



WPD Virtual Statcom WP3 report

For: Western Power Distribution

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Executive Summary

Political and social forces in the UK are driving the change towards clean low carbon technologies such as renewable generation. As renewable distributed generators (DGs) are becoming integrated into existing electricity networks, technical constraints arise that can limit the total amount of generation or load a network can host. The Virtual Statcom project is an innovation project that seeks to investigate the technical feasibility of increasing the network hosting capacity, for both generation and load, by optimising the reactive power dispatch of DGs.

As part of this investigation two main algorithms have been developed. The first is an algorithm to determine the generation and load hosting capacity of a network and the second is an algorithm to optimise the reactive power dispatch of existing generators with the aim to increase hosting capacity. This report presents the graphical user interface (GUI) that has been developed to allow users to run the Virtual Statcom algorithms.

The Virtual Statcom GUI was developed using agile development and testing cycles to successfully develop a GUI that meets the following functional requirements:

- Allows the user to evaluate the existing capacity of the selected network zone. This can be any network and not necessarily one of the four zones used for the Virtual Statcom development.
- Allows the user to run the optimisation algorithm for the network they select and evaluate the new network capacity.
- Allows the user to perform the above two functions in snapshot scenarios or in time-series studies.
- Present the summary results in a clear way.
- Output the detailed results in an Excel spreadsheet.

The development of the Virtual Statcom GUI provided several learnings that should be considered for future projects of a similar nature. The use of an agile development and testing approach when developing the GUI ensured an efficient process that met the functional and user requirements of the project. Additionally, future projects should consider prior to the onset of the GUI development; the configuration of end user systems where the GUI will be deployed, defining detailed functional requirements and defining user acceptance criteria.

Table of Contents

1. Introduction	1
1.1. Introduction to Project	1
1.2. Introduction to This Report.....	1
2. GUI Functional Requirements.....	2
3. Initial GUI Design.....	3
3.1. Main GUI window	3
3.2. Secondary User Interface Windows.....	6
4. GUI Development and Testing.....	8
4.1. Virtual Statcom GUI Revision 1	8
4.2. Virtual Statcom GUI Revision 2	11
4.3. Virtual Statcom GUI Revision 3	14
5. Final GUI.....	17
5.1. Main GUI window	17
5.2. Functionality	18
5.3. Network Selection and Data Extraction Functionality	18
5.4. Capacity Evaluation Functionality.....	21
5.5. Snapshot and Timeseries Functionality	23
5.6. Output Functionality	25
6. Key Learnings and Recommendations.....	28
6.1. Learnings.....	28
6.2. Recommendations	29
References	30

Table of Abbreviations

Abbreviation	Term
DG	Distributed Generator
FPL	Flexible Power link
LTDS	Long Term Development Statement (Nov 2018)
MW	Megawatts, unit for real power
Mvar	Mega volt-amperes reactive, unit for reactive power
NIA	Network Innovation Allowance
NOP	Normally open point
OPF	Optimal power flow
ORPD	Optimal reactive power dispatch
p.u.	Per unit
pf	Power Factor
PSC	Power Systems Consultants UK Ltd
PSS/E	Power System Simulator for Engineering
Python	A high-level, general-purpose programming language
RPF	Reverse power flow
SCADA	Supervisory Control and Data Acquisition
Statcom	Static Synchronous Compensator
UKPN	United Kingdom Power Networks
VBA	Visual Basic for Applications
WP	Work Package
WPD	Western Power Distribution

1. Introduction

1.1. Introduction to Project

Western Power Distribution (WPD) has engaged Power Systems Consultants UK Ltd. (PSC) to deliver an innovation project known as the Virtual Statcom, the project is being run by WPD and funded under the Ofgem, Network Innovation Allowance (NIA).

As an increasing number of distributed generators (DGs) connect to distribution networks, technical constraints arise that can limit the total amount of generation a network can host. To overcome the technical constraints associated with distributed generators and continue to operate a safe, secure and reliable network, WPD undertake traditional network reinforcements as well as initiating and leading innovation projects to develop new solutions. A key focus of innovation projects is to increase the utilisation of existing assets to defer network reinforcements. The Virtual Statcom project fits in this category of project.

The objective of the Virtual Statcom project is to determine the technical feasibility of increasing network hosting capacity, for both generation and load, through implementing an algorithm to control and coordinate the reactive power output of existing generators in the distribution network.

If the project demonstrates benefit, it will enable more generation and load to be connected to the distribution network without the need for network reinforcement.

The project is structured into the following 5 main work packages (WP):

- WP1 - Data gathering/validation and study zone selection.
- WP2 - Power flow simulations & Virtual Statcom algorithms.
- WP3 - Graphical User Interface.
- WP4 - Time series comparison studies.
- WP5 - Virtual Statcom feasibility study reporting.

The work packages are being delivered in order, except WP3 and WP4 which are being delivered in parallel.

1.2. Introduction to This Report

This report details the work completed in delivering WP3. WP3 developed a Graphical User Interface (GUI) to enable users to run the Virtual Statcom algorithms.

- Section 2 details the functional requirements for the Virtual Statcom GUI.
- Section 3 presents the initial GUI design.
- Section 4 provides a summary of the development and testing of the Virtual Statcom GUI.
- Section 5 presents details of the final Virtual Statcom GUI implemented.
- Section 6 provides the learnings and recommendations from the development of the GUI.
- Appendix A provides the user guide for the Virtual Statcom GUI

2. GUI Functional Requirements

The Virtual Statcom project developed algorithms to determine the technical feasibility of increasing network hosting capacity, for both generation and load, by optimising the reactive power output of existing generators in the distribution network.

To facilitate easy usage of the Virtual Statcom algorithms, development of a Graphical User Interface (GUI) was required. The following sets out the functional requirements for the GUI from the project collaboration agreement between PSC and WPD [1]:

D3-1 Graphical User Interface (GUI) Functional Specification

This includes the functional specification of the Graphical User Interface. The main functions of the Graphical User Interface must include the following:

- a) Allow the user to evaluate the existing network capacity of the network they select. This can be any network and not necessarily one of the four selected zones.*
- b) Allow the user to run the optimisation algorithm for the network they select and evaluate the new network capacity.*
- c) Allow the user to perform the above two functions in snapshot scenarios or in time-series studies.*
- d) Present the summary results in a clear way.*
- e) Output the detailed results in an Excel spreadsheet.*

D3-2 Implementation of Graphical User Interface

This includes the implementation of the GUI and all required rounds of review and testing until it is approved by WPD.

3. Initial GUI Design

This section provides the initial design developed for the GUI to meet the functional requirements set out in Section 2. The development of the initial design was undertaken in consultation with WPD following the development and review of a GUI concept and functional description [2].

3.1. Main GUI window

The purpose of the GUI is to allow a user to interact with the Virtual Statcom algorithms developed as part of the Virtual Statcom project. Details on those algorithms are detailed in the WP2 and WP3 reports [3] [4].

The initial design decisions were based on providing a user interface that followed a logical, sequential process to allow the user to configure all relevant parameters required to run the Virtual Statcom algorithms. The intention of using a sequential process for the GUI was to guide the user's interaction and facilitate ease of use of the Virtual Statcom algorithms. For example, a user needs to load PSS/E case to run any studies and so the GUI requires the loading of a PSS/E case prior to any other options being available to the user. The sequential process follows the following high-level steps:

1. Load a PSS/E case
2. Select a network zone or zones.
 - 2.1. Select specific generators to include in the Virtual Statcom studies (by default all existing generators are included).
3. Configure limits and settings for power system studies.
4. Select type of hosting algorithm to run (generation hosting or load hosting).
 - 4.1. Configure locations where dummy generation¹ should be added.
5. Select the hosting capacity evaluation approach².
6. Select contingencies³ to include in the Virtual Statcom studies (by default studies are only run on the intact system).
7. Select where results will be saved and run the studies.

Figure 3-1 shows the initial layout design of the main GUI window with components grouped based on this process.

¹ Dummy generation is the term used in the Virtual Statcom project to describe new generators that are added to a PSS/E case. Details of the location and placement of dummy generators are included in Virtual Statcom WP2 Report [3].

² The Virtual Statcom developed two capacity evaluation study approaches (traditional planning and per contingency). The approaches are detailed in Virtual Statcom WP2 Report [3]

³ A contingency is the terminology used to describe the removal of a power system asset(s) (e.g. a transmission line, a transformer) from a network in its normal operation configuration. Details of contingency types and naming conventions used in the Virtual Statcom project are included in as an appendix to the user guide in Appendix A.

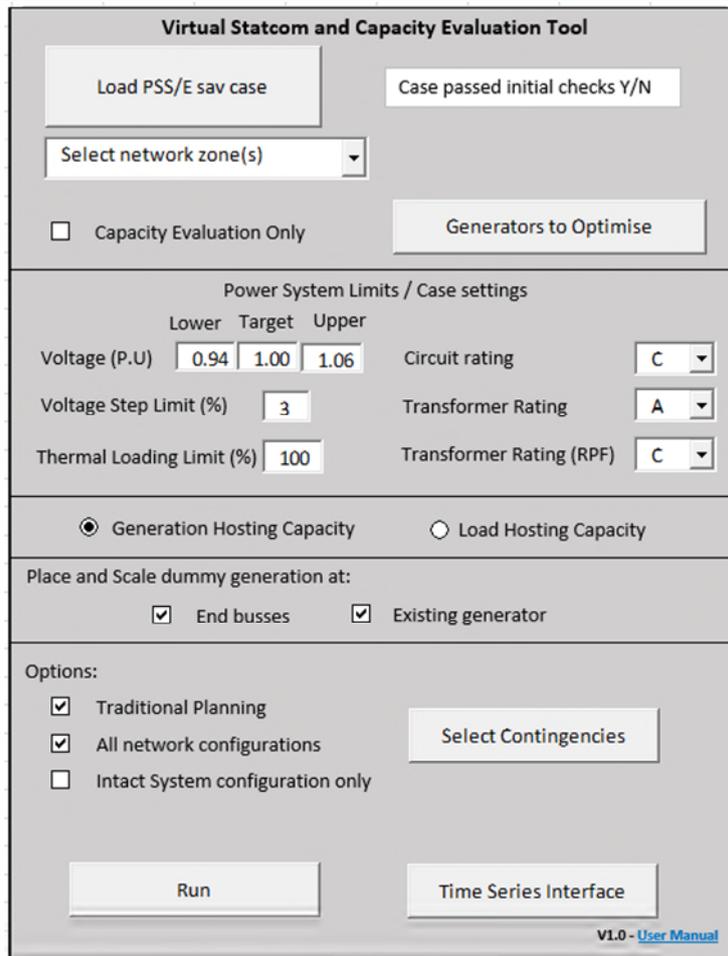


Figure 3-1 Main Virtual Statcom GUI window

Table 3-1 details the original design intent and the initial interaction considerations for the main GUI window.

Table 3-1 - Main GUI window initial design intent

GUI component	Original design intention	Interaction considerations
Load PSS/E SAV Case Button	To allow the user to load a PSS/E sav case.	<ul style="list-style-type: none"> • First action available to the user. • Other GUI components available to the user only if PSS/E case passes initial convergence checks (i.e. a valid PSS/E case).
Select Network Zone(s) drop-down	To allow the user to select network zones for study based on the loaded PSS/E sav case.	<ul style="list-style-type: none"> • Requires a valid PSS/E case.
Capacity Evaluation Only checkbox	To allow the user to run the capacity evaluation algorithm only.	<ul style="list-style-type: none"> • Requires a valid PSS/E case.

GUI component	Original design intention	Interaction considerations
Generators to Optimise button	To load a window to allow the user to select specific generators to include in the Virtual Statcom algorithm.	<ul style="list-style-type: none"> Requires a valid PSS/E case. Available to the user if Capacity Evaluation checkbox is not ticked.
Power System Limits / Case Settings input boxes	To allow the user to configure the power system limits and branch ratings to be used when running the Virtual Statcom algorithms.	<ul style="list-style-type: none"> Ratings drop-downs require a valid PSS/E case.
Generation Hosting and Load Hosting radio boxes	To allow the user to select to run either the generation hosting algorithm or the load hosting algorithm.	
Place and scale generation at checkboxes	To allow the user to place dummy generation at existing generator locations or/and end buses	
Options checkboxes	To allow the user to run a traditional planning study or to run a per contingency study for selected contingency configurations.	
Selection Contingencies button	To load a window to allow the user to select the contingencies to be included in the Virtual Statcom algorithms.	<ul style="list-style-type: none"> Requires a valid PSS/E case.
Time Series interface button	To load a window to allow the user to configure time series data.	<ul style="list-style-type: none"> Requires a valid PSS/E case.
Run button	User runs a study with user configured parameters from GUI and with results saved in user selected location.	<ul style="list-style-type: none"> Requires a valid PSS/E case.

3.2. Secondary User Interface Windows

3.2.1. Generator Selection Window

Figure 3-2 shows the original design of the Generator Selection window. This window was designed with the intention of allowing the user to select the generators to include in the Virtual Statcom optimisation algorithm. A decision to have all generators selected by default was made to have the greatest number of generators available for reactive power dispatch during a Virtual Statcom study. Select All/ Select None buttons were included in the design to allow the user to easily select all or none of the displayed generators as appropriate.

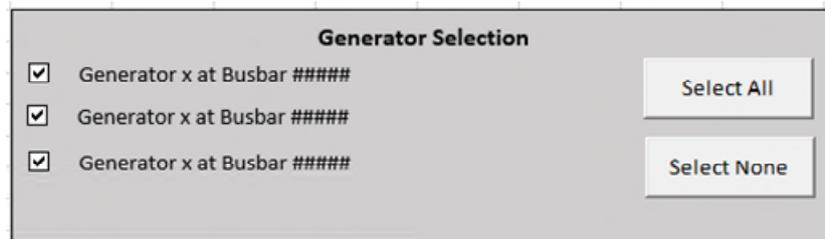


Figure 3-2: Selection of specific generation

3.2.2. Contingency Selection Window

Figure 3-3 shows the original design of the Contingency Selection window. This window was designed with the intention of allowing the user to select the contingency configuration to include in the Virtual Statcom algorithms. Select All/ Select None buttons were included in the design to allow the user to easily select all or none of the displayed contingencies as appropriate.

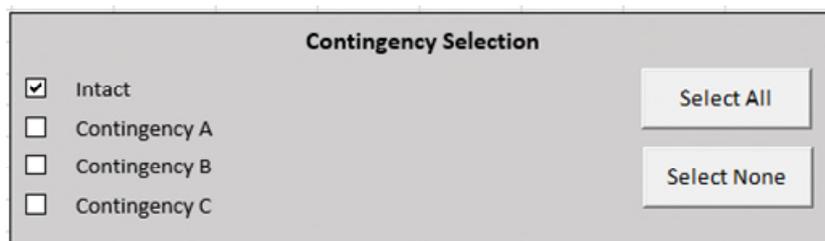


Figure 3-3: Selection of specific contingencies

3.2.3. Time Series Interface Window

Figure 3-4 show the original design of the Time Series Interface window. The Time Series interface window was designed to allow the user to configure time series generation and load data to be able to run time series analysis.

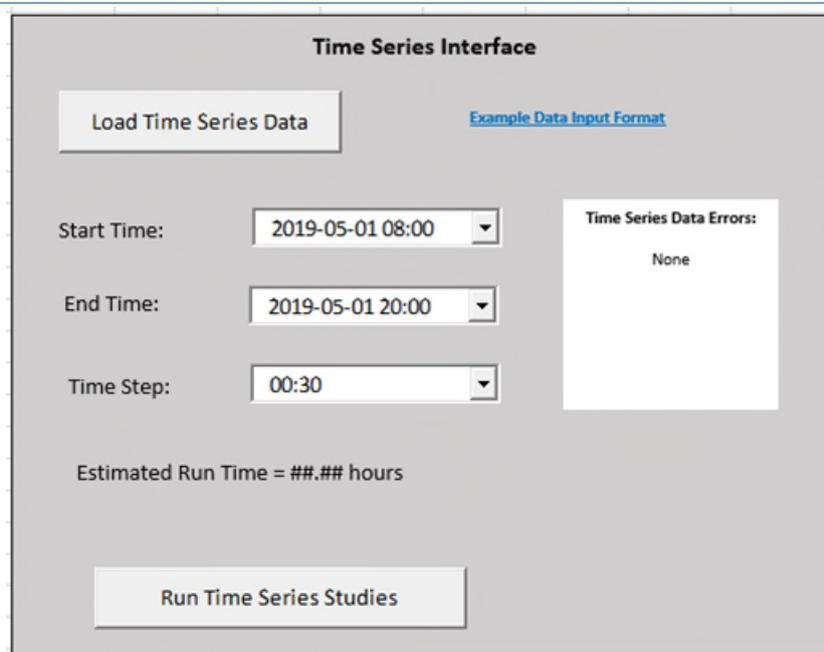


Figure 3-4: Time series interface

Table 3-2 details the original design intent and the initial interaction considerations for the time series interface window.

