Pricing Prototype Program: User Guide

Introduction

This user guide has been prepared by the staff of the Australian Energy Market Commission (AEMC) to inform interested stakeholders as part of the Optional Firm Access, Design and Testing review. It does not necessarily represent the views of the Commission or any individual Commissioner.

The AEMC acknowledge the assistance of Jervis Whitley of whit. and David Smith of Creative Energy Consulting in preparing this user guide.

Disclaimer

The AEMC notes that the prototype pricing model, and the indicative prices produced by the prototype pricing model, are provided by the AEMC to stakeholders for information. These prices should **NOT** be used as a guide to what generators may pay if optional firm access was implemented.

Stakeholders are not permitted to commercialise the model or any information contained in it. While the AEMC has endeavoured to ensure the content of the model is accurate, adequate or complete, it does not represent or warrant its accuracy, adequacy or completeness. The AEMC does not warrant or represent that the information in this document is accurate, reliable, complete or current. To the extent permitted by law, the AEMC and its advisers, consultants and other contributors to the model (or their respective associated companies, businesses, partners, directors, officers or employees) will not be liable for any errors, omissions, defects or misrepresentations in the information contained in the model, or for any loss or damage suffered by persons who use or rely on the model (including by reason of negligence, negligent misstatement or otherwise).

Prototype pricing model version history

Date	Version number	Comments
31/10/2014	d1e88a5700edd7aafebad545961dae6e666676ee	Released with Optional Firm Access Design and Testing Supplementary Report: Pricing
12/03/2015	ebaa6de6c3d57e022f1de5deeff69db9c9a57234	Released with Optional Firm Access, Design and Testing Draft Report Unchanged for release of Optional Firm Access, Design and Testing Final Report

Instructions for first time users - Quick Start Guide

How to use the program for the first time

Download the zipped file containing the program, and extract it/unzip it. To correctly extract - right click on the zipped file and select extract all.

The program has a text document called VERSION. This has a number that represents the release of the model. Stakeholders can quote this number when reporting issues they have identified in the model, or in discussions with the AEMC. This user guide refers to version:

commit ebaa6de6c3d57e022f1de5deeff69db9c9a57234

The program will have input data for a NEM region pre-loaded – Victoria. To change the NEM region, the input data will need to be changed. Input data for every region is provided in a separate subfolder within the *inputs* folder. To allow the model to use the required regional input data, do the following:

1. Delete the seven excel files and one text file that are currently in the *input* folder of the program.
2. Copy the eight files from the appropriate subfolder in the *inputs* folder.
3. Paste these eight files into the *input* folder of the program (ie, bring these files up one "level" within the folder structure).

Now, open the program named *run.exe*. A small black background window will appear. The program will take a few moments to load up the input files.

After loading up the input files, the following text will appear in the window

```
Model Access Pricing shell, welcome.
help for help
quit to exit.
```

Type *nodes* and press return.

The program will provide a list of all transmission network nodes in its input data.

Each node has a number and a name. The number of nodes will depend on which NEM region is included in the input data set.

Type *lines* and press return.

The program will provide a list of all transmission lines in its input data. Each line has a number and a label. The number of lines will depend on which NEM region is included in the input data set.

Data about the nodes and lines are included in the input files the program loads up when you start the program. This data can be changed as the topology of the real network changes or better information is obtained about the existing network. This information can be amended by the user.

As an example, type *node 33* and press return.

The program will return the name of the *node 33* in the data set. In the Victorian region this is *3LYB500* (better known to us as Loy Yang B).

Typing this command sets the program to focus only on one node: *node 33.*

Type *run* and press return. The program has an assumed default access amount request of 200 MW firm access request for a 20 year term.

The program returns the following text.

LRIC
$/kW

name	200	400	600	800	1000	1500	2000	2500	3000
3LYB500	116.9	97.2	118.0	130.6	142.5	182.1	176.5	169.9	168.7

The text may be forced onto the next line if the window is not wide enough.

The text can be interpreted as follows:

- The LRIC access price for a firm access request of 200 MW at node 33 (3LYB500) is $116.9/kW (rounded to one decimal place)
- The LRIC access price for a firm access request of 1000 MW at node 33 (3LYB500) is $142.5/kW (rounded to one decimal place)

The LRIC access price is the total LRIC cost over the life of the firm access request.

The access price has been calculated using a set of transitional access levels loaded up into the program through the input files. The preloaded transitional access levels are based on the values that AEMO produced for the AEMC as part of this project.[1] These levels of transitional access (and timeframe) can be changed by the user, with further ones added or removed, in the input data files.

The MW level of the firm access request can be changed via the *access* command.

Type *access 500* and press return.

[1] The report is available on our website here.

The program will return that the new selected MW firm access amount is 500, whereas the default MW firm access amounts are the other reported amounts.

```
200
400
500 <-selected<-new
600
800
1000
1200
1500
2000
2500
3000
```

If you type *run* and press return again, the program will return the following text:

LRIC
$/kW

name	200	400	500	600	800	1000	1500	2000	2500	3000
3LYB500	116.9	97.2	116.8	118.0	130.6	142.5	182.1	176.5	169.9	168.7

LRIC
$/kW

This text can be interpreted as follows:

- The LRIC access price for a firm access request of 500 MW at node 33 (3LYB500) is $116.8/kW (rounded to one decimal place).

Exporting and viewing the results

Type *export* and press return.

