PSC Harmonics User Guide

For: Australian Energy Market Operator

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Power Systems Consultants Australia Pty Ltd

Client Reference:

PSC Reference: JA7896-03-1

Revision: 1

Date: 12th June 2020

Document History

Revision	Date	Description of changes
0	28-05-2020	Initial Version
1	29-07-2020	Updated to address AEMO comments

Revision	Date	Author	Peer Review	Approved
0	28-02-2020	David Mills		
1	29-07-2020	David Mills		

Script Version History

Revision	Date	Description of changes
1.0	12-06-2020	Initial Version
1.1	03-07-2020	Inclusion of ConvexHull calculation for impedance loci
1.2	18-07-2020	Inclusion of contingencies by line name

Contents

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1. Introduction

The Australian Energy Market Operator (AEMO) has engaged PSC to develop a tool that allows them to carry out frequency scans using DIgSILENT PowerFactory. This report provides details of this Python based tool that integrates with PowerFactory to carry out studies which allows the following different options:

- Frequency scans on multiple PowerFactory project, study case and operating configurations
- Frequency scans for multiple network configurations representing system contingencies
- Exporting the results into a spreadsheet for identified terminals and consisting of:
    - Self-impedance (Resistance, Reactance and Impedance values)
    - Mutual-impedance (Resistance, Reactance and Impedance values)

The following sections set out how to install, provide inputs and run the tool.

2. Installation

To be able to run these scripts the user will need to have DIgSILENT PowerFactory 2017 or later and Python 3.5 or later.

2.1. Python Packages

In addition to the standard python packages the following packages will also be needed. The specific versions of these packages that the tool has been developed and tested with are included in the file, requirements.txt file included as part of the PSC Harmonics tool:

- pandas
- numpy
- xlrd
- openpyxl
- Pillow
- XlsxWriter
- scipy
- matplotlib
- shapely

2.2. DIgSILENT PowerFactory Model

These scripts have been developed and tested on the following PowerFactory versions; it is assumed that later versions will continue to be compatible but should be tested before results are relied upon. Within the PSC Harmonics tool there is a directory called, tests, within which are a number of tests results which can be used for this purpose.

- PowerFactory 2017
- PowerFactory 2018
- PowerFactory 2019

Additionally, to run a frequency scan in PowerFactory and therefore to run these scripts the model must be able to achieve a convergent load flow and have access to the “Power Quality and Harmonic Analysis” module.

2.3. Inputs Spreadsheet

There are a number of inputs required to setup the studies and determine what outputs should be included. These are provided via the Inputs Spreadsheet which is included as part of the PSC Harmonic tool package. Further details on these inputs are included in section 0.

3. Process

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

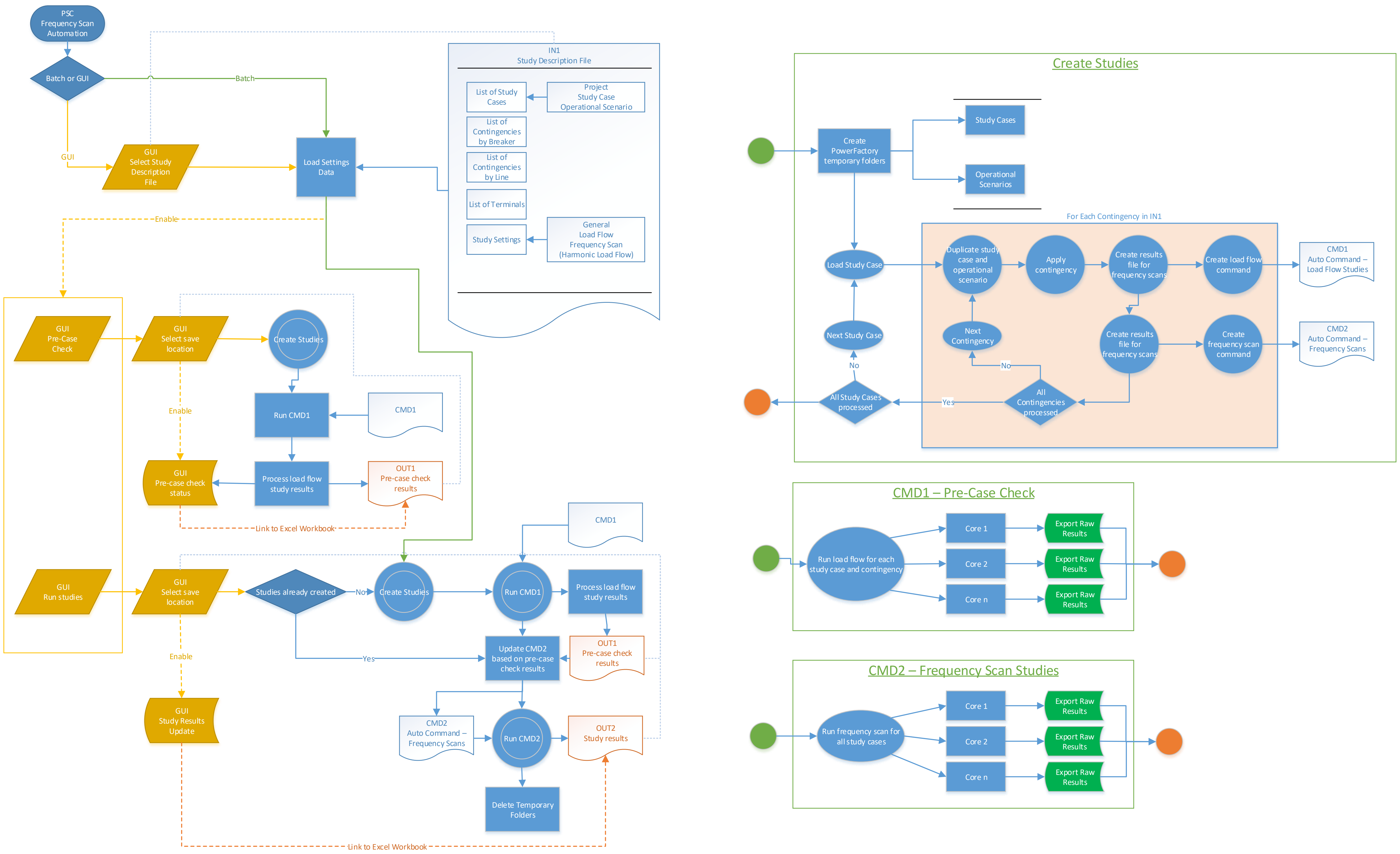

Figure 3-1: Flowchart for PSC Harmonics Tool

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4. Execution

These scripts can be run from PowerFactory or directly from a Python interpreter, the results and process are the same. They can also be run in either a batch mode or via a graphical user interface.

4.1. PowerFactory Execution

If running from PowerFactory you will need to complete the following process to create a new .ComPython command:

1. Load the Data Manager
2. Select the current user
3. Click New Object
    a. Select DPL/Python Command and more
    b. Under element, select: Python Script (ComPython)
4. Give the new .ComPython object a suitable name
5. Click Script
6. Select to add a Script file and navigate to the location that you have saved PSC Harmonics tool in
    a. Select PSC_Harmonics_Batch.py for batch based operation (section 4.4)
    b. Select PSC_Harmonics_GUI.py for a graphical user interface based operation (section 4.4)

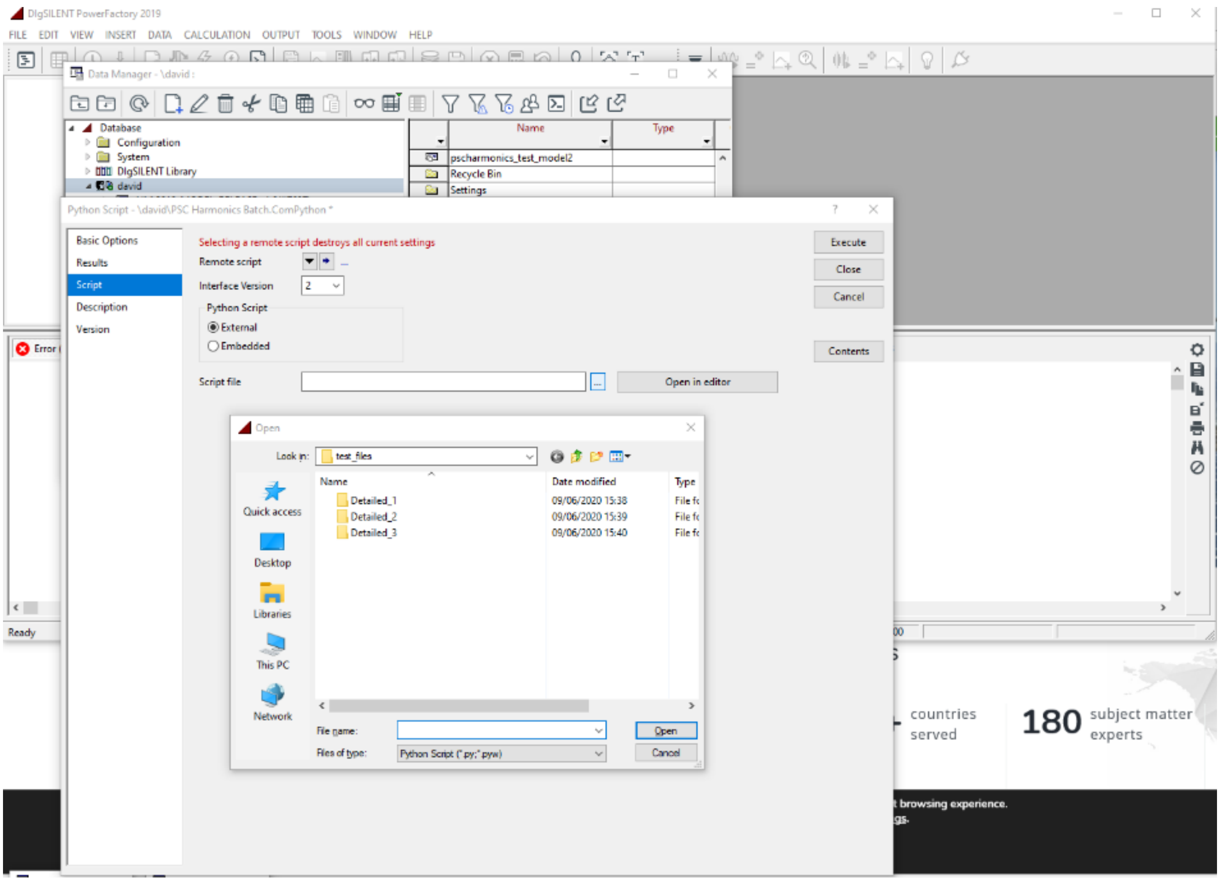

Figure 4-1: Adding a .ComPython command to PowerFactory 2019

4.2. Python Interpret Based Execution

If running from Python directly either:

- Open and run the script PSC_Harmonics_GUI.py (section 4.4) or PSC_Harmonics_Batch.py (section 4.5) in a suitable Python 3.5+ interpreter
- Open a command prompt in the location of PSC Harmonics tool and type one of the following commands:
    - "python PSC_Harmonics_GUI.py" (section 4.4)
    - "python PSC_Harmonics_GUI.py" (section 4.5)

4.3. Log Files

When the study is run via either method log files (*.log) are automatically created and saved in the PSC Harmonics tool folder labelled "logs". Once the number of files in this folder exceeds 500 the user will be warned and once there are more than 700 the oldest will be deleted.