Table 3-2 – Time series interface window initial design intent

GUI Component	Original design intention	Interaction considerations
Load Time Series Data Button	To allow a user to load time series generation and load data for a PSS/E sav case network.	
Time Series Data Errors display box	To provide user information only the quality of the time series data.	<ul style="list-style-type: none"> Requires time series data to be loaded.
Example Data Input Format hyperlink	To provide an example format for the input that needs to be provided.	<ul style="list-style-type: none"> Requires time series data to be loaded.
Start / End Time and Time Step	To allow a user to select the start time and end time and time step to use for time series studies	<ul style="list-style-type: none"> Requires time series data to be loaded.
Run Time Series Studies Button	To allow the user to run time series studies.	<ul style="list-style-type: none"> Requires time series data to be loaded.

4. GUI Development and Testing

The development of a GUI is an agile process as differences in user intentions and systems are observed. Figure 4-1 shows the agile approach used to develop the final GUI.

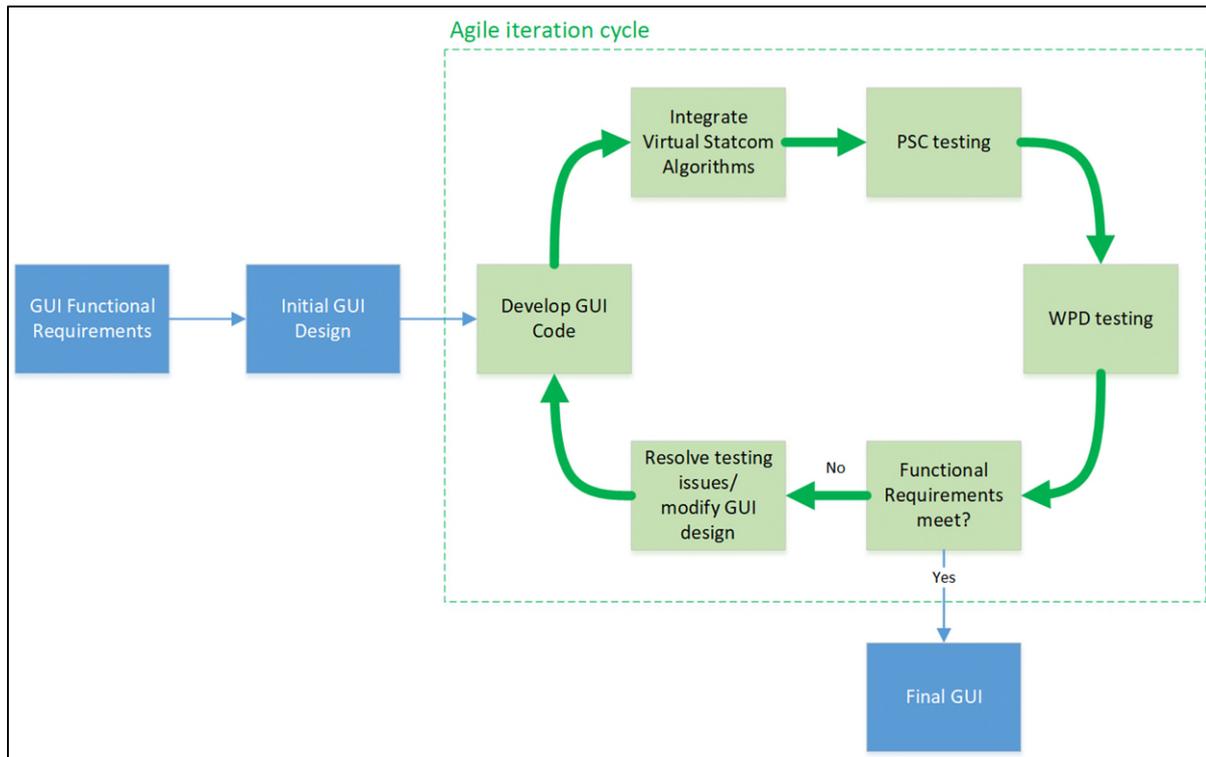


Figure 4-1 - Virtual Statcom GUI agile development approach

The Virtual Statcom GUI underwent two agile iteration cycles to produce the final GUI (Section 0). Throughout the development and testing iteration cycles a formal process of capturing testing comments and development resolutions was used to track progress towards a GUI that met the functional requirements. The code development was managed using a code repository and revision control between PSC and WPD was implemented and managed through an online shared folder.

This section presents a summary of the development and testing of the Virtual Statcom GUI.

4.1. Virtual Statcom GUI Revision 1

The purpose of the GUI Revision 1 release was to ensure that the GUI could run on non-PSC computers and that the user could successfully run the Virtual Statcom algorithms. An advantage of the agile approach used in the development of the GUI meant that functionality was added incrementally to the GUI and that full functionality is not required before user testing can begin. The GUI Revision 1 was limited to only providing per contingency functionality as the traditional planning algorithm had not been integrated into the GUI at the time of release. This section provides a summary of the development and testing of the Virtual Statcom GUI Revision 1.

4.1.1. Development

The development of GUI Revision 1 involved integrating the Virtual Statcom hosting evaluation and optimisation algorithms with a GUI so that the algorithms could be run from the GUI. Up until a GUI was developed the algorithms were limited to being run from a Python development environment.

The Virtual Statcom GUI Revision 1 was developed in Python using the Tkinter package and based on the initial GUI design from Section 3. Tkinter was selected as it is an open-source Python package that effectively allows GUIs to be developed and comes as standard with a typical Python installation.

Improvements to Initial Design

During the development of GUI Revision 1, two areas of the initial design were modified to improve the operation of the GUI.

- 1) Network Zone(s) Selection window - pop-up window (Figure 4-2) was implemented over a drop down list to select network zones. A window with scrollable function was preferred over a drop-down list due to the high number of zones in the WPD SW PSS/E model, which contains 56 defined network zones.

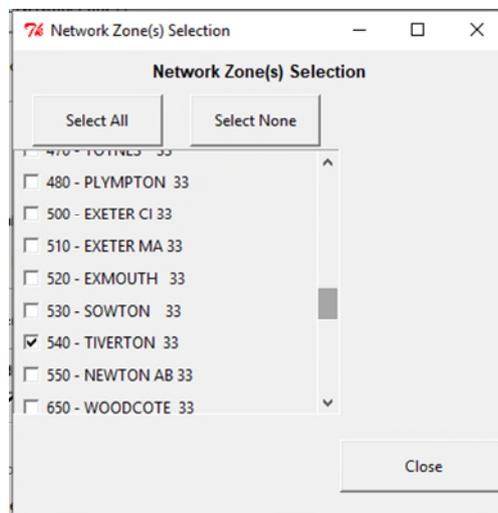


Figure 4-2: Zone selection window

- 2) Study options and contingency options were separated to clarify the options available to a user, shown in Figure 4-3.

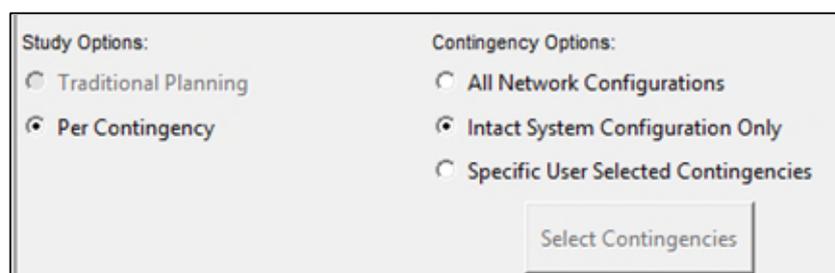


Figure 4-3: Study Options and Contingency Options

Python Packages

The Virtual Statcom algorithms developed make use of various Python packages. These Python packages are required to be installed on a computer to run the GUI and to be able to run the Virtual Statcom algorithms. Tests of the Python packages installed on WPD computers showed that the computers would require additional Python packages to be installed. To ensure that the GUI could be run on WPD's computers, a script was developed to automatically detect and install missing packages. This script is executed when the GUI is loaded to install missing packages identified. The Python packages needed to run the Virtual Statcom GUI are included in the User Guide in Appendix A.

4.1.2. Testing

The first round of WPD testing of the Virtual Statcom GUI provided a good understanding of first-time user issues. This section provides a summary of the GUI operation and script operation issues identified during this test round. GUI operation issues are related to the GUI windows, buttons, check boxes etc. Script operation issues are related to the Virtual Statcom hosting and optimisation algorithms.

GUI Operation Issues Identified

The testing of the Virtual Statcom GUI Revision 1 identified multiple GUI operation issues that needed to be resolved. The following high-level list provides a summary of these:

- Appearance and behaviour of popup windows problematic.
- Incorrect functionality of check boxes and buttons.
- No error/nonsense checking of user inputs provided.

Script Operation Issues Identified

The testing of the Virtual Statcom GUI Revision 1 identified script operation issues that needed to be resolved. The following high-level list provides a summary of these:

- Runtime errors were identified for multiple networks when running the Virtual Statcom algorithms.
- If a network had no runtime errors the Virtual Statcom algorithms took a long time to complete individual Virtual Statcom studies.
- A high number of temporary files were being created and saved when algorithms ran.
- The output of power flow results to PSS/E progress window was not needed.
- Logging function was not being handled as expected.
- The summary results were not clearly presented.

4.1.3. Functionality Assessment

Table 4-1 provides a high level functionality assessment of the Virtual Statcom GUI Revision 1 against the functionality requirements presented in Section 2.

Table 4-1 -GUI Revision 1 Functionality assessment

#	GUI Functional Requirements	Functional Requirements Assessment
1	Allow the user to evaluate the existing network capacity of the network they select. This can be any network and not necessarily one of the four selected zones.	Major GUI operation and/ or script issues
2	Allow the user to run the optimisation algorithm for the network they select and evaluate the new network capacity.	Major GUI operation and/ or script issues
3	Allow the user to perform the above two functions in snapshot scenarios or in time-series studies.	Minor GUI operation and/ or script issues
4	Present the summary results in a clear way.	Minor GUI operation and/ or script issues
5	Output the detailed results in an Excel spreadsheet.	Requirement met

4.2. Virtual Statcom GUI Revision 2

The purpose of the GUI Revision 2 release was to test that the issues identified in the first round of testing had been resolved and that all functional requirements were met. This section provides a summary of the development and testing of the Virtual Statcom GUI Revision 2.

4.2.1. Development

The development of GUI Revision 2 involved resolving the issues/bugs identified in the first round of testing, minor improvements were also implemented. This subsection provides a summary of improvements to the initial GUI design, GUI operation updates and script operation updates implemented during the development of the GUI Revision 2.

Improvements to Initial Design

During the development of GUI Revision 2, one new feature was added to the initial design to improve the operation of the GUI.

- 1) Summary of Input Parameters - a new pop-up window was included in the GUI to provide a summary of the user's inputs to allow the user to confirm the study parameters before proceeding with running a study.

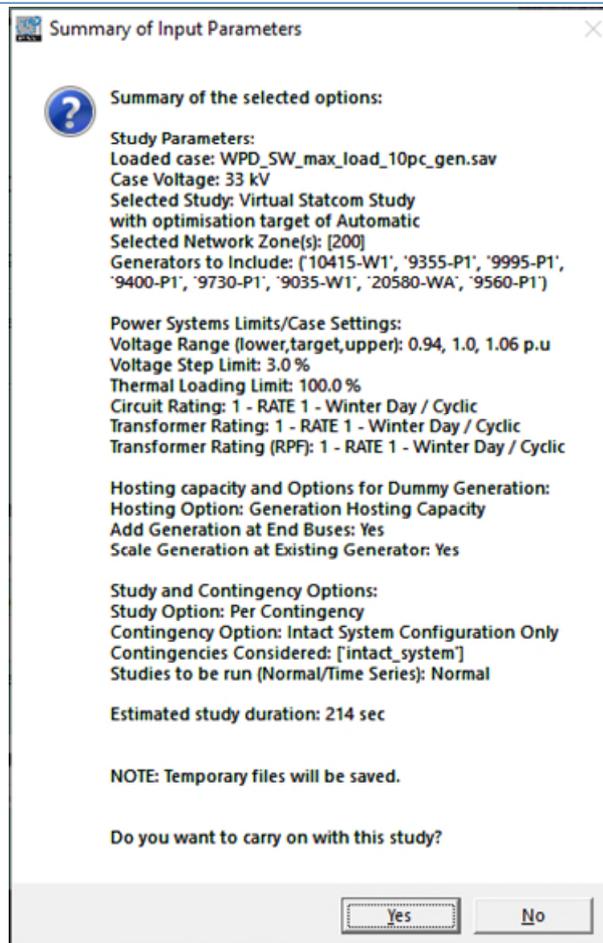


Figure 4-4 Summary of Input Parameters window

GUI Operation Updates

The testing of the Virtual Statcom GUI Revision 1 identified multiple GUI operation issues that needed to be resolved. The following is a high-level list of the GUI operation updates implemented in GUI Revision 2.

- The appearance/behaviour of popup windows was updated.
- The functionality of check boxes and buttons was updated.
- Limit/nonsense checking of user inputs was added.

Script Operation Updates

The testing of the Virtual Statcom GUI Revision 1 identified both major and minor script operation issues that needed to be resolved.

The major issue identified was the length of time the studies took to run individual Virtual Statcom studies. Time profiling of the Virtual Statcom algorithms was undertaken to determine if any speed improvements could be made. The time profiling identified that one function, which was used in both the hosting capacity and optimisation algorithms, was imposing a significant time burden on the runtime of the algorithms. Investigation of the function showed that the time burden was a result of the function performing multiple calls to the PSS/E Application Program Interface (API) to retrieve

data. The function was updated in GUI Revision 2 to minimise calls to the PSS/E API and carry out the data storage and processing within the Python environment wherever possible.

Additional, minor script operation issues were also resolved in the development of Revision 2 of the GUI. The following is a high-level list of the additional script operation updates implemented in GUI Revision 2.

- Algorithms updated to resolve runtime errors.
- A check box to allow the user the option to not save temporary files was added.
- The output of power flow results to PSS/E progress window was disabled.
- Error logging of algorithms updated.
- Improvements to the output results including providing more meaningful column names.
- Assessment based on a traditional planning methodology was implemented in the GUI.

4.2.2. Testing

The second round of WPD testing of the Virtual Statcom GUI provided a refined understanding of underlying user issues and determined whether updates had addressed issues identified in the first round of testing.

The GUI operation issues identified in testing Revision 1 were resolved by the updates included in Revision 2. The script operation issues identified in testing Revision 1 were mostly resolved by the updates included in Revision 2. Most notably the testing of GUI Revision 2 quantified the speed improvement of the algorithms in Revision 2 having an average drop in the time to complete studies of 68% compared to Revision 1.

This subsection provides a summary of the GUI operation and script operation issues identified during the second test round.

GUI Operation Issues Identified

The testing of the Virtual Statcom GUI Revision 2 identified further GUI operation issues that needed to be resolved. The following high-level list provides a summary of these:

- Appearance and behaviour of popup windows problematic.
- Desire to improve the overall appearance and presentation of the GUI
- Error/non-sense checking of user inputs functionality was not as expected.
- Time series pop up window functionality was cumbersome.

Script Operation Issues Identified

The testing of the Virtual Statcom GUI Revision 2 identified that the incorrect selection of some zones by the user could cause errors during runtime. Although this could be overcome through user understanding of the network arrangement it was decided to implement a function to remove the possibility for the user.

4.2.3. Functionality Assessment

Table 4-2 provides a high level functionality assessment of the Virtual Statcom GUI Revision 2 against the functionality requirements presented in Section 2.

Table 4-2 -GUI Revision 2 Functionality assessment

#	GUI Functional Requirements	Functional Requirements Assessment
1	Allow the user to evaluate the existing network capacity of the network they select. This can be any network and not necessarily one of the four selected zones.	Major GUI operation and/ or script issues
2	Allow the user to run the optimisation algorithm for the network they select and evaluate the new network capacity.	Minor GUI operation and/ or script issues
3	Allow the user to perform the above two functions in snapshot scenarios or in time-series studies.	Minor GUI operation and/ or script issues
4	Present the summary results in a clear way.	Requirement met
5	Output the detailed results in an Excel spreadsheet.	Requirement met

4.3. Virtual Statcom GUI Revision 3

The Virtual Statcom GUI Revision 3 has been issued alongside this report. GUI Revision 3 provides a release that resolves the outstanding issues identified in the second round of testing. This section provides a summary of the developments carried out in Revision 3.

4.3.1. Development

The development of GUI Revision 3 involved resolving the issues/bugs identified in the second round of testing, some minor improvements were also implemented. This subsection provides a summary of these improvements.

Improvements to Initial Design

During the development of GUI Revision 3, three new features were added to the initial design that improved the appearance and operation of the GUI.

- 1) Zone Selected display – in the previous releases of the GUI, after a user had selected a zone in the Network Zone(s) Selection window, the user was not able to see what zone had been selected after returning to the main GUI window. Figure 4-5 shows the field that was added to display the selected PSS/E zones.
- 2) Feeder Group Optimisation options – three optimisation objective functions were developed as part of the Virtual Statcom project to optimising reactive power set points. Figure 4-5

shows the drop-down box was added to the main GUI window which allows the option to optimise based on the automatic, thermal or voltage methods [4].

