2nd December 2014

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Lodged Electronically: www.aemc.gov.au Reference EPR0039

Dear Richard

OPTIONAL FIRM ACCESS – PROTOTYPE PRICING MODEL

The AEMC has released its Supplementary Report on Optional Firm Access, Design and Testing and the associated prototype pricing model. The attached report sets out the results of applying the prototype model to a small number of test cases with reference to the NSW region. Some observations on the operation of the model and some suggestions for improvement are provided. The main observations are:

- The approach to the modelling of the generation dispatch pattern can lead to a distortion of the normal power flows in the Sydney area 132kV system, which may impact on the calculated LRIC (Section 1).

- The LRIC calculation is dependent on the assumed generation dispatch (Section 2). It may be necessary to modify the dispatch pattern to ensure that the loading on the main transmission system reflects the levels of loading that may be expected to drive the need for future augmentations.

- The model's stylised methodology may result in a set of network augmentations that may differ from those of a traditional transmission planning approach (Section 3). In some cases the planning augmentation may lead to a lower LRIC but in others it may yield a higher LRIC.

With respect to the first of these observations, there are a range of options to improve the pricing model, as discussed in Section 1.

With the second of these, changes to the input data may adequately resolve the issue. There may remain however a difference between the pricing model, which adopts a stylised methodology, and a traditional planning approach.

The third issue may be able to be resolved in some situations by using a selected range of augmentations rather than the line duplication approach in the pricing model.

Further comments on the pricing model and data are provided in the following areas:

- The network model (Section 4);
- Line and transformer costs (Section 5);
- Line ratings (Section 6);
- The application of "Continuous" and "Short Time" ratings (Section 7);
- Fault level constraints (Section 8);
- The inclusion of stability constraints (Section 9); and
- The power flow solution and user interface (Section 10).

I trust that these results, suggestions and comments are of assistance in the further development of the prototype pricing model. If you have any questions regarding this information please contact me at fam_parker@bigpond.com.

Yours sincerely

C J Parker

Dr Col Parker

OPTIONAL FIRM ACCESS – PROTYPE PRICING MODEL - OBSERVATIONS

1. POWER FLOW IMPACTS OF THE GENERATION DISPATCH

The pricing model applies a generation dispatch, determined by the total of generator access quantities, to a regional demand which is derived from a load forecast. The AEMC has provided the access quantities and the total of these in NSW exceeds the regional forecast demand. For the purpose of solving a load flow the pricing model balances this excess generation by placing an additional load at the reference node. This section examines the impact of the additional load on the LRIC for a hypothetical new southern NSW generator.

The impact of the generation dispatch has been examined by assessing the power flows and LRIC for a 400MW generator at Gullen Range (bus 2GUL330) on the 330kV line between Yass and Bannaby. The pricing model calculates the LRIC as $126.1/kW or $50.5M.

In the AEMC dataset the total of the generation input (the total of the generator access quantities) in the base case is 14795MW[1]. The total regional load for 2014 in the load forecast is 12574MW[2]. The excess of generation over load in the region is therefore about 2220MW. In the power flow model used by the pricing model this difference is represented by an additional load at the reference (or slack) node, which in the case provided is at the Sydney West 132kV bus.

The regional losses, which might amount to the order of 500MW at this load level, are ignored.

There is also no industrial load in the forecast provided. TransGrid forecasts a total industrial load of 980MW[3]. This would normally be allocated at the industrial load buses, in particular at Tomago, but in the load flow model it is effectively represented by part of the excess load that has been placed at the reference node. In reality the major Tomago smelter load is located between the Hunter Valley power stations and the Central Coast power stations and hence imposes a load on the network in these areas but does not load the network south of the Central Coast. By imposing this additional load at Sydney West the loading on the 330kV system into Sydney is increased, which would advance any network augmentations to the Sydney area.