Log files are automatically named based on the date and time the study is started in the format: YYYYMMDD_hhmmss (i.e. 20200601_151524 represents 15:15:24 on the 1st June 2020).

Log files are produced with prefixes relating to the categories detailed in Table 4-1.

Table 4-1: Log file prefixes

Prefix	Contents
ERROR_	Stores and error messages that have been raised during execution. These are messages which have either stopped the study running or have allowed the study to run but mean the results may be unreliable. This file is only produced if an error actually occurs.
INFO_	Stores information messages which relate to the study settings, progress and results that have been created. This file is produced for every study.
DEBUG_	Stores detailed information regarding each step of the study, actions that have been taken, assumptions that have been made, etc. The purpose of this output is for debugging if there are any errors running the studies. This file is only produced if an error has occurred which has forced the script to stop. It can also be set to be produced in all cases by setting the variable DEBUG to True in the python file pscharmonics\constants.py

All info and error log messages are also output to the PowerFactory or Python windows

4.4. Batch Mode Operation (PSC_Harmonics_Batch.py)

This mode will just run the PSC Harmonics tool using inputs detailed in the file named, "PSC_Harmonics_Inputs.xlsx". The user will not be asked for any further inputs and the outputs will be saved in the results location detailed in the inputs. If there are any warnings or errors these will be reported in the progress window and saved in log files located within the PSC Harmonics tool directory.

4.5. Graphical User Interface (PSC_Harmonics_GUI.py)

The first window that will appear once the script has initialised is the main user interface shown in Figure 4-2. The first option that is available to the user is to select the PowerFactory version that they wish to use for these studies (section 4.5.1).

The main user interface allows the user to run different aspects of the study as set out below and initially only two options are available to the user:

- Select Settings File (section 4.5.1):
- Combine previous study results (section 4.5.5)

If the user chooses to run a new study by selecting a settings file, once the file has been loaded and PowerFactory initialised the following buttons will become enabled:

- Run pre-case check (section 4.5.3)
- Run study (section 4.5.4)

The buttons to review results (Review Pre-Case Check Results, Review Study Results, Review Combined Study Results) only become enabled once the associated study has been carried out successfully. If a study is unsuccessful the user interface will display an error message and go into the error state detailed in section 4.5.6.

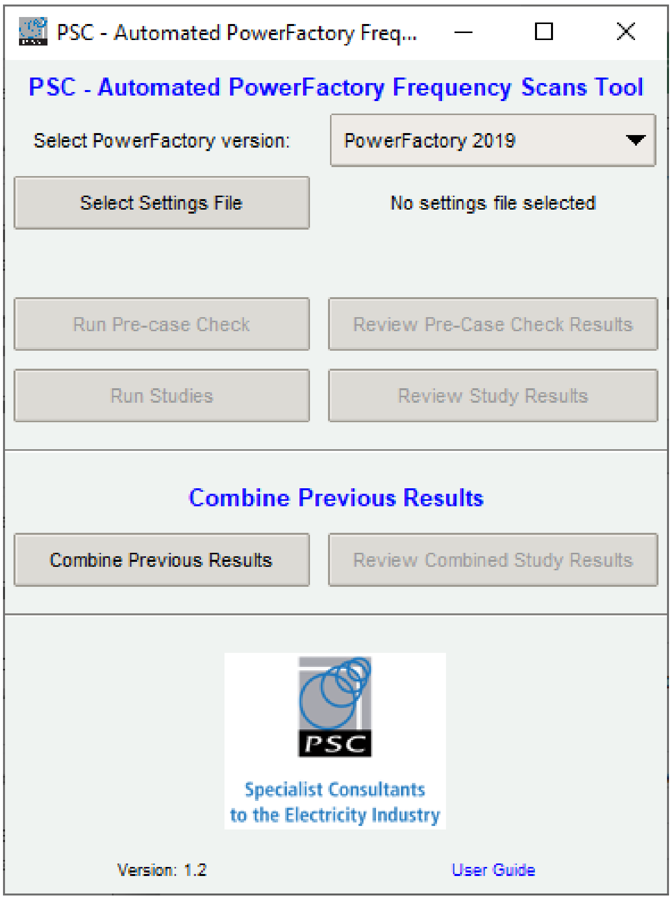

Figure 4-2: Main user interface window

4.5.1. Select PowerFactory version

This drop down box is pre-populated with the PowerFactory versions that have been identified on the machine and defaults to the latest version. The user may wish to change this to the PowerFactory version which already has then network model they wish to run studies on imported.

4.5.2. Select Settings File

The user will be asked to select an inputs file which must be in the format described in section 0.

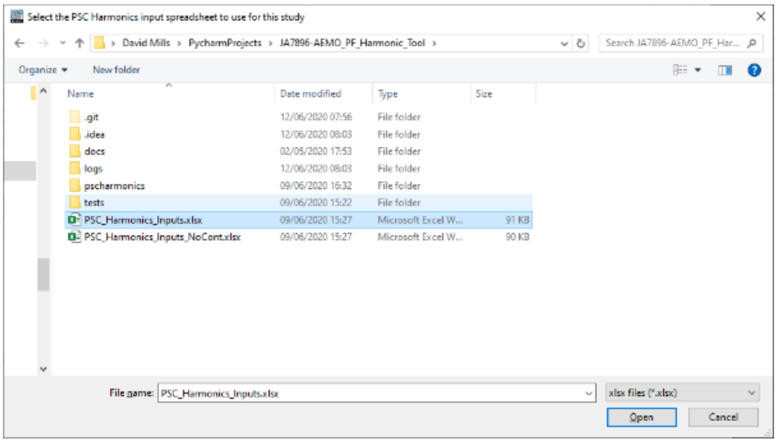

Figure 4-3: User to select input settings file

After clicking Open the Inputs file will then be loaded and the following process steps take place, once completed the “Run Pre-case Check” and “Run Studies” buttons become enabled:

1. Import Settings
2. Initialise PowerFactory
3. Check that the Projects, Study Cases and Operating Scenarios detailed in the Inputs (section 5.3) exist

4.5.3. Run Pre-case Check / Review Pre-Case Check Results

Running the pre-case check will loop through each of the provided cases and contingencies to run a load flow. The load flow settings will be based on the inputs provided (section 0) and uses the same command that is run when carrying out frequency sweeps. The purpose of running this pre-case check is to confirm all of the contingencies have a convergent load flow as those which are not will not be able to have a frequency sweep carried out.

Figure 4-4 shows the window that will pop-up asking the user to select a results file for the pre-case check.

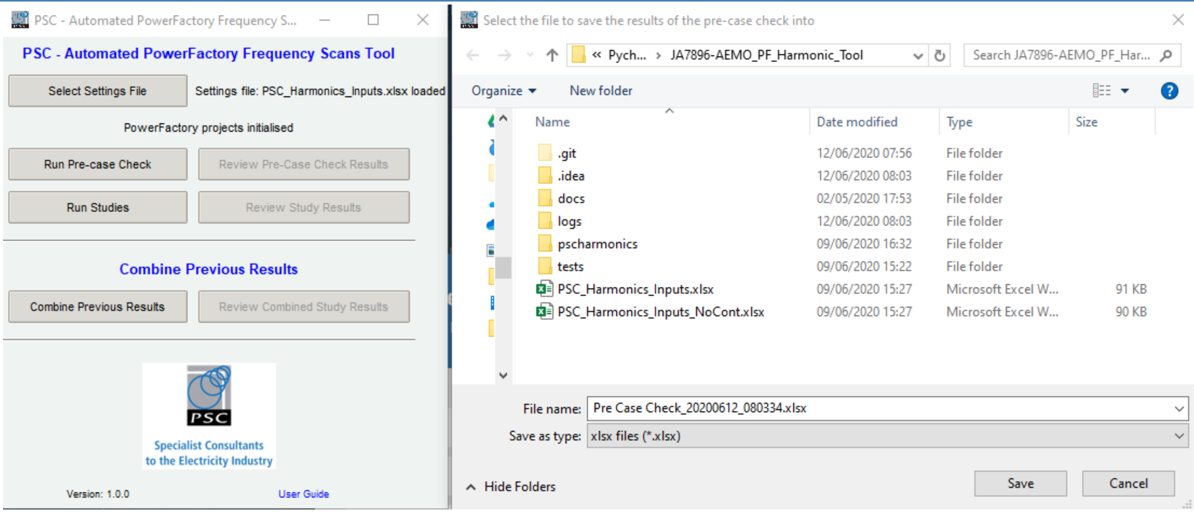

Figure 4-4: User to pre-case results file

Once the pre-case check has been completed the button “Review Pre-Case Check Results” will be enabled. Clicking this will open excel and load the spreadsheet of the results, the layout of which is detailed in section 6.1.

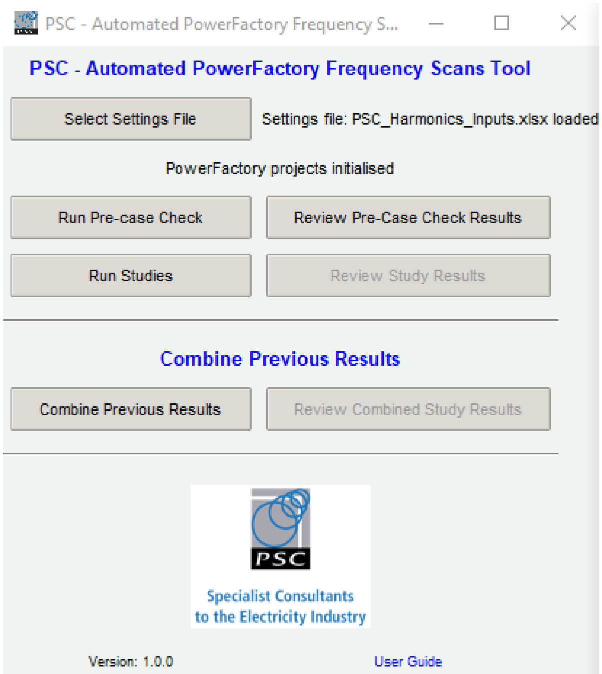

Figure 4-5: Once pre-case check is run the “Review Pre-Case Check Results” button is enabled

4.5.4. Run Studies / Review Study Results

Selecting to run studies will carry out the frequency scans for every scenario and contingency. If a pre-case check has already been run then the contingencies identified in that output which are non-convergent will be skipped, if it has not been run then it will be run but no pre-case output will be produced.

Figure 4-6 shows the pop-up that will ask the user to select the overall results file. A new folder will also be created (6.2.1) with the same name into which the following files will be saved:

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- The inputs file
- A raw output of the frequency scans for each contingency case studied.

This folder can be used to combine multiple sets of studies into a single results file as detailed in section 4.5.5.

