CONNECTION ASSESSMENT SOFTWARE (CASES)

Design and Decision Support Tool for Embedded Generation Connections

Contract Number: K/EL/00268/00/00

URN NUMBER 04/1445

dti

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Contractor

Econnect Ltd

The work described in this report was carried out under contract as part of the DTI Technology Programme: New and Renewable Energy, which is managed by Future Energy Solutions. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the DTI or Future Energy Solutions.

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EXECUTIVE SUMMARY

The government has set targets in recent years for the percentages of the UK's electricity supply it would like to see provided by renewable energy sources. Renewable energy generators often generate smaller amounts of energy than traditional fossil fuel power stations and are connected to the Distribution Network (operating at medium and low voltages) as embedded generation. The expected increase in volume and output of smaller renewable energy generation schemes will put increasing pressure on Distribution Network Operators to assess potential embedded generation connections.

The cost of assessing the viability of a connection is often significant and may be difficult to justify especially for smaller projects. There are a large number of technical issues to consider when assessing an embedded generation connection. These are evaluated using a diverse range of methodologies and tools. Existing industry standard software is often difficult to use, requiring specialist training, and such software is not specifically targeted to assess the connection of embedded generator.

The aim of this project is to research and develop innovative software specifically designed to carry out studies of connecting embedded generation to the distribution network. The objectives for the software are to provide the following:

- A calculation suite, which carries out the assessment of the main issues that are normally encountered when connecting embedded generation to the distribution network
- A costing module, which estimates budget costs for the connection in a clear and consistent way
- A simple and intuitive user interface, which is capable of displaying a model of the existing network and of the new connection in a graphical manner
- Extensive libraries of equipment specifications and installed budget costs
- An automatic report generation facility, which exports the software data using user specified templates
- An extensive help system, which guides the user through the connection process, giving assistance to interpret the calculation results and suggesting how to resolve connection problems
- Potential import and export interfaces with existing Power System Analysis tools and user's own database systems

The software provides the following benefits:

- Ability to assess rapidly the lowest connection cost
- Processing of a large number of alternative connections
- Improvement in consistency and quality of connection studies

- Training for non-experts
- One- stop tool for connection assessments

The software is aimed at several types of users, including Distribution Network Operators, Developers and Academia.

This report includes a demonstration of a practical example of how the software is used to assess an embedded generator connection.

This research project is now complete and has been concluded by the development of a pilot software tool. Further work is required to convert the pilot software into a commercial software product, and having been convinced of the worth of this product, Econnect is actively pursuing these next steps.

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GLOSSARY

Cable	A conductor that carries current. It is usually located underground in buried trenches. When located above ground, it is mounted onto a support, not hung from poles or pylons
Circuit Breaker	A piece of switchgear equipment which is designed to protect an electrical network from the damage of fault (See Section 5.6)
Consultant	A company involved in providing consultancy advice, for example on the feasibility of connecting an embedded generation scheme to the distribution network
Current Flow Value	The values of the current flowing through the equipment in an electrical network
Current Rating	The rating of equipment with respect to the maximum amount of current that can flow through the equipment under normal operating conditions and without incurring any damage to the equipment
Developer	A company involved in the identification, design, build and commissioning of for example new embedded generation
Distribution Network	The part of the electrical network of a country or region, which carries current at medium and low voltage. In England the voltage for the distribution system range from 132kV to 230V. In other parts of the UK and abroad the definition of the voltage range may be different
Distribution Network Operator	A company responsible for operating the part of the electrical network classified as ‘Distribution Network’. In the UK, these companies are independent and privately owned. In other countries, these companies may be state owned
DNO	Abbreviation for Distribution Network Operator
DTI	Department of Trade and Industry (a department of the UK government)
Electricity Supplier	A company responsible for supplying the end customer with electricity. In the UK, these companies are independent and privately owned. In other countries, these companies may be state owned
Embedded Generation/Generator	A generator plant that is connected to the Distribution Network
Fault (level)	See Section 5.6
Fault Engine	A generic software element that calculates fault levels in an electrical network

	an electrical network
Fault Level Values	See Section 5.6
Fault Rating	See Section 5.6
Flicker	See Section 5.5
Flicker Factor	The measure of flicker created by an item of electrical equipment, including generators. See Flicker (Section 5.5)
Generator/ Generation	Plant equipment that generates power (into to an electrical network)
Interconnected (Distribution) Network	A distribution network where there are one or more closed loops under normal operation. Two or more parts of the electrical network are supplied with power from different sources and are connected together.
kV	Kilo Volt. The unit of voltage to define the operating voltage of equipment in an electrical network
kW, MW	Kilo Watts, Mega Watts. The unit of power used to define the amount of power that may flow in an electrical system
Load	Plant equipment that absorbs power from an electrical network
Load Flow Engine	A generic software element that calculates voltages, currents and power flows in an electrical network
Low Voltage Network	The part of the electrical network of a country or region, which carries current at low voltage. In England the voltages for the low voltage system start from below 1000V. In other parts of the UK and abroad the definition of the voltage range may be different. Low voltage networks are part of the Distribution Network
Network Reinforcement	Replacement of existing network equipment required before a new customer (for example an embedded generator) may be safely connected to the electrical network
NFFO (Non-Fossil Fuel Obligation) rounds	An obligation placed on electricity suppliers to purchase a proportion of their electricity from Renewable Sources. This is the precursor to the Renewables Obligation scheme
Overhead Line	An above ground conductor carrying current. These are hung from poles or pylons.
Point of Common Coupling	The Point of Common Coupling is the point in the network where the connection for the new embedded generation is also used for the connection of another user
Point of Supply	The Point of Supply is the point where the ownership of assets changes from the DNO to the developer. It is also the point where the electricity metering equipment for the

	new connection is located which enables the tracking of energy exported and imported by the new generator.
Power Factor	The measure of the amount of usable power produced by a generator. The value of the power factor is an indication of the efficiency of the generator. Power factor values can be between 0 to 1. A value of 0 means that no power is produced. A value of 1 means that the generator produced the maximum possible usable power. In practice, power factor values range from 0.6 to 1 depending on the type of equipment
Power System Analysis tool	A software tool designed to analyse a part or the whole of an electrical system
Quality of Supply	The measure of the quality of electricity available to end customers (See Sections 5.4 and 5.5)
Radial (Distribution) Network	A distribution network where there are no closed loops under normal operation
Renewables Obligation	An obligation places on electricity suppliers to purchase a proportion of their electricity from Renewable Sources. This is the successor to the NFFO scheme
ROC	Renewables Obligation Certificate
Tee Connection	A connection where a new part of an electrical network is connected to an existing Overhead Line or Cable linking two points in that network
Thermal Limits	See Section 5.3
Transformer	A piece of equipment that transforms voltage from one value to another. For example, a transformer may change a voltage value from 11kV to 690V
Transmission Network	The part of the electrical network of a country or region, which carries current at high voltage. In England the voltages for the transmission system range from 400kV to 275kV. In other parts of the UK and abroad the definition of the voltage range may be different
Voltage Rise	See Section 5.2
Voltage Step	See Section 5.4
Voltage Value	The values of the voltage at any point in an electrical network
Switchgear	A piece of equipment, which is designed to separate one part of an electrical network from another under abnormal operational conditions. Some switchgears have protective capabilities, such as Circuit Breakers

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1 INTRODUCTION

1.1 Background

The government has set targets in recent years for the percentages of the UK's electricity supply it would like to see provided by renewable energy sources. It also has put an Obligation on all electricity suppliers in England, Wales and Scotland to purchase a proportion of their energy from renewable sources (ROC), with a price cap limiting the costs they can pass on to consumers.

Traditional fossil fuel power stations usually generate large amounts of electricity and are connected to the National Electricity Grid via the Transmission System (operating at high voltages). In contrast, renewable energy generators often generate smaller amounts of electricity and thus may be connected to the Distribution Network (operating at medium and low voltages), as embedded generation. The exception to this connection method is the current development of large offshore wind farms, which have a capacity similar to that of some of the smaller fossil fuel power stations.

The expected increase in volume and output of smaller renewable energy generation schemes will put increasing pressure on Distribution Network Operators (DNOs) to assess potential embedded generation connections.

The cost of assessing a connection is often significant. The assessment of a grid connection is an involved process requiring specialist electrical engineering expertise. There is also no standard process for determining the viability of a connection. Developers (especially of smaller projects) often find it difficult to justify the cost of these studies given the risks inherent in project development.

In assessing an embedded generation connection, there are a large number of issues to be evaluated, including steady state voltage rise, thermal rating issues, step voltage changes, flickers and fault levels in addition to the range of non technical issues such as planning permission. DNOs, developers and consultants use a diverse range of software, methodologies and techniques to assess different technical aspects of the connection of a project. The existing industry standard software packages are often difficult to use. They require specialist training and understanding, and are not specifically targeted at studies of embedded generation connection assessments.

The work to design a feasible connection and provide a cost estimate can be time consuming and requires skilled and experienced staff, especially to achieve consistency and quality and to maintain quality of supply to other network customers.

DNOs were heavily pressed during NFFO (Non-Fossil Fuel Obligation) connection application periods in assessing the connection applications put forward. The Renewables Obligation has also lead to an increased workload for all parties involved.

To date, Econnect has reviewed over 20,000MW of grid connections of mainly renewable energy embedded generation projects. These connection projects have been undertaken for a wide range of clients, and in a wide range of situations.

Therefore Econnect has considerable experience of the issues, pitfalls and requirements of renewable energy generator connection assessments.

1.2 Aims and objectives of this project

The aim of this project is to research and develop innovative software specifically designed to carry out connection studies for embedded generation. The primary objective for the software is to assess the feasibility of connection of generators rated from 100kW to 5MW to the radial distribution networks (e.g., to 11kV feeders). It is designed so that it can be extended to assess connections to interconnected 11kV systems, to low voltage systems and connections at 33kV and above. The software is to be used as a decision, support and training tool for DNOs, consultants and developers.

The software has the following key functions:

- A calculation suite, which carries out the key primary calculations for assessing grid connection of embedded generators. Mathematical modules perform technical calculations, such as voltage rise, thermal limits, flicker, voltage step and fault levels. These modules have been developed in association with the University of Manchester Institute of Science and Technology (UMIST) and are based on current standards (IEC and other national and international engineering recommendations) and established design methods.
- A costing module provides connection cost estimates in a clear and consistent way
- A graphical user interface capable of displaying single line diagrams associated with a connection. Data input is largely visual, utilising a drag and drop approach to add components to a single line diagram for the proposed connection
- Extensive libraries are available containing data regarding equipment and costs. It is possible to store, retrieve and edit the generator and network data associated with a particular connection, enabling scenarios to be rapidly altered and / or re-run. As the content of data libraries are likely to change, methods of maintenance have been devised so that users of the software can upload updates from the Internet
- Automatic report generation, exporting the data stored within the software for a particular project in a user specified format
- An extensive help system guides the user through the connections process, including assistance in using the software, information on grid connection assessment and process, pointers and links to standards, codes and best practice, interpretation of the results of calculations, suggestions to resolve connection problems and pointers to issues which may require further assessment, such as protection design, improvements and settings
- Potential for import and export interfaces with existing Power System Analysis tools and user's own database systems

The software runs on PCs with an average specification and under a range of Windows operating systems.

1.3 Benefits

The main beneficiaries of this project are identified as being all parties involved in the assessment of embedded generation to a Distribution System. This includes DNOs, consultants and developers.

The benefits of the project include the following:

- The possibility of achieving lower connection costs through the comparative assessment of connection alternatives which satisfy engineering limits
- The processing of a higher number of connections, within a shorter timescale than previously achieved, thanks to a simple and user-friendly graphical interface
- Improved consistency and quality of grid connection assessments and costing
- Reduced potential for undetected adverse impacts of connection on other customers, quality of supply and safety
- A training tool to help engineers and developers understand the key connection issues, using extensive engineering help, test cases and worked examples
- Lower connection assessment costs for DNOs and project developers, especially for smaller projects (less than 5MW), resulting in lower cost Renewable Energy in the UK
- Improved competitiveness of UK users of the software in international markets when carrying out grid connection assessments, particularly as the UK is seen as a world leader in open access to electricity networks

1.4 Collaborators

Econnect is pleased to acknowledge the support of the following people and organisations on this project.