The program now exports its calculated output to an Excel file and produces two pdf files containing charts. These export files have been saved in a folder called *Output*. The Excel file is named accordingly: “results-33-500MW-2033.xls”. This reflects the fact that it is the results associated with node 33 in Victoria, a 500 MW firm access request, with the access request ending in 2033.

The data in the results file can be examined directly. Details of its contents are provided in the section “Output File” below.

Alternatively, to view ready-made charts and tables that display the model results, do the following:

1. Locate the “LRIC Reporting v5” Excel file. This will already be in the *Output* folder.

2. Open the Excel file. If there is a security warning then click “enable content”.
3. When a new window pops up, click on Update.
4. When a new window pops up, click on the Edit Links window.
5. In the next window, click on “Change Source” and navigate to the results-33-500MW-2033.xls file. Select this file. (This may be quicker if the results-33-500MW-2033.xls file is already open in excel).
6. Once this file has been loaded, click on “Open Source”.
7. The results should now be displayed in the LRIC Reporting spreadsheet.

The worksheets on the LRIC Reporting spreadsheet are described below. In many cases, the tables have been coloured using Excel conditional formatting to highlight salient numbers.

The *global* tab provides the input settings that relate to the output. In particular, it shows the location and amount of access. The meanings of the other parameters are described in the section “Input Files” below.

The *xcount* tab provides a summary of the baseline expansion plan. The numbers in the table shows the number of modelled expansions on each line in each year. A numeric 1 implies one expansion “lump” which is the scale-efficient expansion *divided by the line meshedness* (the concept of meshedness is explained in the appendix). For example, if the scale-efficient expansion is 1000MW and the line meshedness equals 5, a “1” in the table implies a 200MW expansion. The meshedness effect means that there will be more, smaller expansions than in real-life planning.

The *inc_xcount* tab provides the *change* in expansion in the adjusted plan compared to the baseline plan. A positive figure means an expansion in the adjusted plan that was not in the baseline plan. A negative figure means an expansion in the baseline plan that no longer exists in the adjusted plan. In many cases a baseline expansion will be advanced in the adjusted expansion.

The results tab provides detailed results for every line for the particular access request. The fields in the columns are explained in the table below. There are also some hidden columns containing internal calculations; these columns are not described in the table below.

Column Name	**Meaning**
name	Line name from input file
Meaning	Plain English description of line
Type	“L”=line; “T”=transformer
From/to volts	Rated voltages at either end of line

Base NPV Lumps	The net present value (using WACC as the discount rate) of the XCOUNT values. The more and the sooner the expansions, the higher the NPV value
Adj NPV Lumps	The NPV value for expansions in the adjusted scenario
Inc NPV Lumps	The difference between Adj and Base NPV Lumps. A positive number implies expansions have been created or advanced in the adjusted scenario, giving rise to some LRIC on that line
Initial capacity	The thermal rating of the line in the baseline network in the first year of the requested access term
Initial flow	The modelled flow on the line in the first year of the requested access term. The sign indicates the flow direction: for example, on the Altona to Brooklyn line, a positive number would indicate a flow from Altona to Brooklyn and a negative number indicates a flow from Brooklyn to Altona.
Security Adjustment	The amount by which the initial flow is increased on the line under the worst case single contingency.
Initial Spare capacity	The amount by which initial flow could be increased before the network becomes insecure. This equals the initial capacity minus the initial flow minus the security adjustment.
Inc Flow	The amount (in absolute terms) by which the access request would *change* the initial flow. Inc flow will occur on lines that are on a flow path between the access node and the RRN. The inc flow can drive expansion advancement which, in turn, drives LRIC.
Adj Spare capacity	The initial spare capacity in the adjusted scenario. This is the initial spare capacity minus the inc flow, with sign corrections for flow direction etc. A negative spare capacity number implies that immediate expansion is required on that line.
LRIC$	The LRIC cost (in $m) for that line, associated with the access request. Total LRIC (summed over all lines) is provided in row 2. LRIC is not permitted to be negative and is set to zero where the access request causes modelled expansions to be deferred.
LRMC$	The LRMC cost (in $m). This represents what the LRIC would be if there were no spare capacity and no lumpiness in the network. It is the inc flow multiplied by the $/MW expansion cost. Like LRIC, LRMC is not permitted to be negative and will instead be set to zero where the access request causes a reduction in line flow.
Deep Connection$	The $m cost of any expansions in the adjusted scenario that occur in the first year of the access request.

The *line_chart* tab provides a graph of line flow and line capacity on a particular line, which can be selected by the user by changing the line index number in the yellow-shaded cell (K1). The capacity is adjusted by the security adjustment, so an expansion occurs (represented by a step increase in the line capacity) every time the flow level reaches the capacity level.

The “negative capacity” is also represented on the graph because it is possible in some cases for the line flow to reverse over time and for the reversed line flow to prompt expansion of the line capacity.

The *node_chart* tab shows how LRIC, LRMC and deep connection vary by access amount. They are expressed in $/kW terms. LRMC is constant in $/kW terms because the $ charge is always proportional to access amount. The node represented is usually the access request node. However, other nodes can be presented if the user inputs an index number into the yellow-shaded cell (B1), which should otherwise be left blank. This should only be used if the results file contains pricing data for all nodes (an explanation on how to do this is provided below).

The *node_lookup* tab provides a look-up table showing the plain English meaning of all of the node names.

The *look_up* tab provides internal working data only and is not useful for the ordinary user.

Exporting other access amounts

Now, go back to the program, type in *access 1000* and press return.