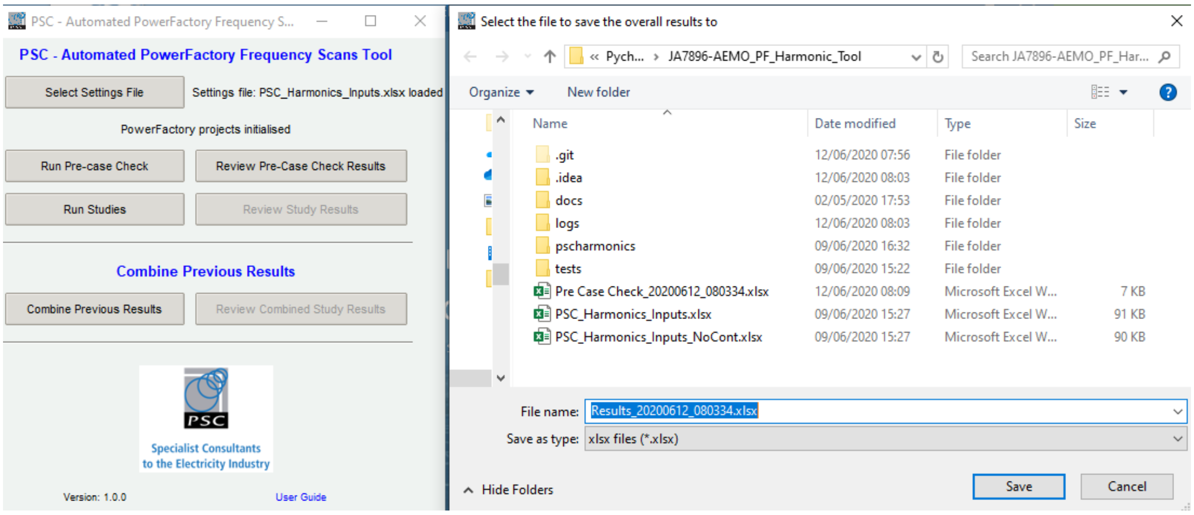

Figure 4-6: User to overall results file

On completion of the studies a single spreadsheet will be produced with the raw data and graphs of the self-impedance for each terminal, scenario and study case as detailed in section 6.2.2. The button “Review Study Results” will also be enabled which if clicked will open Excel and load the overall results spreadsheet.

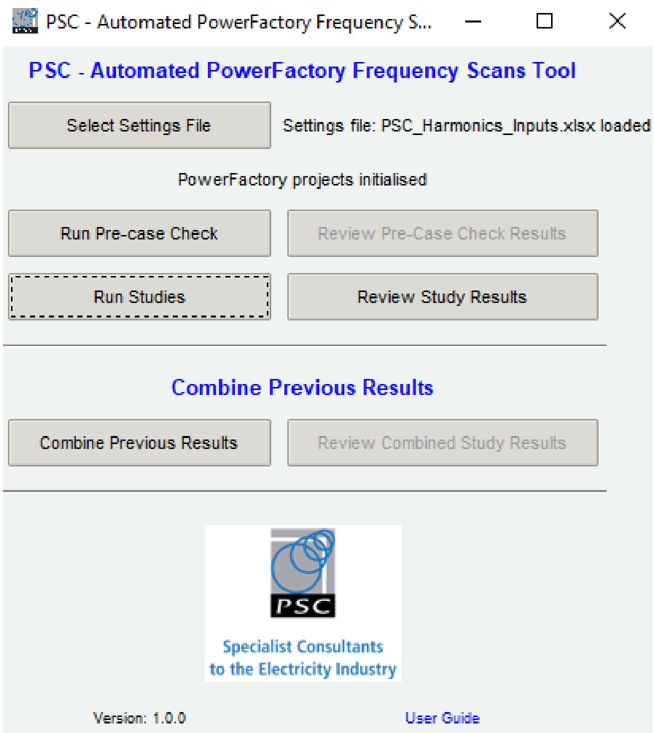

Figure 4-7: Once Run Studies is complete the “Review Study Results” button is enabled

4.5.5. Combine Previous Results / Review Combined Study Results

If multiple different studies have been carried out it is possible to combine their raw output into a single spreadsheet by selecting the Combine Previous Results button. No initial settings files will need to have been imported and access to a PowerFactory license is not required.

A new window will popup as shown in Figure 4-8 and the user can select previously produced folders which will be combined into a single results file. Once all the folders have been selected the Process Results button will allow the user to select a file to save the combined results into.

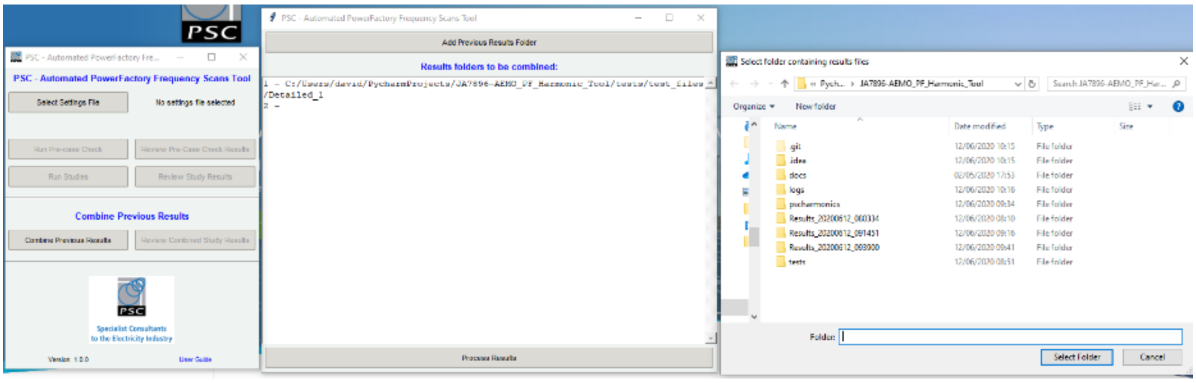

Figure 4-8: Combine previous set of raw study results

Once the results have been combined the button “Review Combined Study Results” will be enabled and if clicked will open Excel and load the overall results spreadsheet.

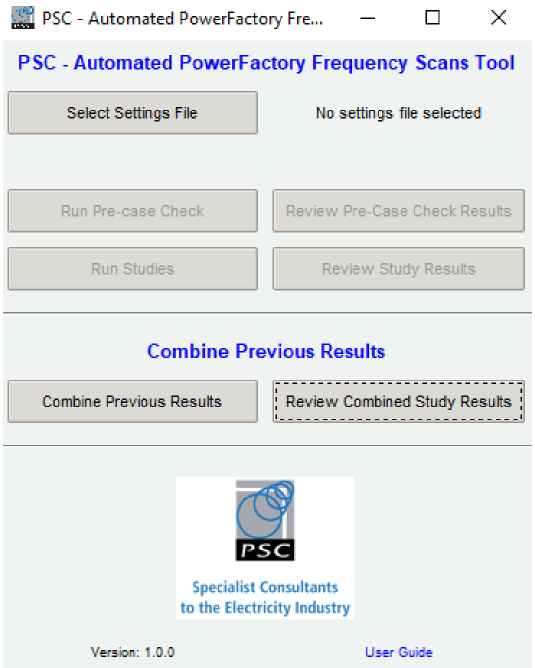

Figure 4-9: Once results combined the “Review Combined Study Results” button is enabled

4.5.6. Error Occurs when Running Studies

If any errors occur during loading files or running studies the GUI will enter an error state as shown in Figure 4-10. The status message will display ERROR: followed by a short message summarising the error that occurred. Further details as to the specific error will be detailed in the PowerFactory or Python output window and the associated error logs (section 4.3)

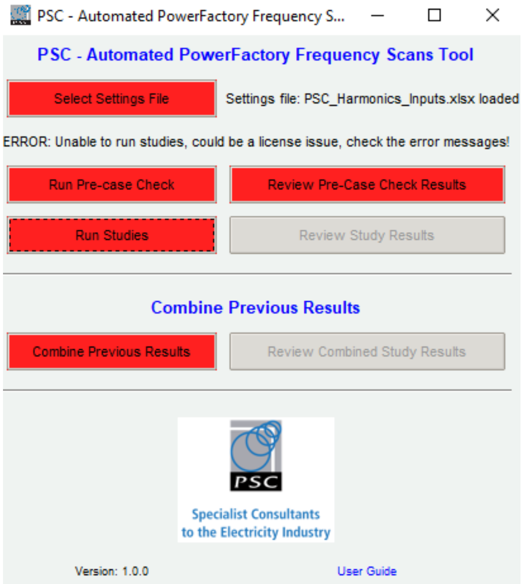

Figure 4-10: Error Occurred Whilst Running Studies

5. Inputs Spreadsheet

The inputs spreadsheet is used to define the parameters for the study and consists of the worksheets detailed in the following sections. An example of a completed inputs spreadsheet is included with the PSC Harmonics tool and also contains some further commentary to describe to the user the specific inputs in more detail.

5.1. Cover Sheet

This worksheet is just used to provide an overview and version history of the tool, it is not used directly by the PSC Harmonics tool for the studies.

5.2. Study_Settings

This worksheet allows the user to select some of the key attributes for the study and are described alongside the input and in Table 5-1.

Table 5-1: Inputs worksheet, Study_Settings attributes

Attribute	Description
Results_Export_Folder	This is the folder that results will be saved in when running in batch mode.
Excel_Results	This is the name of the file that will be used for the results when running in batch mode.
Pre_Case_Check	This determines whether a pre case check is carried out when running in batch mode
Delete_Created_Folders	During the study a number of temporary folders are created in PowerFactory and this determines whether these are deleted on completion of the studies.
Export_to_Excel	This determines whether the results should be exported to excel when running in batch mode
Excel_Export_RX	This determines whether the R and X values should be exported alongside the Z values
Excel_Export_Z12	This determines whether mutual impedance values should also be exported
Include_Intact	This determines whether a study should be included for the intact system as well as the contingencies
Include_Convex	This determines whether the impedance loci plots should be included in the export (section 6.2.2)

5.3. Base_Scenarios

This worksheet allows the user to specify the following items relating the PowerFactory model studies are to be run on and all columns need to be populated:

Table 5-2: Inputs worksheet, Base_Scenarios attributes

Attribute	Description
Name	This is a user configurable unique name used to reference the Database, Studycase and Operational Scenario combination. The entries in this column should be unique.
Database	This is the PowerFactory database that contains the study case and operating scenario to be run. This should already be loaded into the PowerFactory version which is being run.
Studycase (.IntCase)	This is the specific PowerFactory study case which should be activated
Operational Scenario (.IntScenario)	This is the Operational Scenario that should be activated with the Studycase.

5.4. Contingencies

Contingencies can be defined by either specifying the circuit breakers that should be opened or the name of the line[1] that should be switched out. These can be detailed in one of two methods, either a pre-prepared PowerFactory .ComSimoutage command can be detailed or the individual elements listed. If the latter, then a .ComSimoutage command will be created that represents each of the contingencies and used for the pre-case check.