- 3) Colour and Appearance - Figure 4-5 shows updates made to the colour scheme of the GUI to complement WPD company colours and soften the general buttons.

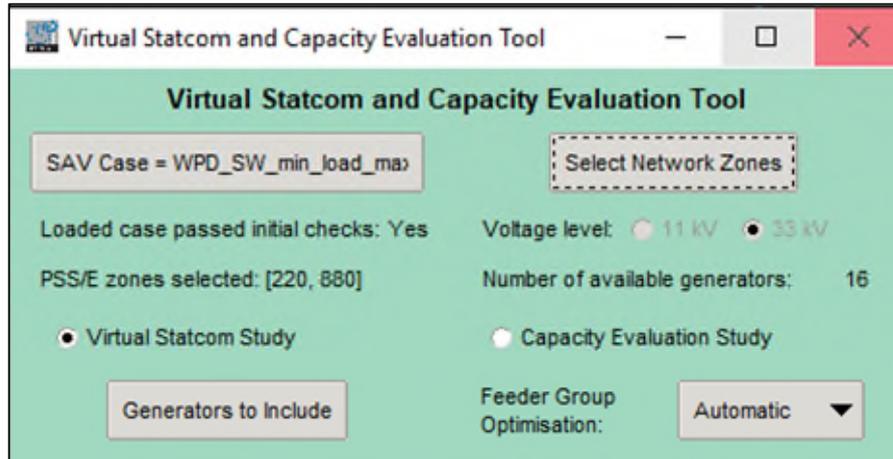


Figure 4-5 - Main GUI with zone selected field and feeder group optimisation options

GUI Operation Updates

The testing of the Virtual Statcom GUI Revision 2 identified multiple GUI operation issues that needed to be addressed.

The main issue identified was with the operation of the time series pop up window. To resolve this issue the design of the Load Time Series Data window was updated to make it more user friendly and error checking on date values was included. The user guide included in Appendix A details the Load Time Series Data window functionality.

The behaviour of all popup windows was also updated to not allow multiple windows to respawn if the window calling button was pressed when the window was already open.

Script Operation Updates

The testing of the Virtual Statcom GUI Revision 2 identified script operation issues that needed to be resolved.

The major issue identified was that runtime errors were occurring when certain networks were selected. Investigation of the network(s) that caused runtime errors showed that the runtime errors occurred when two or more radial BSP networks were selected or if a BSP that was in parallel with another BSP was selected individually. This was causing runtime errors as the Virtual Statcom algorithms developed require either radial BSPs to be selected or all BSPs networks in a parallel group of BSPs to be selected. To resolve this a function was developed to determine which BSPs are radial BSP and which BSPs are in parallel. Figure 4-6 shows the updated Network Zone(s) Selection window that allows the user only to select one radial BSP or one group of parallel BSPs.

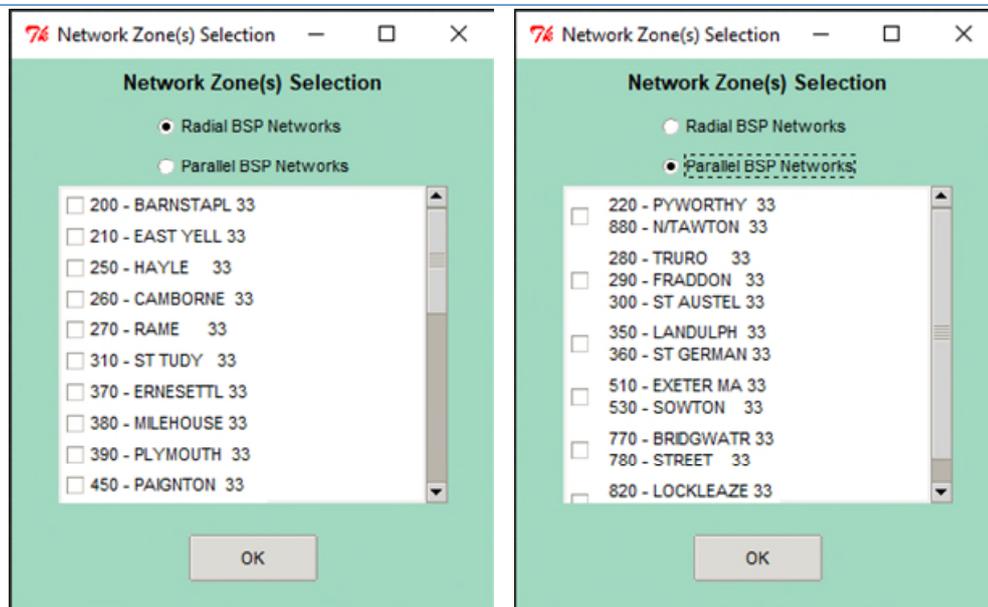


Figure 4-6: Zone selection window for Radial and Parallel Networks

Additional script operation updates were also implemented in the development of Revision 3 of the GUI. The following is a high-level list of the additional script operation updates in GUI Revision 3.

- Collating time series results.
- Plotting time series results.
- Plotting per contingency results.
- Autofit of output excel result files.

4.3.2. Testing and Final GUI Development

WPD testing of the Virtual Statcom GUI Revision 3 identified minor script operation issues that needed to be resolved. The following high-level list provides a summary of these:

- Plotting of per contingency results for certain networks was causing an error.
- The Bath 33 kV BSP network was not able to be selected as a study network.
- One network test was taking much longer than expected to run the study.

Investigation of the minor script operation issues found the source of plotting and Bath 33 kV BSP network issues was related to networks with no existing or in-service generation. The unexpected length of operation for one network test was caused by the code not correctly handling a situation where the branch ratings used caused initial voltage and thermal violations in a network. All minor issues were resolved by the final development and resulted in a minor GUI revision being released; GUI Revision 3.2.

5. Final GUI

This section presents the final GUI (Revision 3.2) developed to meet the functional requirements set out in Section 2.

5.1. Main GUI window

Figure 5-1 shows the main window used for interfacing with the Virtual Statcom algorithms. A user guide for the Virtual Statcom GUI is included in Appendix A.

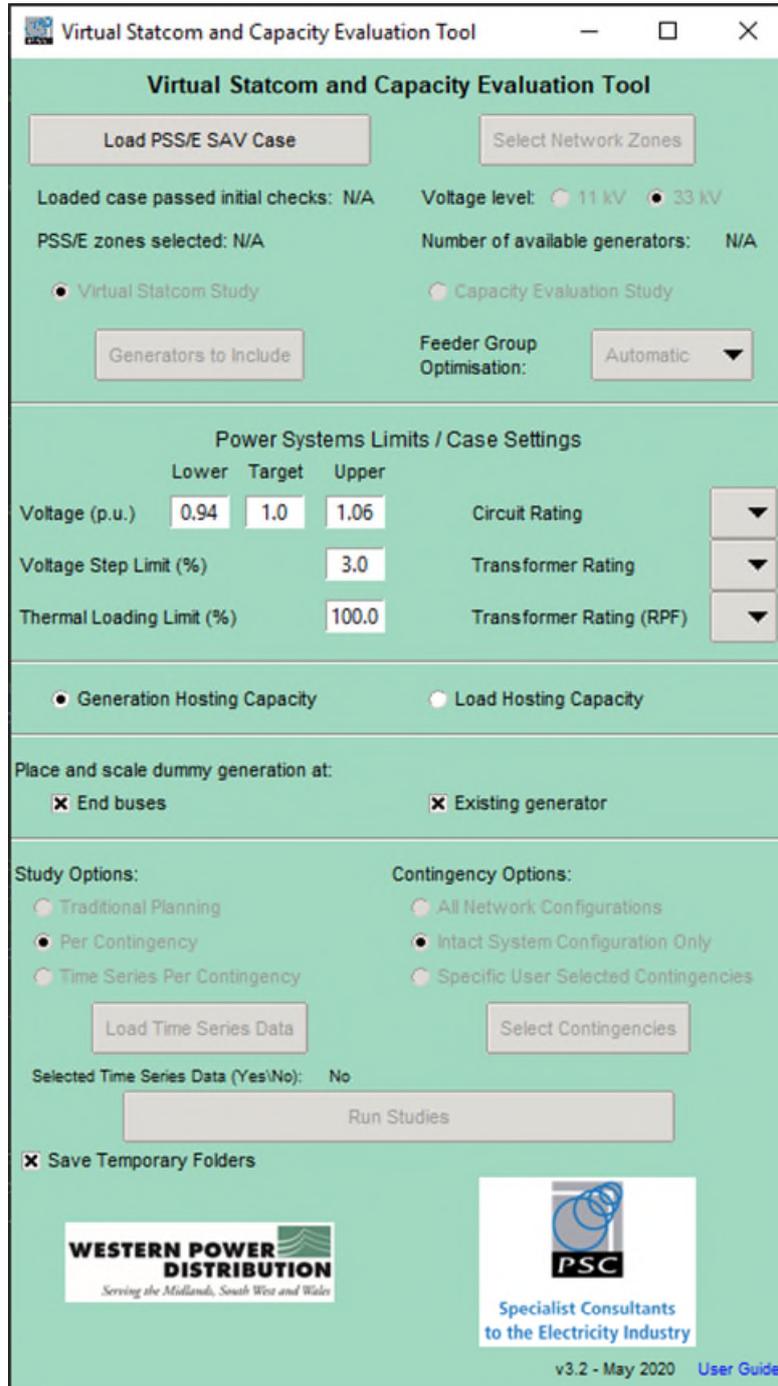


Figure 5-1 Main Virtual Statcom GUI window

5.2. Functionality

Table 5-1 provides a high level functionality assessment of the Virtual Statcom GUI Revision 3 against the functionality requirements presented in Section 2. The remainder of this section details how the final GUI achieves these functional requirements.

Table 5-1 -GUI Revision 3.2 Functionality assessment

#	GUI Functional Requirements	Functional Requirements Assessment
1	Allow the user to evaluate the existing network capacity of the network they select. This can be any network and not necessarily one of the four selected zones.	Requirement met
2	Allow the user to run the optimisation algorithm for the network they select and evaluate the new network capacity.	Requirement met
3	Allow the user to perform the above two functions in snapshot scenarios or in time-series studies.	Requirement met
4	Present the summary results in a clear way.	Requirement met
5	Output the detailed results in an Excel spreadsheet.	Requirement met

5.3. Network Selection and Data Extraction Functionality

The Virtual Statcom GUI revision 3.2 allows a user the ability to load a PSS/E sav case and select a BSP or Primary networks to undertake Capacity Hosting Evaluation Studies and Virtual Statcom Studies. The GUI provides this functionality through the Load PSS/E SAV Case button and the Network Zone(s) Selection Window.

5.3.1. Load PSS/E SAV Case Button

The function of the Load SAV Case button is to load a user selected PSS/E sav case, perform initial convergence checks and extract case datasets from the PSS/E sav case to be used in subsequent steps. Figure 5-2 shows the process run when the Load SAV Case button is clicked. The white cylinders in the process flow chart represent the datasets that are defined in the process.

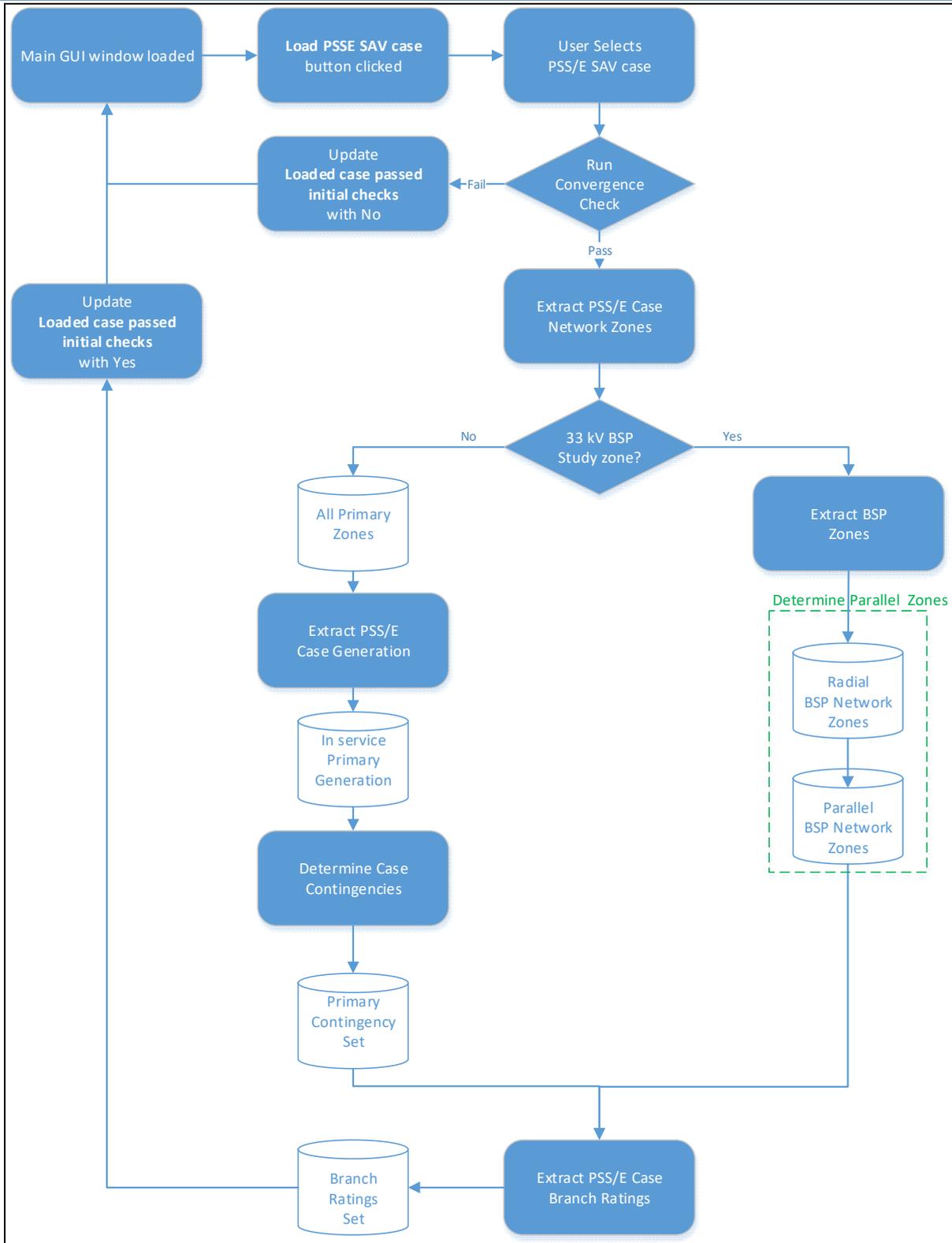


Figure 5-2 - Load PSS/E SAV case button process

5.3.2. Select Network Zone(s) Button/ Network Zone(s) Selection Window

The function of the Select Network Zone(s) button is to open the Network Zone(s) Selection window to allow a user to select any radial BSP zone or parallel BSP zones. The Select Network Zone(s) button is only available to the user for BSP networks, as in the Primary networks all zones are selected (Figure 5-2).

After a user has selected a radial BSP zone or parallel BSP zones, datasets are extracted from the PSS/E sav case to be used in subsequent processes. Figure 5-3 shows the process run when the Select Network Zone(s) button is clicked. The white cylinders in the process flow chart represent the datasets that are defined in the process. The white cylinders with dotted outlines in the process flow chart represent the dataset that are defined in previous processes.

