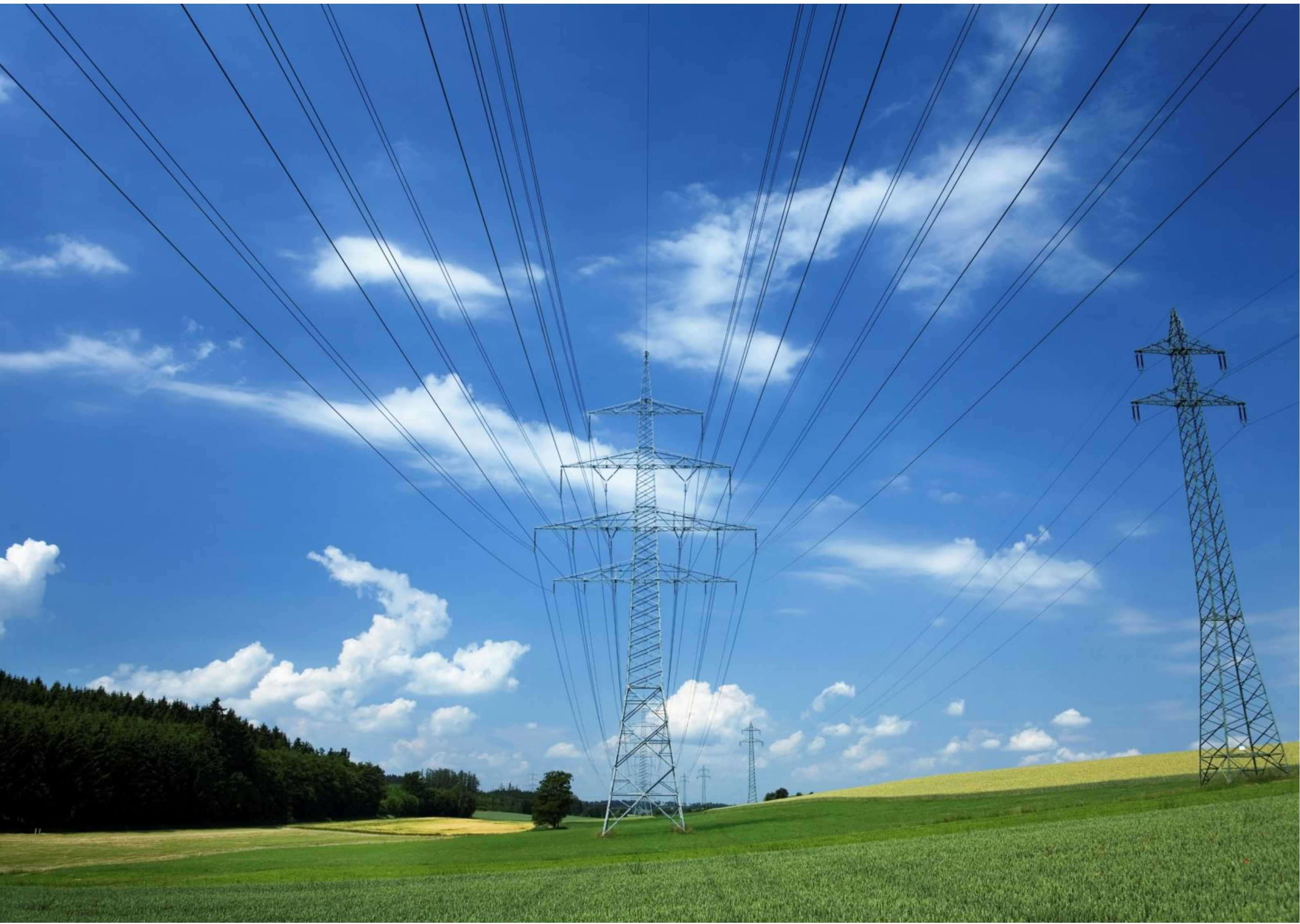
Project Energy Connect

Steady State Market Integration Studies

AEMO

29 May 2023

→ **The Power of Commitment**



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The Power of Commitment

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1. Introduction

Project Energy Connect (PEC) is a landmark electricity transmission project to deliver a physical interconnection between the power networks of South Australia and New South Wales (with Victoria also connected via a spur connecting Red Cliffs and Buronga). Operated at 275 - 330 kilovolt (kV) voltage level, this 900-km-long above-ground transmission line which is being constructed jointly by ElectraNet and Transgrid will connect Robertstown in South Australia with Wagga Wagga in New South Wales, via Buronga (Figure 1). In total, the project will provide approximately 800 megawatts (MW) of transfer capacity between New South Wales and South Australia power networks, expected to be delivered in two phases (which are marked correspondingly in blue and greenish yellow as in Figure 1):

– Phase 1 (150 MW bi-directional capacity across PEC). The first phase will comprise of the connection between Robertstown and Buronga. This capacity for this stage is expected to be released on 1 July 2024.
– Phase 2 (increasing the combined transfer limit across Heywood and PEC interconnectors: 1,300 MW import into South Australia; and 1,450 MW export). The second phase comprises of the connection between Buronga and Wagga Wagga. Full capacity release for this stage is currently expected on 1 July 2026.