Mr Dave Openshaw, Mr Douglas Ellis and their colleagues at EDF Energy (Eastern), the largest distribution network operator in the UK, has continuously and significantly been involved in the project, providing input and feedback at each stage in the project. They have assisted in the process of requirements capture and scope definition of the software, reviewed the design of the software at different stages and provided expert feedback on the developed pilot software.

Professor Nick Jenkins at UMIST has been a close collaborator on the project, providing invaluable expert advice on the selection and methodology for the calculation engines used in the software.

A number of other parties have expressed interest in the software, including the DNO Central Networks and the developers Powergen and Innogy. They have provided valuable input in the process of requirements capture and scope definition.

Equipment manufacturers have provided input into the library of equipment and costs, supplying data to the project in a standard spreadsheet format, which can

easily be uploaded into the software's underlying databases. These manufacturers include ABB, Pauwels, Schneider, Siemens, Alstom and AEI Cables.

1.5 Project overview

The activities performed by Econnect to research and develop the Connection Assessment Software were as follows:

- Requirement capture and scope definition
    - At the start of the project, a wide range of potential users were consulted to find out what features the software would include
    - The main method for obtaining requirements for data capture was a road show, where interested parties were visited, the project was presented and feedback obtained
    - This resulted in a document which includes all required features for the software
- Top Level Design
    - A prototype was developed based on the information from the requirements capture, and this was presented at the DTI conference on Embedded Generation in Birmingham 2002
    - Feedback on the prototype from Econnect internal and external sources provided additional information which was incorporated into the top level design for the software
- Detailed design, software creation and testing
    - From the top-level design, detailed design of the individual components of the software was carried out. From the detailed design documentation, the software was created and tested
    - User-visible aspects of the detailed design were reviewed internally at Econnect and externally with the project partners
    - The project was presented at the DTI conference on Embedded Generation in Birmingham 2003. The demonstration included a range of design features for the pilot software being developed
- Software Build and System Tests
    - The individual components were assembled into the pilot software
    - The pilot software has been reviewed internally at Econnect and externally with the project partners
    - The results of the calculation and costing suites have been tested against existing Power System Analysis tools and Econnect connection assessment projects. They were found to give satisfactory results
    - The pilot software was presented at the DTI conference on Embedded Generation in Birmingham 2004. The demonstration included a realistic

example of assessing the connection of a small wind generation to the Distribution Network

- Project dissemination
    - The project was presented at the DTI Embedded Generation Conferences in Birmingham in 2002, 2003 and 2004, which provides Econnect with valuable feedback from the industry
    - The project was also presented at a seminar of the Sustainable Energy Expo 2002 at Olympia in London

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2 SOFTWARE FUNCTIONALITY

2.1 Overview

The software is organised in seven elements, as shown in Figure 1.

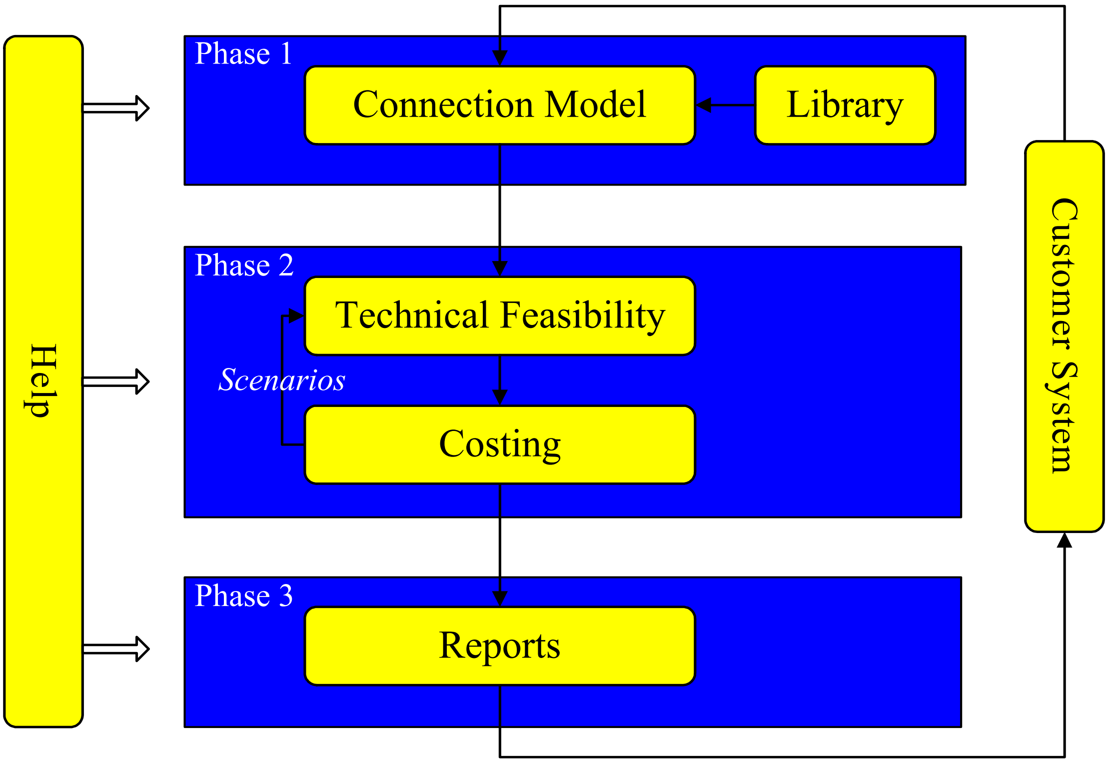

Figure 1: Software Overview

The seven elements are as follows:

- *Connection Model*: element that enables the user to create a model for the connection. This model is the basis for the technical assessments and budget costing
- *Library*: element that enables the user to include in their model pre-defined and actual equipment specifications and budget costs
- *Technical Feasibility*: element that enables the user to carry out the required technical assessments for the connection, based on the connection model created
- *Costing*: element that enables the user to carry out a budget costing for the connection, based on the connection model created
- *Reports*: element that enables the user to automatically create a report using customised templates. The reports include the data entered by the user and created by the software
- *Help*: element that provides guidance to the user in how to assess the connection of an embedded generation and how to operate the software. Reference material and tutorials are also included in this element
- *Customer System*: element that enables the user to import and export data between this software and other systems. This element may be specific to each customer and will be developed to order based on the user's requirement.

There are three main steps in using the software:

- *Phase 1*: create a model for the connection of the new embedded generation
- *Phase 2*: carry out technical assessments and establish budget costing for first connection scenario. If required, build alternative scenarios and assess them as for the first scenario
- *Phase 3*: when all scenarios have explored and the connection options have established, create a report showing the results of the assessments and budget costing

Each of the elements in the software are explored in greater detail in the following sections.

2.2 Connection Model

The connection model enables the user to create a model for the connection of a new embedded generation. This model includes the following data.

- Existing network information
- The new embedded generation and the way it is connected to the existing network

The connection model consists of a diagram that graphically shows the topology of the existing network and the connection for the new embedded generation. The diagram is made up of a series of standard equipment linked together, each with a set of technical specification and budget costs data.

The user builds the connection diagram using a drag and drop method from the toolbar in the software. Each piece of equipment is added to the diagram in turn. The links between the pieces of equipments are then added to complete the diagram. The technical specification and budget costs for each piece of equipment is accessed via a mouse double click on the diagram.

The information in the connection model forms the basis for the calculation suite and the whole connection assessment process.

Some of the data is common to all calculation engines, whilst other data is specific to one or more calculation engine. Common data is highlighted as a mandatory input when the user enters the data. Further information is provided when a piece of data is specific to one or more type of calculation.

The software enables the user to include the following standard pieces of equipment into the connection diagram:

- Circuits, including overhead lines and cables
- Transformers
- Switchgear
- Generators

- Loads

The connection model also allows the existing network to be represented. This representation is denoted ‘Source Substation’.

In addition, the software provides the means to identify the Point of Common Coupling and the Point of Supply for the connection.

An example of a connection diagram is shown in Figure 5.

One difficulty in creating a connection model is that the user needs to enter accurate and meaningful information for the underlying technical specification and budget cost data. The accuracy of the result from the calculation engines is highly dependent on correct data entry. To address this problem, the software provides a number of helpful features:

- Library of pre-defined equipment that can be dropped directly onto a connection diagram (see Section 2.3)
- Help information on the source of the data and how to obtain it (see Section 2.7)
- Validation of the data entered, with warnings for entries containing suspect data

2.3 Library

The software includes two libraries:

- Pre-defined library, which Econnect creates, supplies and maintains. Updates to users would be provided on a regular basis
- User-defined library, which the user creates and maintains

As part of this project, Econnect has gathered equipment technical specification and budget costs from a range of manufacturers. This information is invaluable to the user, who only has to decide which equipment to use in the connection model. The help system provides very specific guidance on how to decide which piece of equipment to use.

When using the pre-defined library in conjunction with the help system, the risks of typing errors and wrong data entry are very much reduced. This pre-defined library is particularly useful when creating the part of the model that relates to the new connection.

The existing network model is different in that the equipment already exists and it is a matter of finding out the required information and entering it into the connection diagram.

It is often the case that existing networks within the geographical area of a particular DNO have been designed using a standard policy regarding what equipment is used. When creating a model of the existing network it is therefore likely that the same type of equipment will be added to the model many times.

The user-defined library enables the user to create one instance of the particular standard piece of equipment and reuse it within a connection model and across other connection models in different connection assessment projects.

The user-defined library also enables the user to extend the pre-defined library with own preferred equipment information and supplement the information that Econnect supplies with the software.

The pre-defined library is read-only and the user cannot alter it. The user, however, can edit the user-defined library.

The library is simple to operate. To add a piece of equipment to the connection diagram from the pre-defined or user-defined library, the name of the equipment is dragged from the library screen and dropped into the connection diagram screen. Both screens can be viewed side by side to make the drag and drop operation easy.

An example of using the user-defined library is shown in Figure 6.

2.4 Technical Feasibility

The software performs the following technical feasibility assessments:

- Voltage Rise Assessment
- Thermal Limits Assessment
- Voltage Step Assessment
- Flicker Assessment
- Fault Levels Assessment

These assessments address the main issues that are normally encountered when analysing the connection of an embedded generation to the distribution network [1].

An overview for each of these assessments is provided in Section 5. The method for carrying out the technical feasibility studies and assessing their results is provided in Table 1.

Technical Calculation	Method	Results Assessments
Voltage Rise	Compute voltage values throughout the connection model	Assess the voltage values according to limits set by both statutory regulation [3] and DNO own standards
Thermal Limits	Compute current flow values through pieces of equipment in the connection model	Assess the current flows with respect to the maximum current rating of each piece of equipment
Voltage Step	Compute voltage values with the new generation running and without the new generation running	Assess the change in voltage values with and without the new generation according to limits set by both statutory regulation [4] and DNO own standards
Flicker	Compute flicker factor for the new generation (wind generation only) [5]	Assess the flicker factor for the new generation according to limits set by statutory regulation [4]
Fault Levels	Compute fault level values throughout the connection model [6, 7, 8]	Assess the fault level values with respect to the maximum fault rating of each piece of equipment

Table 1: Technical Calculation Methods and Results Assessments

This software uses industry standard load flow and fault engines to compute voltage, current and fault level values on the network modelled.

The software provides default limit values for assessing the results of the technical calculations. These limits correspond to the standard values used in the UK on Distribution Networks. When using this software to evaluate the connection of embedded generations outside the UK, the user can override the UK specific limits with those applicable to the country where the embedded generation is to be connected.

The software processes the results of the calculations according to the relevant limits into a simple three-tier rating, using a traffic light system:

- Green: no foreseen problems arises from the result of the calculation

- Amber: there may be a problem identified from the result of the calculation. Further studies are needed to establish if the problem will actually cause difficulties in connecting the embedded generation
- Red: a problem is identified which will cause difficulties in connecting the embedded generation. Further studies are required to establish a solution to the problem

The results of the assessments are evaluated and the software provides guidance where the results do not show all-clear (green) results.