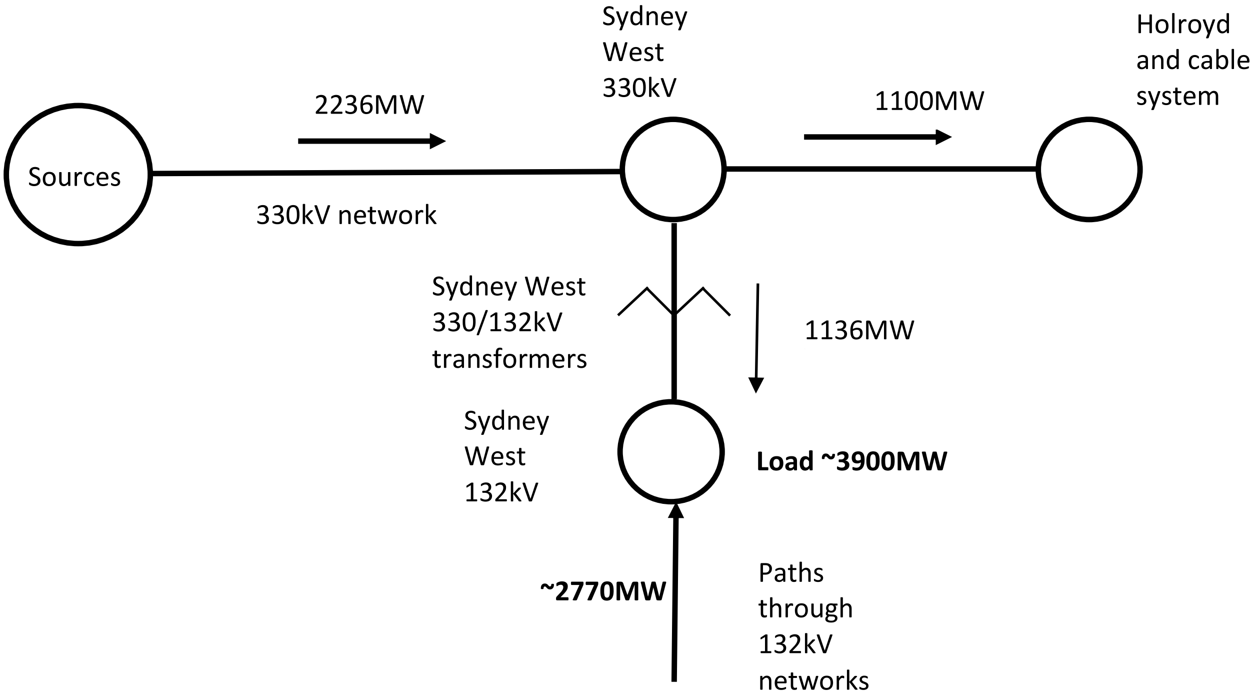
When the Gullen Range 400MW generator is added an additional 400MW load is also placed at the Sydney West 132kV bus.

The following figure illustrates approximately the resulting power flows around the Sydney West 132kV bus at the start of the study period. There are a number of 330kV lines supplying Sydney West and there are also 330kV lines to the Holroyd bus which supplies the new 330kV underground cable system at Rookwood.

[1] AEMC results spreadsheet – “access” page.

[2] AEMC Demand Forecast spreadsheet

[3] TransGrid Transmission Annual Planning Report 2014 page 125.



The load at the Sydney West 132kV bus is made up of:

Forecast load at the bus	1284MW
Difference between total access and demand	2220MW
Additional Gullen Range generation	400MW
Total	about 3900MW

Under system normal conditions the demand at the Sydney West 132kV bus (and the connected 132kV substations) would be supplied by the Sydney West 330/132kV transformers. The power flow through the transformers at the time of peak load would exceed the forecast bus load and may approach the firm rating of the five Sydney West transformers, which the AEMC indicate as 1500MW[4]. In practice the power flow in the 132kV system connected at Sydney West is expected to be in a direction away from the Sydney West 132kV bus rather than towards it as shown in the above figure.

Hence in the LRIC model a large part of the 3900MW load is supplied through the 132kV system from other 330/132kV substations in the greater Sydney area. There are a number of parallel 132kV paths from the 330/132kV substations at Holroyd, Regentville, Liverpool and Macarthur. There are also 132kV paths from the inner Sydney 132kV cable network. The additional load that has been placed on these 132kV networks, as a result of the excess generation, can lead to a need for augmentation in the 132kV networks.

[4] The AEMC spreadsheet "aemc-lines" shows five transformers each rated at 375MVA, giving a firm rating (allowing for one transformer outage) of 1500MVA.

This may account for the major components of the overall LRIC of $50.5M for the Gullen Range generator, which are broadly:

Area of the network augmented	**Approximate contribution $M**
132kV network around Sydney	27
Sydney area 330/132kV transformers	4
Sydney 330kV cables	1
Wallerawang 132kV system	12
Gunning Wind farm 132kV system (near Gullen Range)	2

In this case study there are no augmentations to the direct 330kV transmission path from Gullen Range to the reference node. There were some augmentations related to the Gunning Wind farm area which is connected to a parallel 132kV path in the Gullen Range area.

The calculated LRIC for Gullen Range is dominated by costs in the Sydney area of the network and hence does not reflect the cost for advancing works on the transmission path from Gullen Range to the reference node.

It should be noted that the cost of the Sydney 330kV cable augmentation and some 132kV augmentations in the dataset may be significantly underestimated due to the need for improved cost estimates for cable development. If the high costs of cable augmentations were captured in the dataset then the LRIC for Gullen Range would be more heavily dominated by Sydney area works.

In practice whilst a new 400MW generator in the south could lead to the advancement of some 330kV and 132kV augmentations in the Sydney area it is expected that these would be relatively minor.