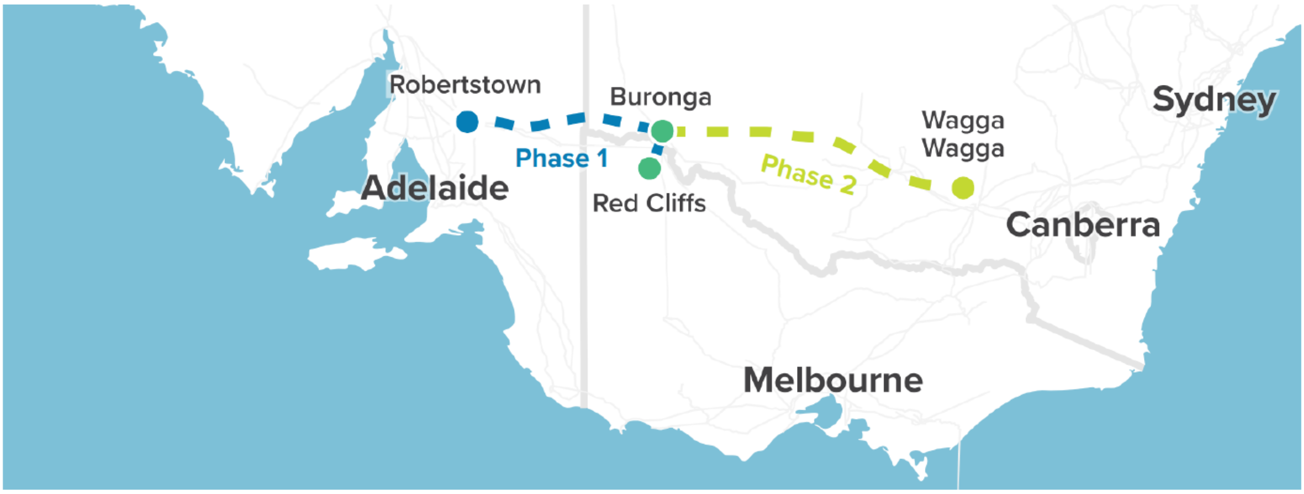

Figure 1 Project Energy Connect line route[1].

GHD was engaged by AEMO to conduct power system studies to assess the impact of the integration of this interconnector onto the National Electricity Market (NEM) in Phase 1 under various dispatch scenarios. The primary objective of this study was to check if the +/- 150 MW dispatch contributed to, or worsened thermal constraints in either South Australia, New South Wales, or Victoria due to flows though the interconnector.

To undertake this assessment, GHD conducted analysis using two AEMO provided NEM PSSE models with agreed upon dispatch scenarios (with PEC dispatched at maximum import and export conditions) to evaluate thermal constraints under a number of different dispatch scenarios for generators within the NEM. To evaluate this large number of scenarios, Python scripting was used to take transmission assets out of service, modify the dispatch of individual generating units, and to output the loadings of transmission lines and transformers into CSV files, with further scripting then used to interrogate these outputs to find thermal overloads, and overloads attributable to specific generator dispatch setpoints.

1.1 Purpose of this report

This report presents and technical details of the work that has been completed by GHD to assess the impact Phase 1 of Project Energy Connect integration has on thermal loadings of transmission assets on the NEM. It serves as a high-level summary of the tools developed in Python to automate PSSE load flow studies, and analyse

[1] Source: Project Energy Connect Fact Sheet, 19 May 2023. Available at: **https://www.projectenergyconnect.com.au/download.php?id=8**

the outputs, a summary of the analysis undertaken to understand the impacts of the integration, and finally, details of key results of the analysis.

1.2 Scope and limitations

This report: has been prepared by GHD for AEMO and may only be used and relied on by AEMO for the purpose agreed between GHD and AEMO as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than AEMO arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section(s) 1.3 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

The Python tools developed by GHD for this analysis are available to AEMO for informational purposes only, in order AEMO to understand the methodology behind the assessment of the PEC integration study. GHD has developed these tools using Python and freely available open-source libraries and makes no guarantees as to this tool working as intended on different Python versions or and will not provide technical support to facilitate their use.

1.3 Assumptions

GHD has relied on the following assumptions for undertaking these works:

– The PSSE models provided by AEMO are accurate and have thermal ratings representing their true capability.
– The PSSE “Normal” MVA rating for the asset was used as the base rating for the analysis performed.
– Assets below 66 kV have been excluded from analysis.
– Analysis was undertaken for the system for intact and N-1 conditions. N-1-1 conditions were not considered.

2. Method - workflow and scripting

The process created to study the market integration of PEC stage 1 required three major tasks for completion:

– Creating scenario files for study, including the base case and contingency cases.
– Running load flow to produce preliminary result files.
– Processing and analysing the preliminary result files to obtain meaningful results.

To complete a full analysis of the impact on the NEM, the number of contingencies considered was extremely high, considering NEM assets > 66 kV, including transformers and branches in PSSE. Across the three regions of the NEM considered for analysis (SA, VIC & NSW) there was therefore a need to study thousands of post-contingent conditions, along with thousands of generator dispatch conditions. The number of iterations required to accomplish the analysis under this approach therefore required an automated approach.

To increase the speed of analysis and avoid errors from manual data entry GHD developed Python scripts for automation of the PSSE studies, and the data entry and extraction processes. Accordingly, three Python scripts were written to carry out each task, as shown in Figure 2. The first two Python scripts accept input parameters from a spreadsheet named “PEC Loadflow Data.xlsx” contained within the same folder. The script for the third task has its own settings embedded and is not reliant on external inputs. A detailed explanation of each script is discussed in the subsections below.

PEC Create Contingency Scenarios Automation p27.py	8/03/2023 3:47 PM	Python Source File	8 KB
PEC Loadflow Automation p27.py	17/03/2023 10:45 AM	Python Source File	11 KB
PEC Loadflow Data_NSW.xlsx	20/03/2023 10:31 AM	Microsoft Excel W...	551 KB
ResultProcessingCSV.py	16/03/2023 1:50 PM	Python Source File	6 KB

Figure 2 Scripts and workbook for setting data.