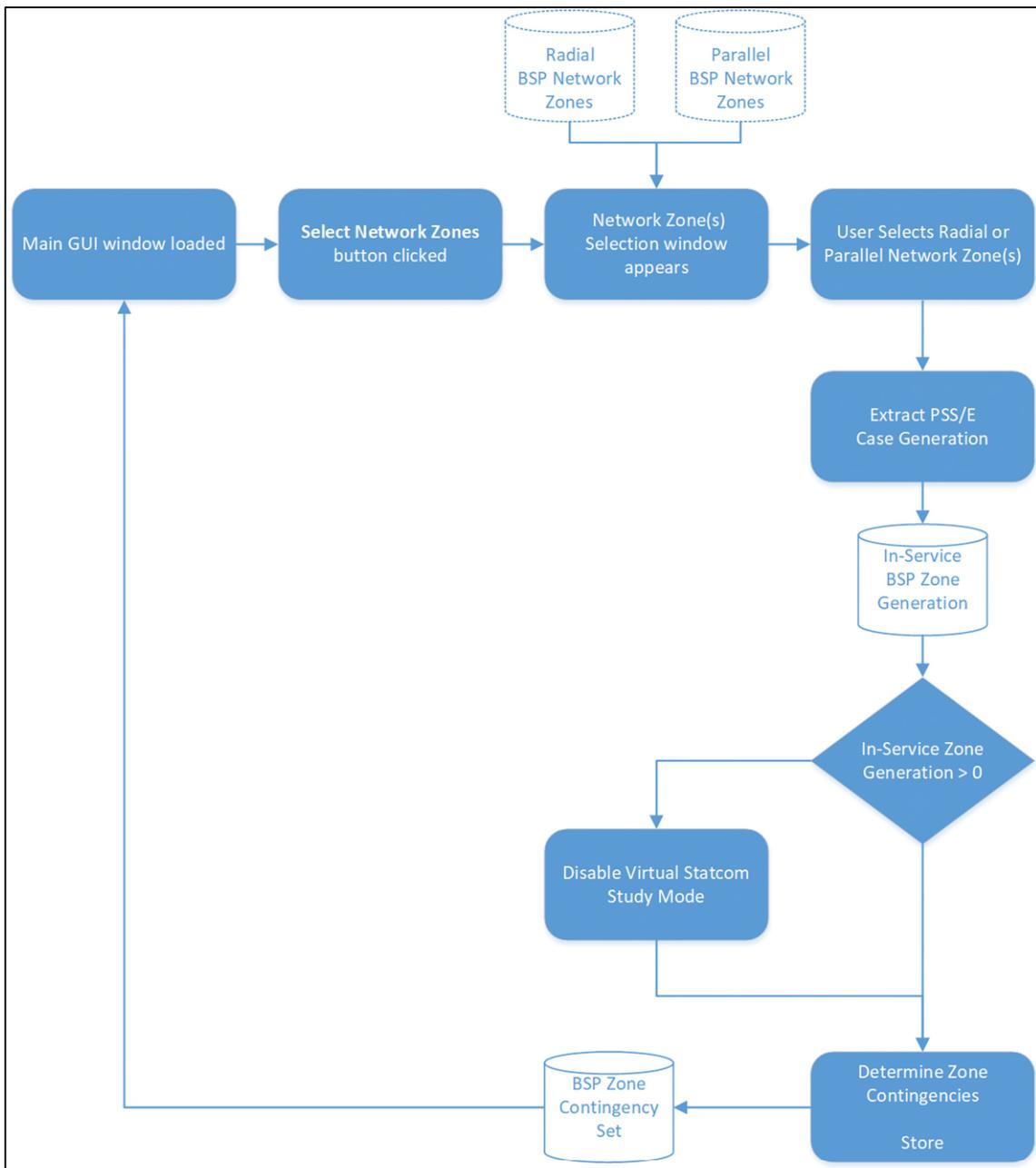


Figure 5-3 Select Network Zone button process

5.4. Capacity Evaluation Functionality

The Virtual Statcom GUI provides the following two study modes to users:

1. Capacity Evaluation Study
2. Virtual Statcom Study

This section details how the Capacity Evaluation Study and Virtual Statcom Study modes meet the GUI functional requirements of Section 2.

5.4.1. Capacity Evaluation Study

The Virtual Statcom GUI revision 3.2 allows a user to evaluate the existing network hosting capacity through the selection of the Capacity Evaluation Study option on the main GUI window. Further options on the main GUI window allow the user to:

- Select either to evaluate Generation Hosting capacity or Load Hosting capacity.
- Configure the power system limits and ratings, to be considered by the algorithms when evaluating the hosting capacity (Section 5.4.3)
- Select the hosting evaluation approach, Traditional Planning, Per Contingency or Time Series Per Contingency (Section 5.4.4).
- Select which contingency configurations to evaluate the hosting capacity (Section 5.4.5)

If the user selects to evaluate the generation hosting capacity of a network, the location of dummy generation to scale in the hosting capacity algorithm can be selected by the user to be located at either existing generator locations or end buses or both. If the user selects to evaluate load hosting capacity all existing loads will be set to be scaled during the hosting capacity algorithm.

5.4.2. Virtual Statcom Study

The Virtual Statcom GUI revision 3.2 allows a user to run the optimisation algorithm for a selected network and evaluate the new network capacity after optimisation, through the selection of the Virtual Statcom Study option on the main GUI window. Further options on the main GUI window allow the user to:

- Select either to evaluate Generation Hosting capacity or Load Hosting capacity.
- Configure the power system limits and ratings, to be used by the algorithms when evaluating the hosting capacity (Section 5.4.3)
- Select the hosting evaluation approach, Traditional Planning, Per Contingency or Time Series Per Contingency (Section 5.4.4).
- Select which contingency configurations to evaluate the hosting capacity (Section 5.4.5)

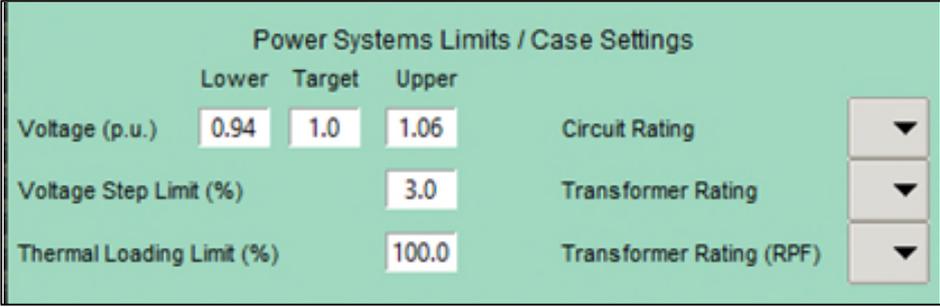
If the user selects to evaluate the generation hosting capacity addition options are available to the user on the main GUI window to:

- Select the existing network generators to include in the optimisation algorithm.

- Select the optimisation method to be used when optimising the reactive setpoints of existing generators selected.
- Select the location of dummy generators to be scaled.

5.4.3. Power System Limits / Case Settings

Figure 5-4 shows the input boxes and drop-down lists, from the main GUI window, that allow a user to configure the power system limits and branch ratings to be used by all Virtual Statcom algorithms when determining compliance. The default values are shown in Figure 5-4.



	Lower	Target	Upper	
Voltage (p.u.)	0.94	1.0	1.06	Circuit Rating
Voltage Step Limit (%)		3.0		Transformer Rating
Thermal Loading Limit (%)		100.0		Transformer Rating (RPF)

Figure 5-4 Main Virtual Statcom GUI window: Power System Limits/ Case Settings

5.4.4. Study Options

When performing either a Virtual Statcom Study or Capacity Evaluation Study the main GUI window provides the user three study options to select between. The study options configure the hosting capacity methodology to use when evaluating hosting capacity. The options available to the user are

1. Traditional Planning
2. Per Contingency
3. Time Series Per Contingency

Traditional Planning Methodology

If a user selects the Traditional Planning option, then when the algorithms are run all contingency configurations selected by the user are assessed for each scaled level of generation. At a high level the algorithm performs the following steps:

1. Scale all available dummy generators.
2. At this new generation level
 - a. Check the intact system for power system violations.
 - b. Check user selected contingency configuration system for power system violations.
3. Resolve the power system violations by scaling back the dummy generator causing the violation.
4. Stop scaling any dummy generator the was scaled back to resolve a violation.
5. If there are still dummy generators available to be scaled, return to Step 1.

Per Contingency Methodology

If a user selects the Per Contingency option, then when the algorithms are run all contingency configurations selected by the user are assessed individually while scaling generation. At a high level the algorithm performs the following steps:

1. Set the case for first/next contingency configuration.
2. Scale all available dummy generators.
3. At this new generation level - check the contingency configuration for power system violations.
4. Resolve the power system violations by scaling back the dummy generator causing the violation.
5. Stop scaling any dummy generator the was scaled back to resolve a violation.
6. If there are still dummy generators available to be scaled, return to Step 2.
7. If there are contingencies configuration remaining to be assessed return to Step 1.

Time Series Per Contingency

If a user selects the Time Series Per Contingency option, then when the algorithms are run all contingency configurations selected by the user will have the per contingency methodology applied for each time series case configured as described in Section 5.5.1.

5.4.5. Contingency Options

When performing either a Virtual Statcom Study or Capacity Evaluation Study the main GUI window provides the user three contingency options. The details of contingency definition and naming conventions used in the GUI are included as an appendix to the user guide in Appendix A. The options available to a user when selecting contingencies are:

1. All network configurations
2. Intact system Configuration only (this is the default option)
3. Specific User Selected Contingencies.

5.5. Snapshot and Timeseries Functionality

The Virtual Statcom GUI allows a Capacity Evaluation Study or a Virtual Statcom Study to be run on a snapshot generation scenario or using generation and load time series data.

Snapshot scenarios studies are the default for the Virtual Statcom GUI, but the GUI allows for time series studies to be configured using a time series interface window.

This section provides details of the time series interface and the options available to be run when the run button on the main GUI window is clicked.

5.5.1. Time Series Interface

The time series interface shown in Figure 5-5 allows a user to select the time series data that they wish to use and run data for different time series steps. The Load Time Series data window is opened through a user selecting the Time Series Per Contingency option and clicking the Load Time Series Data button on the main GUI window.

To run time series studies the user will be asked to select a spreadsheet which contains the time series generation and load data in a pre-defined format. The user guide in Appendix A contains details of configuring time series studies and an example of the pre-defined time series data format required.

Once time series data is imported into the Load Time Series Data window the the start date and time fields are updated to be the first time series date and time value in the imported data.

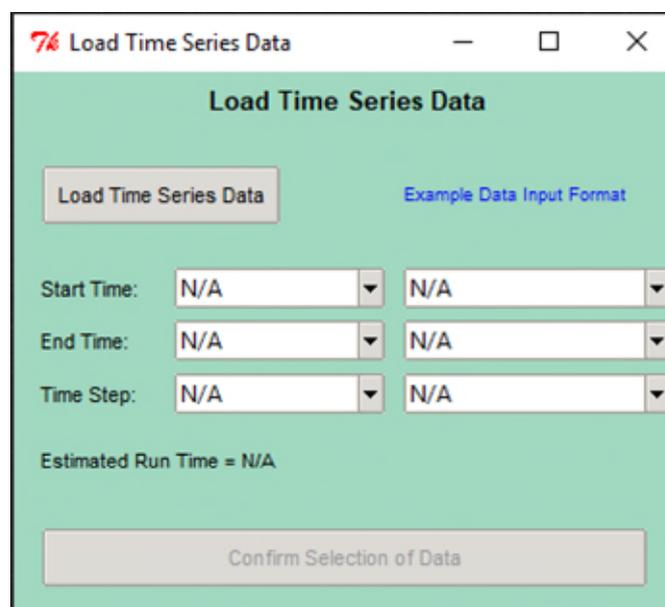
The screenshot shows a software window titled '76 Load Time Series Data'. The window has a light green background and a title bar with standard minimize, maximize, and close buttons. The main content area is titled 'Load Time Series Data' and contains a 'Load Time Series Data' button on the left and a blue link 'Example Data Input Format' on the right. Below these are three rows of dropdown menus for 'Start Time', 'End Time', and 'Time Step', each with two columns of 'N/A' options. Underneath the dropdowns, it says 'Estimated Run Time = N/A'. At the bottom of the window is a large, light grey button labeled 'Confirm Selection of Data'.

Figure 5-5: Time Series Interface

5.5.2. Run Button

The Virtual Statcom GUI allows a user to run various studies on a user selected PSS/E case through user selection of the GUI options. Figure 5-6 and shows the Virtual Statcom study options available to a user for snapshot scenarios and time series scenarios, the default options are shown by the bold paths.

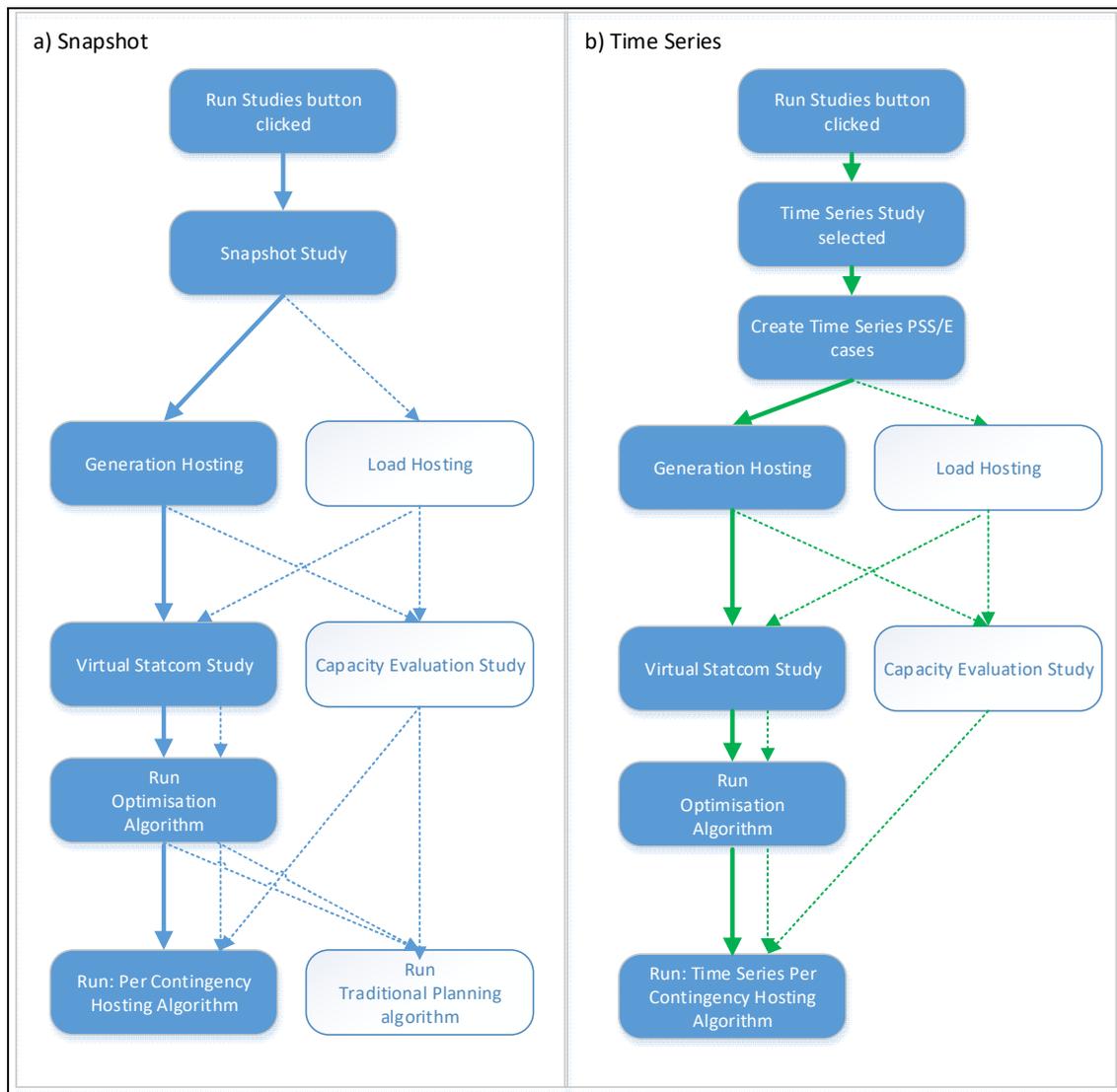


Figure 5-6: Run button study decision trees

5.6. Output Functionality

After the Virtual Statcom studies have been run from the Virtual Statcom GUI, output files are saved in the user selected folder. The Virtual Statcom algorithm produces a summary excel spreadsheet, multiple detailed excel files and plots results to help a user analysing the results.

5.6.1. Virtual Statcom Snapshot Studies Outputs

Excel File Outputs

After the completion of a Virtual Statcom snapshot study, the script saves the following excel files:

1. Hosting results comparisons - This excel file contains a comparison of the generation/load hosting capacity in MW before and after optimisation, for the contingencies selected.
2. Generation comparisons - This excel file contains a comparison of zone generators real and reactive power output before and after optimisation.
3. Load comparisons - This excel file contains a comparison of zone loads real and reactive power before and after optimisation.
4. Branch loading comparisons - This excel file contains a comparison of zone branch (lines/cables) loadings before and after optimisation.
5. Transformer forward power loadings comparisons - This excel file contains a comparison of zone transformer forward power loadings before and after optimisation.
6. Transformer reverse power loadings comparisons - This excel file contains a comparison of zone transformer reverse power loadings before and after optimisation.
7. Bus voltage comparisons - This excel file contains a comparison of zone bus voltages before and after optimisation.

If a user selects a Capacity Evaluation study the output Excel files only contain before optimisation data.

Plot Outputs

After the completion of a Virtual Statcom snapshot study, the script creates and saves plots for the network. Plots are created before and after the optimisation showing the following hosting algorithm iteration data for each contingency configuration:

1. 33 kV bus voltages
2. 11 kV bus voltage
3. Branch loading of feeders connected to the BSP or Primary bus.
4. Generation or Load that was scaled.

If a user selects a Capacity Evaluation study the output plots files only contain before optimisation data.

5.6.2. Virtual Statcom Snapshot Studies Outputs

Excel File Outputs

After the completion of the time series studies, the script saves the excel files described in Section 5.6.1 for each time step. The hosting comparison excel files for each time step are also combined into a single excel file to help a user analyse the complete time-series results.