This sets the firm access amount to be 1000 MW at node 33.

Type *export*. Open the file *results-33-1000MW-2040.xls* in the *Output* folder. The data in the new results file can be viewed using the *LRIC reporting* spreadsheet by editing the links in that spreadsheet. This is done by:

1. Clicking on edit links under the data tab in the menu (may vary in different Excel versions).
2. Click on “change source” and find the new results file in the browsing window (again, this may be quicker if the file *results-33-1000MW-2040.xls* is already open in excel).
3. Click on “open source” and the results should now be displayed in the spreadsheet.

Now go to the program shell window and type *node 25*. This selects the node *3HEY500* (better known to us as the Victorian side of the Heywood interconnector between Victoria and South Australia). Type *run* (or *run 25* a shortcut which removes the need to type *node 25* earlier). This runs for the program for *node 25* with an access request of 1000 MW.

Export the results (using *export filename* e.g. *export*) to examine them more carefully. Again, the *LRIC reporting* spreadsheet can be used as above.

You can calculate the LRIC, LRMC and deep connection costs for firm access requests on all nodes of the network by deselecting a particular node. Type *node clear*. This deselects the existing node. Type *run*. This may take some minutes (up to an hour, depending on your computer and the size of the transmission network model being used in the program) to calculate the LRIC, LRMC and deep connection costs for all the firm access amounts specified in the input data.

Exporting the results of this ‘all nodes’ LRIC calculation does not provide you with network flow information or network expansion information – you need to select a particular node and a particular firm access quantity to obtain the network flow and network expansion plan.

Type *quit* or *exit* to exit the program.

Exporting other access terms

The default access request is for a 20 year access term, i.e. which starts in 2014, and ends in 2033. This is specified in the settings.txt file in the *input* sub-folder. Therefore, all the above results were for a 20 year access term.

The length of the access request can be changed using the *lastyear* command. The access term will still commence in 2014 but will end at the year specified. The start of the access term can be changed in the settings.txt file in the *input* sub-folder.

Reopen the *run.exe* program file. Enter *node 33* to select Loy Yang B. Enter *lastyear 2023,* and then type *run.*

This will return the following text:

LRIC
$/kW

name	200	400	600	800	1000	1500	2000	2500	3000
3LYB500	69.8	89.5	92.9	86.3	121.5	167.3	169.8	163.1	164.1

The text can be interpreted as follows:

- The LRIC access price for a firm access request of 200 MW at node 33 (3LYB500) for 10 years is $69.8/kW (rounded to one decimal place).
- The LRIC access price for a firm access request of 1000 MW at node 33 (3LYB500) for 10 years is $121.5/kW (rounded to one decimal place).

Changing the input settings

The settings are all contained in a file called *settings.txt* contained in the *inputs* folder. After making an edit to this file, save and close it, then also close and reopen the *run.exe* program. Detailed information about the settings and input files are contained in the following sections.

The following settings may be changed from within the program, as noted above:

- Access amounts via the *access* command.
- Last year of access request via the *lastyear* command.

The rest of this User Guide contains more detailed information about the program for interested users.

Program layout

The program in its compiled form consists of the following high level layout:

- run.exe, the executable program;
- inputs, a folder storing all of the program inputs and settings;
- output, a folder containing the exported results spreadsheet and associated pdf charts;
- errors.log, an error file that contains details of any program crashes or warnings about islanding (singular matrices); and
- miscellaneous supporting files and other files are important for program execution but not required to be inspected directly by users.

Input files

These are stored in the *inputs* folder as *csv (comma separated value)* files. Excel can read and write CSV formatted files. The data in these files can be edited by the user before the files are loaded into the program. It also contains *settings.txt* which controls the options for how the program runs.

aemc-nodes.csv

Used to describe the nodes that form part of the network. Together with aemc-lines.csv they describe the topology of the network, and must not have any stranded nodes or islands.

Column name	**meaning**	**requirements**
name	The name of the node	must be connected to the grid and not islanded
zone	The name of the zone	must be present in the zone_growth.csv file
region	The NEM region for this node	

aemc-lines.csv

Edge data for both lines and transformers that describe characteristics like capacity and length. The combination of from voltage, to voltage, size and type must be present in the linetypes.csv file in the inputs folder.

Column Name	**Meaning**	**Requirements**
name	Line name	
from name	name of the from node	must be in the aemc-nodes.csv file

to name	name of the to node	must be in the aemc-nodes.csv file
admit	effective admittance	must be updated when dupe setting is changed.
cts rating	continuous rating (MW)	
st rating	short term rating (MW)	
type	L=line, T=Transformer	L/T
size	size of element (L=Low, M=Medium, H=High)	L/M/H
length	crow flies distance between nodes (or =1 for transformer)	
dupe	number of parallel duplicates	
region	the NEM region for this node	
from voltage	voltage at from node (kV)	
to voltage	voltage at to node (kV)	
stype	Class of line used for stylised growth, Local, Middle or Core	L/M/C
ckt	circuit identifier	usually 1

aemc-access.csv

Lists the assumed pre-existing firm access agreements of power stations.

Column Name	Meaning	Requirements
name	Name of power station	
MW	Registered capacity (from SOO) (MW)	
node	name of node connected to	must be in aemc-nodes.csv
firm	assumed agreed access level (MW)	
start	first year of access agreement	
end	last year of access agreement	

aemc-zones.csv

Models the general growth of firm access in a node zone, as opposed to specific access of a known power station.