2.1 Script for creating contingency scenarios

The script for creating Contingency Scenarios, named "PEC Create Contingency Scenarios Automation p27.py", reads input data from an excel workbook to produce output files required for the first stage of analysis.

The script has a set of outputs:

– PSSE .sav files created for intact and N-1 system conditions.
– An Excel workbook (.xlsx) file named "Scenario_List" which contains a list of the PSSE files and gives details of convergence mismatch for each scenario.

The script requires inputs from the "PEC Loadflow Data" Excel spreadsheet – which defines:

– Names of base PSSE .sav files to develop output scenarios from – Original Cases tab.
– Region of the NEM to assess contingencies in (i.e., NSW, VIC, or SA) – Original Cases tab.
– Convergence mismatch tolerance – Misc tab.
– Convergence iteration threshold – Misc tab.

Other inputs taken from the Misc tab include the naming convention for the generated files, which by default comprises of the format of a prefix, followed by a number i.e., PEC_Scen_0001.

Finally, the worksheet "Branches" consists of all transformer and non-transformer branches related to the three states of interest, NSW, VIC and SA. In this sheet, we can exclude an element from the list of contingencies by setting its "isContingency" field to FALSE (Figure 3) or include it by setting the field to TRUE.

Branch_ID	Base_Scen	Branch_Name	Branch Type	ibus	jbus	kbus	ickt	Rating_MVA	inTest	isContingency	Branch_State
2331	A	X3-1	Line	220882	220887		2	442	TRUE	TRUE	NSW
2332	A	927/2-0	Line	224041	292040		1	455	TRUE	TRUE	NSW
2333	A	926/2-0	Line	224043	291640		1	455	TRUE	TRUE	NSW
2334	A	C3-0	Line	227690	258890		2	549	TRUE	TRUE	NSW
2335	A	C1-0	Line	227691	258890		1	549	TRUE	TRUE	NSW
2336	A	X5-1	Line	230880	230881		1	381	TRUE	TRUE	NSW
2337	A	8J-D	Line	231690	231691		3	1360	TRUE	TRUE	NSW
2338	A	8M-D	Line	231690	231692		5	1342	TRUE	TRUE	NSW
2339	A	8C-D	Line	231690	231693		2	1307	TRUE	TRUE	NSW
2340	A	8L-D	Line	231690	231694		4	1342	TRUE	TRUE	NSW
2341	A	90T-0	Line	237240	237241		1	365	TRUE	TRUE	NSW
2342	A	91H/3-0	Line	245443	245444		2	205	TRUE	TRUE	NSW
2343	A	89-A	Line	250490	250491		1	915	TRUE	TRUE	NSW
2344	A	8511/2-0	Line	250530	271630		1	64	TRUE	FALSE	NSW
2345	A	94Y-0	Line	257640	257641		1	413	TRUE	TRUE	NSW

Misc | Scenarios | Original Cases | Generators | Branches

Figure 3 Branches sheet in the PEC Loadflow Data workbook.

The Python script develops:

– Basic intact system cases – functionally identical to the base .sav cases.
– Contingency .sav cases for every element selected in the Excel spreadsheet – based on the number of "original scenarios" defined. For the PEC integration, two scenarios were studied per region, with PEC flows at maximum in either direction.
– An output spreadsheet giving details of the scenarios created and identifies any convergence issues with load flows carried out to test the validity of the scenarios created.

PEC Create Contingency Scenarios Automation p27.py - H:\PEC Create Contingency Scenarios Automation p27.py (3.7.9)

File Edit Format Run Options Window Help

```
        #Save the record to dataframe
        scenList.loc[thisIndex,:] = thisIndex, theCaseFirst["Description"], None, savFileString, theCaseFirst["Contingency_State"], systMismatch

    #NOW create lots of scenarios by taking lines out of service
    for idx, theCase in caseList.iterrows(): #iterate for each base case
        print()
        print("Create Scenarios from original case:")
        print(theCase)

        #start PSSE and run loadflow
        fileName = theCase["Sav_File"]
        psspy.psseinit(80000)
        suppress_psse_output()

        contingencyLineList =  lineList[lineList["Branch_State"] == theCase["Contingency_State"]]

        for idy, theLine in contingencyLineList.iterrows():
            #create Scenario Data
            thisIndex =  len(scenList)+1
            thisIndexString = str(thisIndex).zfill(settingsData["Sav File Leading Zeros"])
            savFileString = settingsData["Sav File Prefix"] + thisIndexString + ".sav"
            lineOOS = theLine["Branch_Name"]

            #run first load flow
            psspy.case(fileName)
            ierr = psspy.rsol([1,1,0,0,1,1,0,0,0,0],[500, 5]) # Run "Robust Loadflow" without flat start

            #set line to OOS
            iBus = int(theLine["ibus"])
            jBus = int(theLine["jbus"])
            ickt = str(theLine["ickt"])
            psspy.branch_chng_3(iBus,jBus,ickt,[0,_i,_i,_i,_i,_i],[_f,_f,_f,_f,_f,_f,_f,_f,_f,_f,_f,_f],[_f,_f,_f,_f,_f,_f,_f,_f,_f,_f,_f,_f],theLine["Branch_Name"])
            error = psspy.island()
            if(error == 1):
               psspy.tree(2,1)

            #do more loadflows until it converges OR goes over the iteration limit.
            systMismatch = doRobustLF(fileName, settingsData["Convergence Mismatch Threshold"], settingsData["Convergence Iteration Threshold"])

            #save as Scenario
            savFileText = cwd + """\\""" + settingsData["Scenario File Folder"] + """\\""" + savFileString
            ierr = psspy.save(savFileText)

            #add data to Scenario List
            scenList.loc[thisIndex,:] = thisIndex, theCaseFirst["Description"], lineOOS, savFileString, theCase["Contingency_State"], systMismatch
        #end loop per line
    #end loop per original case
```

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Figure 4 ***Script for creating contingency cases.***

The purpose of this script was to develop stable base files for further analysis, which would consider the NEM under intact and N-1 conditions after a contingency. The script was run three times to create contingency scenarios for each region studied for analysis, and the output “Scenario List” excel spreadsheet was checked to assess whether any outages had resulted in non-convergent conditions. After initial testing, some alterations to the script were made, which were found to resolve non-convergent condition issues, including;

– Solving a robust load flow after an outage to create an N-1 scenario.
– Taking islanded assets out of service after an outage (done using the TREE command in PSSE)

With these changes to the script made, the PSSE .sav files produced were found to be robust, and suitable for further analysis.