One approach to resolving this issue for Gullen Range may be to ignore any excessive loadings in the Sydney area 132kV network and 330kV cable network and limit the LRIC model to the main transmission path from the generator to the reference node. As a test of this approach the Sydney area 132kV network limitations were removed by bypassing various parts of this network using some pseudo connections. The following were the outcomes:

Gullen Range Access MW	**Original LRIC calculation $/kW**	**Modified LRIC calculation $/kW**
200	115.1	18.4
400	126.1	13.5
600	123.6	11.8
800	134.3	34.5
1000	132.7	41.5

For a 400MW access the LRIC was $13.5/kW or about $5.5M with the following main components:

Area of the network augmented	**Approximate contribution $M**
132kV network around Sydney	Now zero
Sydney area 330/132kV transformers	Near zero
Sydney 330kV cables	Now zero
Eraring – Vales Pt 330kV	0.2
Gunnedah area	0.2
Muswellbrook – Kurri area 132kV	3
Mt Piper 330/132kV transformer	0.1
Gunning Wind farm 132kV system (near Gullen Range)	2

Some of the contributions above need to be further investigated. The Eraring – Vales Pt area, Gunnedah area and Muswellbrook area are geographically and electrically remote from Gullen Range and hence their contributions to the LRIC would still seem to be as a result of the generation dispatch.

1.1 Opportunities to Improve the Model

There are a number of options that might be considered for better matching the total generation and load and for limiting the impact of the 132kV networks:

- The region's industrial load could be broadly estimated from public sources and appropriately located, based on publicly available information. An approximate distribution of the load would improve the accuracy of line power flows in the model.
- Represent the losses on the system by either increasing the loads or scaling back the generation. Perhaps the generator and load Marginal Loss Factors could provide a guide.
- Distribute any excess generation amongst some major Sydney 330kV buses which are close to the reference node. This would lower the flows in parallel 132kV networks.
- Bypass the 132kV networks (such as by using pseudo connections as above) or remove the 132kV networks altogether.

These options could be readily tested with modifications to the data for the pricing model.

2. IMPACT OF THE GENERATION DISPATCH

The planning for future augmentations to the NSW main system are based around expected patterns of power flow in the network which are dependent on assumed generation dispatch patterns[5]. The assumed generation patterns are intended to reflect the types of patterns that would be experienced over peak load periods.

Broadly the pricing model sets the output of each existing generator according to the specified access quantities. Hence the LRIC is determined for one particular generator dispatch pattern.

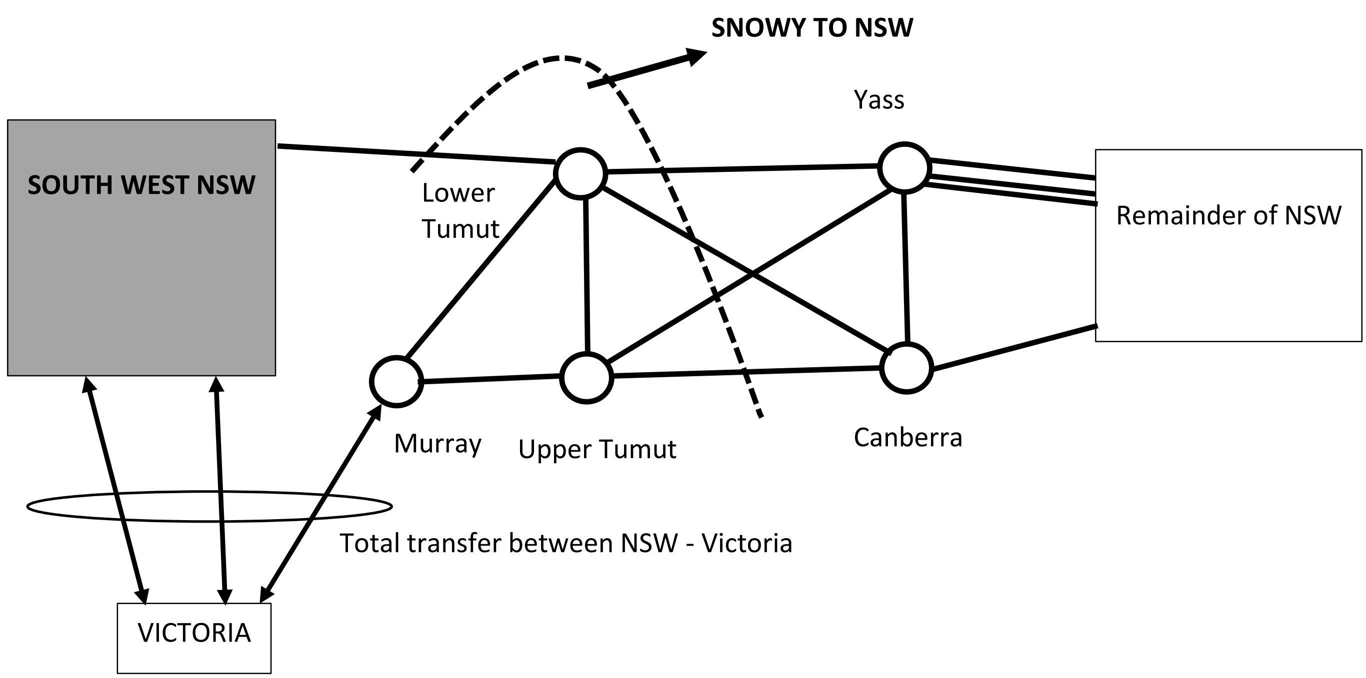
[5] TransGrid Transmission Annual Report 2014 Appendix 1.