The advice is embodied in the help system, which provides recommendations on how to resolve a non-favourable assessment (amber or red), including the need for more advanced studies not currently covered by this software.

Examples of calculation results are shown in Figure 8, Figure 9, Figure 10, Figure 11 and Figure 12.

2.5 Costing

The software performs an assessment of the cost of connecting the embedded generation to the existing network modelled in the connection diagram.

The costing calculation is based on budget as installed costs and is intended for two purposes:

- To provide a means of carrying out a comparative assessment between different connection options
- To calculate an approximate value for the total cost of the connection

The budget installed costs underlying the costing calculation have been obtained from equipment manufacturers and from Econnect's own internal knowledge. It is important to note that some of the equipment purchased for building connections is not available as commodities on the market place. For example, transformers are custom built for each client, and the actual price that will be paid when the transformer is purchased will depend on external factors such as the current market demand, the relationship between the manufacturer and the purchaser etc.

Budget costs displayed in the software are supplied with an accuracy margin expressed in terms of plus and minus a percentage on the price quoted, for example £10,000 +/- 15%.

The costing is nevertheless a very valuable tool, which we believe is a unique feature of this software. One of the first tasks in assessing a connection is deciding at which point on the existing network to connect the generation. This task is traditionally carried out by examining the technical constraints for each potential connection point. This software provides the user the means to also include the commercial aspects when assessing each connection point.

The costing calculation takes into account the following aspects:

- Budget installed cost for the new equipment required to connect the new embedded generation to the existing network

- Budget installed cost for replacing any existing network equipment which has its technical limits exceed as a result of connecting the new embedded generation (network reinforcement)
- Budget installed cost for other activities related to the connection, including design, planning, installation, testing and commissioning, civil works and operation and maintenance

The current scope of the costing calculation includes all the equipments required for the connection, but excludes the cost for the generator itself, which does not vary for a particular type and number of generators. This cost is usually accounted for in the overall project costs for the new generation. The connection cost is a constituent of this overall cost.

An example of the result of the costing calculation is shown in Figure 13.

2.6 Reports

The software provides the facility to automatically generate one or more reports. The reports are created in a standard format that can be read by most available word processors. The software takes the information that it holds for a given connection project and exports it to the report according to a specified template.

The data that is available for inclusion in reports covers the following topics:

- General project information about the new embedded generation scheme, usually added to an introduction section
- General information about each assessed connection scenario
- Summary results for each technical calculation and budget costing performed for each connection scenario
- Detailed information for each technical calculation and budget costing performed for each connection scenario

The software is provided with a default report template that also includes additional information in terms of background for the assessment carried out, conclusion and recommendations for the developer to progress the project.

Alternatively, the user may wish to use their own template, in line with their company quality system. The template can simply be submitted to Econnect, who would then process it so that it is in the required format for the automatic reporting module.

In addition to reports, the software can also produce part pre-filled DNO connection application forms. The software treats these forms as another type of template.

An example of an automatically generated report is shown in Figure 14.

2.7 Help

The software is provided with an extensive help system. This help system includes the following:

- Help on how to carry out the assessment of an embedded generator connection
- Help on how to use the software
- Tutorial material, which includes worked examples
- Reference section, including links to relevant standards and codes of practice

The software provides help on the grid connection assessment process, how to interpret the results of the calculations, suggestions on how to resolve unfavourable assessments and provides pointers to issues which may require further assessment such as protection design, improvement and settings.

A view of the help system is shown in Figure 15.

2.8 Customer System

The software has been designed so that it can interact with third party software packages and other customer systems. The interaction would be in the form of data import and export facilities.

Where there are customer requirements for importing or exporting data in a given format, the data import/export facility will be developed for the particular format requirement. Formats specified could be other existing software packages, for example Power System Analysis tools, or customer own format in line with their internal IT system.

3 SOFTWARE DEMONSTRATION

3.1 Overview

The aim of the software demonstration is to provide a practical example of how the software is used to assess a realistic connection for an embedded generator.

The demonstration is provided in two formats:

- A video of the software showing how a user operates the software throughout the demonstration
- A series of still figures showing how the software appears on the screen at different stages of the demonstration

The video is provided as a separate file, which requires the user to have the necessary software installed on their PC in order to view it. Refer to Section 3.3 for details.

If the user cannot view the video of the software, the still figures are provided as an alternative way to demonstrate the capabilities of the software. The figures are provided in Section 6 of this document.

3.2 Demonstration Project

The demonstration project provided with this report is also one of the tutorials included in the help system.

The project aims at assessing the connection of a new wind generation scheme of capacity 1.2MW to an existing 11kV radial feeder, which already has an embedded generator of capacity 2MW connected. The model for the existing network and the new generator is shown in Figure 2.

The owner of the new wind generation scheme wishes in the first instance to run the generator at maximum capacity in order to maximise the income from the power exported to the grid.

The new generation scheme is close to the end of the existing 11kV feeder, so the first connection option considered is a tee connection near to the end of the overhead line.

The first assessment carried out is a voltage rise calculation. Voltage rise issues are the most likely problem to occur when connecting to rural radial networks. The voltage rise assessment result is amber, indicating that there may be an issue. After consulting the software help system for compliance with the voltage rise limits, the user decides that the owner may be prepared to reduce the power factor on the generation scheme in order to operate with the designed connection without further problem.

The next step is therefore to carry out a second voltage rise calculation where the power factor for the generator is reduced. The second case study reduces the power factor from 1 to 0.98 to see if this will change the result of the voltage rise assessment. The voltage rise assessment result is green this time, indicating that the reduction in power factor has been enough to resolve the issue. Further consultation with the help system indicates that there are commercial implications in reducing the power factor, but the user decides that these implications will have minor consequences compared to the ability to connect without further problem.

In addition to voltage rise issues, the user next checks for all other potential technical problems. The following calculations are therefore run: thermal limits, voltage step, flicker and fault levels. The results of all these further assessments are green, indicating that there are no foreseen problems in those areas. Next a budget cost calculation is run to check that the cost of the connection is within the budget range of the project.

Lastly the user generates a report, which is then sent to the developer or owner of the new wind generation scheme so that a decision can be made about proceeding with this generation project.

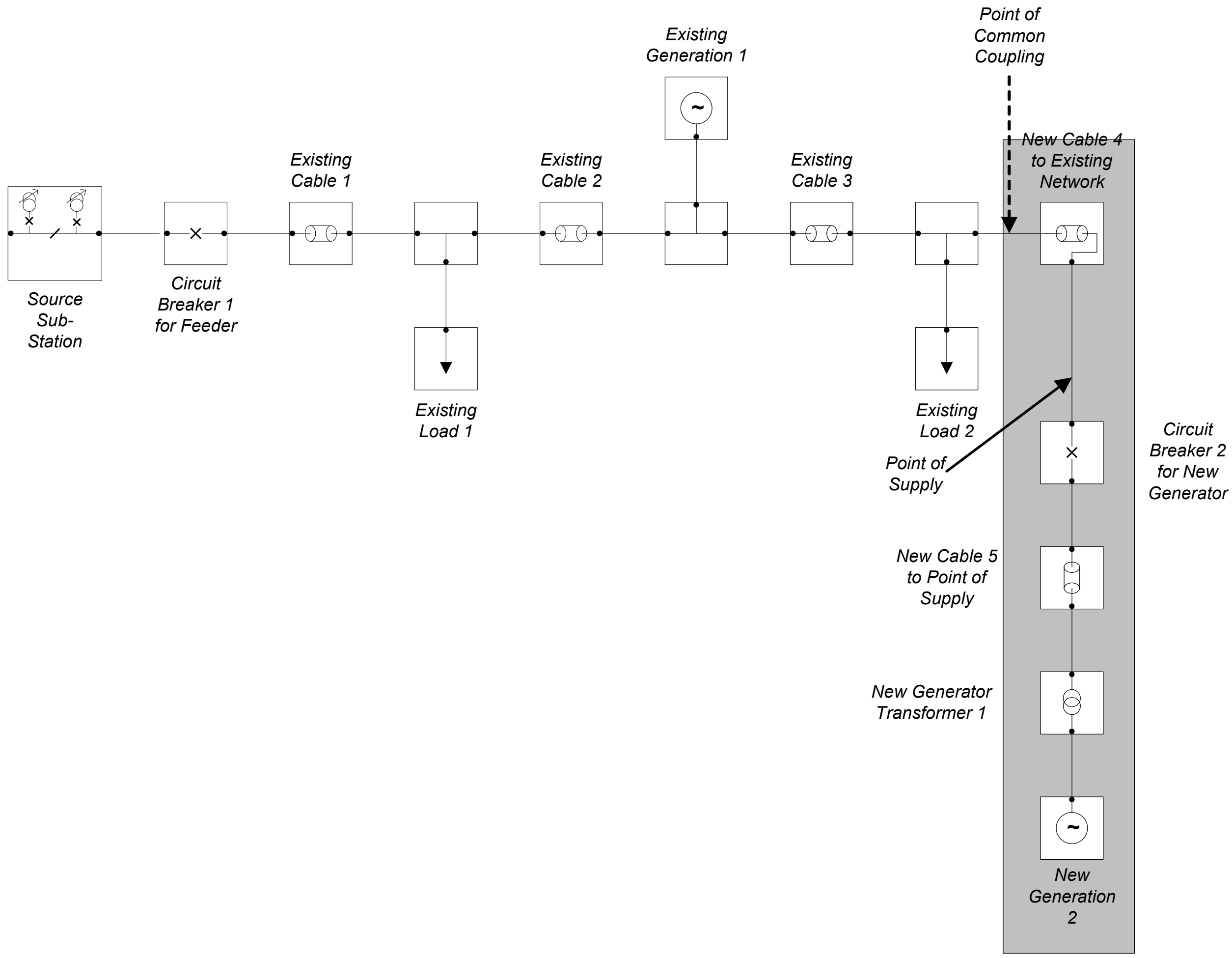

Figure 2: Demonstration Network

The steps in using the software for the demonstration project are explained in Table 2. A reference to the Figures in Section 6 is provided in Table 2 for those who are not able to view the video. It is beneficial to run the video at the same time as reading the contents of Table 2 to understand the dynamics of the software. The video includes captions showing the name of each step and can be paused whilst the 'details' column in Table 2 is read.

Step	*Details*	*Figure No.*
Create a new connection project	This step creates a new project in the software underlying database and stores information about the project including: • Project identification • Type of generation (Wind) • Project overall parameters (units, system frequency etc.)	Figure 3
Create a new connection option in the project	This step will enable the user to specify the model for the connection. In this example there is only one connection option. When there is the option to connect to other points on the network, additional connection options would be created, each with a different model for that part of the existing network	Figure 4
Create the model for the connection option	The user works with the drawing canvas available and draws the connection diagram. Each equipment component is added to the diagram and their properties are set either directly via manual entry or by dragging and dropping existing equipments from the library	Figure 5 Figure 6
Create a first case study for the connection option	This step enables the user to specify specific parameters for the equipment before carrying out any technical assessments. All case studies use the same connection model topology but have their own set of underlying parameters. This arrangement enables the user to carry out comparative assessments for the connection option. In this example, the first case study will be to assess the feasibility of the connection model without modifications	Figure 7
Carry out a voltage rise assessment for the first case study	The overall result for the voltage rise assessment is amber. At this point, the user consults the help system and decide to try to reduce the power factor of the generator from 1 to 0.98	Figure 8
Create a second case study for the connection option	The user modifies the model's parameters for this second case study so that the new generator power factor is set to 0.98. Note that the original parameters set for the connection diagram are not affected. Only the parameters for this case study are modified	Figure 7
Carry out a voltage rise assessment for	The overall result for this voltage rise assessment is green. At this point, the user is satisfied that	Figure 8

Step	*Details*	*Figure No.*
the second case study	the voltage rise issue has been resolved and can proceed to check all the other potential technical problems	
Carry out Thermal limits, Voltage Step, Flicker and Fault level assessments for the second case study	Each calculation is carried out in turn and the result is green in each case	Figure 9 Figure 10 Figure 11 Figure 12
Carry out a calculation of the installed cost for the second case study	This step is used to check that the overall budget cost for the connection is within the budget range for the project	Figure 13
Create a report	Create a report for communicating the results of the connection assessment to interested parties (for example the developer)	Figure 14

Table 2: Steps in Demonstration Project

3.3 Viewing the Video

The video provided with this report is in the form of a file in a Microsoft Windows Media format 'avi'. To view this file on a Microsoft Windows machine, you need a copy of the ''Windows Media Player' software, which is normally available with a standard installation of the Windows operating system. If the software is not available or you are using a non-windows operating system, please refer to your IT department for help, showing them the type of video file. Please refer to Section 6 of this report for a still version of some of the frames in the video.