2.2 Generating data from scenario files

A second script, “PEC Loadflow Automation p27.py was created to analyse the created scenario .sav files, by changing generator dispatch within the files, to assess the impact on asset loadings on the NEM.

Inputs required for this sheet are:

– Scenario List – this is defined in the “Scenarios” tab of the workbook – and requires that Column E be updated with the list of .sav files to be processed.
– Generators List – in the “Generators” tab of the workbook, information about generators of interest needs to be filled, including the PSSE bus that the machine connected to, the ID of the machine and an indication that the machine should be included in the scenario (column “inTest” set to 1).

Due to the issue of available working memory, the script could only run with a reasonable set of scenario files each time rather than the full set at once. The size of set is not a fixed number and depends on the characteristics and specifications of the machines used for the analysis, as well as the increment chosen for generator dispatch changes.

The input settings for this script can be easily adjusted on the “Misc” sheet (Figure 5) of the workbook. The two most important factors for running the load flow script are the value of “Generator Dispatch Increment” (MW) and “Branch Loading Report Threshold” (%). The “Generator Dispatch Increment” value indicates the step change in a particular generators output in each run, with the range is from 0 to the maximum dispatch capability. The value of "Branch Loading Report Threshold" is utilized as a threshold to decide whether to capture a branch loading into a DataFrame before exporting the result into a csv file.

ID	Tag_Name	Value	Notes
1	PSSE_Version	34.X	
2	Client	AEMO	
3	Generator Dispatch Incriment	20	MW
4	Full Results Folder	Results - Full	
5	Summary Results Folder	Results - Summary	
6	Branch Loading Report Threshold	80	%
7	Do Test	1	
8	Scenario File Folder	Scenario Files	
9	Sav File Prefix	PEC_Scen	
10	Sav File Leading Zeros	5	
11	Convergence Mismatch Threshold	2	
12	Convergence Iteration Threshold	10	

Figure 5 Settings data for the first two tasks

The output files are stored automatically in the created windows folder "Results – Full". Each .sav scenario file will produce a corresponding .csv result file, where each line contains data about a branch with loading greater than the predefined threshold. This process created the preliminary raw data which could then be further analysed to examine problematic contingencies and generator dispatch conditions.

2.3 Data processing and analysis

The purpose of this study was to assess the impact of PEC integration of the NEM under different dispatch conditions. To assess thermal imitations as an impact of PEC, the final analysis needed to consider:

- The maximum loading of a branch across all contingency scenarios – this could be used to assess whether any new constraints had been worsened or identified as a result of PEC integration.
- The generator dispatch increment that results in a transition of branch loading across 100% - this could be used to identify problematic dispatch conditions which might impact asset loading.

By utilizing some data process and analysis techniques with DataFrame in pandas, this information of interest was precisely extracted and exported into final result spreadsheets. The script "ResultProcessingCSV.py" was developed to undertake this analysis (Figure 6).

ResultProcessingCSV.py - H:\ResultProcessingCSV.py (3.7.9)