This section covers the following:

- The power flows in the Snowy to NSW network;
- An investigation into the impact of modifying the pricing model generation dispatch on the LRIC for a hypothetical new southern NSW generator;
- Some comments on the implications of the assumed generation dispatch for other parts of the NSW system;
- Some comments on the impact on wind farms; and
- Some opportunities for improvement of the model.

2.1 <u>Snowy to NSW system loading</u>

The Snowy power stations together with power flow over the interconnections with Victoria supply south west NSW, with the remainder flowing on to the NSW system at Yass and Canberra, as shown below. The flow “Snowy to NSW” in the figure significantly loads the lines between the Snowy power stations and Yass / Canberra and further loads the lines between Yass / Canberra and the remainder of the NSW system. In the past the ratings of the Snowy to Yass / Canberra lines have constrained power flow from Snowy at times of peak load.



The pricing model results show the Snowy to NSW power flow (for the case study of Section 1) for 2014:

Pricing Model - Case of Section 1	**Past peak power transfers**[6]
1085MW	Above 2500MW

Hence the pricing model dispatch pattern does not load the southern system to the levels experienced at times of peak load.

The reasons for the low loading in the pricing model include:

- The dispatch of generation at Upper Tumut and Lower Tumut, noting that Uranquinty generation (embedded in south west NSW) is operating at a reasonable output.
- The modelling of Murray generation. Murray is treated as within the Victorian region with no power flow to the Snowy stations.
- The absence of interconnection power flows.

The AEMC has indicated that they are considering the inclusion of interconnection power flows.

The high power flows from Snowy to NSW become important when modelling the impact of southern NSW generators.

<u>LRIC Outcomes for a Southern NSW Generator</u>

A new 1000MW generator at Gullen Range is assumed. The total generation in NSW varies from 15595 at the start of the modelling period to 16957 by 2023[7]. The regional demand is 3072 less than the generation in 2013, with this excess reducing to 2297 by 2023.

Two cases are considered:

- A basic pricing model study with the generation dispatch as determined by the AEMC data provided; and
- A modified generation dispatch with the excess generation largely removed. The outputs of Liddell, Wallerawang and Vales Pt are reduced by 1000MW, 500MW and 660MW respectively. The quantum of changes to these generator outputs are for the purpose of illustration only.

The reason for selecting the Liddell, Wallerawang and Vales Pt power stations is that they are north and west of the reference node whereas Gullen Range is in the south. This makes them electrically remote from Gullen Range and they don't strongly share common transmission paths to the reference node.

[6] Snowy to NSW power transfers are described in the TransGrid's Transmission Annual Planning Report 2014 page 84 and page 138.

[7] "Access" spreadsheet

The following LRIC values resulted[8]:

Access	Basic study per AEMC data $/kW	Modified generation dispatch $/kW
200	18.4	10.4
400	13.5	52.4
600	11.8	48.4
800	34.5	50.2
1000	41.5	65.6

For a 1000MW generator the total LRIC values are as shown below:

Basic study	Modified dispatch
$41.5M	$65.6M

Some of the main components of the LRIC are[9]:

	Basic LRIC study $M	Modified dispatch LRIC study $M
Bannaby – Gullen Range 330kV	26.5 (augmented in 2018)	27.5 (augmented in 2015)
Bannaby – Sydney West 330kV	Not required	17.8 (augmented in 2022)
Gunning Wind Farm 132kV system	4.9	5.2
Muswellbrook – Newcastle area 132kV systems	7.5	0.4

In the basic study the 1000MW generator forces the installation of a new line from the power station to Bannaby, but no other augmentations to the main 330kV transmission paths to Sydney are required. The modified dispatch results in an advancement of the reinforcement to Bannaby and a new line from Bannaby to Sydney West.

The change to the generation dispatch increased the power flow north of the Snowy and Yass / Canberra areas. This increased the Bannaby to Sydney West line loading. The increased power flows were sufficient to advance the Bannaby – Gullen Range line and require a new Bannaby – Sydney West line.

For example, the Snowy to NSW power transfer and Bannaby – Sydney West line loading in 2021 (the year before the Bannaby – Sydney West line augmentation in the modified dispatch study) were[10]:

[8] In each study the 132kV networks in the Sydney area were bypassed, as discussed in Section 1, to remove their influence on the LRIC.

[9] There appear to be some anomalies in the components that have not been further investigated. Some western Sydney 132kV lines and a Cowra – Forbes 132kV line are involved.

[10] Sheet "adj_baseflow" of the results sreadsheet

	Basic LRIC study	**Modified dispatch LRIC study**
Snowy to NSW	1240	1350
Bannaby – Sydney West line loading	820	930

2.2 Other Parts of the NSW System

The power flows in other parts of the NSW system are also affected by the generation dispatch. Some examples are set out below.