To operate the video, follow the instructions below:

- Save the Zip file onto your hard drive. The file is likely to be supplied by Email or on CD. The zip file is named 'CASESReportVideo.zip'
- Extract the 'CASESReportVideo.avi' from the zip file
- Double click on video file 'CASESReportVideo.avi'
- The video should start automatically

If this does not work, follow the alternative instructions below:

- Open the ''Windows Media Player' program, using your 'Start' menu. You are likely to find the ''Windows Media Player' under the 'Programs'→'Accessories'→'Multimedia' section of the 'Start' menu
- From the menu of the ''Windows Media Player' program, click File, then click Open
- Browse to your hard drive

- Select ‘CASESReportVideo.avi’ and click Open
- The video should start automatically

If the image in the video does not look clear, change the zoom factor (click menu ‘View’ then ‘Zoom’) or switch to full screen (click menu ‘View’ then ‘Full Screen’). Each part of the video can be replayed or skipped by pressing the respective Previous and Next buttons.

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4 CONCLUSIONS

4.1 Applicability of the Software

This software is specifically designed to carry out connection studies for small embedded generation projects. The primary objective was to develop pilot software to assess the feasibility of connecting generators rated from 100kW to 5MW to the radial distribution networks (e.g., 11kV feeders). The software has been designed so that it can be extended to assess connections to low voltage networks, interconnected 11kV systems, and connections at 33kV and above.

Applications for the software are as follows:

- Design, assess and cost the connection of embedded generations to distribution networks
- Provide the means to undertake a quick initial assessment of a connection, to rapidly establish the viability of the connection
- Act as a training tool for electrical engineers or other engineers not familiar with the specifics of electrical power systems and the connection process for embedded generation

The software acts as a support and decision tool for carrying out connections studies.

4.2 Users of the Software

This tool is aimed at several types of users:

- Distribution Network Operators (DNOs)
- Developers
- Academia

We anticipate that DNOs will use this software in addition to their existing Power System Analysis tools, transferring existing network data between this software and their other tools.

Further benefits to DNOs could include the following:

- Connection costings
- Simple and intuitive user interface
- Equipment library
- Automatic report generation
- Assessments of results
- Extensive engineering help

Developers could use this software to quickly assess the viability of a generation site, as it requires much less specialist knowledge than other tools currently available on the market.

Academia would benefit from using the tool on their teaching courses, where it would provide a practical example of assessing an embedded generation connection as well as extensive background information on the connection process itself.

4.3 Benefits of the Software

The software provides the following benefits:

- Ability to assess rapidly the lowest connection cost
- Processing of a large number of alternative connections
- Improvement in consistency and quality of connection studies
- Training for non-experts
- One- stop tool for connection assessments

The ability to simultaneously assess alternative connection scenarios results permits the selection of the least cost connection option, while at the same time satisfying engineering limits.

The simple and easy user interface makes for a very practical tool which speeds up the operations required for processing increasing number of embedded generation connection applications.

As there is no set way of assessing a grid connection, this tool enables the users to ensure consistency and quality in the assessment process of all their projects.

The tool can be used as a training aid for non-expert engineers to assess straightforward connections, only requiring final checking by more experienced engineers.

The tool aims to cover all aspects of the connection process, linking together the technical and commercial aspects of the connection in a move to reduce the costs of examining connections for smaller generation schemes to determine their viability.

4.4 Further Work

This research project is now complete and has been concluded by the development of a pilot software tool.

Further work is required to convert the pilot software into a commercial software product, and having been convinced of the worth of this product, Econnect is actively pursuing these next steps.

4.5 How to obtain the Software

The commercial software product will be available from Econnect Ltd in the near future. Please contact Econnect Ltd to register your interest and to receive updates on the progress towards a commercial product.

Econnect Ltd contact details are enclosed below.

Web Site	www.econnect.co.uk
Email	info@econnect.co.uk
Telephone	+44 (0) 1434 613600
Fax	+44 (0) 1434 609080
Address	Econnect Limited,
	Energy House
	19 Haugh Lane Industrial Estate
	Hexham
	Northumberland
	NE46 3PU
	UK

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REFERENCES

1 Energy Networks Association (replacing the 'Electricity Association', UK-based association), Engineering Recommendation G59/1, 'Recommendations for the connection of embedded generating plant to the Public Electricity Suppliers distribution systems'. Web site 'www.ena-eng.org'

2 Department of Trade and Industry (DTI, UK government), Distributed Generation Programme, Technical Steering Group (TSG) of the Distributed Generation Co-ordinating Group (DGCG), K/EL/00318/REP and URN 03/1631, 'Technical Guide to the Connection of Generation to the Distribution Network', Keith Jarret, Jonathan Hedgecock, Richard Gregory, Tim Warham, Power Planning Associated, 2003

3 Her Majesty's Stationery Office (HMSO, UK government), Statutory Instruments 2002 No. 2665, 'The Electricity Safety, Quality and Continuity Regulations 2002'. Web Site 'www.hmso.gov.uk'

4 Energy Networks Association (replacing the 'Electricity Association', UK-based association), Engineering Recommendation P28, 'Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom'. Web site 'www.ena-eng.org'

5 International Electrotechnical Commission, IEC 61400-21 (2001-12), 'Wind turbine generator systems - Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines'

6 International Electrotechnical Commission, IEC 60909-0 (2001-07), 'Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents'. Web site 'www.iec.ch'

7 Energy Networks Association (replacing the 'Electricity Association', UK-based association), Engineering Recommendation G74, 'Procedure to meet the requirements of IEC 909 for the calculation of short-circuit currents in three-phase AC power systems'. Web site 'www.ena-eng.org'

8 Energy Networks Association (replacing the 'Electricity Association', UK-based association), Technical Report No. 120, 'Calculation of fault currents in three-phase AC power systems (Application Guide to Engineering Recommendation G74)'. Web site 'www.ena-eng.org'

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5 APPENDIX A – TECHNICAL ASSESSMENTS DEFINITION

This section provides general background information on the technical assessments that the software performs, including definition and associated information.

A technical guide for the connection of embedded generation to the Distribution Network already exists [2] and this section makes reference to this guide where relevant. Any literal reproduction of material from this guide is clearly marked in italics.

5.1 General

C.3.1 Connecting an embedded generation scheme to an electricity distribution network will affect the operation and performance of the network. The DNO will be concerned to maintain network safety, and to ensure that operation of the scheme does not cause problems for nearby electricity users. In particular the DNO will wish to establish that:

- *Voltage levels are kept within statutory limits*
- *Thermal ratings of equipment are not exceeded*
- *Voltage disturbance effects in terms of step changes and flicker are kept to a minimum and are within nationally accepted limits*
- *Fault ratings of switchgear and cables are not exceeded*

C.3.2 Through careful design of the connection arrangement, the developer and the DNO can ensure that the scheme does not cause problems. In some cases, distributed generators can enhance the performance of the network.

The software is designed to provide an assessment of all the main effects on the network of connecting a new embedded generation to the distribution system.

5.2 Voltage Rise

A.3.13 The control of voltage levels in distribution networks is an important issue, due to the need to maintain consistent supplies to electricity users. Although DNOs try to keep system voltages close to their nominal levels, the actual voltage varies from point to point around the system, and also with time as the load on the system changes. Voltages tend to fall when people are using a lot of electricity and they are often lower at the ends of long distribution lines.

A.3.14 Conversely, power in-feeds from distributed generators tend to increase local voltage levels.

The voltage rise assessment is designed to provide the software user with an assurance that voltage levels can be kept within statutory limits.

5.3 Thermal Limits

C.3.11 Each element of the distribution infrastructure - lines, cables, transformers etc has a limited current-carrying capacity. If it is loaded above this limit for an extended period of time, it will overheat. For this reason, the current-carrying capacity of the

device is referred to as its thermal rating. Loading a device beyond its thermal rating may lead to permanent damage, or even to a dangerous event such as a fire or explosion.
C.3.13 Connecting a generator to a distribution system has the effect of changing the current flows in the system.

The thermal limits assessment is designed to provide the software user with an assurance that changed current flows due to the new embedded generator do not exceed the thermal limits of the existing and new equipment related to the connection.

5.4 Voltage Step

C.3.20 The process of starting a distributed generator can sometimes cause step changes in voltage levels in the distribution network.
C.3.21 Step voltage changes will also occur whenever a loaded generator is suddenly disconnected from the network due to faults or other occurrences.
C.3.22 The magnitude of a step voltage change depends on the method of voltage control, types of load connected and the presence of other local generation.

The voltage step assessment is designed to provide the software user with an assurance that starting and disconnection of the new embedded generator will not cause step changes in voltage to exceed the statutory limits.

5.5 Flicker

C.3.34 Voltage flicker refers to rapid fluctuations in the voltage level on a distribution system. These fluctuations can be very annoying for local electricity users, as they cause incandescent lamps to 'flicker' instead of producing a steady light.

The flicker assessment is designed to provide the software user with an assurance that any rapid fluctuations in voltage levels due to the new embedded generator do not exceed statutory limits.

5.6 Fault Levels

A.3.20 Although distribution networks are very reliable systems, electrical faults do occur. These faults may be caused by events such as an overhead line breaking, or the accidental excavation and damage to an underground cable. When these things happen, very high currents can occur at the fault and in the parts of the network that feed current into the fault. If they are not quickly detected and stopped, these fault currents are a risk to life and can cause extensive damage to cables, transformers and other equipment, as well as affecting the supply of electricity to consumers.
A.3.21 To protect people and to guard the distribution infrastructure from the effects of faults, fuses and circuit breakers are fitted at strategic points in the network, together with other systems which trip the circuit breakers on detection of unusually

high currents or other abnormal conditions. These circuit breakers and tripping devices are known as protection systems.
A.3.26 At a given moment, every point in a distribution network has a particular fault level. The fault level is a measure of the current, which would occur in the event of a fault at that point.

The fault levels assessment is designed to provide the software user with an assurance that any fault currents that may occur when the new embedded generator is connected do not exceed statutory limits.

