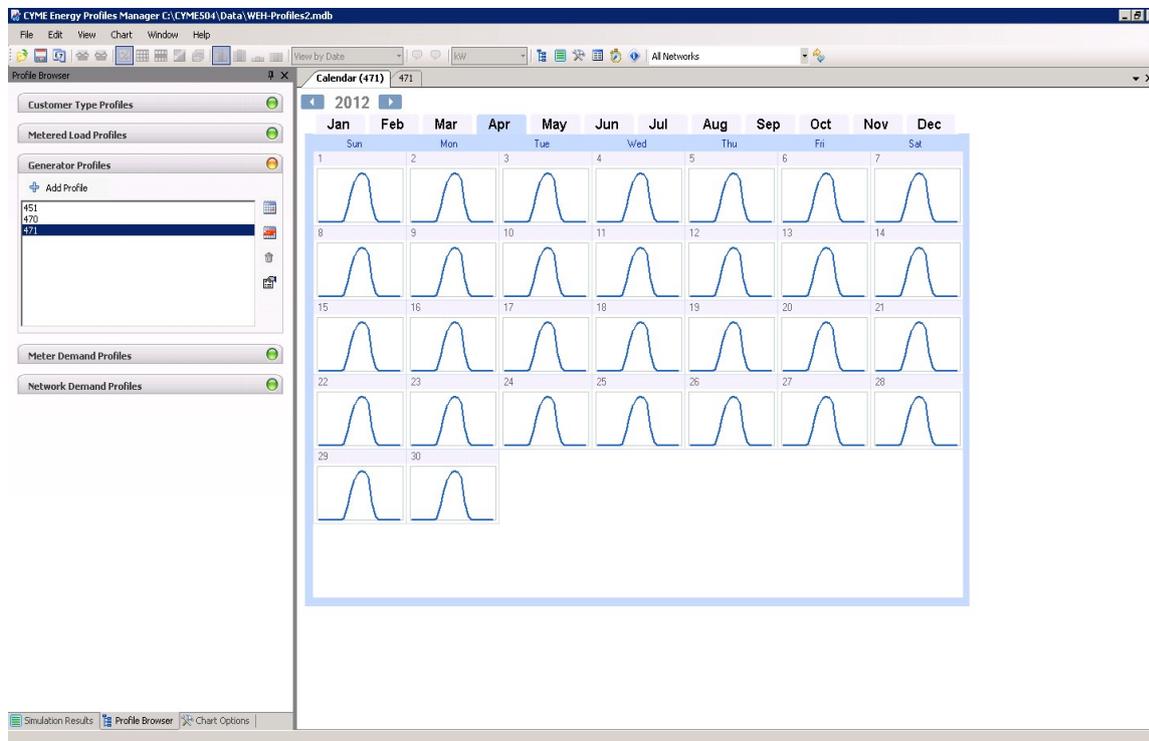


Figure 15 - Example of a month of generation profiles

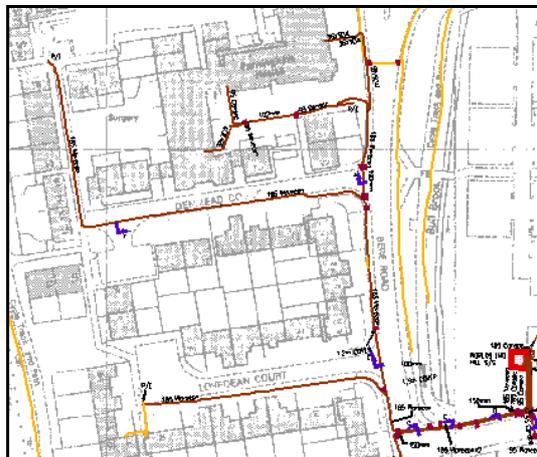
The image in Figure 15 is clearly not representative of a typical generation profile in the UK, the purpose was to illustrate that the system has the functionality to handle multiple profiles. The load profiles are fully configurable and can incorporate differing generation types, weather and seasonal variations.

5.6 Practical Application

A number of successful outcomes were achieved by the project along the path to creating the fully automated Network Modelling Environment in the Tier 2 project. Data was successfully automatically migrated from SSEPD's existing GIS into the Smallworld Electric Office, and displayed with Ordnance Survey MasterMap background. From Smallworld Electric Office the data was transferred to CYMDIST to run analysis and brought back to Smallworld Electric Office.

An initial study area of the twenty substations was migrated, followed by part of another substation, World's End Hill. The first migration established that the process could be achieved. This will be built on for the Tier 2 project migration, and will be used to augment the data by making the customer network link so the spot loads in CYMDIST can have unique identifiers. The second migration was carried out in order to be able to use data from a substation where monitoring equipment was installed. Data was semi-manually migrated from Smallworld Electric Office to CYMDIST, this allowed SSEPD personnel to experience the data in the power analysis tool, and for studies to be run.

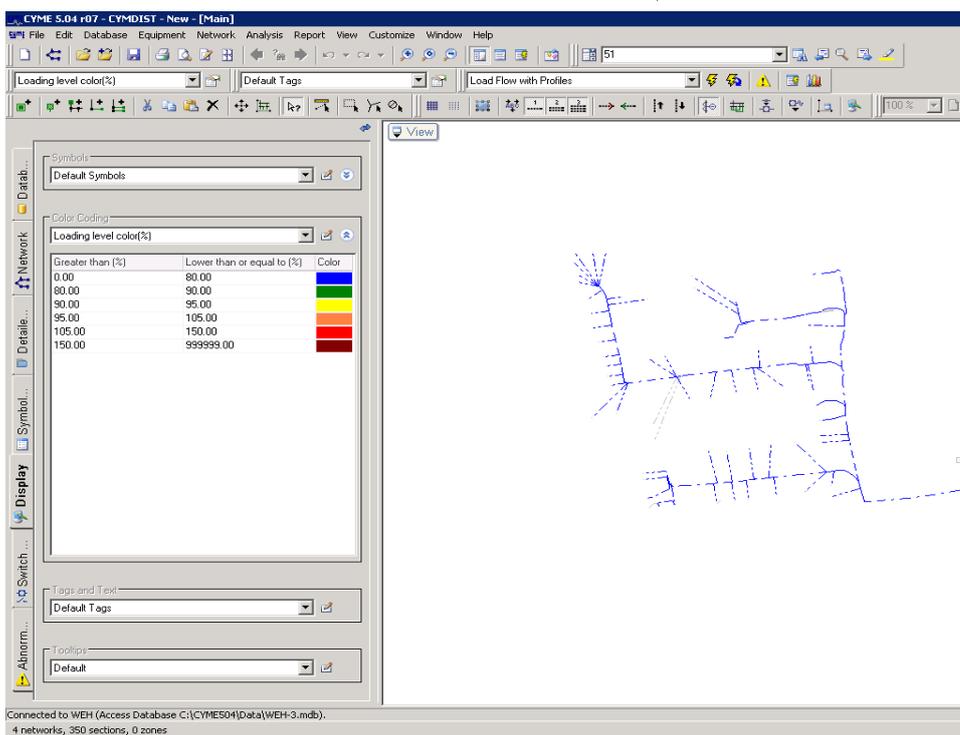
The image in Figure 16 shows on a simplistic level how the data is moved from each system. The data transfer between our GIS and Smallworld Electric Office is fully automated and takes about 1 minute to migrate a single distribution substation. This is a single transfer of data flowing in one direction. The link between Smallworld Electric Office and the modelling environment is a manual process; the data flows into the modelling software, the required calculations are performed and the data is returned to Smallworld Electric Office. To model a single feeder circuit takes approximately 30 seconds within the modelling environment.