A. Hunter Valley and northern system

The power flow south of the Hunter Valley and any future need for augmentation are governed by:

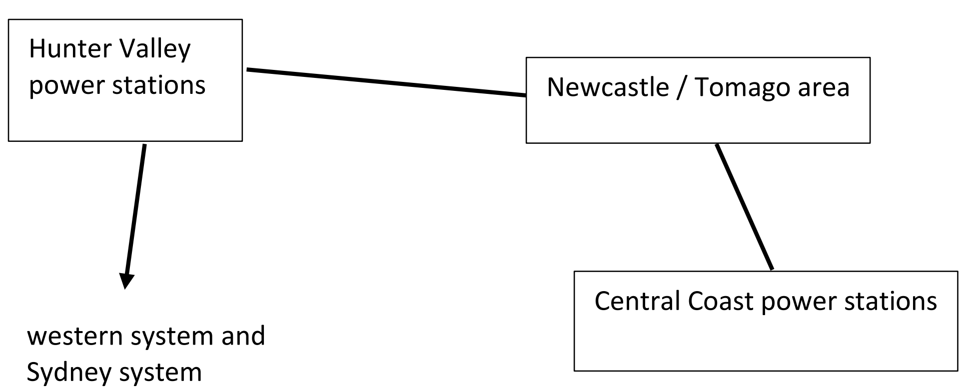
- The output of the Hunter Valley power stations - Bayswater, Liddell and Redbank;
- The power transfers over QNI;
- The load north of the Hunter Valley; and
- The development of northern power stations.

It would be necessary to model the QNI power flows in particular when calculating the LRIC for a new generator in the Hunter Valley area.

The power flows over QNI also significantly affect the power flows in the 330kV system in the Armidale and Tamworth areas. The augmentation works to connect new generation north of the Hunter Valley will need to take QNI power flow conditions into account.

B. Hunter Valley – Central Coast system

The Hunter Valley to Central Coast system is shown below.



The power flow between the Hunter Valley and the Newcastle area tends to increase as a result of:

- Increased Hunter Valley generation, or increased generation further north;
- Increased load in the Newcaslte area, including the Tomago smelter load; or
- Reduced generation in the Central Coast

Hence it is necessary to ensure that appropriate dispatch patterns are examined. For example if a new generator was to be connected in the north then a planning study might examine whether the new generator might displace say a Central Coast generator and increase the power flow on the lines from the Hunter Valley to Newcastle. The LRIC study might instead allow for all of the generators to be operating at their access values. Hence there may be a disjoint between the LRIC study and a planning study.

C. Connections between Power Stations

This latter situation extends to the connection between nearby generators. There are a number of closely connected power stations in NSW, for example Bayswater and Liddell. The power flow between the two power stations increases if the output of one power station is increased relative to the other. Hence in a planning study various dispatch patterns might be considered in testing the need for an augmentation between the power stations. The LRIC study might not show the need for augmentation if all generators are set at their access levels.

<u>Augmentations Associated with Wind Farms and Other Renewables</u>

A planning study associated with wind farms or other intermittent generators would normally take into account the correlation of the output of the renewable generation with the peak power flows in parts of the system. Hence in a planning study the augmentations required for a wind farm could be different to those for say a gas turbine installation.

In the above case for a new 400MW generator at Gullen Range it may be the case that there would be a low probability that the peak output of a wind farm at the site would correlate with a high output from Snowy. Hence in a planning study a new 330kV line from Gullen Range to Bannaby or from Bannaby to Sydney may not be required and there may be a very low risk of constraining southern generation. A different finding might result for a gas turbine installation.

The LRIC study is based on generator access quantities and hence would not differentiate between traditional and renewable generation. All the generation would be dispatched according to the access requirements.

Hence if a LRIC study is carried out for a new renewable generator it seems still necessary to determine if it is really necessary for the LRIC to be paid or for augmentation works to be undertaken.

<u>Options for Modifying the Dispatch in the Pricing Model</u>

There is a disconnect between the types of generation patterns considered in a planning study and the stylised approach of the LRIC pricing model. The pricing model may not fully stress the system whereas a planning approach would cover a greater range of system loadings but possibly not all conditions.

Consideration could be given to the following options relating to the dispatch of generation in the pricing model.

- Interconnector flows could be included. One option would be to base these on historical peak flows that correlate with the access levels of the generators.

- The network connections to Murray and a suitable access quantity for Murray could be included in the model.

- In order to test the need for network augmentations it would be possible to adopt generation dispatch patterns that reflect historical peak load conditions. A high power flow from the north towards Sydney and a high power flow from the south towards Sydney are two patterns that could be considered. For the high power flow from the north the northern generators could be loaded to their access levels and for a high power flow from the south the southern generators could be loaded to their respective access levels. Consideration could be given to averaging the resulting LRIC outcomes or adopting the larger of the outcomes.

  The testing of a range of dispatch patterns may however end up more like a planning type of study than an LRIC calculation.

- If the proponent of a renewable generator was interested in the impact of their intermittent generation on the LRIC value the pricing model could be used to dispatch them at various de-rated levels. For example a wind farm might only expect to operate at say 5% of its output when other generators in the area are operating near their access levels. Hence the LRIC model could have a user defined level of de-rating for each access quantity.

  The pricing model already provides LRIC values for a range of access quantities, as defined by the user, and perhaps the AEMC might consider that this capability is already available.