6 APPENDIX B – SOFTWARE DEMONSTRATION SCREENS

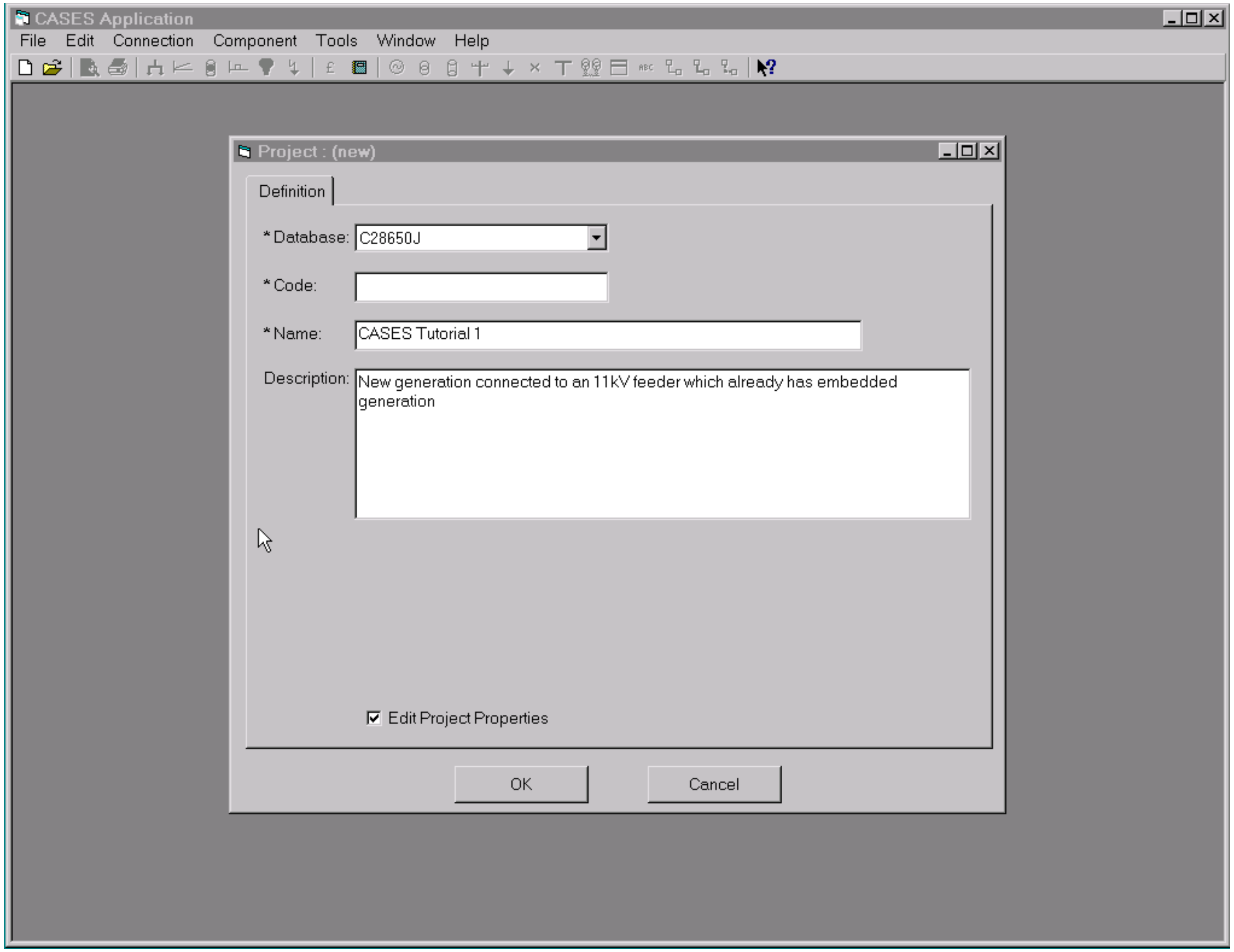


Figure 3: Create a New Project

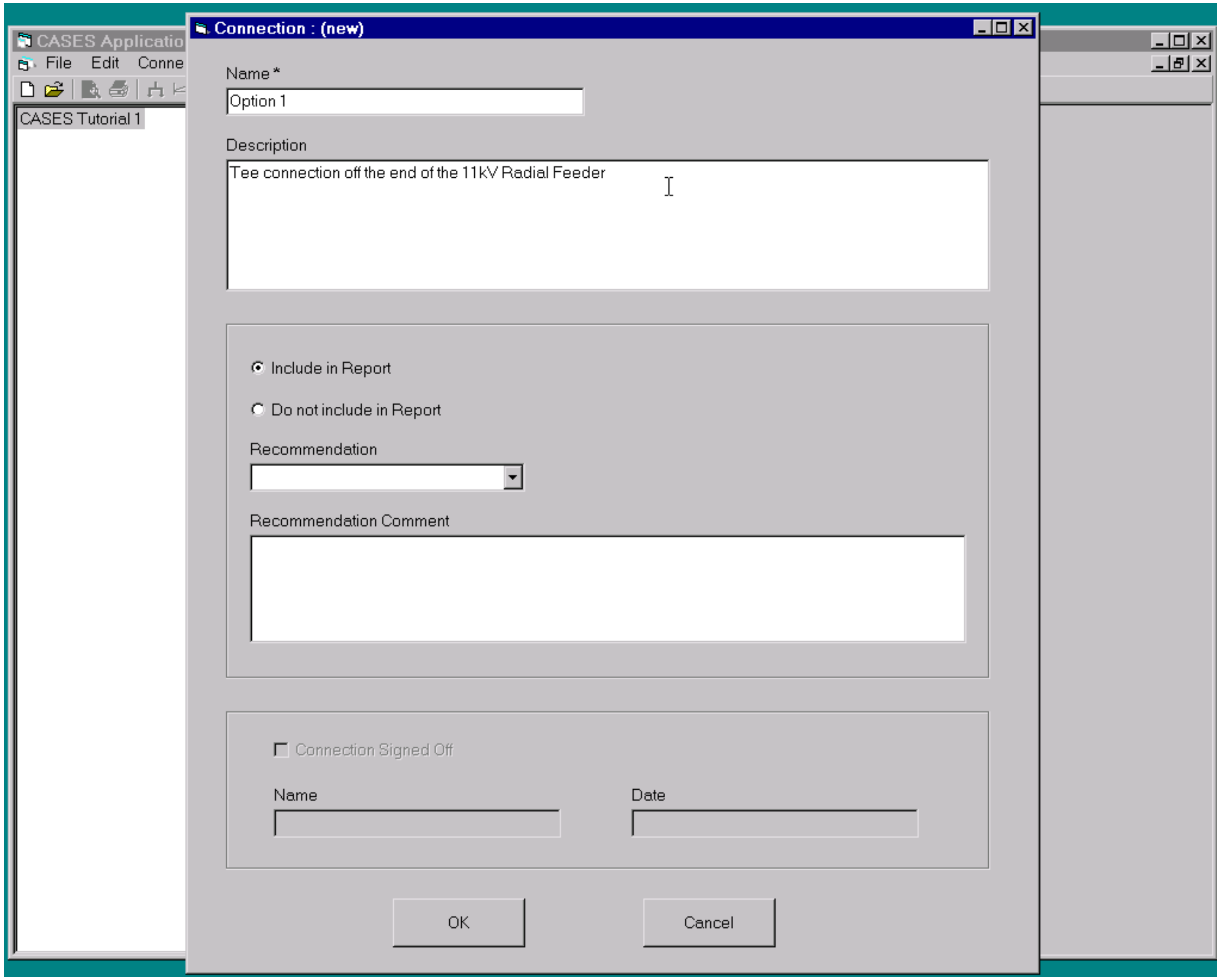


Figure 4: Create a New Connection Option

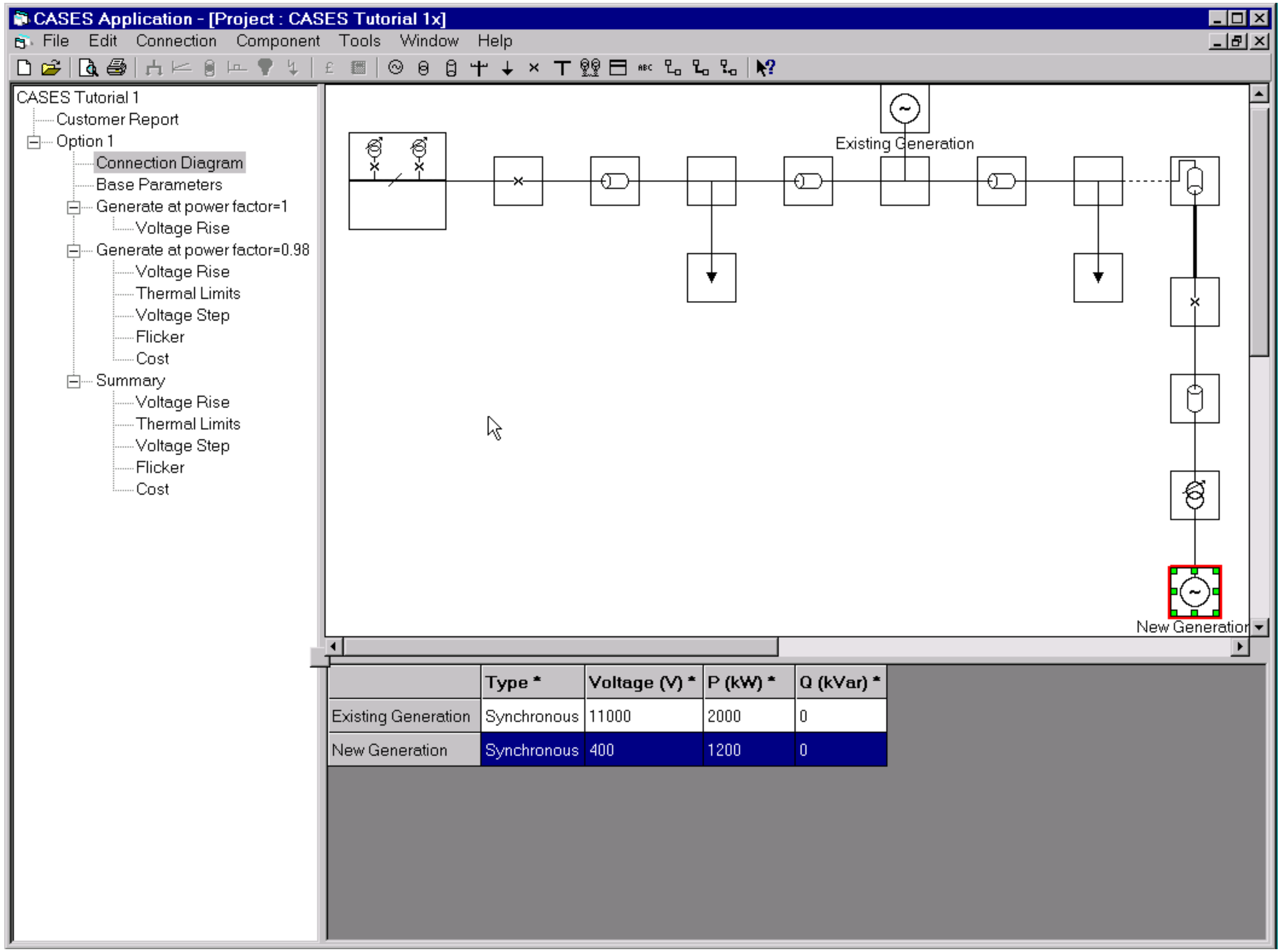


Figure 5: Create a Connection Diagram

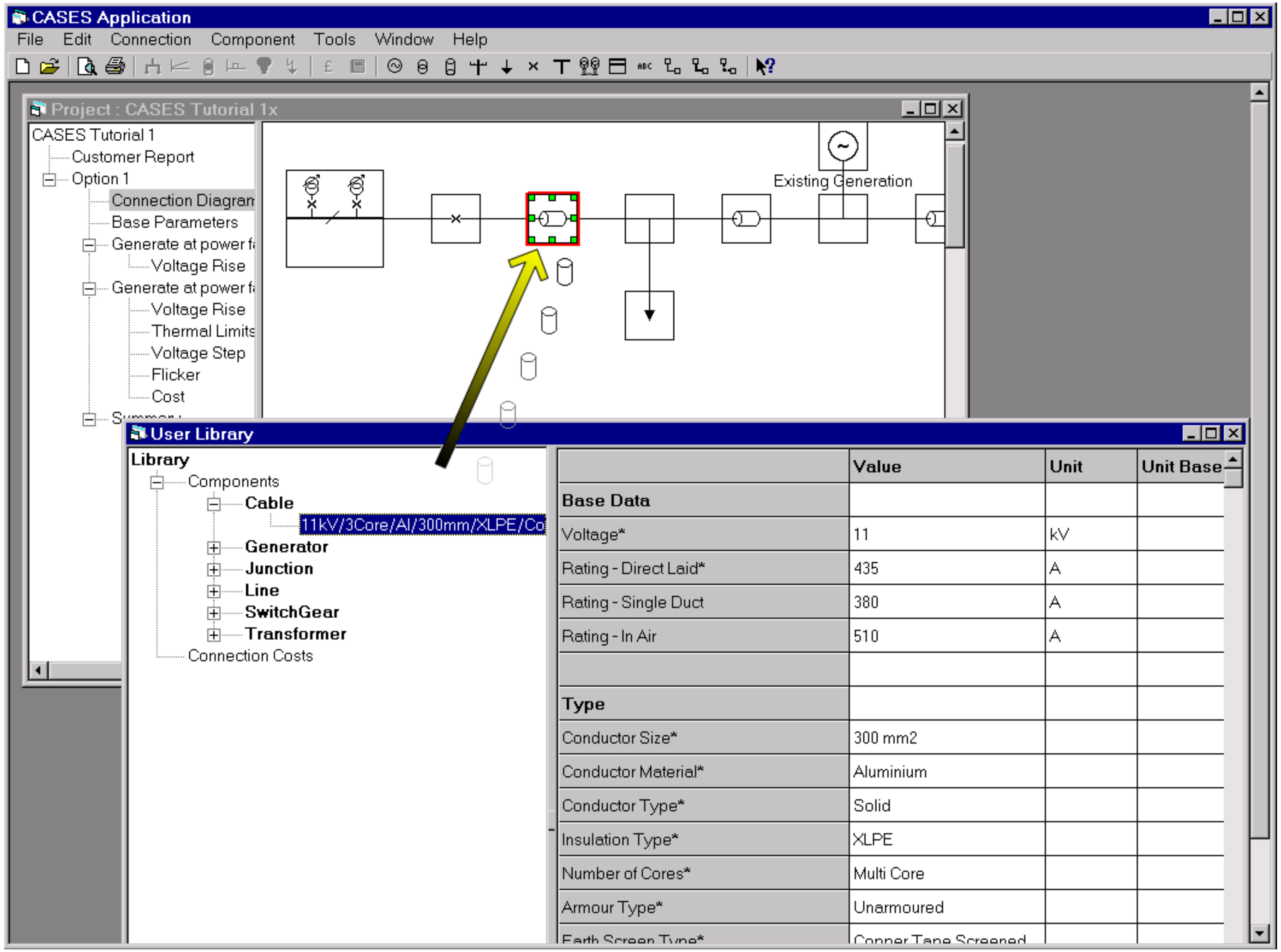


Figure 6: Use the Library

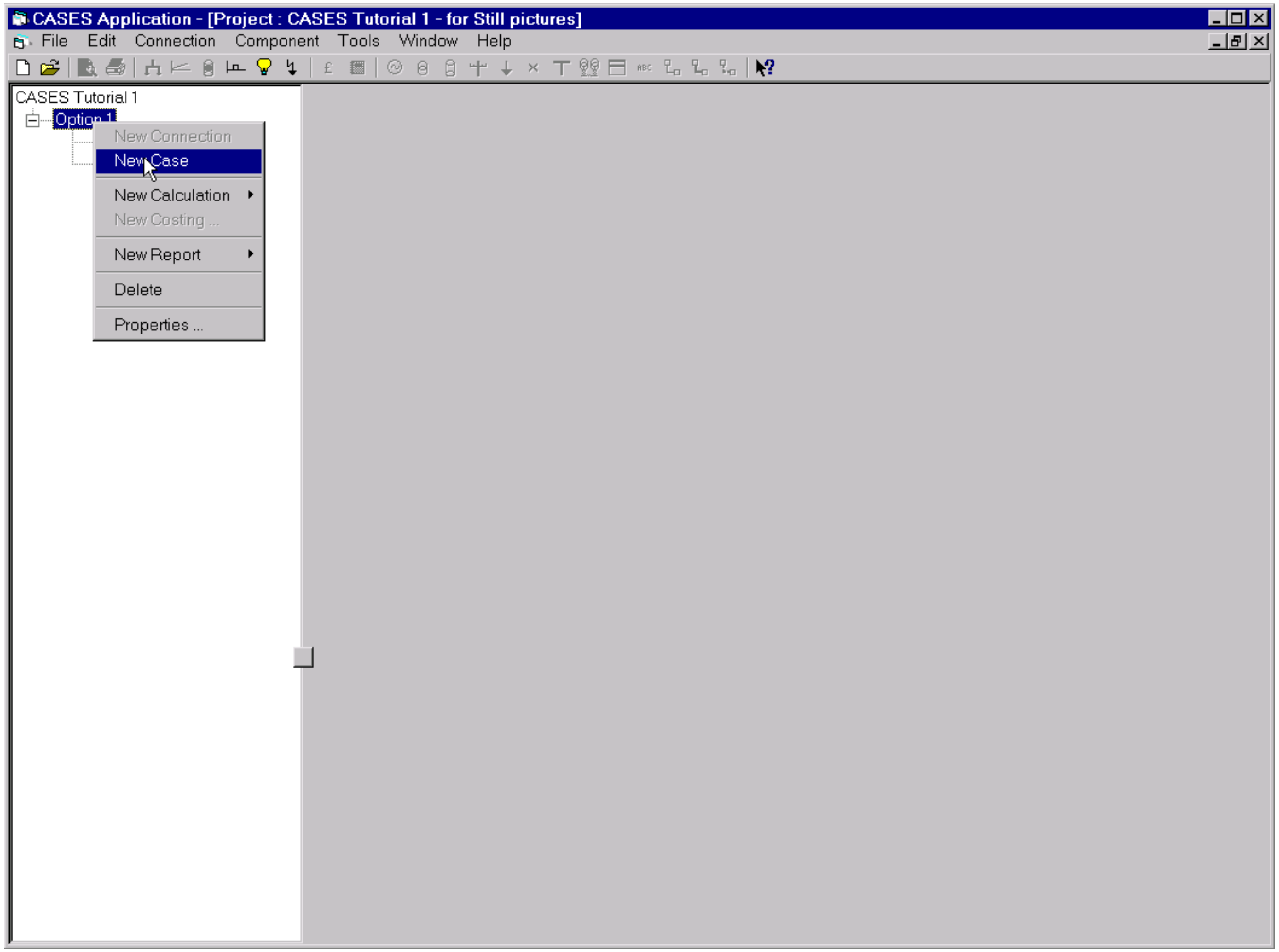