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```
resultDF = pd.DataFrame()
for i in range(0, len(inspectList)):
    for j in range(0, len(uniqueGenKey[i])):
        print("Working on the inspectList No.",i+1)
        print("Examining GPK:", uniqueGenKey[i][j])
        miniDF = inspectList[i][inspectList[i]['Gen_Pri_Key'] == uniqueGenKey[i][j]]
        if(miniDF.empty):
            print("Empty mini DataFrame detected!!!")
            continue
        else:
            print("Examining the following mini DataFrame:")
            print(miniDF)
            maxLoading = max(miniDF.Branch_Loading)
            minLoading = min(miniDF.Branch_Loading)
            print("Maximum Loading:", maxLoading)
            print("Minimum Loading:", minLoading)
            if(maxLoading > 100 and minLoading < 100):
                print("Eligible for inspecting the transition!")
                #Find the transition point
                max100 = max(t for t in miniDF['Branch_Loading'] if t < 100)
                min100 = min(t for t in miniDF['Branch_Loading'] if t > 100)
                print("The transition is from",max100,"to",min100)
                GPKmax = miniDF[miniDF['Branch_Loading'] == max100]
                GPKmin = miniDF[miniDF['Branch_Loading'] == min100]
                print(GPKmax)
                print(GPKmin)
                #Append the transition point to the array
                rDF = GPKmax.append(GPKmin)
                resultDF = resultDF.append(rDF)
                #resultArray.append(GPKmin)
            else:
                print("NOT eligible for inspecting the transition")
                print("---------------------------------------")
                continue
        print("===================================")
print("*******************************************************")
print(resultDF)
resultDF.drop('Unnamed: 0', axis=1).to_excel('Result.xlsx')
```

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Figure 6 Script for data processing and analysis.

Due to the issue with working memory, it is advisable to process .csv files in batch rather all at once. The most convenient method is to create a new folder and bring a number of .csv files and this Python script to that folder. After multiple runs on different folders, the outputs can be appended into one. Given the same computer's specification as in Section 2.2, the batch size is about the same (500 files/run).

The outputs of this script are two spreadsheets, one which defines maximum branch loading across all scenarios, (Figure 7) and one which shows the generator dispatch change that produces the transition of branch loading from below 100% to above 100% (Figure 8). In Figure 8, a pair of lines in blue and white indicates information about the branch before and after the transition over 100% loading.

Scen_ID	Gen_Pri_Key	Gen_Dispatch	Branch_ID	Branch_Loading	Branch_Name	Branch_Type	iBus	jBus	ickt	Rating_MVA	Branch_State	FromBusName	ToBusName
1590	215201_1	560	1	145.0367279	9UJ-0	Line	209446	218640	1	136	NSW	2BOGABR_132G132.00	2BGNBRY_132A132.00
1590	215202_2	180	2	190.2919464	9U3/2-0	Line	209446	238740	1	126	NSW	2BOGABR_132G132.00	2GUN_BO_132A132.00
175	249503_1	0	4	122.9644547	997/1-1	Line	210044	228640	1	99	NSW	2ALBURY_132E132.00	2COROWA_132A132.00
1038	280006_6	560	19	51.49404526	966/1-0	Line	211640	211740	1	113	NSW	2ARMIDL_132A132.00	2ARMI_T_132A132.00
1590	215202_2	120	20	113.6697083	96T-0	Line	211640	235640	1	126	NSW	2ARMIDL_132A132.00	2GLENIN_132A132.00
1590	215202_2	120	21	220.0586548	96N-0	Line	211640	242040	1	110	NSW	2ARMIDL_132A132.00	2INVERL_132A132.00
1038	280006_6	560	28	53.62815857	966/2-0	Line	211740	245641	1	102	NSW	2ARMI_T_132A132.00	2KOLKHN_132B132.00
1780	279206_6	0	42	103.6146393	X3-0	Line	213680	220887	1	442	NSW	2BALRAN_220A220.00	2BURNGA_220H220.00
634	272902_1	40	43	123.8087158	X5-0	Line	213680	230881	1	381	NSW	2BALRAN_220A220.00	2DAL_PT_220B220.00
1040	272901_1	90	44	93.98604584	X8-0	Line	213680	249580	1	274	NSW	2BALRAN_220A220.00	2LIMON1_220A220.00

Figure 7 Excerpt from the Maximum branch loading file for NSW.

Scen_I	Gen_Pri_Ke	Gen_Dispatc	Branch_I	Branch_Loadin	Branch_Nam	Branch_Typ	iBus	jBus	Rating_MV	Branch_Stat	Gen_Bu	Gen_ID	Gen_Name	FromBusName	ToBusName
38	272902_1	80	43	99.86495972	X5-0	Line	213680	230881	381	NSW	272902	1	Sunraysia Solar Farm	2BALRAN_220A220.00	2DAL_PT_220B220.00
38	272902_1	100	43	106.5385361	X5-0	Line	213680	230881	381	NSW	272902	1	Sunraysia Solar Farm	2BALRAN_220A220.00	2DAL_PT_220B220.00
38	272902_1	80	1039	99.86495972	X5-0	Line	213680	230881	381	NSW	272902	1	Sunraysia Solar Farm	2BALRAN_220A220.00	2DAL_PT_220B220.00
38	272902_1	100	1039	106.5385361	X5-0	Line	213680	230881	381	NSW	272902	1	Sunraysia Solar Farm	2BALRAN_220A220.00	2DAL_PT_220B220.00
39	272902_1	40	1127	97.96212006	X3-1	Line	220882	220887	419	NSW	272902	1	Sunraysia Solar Farm	2BURNGA_220C220.00	2BURNGA_220H220.00
39	272902_1	60	1127	101.7727814	X3-1	Line	220882	220887	419	NSW	272902	1	Sunraysia Solar Farm	2BURNGA_220C220.00	2BURNGA_220H220.00
39	272902_1	40	2331	97.96212006	X3-1	Line	220882	220887	442	NSW	272902	1	Sunraysia Solar Farm	2BURNGA_220C220.00	2BURNGA_220H220.00
39	272902_1	60	2331	101.7727814	X3-1	Line	220882	220887	442	NSW	272902	1	Sunraysia Solar Farm	2BURNGA_220C220.00	2BURNGA_220H220.00
43	212501_3	20	48	99.47411346	999-0	Line	213744	228840	65	NSW	212501	3	Avonlie Solar Farm	2_BANGO_132E132.00	2_COWRA_132A132.00
43	212501_3	0	48	100.0187988	999-0	Line	213744	228840	65	NSW	212501	3	Avonlie Solar Farm	2_BANGO_132E132.00	2_COWRA_132A132.00
43	215202_2	580	48	99.96076202	999-0	Line	213744	228840	65	NSW	215202	2	Bayswater	2_BANGO_132E132.00	2_COWRA_132A132.00
43	215202_2	600	48	100.0385056	999-0	Line	213744	228840	65	NSW	215202	2	Bayswater	2_BANGO_132E132.00	2_COWRA_132A132.00