SSEPD's current GIS



Smallworld Electric Office



CYMDIST

Figure 16 - The same low voltage feeder circuit shown in the various system interfaces



5.6.1 Results

The system ran multiple scenarios using estimated customer load profiles provided by the University of Reading for a feeder based on previous research. The profiles provide a base for the differing scenarios to be built from and at the same time help to validate the work University of Reading are completing through comparison with actual monitored values. These were provided in a '.CSV' format that was manipulated into the CYMDIST ASCII format and imported into the Energy Profile Manager module of CYMDIST. Power flow analysis was carried out on the feeder using these load profiles, and also some modifications of these profiles to test failure scenarios.

All the modelling detailed in this section concerns the thermal and voltage limitations of the network plant. The colour key highlights the cable sections outwith the set thermal limit in amps per phase e.g. light red is approaching 95% of the limit red is 125% and brown is more than 150% of the current limit.. The voltage can be viewed at any point on the network and can be configured with limits of volts per phase. On these examples the colour key related to the thermal cable boundaries of the network infrastructure.

The CYMDIST screenshot in Figure 17 shows a single feeder from the World's End Hill substation thematically mapped for the forecast loads at 20:00 on April 17th 2012. The majority of the network is below 50% of its rated capacity, with just the cables between the substation and the first branch in the 50-80% capacity band. The University of Reading load forecasts were manipulated to show an across the network increases of 50% and 100% in load. With a 50% increase the network would still cope, but with a 100% increase in load those same cables from the substation to the branch would be at 105% of their rated capacity.