3. NETWORK AUGMENTATION OUTCOMES OF THE MODEL

The stylised methodology of the pricing model effectively duplicates a line when it is seen to overload. The pricing model thus tends to create multiple lines between nodes. Given a need for network augmentation traditional transmission planning generally involves the testing of various options, which may not necessarily involve line duplication. A planning study may identify other options, including:

- network augmentations in other parts of the system;
- selection of different line types, such as developing higher rated lines;
- replacement of an overloaded line by a higher rated line or a double circuit line, depending how difficult it would be to acquire an easement;
- moving to a higher voltage, for example supporting a 132kV system with a 330kV development; or
- power flow control to better balance line loadings.

The pricing model may identify the need for augmentations to the Sydney area 330kV and 132kV cable network. The forward planning for reinforcements to the Sydney area cable network is a complicated matter. There are many constraints on cable developments and it is not credible to assume that a cable can be duplicated to resolve an overload. Some options to address this are:

- Leave the cable network out of the model data and connect the related loads to the outdoor Sydney substations at Sydney South, Sydney North and Sydney West; or

- Use a small number of predefined large scale augmentations to relieve overloads.

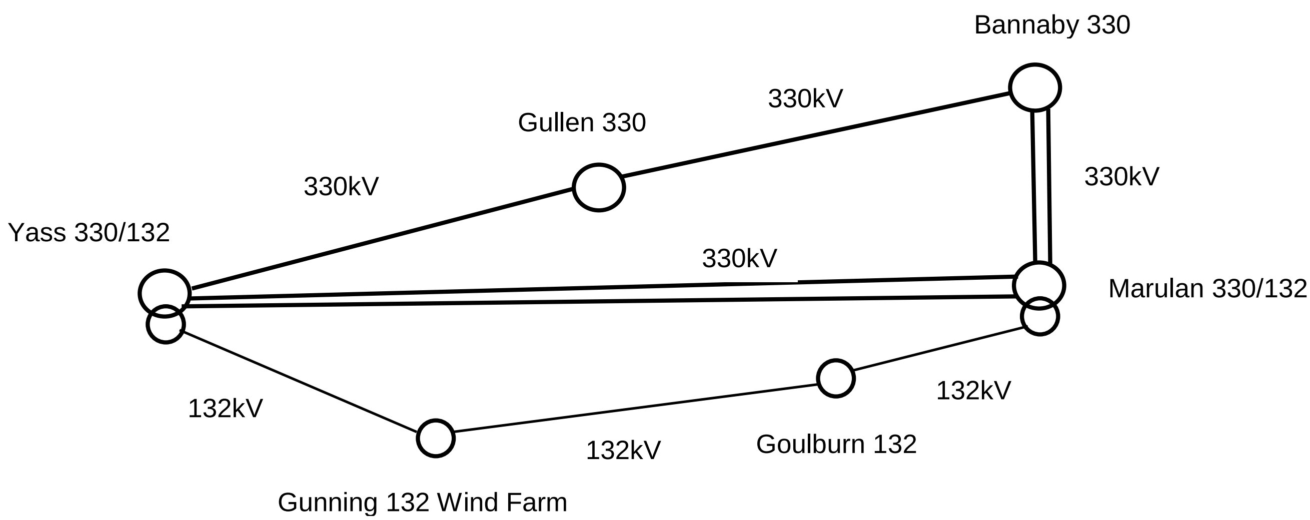
This section compares, for three cases, the outcomes of the model to what a transmission planner might consider feasible. In all cases it is assumed that only line augmentations would be undertaken.

The cases are:

1. Gunning Wind farm – augmentation of the 132kV network in the area.
2. Reinforcement of the network between the Bannaby area and Sydney
3. Reinforcement of the Snowy to NSW power transfer capability

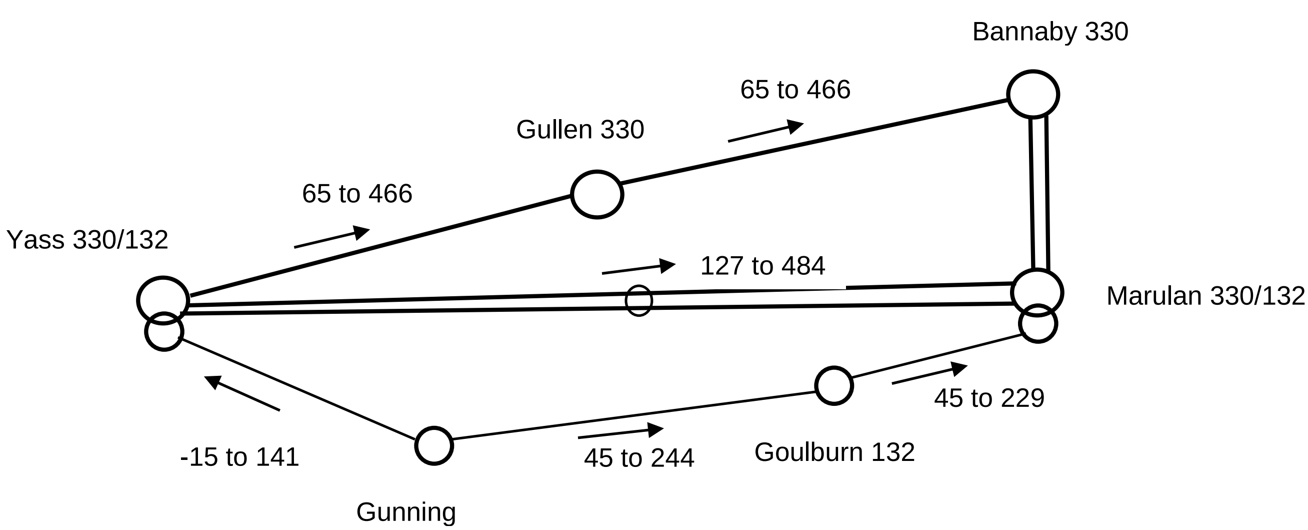
CASE 1: YASS - GUNNING – GOULBURN – MARULAN 132kV NETWORK