Plot Outputs

After the completion of the time series studies, the script creates plots to compare the results.

If the Virtual Statcom Study Mode has been run the following two plots per contingency are created:

1. Time series hosting comparison plot showing:
 - Load and Generation vs Time
 - MW hosting vs time
 - % Increase vs time
2. Losses comparison plot showing:
 - Losses % vs time

If the Capacity Evaluation Study Mode has been run one plot per contingency is created:

1. Time series hosting showing:
 - Load and Generation vs Time
 - MW hosting vs time
 - Losses % vs time

6. Key Learnings and Recommendations

The development of the GUI, to allow users to run Virtual Statcom and Capacity Evaluation studies, generated multiple learnings that could provide benefit to projects in the future. This section provides a summary of the key learnings from the project and recommendations to future projects.

6.1. Learnings

The planned approach of using agile development and testing cycles proved to be an effective way to develop the GUI to meet the functional requirements (Section 2). The main advantage of the agile approach used was that it allowed functionality to be added incrementally to the GUI which enabled user testing to be undertaken before the GUI was finalised. This allowed the GUI development team to understand and resolve user issues and guide the design of the GUI through its development.

The main areas of learnings that arose through the user testing and feedback process were:

- End user operating systems and installation differences
- GUI ease of use and aesthetics
- Functional requirements and user acceptance criteria
- Python 2.7 end of support

The following subsections provide more detail on each of these.

6.1.1. End User Operating Systems and Installation Differences

An understanding of the end user operating systems is critical to ensure that any software developed can run on these systems. During the development of the GUI the team identified that the WPD Python installation was non-standard and would need additional Python packages to be installed. These packages would be required to ensure successful use of the GUI and the stability of the Virtual Statcom algorithms. Early on during the development process a stand-alone test package was developed to confirm the state of the installation and quickly identified the missing packages. This learning early on enabled an automated solution to be developed and integrated into the complete GUI package to identify any missing dependencies, alert the user and carry out the necessary installation. Carrying out this testing early on during the development process ensured the more complex and complete GUI could be reliably tested without issues relating to the WPD Python installation creating running issues and potential delays.

A further learning was generated from determining how to deliver the GUI and Virtual Statcom algorithms to WPD's systems. A shared folder was set up between PSC and WPD using SharePoint to transfer the GUI revisions to WPD. File transfer was preferred over emailing due to the total file size and number of files, and the use of SharePoint allows for access security and traceability.

6.1.2. GUI Ease of Use and Aesthetics

The agile approach to the development and testing of the GUI successfully enabled end user feedback on the ease of use of the GUI. The feedback from WPD provided the GUI development team valuable insights into end user interaction expectations and aesthetics of the GUI, and these were able to be incorporated into the GUI final design.

This process provided two key areas of learning, it ensures that the algorithms run as expected and identifies any errors / delays as a result of different inputs or settings. It also demonstrated the differences between how users interact with the tool and allowed the team to control the interaction to prevent the user running invalid studies.

6.1.3. Functional Requirements and User Acceptance Criteria

The functional requirements set out in Section 2 provided the high-level design direction for the GUI. The nature of using an agile development and testing approach provides the opportunity for further functional and user acceptance requirements to arise during its development. This is an advantage of the agile approach and results in a high-quality, user specific experience. Further requirements were identified during the Virtual Statcom GUI development and testing iteration cycles, these were tracked and implemented. The implementation of the further requirements provided the learning that it is important to define detailed functional requirements and define acceptance criteria as early as possible to streamline the development of a GUI.

6.1.4. Python 2.7 End of Support

WPD make use of the Python installation that comes with PSS/E versions 32 and 34 as the execution engine for run these scripts. Those PSS/E installations comes with Python 2.7 and in the case of PSS/E version 32 are only compatible with Python 2.7. During this project, Python 2.7 has stop being supported and development of Python packages has moved across to Python 3+. In the case of the Virtual Statcom GUI this had no significant impact since it was developed to install the necessary packages to ensure ongoing compatibility with Python 2.7.

Python 3+ has made some significant changes to its underlying processing and therefore a lot of the existing packages used as part of this project exist in two versions, one version compatible with Python 2.7 and another with Python 3+. As a result, updating to Python 3+ is not a simple case of installing the latest version since changes in packages and dependencies will also need to be reviewed and tested to ensure continued operation.

Going forward packages will no longer be developed for Python 2.7 and so future projects will need to make use of Python 3+. Python 3+ is not compatible with PSS/E version 32 and so WPD will need to either make use of Python 2.7 for projects required to run in PSS/E version 32 or be aware that new tools will only be compatible with PSS/E 34.

6.2. Recommendations

Section 4 and the learnings described in Section 6.1 support that the agile approach successfully allowed a GUI to be developed to meet a set of functional requirement. Future projects of a similar nature should make use of agile testing and development cycles when developing a GUI. When undertaking an agile approach for the delivery of a GUI, consideration prior to onset of the GUI development should be taken to; understand end user systems, define detailed functional requirements and define user acceptance criteria.

Future projects using Python to automate PSS/E should also be aware that Python 2.7 stopped being supported as of January 2020. Subsequent projects will need to make use of Python 3+ unless backwards compatibility with PSS/E version 32 is required.

References

- [1] Western Power Distribution & Power System Consultants UK, *Network Innovation Allowance Virtual Statcom Project Collaboration agreement*, 2018.
- [2] D. Mills, "JK7261-GUI-01-01: GUI Note - Concept for Virtual Statcom Graphical User Interface," PSC, Warwick, UK, 2020.
- [3] G. McCormick, "JK7261-TR-03 Rev 03 - WPD Virtual Statcom WP2 Report," PSC UK, Warwick, UK, 2019.
- [4] G. McCormick and D. Mills, "JK7261-TR-04: WPD Virtual Statcom WP4 Report," PSC, Warwick, UK, 2020.



Appendix A GUI User Guide



WPD Virtual Statcom GUI User Guide

For: Western Power Distribution

Prepared by: Grant McCormick (Senior Consultant)

Power Systems Consultants UK Ltd

Client Reference: NIA_WPD_37

PSC Reference: JK7261-GUI-02-02

Revision: 02

Date: 26th May 2020



Document History

Revision	Date	Description of changes
0A	28-02-2020	Initial Issue for WPD testing
0B	30-03-2020	Revised issue for WPD GUI testing round 2
01	07-05-2020	Revision 1 issued to WPD contains revisions from GUI updates from WPD second test period.
02	26-05-20	User Guide Revision 02 – to accompany GUI Rev3.2 release, minor updates to user guide.

Revision	Date	Author	Peer Review	Approved
0A	28-02-2020	Grant McCormick	David Mills	
0B	30-03-2020	Grant McCormick	David Mills	
01	06-05-2020	Grant McCormick	David Mills	David Mills
02	26-05-20	Grant McCormick	David Mills	David Mills





Script Version History

Revision	Date	Description of changes
1.0	04-03-20	Initial GUI Version for WPD user testing round 1
2.0	30-03-20	Updated GUI Version for WPD user testing round 2
3.0	06-05-20	Final updated GUI Version for WPD
3.2	26-05-20	Minor bug fixes



Contents

1. Introduction	3
2. Installation	3
3. Process	4
4. Virtual Statcom GUI execution.....	5
5. Main User Interface	5
6. Load Time Series Data Interface	16
7. Outputs from Studies.....	18
8. Log Messages	19
9. Trouble shooting	19
Appendix A – Contingencies for Virtual Statcom and Capacity Evaluation tool.....	20
Appendix B – Timeseries Data Requirements.....	21

1. Introduction

Western Power Distribution (WPD) engaged Power Systems Consultants UK Ltd. (PSC) to deliver an innovation project known as the Virtual Statcom, the project was run by WPD and funded under the Ofgem, Network Innovation Allowance (NIA_WPD_037).

The Virtual Statcom project created scripts to determine the technical feasibility of increasing the network hosting capacity, for both generation and load, through implementing an algorithm to control and coordinate the reactive power output of existing generators in the distribution network.

To enable ease of interaction with the Virtual Statcom scripts created, a graphical user interface (GUI) was developed. This user guide sets out the high-level concept for the GUI and details how a user can be interacted with the GUI.

2. Installation

To be able to run these scripts the user will need to have PSSE version 34 and Python 2.7 installed.

2.1. Python Packages

There are also the following python package dependencies required as part of this script and these are provided with the package, if these are not already installed, they will be installed during first run as detailed in section 2.2:

- setuptools
- six
- jdcal
- numpy
- pandas
- pywin32
- matplotlib
- Pillow
- XlsxWriter
- Pyswarm
- Xlrd

2.2. Missing Python Package Installation

If when running the main script Python detects that the packages listed in section 2.1 are not installed, then these will be installed locally. The user will receive a notification that these are being installed and it may take longer to run than normal. These can be installed manually by execution of the batch file: JK7261_Missing_Packages.bat

Running of this script should not require manual user intervention if the user has located the files in a location that they have write access permissions.

Once this installation has completed the user may need to close and restart PSSE before re-running the script. If the same installation takes place for a second time then there was an issue completing the installation and the user should review the file named “install_errors.log” located within the folder “python_packages” to see why the error occurred.

3. Process

The flowchart shown in the figure below sets out the computation process that is being carried out by the scripts.

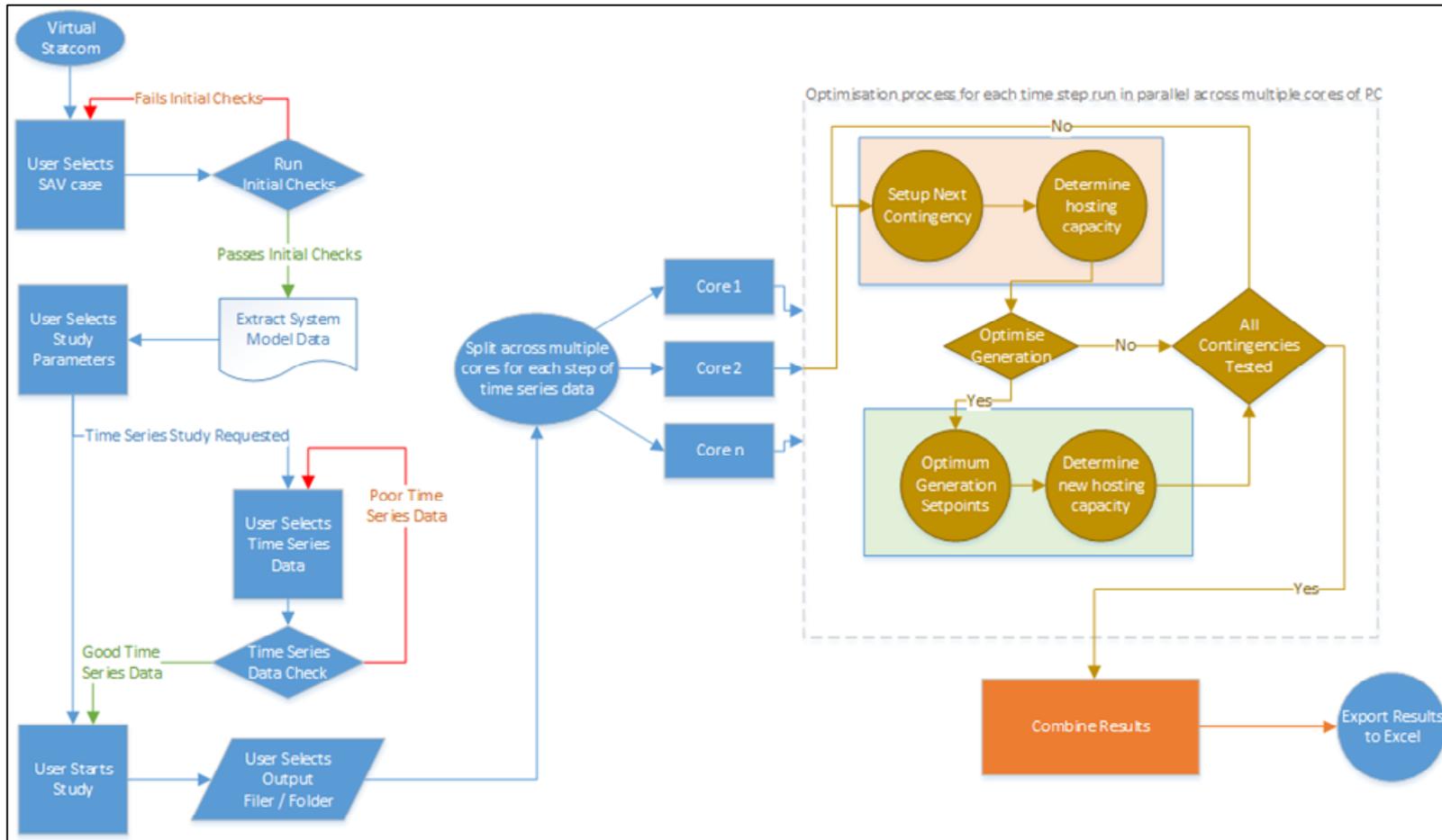


Figure 3-1: Flowchart for WPD Virtual Statcom Tool

4. Virtual Statcom GUI execution

These scripts can be run from PSSE or directly from Python, the results and process are the same. The following sections show the process of running the studies from either PSSE or Python.

4.1. PSSE Based Execution

If running from PSSE, click the tool to run automation files and then select the WPD_Virtual_Statcom.py script.



Figure 4-1: WPD_Virtual_Statcom.py from PSSE

4.2. Python Based Execution

If running from Python directly, run the script WPD_Virtual_Statcom.py in python 2.7 and the execution will follow the same procedure as detailed below.

5. Main User Interface

The first window that will appear once the script has initialised is the main user interface shown in Figure 5-1. The main user interface allows the user to configure the main parameters for the Virtual Statcom and/or hosting capacity algorithms which include:

- Virtual Statcom settings (section 5.1):
 - Load PSS/E SAV case for the Virtual Statcom to be run on (section 5.1.1).
 - Zone selection (section 5.1.2).
 - Study mode (section 5.1.3)
 - Generators to include (section 5.1.4).
 - Feeder Group Optimisation method (section 5.1.5)
- PSSE case settings (section 5.2):
 - Power system violation limits (section 5.2.1).
 - Branch ratings (section 5.2.2).
- Study options (section 5.3):
 - Generation or load hosting option (section 5.3.1)
 - Hosting capacity methodology options (section 5.3.2)
 - Contingency selection options (section 5.3.3).
- Run Studies (section 5.4):

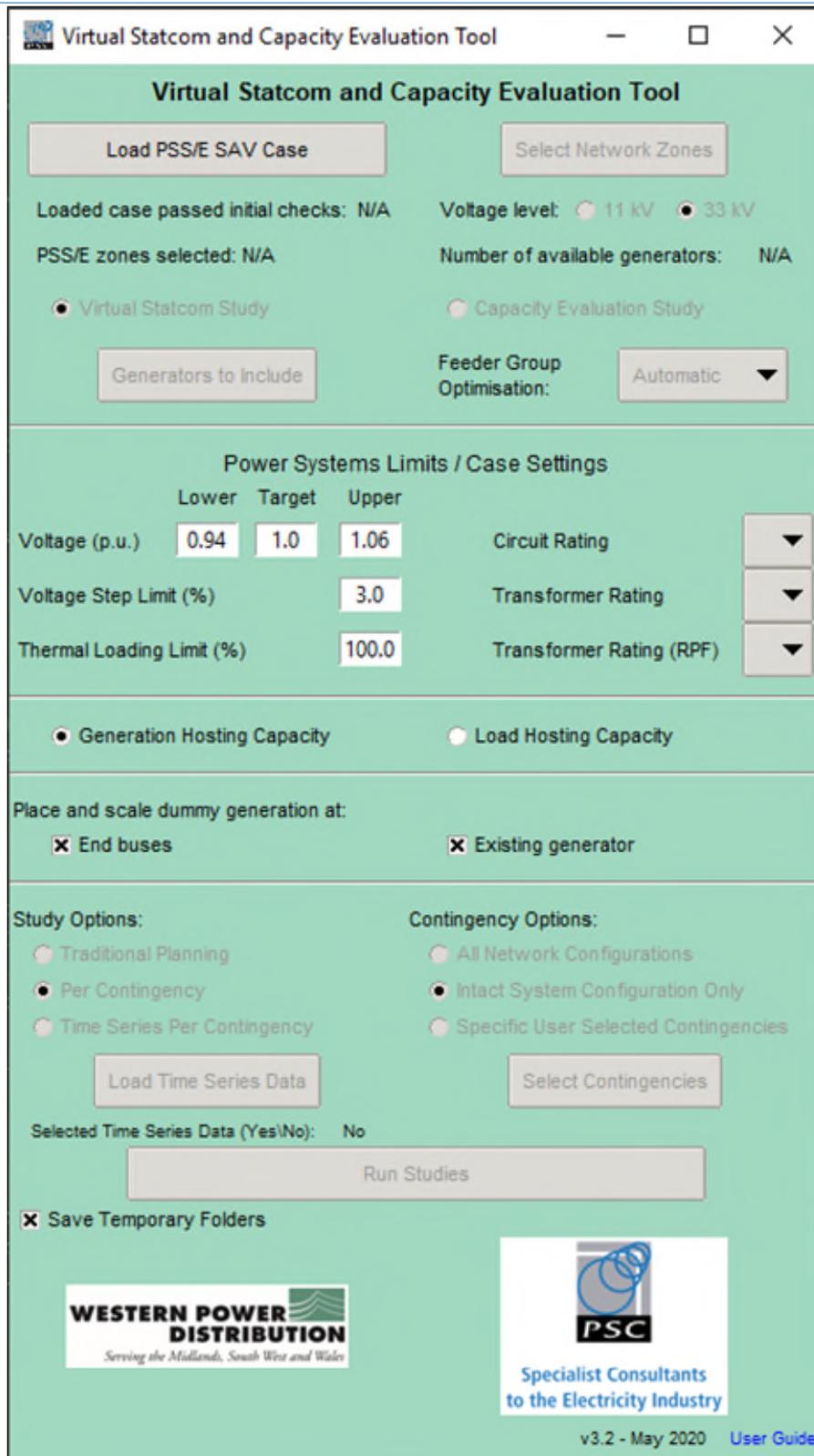


Figure 5-1: Main user interface window

5.1. Virtual Statcom Settings

5.1.1. Load PSS/E SAV Case

- When the user clicks the **Load PSS/E SAV Case** button a popup window will ask the user to select a PSS/E SAV case.