There are two separate worksheets available to specify the contingencies to be taken named:

- Contingencies_Breakers
- Contingencies_Lines

Contingencies can be specified in either or both of these worksheets. If the same name is specified for a contingency in both worksheets then this will be treated as the same contingency configuration with the switching actions associated with the switches and lines both being applied. The following sub-sections detail the options available for each worksheet.

5.4.1. Contingencies_Breakers

Up to 9 different circuit breaker operations can be detailed as part of a single contingency, any with no entry in the station name will be ignored. Table 5-3 provides some more details of the required details when listing out contingency operations.

[1] This can represent either an individual line (.ElmLine) or branch (.ElmBranch) in the PowerFactory model.

Table 5-3: Inputs worksheet, Contingencies_Breakers attributes

Attribute	Description
Name	This is a user configurable unique name used to reference this specific contingency and the entries in this column should be unique.
Breaker 1 – Station	This is the name of the PowerFactory substation that contains the relevant circuit breaker. This must be exactly as written in PowerFactory
Breaker 1 – Breaker Name	This is the name of the switch element in PowerFactory which should be operated and must be written exactly as written in PowerFactory.
Breaker 1 - State	This is the state of that switch that should be considered for this contingency

5.4.2. Contingencies_Lines

Up to 9 different lines can be identified for outage operations as part of a single contingency, any with no entry in the line name will be ignored. Table 5-4 provides some more details of the required details when listing out contingency operations.

Table 5-4: Inputs worksheet, Contingencies_Lines attributes

Attribute	Description
Name	This is a user configurable unique name used to reference this specific contingency and the entries in this column should be unique.
Line 1 – Line / Branch Name	This is the name of the line (.ElmLne) or branch (.ElmBranch) in PowerFactory that should have the operation carried out. This must be written exactly as written in PowerFactory
Line 1 - Status	This determines whether the eventual status of the line is to be switched in (In Service) or switched out (Out of Service)

5.5. Terminals

This worksheet allows the user to specify the specific terminals they wish to obtain frequency results for. A new worksheet will be produced for each of these terminals in the outputs (section 6.2.2) showing the self- and mutual-impedance values as appropriate. During the pre-case check the existence of each of these terminals within the PowerFactory model will also be checked.

The following table details the inputs required for each terminal results are needed from.

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Table 5-5: Inputs worksheet, Terminals attributes

Attribute	Description
Name	This is a user configurable unique name used to reference this specific terminal. There is a maximum length of 19 characters for this name to avoid exceeding the maximum character limit in PowerFactory.
Station	This is the name of the PowerFactory substation that contains the relevant terminal. This must be exactly as written in PowerFactory
Terminal	This is the name of the terminal element in PowerFactory and must be written exactly as written in PowerFactory.
Mutual	This is to declare whether this terminal should be considered for the calculation of mutual impedance. For very large studies calculating mutual impedance can take a significant time and removing those which aren't necessary can speed up the processing. If set to TRUE then mutual impedance will be calculated to and from this terminal to each of the others.

5.6. Loadflow_Settings

This worksheet allows the user to specify the load flow settings to be used by PowerFactory. These can be detailed in one of two methods, either an existing PowerFactory .ComLdf command can be detailed or the individual settings listed. If the latter, then a .ComLdf command will be created based on those settings and used for both the pre-case check and the frequency sweeps.

Details of the specific settings can be found within the PowerFactory user manual

5.7. Frequency_Sweep

This worksheet allows the user to specify the Frequency sweep settings to be used by PowerFactory. These can be detailed in one of two methods, either an existing PowerFactory .ComFsweep command can be detailed or the individual settings listed. If the latter, then a .ComFsweep command will be created based on those settings and used for both the frequency sweeps.

Details of the specific settings can be found within the PowerFactory user manual.

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6. Outputs from Studies

Outputs from these studies are produced in the form of spreadsheets and will be either:

- Pre-case Check results
- Overall Complete study results

6.1. Pre-Case Check

The pre-case check allows the user to confirm that all contingencies are convergent, and terminals can be found. The spreadsheet produced provides two worksheets; Contingencies and Terminals.

Contingencies

The Contingencies worksheet will detail the name of the case and contingency along with the PowerFactory project, study case and operating scenario that was considered. A status is provided showing whether the contingency is convergent for the load flow settings provided (section 0). Those which are non-convergent will not be considered in the complete results run since PowerFactory requires a convergent load flow to carry out a frequency sweep.

Terminals

The Terminals worksheet will detail the name of the PowerFactory Database and whether the terminal can be found. In the case of those which also require mutual impedance data to be returned it will detail the names for those and the mutual element (.ElmMut) that has been created in PowerFactory. Results for those terminals which cannot be found in a PowerFactory Database will not be considered in the results.

6.2. Complete Results

The production of the complete results is carried out in two stages; exporting the raw results and then combining into an overall processed results output.

6.2.1. Raw Results Folders

To speed up the processing PowerFactory will attempt to carry out the frequency scans using parallel processing utilise all of the processors available on the computer. After the frequency for each contingency is completed the results are saved into the raw results as a .csv file named suitable to identify each of the results.

A copy of the inputs spreadsheet is also saved in this folder to allow the specific inputs for each study to be investigated further.

As detailed in section 4.5.5, these previously exported results can also be combined together from multiple studies into a single overall results file.

6.2.2. Processed Results

Once all of the results have been completed, they will be combined into a single excel results file and graphs produced accordingly. The single results file consists of a new worksheet for each terminal and is populated with the following data:

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Self-Impedance Values (Z_1, R_1 and X_1)

In all cases there will be table showing the self-impedance for the specific terminal during each study case, operating scenario and contingency combination. Graphs are also automatically produced based on this data and will be shown for the following combinations:

- For each study case a single graph showing the self-impedance during each contingency
- For each contingency a single graph showing the self-impedance during each study case

If the user has selected to include the R and X values as well (section 5.2) then these will also be exported for each study case, operating scenario and contingency combination. No graphs are automatically produced for this data.

Mutual-Impedance Values (Z_{12}, R_{12} and X_{12})

If the user has selected to include the mutual impedance values (section 5.2) then for those terminals it has been requested for (section 5.4.2) there will also be a table showing the mutual-impedance. This will show the mutual-impedance from that terminal to all other terminals for each study case, operating scenario and contingency configuration. No graphs are automatically produced for this data.

If the user has selected to include the R and X values as well (section 5.2) then the mutual R12 and X12 values will be output alongside the Z12 values for each study case, operating scenario and contingency combination. No graphs are automatically produced for this data.

Impedance Loci

If the user has selected the option Include_Convex on the settings page then in addition to exporting the self-impedance values for the resistance and reactance plots will be included for each harmonic order. The loci plots will be included on the export spreadsheet below the raw data and show the outer boundaries of all of the R_1 and X_1 values associated with each harmonic order. For example, harmonic order 3 covers the frequency range 75 to 125 Hz. A table is also provided showing the R and X values associated with the Convex Hull that surrounds the R_1 and X_1 values covering all of the contingencies that have been carried out.

7. Troubleshooting

If you experience issues running this tool, then you are advised to review the PowerFactory or Python console output or the associated log files (section 4.3). These log files should provide details of the error in your input or model that is preventing the study from completing. If you require further support you are advised to contact David Mills (david.mills@PSCconsulting.com) who may be able to provide further support.

Appendix A – Tool Validation

This section presents calculations demonstrating the validation carried out to confirm that the PSC Harmonics tool produces the same export as that produced if a manual set of studies are performed using DIgSILENT PowerFactory.

This validation activity was carried out using PowerFactory 2019 and the AEMO model named "AEMO_VIC_V0_20200723.pfd". Copies of the model, input settings and automated results are included in the PSC Harmonics tool folder "..\tests\validation_results".

To carry out the validation the self-impedance was calculated for the following study case and operating scenarios:

Name	Database	Studycase (.IntCase)	Operational Scenario (.IntScenario)
HighLoad	AEMO_VIC_V0_20200723	High Load Case	HighLoadTap
MedLoad	AEMO_VIC_V0_20200723	Medium Load Case	MediumLoadTap
LowLoad	AEMO_VIC_V0_20200723	Low Load Case	LowLoadTap

The validation process determined the self-impedance at the following terminals in the AEMO model:

Name	Station	Terminal
MOOR 220	MOORABOOL 500KV	201258_MLTS_7MN2
MOOR 500	MOORABOOL 500KV	201247_MLTS_6MN2
KEIL 220	KEILOR 500KV	201357_KTS_7MN2
KEIL 66	KEILOR 500KV	201337_KTS_3MN1
SMORANG 330	SOUTH MORANG 500KV	201288_SMTS_5MN2
SMORANG 500	SOUTH MORANG 500KV	201277_SMTS_6MN1

The self-impedance at these nodes were calculated in 5 Hz steps covering the frequency range 50 to 2500 Hz for the following contingency configurations for breaker operations:

General	Breaker 1			Breaker 2		
Name	**Station**	**Breaker Name**	**Status**	**Station**	**Breaker Name**	**Status**
CB Outage 1	MOORABOOL 500KV	Switch_1196890	Open			
CB Outage 2	KEILOR 500KV	Switch_209960	Open	KEILOR 500KV	Switch_209961	Open

For line outages the following contingencies were compared.

General	Line 1	
Name	**Line / Branch Name**	**Status**
Test Line 1	207466_MLTS_BATS 1 220kV	Out of Service

The following sub-sections present a comparison between the manual (solid-lines) and script based (dashed lines) for each of the nodes. The results completely overlay each other showing no differences between the values.