In the AEMC network model the Yass – Gunning – Goulburn – Marulan 132kV network parallels the main 330kV network between Yass and Marulan / Bannaby, as shown below:



The output of the Gunning Wind Farm commences at about 30MW at the start of the study in 2013 and rises to about 80MW by 2030.

In the absence of any generation at Gullen Range, the pricing model produces the base power flow as shown below. The power flows are for 2013 and 2030.

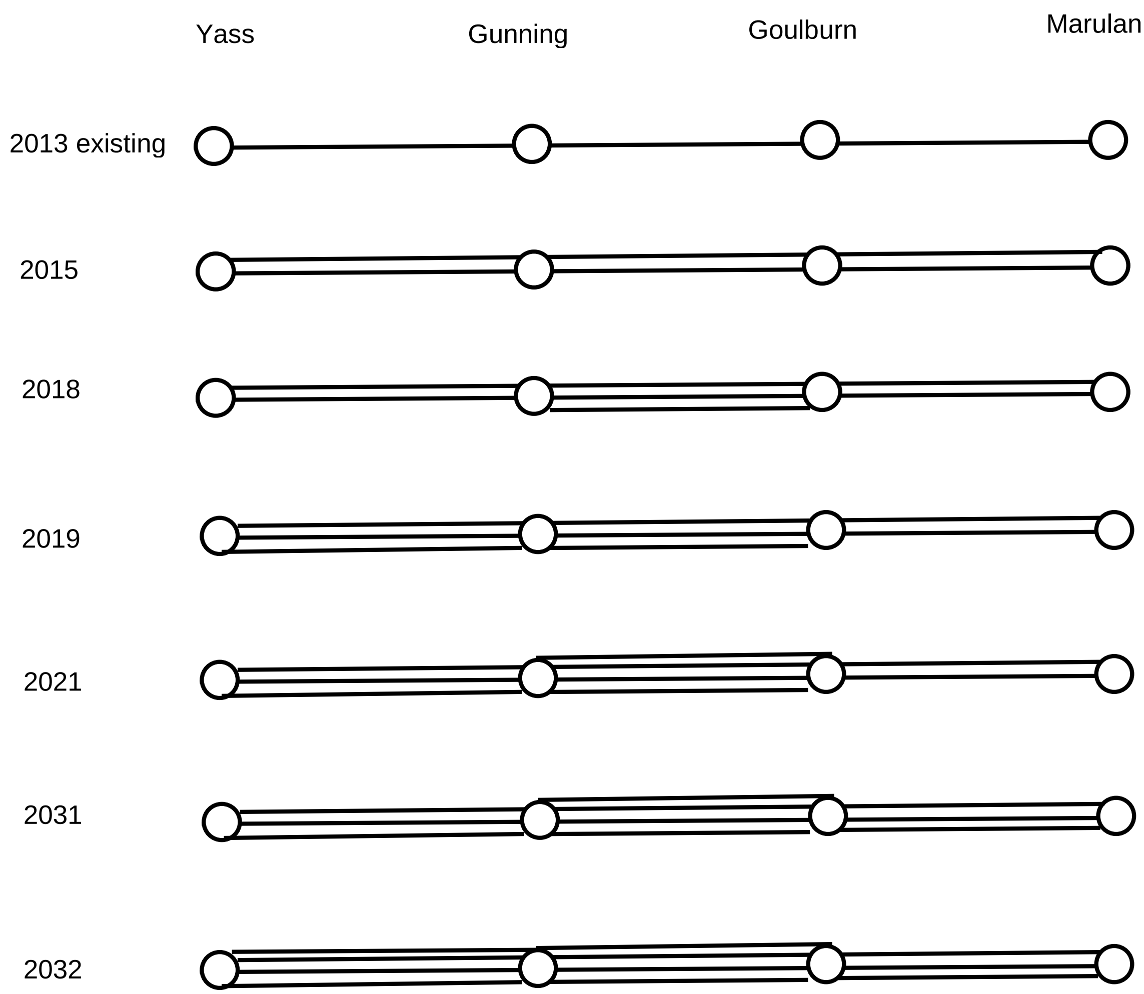


The 132kV lines have the following ratings:

	Continuous	Short Time
Yass - Gunning	97	106
Gunning - Goulburn	97	106
Goulburn - Marulan	183	183

It is clear that there is insufficient 132kV line capability, both under normal system conditions and following the outage of a parallel 330kV line.