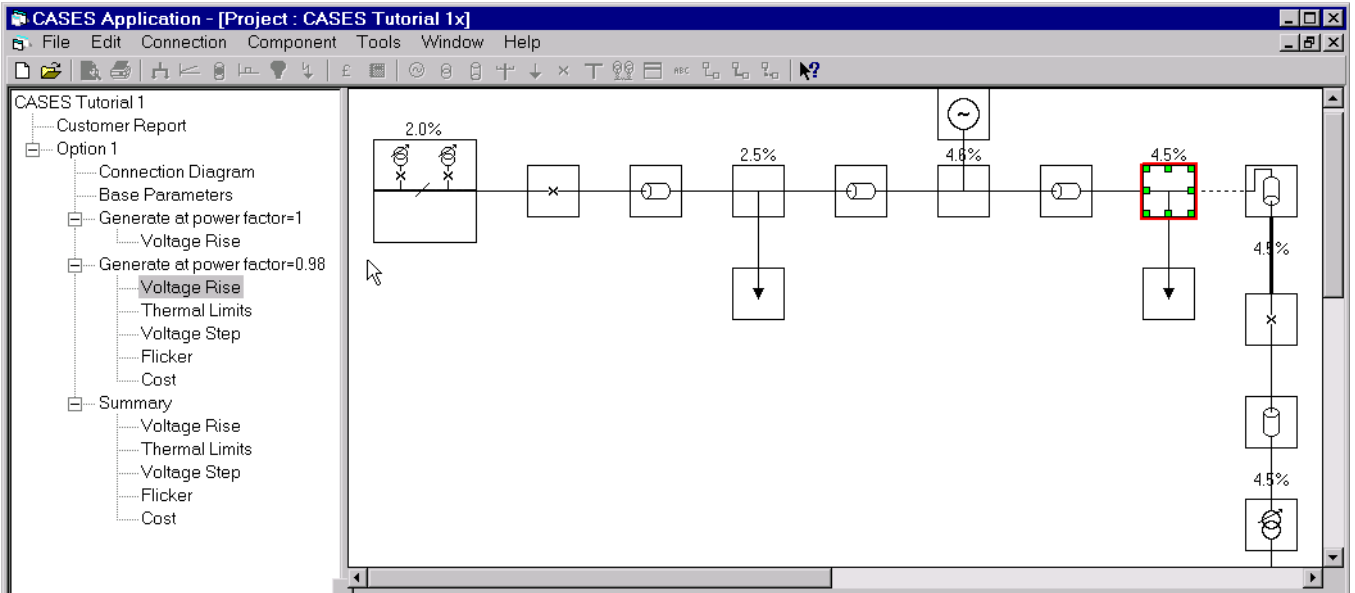


Figure 7: Create a Case Study



	Volt C	Rise C
ConnSourceSubStation_1	1.02pu	2%
ConnJunction_4	1.024pu	2.45%
ConnJunction_7	1.046pu	4.55%
ConnJunction_10	1.045pu	4.48%
Copy Of 11kV/3Core/Al/300mm/XLPE/CoTape/Unarm_835	1.045pu	4.5%
Copy Of 11kV/3Core/Al/300mm/XLPE/CoTape/Unarm_837	1.045pu	4.5%
New Generation	1.043pu	4.32%
Overall	Green	
Limit		6%