Column Name	Meaning	Requirements
node	name of node	must be in aemc-nodes.csv
zone	name of zone	must be in zone_growth.csv
percent of zone	what % of growth for the zone occurs at the node	the total % for a zone should total 100%

aemc-demand-forecast.csv

Models the forecast demand at each node over the first ten years.

Column Name	Meaning	Requirements
load node	load node at which load attached	
net node	shared network node at which load node attached	
volts	not used	
poe	percent poe	should be 10% POE, other POE values not supported yet
2013-20XX	forecast demand for this node in this year	

zone_growth.csv

Defines the different zones, to which the nodes are allocated in nodes. It defines the assumed short-term and long-term growth rates in each zone: ie, the aggregate background MW annual increase in access across each zone.

Note that the regional reference node must always be node 1.

Column Name	Meaning	Requirements
zone	Name of zone	
reference	zone identifier	these generally match a zone name in aemc-zones.csv

st_growth	short term growth	annual mw growth in short term timeframe
lt_growth	long term growth	annual mw growth in long term timeframe

linetypes.csv

Description of linetypes and their costs used for network augmentation.

Column Name	Meaning	Requirements
type	L=Line, T=Transformer	L/T
from voltage	node from voltage in kV	
to voltage	node to voltage in kV	
size	size of the line	L/M/H
lumpiness	expansion lumpiness in MW to account for non-incremental nature of updates	
cost	cost in $/MW for transformer or $/MWkm for line expansion	do not enter units, only the number
fixed cost	a fixed cost in $. Is added to the calculated (variable) "cost" (see above)	do not enter units, only the number

settings.txt

A settings file in the TOML format (https://github.com/toml-lang/toml). Changed values here will be used on the next program run - so exit and restart the program if you change these values.

Column Name	Meaning	Requirements
amounts	The program runs multiple access requests at the same time. Put as many access requests amounts as you like in this comma separated list. In order to speed up the program, only include the amounts that are required and/or of interest to the user.	The LRIC is reported as the cost divided by the access amount MW. An access request of 0 MW will result in a divide by zero output (nan - Not a Number).
first_year	first year of the access request (inclusive)	

last_year	last year of the access request (inclusive)	
base_year	first year of demand forecast values and of pricing studies	
lt_base_year	first year of lt growth assumptions	
forecast_horizon	last year of full load flow analysis	
forecast_last_year	final year of all studies	
wacc	discount rate for NPV and carrying cost	
limit_offset	chooses which type of element rating is used, 0=cts_rating, 1=st rating for normal capacity	0/1
[offset] table	additional generation applied to a node or series of nodes, with a growth factor per year	for use in calculating inter-regional access prices (discussed below).
[zone_growth] filename	the location of the zone growth values (see zone_growth.csv above)	
[flow_model] table	describes the stylised fractional annual growth, occurring beyond the horizon year for various line classes (called stypes).	
[linetypes] filename	the location of the linetypes table (see linetypes.csv above)	

Output File

The output file is an Excel file in the *Output* folder with a name beginning with “results” and ending with any suffix that the user has provided.

The *lric_matrix* tab provides more detailed information about the LRIC cost (in $/kW).

The *lrmc_matrix* tab provides the long run marginal cost for the firm access requests (in $/kW). Note that this is a constant price per kW regardless of the access request amount.

The *deepc_matrix* tab provide the deep connection cost for the firm access requests (in $/kW).

The *results* tab provides the LRIC, LRMC and DCC cost (in $m) for each individual line or transformer.

The *settings* tab shows the settings at the time the program exported the results. Useful information such as the node and access request amount and years of access request are shown here.

The spreadsheet also contains information on other tabs (see below) about how the transmission network is projected to be developed:

- *without* any firm access requests but taking into account the transitional access of existing generators;
- *with* firm access requests (and taking into account the transitional access arrangements for existing generators). By default, the program calculates the network development plan under 200 MW of firm access at the node the user specifies – in this case node 33.

The *baseflow* tab shows maximum network flows on each transmission line in the absence of any firm access requests.

The *adj_baseflow* tab shows maximum network flows on each transmission line in the presence of the firm access request (here, set to be 200 MW at node 33).

The *xcount* tab indicates the baseline network expansion – i.e. in the absence of firm access requests. In general, the program expands the network by duplicating an existing line. A number in a cell indicates that the line is duplicated within the year.

The *adj_xcount* tab indicates how the network is projected to expand given a firm access request (here, 200 MW at node 33). The difference in the discounted costs between the baseline network expansion and this adjusted network expansion is the total LRIC cost of the firm access request.

The *ra* tab shows the reliability access, which is an additional forecast firm access which ensures that aggregate firm access across the model matches aggregate forecast demand.

The *security* tab displays an adjustment factor that reflects the need to ensure there is sufficient network capacity to ensure system security.

The *xcap and adj_xcap* tabs contain the capacity profiles for each element. Over the years, you will notice that some lines will have lumpy capacity expansion applied, according to calculated capacity shortfalls. If capacity is not exceeded, it is left unchanged.

You can find further detail about these tabs later in this User Guide.

Using the software – further information

Starting it up

To begin, double click the *run.exe* file. You should see a little black coloured command and response terminal appear.

If it does not appear, or there is a message about extracting the file, try unzipping the folder first. Right click on the zipped file and select *extract to*.