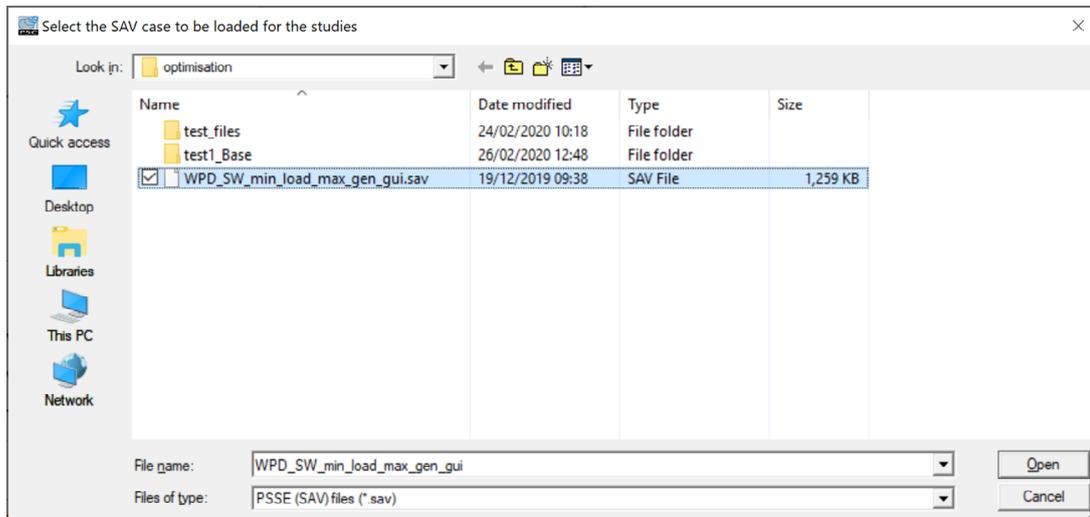


Figure 5-2: User to select PSS/E SAV case to be loaded

- After user selects a PSS/E SAV case the user will be prompted to confirm if the case is a 33 kV network. This sets the case voltage for the scripts.

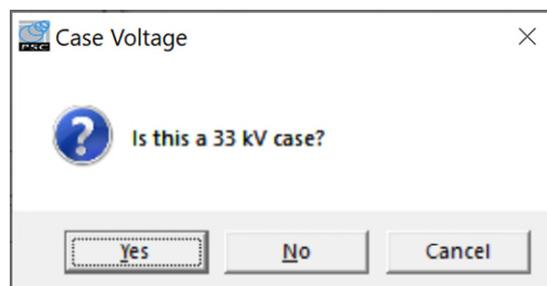


Figure 5-3: Case Voltage dialogue question box

- After the case voltage has been set, the script loads and runs initial convergence checks on the PSS/E sav case and updates the GUI with 'Yes' or 'No'. The case filename is also added to the button.

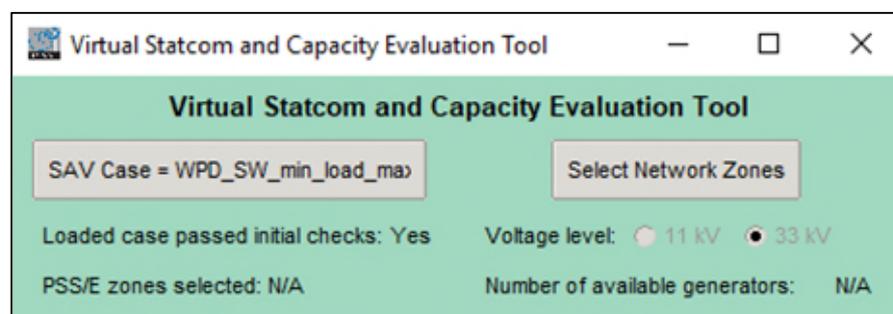


Figure 5-4: Loaded case passed initial checks

5.1.2. Zone Selection

- When the user clicks the **Select Network Zones** button a popup window will ask the user to select the zone (or zones) the user wishes to assess.
- The user can then select either **Radial BSP Networks** or **Parallel BSP Networks**
- After selection the user can use the **OK** button or **X** to close the dialog box.
- If the Zones selected contain no in service generation a warning message will be displayed.
- Once a networks zone(s) has been selected 'PSS/E zones selected:' on main GUI window will be updated with the zone number(s).

Note: If the case voltage is 11 kV then all zones in the case will be selected, and the **Select Network Zones** button is greyed out.

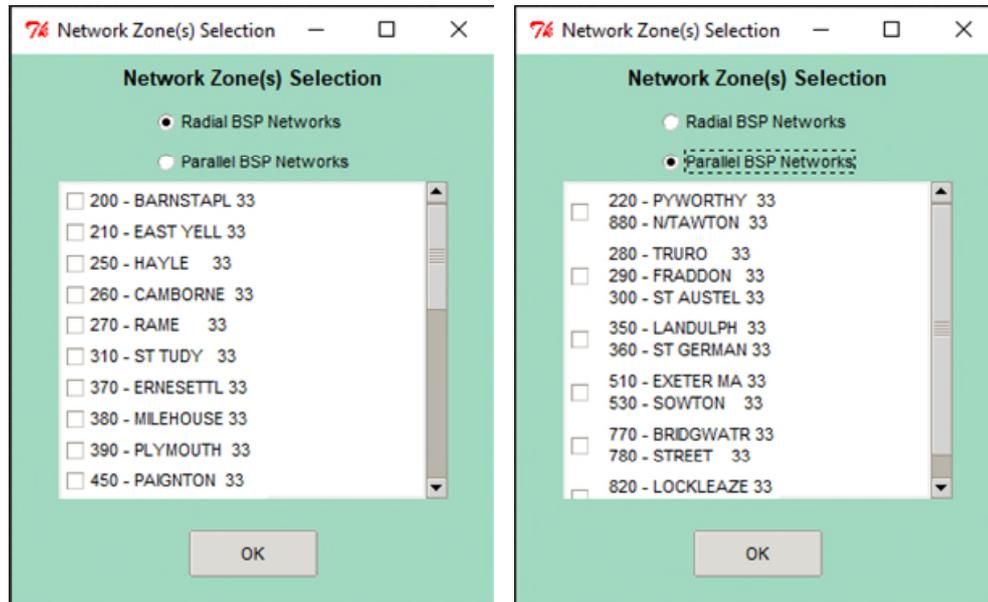


Figure 5-5: Zone selection window for Radial and Parallel Networks

5.1.3. Study Mode

Once a network is selected the user can select the following studies options:

- **Virtual Statcom Study**, this study mode performs:
 - Evaluation of hosting capacity with initial case reactive power dispatch.
 - Reactive power dispatch optimisation of the 'Generators to Include' (Section 5.1.4)
 - Evaluation of hosting capacity with optimised case reactive power dispatch.
- **Capacity Evaluation Study**, this study mode performs:
 - Evaluation of hosting capacity with initial PSS/E case reactive power dispatch.

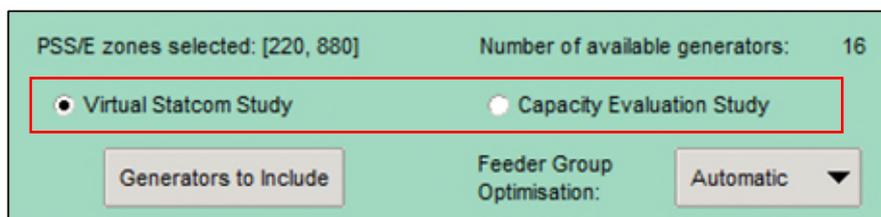


Figure 5-6: Study mode selection

5.1.4. Generators to Include

- The user can click the **Generators to Include** button if the **Virtual Statcom Study** mode has been selected.
- When the user clicks the **Generators to Include** button a popup window will ask the user to select existing generators in the study zone to be used for optimised reactive power dispatch. The default is for all zone generators at the case voltage level to be selected.
- After selection the user can use the **OK** button or **X** to close the dialog box.

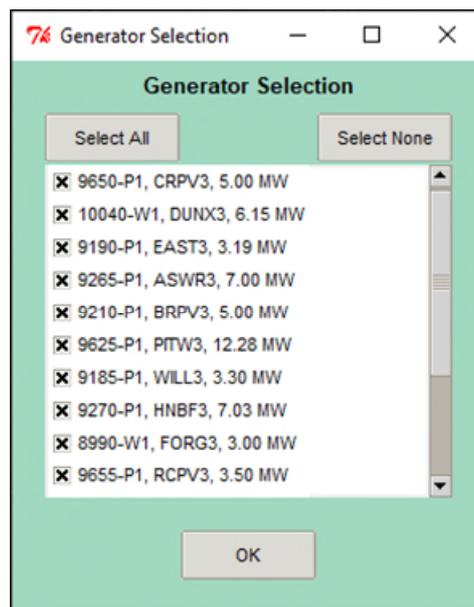


Figure 5-7: Generator selection window

5.1.5. Feeder Group Optimisation Method

- The user can click the **Feeder Group Optimisation** dropdown if the **Virtual Statcom Study** mode has been selected.
- The user can select from 3 optimisation modes:
 1. **Thermal** – the optimiser will aim to minimise the thermal loadings.
 2. **Voltage** – the optimiser will aim to minimise network voltages.
 3. **Automatic** – the optimisation will aim to create generation head room by balancing thermal loadings and bus voltages.

Note: For load hosting capacity the optimisation method is set to thermal.

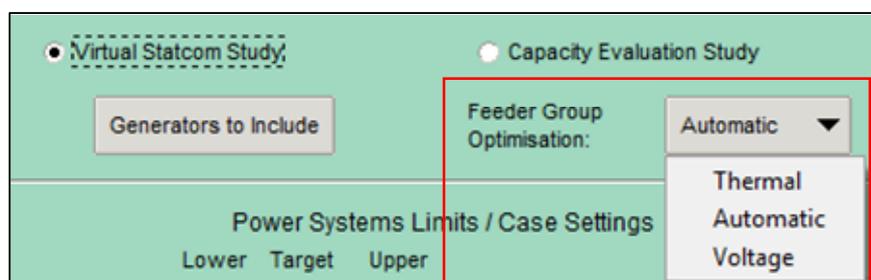


Figure 5-8: Feeder Group Optimisation method

5.2. PSSE Case Settings

5.2.1. Power System Violation Limits

- A user can specify the bus voltage (high/low), voltage step limit and thermal loading percentage to be used in PSS/E when assessing power system violations. The defaults are shown in Figure 5-9.

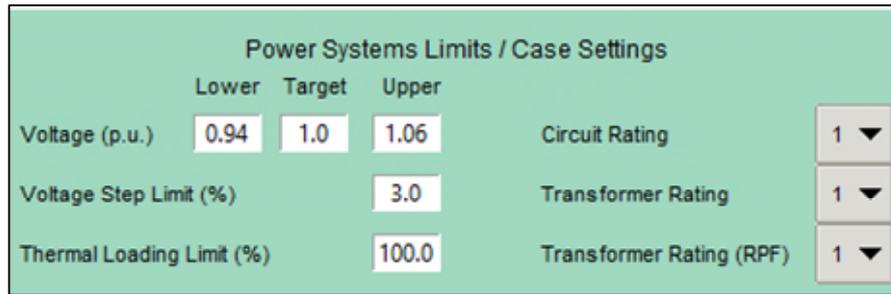


Figure 5-9: Power system limits/case setting GUI

5.2.2. Branch Ratings

- The algorithm requires the user to select three branch ratings:
 - **Circuit Rating** for cables and lines.
 - **Transformer Rating** for forward power flow (i.e. power flow from HV -> LV)
 - **Transformer Rating (RPF)** for reverse power flow (i.e. power flow from LV -> HV)
- A user can each rating to be used from the dropdown selection panel.
- The ratings displayed in the dropdown list are the ratings/descriptions from the PSS/E SAV case loaded.

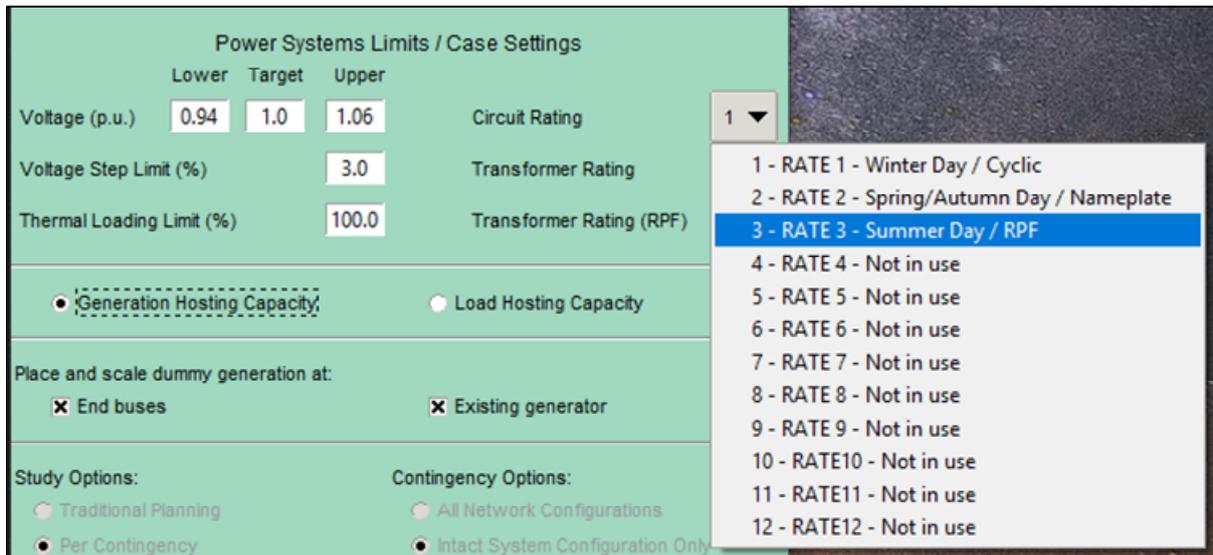


Figure 5-10: Branch rating selection drop down

5.3. Study Options:

5.3.1. Hosting Capacity Options

The hosting capacity of a network is defined as the total amount of generation or load that can be accommodated without violating pre-defined operational, physical and statutory limits.

- The user has the option to select which hosting algorithm to run;
 - **Generation Hosting Capacity**
 - **Load hosting Capacity**



Figure 5-11: Generation or Load hosting options

5.3.1.1. Generation hosting capacity algorithm

The generation hosting capacity algorithm scales up the real power of dummy generators until power system network issues arise in the study zone. The sum of the existing generation and dummy generation is the networks generation hosting capacity.

The generation hosting capacity algorithm can place new generators ('dummy generators') at either:

- a) The end buses of the network study zone.
- b) The existing generator busses.
- c) Both a) and b)

The location of the new generation is determined by the user options shown in Figure 5-12.

- If the user selects the **Generation Hosting Capacity** option, the user can select where to place dummy generators. The default option is for dummy generators to be placed at end buses and existing buses.

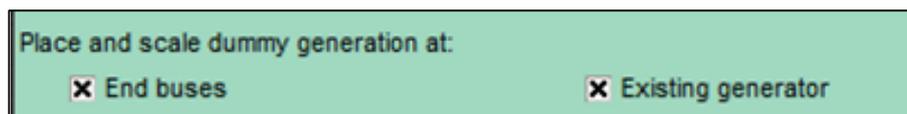


Figure 5-12: Generation Placement options

5.3.1.2. Load hosting capacity algorithm

If the user selects **Load Hosting Capacity** option, the algorithm will scale the real and reactive power of the existing network loads until power system network issues arise in the study zone. The sum of the scaled loads is the networks load hosting capacity.