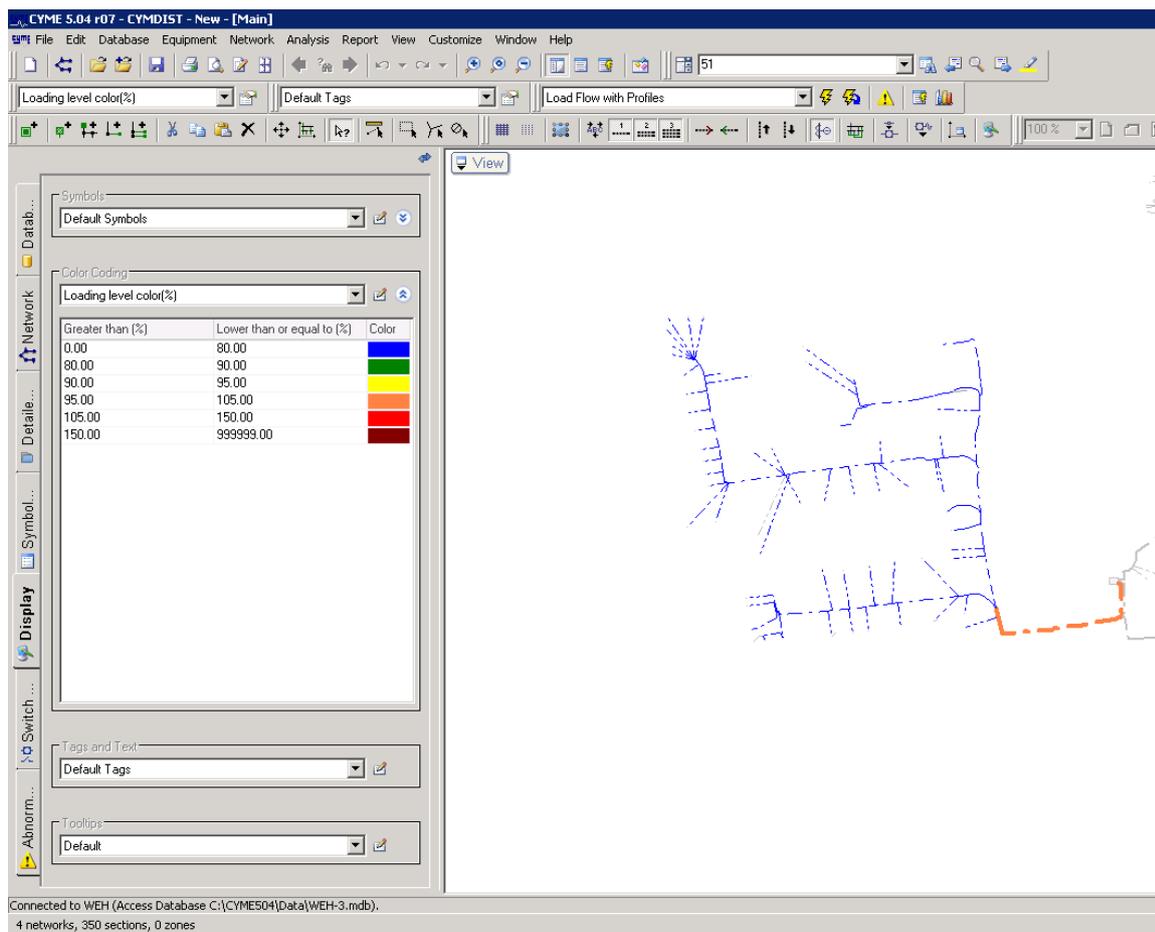


Figure 17 - -17th April 20:00 Forecast Network Loading 50% increase

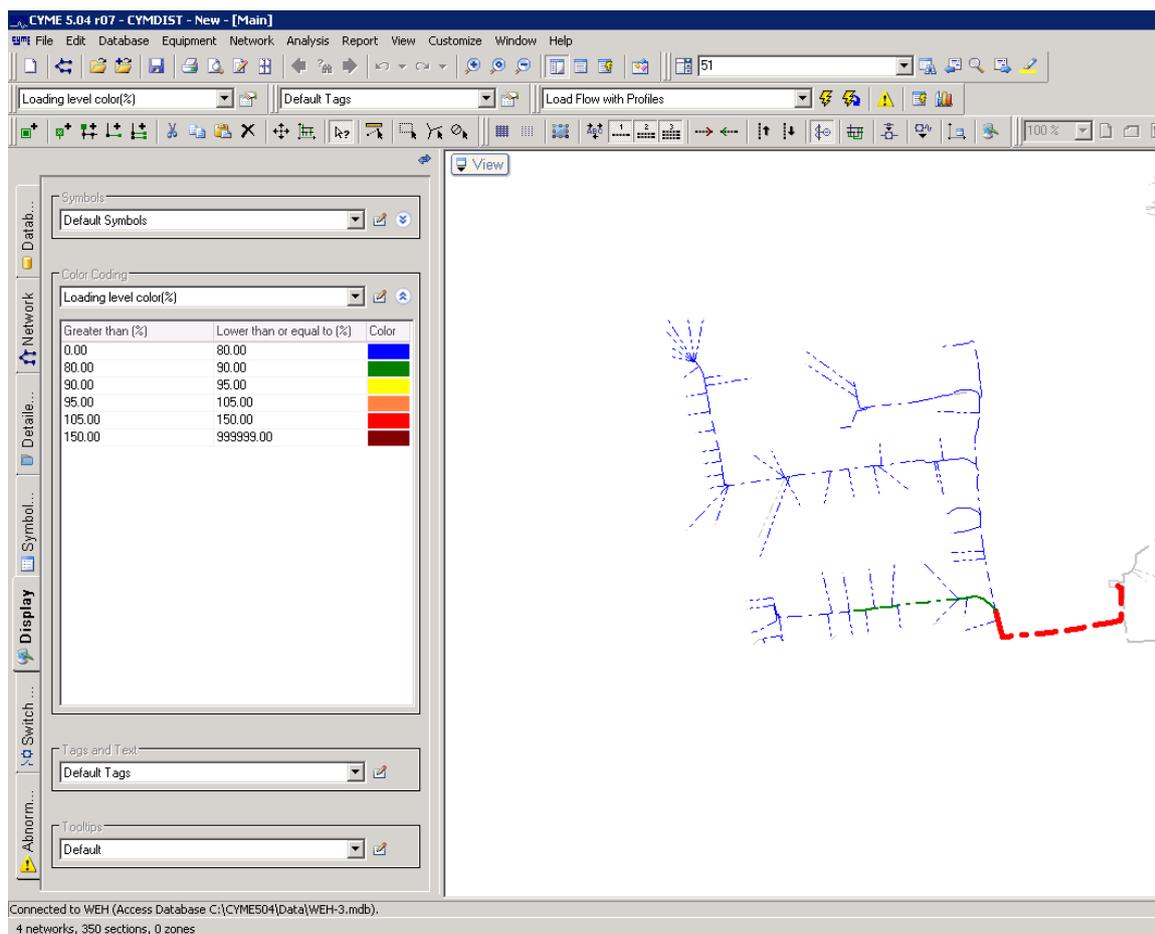


Figure 18 – CYMDIST -17th April 20:00 Forecast Network Loading 100% increase

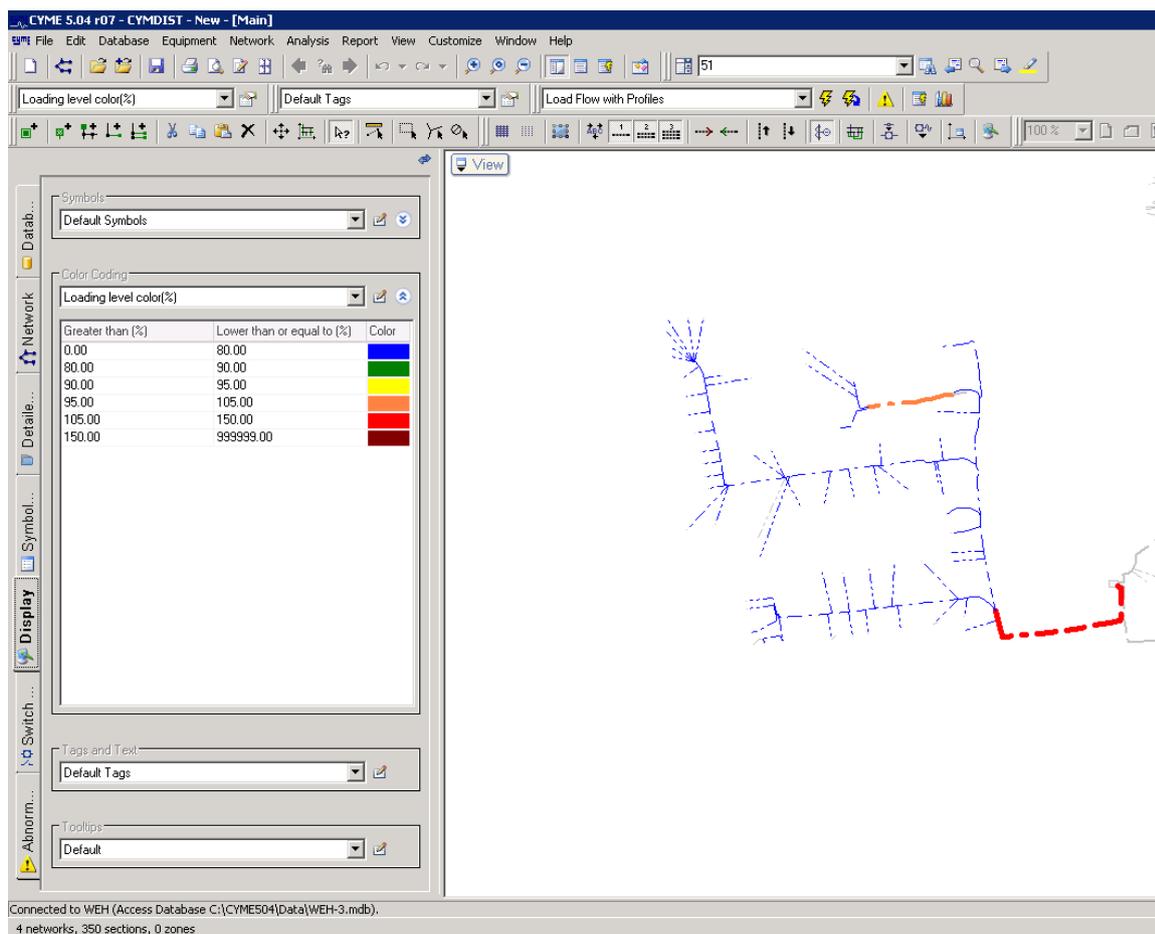


Figure 19 – CYMDIST -17th April 20:00 Forecast Network Loading - adding to the loads just at Farningham Hall

The modelling illustrated in Figures 19-20 shows the implications of adding additional loads in a specific location. This would be representative of a new connections application received by the distribution business. The new load clearly displays that the network would be over the limit near to the substation and approaching the limit close to the point of connection represented by the red and orange sections.