Finding your way around

The available commands appear when you type *help* and press enter. You can get help on any other command by typing *help* followed by the name of that command and pressing enter eg, *help nodes.*

Running a study

You may run a full study that simulates an access request at every single node, for a variety of sized access requests. Or you may focus on a single node. The former will take longer to calculate, while the latter will give you only a narrow slice of results to view.

To run a study on all nodes. First check which node is currently selected:

```
> node

all (none selected)
```

or

```
> node

ARM330
```

In the second case, Armidale 330 has already been selected, to clear the selection type

```
> node clear

all (none selected)
```

So with no current node selected type

```
> run

running all (none selected)

0.1% complete…

…
```

At the conclusion of the study, the LRIC results for every node and access request will be printed to the terminal.

Exporting results

To export results after running a study type

```
> export
```

You can also postfix a title to the end of the exported filename

```
> export study1
```

or even

```
> export -nsw
```

The results are stored in the *outputs* folder a file called *results-nodenumber-access_amountMW-last_year.xls* or *results-nsw.xls* (if you picked -nsw as your postfix).

Note that exporting may take some minutes to complete.

Interpreting the results spreadsheet – detailed explanation

lric_matrix tab

These are the LRIC calculations for each node and access request studied. The values are in $/kW (per kW of access request).

lrmc_matrix / deepc_matrix tab

The LRMC and deep connection calculations for each node. The LRMC does not vary by access amount. Both are given in $/kW.

If you had selected a node and access amount inside the program the following sheets will also be exported:

results

The LRIC, LRMC and Deep Connection charges in $m for every single line in the study case.

adj_baseflow and baseflow

This worksheet shows the line flows for each year in the baseline scenario (*baseflow*) and for the adjusted scenario (*adj_baseflow*).

Baseline line flows are calculated differently for year<horizon and year>horizon. Horizon is the forecasting horizon which is a user input on in the *setting.txt* file.

For year<horizon, the line flows are calculated from a load flow generated by the assumed nodal injections calculated on injection. This is done by multiplying the injection vector by the base_flow matrix calculated on base_flow. (The base_flow worksheet is discussed below.)

For year>horizon, the flow on each line is assumed to show exponential growth, anchored on the flow in year=horizon. The rate of growth is dependent on the *stype* of the line, sourced from lines, as described by a user-input lookup table in the settings file.

In the adjusted scenario, the line flows are the baseline lineflows, adjusted by the access request which is treated as an additional injection at the requested node. This associated extra line flow is calculated by multiplying the relevant column in the base_flow matrix by the requested access amount.

For regions where demand surpasses supply, reliability access will cover the shortfall. The shortfall in supply is reflected at the RRN.. Where supply surpasses demand, again the shortfall will be reflected at the RRN for that region (for the purpose of the load flow calculations).

Incremental Usage is only added in the years for which the access request applies.

initial_xcount / xcount / adj_xcount

This provides a count of the number of lumps of capacity expansion in each year on each line.

Again, the *xcount* sheet displays this for the baseline and the *adj_xcount* for the adjusted scenario.

The count is based on the capacity profile calculated in xcap. Expansion is defined to occur in the year prior to the capacity increase. E.g. if:

CAP2012=CAP2011+2 x LUMP

then

COUNT2011=2 (although not exactly 2, as discussed below)

To provide smoothness in the LRIC calculation, expansion is assumed to occur at the point in the prior year when, assuming linear demand growth, capacity would have been exhausted.

For example, suppose that CAP2011=1000, SEC=100 FLOW2011=800, FLOW2012=1100.

The security-adjusted flow is 900 in 2011 and 1200 in 2012, the latter exceeding 2011 capacity. Thus, expansion must occur sometime in 2011.

Since flow growth is 300 MW over the year and spare capacity at the start of the 2011 is 100 MW, this capacity will be exhausted one third of the way through the year, assuming linear growth.

To model this financially in NPV terms, the COUNT variable is adjusted by the discount rate, WACC. Suppose WACC is 10 per cent. A single lump of expansion at the start of the year is reflected in COUNT=1. A single lump of expansion almost at the end of the year has COUNT=1-WACC= 0.90. Therefore, an expansion one third of the way through the year has COUNT = 1-0.33*WACC = 0.967.

In general, if there is an expansion then:

COUNTPY = #lumpsPY x [1 – WACC x (SPARE CAPPY/FLOW GROWTHPY)]

SPARE CAPPY = CAPPY – ABS(FLOWPY) – SEC

FLOW GROWTHPY = ABS(FLOWCY-FLOWPY)

#lumpy expansionsPY = (CAPCY-CAPPY)/LUMP

This formula is not correct where there are multiple expansions in a year, since these could be assumed to be spread through the year rather than all occurring near the start of the year. However, occurrences of this are quite rare.

If capacity is insufficient in the first year modelled, expansion must have occurred sometime in the “initial” period prior to the first year. The timing of this is unknown and so no discount factor is applied to the COUNT variable. It is assumed to occur at the start of the base year.

The NPV of the COUNT variable in the expansion path is then calculated by applying a discounted cashflow calculation to the annual COUNT. It is calculated for the base and adjusted scenarios and the INC NPV (in the bottom matrix only) is the difference between the two.

The total $m cost of expansion in a year is calculated by multiplying the COUNT and the lumpy expansion cost (from results) for each expansion and aggregating these.

xcap / adj_xcap

This contains the capacity profile for each element.

xcap displays the capacity profile for the baseline scenario and *adj_xcap* displays the profile for the adjusted scenario.