43	215203_3	440	48	99.96194458	999-0	Line	213744	228840	65	NSW	215203	3	Bayswater	2_BANGO_132E132.00	2_COWRA_132A132.00
43	215203_3	460	48	100.0767975	999-0	Line	213744	228840	65	NSW	215203	3	Bayswater	2_BANGO_132E132.00	2_COWRA_132A132.00

Figure 8 Excerpt from the result file for transition over 100% due to generator dispatch for NSW.

3. Result analyses

Details of results from the analysis undertaken for this project are given in this section, along with a brief explanation as to the methodology undertaken for each region assessment.

Contingency analysis was undertaken in South Australia, NSW, and VIC for N-1 conditions, including two base .sav cases under intact conditions. Circuits for N-1 analysis were selected with the following criteria:

– Had a non-zero MVA rating assigned.
– Non-transformer branches.
– Voltage greater than or equal to 66 kV (in VIC greater than or equal to 220 kV).

Contingency analysis was based on base cases developed by AEMO, with two scenarios considering bi-directional flows on PEC, at its rated Phase 1 maximum allowed transfer of 150 MW. These transfers coincided with relatively high flows on PEC, with approx. 360 MW import and 440 MW export from SA to VIC on Heywood respectively.

3.1 SA Results

To produce the South Australia results, individual generator units within this state were varied by increments of 20 MW up to their Pmax rating – with the swing bus located within South Australia at Torrens Island B – therefore preserving the relative flow on PEC in each scenario. Line loadings > 80% based on the NORM rating in PSSE were extracted for each scenario in CSV files, and further analysis was performed on the processed CSV files to produce aggregated results in Excel spreadsheets. Particularly, the following results were recorded:

– Highest loading reported for each circuit.
– Any overloads caused by generator dispatch changes, i.e., a change from <100% loading to >100% loading.

A list of the generators considered for analysis is shown in Table 1 – overall 73 individual units in SA were selected, based on dual criterion of size, and proximity to PEC.

Table 1 Generators considered in analysis (South Australia).

Generator List (A-L)	(M-Z)
Angaston	Mintaro GT
Barker Inlet Power Station	Osborne
Bungala One Solar Farm	Pelican Point
Bungala Two Solar Farm	Port Augusta Renewable Energy Park – Solar
Cathedral Rocks	Port Augusta Renewable Energy Park – Wind
Clements Gap Wind Farm	Port Stanvac 1
Dry Creek GT	Quarantine
Hallett 4 North Brown Hill	Snowtown S2 Wind Farm
Hallet GT	Snowtown Wind Farm
Hallett Stage 1 Brown Hill	Tailem Bend – Solar
Hallett Stage 2 Hallett Hill	Torrens Island B
Hornsdale Power Reserve Unit 1	Waterloo Wind Farm
Hornsdale Wind Farm Stage 1	Wattle Point
Lincoln Gap Wind Farm	Willogoleche Wind Farm

The undertaken analysis showed that:

- 12 monitored circuits reported loading >100%.
- 7 of those circuits were in SA, with the remaining 5 in NSW.
- 7 of those circuits reported loading >100% attributable to a specific change in generation dispatch – 4 of these were in NSW and therefore did not appear to be overloaded by specific generators, but rather impacted by general changes in power flows across the network.

The circuits of interest in this case are presented below.

Table 2 Worst case overloads reported – All scenarios – SA results.

Branch Name	Post-contingent loading %	iBus Name	jBus Name	Import/Export Scenario	Overloaded for PEC import / export?
999-0	113.39	2_BANGO_132E	2_COWRA_132A	SA Import	N
89P-0	195.87	2GOONUM__66A	2_PARKS__66A	SA Import	N
89J-0	369.75	2_PARKS__66A	2PARKES__66A	SA Import	N
MBKYAD_T-0	301.95	5CULTAN_132B	5MIDBCK_132C	SA Import	N
MUNELD_1-ME	112.96	5ELIZAB__66A	5MUNNOP__66A	SA Export	N
NWBMON_1-B1	104.70	5MONASH_132C	5NORWST_132A	SA Export	N
NWBMON_2-B1	142.15	5MONASH_132C	5NORWST_132A	SA Export	N
ROBMW3_2-P3	101.44	5MWPS3__132A	5ROBERT_132A	SA Export	N
ROBNWB_1-N1	122.97	5NORWST_132A	5ROBERT_132A	SA Export	N
PARKES_1H	116.85	2_PARKS__66A	2_PARKS_132A	SA Import	N

Branch Name	Post-contingent loading %	iBus Name	jBus Name	Import/Export Scenario	Overloaded for PEC import / export?
PARKES_2H	113.55	2_PARKS__66A	2_PARKS_132A	SA Import	N
HRN_WF_T_4	110.61	5HORNSD__33K	5HORNSD_275H	SA Export	Y

Of the circuits reporting overloads for generators ramping in SA, none were reported at transmission level (>=220 kV) except for the 2-winding transformer connecting the Hornsdale WF. This overload was not due to PEC integration, instead being due to the Hornsdale BESS ramping and was reported independent of whether import or export condition for PEC was considered. Two circuits were reported overloaded for > 300% of rating, despite not being overloaded during normal dispatch conditions, however these overloads were repeated in many dispatch conditions. The 89J-0 transformer appeared extremely vulnerable to overload due to a high pre-contingent loading, and the MBKYAD_T-0 reporting of an extremely high overload appears to be a one-off result likely caused by a power flow convergence issue, although other overloads of the circuit closer to 100% of rating are reported.

The remaining overloads primarily were reported at 132 kV in both SA and NSW. The 132 kV circuits between Monash, Norwst, MWPS and Robertstown should be of interest to AEMO, as these overloads were only reported under SA Export conditions and appear to have been influenced by PEC dispatch conditions combined with generator loadings.

3.2 NSW Results