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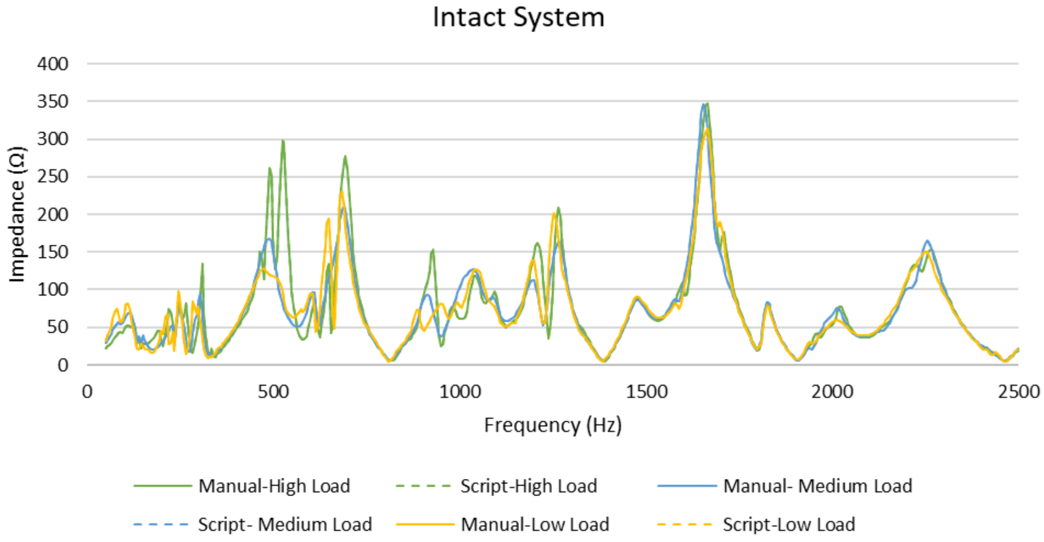
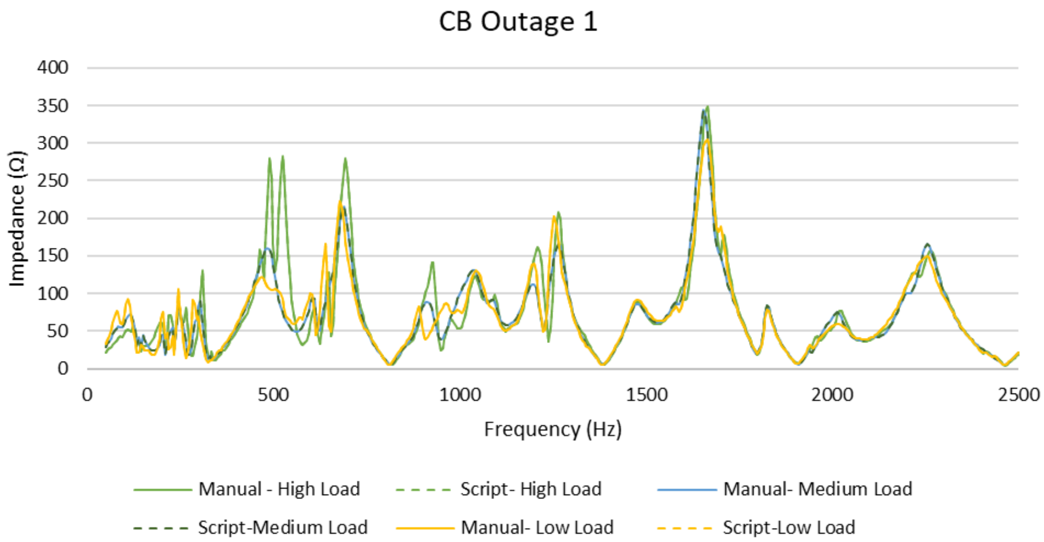
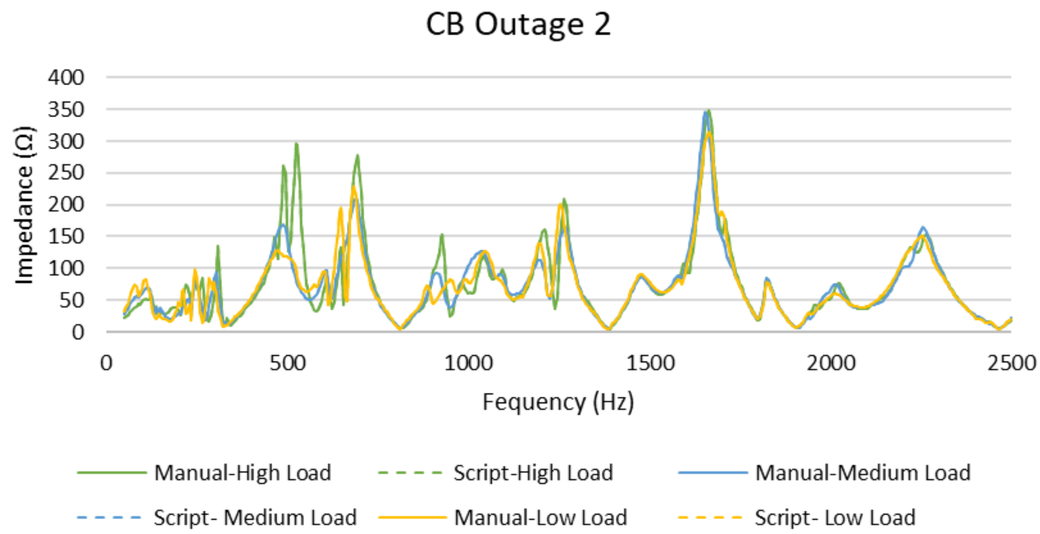
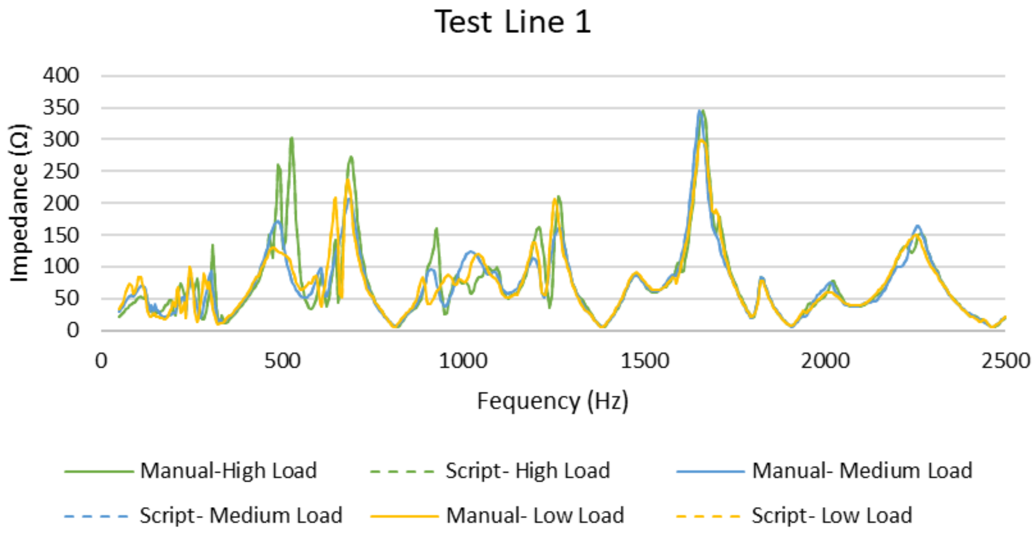
A1 – Terminal: Moor 500









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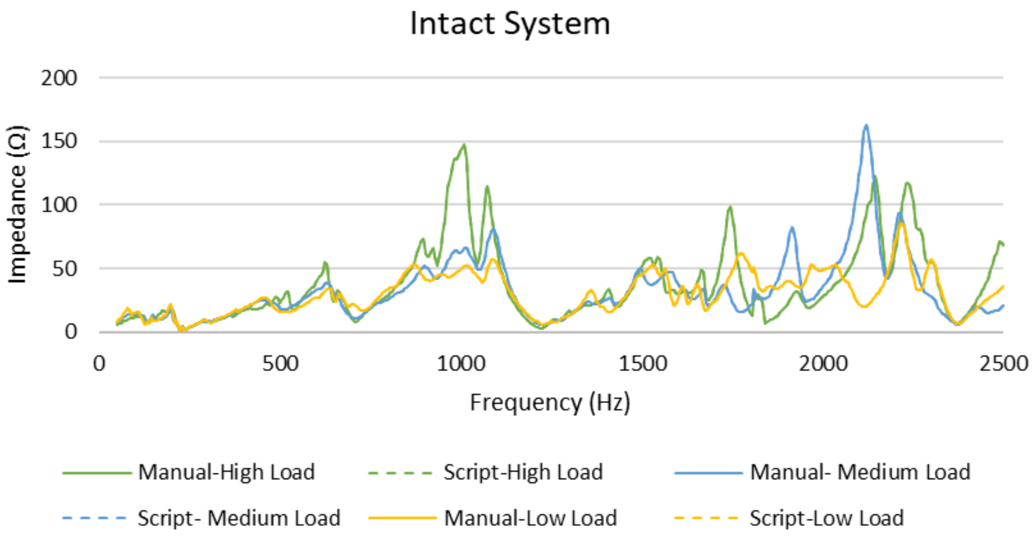
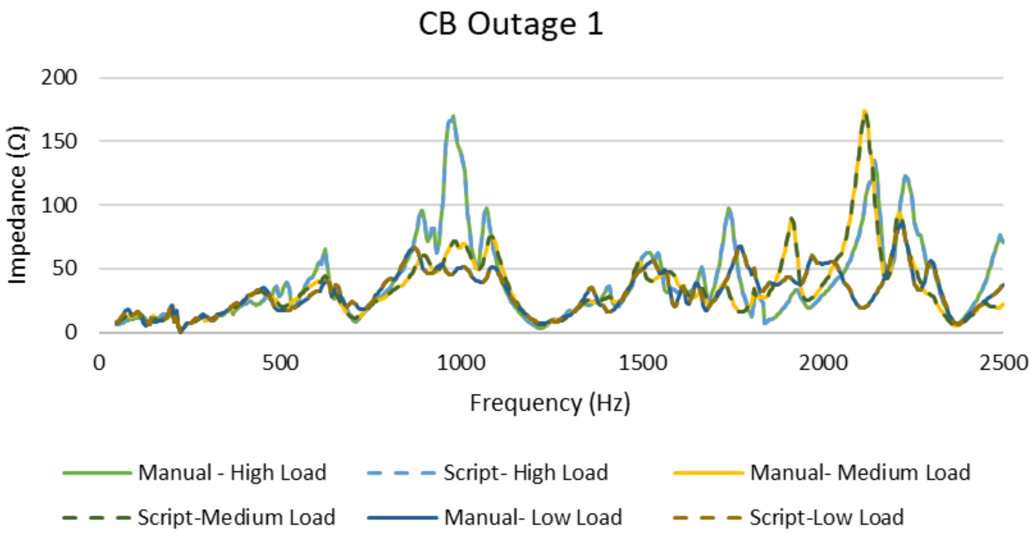
A2 - Terminal: Moor 220