The xcap for each year is calculated iteratively from the previous years, using the following algorithm:

First, check to see whether current year flows exceed prior year capacity, allowing for the security adjustment:

Is CAPPY<ABS(FLOWCY)+SEC ?

If the capacity is exceeded, add lumpy capacity as required:

CAPCY = CAPPY + LUMP x ROUNDUP(capacity shortfall/LUMP)

FLOWCY is sourced from *baseflow*: either the baseline or adjusted scenario for the relevant year

ROUNDUP increases the amount in brackets to the next higher integer

SEC is the security adjustment

Capacity shortfall is the amount by which the RHS of the inequality above exceeds the LHS.

If the capacity is not exceeded, capacity is left unchanged

CAPCY=CAPPY

security worksheet

This worksheet displays a security adjustment factor to reflect the need to ensure that there is sufficient network capacity in order to ensure system security.

The analysis is carried out using assumed injections and flows in the base year.

For example, suppose that the baseflow on a line is 600 MW and the normal capacity (ie, continuous rating) of the line is 1000 MW. The initial spare capacity is then 400 MW. However, suppose that under a contingency, the flow increases to 900 MW and the contingent capacity (based on the short-term rating) is 1200 MW. Under this condition, the spare capacity has reduced to 300MW. The security adjustment is then defined as 100MW, to represent that the true spare capacity is actually 100 MW less than the amount calculated under normal conditions. (It is recognised that this is an approximation to the true impact of security constraints).

The algebra for calculating line flows under system secure conditions is described in the Appendix.

The program calculates line flows under all possible contingencies: eg, contingency 5 is the outage of an element of composite line number 5. The algebra for this is described in the Appendix.

ra

Reliability Access sheet adds additional forecast firm access to ensure that aggregate firm access across the model matches aggregate forecast demand.

Any *offset* applied using the *offset* table in the *settings.txt* file will be modelled as an additional amount of reliability access for that node (which should be the RRN for the purpose of inter-regional pricing).

This mimics a situation where a TNSP provides additional Reliability Access (RA) to ensure that demands-side reliability standards are met.

The deficit for each year, between demand and access is based on totals sourced from demand, access and zone_growth. The deficit is then shared between nodes in proportion to the ST or LT growth rates (depending on the year) which are calculated on zone_growth. In effect, then, the RA adjusts the rates of zone growth so that demand growth and access growth are balanced.

access / adj_access / demands

These worksheets show the access amounts, adjusted access amounts and demands at each node right up until and including the forecast horizon year. These values, along with the reliability access form the net power injections at each node, and are used to calculate the load flows.

net_demand / adj_net_demand / ref_node / adj_ref_node

The *net_demand* and *adj_net_demand* show the net power injection at each node used for calculation of load flows. While the *ref_node* shows the additional slack demand at the reference node which results from the load flow calculation and *adj_ref_node* shows slack at the reference node inclusive of the requested access_amount.

other commands

see the list of nodes and lines

you can use *nodes* and *lines* to print a list of all nodes and lines in the working case.

Hit *Enter* to continue through the list, type *q* then hit *ENTER* to quit.

You can also filter the results by node name or line name by typing in a portion of text after lines and nodes eg:

```
nodes ARM
```

or

```
lines ARM
```

set access amounts

For exporting, you will need to set the access and node you would like detailed results on. Use the *node* command to set a node, eg:

```
node 9
```

And the *access* command to change the access amount:

```
access 200
```

You can clear all the set access amounts:

```
access clear
```

And set a new range of access amounts:

```
access 10, 100, 250, 500
```

Changing the access last year

The final year of the access request may also be changed

```
lastyear 2042
```

looking at baseflows and xcount

You can look at the baseflows for a single line over the entire year range, or for all lines in a single year.

The `bf` command is a synonym for `baseflows:`

```
bf 2014
```

shows all baseflows for all lines in the year 2014

while

```
bf 20
```

shows the baseflows for line 20 for all years. The line number corresponds to the line number you can see from the lines command.

Blank entries in the resulting table are zeros.

Hit *enter* to continue through the results or *q* to quit.

Interpreting the NPV and Node PDF charts

The npv chart shows the LRIC, LRMC and Deep connection price for each of the nodes in the system, with the price in $/kW on the y-axis and each node shown on the x axis. The values are for the node / access combination set before exporting the results

The node chart shows the LRIC, LRMC and Deep connection price for a range of access request amounts at a single node.

Automating the software

For undertaking hundreds of studies at the same time, use the automation mode. You will need to change the way you use the program slightly, but the benefits are that it will run through multiple calculations in one session.

There are four steps to setting up an automated session:

1. Remove all the files from directly within the *inputs* folder and instead put them in a subfolder within the *inputs* folder (ie, move the files down one “layer” in the folder structure).

2. Copy the file *automation.csv* from the *automation* subfolder inside the *inputs* folder and place directly into the *inputs* folder. The format of *automation.csv* will be explained in the next section.

3. Edit the *automation.csv* file to prescribe which runs you wish the model to undertake (this is explained in more detail below).

4. *run* the program as normal – the presence of the *automation.csv* file is enough to switch the model into the automated mode. Depending on the number of runs, it may take a long time (hours or even days) to finish the automation.

The *automation.csv* file

As discussed in step 2 above, in order to automate the program, you must set up the automation.csv file.

Each row of the file represents an individual run that the model will undertake. By populating a row with information, this tells the program what the run should be.