5.3.2. Hosting Capacity Methodology Options

- The user can select from three hosting capacity methodologies:
 - **Traditional Planning**
 - **Per Contingency**
 - **Time Series Per Contingency**

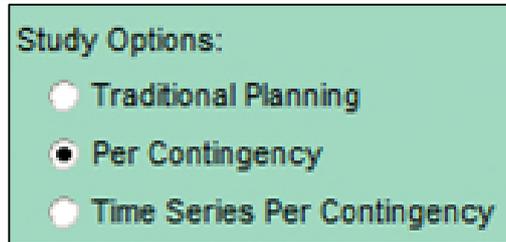


Figure 5-13: Hosting capacity methodology options

5.3.2.1. Traditional Planning methodology

If the user selects the **Traditional Planning** option, then all contingency configurations selected by the user are assessed for each scaled level of generation. At a high level the algorithm performs the following steps:

1. Scale all available dummy generators.
2. At this new generation level
 - a. Check the intact system for power system violations.
 - b. Check user selected contingency configuration system for power system violations.
3. Resolve the power system violations by scaling back the dummy generator causing the violation.
4. Stop scaling any dummy generator that was scaled back to resolve a violation.
5. If there are still dummy generators available to be scaled, return to Step 1.

5.3.2.2. Per Contingency methodology

If the user selects the Per Contingency option, then all contingency configurations selected by the user are assessed individually while scaling generation. At a high level the algorithm performs the following steps:

1. Set the case for first/next contingency configuration.
2. Scale all available dummy generators.
3. At this new generation level - check the contingency configuration for power system violations.
4. Resolve the power system violations by scaling back the dummy generator causing the violation.
5. Stop scaling any dummy generator that was scaled back to resolve a violation.
6. If there are still dummy generators available to be scaled, return to Step 2.
7. If there are contingencies configuration remaining to be assessed return to Step 1.

5.3.2.3. Time Series Per Contingency

If the user selects the **Time Series Per Contingency** option, then all contingency configurations selected by the user will have the per contingency methodology applied for each time series case configured by selecting the **Load Time Series Data** button.



Figure 5-14: Hosting capacity methodology options

- After the user selects the **Time Series Per Contingency** option, the **Load Time Series Data** button will become available to the user.
- Once the user clicks on the **Load Time Series Data** button the time series interface popup (see Section 6).

5.3.3. Contingency Selection Options

- The user can select the contingencies to include in the studies. Typically, a contingency of a BSP or Primary tie transformer will be the most limiting contingency for generation and load hosting capacity, for details of contingency definition and naming conventions see Appendix A.
- There are three user options available to select contingencies:
 - **All network configurations**
 - **Intact system Configuration only** this is the default option
 - **Specific User Selected Contingencies.**

Note: The time taken for the algorithm to complete is dependent on the number of contingencies selected.

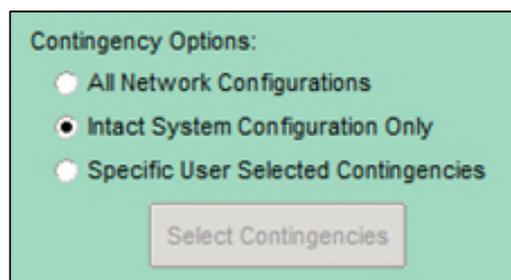


Figure 5-15: Contingency options

- If the user selects **Specific User Selected Contingencies** and clicks the **Select Contingencies** button a popup window will ask the user to select study zone contingency configuration they wish to be assessed in algorithms.
- After selection the user can use the **OK** button or **X** to close the dialog box.

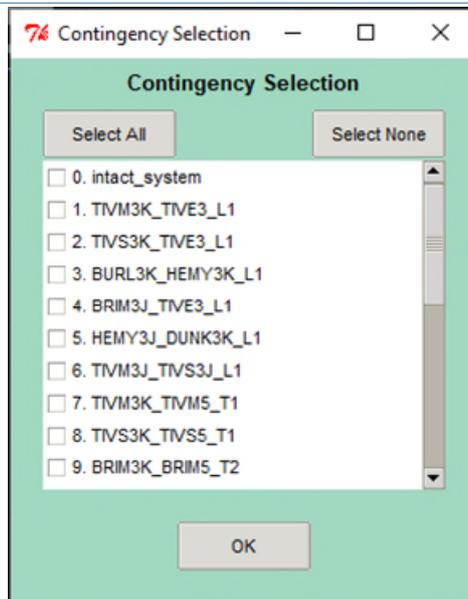


Figure 5-16: Contingency Selection window

5.4. Run Studies

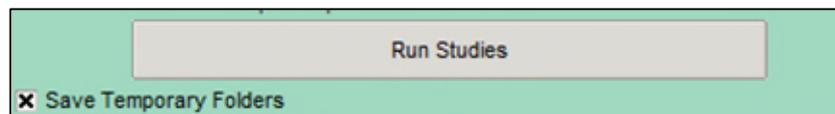


Figure 5-17: Run Studies button

When the user clicks on the **Run Studies** button a window will popup asking for the filename of the results file in the format *.xlsx. This file can be saved anywhere the user has appropriate file permissions to save to.

The user can also select to **Save Temporary Files** by checking the tick box

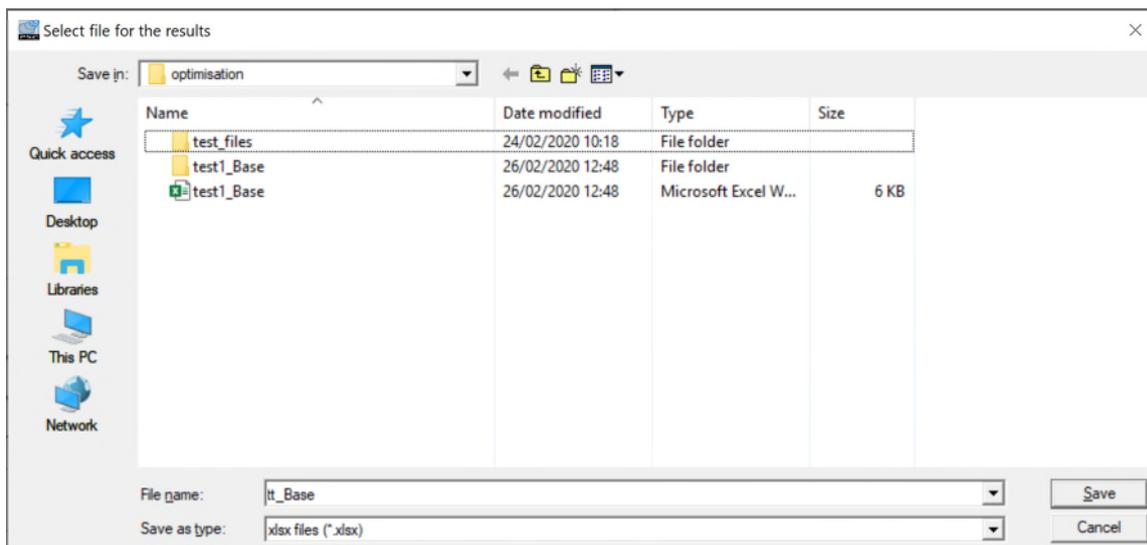


Figure 5-18: User to select file for the results to be saved in

- After a save location has been selected by the user a Summary of Input parameter window will appear, shown in Figure 5-19. This gives the user the option to proceed with the study by selecting **Yes** or returning to change the setting by selecting **No**.
- This summary is also saved to the logs folder.

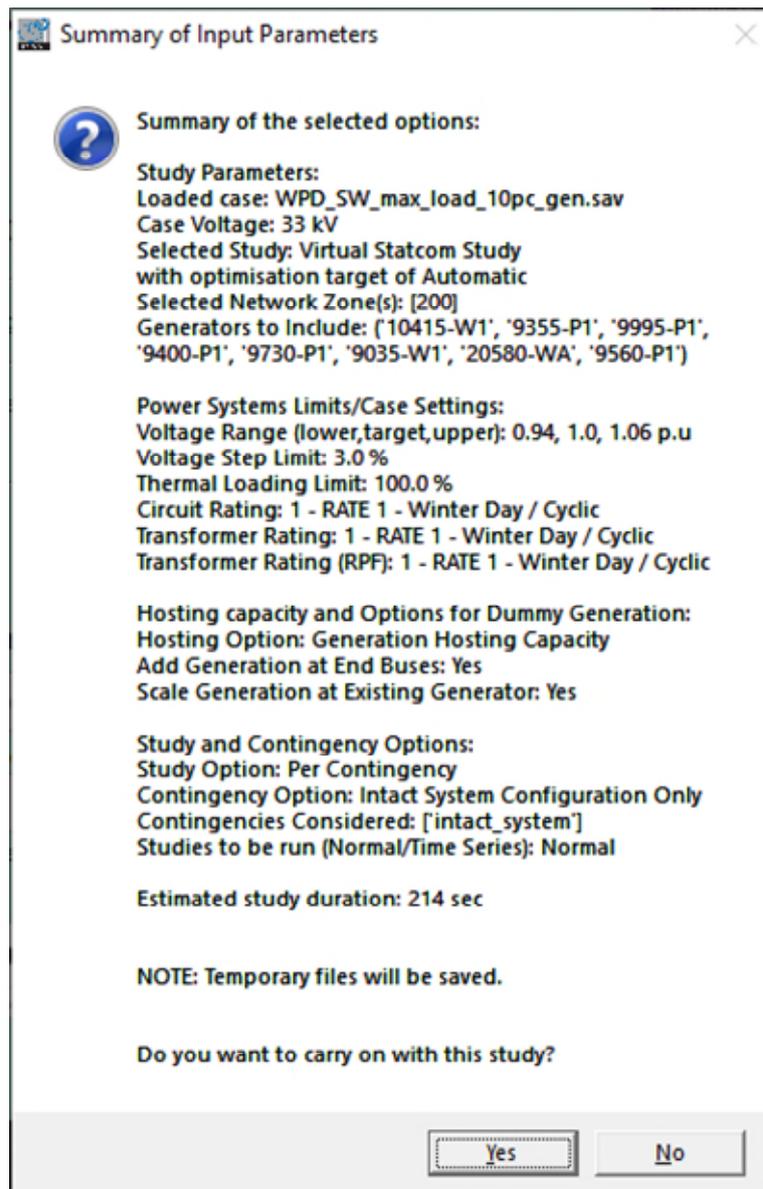


Figure 5-19 - Study summary input parameters pop up

6. Load Time Series Data Interface

After the user clicks on the **Load Time Series Data** the time series interface shown in Figure 6-1 will popup. The user's selections from the main interface will apply to the time series studies.

To run the time series studies extra time series data is required, see Appendix B for the time series data requirements.

The loading of this time series data is configured by the Load Time Series Data interface and consists of:

- Load time series data (generation and load).
- Specify a time period and time step.
- Confirming the selection of data, time period and time step.

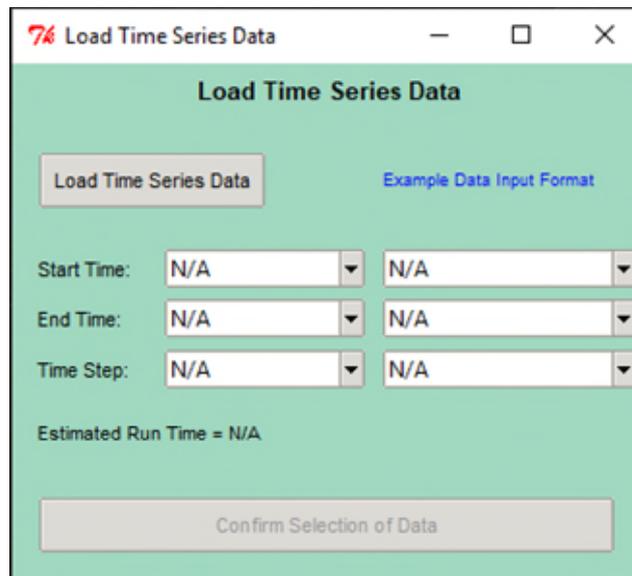


Figure 6-1: Time Series Interface

6.1. Load Time Series Data

- When the user clicks the **Load Time Series Data** button a popup window will ask the user to select a excel spreadsheet containing time series rules data (see Appendix B).

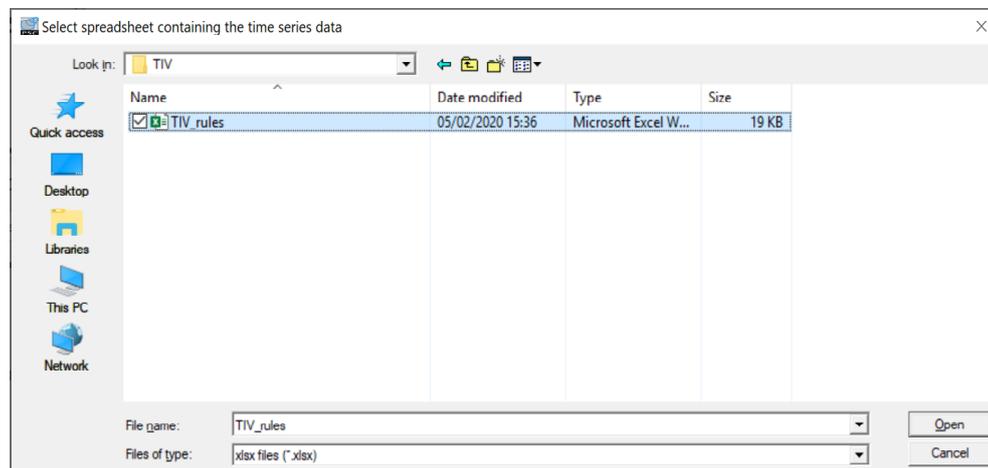


Figure 6-2: Time Series Interface

6.2. Specify Time Period and Time Step

- The user can select **Start Time**, **End Time** and **Time Step** by using the drop-down options.

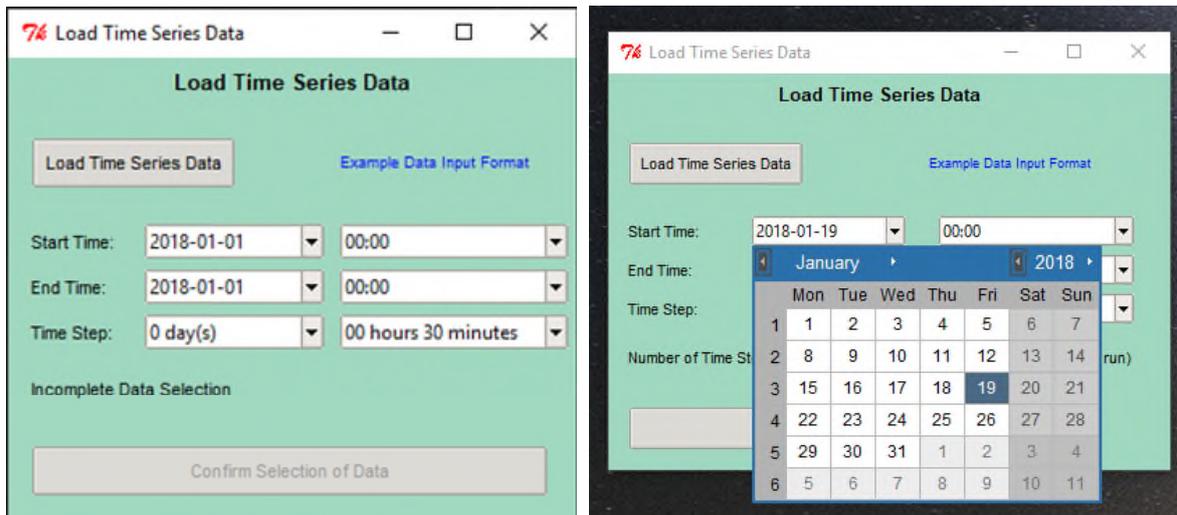


Figure 6-3: Time Series time selector

- Once the user has selected the time period and time step the user can run the time series study clicking on the **Confirm Selection of Data Studies** button.