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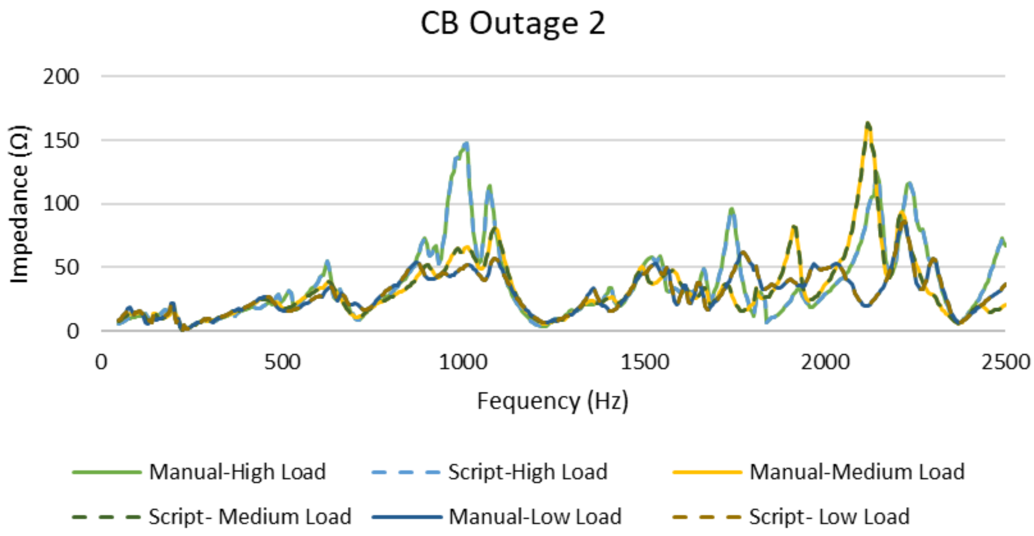
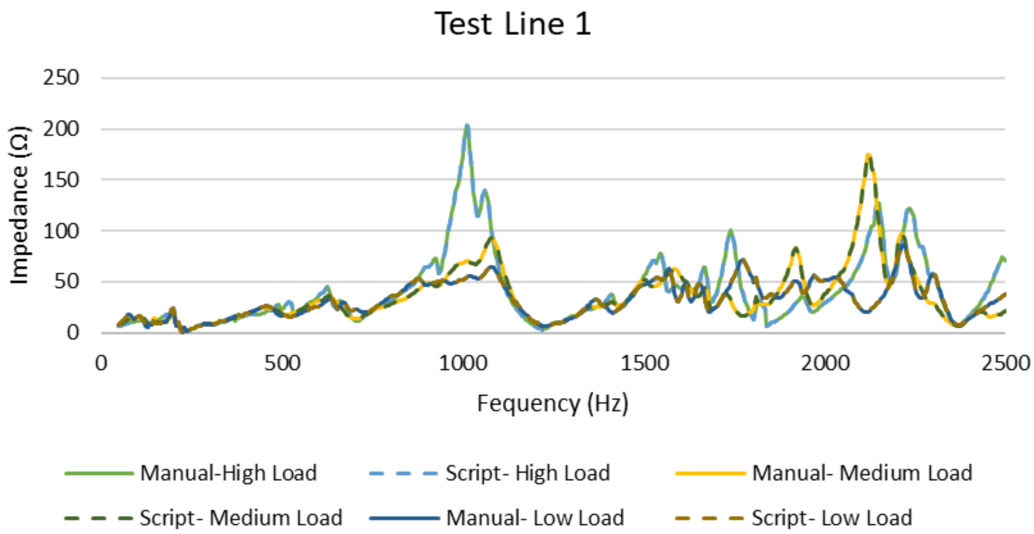
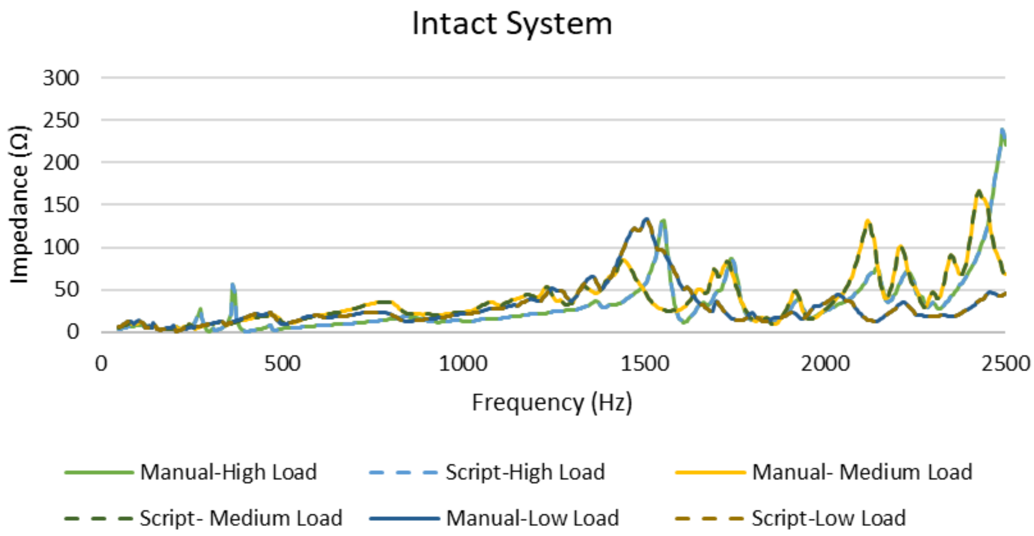
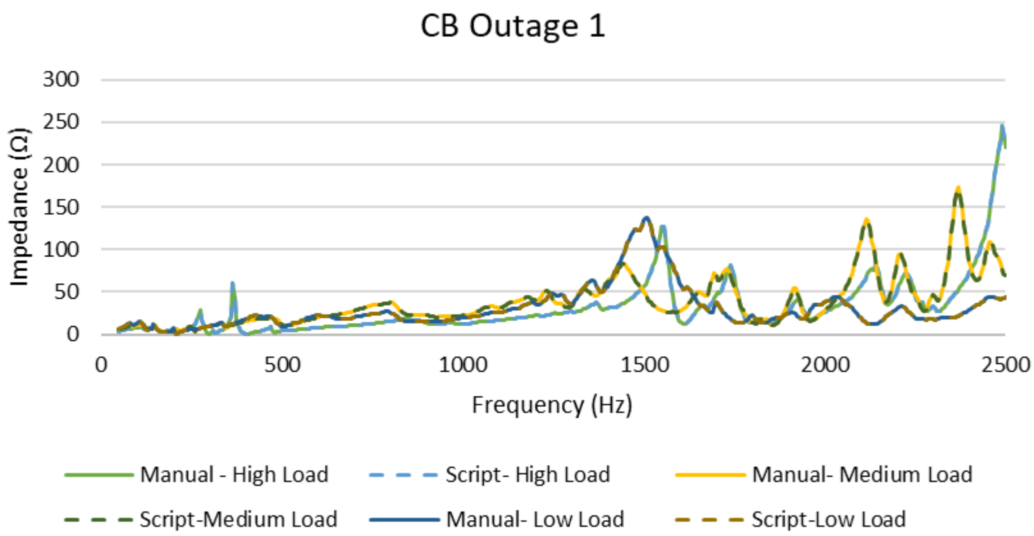

CB Outage 2
Impedance (Ω)
200
150
100
50
0
0
500
1000
1500
2000
2500
Fequency (Hz)
Manual-High Load
Script-High Load
Manual-Medium Load
Script- Medium Load
Manual-Low Load
Script- Low Load


Test Line 1
Impedance (Ω)
250
200
150
100
50
0
0
500
1000
1500
2000
2500
Fequency (Hz)
Manual-High Load
Script- High Load
Manual- Medium Load
Script- Medium Load
Manual- Low Load
Script- Low Load

A3 - Terminal: Keil 220





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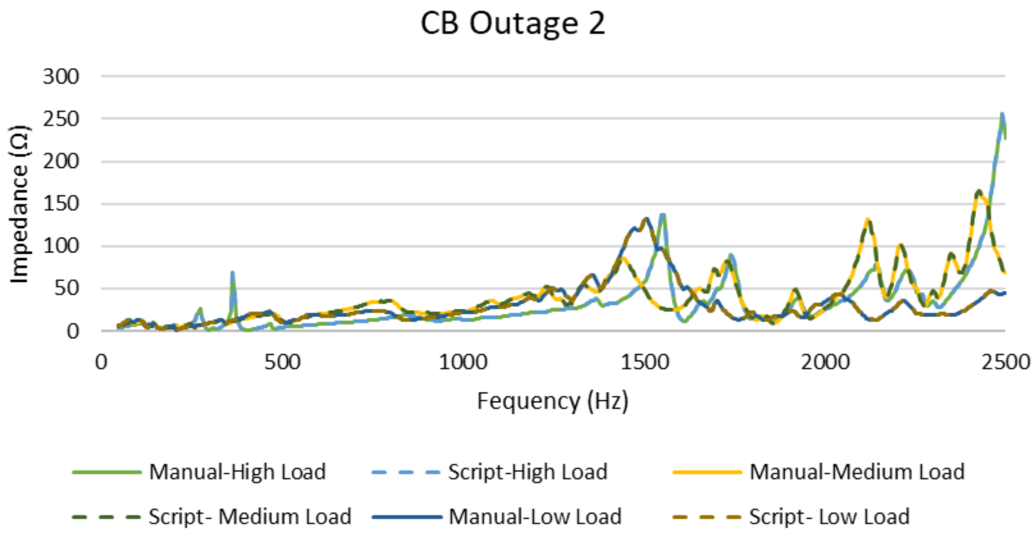
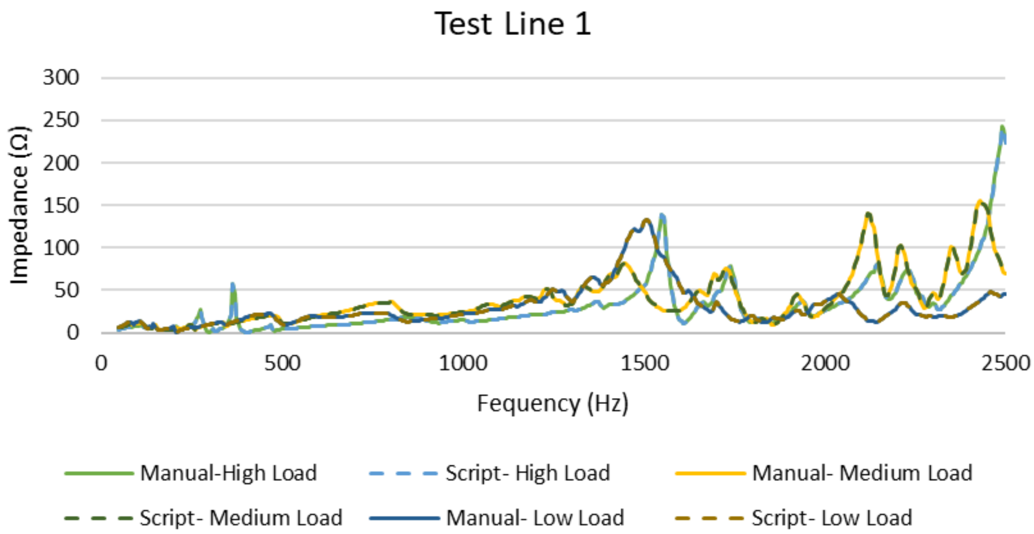
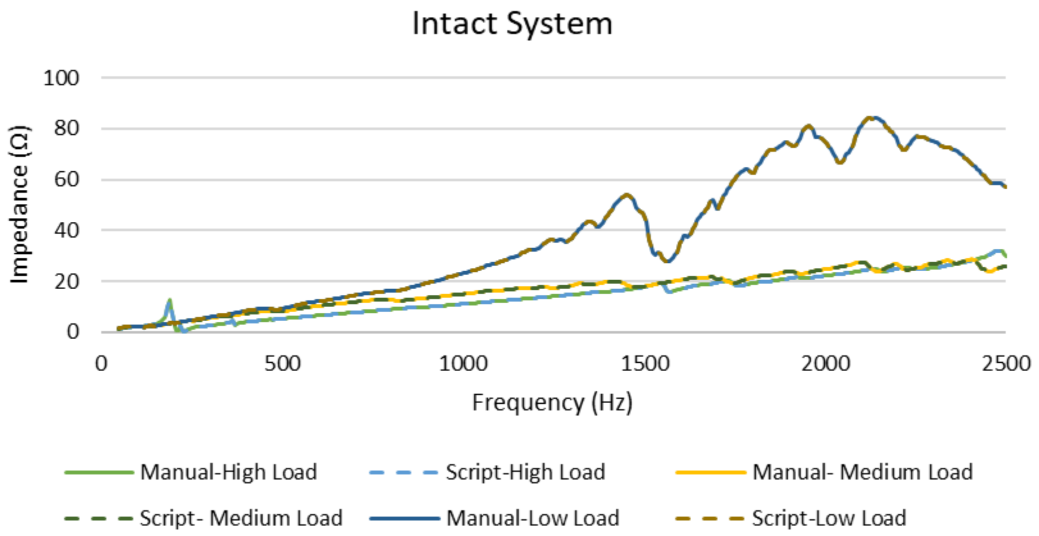
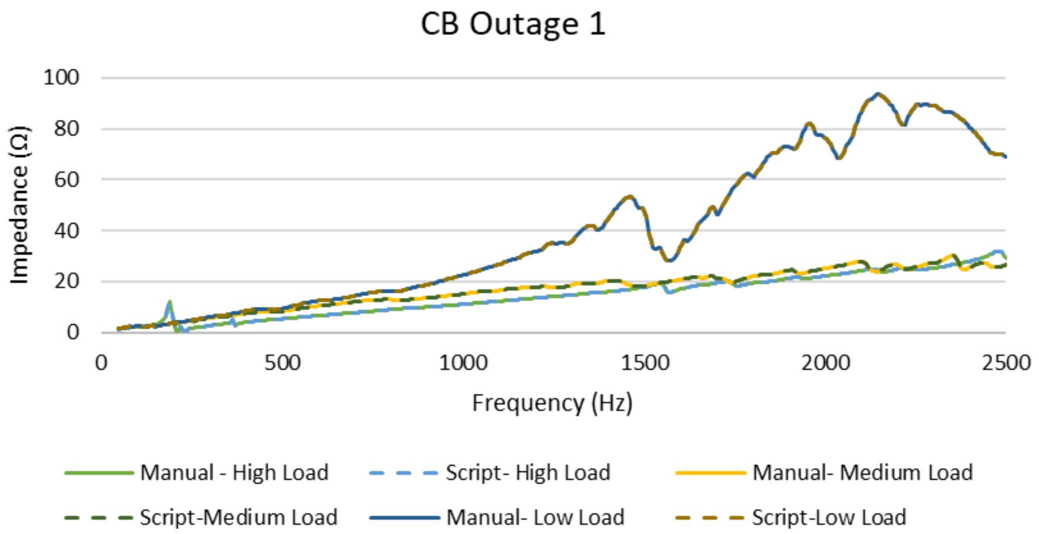
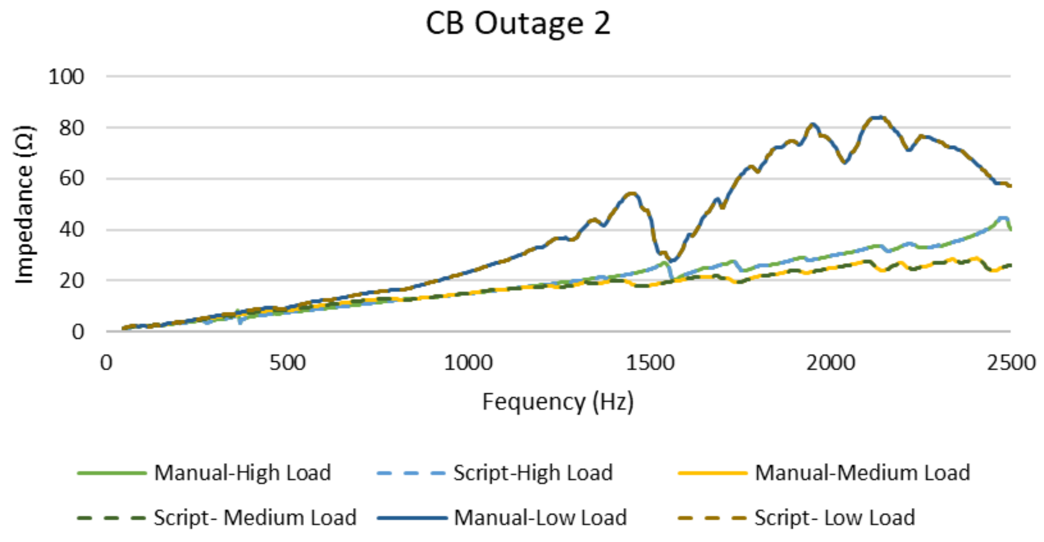