This automation.csv has the following columns:

Column Name	**Meaning**	**Requirements**
access	the access request amount in MW	must be a single number like 200 or 400
last year	the last year of the access agreement	
wacc	discount rate for NPV and carrying cost	Must be a fraction between 0 and 1. A 5% WACC would be written as 0.05
middle flow growth	long term line growth	A fraction between 0 and 1

demand growth	short term demand growth (annual percentage change, starting at 2013 value in *aemc-demand-forecast*)	A fraction between -1 and 1. For instance 0.01 means 1% exponential growth on the demand in 2013 (in the aemc-*demand-forecast.cvs* file). Can be the word “None” if it should not apply and the forecast demands are to be used from the aemc-*demand-forecast.cvs* file).
region	the name of the *inputs* subfolder to take the input data from	Must match the name of one of the *inputs* subfolders exactly.
access growth	short term access growth (annual percentage change, starting at 2013 value in *aemc-demand-forecast*)	A fraction between -1 and 1. Fixed annual MW increase in firm access as a percentage of total initial firm access (as per *aemc-access.cvs* file). Can be the word “None” if it should not apply and the *zone_growth.cvs* should be used.
offset node	name of node to apply offset to	Must match a node in aemc-nodes, can be “None” if no offset should be applied
offset	the amount of offset to apply at this node.	Positive number. The word None if it should not apply
offset_growth	The amount to grow the offset by per year	a fraction between -1 and 1. a 5% growth would be 0.05
name	Appended to the results xls file so you know which file represents which run	

For example, the following automation.cvs file will undertake 8 studies. Each study will draw upon data within the subfolder *vic* (within the *inputs* folder). The only difference between each of the 8 studies will be the WACC – which will vary between 4% and 10%. Results files will be placed in the outputs folder, labelled as *vic_wacc_X.*

access	last year	wacc	middle flow growth	demand growth	access growth	region	offset node	offset	offset_ growth	name
400	2033	0.04	0.01	None	None	Vic	none	none	0	vic_wacc_4
400	2033	0.05	0.01	None	None	Vic	none	none	0	vic_wacc_5
400	2033	0.06	0.01	None	None	Vic	none	none	0	vic_wacc_6
400	2033	0.064	0.01	None	None	Vic	none	none	0	vic_wacc_6.4
400	2033	0.07	0.01	None	None	Vic	none	none	0	vic_wacc_7
400	2033	0.08	0.01	None	None	Vic	none	none	0	vic_wacc_8
400	2033	0.09	0.01	None	None	Vic	none	none	0	vic_wacc_9
400	2033	0.1	0.01	None	None	Vic	none	none	0	vic_wacc_10

Turning off automation mode

You must remove the automation.csv file from the *inputs* folder, and place any input files you would like to study back into the *inputs* folder (rather than a subfolder). It is harmless to allow the subfolders to remain.

Inter-regional access prices

Inter-regional access prices can be derived using the input files in eight subfolders in the *inputs* folder.

Each of these subfolders represents a "directional bi-region" – they contain combined input data from two adjacent NEM regions. For example, the folder:

- *nswtovic* contains all the nodes, lines, generators etc. for NSW and Victoria, with the Victorian RRN representing the RRN of the entire "bi-region", meaning that Victoria is the importing region and NSW the exporting region; and
- *victonsw* contains all the nodes, lines and generators for NSW and Victoria, with the NSW RRN representing the RRN of the entire "bi-region", meaning that NSW is the importing region and Victoria the exporting region.

Copy the contents of one of these folders directly into the *inputs* folder.

The baseline level of inter-regional access is set in the *settings.txt* file. For example, in the *settings.txt* file:

```
[offset]

table = [

("node", "offset", "growth"),

("2SYW132", 1500, 1.00)
```

means that 1500MW of inter-regional access will occur in the base year from the NSW RRN (2SYW132) to the adjacent region's RRN. This 1500MW will be fixed over time (ie, because it has an exponential growth factor of 1.00). The MW offset in the *settings.txt* file should be the <u>gross</u> inter-regional flow in the baseline (ie, <u>not</u> net of any inter-regional flow in the opposite direction).

Always set the "node" in the *settings.txt* file to be the exporting region's RRN. Ie, for the *nswtovic* directional bi-region, 2SYW132 should be the node quoted in the *settings.txt* file, since this is the NSW RRN.

Now, run the program by clicking on the *run.exe* file.

Select the exporting region's RRN as the node for the study. Ie, type *nodes* and press enter. In the resulting list, find the RRN for the exporting region. This will be the first listed node for that region – for the *nswtovic* bi-region, all the Victorian nodes (beginning with 3) will be listed first, then all the NSW nodes (beginning with 2) will be listed second. So the first listed NSW node, "2SYW132", is node number 74, which is the RRN for NSW.

Select this node, by typing *node 74* and pressing enter.

Now type *run* to run the model, as normal.

The resulting outputs will be for an access request between node 74 of the bi-region (ie, the NSW RRN) to the bi-region's RRN (ie, the Victorian RRN).

Appendix: Meshedness and Contingency Analysis

This appendix discusses the algebra used in calculating meshedness and security adjustments in the model.

Distribution Factors

Suppose that we take a line in the network model and inject 1MW at one end of the line and withdraw 1MW at the other end, with no other injections or withdrawals across the network. Some of the 1MW will flow along the line itself, with the remainder flowing "around" the line, along other paths in the network.

Define a distribution factor d_{ij} which is the MW flow through line i when the 1MW injection and withdrawal is across the ends of line j. These distribution factors become important when considering meshedness and contingencies as discussed below.