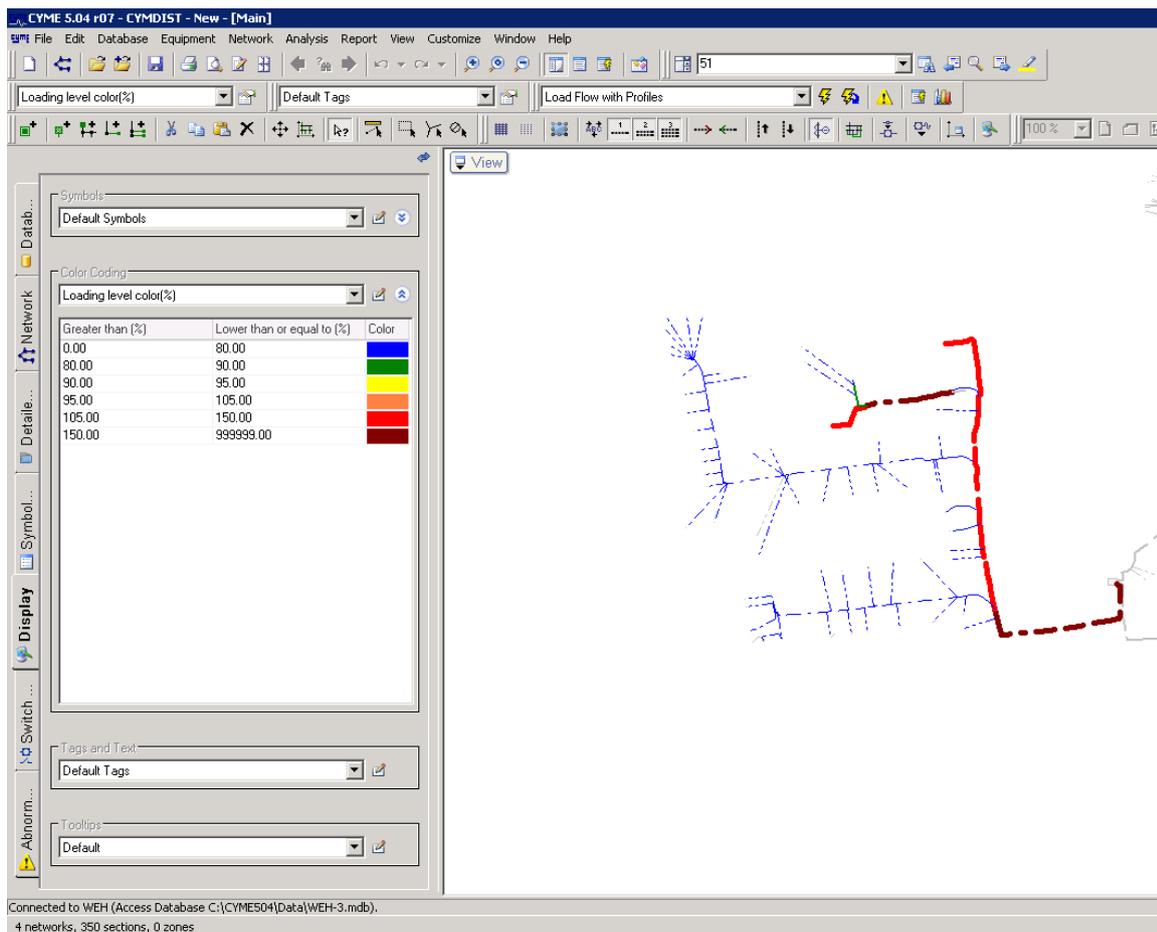


Figure 20 - CYMDIST -17th April 20:00 Forecast Network Loading - adding considerably to the loads just at Farningham Hall

Figure 20 shows the effect of a significant increase in load at a particular location on the network. The network is clearly over the rated thermal capacity at multiple points, demonstrating that this new load increase could not be accommodated without significant reinforcements.

The analysis displayed in this section is only a small fraction of the modelling that SSEPD engineers in conjunction with GE and CYMDIST staff trialled as part of the project. Extensive work was completed looking at the voltage implications on the network from load increases and distributed generation. More complex analysis around power quality e.g. phase angle, harmonics etc was investigated to a lesser extent, on a subjective basis. The work completed proved that purely from an electrical modelling perspective the power analysis tool operated as expected.

5.7 Comparison with live data

As the project team took the decision not to fully automate the link between Smallworld Electric Office and CYMDIST, additional work was completed on the modelling side. It was therefore decided that the modelling tool would be used in a live situation on an actual feeder. This would allow the project team to understand how the tool performs under real conditions and provide valuable feedback regarding any issues or problems encountered. The load profiles were provided by the University of Reading, based on their ongoing work under our Tier 2 project.

5.7.1 Worlds End Hill Analysis

For this analysis the University of Reading was provided with a set of 91 addresses supplied by an individual low voltage feeder from the World's End Hill substation. They returned load profile forecasts for a two week period near the end of April 2012 by pairing the Bracknell locations with load profiles derived from the Energy Demand Research Project. These load profiles were successfully imported into CYMDIST with Address Layer 2 Topographic Identifiers (TOIDs) - the spot loads on the network were also given these TOIDs as a reference. This allowed various load flow analysis scenarios to be run. The forecast data could then be compared with actual data obtained from the monitoring equipment installed at the substation. The purpose of this work was to prove the modelling tool could cope with the customer data in this format and to aid with the validation of the work University of Reading are completing on forecast demand.

The chosen dates for the University of Reading load profiles were in April 2012. This allowed them to use data from April 2011 in the creation of the profiles and avoided any Bank Holidays. The analysis was run for a number of time periods. Table 1 below shows the forecast data versus actual data at 20:00 on April 17th 2012.

Table 1 - Comparison of modelling against measured values 20:00 17th April 2011

Phase	Proportion of load on each phase	Actual Current (A)	Forecast Current (A)
L1 (Red)	23.3%	90.50	105.1
L2 (Yellow)	48.4%	187.63	219.0
L3 (Blue)	28.3%	109.88	129.3

The data in table 1 is an example of using the modelling tool in practice to incorporate forecast demand and validate the results with actual monitored data. The results of the analysis are not particularly important from the modelling perspective – the accuracy is primarily down to the University of Reading work and not the modelling tool. The forecast demand was slightly higher than the monitored actuals for a 30 minute average on all three phases, which on this feeder are not particularly well balanced. The analysis was completed on the same feeder on additional days and the results were consistent. Although the results are in the right level of magnitude there are a number of issues still to address from the University of Reading side, e.g. unmetered loads such as street lights. On the modelling side the length of service cables which are not recorded accurately in the current GIS may need to be addressed in future work. As stated this does not validate the modelling tool, it does however prove that the system can successfully incorporate dynamic load profiles and complete analysis on a live feeder, replicating analysis that SSEPD currently complete with static profiles.