To produce the NSW results, individual generator units within this state were varied by increments of 20 MW up to their Pmax rating – with the swing bus located within NSW at Earing/Bayswater as they were located by default in the AEMO setup cases. As therefore preserving the relative flow on PEC in each scenario. Line loadings > 80% based on the NORM rating in PSSE were extracted for each scenario in CSV files, and further analysis was performed on the processed CSV files to produce aggregated results in Excel spreadsheets. Again, the record of interest includes all highest loading on every circuit as well as any overloads caused by generator dispatch changes, i.e., the transition of branch's loading across 100% threshold.

A list of the generators considered for analysis is shown in Table 3 – overall 45 individual units in NSW were selected, based on a dual criterion of size, and proximity to PEC.

Table 3 Generators considered in analysis (New South Wales).

Generator List (A-K)	(K-Z)
Avonlie Solar Farm	Limondale Solar Farm 1
Bayswater	Mt Piper
Broken Hill Solar Plant	Sunraysia Solar Farm
Coleambally Solar Farm	Tallawarra
Collector	Tumut 3
Darlington Point Solar Farm	Upper Tumut
Eraring	Uranquinty
Finley Solar Farm	Vales Point B
Hillston Sun Farm	

The undertaken analysis showed that:

– Sixteen circuits in NSW reported overloads under N-1 conditions – with the majority of worst-case overloads being reported under conditions where South Australia was exporting.

– Of the overloads reported – 12 of these could be attributed to specific generator dispatch conditions i.e. the change in dispatch of a generator resulted in an overload, rather than this being a generic outcome of the post contingent condition under the scenario tested.

– Eleven unique generators in NSW were involved in these overload conditions.

The worst-case overloads for each circuit, as well as their overload condition are reported in Table 4.

Table 4 Worst case overloads reported – All scenarios – NSW results.

Branch Name	Post-contingent loading %	iBus Name	jBus Name	Import/Export Scenario	Overloaded for PEC import / export?
997/1-1	122.96	2ALBURY_132E	2COROWA_132A	SA Export	N
X3-0	103.61	2BALRAN_220A	2BURNGA_220H	SA Import	N
X5-0	123.81	2BALRAN_220A	2DAL_PT_220B	SA Export	Y
X7-0	107.01	2BALRAN_220A	2SUNRAY_220A	SA Export	N
999-0	154.27	2_BANGO_132E	2_COWRA_132A	SA Import	Y
9GM-0	106.05	2_BANGO_132E	2_YASS__132A	SA Export	N
9R7-0	156.36	2COMBLY_132A	2COLEMB_132A	SA Export	N
99T-0	160.77	2COMBLY_132A	2DAL_PT_132A	SA Export	N
99L-0	119.65	2COMBLY_132A	2DENILQ_132B	SA Export	Y
997/2-1	116.41	2COROWA_132A	2MULWAL_132D	SA Export	Y
99D-0	156.72	2DAL_PT_132A	2YANCO__132A	SA Export	Y
94P-0	100.93	2MANILD_132A	2MOLONG_132A	SA Export	N
94T-0	114.01	2MOLONG_132A	2ORANGN_132A	SA Export	N
94K/1-0	113.73	2NY_DUB_132A	2WELING_132A	SA Export	N
YASS_2H	106.50	2_YASS__132A	2_YASS__330A	SA Export	N
X3-1	108.79	2BURNGA_220C	2BURNGA_220H	SA Export	Y

Of the circuits reporting overloads, some were clearly geographically and electrically linked to PEC transfers, with 220 kV circuits around Balranald and Buronga – including assets forming part of PEC reporting overloads under export and import conditions.

Other circuits were more isolated from PEC geographically, and it is not clear if PEC influenced their overload. For instance, the Bango – Cowra 132 kV circuit is reported as overloaded under a variety of conditions under both export and import conditions, and due to generators geographically distant from the interconnector – for overloads in these cases it is more likely that they are caused by pre-existing network constraints. A number of overloads involving solar farms in the west of NSW were reported, i.e. Limondale & Sunraysia SF's, and it is likely these constraints arose due to existing constraints on the network.

Conditions involving circuit overloads as well as generators involved in influencing overloads via dispatch changes are submitted in Appendices to this report.

3.3 VIC Results

Under the same routine, individual generator units within VIC were varied by increments of 20 MW up to their Pmax rating– with the swing bus located within VIC at PSSE bus 374001. Line loadings > 80% based on the NORM rating in PSSE were extracted for each scenario in CSV files. Further analysis was performed on the processed CSV files to produce aggregated results in Excel spreadsheets, collating data about all highest loading on every circuit as well as any overloads caused by generator dispatch changes, i.e., the transition of branch's loading across 100% threshold.

A list of the generators considered for analysis is shown in Table 5– overall 76 individual units in VIC were selected, with primary criteria for the selection being based on size.

The Victoria transmission network is connected to Buronga in NSW at 220 kV as part of PEC stage 1. Under guidance from AEMO, all circuits at 220 kV or greater were assessed for Victoria to determine the impact of this connection on overloads.

Table 5 Generators considered in analysis (Victoria)

Generator List (A-L)	(M-Z)
Ararat Wind Farm	Macarthur Wind Farm
Bannerton Solar Park	Moorabool Wind Farm
Berrybank Wind Farm	Mortlake
Bulgana Green Power Hub - Wind Farm	Mortlake South Wind Farm
Crowlands Wind Farm	3MRWURA__WF
Dundonnell Wind Farm	3MURAWR__WF
Karadoc Solar Farm	Murray 1
Kiamal Solar Farm - Stage 1	Murray 2
Kiamal Solar Farm - Stage 2	Newport
Loy Yang A Power Station	Valley Power
Loy Yang B	Victorian Big Battery
	Waubra
	Wemen Solar Farm
	Yallourn W
	Yatpool Solar Farm
	Yendon Wind Farm

The analysis undertaken showed that:

– Seven circuits in VIC reported overloads under N-1 conditions.
– Changes in generator dispatch in VIC caused reported overloads in NSW.
– Of the overloads reported – all of the VIC circuit overloads could be attributed to specific generator dispatch conditions, i.e. the change in dispatch of a generator resulted in an overload, rather than this being a generic outcome of the post contingent condition under the scenario tested.