The distribution factors can be calculated from the baseflows contained on the base_flow worksheet. The base_flow, b_{ik}, is the flow on line i from an injection of 100 MW at node k and its withdrawal at the RRN. Placing 100 MW across the line ends is equivalent to super-imposing two load flows:

an injection of 100 MW at the start node for the line and withdrawal from the RRN

an injection of 100 MW at the RRN and withdrawal at the end node

Thus, the distribution factor can be calculated by adding these two flows together:

$$d_{ij} = [b_{is(j)} – b_{ie(j)}]/100$$

where:

s(j) is the start node for line j

e(j) is the end node for line j

Line Meshedness

One important distribution factor is dii for a line i. This is the proportion of the flow that flows through the line itself rather than around the network. It must take a value between 0 and 1. If it is one, then the line i is radial: ie the line is the only path connecting the start and end nodes.

The meshedness of line i is defined by the formula:

Line meshedness = $\mu^l_i = 1/d_{ii}$ (μ is the greek letter "m" for "meshedness")

For a radial line μ^l=1. Generally, in a meshed network, μ^l>1.

Consider a network where the only paths between the start and end nodes of line i are duplicate, identical lines between the same two nodes. If there are n duplicates in total (ie line i together with n-1 other parallel lines), then clearly only 1/nth of the flow between the two nodes travels on line i. Therefore the line has meshedness n.

Thus, generally, the meshedness reflects the number and size (admittance) of paths parallel to line i.

Duplicates and Circuit Meshedness

In the LRIC model, identical parallel circuits are generally modelled as a single, composite line, together with a duplication factor, D. The admittance of the composite line is simply the product of the admittance of each component multiplied by D.

There is a need to distinguish between the meshedness of the modelled, composite line and the meshedness of the individual component circuits of that composite. Since d_{ii} MW flows across the composite line, d_{ii}/D MW flows over each circuit. Therefore, the circuit meshedness is simply:

$$\text{Circuit meshedness} = \mu^c_i = D/d_{ii} = D * \mu^l_i$$

Contingency Analysis

The LRIC model needs to work out the post-contingent flows when a single circuit (which may be a single component of a composite line) fails. Since this changes the topology of the network, the LRIC model is not able to recalculate the base_flows for this contingency. However, this is not necessary.

Instead, the security analysis works by adding a paired injection-withdrawal across the start and end nodes of the contingent line and calculates how this adds to the flows on other network elements.

For example, suppose that the contingency is line j and:

F_j is the pre-contingent flow on line j

μ^c_j is the circuit meshedness of a circuit on line j

Pre-contingency, the circuit carries F_j/D MW from node s(j) to node e(j). Post-contingency, that flow must still be carried between the two nodes, since otherwise there would be a shortfall or surplus at these nodes. Since a circuit on line j has failed, the extra flow must be carried across the rest of the network. This flow will be spread across network elements according to the distribution factors discussed above.

In the network model, if an injection/withdrawal P is added across the start and end nodes of line j, then P/μ^c_j will flow through a circuit of line j and $P \times (1-1/\mu^c_j)$ will flow along other network paths: including any remaining circuits on line j. We want to find the flows when F/D flows across other network paths. Therefore:

$$F/D = P \times (1-1/\mu^c_j)$$

$$P = F/D \times \mu^c_j /(\mu^c_j -1) \equiv F \times v_j$$

Where

$$v_j \equiv 1/D \times \mu^c_j /(\mu^c_j -1)$$ (v is the greek letter "nu", which is the one after μ)

This flow is distributed according to the distribution factors defined above

extra, post-contingent flow on line i = $d_{ij} \times F_j \times v_j$

Giving a total post-contingent flow as:

$$H_{ij} = F_i + d_{ij} \times F_j \times v_j$$

Where:

H_{ij} is the flow on line i following an outage on an element of line j

Self-contingency

This formula is not correct in the case of a self-contingency where i=j. In this case, two adjustments must be made:

- the pre-contingent flow F_j/D on a circuit of line j is lost and so must be subtracted from the post-contingent flow;
- since the admittance of the composite line j is reduced by a factor (D-1)/D, the redistributed flow through that line will reduce by a corresponding amount

Therefore, in this special case:

$$H_{ii} = (D_i-1)/D_i \times F_i + (D_i-1)/D_i \times d_{ii} \times F_i \times v_i$$

$$= (D_i-1)/D_i \times \{F_i + d_{ii} \times F_j \times v_i\}$$

If line i is not duplicated (D=1), obviously the post contingent flow H_{ii} is zero.

Contingency on a Radial Line

If line i is radial, then, d_{ii}=1, μ^c_i=D and so v_i =1/(D-1). If D=1 then v is undefined. A contingency on an unduplicated, radial line will split the network into two islands, for which there is no power flow solution. Therefore contingent flows cannot be calculated in this situation. This situation can be ignored for the purposes of LRIC modelling, since such a situation should never arise under system normal conditions. (In the spreadsheet, μ is set equal to zero in this situation and so the security adjustment is based on the pre-contingent flow)

If the line is radial and composite (D>1) then the self-contingency formula is:

$$H_{ii} = (D_i-1)/D_i \times \{F_i + d_{ii} \times F_i \times v_i\}$$

$$= (D-1)/D \times F \times (1 + 1/(D-1))$$

$$= (D-1)/D \times F \times D/(D-1) = F$$

This is intuitively obvious. If the line is radial, the power has nowhere else to go and so must continue to flow through line i.