5.8 Technology Readiness Level (TRL)

At the outset of the project there was not an existing modelling tool which could autonomously re-create the low voltage network from existing information systems and perform modelling calculations with a simple-to-manipulate interface. The fundamental software to complete the electrical modelling is however an established product; the development work concerned is the integration and adaptation completed to create the various interfaces between the software applications.

The project has successfully demonstrated the concept of an autonomous tool to transfer data between existing and new software systems. The work on the proof of concept has demonstrated the system in a relevant environment comparing actual network data with the forecasted data. Parts of the system are semi-autonomous and hence it is not considered a product or finished software, it was simply a quick implementation to prove the functionality was possible. As the aim of the project was to integrate existing systems which had not been used together previously, it was difficult to put a starting figure on the TRL. The justification discussed puts the TRL at 6 upon completion of this Tier 1 project.

In addition the project has demonstrated for first time the use of modelling on an actual feeder with dynamic profiles. This is a considerable step forward from the industry standard of static loads assigned to each customer. This has the potential to allow networks to run much closer to the limits and hence defer network investment, supporting the TRL justification.

6 Performance compared to original project aims, objectives and success criteria

The fundamental issue the project set to address was the lack of visibility the distribution business had of new and emerging low carbon devices connecting to the low voltage network. In addition to the lack of visibility there was no simple method of quantifying the impact the technologies were having on the network in terms of pushing the voltage and thermal limitations.

The project has brought the issue of low carbon devices on the low voltage network to the attention of multiple parts of the distribution business. This has led to the intention to integrate distributed generation within our existing GIS system – this will make it much simpler to understand the number of devices connected to our network in the future. The extent to which original objectives and success criteria have been met is summarised in the tables below.

Table 2 - Extent to which objectives have been met

Objective	Commentary
Recording and reporting on the deployment of low carbon devices;	Low carbon devices are held internally within an SSEPD system, 'SIMS', this system can generate reports. The reports run can now be integrated with the modelling environment to capture any updates. The intention moving forward is that the low carbon device data will be held within GIS. Bespoke dynamic load profiles have been created within the proof of concept project to pick up the devices and hence capture the various parameters within the power analysis tool.
Modelling the impact of deployed low carbon devices;	The use of example load profiles created for solar PV, electric vehicles, heat pumps etc. has been demonstrated. The system allows the profiles to be added to every node to simulate the effects of a whole street of electric vehicles for example. This can also be used to demonstrate a progressive adoption of low carbon devices over a 5 year period for instance and hence highlight areas that would require reinforcement or re-allocation of loads.
Managing multiple scenarios of low carbon low voltage networks	The modelling tool has the functionality to allow various low voltage scenarios to be trialled, for instance altering the load distribution across phases, increasing conductor size, changing tap settings at the distribution transformer etc. This allows the user to model multiple situations to find the most suitable network configuration to meet the requirements without the need for lengthy manual calculations. In order to add in low carbon devices the user simply needs to add in additional load profile, this can be completed very quickly and simply.
Performing power analysis of these networks that includes distributed generation and load profiles. A comparison of different power analysis engines is included in this project;	The project as required investigated multiple power analysis tools in order to provide the most suitable software from both an electrical modelling perspective and a software integration point of view. Full details of the power analysis investigation can be found in Appendix IV & V.

The success criteria were to analyse and report on the items detailed in Table 3 below.

Table 3 - Extent to which success criteria have been met

Objective	Commentary
The modelling and analysis capabilities of the technologies involved;	The proof of concept has successfully demonstrated that the software can perform the required analysis from basic voltage and thermal calculation through to complex power quality computations. The system has a simple interface based on a colour scheme to highlight parts of the network outwith the limitations for the basic calculations, this data is fed back from the analysis tool into Smallworld Electric Office. The more complex power quality scenarios are handled within the analysis tool directly. The project however also established that these solutions are as yet not fully scalable without the development of data migration strategies and data cleansing considerations.
The delivered environment capabilities of analysing future scenarios, with estimated load profiles and distribution generation take-up, facilitating the identification of HV/low voltage substations that will most likely require reinforcement	The proof of concept system has demonstrated that it is capable of handling customisable load profiles for both demand and generation. The load profiles can be assigned to a particular part of the network, to reflect the energy use at that point (domestic or commercial property) allowing appropriate analysis to be completed. The analysis can be run on an instantaneous basis or over a set time period. The project has proven analysis over various periods from multiple hours up to 5 years ahead.

Table 3 continued – Extent to which the success criteria have been met

Objective	Commentary
A low carbon network DNO reporting structure to Ofgem	<p>This part of the project was originally intended to provide a foundation for further proposed work on a reporting structure as part of the Thames Valley Vision (TVV) LCNF Tier 2 project, which this Tier 1 project was designed to support. It was removed following discussions with Ofgem on the structure of the NTVV Tier 2 project (developed as a successor to the TVV bid, which did not receive funding). These discussions concluded the outcome would not deliver the expected benefit within the timescales and therefore did not justify the time and financial contribution necessary to deliver. This removal from the new Tier 2 project negated the need to complete this section under the Tier 1 proof of concept. This section was removed before any time or effort was expended on the task and hence there was a direct reduction in costs from GE Digital Energy, see table 4.</p>

7 Required modifications to the planned approach during the course of the Project

During the course of the project execution it was necessary to implement a change control process with GE on a number of occasions in order to adapt the initial project proposal to the learning and issues the project team experienced. A summary of the noteworthy change requests is detailed below:

7.1 MPAN

Association to MPANs was removed from the project scope as there were data security issues identified which could not be resolved in line with the project schedule. It was decided to simulate the attachment of load profiles to supply points within the Tier 1 project with these issues being addressed fully as part of the NTVV Tier 2 project to follow. The proof of concept project still included the functionality to allow for the inclusion of MPANs for future implementation. Refer to section 5 for further details.

7.2 Smallworld Electric Office integration with CYMDIST

At the conception of the project it was planned to develop an automated process in order to transfer the data from Smallworld Electric Office to the selected power analysis tool. As the project was executed SSEPD were made aware that a future product release from GE would allow this functionality to be delivered by product instead of bespoke code. As a result it was decided not to implement this requirement during the Tier 1 project but rather transfer the data by a manual process instead. This decision was made as GE stated they would be creating this interface and funding it themselves, therefore it did not seem appropriate to spend LCNF funds on something that would become obsolete. As this part of the project was completed manually it allowed more time to focus on the different scenarios detailed in section 5.7.

8 Significant variance in expected costs and benefits

8.1 Overview

The project was managed using a fixed price contract with GE Digital Energy to create the software application to meet the project objectives. This meant that GE took the risk if the migration work was significantly more difficult / time consuming than expected for instance. As GE were required to build this risk into the costing of the work it is acceptable that this method is more expensive than a time and materials based contract. SSEPD feel that this is the preferred method when working on software based projects funded by the LCNF as any overruns in budget would not be covered by Ofgem.