Figure 8: Voltage Rise Assessment

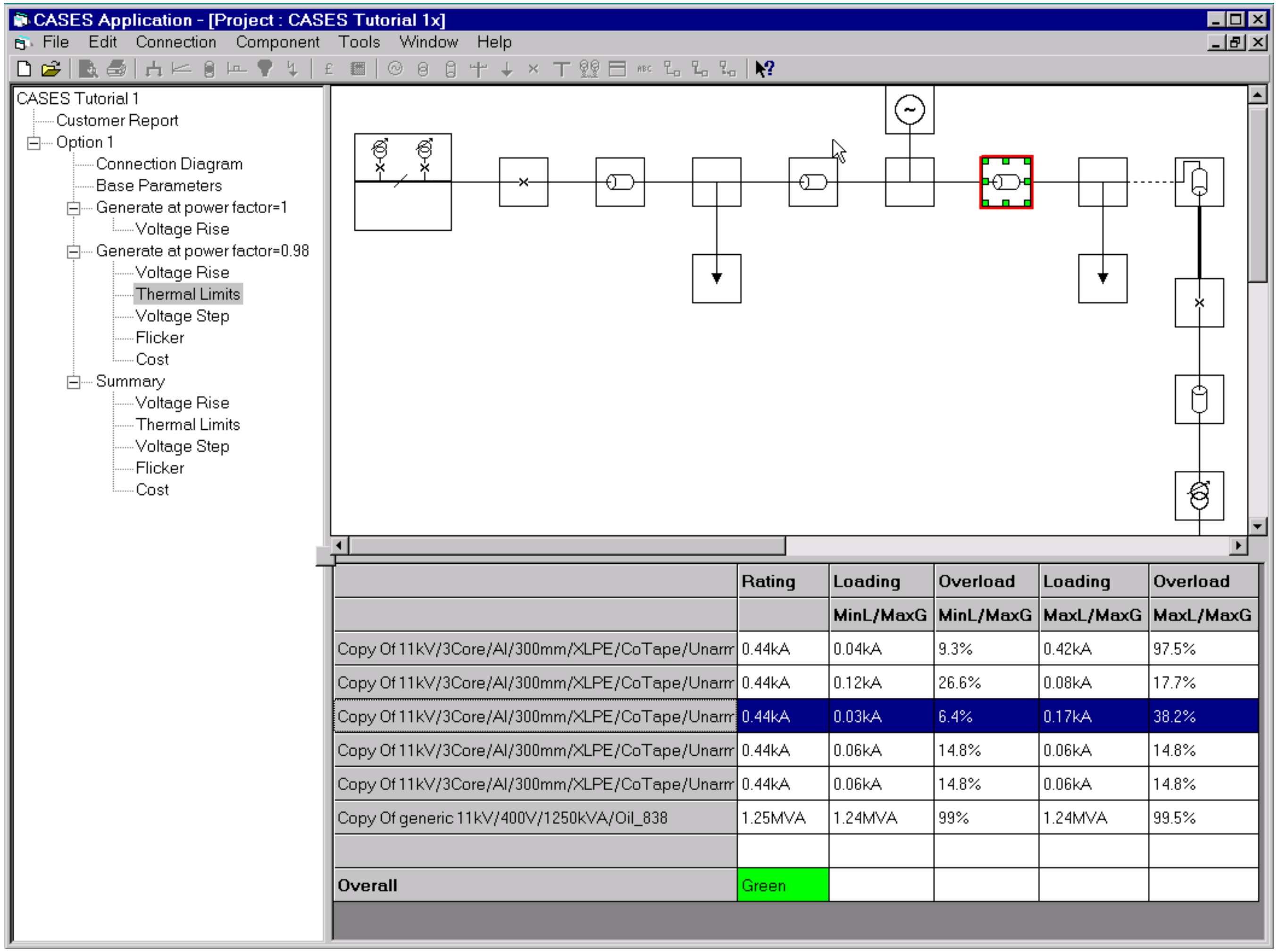


Figure 9: Thermal Limits Assessment

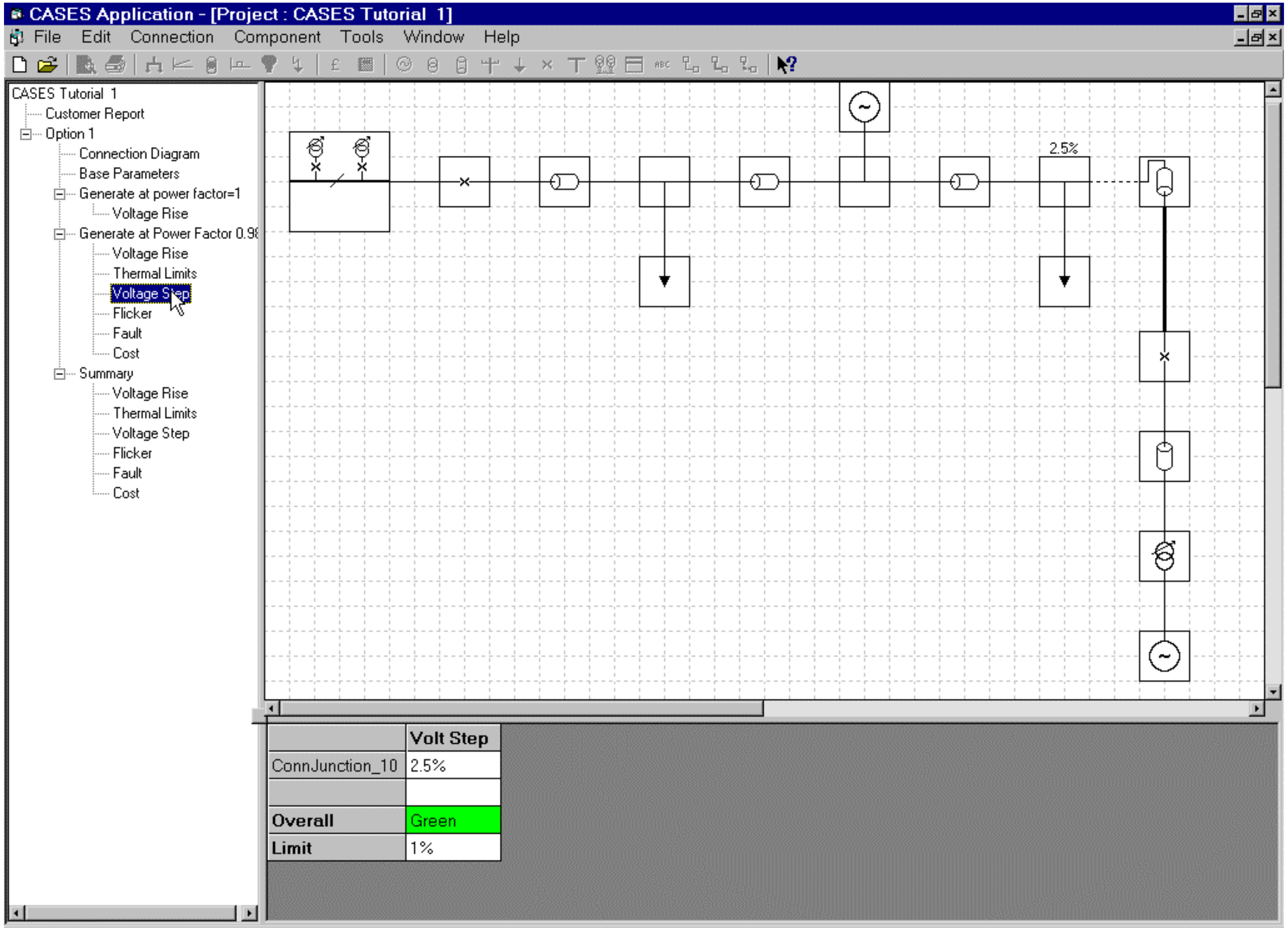


Figure 10: Voltage Step Assessment

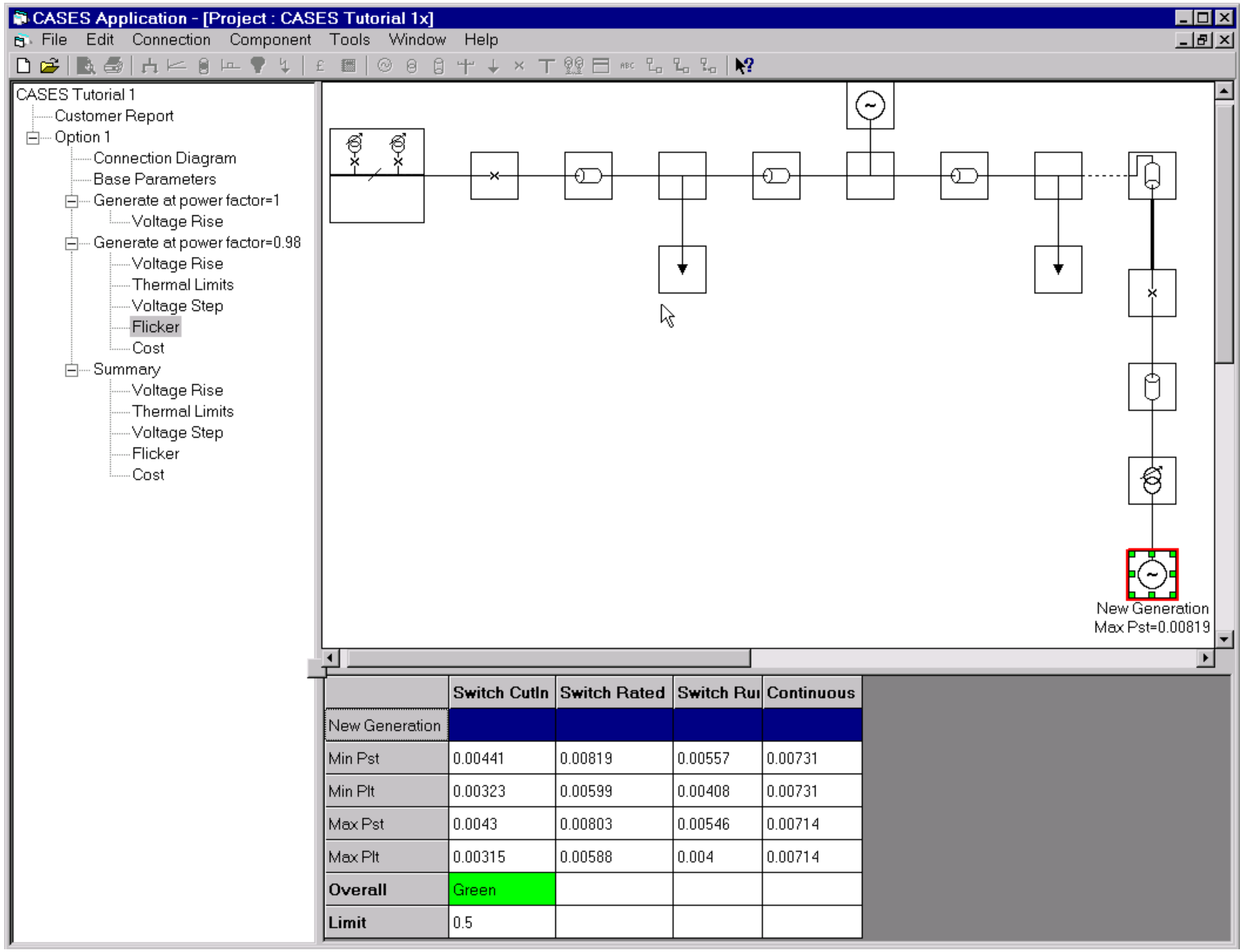


Figure 11: Flicker Assessment

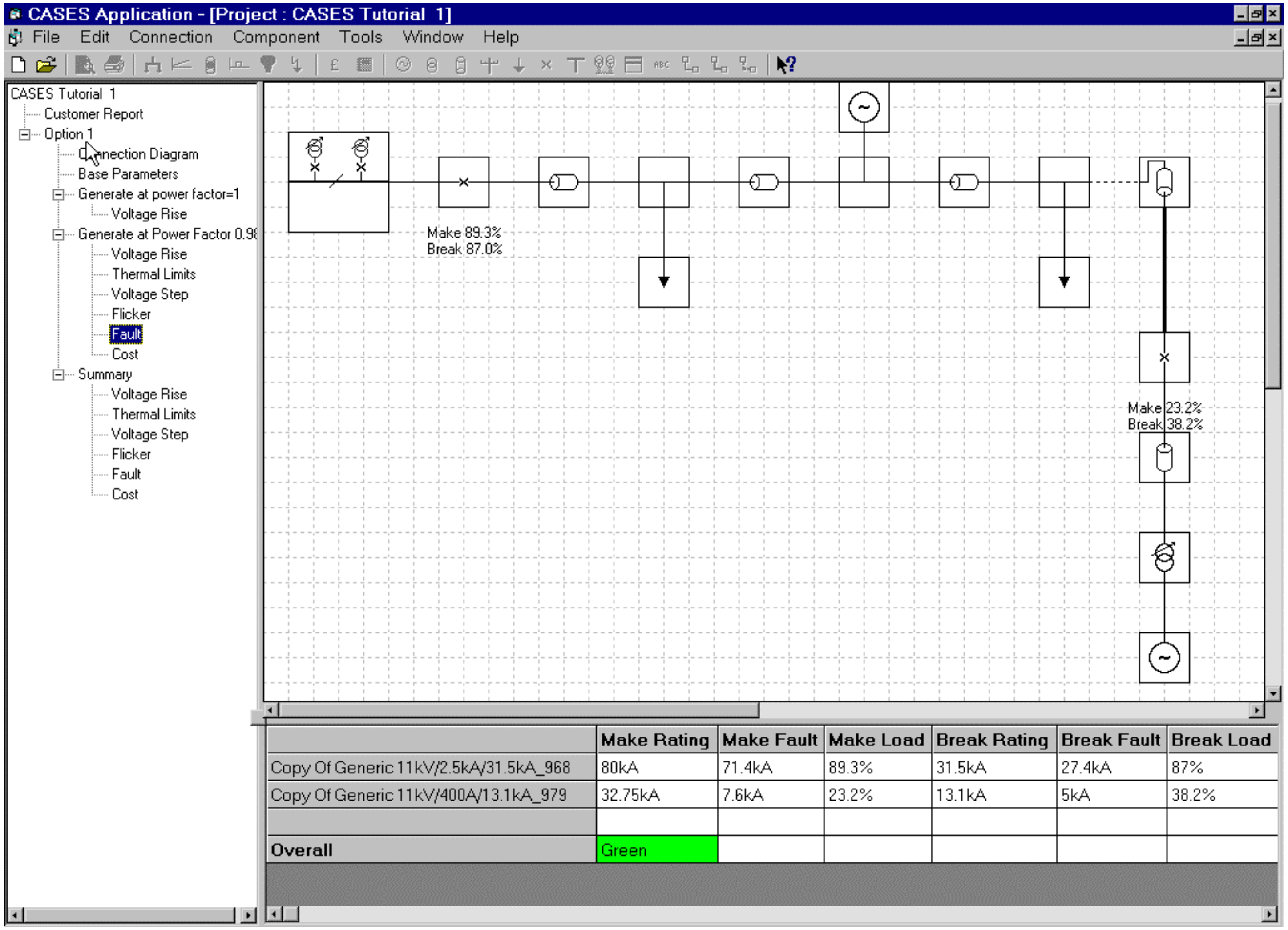


Figure 12: Fault Levels Assessment

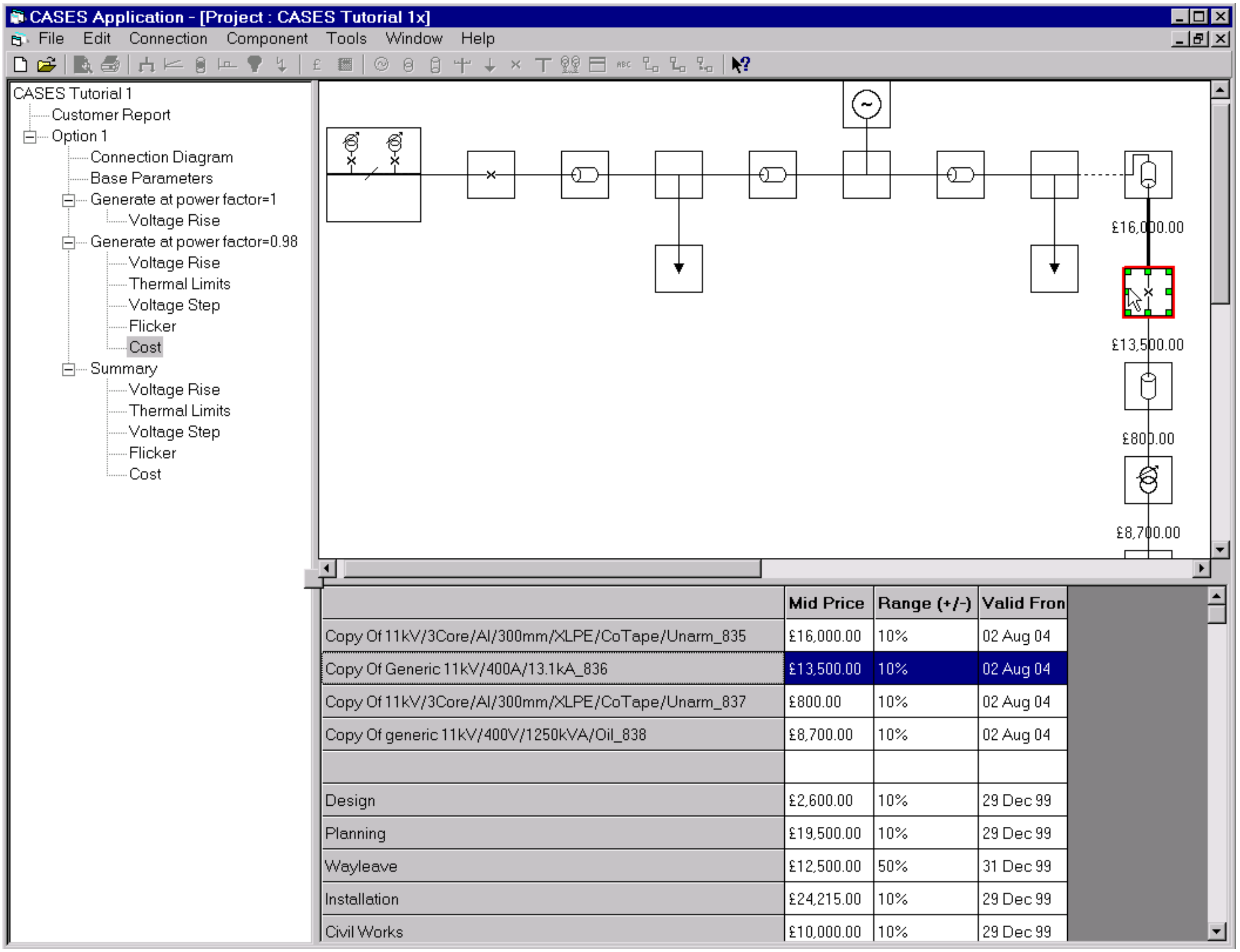
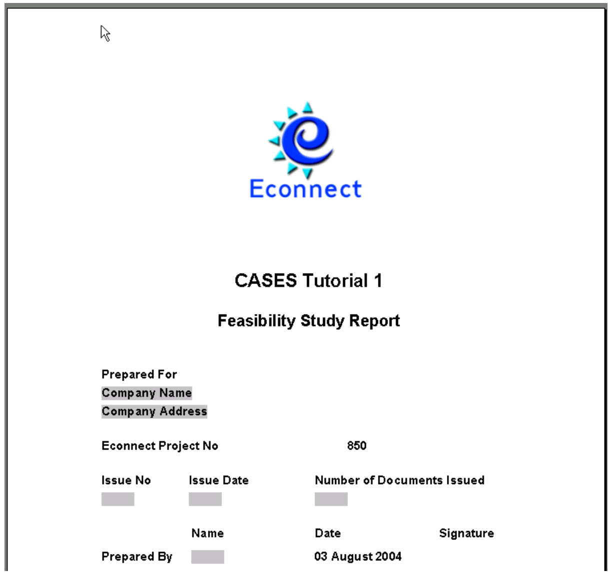
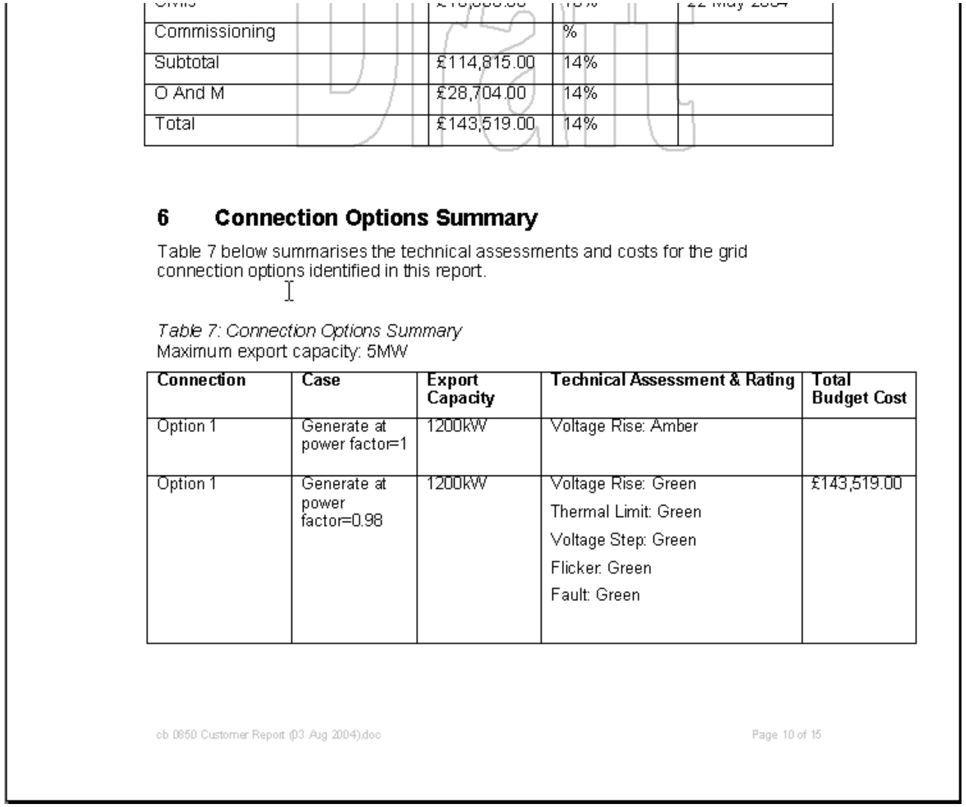


Figure 13: Costing Assessment





Commissioning		%	
Subtotal	£114,815.00	14%	
O And M	£28,704.00	14%	
Total	£143,519.00	14%	

6 Connection Options Summary