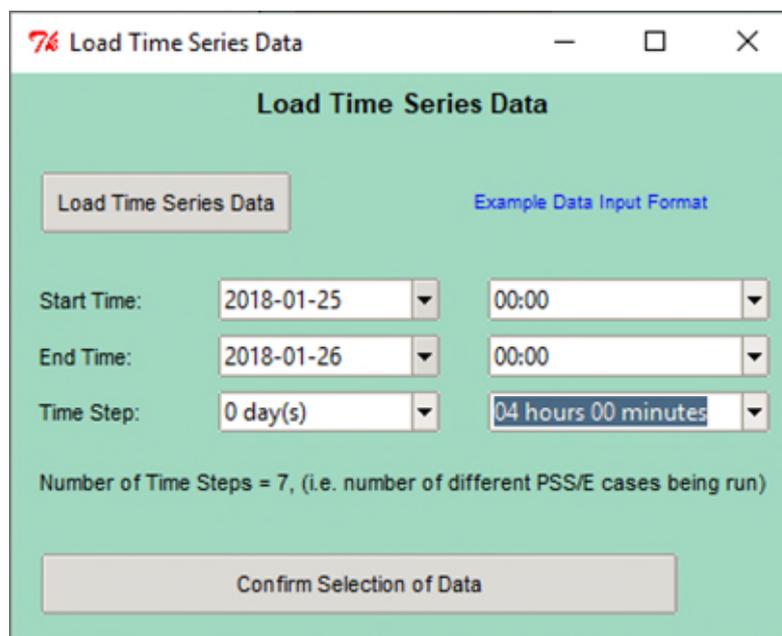


Figure 6-4: Time Series interface with period and time step selected

- After user clicks on the **Confirm Selection of Data** button the main GUI window will appear and the message under the **Load Time Series** button will change to Selected Time Series Data (Yes/No): **Yes**.

7. Outputs from Studies

7.1. Outputs from Non-Time Series Studies

7.1.1. Excel File Outputs

After the completion of the non-time series studies, the script saves the following excel files:

- 1. Hosting results comparisons** (*file name typed by user*)
This excel file contains a comparison of the generation/load hosting capacity in MW before and after optimisation, for the contingencies selected.
- 2. Generation comparisons** (*Generation.xlsx*)
This excel file contains a comparison of zone generators real and reactive power output before and after optimisation.
- 3. Load comparisons** (*Load.xlsx*)
This excel file contains a comparison of zone loads real and reactive power before and after optimisation.
- 4. Branch loading comparisons** (*Branch Loading.xlsx*)
This excel file contains a comparison of zone branch (lines/cables) loadings before and after optimisation.
- 5. Transformer forward power loadings comparisons** (*Two Winding Loading.xlsx*)
This excel file contains a comparison of zone transformer forward power loadings before and after optimisation.
- 6. Transformer reverse power loadings comparisons** (*Two Winding RPF Loading.xlsx*)
This excel file contains a comparison of zone transformer reverse power loadings before and after optimisation.
- 7. Bus voltage comparisons** (*Voltages.xlsx*)
This excel file contains a comparison of zone bus voltages before and after optimisation.

Note: If a user has selected the hosting capacity only method the files will only contain before optimisation data.

7.1.2. Plot Outputs

After the completion of the non-time series studies, the script creates and saves plots for the networks feeder groups. Plots are created before and after the optimisation showing the following hosting algorithm iteration data for each contingency configuration:

1. 33 kV bus voltages
2. 11 kV bus voltage
3. Branch loading of feeders connected to the BSP or Primary bus.
4. Generation or Load that was scaled.

Note: If a user has selected the hosting capacity only method the files will only contain before optimisation data.

7.2. Outputs from Timeseries Studies

7.2.1. Excel File Outputs

After the completion of the time series studies, the script saves the above excels files for each time step.

These outputs are also combined into a single excel file is created and saved in a folder called *(file name typed by user + TS collated results)*

7.2.2. Plot Outputs

After the completion of the time series studies, the script creates plots to compare the results. The plots are saved in a folder called *(file name typed by user + TS collated results)*

If the **Virtual Statcom Study Mode** has been run two plots per contingency are created:

- **Plot 1** (called '*contingency number*' + *file name typed by user + TS Generation Hosting*) contains:
 - Load and Generation vs Time
 - MW hosting vs time
 - % Increase vs time
- **Plot 2** (called '*contingency number*' + *file name typed by user + TS Generation Losses*) contains:
 - Losses % vs time

If the **Capacity Evaluation Study Mode** has been run one plot per contingency is created:

- **Plot 1** (called '*contingency number*' + *file name typed by user + TS Generation Hosting(only)*) contains:
 - Load and Generation vs Time
 - MW hosting vs time
 - Losses % vs time

8. Log Messages

When the script is run it will display log messages in either the PSSE or Python window about progress, if any errors or warnings occur these will also be displayed. If an error occurs a log file will be saved in the script folder with contents of the error messages that can then be reviewed / checked to understand if this has a material impact on the results.

9. Trouble shooting

9.1. PSSE Crashing while Virtual Statcom GUI

If PSSE programme crashes or is closed the GUI will stay open. To close the GUI either:

- **Right click** on the PSSE icon on the toolbar and select **Close Window**
- **Ctrl + Alt + Delete** and stop PSSE running.

Appendix A – Contingencies for Virtual Statcom and Capacity Evaluation tool

Contingency Definition:

A contingency in the Virtual Statcom and capacity evaluation algorithms is the removal of one of power system asset from the study network in the normal operation configuration (intact system). After a contingency is removed the study network is in a contingency configuration.

The contingencies considered by the algorithms are; a single circuit, a single transformer/voltage regulator and a single generator (for voltage step limits).

Contingency Naming Convention:

The contingency name is derived from the PSSE branch elements that make it up the format is

From Bus name_To Bus Name_Branch_ID

The following figure shows 3 example contingencies highlighted:

e.g.	Description	Type	Name
1	Circuit contingency (line/cable)	BR (Branch)	BRIM3J_TIVE3_L1
2	Transformer contingency	TW (Two winding)	TIVE3_TIVE1R_G2
3	T'ed circuit contingency	BRT (Branch T)	BURL3J_AYSH3T_L1+ TIVE3_AYSH3T_L1+ AYSH3_AYSH3T_L1

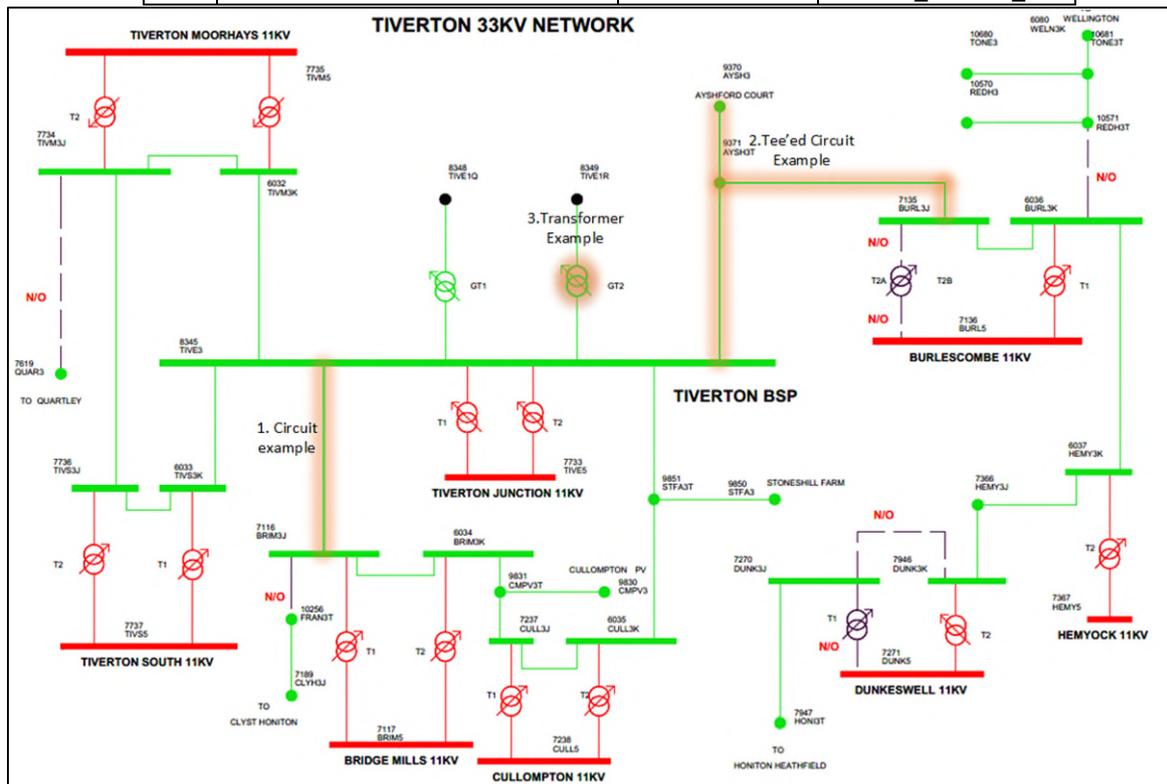


Figure 0-1 - Tiverton 33 kV contingency examples

Appendix B – Timeseries Data Requirements

Multiple files are needed to run the timeseries data.

- A CSV file for each load and generation site containing time series data.
- An excel file containing the mapping rules to map the CSV timeseries data into the PSS/E case.

Tiverton 33 kV BSP Time Series Data Example

The following shows an example of the time series data used for Tiverton 33 kV BSP.

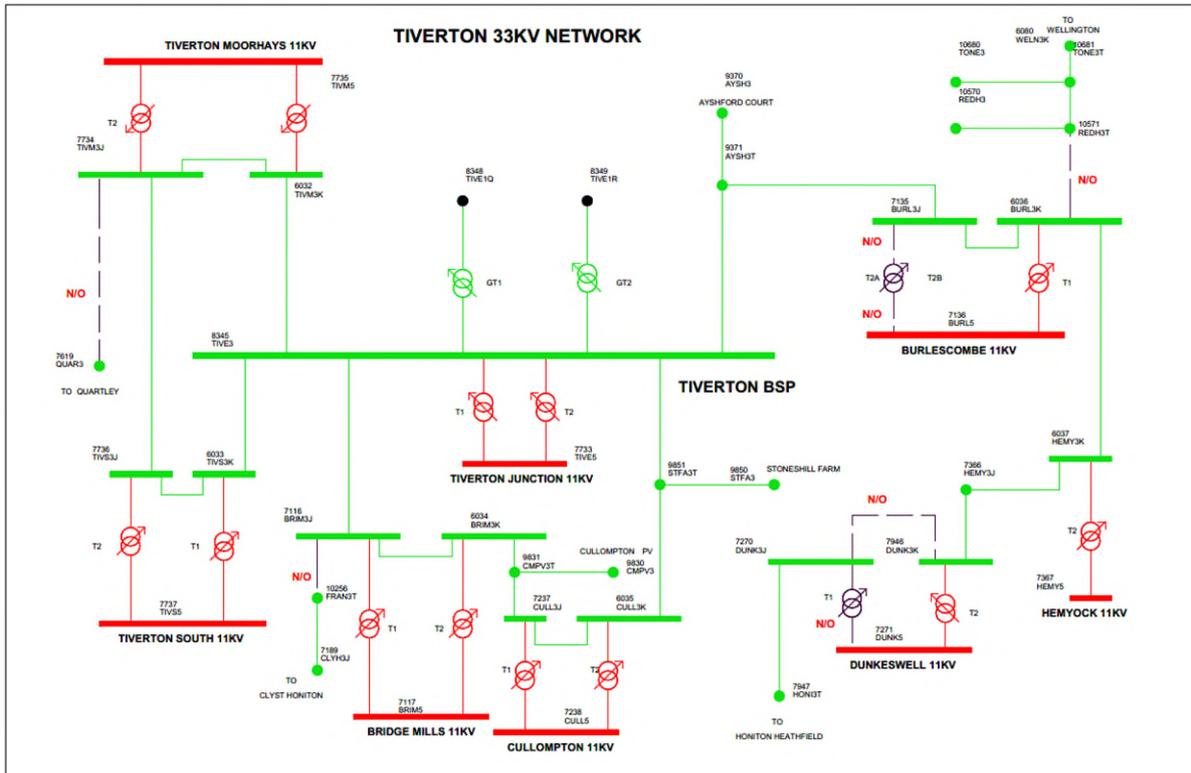


Figure 0-1: Tiverton 33 kV BSP

Tiverton 33 kV BSP Load and Generation .csv Files:

Tiverton 33 kV BSP contains the following load and generation:

Loads	Generation
BRIDGE MILLS	AYSHFORD COURT FARM 33kV SOLAR PARK
BURLESCOMBE	CULLOMPTON 33kV SOLAR PARK
CULLOMPTON	STONESHILL 33kV SOLAR PARK
DUNKESWELL	
HEMYOCK	
TIVERTON BSP	
TIVERTON JUNCTION	
TIVERTON MOORHAYES	
TIVERTON SOUTH	



For each load and generation site, a CSV file with time series data for real and reactive power is required.

e.g. BRIDGE MILLS_PQ.csv

	A	B	C	D	E	F
1	DATE-TIME	P_MW	Q_MVAR	LTDS_MW	LTDS_MVAR	PF
2	01/01/2018 00:30	3.674289581	0.523557909	6.5637	0.935276595	0.99
3	01/01/2018 01:00	3.822699634	0.544705197	6.5637	0.935276595	0.99
4	01/01/2018 01:30	3.772704247	0.53758124	6.5637	0.935276595	0.99
5	01/01/2018 02:00	3.566094308	0.508140918	6.5637	0.935276595	0.99
6	01/01/2018 02:30	3.587208387	0.511149511	6.5637	0.935276595	0.99
7	01/01/2018 03:00	3.513584366	0.500658656	6.5637	0.935276595	0.99
8	01/01/2018 03:30	3.32501466	0.473788929	6.5637	0.935276595	0.99
9	01/01/2018 04:00	3.022114308	0.430627966	6.5637	0.935276595	0.99
10	01/01/2018 04:30	2.759197601	0.393164364	6.5637	0.935276595	0.99

e.g. AYSHFORD COURT FARM 33kV SOLAR PARK_PQ.csv

	A	B	C	D	E	F
1	DATE-TIME	P_MW	Q_MVAR	LTDS_MW	LTDS_MVAR	PF
2	01/01/2018 00:00	0	-0.390634	4.55	0	6.12E-17
3	01/01/2018 00:30	0	-0.521194	4.55	0	6.12E-17
4	01/01/2018 01:00	0	-0.434066	4.55	0	6.12E-17
5	01/01/2018 01:30	0	-0.497122	4.55	0	6.12E-17
6	01/01/2018 02:00	0	-0.433281	4.55	0	6.12E-17
7	01/01/2018 02:30	0	-0.466249	4.55	0	6.12E-17
8	01/01/2018 03:00	0	-0.514391	4.55	0	6.12E-17
9	01/01/2018 03:30	0	-0.478546	4.55	0	6.12E-17
10	01/01/2018 04:00	0	-0.509158	4.55	0	6.12E-17

Tiverton 33 kV BSP Rules Excel Files:

The Tiverton mapping rules file 'TIV rules.xlsx' contains the rules to map each CSV file to a PSS/E load or generation bus.

Load Worksheet:

	A	B	C	D	E	F	G	H	I	J	K	L
1	Site	Type	S/S or Busbar Name	BSP load	Bus/Node	Base kV	Maximum Demand MVA 2017/18	Power Factor	No. Loads	Bus Number	Bus Name	Id
2	BRIDGE MILLS	L	BRIDGE MILLS 11kV	FALSE	BRIMS	11	6.63	0.99	1	7117	BRIMS	11.000 1
3	BURLESCOMBE	L	BURLESCOMBE 11kV	FALSE	BURLS	11	3.52	0.99	1	7136	BURLS	11.000 1
4	CULLOMPTON	L	CULLOMPTON 11kV	FALSE	CULLS	11	8.4	0.99	1	7238	CULLS	11.000 1
5	DUNKESWELL	L	DUNKESWELL 11kV	FALSE	DUNKS	11	3.99	0.99	1	7271	DUNKS	11.000 1
6	HEMYOCK	L	HEMYOCK 11kV	FALSE	HEMYS	11	4.55	0.99	1	7367	HEMYS	11.000 1
7	TIVERTON BSP	L	TIVERTON 33kV	TRUE	TIVE3	33	52.86	0.99	0			
8	TIVERTON JUNCTION	L	TIVERTON JUNCTION 11kV	FALSE	TIVE5	11	11.03	0.99	1	7733	TIVE5	11.000 1
9	TIVERTON MOORHAYES	L	TIVERTON MOORHAYES 11kV	FALSE	TIVM5	11	6.74	0.99	1	7735	TIVM5	11.000 1
10	TIVERTON SOUTH	L	TIVERTON SOUTH 11kV	FALSE	TIVS5	11	12.65	0.99	1	7737	TIVS5	11.000 1

Generation Worksheet:

	A	B	C	D	E	F	G	H	I	J	K	L
1	Site	Type	BSP	Primary	Node in Model	Connection Voltage	Size	Type	Status	Bus Number	Bus Name	Id
2	AYSHFORD COURT FARM 33kV SOLAR PARK	G	Tiverton	33kV Connected	AYSH3	33	4.55	Photovoltaic	Connected	9370	AYSH3	33.000 P1
3	CULLOMPTON 33kV SOLAR PARK	G	Tiverton	33kV Connected	CMPV3	33	4.082	Photovoltaic	Connected	9830	CMPV3	33.000 P1
4	STONESHILL 33kV SOLAR PARK	G	Tiverton	33kV Connected	STFA3	33	5	Photovoltaic	Connected	9850	STFA3	33.000 P1