The work was completed ahead of time and came in on budget. Travel requirements were reduced through the use of 'Webex' and teleconferencing facilities. The use of business 'experts' (SSEPD staff that use modelling tools as part of their daily work) to aid with the technical side of the modelling was significantly over the original estimate. Overall the SSEPD team were particularly happy with the management of the project and would use this fixed price contract again for software development projects.

Table 4 - Total project cost breakdown

Item	Forecast	Actual	Variance (£k)	Variance (%)
Project Management	£60,000	£64,000	4	+7
SSEPD business experts	£10,000	£30,000	20	+ 200
GE contracted work	£240,000	£225,000	15	- 6
Travel	£5,000	£500	4.5	- 90
Overheads	£5,000	£500	4.5	- 90
Total	£320,000	£320,000	0	0

8.2 DNO expectation of benefits

The goal of the project was to prove the concept that the integration between existing information systems and new modelling tools is functionally possible – the project achieved this. At this point it would be unrealistic to state that project had delivered the expected benefits to a DNO. The benefits of the system will be realised based on the results of implementation in the Tier 2 project. However the project has achieved the required objectives to lay the foundations for the full system. It must be made clear that the system in its current incarnation could be used by the

present business to perform detailed network modelling on the 20 substations in the Bracknell area. The system at present is not fully automated and there are still significant areas of the system that require work. The future work under our NTVV Tier 2 and beyond is discussed in detail in section 9 and section 10.

The aim of the final system is to be able to complete modelling in a much shorter time with increased accuracy therefore the expected benefits are primarily to do with reducing time and resources. The various potential users of the system e.g. planner / desk top quoter / operational staff, are very valuable and in high demand, hence a reduction in their time would have significant cost savings to the distribution business.

In addition to the time savings the system can allow for increased accuracy in the models and incorporate low carbon devices. This will allow DNOs to accurately model low voltage networks in a reduced timeframe and hence decrease the chance of the network becoming a barrier to low carbon technologies.

9 Lessons learnt for future projects

This section lists the key lessons from the Tier 1 project, together with the impact on the Tier 2 project, split into sections covering the power analysis tool, data migration and data quality issues, the network modelling environment, and the modelling of low carbon devices.

9.1 Lessons - Power Analysis Tool

Lesson	Impact
Existing interface exists between Smallworld Electric Office and CYMDIST; however the functionality does not extend to the low voltage network.	The additional functionality required has been included on the product road map, and delivery of this capability has been aligned with the NTVV Tier 2 'Model' work stream commitments.
The strategy for transferring the network data from Smallworld Electric Office to CYMDIST was reconsidered. It had been assumed that the Common Interface Model (CIM) would be the standard mechanism for transferring data, partly because the GIS to the Distribution Management System transfer in Tier 2 would use it as well. The evaluation showed that the CIM capabilities of the power analysis tools are not currently up to this. CYME seem to view CIM as a one off migration format rather than a small scale data transfer mechanism that would be needed for this project. As such the version of CIM that is currently supported by CYMDIST is not as up to date as the one supported by Smallworld Electric Office and the status of the functionality within CYMDIST at the end of 2011 was very much in the development phase. CIM is an evolving 'standard' and thus far has not been adopted by the vendors of the power analysis tools.	Further investigation of the existing Smallworld Electric Office – CYMDIST functionality and clarification of the product roadmap established that it would be extended from its current level of functionality to include low voltage networks in time to be of use in NTVV. It was therefore decided to use this as the interface mechanism rather than CIM. As the use of CIM at distribution voltages increases there will be a positive pressure on vendors to be CIM compatible, and this could be leveraged to reduce the cost of ownership by removing the need for a specific point-to-point interface between Smallworld Electric Office and CYMDIST. Increased use and adoption of CIM will encourage vendors to support CIM, this would make future integration simpler. CIM or equivalent should be a criterion for product selection in this field.

Lessons - Power Analysis Tool continued

Lesson	Impact
<p>In carrying out the evaluation it became apparent that low voltage load flow analysis appears to be an emerging requirement to the vendors of power analysis tools, so caution is required when evaluating the capabilities of the products. In some cases the analysis appears to be inherited from that used for higher voltages, which may not be exactly what is required at low voltage where the construction of the network may be different (e.g. the presence of a neutral cable). For Tier 2 it is essential to have SSEPD subject matter experts present at the requirements workshops to ensure that the power analysis tool is fit for purpose.</p>	<p>Recognised need to engage with Subject Matter Expert in evaluation of the CYMDIST analysis capability during the Tier 2 requirements analysis; otherwise analysis may not necessarily be optimised for low voltage power systems.</p>

9.2 Lessons – Data Migration and Data Quality

Lesson	Impact
<p>Current SSEPD GIS has a different data model to Smallworld Electric Office.</p>	<p>The mechanism for migrating the low voltage network data from the existing GIS to Smallworld Electric Office has been proven, therefore it will be possible to reuse the datasets and cleansing work from the Tier 1 project. Some further work will be required to refine the data mappings, and to configure Smallworld Electric Office so that the external field names and enumerator values (e.g. device types) more closely match the naming conventions SSEPD staff are familiar with.</p>

Lessons – Data Migration and Data Quality continued

Lesson	Impact
<p>For the Tier 2 project the intention is that the low voltage network data in SSEPD's existing GIS will be migrated to the NME on a one off basis. Thereafter updates to the low voltage network will have to be made in both the GIS and the NME for the duration of the project.</p>	<p>For Tier 2 a manual process will need to be established to ensure that these updates are managed effectively so that the NME contains the most up to date network information.</p>
<p>CYMDIST contains an equipment database, as does Smallworld Electric Office in the form of cable and equipment specification tables. Consideration will need to be given to the management of the equipment specification data.</p>	<p>For the Tier 2 project a decision will need to be taken about where the master set of equipment data resides and how it is to be maintained.</p>
<p>Approach to cable rating is possibly too simplistic. It was recognised during the showcase that the cable ratings stated in TG-PS-123 or Engineering Recommendation P17; are quoted in Amps per phase, and that this may not be sufficient since neutral current caused by phase imbalance may put the cable outside its thermal rating without exceeding the rating of the phases.</p>	<p>Investigate thermal resistivity capability in CYMDIST during Tier 2 requirements analysis.</p>
<p>Use of ducts needs to be taken into account for the de-rating of cables. Duct data from the current GIS must be migrated into Smallworld Electric Office so that cables that pass through a duct for more than 15 metres can be identified and a de-rating percentage applied when the data for that duct is passed to the power analysis tool.</p>	<p>Ducts need to be included in the migration of data from SSEPD's GIS. More accurate de-rating strategy needs to be investigated.</p>
<p>No phase allocation information is available in SSEPD's current GIS.</p>	<p>During Tier 1 two strategies to achieve this were derived, during Tier 2 a decision is needed on the most appropriate alternative, or development of a different strategy.</p>

Lessons – Data Migration and Data Quality continued

Lesson	Impact
Customer link data is only partially complete.	Need to fully populate the customer link data to connect the load and generation to the low voltage network. The migration process will require assumed service cables to be created as they will not be present in SSEPD's current GIS when the data is supplied for the Tier 2 migration process.