CB Outage 2
300
250
200
150
100
50
0
Impedance (Ω)
0
500
1000
1500
2000
2500
Fequency (Hz)
Manual-High Load
Script-High Load
Manual-Medium Load
Script- Medium Load
Manual-Low Load
Script- Low Load

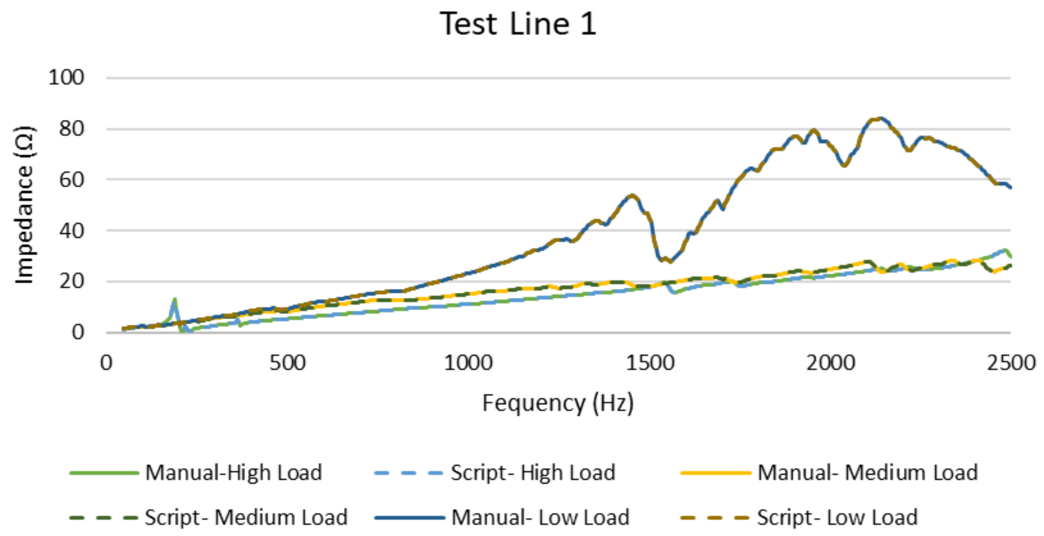

Test Line 1
300
250
200
150
100
50
0
Impedance (Ω)
0
500
1000
1500
2000
2500
Fequency (Hz)
Manual-High Load
Script- High Load
Manual- Medium Load
Script- Medium Load
Manual- Low Load
Script- Low Load

A4 - Terminal: Keil 66

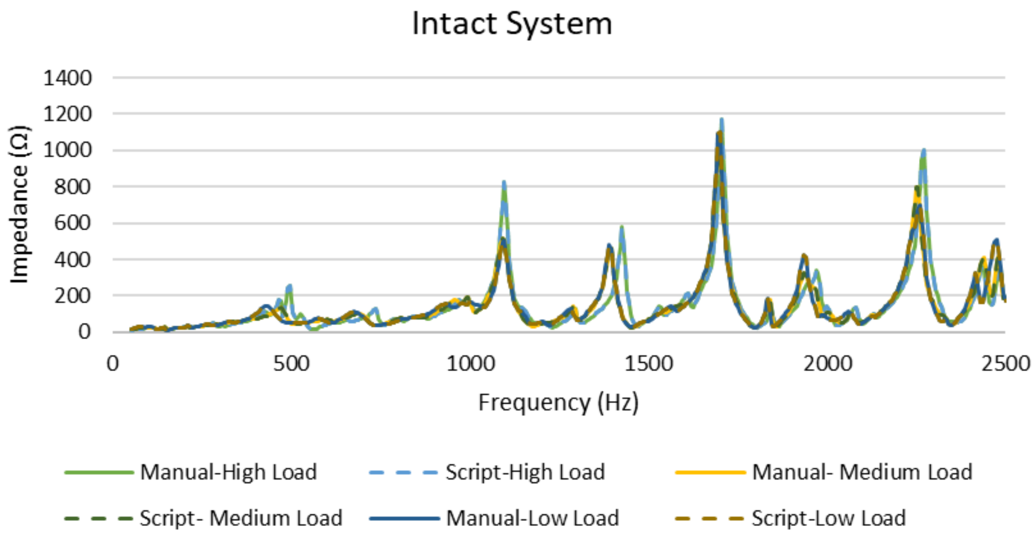


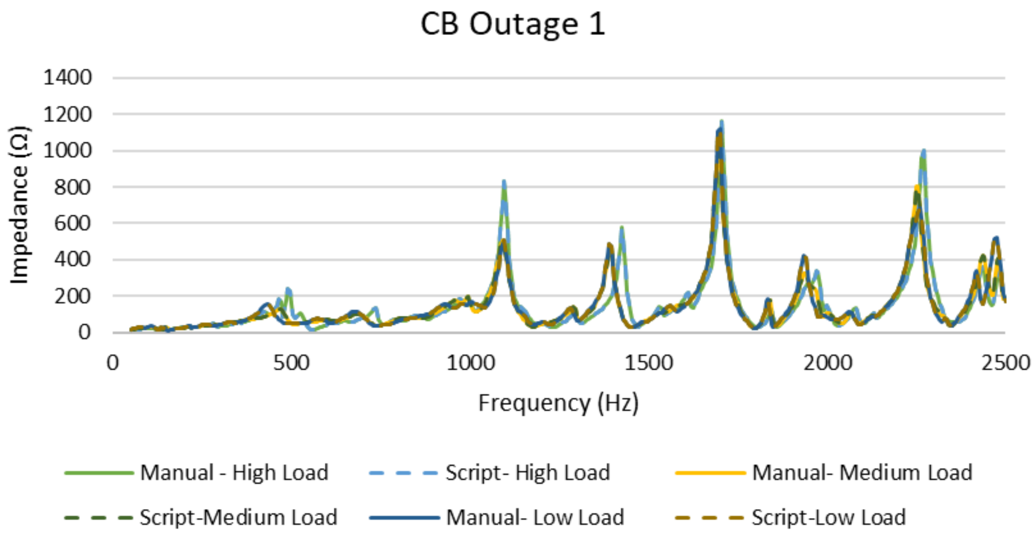


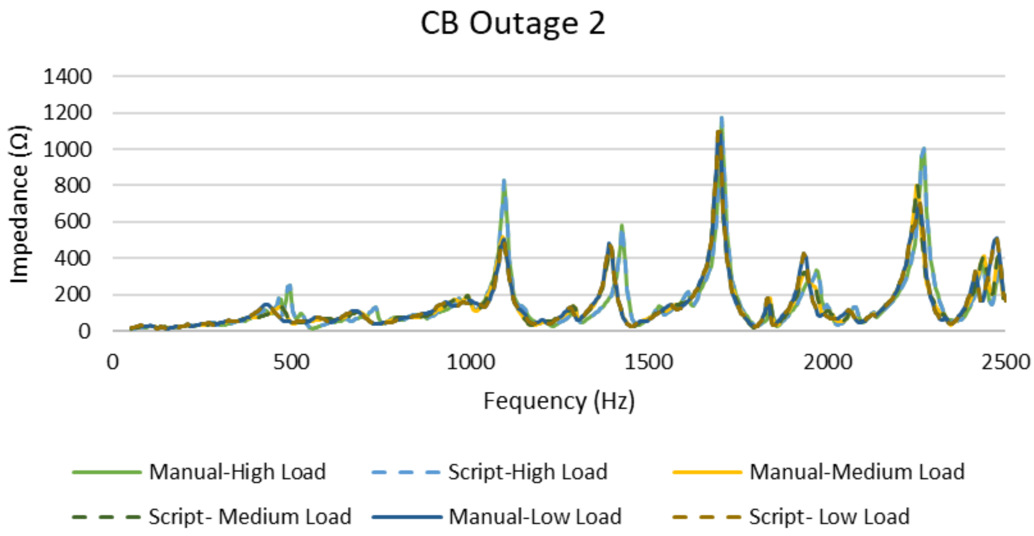

CB Outage 2
Impedance (Ω)
100
80
60
40
20
0
0
500
1000
1500
2000
2500
Fequency (Hz)
Manual-High Load
Script-High Load
Manual-Medium Load
Script- Medium Load
Manual-Low Load
Script- Low Load