– Ten unique generators in VIC were involved in these overload conditions.

The worst-case overloads for each circuit in Victoria, as well as their overload condition are reported in Table 6.

Table 6 Worst case overloads reported – All scenarios – VIC results.

Branch Name	Post-contingent loading %	iBus Name	jBus Name	Import/Export Scenario	Overloaded for PEC import / export?
ARTS_WBTS_STAT-0	130.34	3ARAR_T_220A	3ARAR_T_220B	SA Export	N
BATS_WBTS_220-0	112.40	3BALRAT_220A	3WAUBRA_220A	SA Export	N
KMTS_RCTS_STAT-0	125.44	3KIAMAL_220A	3KIAMAL_220J	SA Export	N
KMTS_RCTS_220-0	120.42	3KIAMAL_220J	3REDCLF_220A	SA Export	N
MLTS_TGTS_220-0	116.75	3MOORAB_220A	3TERANG_220A	SA Export	N

Branch Name	Post-contingent loading %	iBus Name	jBus Name	Import/Export Scenario	Overloaded for PEC import / export?
ROTS_SVTS1_220-0	212.53	3ROWVIL_220B	3SPRING_220A	SA Export	N
ROTS_SVTS2_220-0	212.53	3ROWVIL_220B	3SPRING_220A	SA Export	N

Of the infrastructure in Victoria reporting overloads following contingencies, several are electrically close to the PEC connection, such as circuits connecting to Red Cliffs at 220 kV report overloads on a post-contingent basis. All overloads in Victoria are reported only for conditions where PEC is exporting from South Australia, suggesting that this condition is likely to be more problematic for potential overloads on the VIC transmission network.

4. Conclusions

This analysis has covered a comprehensive assessment of the NEM under a number of post-contingent and dispatch conditions, to assess the impact of the integration of PEC stage 1. This has primarily been concerned with assessing the potential for overloads under post-contingent conditions, and the impact of PEC stage 1 on these conditions. This analysis has shown:

– No overload conditions found to occur under intact conditions on the NEM – with all monitored circuits remaining below their thermal ratings.

– Significant number of overload conditions can occur under N-1 conditions on the NEM; however a majority of these overloads were independent of PEC import / export conditions and therefore do not seem to be directly associated with its integration.

– Limited number of overloads appear to be linked to PEC integration under N-1 conditions, with some electrically close overloads appearing only when PEC is dispatched under specific conditions i.e. importing or exporting.

While the majority of the overloads reported appear to be pre-existing constraints known to AEMO, some of these appear to be directly caused or influenced by PEC integration, or a combination of PEC integration and specific dispatch conditions. For any new overloads that have been reported due to this analysis, if AEMO does not consider its current operational procedures sufficient to manage these overloads, AEMO should consider alternative options, which may include:

– Generator runback schemes

– Limits on PEC transfers

However, it appears for the majority of overloads reported, existing dispatch constraints should be sufficient to manage these issues, as they do not appear to be linked to PEC conditions. Specific details of generator dispatch conditions causing overloads are reported in the Appendices of this report.

Appendices

Appendix A

Results Files

A number of documents will be provided for reference purposes with this memorandum. A brief explanation of the documentation provided is detailed in this section:

NSW Results

- MaxBranchLoadingNSW.xlsx – contains summary of worst-case overloads under NSW dispatch conditions.
- PEC Loadflow Data_NSW.xlsx – contains input data for python tool for NSW results.
- ResultNSW.xlsx – contains summary of all overload conditions caused by generation dispatch in NSW (where change in generation dispatch resulted in loading change on circuit from <100% to >100%
- Scenario_List_NSW.xlsx – contains list of all contingency scenarios for NSW results, along with PEC import/export condition.
- 00001-01066.csv – CSV files containing unconsolidated results for NSW.
- 00001-01066.sav – SAV cases for all N and N-1 cases assessed for NSW.

SA Results

- MaxBranchLoadingSA.xlsx – contains summary of worst-case overloads under SA dispatch conditions.
- PEC Loadflow Data_SA.xlsx – contains input data for python tool for SA results.
- ResultSA.xlsx – contains summary of all overload conditions caused by generation dispatch in SA (where change in generation dispatch resulted in loading change on circuit from <100% to >100%
- Scenario_List_SA.xlsx – contains list of all contingency scenarios for SA results, along with PEC import/export condition.
- 00001-00396.csv – CSV files containing unconsolidated results for SA.
- 00001-00396.sav – SAV cases for all N and N-1 cases assessed for SA.

VIC Results

- MaxBranchLoadingVIC.xlsx – contains summary of worst-case overloads under VIC dispatch conditions.
- PEC Loadflow Data_VIC.xlsx – contains input data for python tool for VIC results.
- ResultVIC.xlsx – contains summary of all overload conditions caused by generation dispatch in VIC (where change in generation dispatch resulted in loading change on circuit from <100% to >100%
- Scenario_List_VIC.xlsx – contains list of all contingency scenarios for VIC results, along with PEC import/export condition.
- 00001-00242.csv – CSV files containing unconsolidated results for VIC.
- 00001-00242.sav – SAV cases for all N and N-1 cases assessed for VIC.

Python Files

- PEC Loadflow Automation p27.py – modifies generator dispatch and creates results, csv files.
- PEC Create Contingency Scenarios Automation p27.py – creates contingency .sav files based on base .sav cases and input data from PEC Loadflow Data.xlsx spreadsheet.
- ResultProcessingCSV.py – creates summary excel spreadsheets.

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