9.3 Lessons – Network Modelling Environment

Lesson	Impact on Tier 2
Significant differences exist between the network representations in Smallworld Electric Office and CYMDIST.	The GIS is being used to provide data for the PAT and in Tier 2. The different ways of handling network topology impact the data referencing, as a single element in the GIS database can be many in the PAT and also the DMS. This difference has been recognised and needs to be communicated to the product team for the interoperability between Smallworld Electric Office and the intended data management system.
The full power of CYMDIST functionality will not be available to the user via Smallworld Electric Office. A “Single Time Mode” analysis of the load at a specific date/time will be available to Smallworld Electric Office users.	Reduce the analysis capability of the CYMDIST product if used as an engine behind the Smallworld Electric Office front-end. CYMDIST has more comprehensive visualisation and reporting tools that expected. As SSEPD and GE become more familiar with the tool during the course of the Tier 2 project it may be that the user interface strategy is re-assessed. More advanced users may prefer the flexibility of reporting and visualising the network within the CYMDIST power analysis tool.

Lessons – Network Modelling Environment continued

Lesson	Impact on Tier 2
Network editing functionality is available in both Smallworld Electric Office and CYMDIST that would facilitate many of the simple reconfiguration options that users would require, changing equipment specifications and adding loads and embedded generation to the network.	It may be simpler to make small ad-hoc modifications directly in CYMDIST rather than updating electric Office and re-exporting the data

9.4 Lessons – Modelling of Low Carbon Devices

Lesson	Impact on Tier 2
Load and generation can be modelled as generic objects, generators, rather than individual specific types.	Adopting this strategy will give the NME flexibility to model new low carbon technologies, rather than be tied to those specifically included in CYMDIST.
The CYMDIST generator objects have the ability to use generation profiles in the load flow analysis.	Generation can be more accurately modelled as continuous data rather than a notional peak input. More realistic modelling is therefore achieved instead of a basic worst case scenario. This will potentially allow networks utilise capacity unused at present.
SSEPD's current GIS will be updated to include the location of Low Carbon Devices.	The data migration must include these Low Carbon Devices, and connect them to the low voltage network in the same way as for customer loads.
The representation of Battery Storage in CYMDIST has not yet been decided.	Clarify the optimal way of modelling battery storage and fully investigate in Tier 2
Un-metered load exists on the low voltage network. Street furniture is the most obvious, but there are also sewerage pumps, and other local authority / public service usages that have become evident during the Tier 1 project. SSEPD's current GIS records some street furniture locations, but the data is not complete.	A strategy needs to be devised to take account of these loads in the Tier 2 project; otherwise the load flow calculations will potentially be missing a significant proportion of the low voltage load in some areas.

9.5 Future use of Low Voltage Network Modelling Environment

The successful transfer of data from SSEPD's current GIS, through Smallworld Electric Office into CYMDIST, and the association of spot loads with load profile information from the University of Reading was a proof of concept of the data flows required for the creation of the Network Modelling Environment in the Tier 2 project. It was possible to undertake power flow analysis with the data obtained. The project unearthed a number of issues that the team would not have been aware of, and which can be addressed in the Tier 2 or taken into account by other DNOs investigating autonomous modelling.

The low voltage power flow analysis that will be able to be carried out with the full Network Modelling Environment under Tier 2 will have two main areas of use. Firstly, reconfigurations of the network can be assessed for viability. This could be a single new network connection up to a brand new housing estate or industrial site. It could also be a temporary switching change to enable network maintenance or backfeed during an outage. Such scenarios would be run with the latest actual load information to determine whether the network's current load if added to would cause a problem. Using the University of Reading forecasts rather than recent actual data, these scenarios could also be run for future periods to establish whether the proposed network reconfiguration may be problematic in the near future.

Secondly the forecasts can be used on the current network configuration to assess where there are problem areas of the low voltage network that may need to be reinforced or reconfigured. This allows a network operator to maintain customers' supply within the legally required parameters, and hence allow network investment to be directed to the most appropriate locations.

9.6 Potential system users

A critical part of any R&D project is an understanding of how the project can benefit the existing business and the future system users. As this project covers a particularly large topic are there a number of potential system users (detailed below). The likelihood of this uptake cannot be determined from the proof of concept project and will only be understood upon completion of the modelling work under our Tier 2 project.

9.6.1 Operational engineers

The system has the potential to provide benefit to our operational teams in the field. Operational engineers are required to backfeed substations or provide back-up generation in the event of a fault. This tool would provide a simple way of modelling the low voltage network to understand whether or not the backfeed / generation is suitably sized to cope with the customer demands. This would most likely be on the basis of up to a week ahead.

9.6.2 Desk top quoters

The system could provide an easy mechanism to quickly evaluate if a new connection can go ahead. For instance the desk top quoter can simply and easily manipulate the network to add additional loads, e.g. a new housing development, at a particular location. The system can then output if the thermal and voltage parameters are within limits or if reinforcement is required. This would initially be completed with a year round analysis and highlight any potential issues in the next 5 years, based on likely load growth, not just on a summer minimum / winter maximum basis.

9.6.3 Network planners

There is a need to look at long term load growth on the low voltage network, particularly with the emerging low carbon technologies becoming more significant under RIIO ED 1/2. The modelling tool could provide the planners with a simple way to analyse the network over 5 – 10 years with a percentage load increase and uptake in low carbon technologies. This would highlight areas requiring reinforcement or not as the case may be, therefore maximising free capacity and potentially deferring significant capital costs. The system could also provide a greater in-depth analysis of the low voltage network in terms of looking at parameters such as harmonics, reactive power etc. This advanced analysis would be completed in CYMDIST directly as opposed to the data being fed back to Smallworld Electric Office.

10 Planned implementation

10.1 Proposed future structure of Network Modelling Environment

In order to move the system forward and ultimately end up in business as usual, additional development work is required. The original scope of the project was to create a proof of concept to determine whether or not it was possible to integrate the existing systems and produce a working application. This has been completed as prescribed, however the intention was always that the software would be refined under the Tier 2 project.

The structure of the proposed Network Modelling Environment, based on the learning from the Tier 1 project, is summarised in the diagram below.