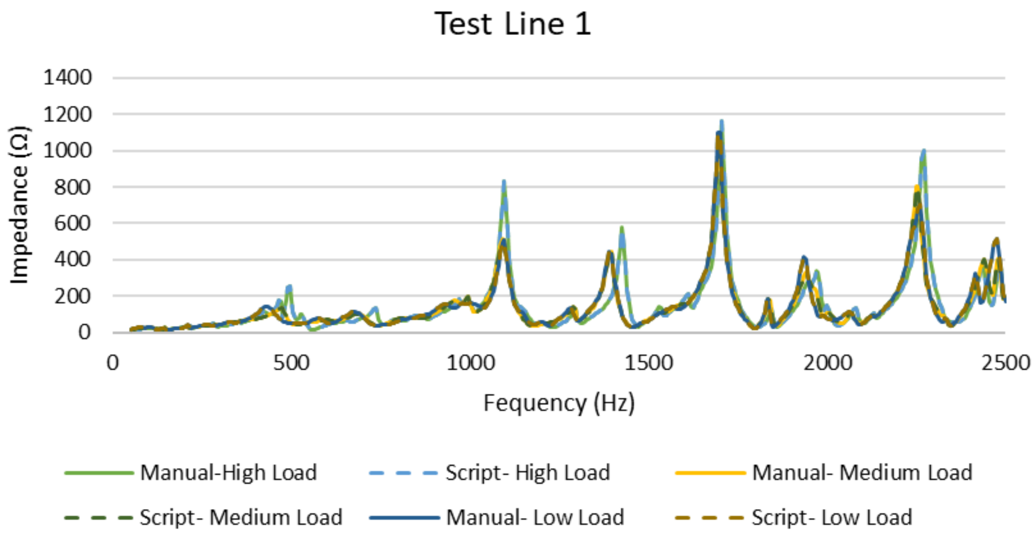

Test Line 1
Impedance (Ω)
100
80
60
40
20
0
0
500
1000
1500
2000
2500
Fequency (Hz)
Manual-High Load
Script- High Load
Manual- Medium Load
Script- Medium Load
Manual- Low Load
Script- Low Load

A5 - Terminal: Smorang 330









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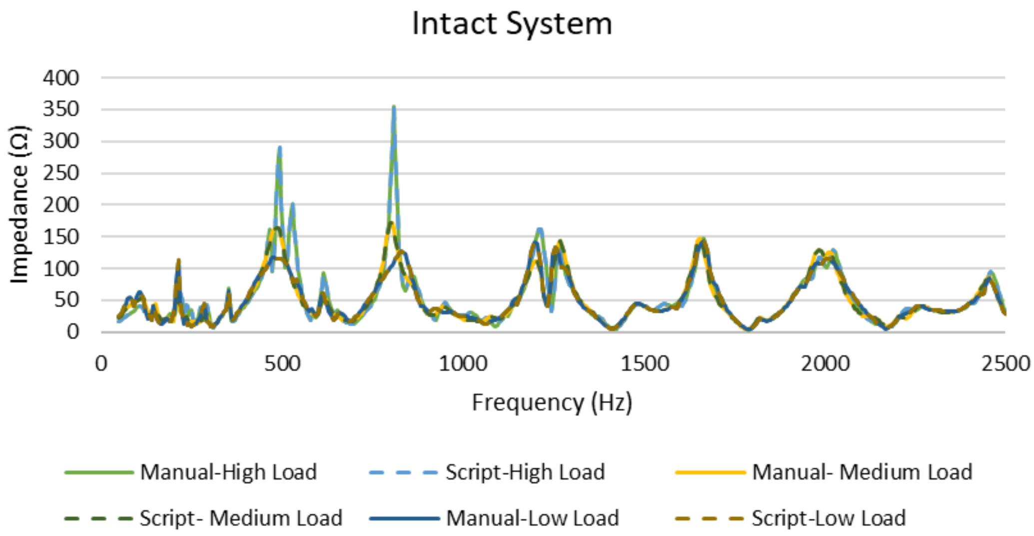
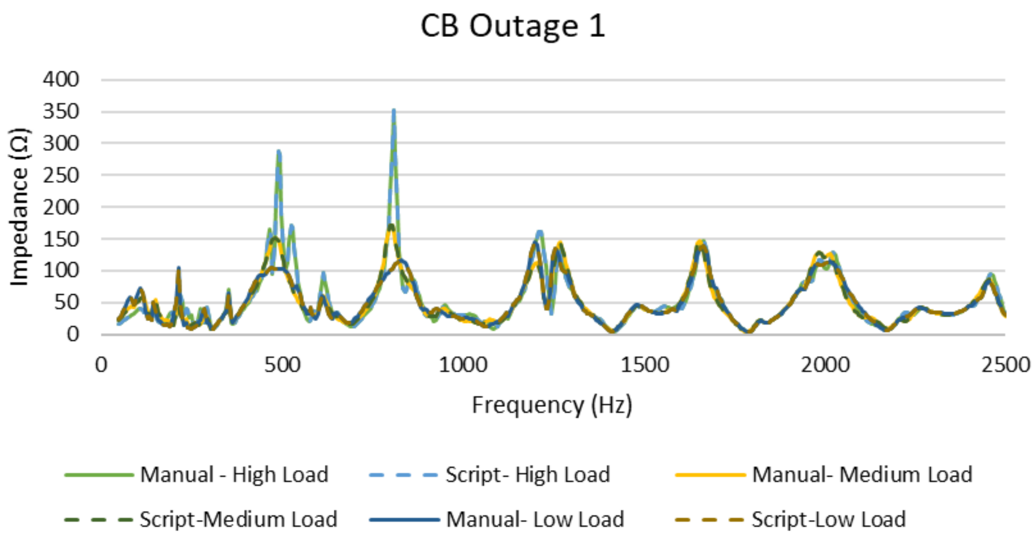
A6 - Terminal: Smorang 550





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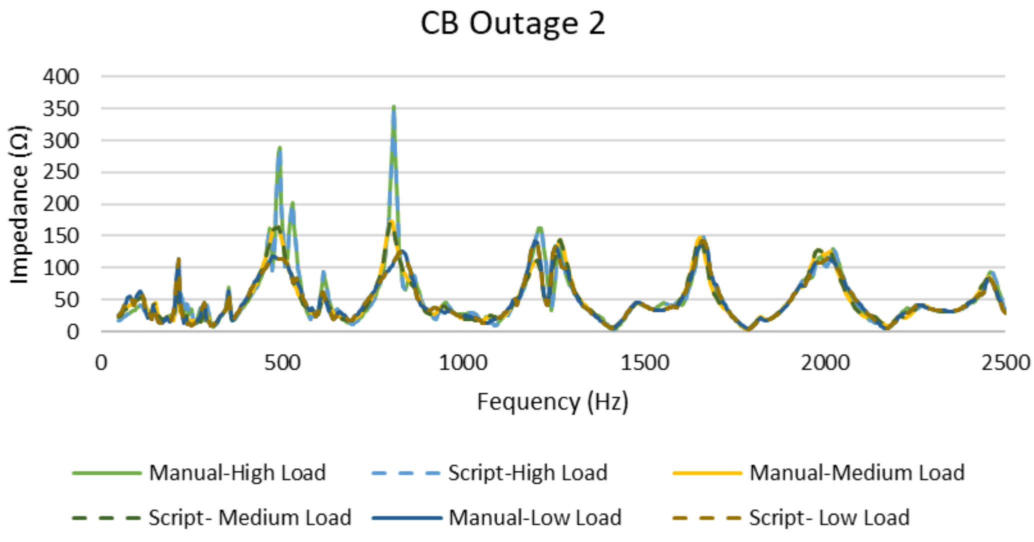

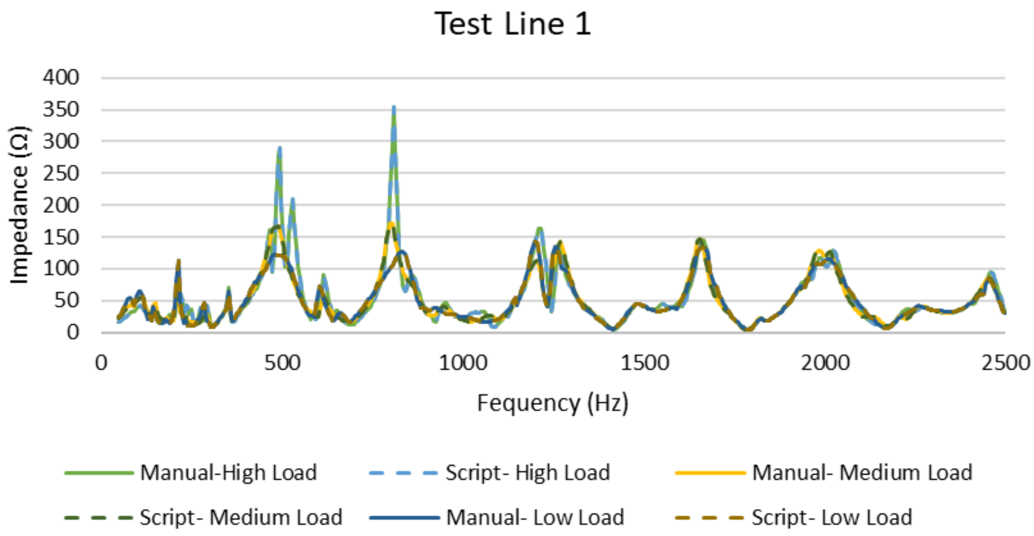

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