Table 7 below summarises the technical assessments and costs for the grid connection options identified in this report.

Table 7: Connection Options Summary
Maximum export capacity: 5MW

Connection	Case	Export Capacity	Technical Assessment & Rating	Total Budget Cost
Option 1	Generate at power factor=1	1200kW	Voltage Rise: Amber	
Option 1	Generate at power factor=0.98	1200kW	Voltage Rise: Green Thermal Limit: Green Voltage Step: Green Flicker: Green Fault: Green	£143,519.00

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Figure 14: Automatic Report

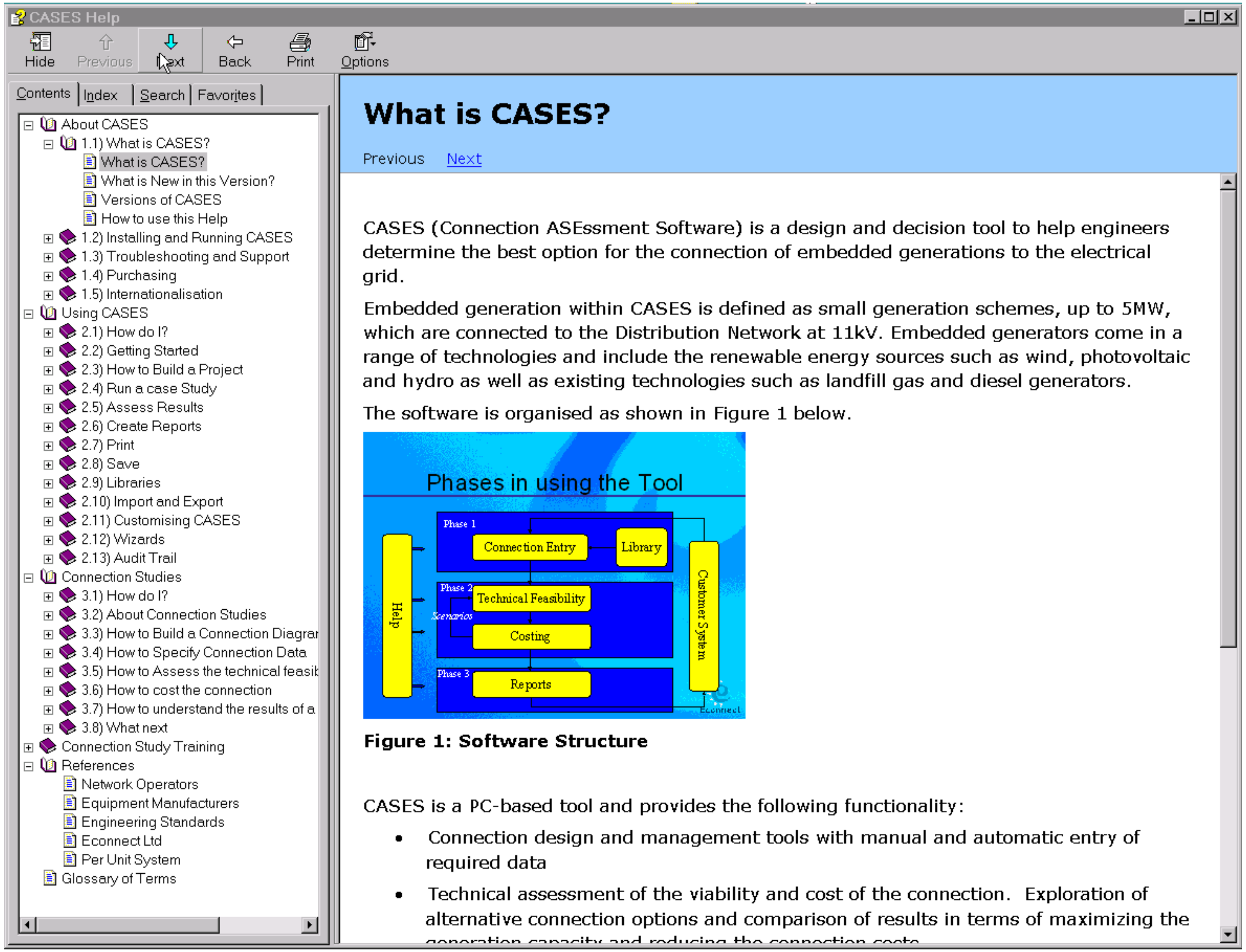

Figure 15: Help System