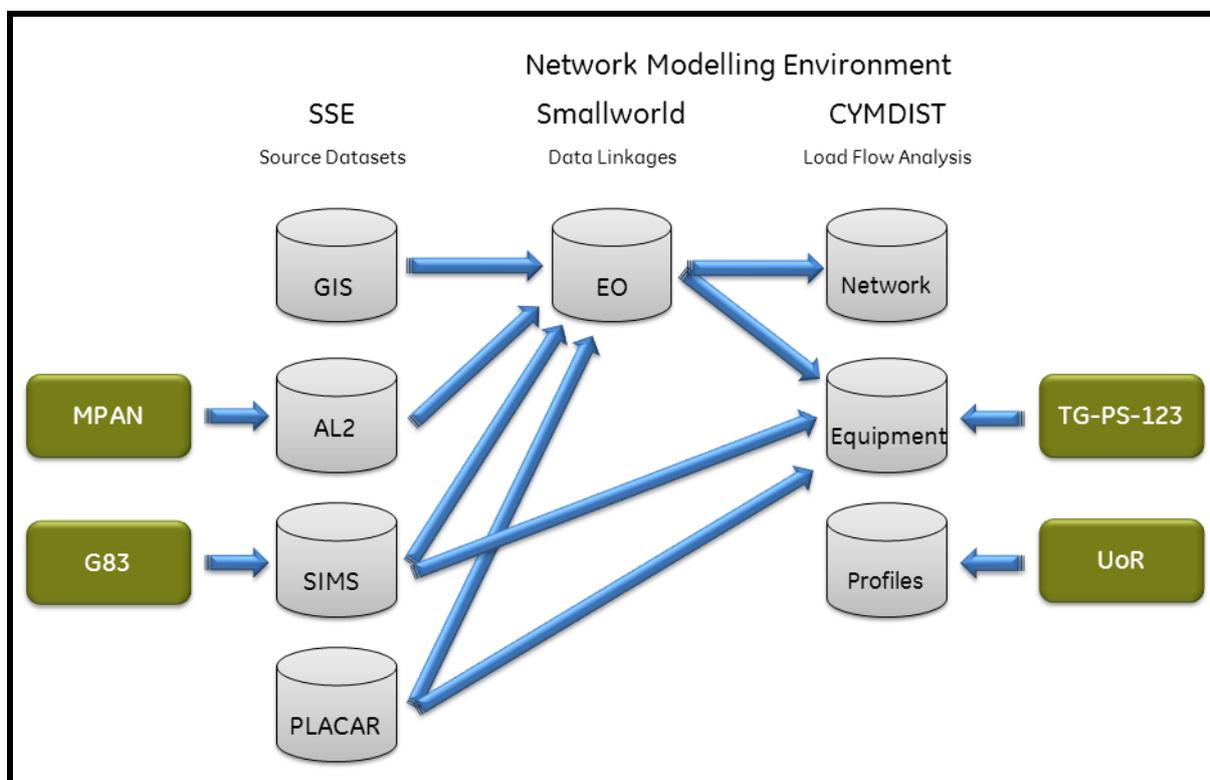


Figure 21 – Proposed system structure under Tier 2

The system at present has a fully automated link between GIS and Smallworld Electric Office only; this will however be modified and refined under the Tier 2 implementation. The other system integration is all performed manually, e.g. a report of the G83 data from SIMS was run – the generation data was then manually integrated with the particular customer. In the Tier 2 implementation the G83 data will be stored within GIS and automatically transferred to Smallworld Electric Office.

The structure proposed for future applications is essentially based on the same foundations as the proof of concept. The system will use live data provided through the use of MPANs, referenced using Address Layer 2 (AL2) and the linkage between each application will be fully automated. The regular users will only have visibility of the Smallworld Electric Office interface with data fed back and forth from the relevant systems. Advanced users will however have the facility to run power analysis within CYMDIST directly. The work the University of Reading are completing on the customer categorisations and predictions for low carbon devices will determine the load profiles for individual customers and provide accurate predictions for future scenarios. This load profile information will be automatically assigned to each MPAN, ready for use within the modelling tool.

In terms of this project becoming adopted by the business there are a number of areas which need to be addressed as highlighted in section 9. In addition there needs to be a detailed cost / benefit analysis to understand the exact advantages that could be achieved in terms of where the project is now. The saving on time and resources has however been detailed clearly within this report.

11 Project replication and intellectual property

The following tables list all physical components and knowledge required to replicate the outcomes of this project, showing how the required IP can be accessed by other GB DNOs. All physical components are either commercial products available for purchase or SSEPD-specific resources/systems for which other DNOs have equivalents. Further detail on replicating any aspect of the project can be obtained on request from jenny.1.rogers@sse.com

Table 5 – Components required for project replication

Component	Products used in project or commercially available equivalents
Distribution network operator Geographical Information System	SSEPD use an older version (v3.1 (0) SP2) of GE's Smallworld GIS. This stores all low voltage cable information and location details. All GB DNOs will have an information system similar to ours, however there will likely be variances in the design and structure of the system and data stored.
Power analysis tool	CYMDIST was the chosen tool for our project however there are many modelling packages that have the same functionality. It is likely that other DNOs will currently use their own preferred analysis tool.
Cable rating data	Each network operator will have their own internal document with required cable ratings for the cables within their distribution area. This information is also available from cable manufacturers and within Engineering Recommendation P17.
Transformer rating data	PLACAR – SSEPD database storing plant information. Again DNOs will have their equivalent systems, this information is available from manufacturers
Geographic customer location data	The Tier 1 project used Address layer 2 to locate customer loads on the network. MPANs in conjunction with MasterMap will be used for the Tier 2. All network operators have access to MPAN data.
Interface software	A bespoke code to integrate the information systems with the chosen modelling environment would need to be written. As the code is so bespoke between systems it is unlikely that the code used by SSEPD would be of use to other DNOs – what is of use are the datasets / data cleansing completed etc.

Table 6 – Knowledge products required for project replication

Knowledge item	Application	IP ownership and availability
Dynamic generation and demand load profiles	The profiles are needed for the modelling. Static profiles could be used however the modelled results would be less accurate. These were mock profiles for the low carbon devices based closely on actual data. The customer load profiles were created by the University of Reading as part of an additional project.	SSEPD, available on request.
Datasets	The critical part of the integration is to define every single parameter that needs to be migrated across to Smallworld Electric Office and to the modelling environment. How the parameter is stored, referenced and defined is the main part of the project that another GB DNO would need to be able to replicate this Tier 1 project.	The basic datasets are detailed within section 4.3, with further information provided in Appendices I, II and III. SSEPD and GE will share further know-how and learning gained from the work on datasets and the migration with other GB DNOs on request.
Data cleansing	The data from the information systems needs to be checked for any errors which could cause issues when migrated into the modelling tool. Depending on the quality of the data this may be a small or large job, i.e. some DNOs may have very accurate cable types however poor records on ducts or overhead lines.	This method is described in section 4.3. The Data Migration Specification spreadsheet in Appendix III displays the parameters of concern. SSEPD and GE will share additional details of the cleansing performed with other GB DNOs on request.