The pricing model determined the following 132kV augmentations:



Hence over about 16 years the model has added 8 new circuits. Part of the reason for this number of circuits was the selection of relatively low-rated line augmentations that then overloaded in subsequent years.

If a new generator is assumed at Gullen Range, with an access requirement of 400MW, the pricing model makes some minor changes to the above augmentation pattern. This is a result of the changes to the power flows in the parallel 330kV and 132kV networks. In this case Gullen Range would attract about a $2M LRIC due to the 132kV network, out of a total LRIC of about $50M.

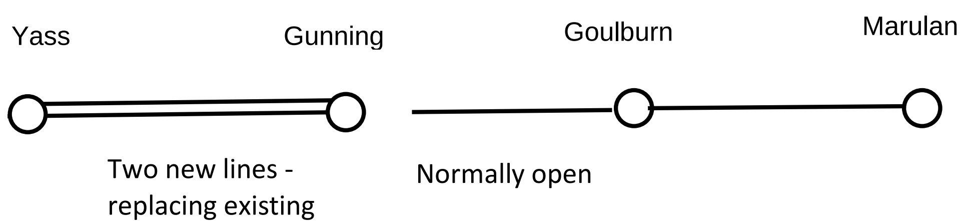
The construction of 8 new circuits in this system is probably not feasible. There would be environmental issues and access to the substations may be an impediment.

A transmission planner might develop other options such as those below. These options have not been fully tested but provide an indication of what may be possible.

<u>Planning Option 1</u>

If firm supply is not required for Goulburn, it may be possible to augment the network with two new 132kV circuits connecting Gunning and Yass (probably replacing the existing low rated line) together with opening of the Gunning – Goulburn line.

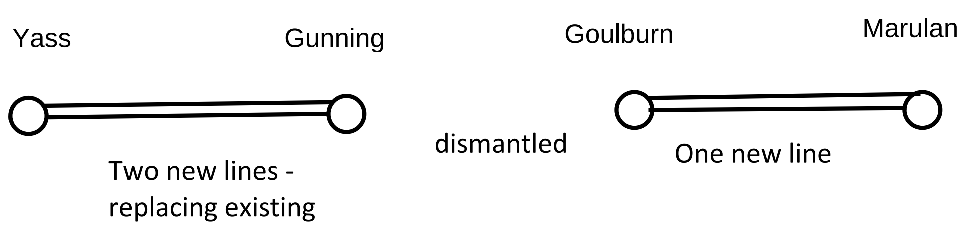
The purpose of opening the 132kV line is to remove the impact of high power flows following the outage of a parallel 330kV line. The open line would operate on a change-over scheme such that on outage of the Marulan – Goulburn line the normally open circuit would be closed with Goulburn then supplied from Gunning. The changeover could be automatic. The new lines could be two single circuit lines or a double circuit line.



One of the new Gunning – Yass lines may be able to be avoided if the Gunning WF does not require firm supply, ie. can tolerate brief unplanned outages of the line.

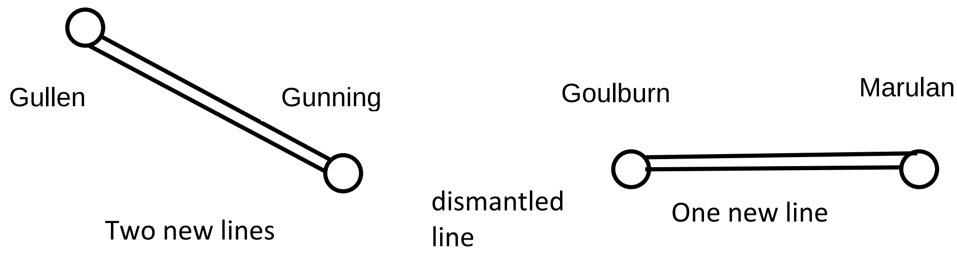
<u>Planning Option 2</u>

To provide firm supply to Goulburn a second low-rated line could be constructed from Marulan to Goulburn. The Gunning – Goulburn line may be dismantled.



Planning Option 3

There may be an option to connect Gunning to Gullen Range using a new double circuit line, instead of to Yass, as shown below. A new 330/132kV transformer would need to be developed at Gullen Range. The Yass – Gunning 132kV line could also be dismantled.



This option may be dearer than the others but would need to be considered in determining the optimal environmental line solution.

There are no doubt a number of other possible options that would need to be explored.

Each of the planning options would reduce the LRIC for Gullen to a small degree (less than $2M of the total $50M).

The stylised methodology of the pricing model may therefore lead to a proliferation of lines whenever an overloaded line is augmented by another line in parallel of the same capacity and whenever there is a transmission path with relatively low-rated lines.

There are a few avenues to consider in improving this outcome:

1. Where multiple augmentations are required replace these with one or more higher rated lines.

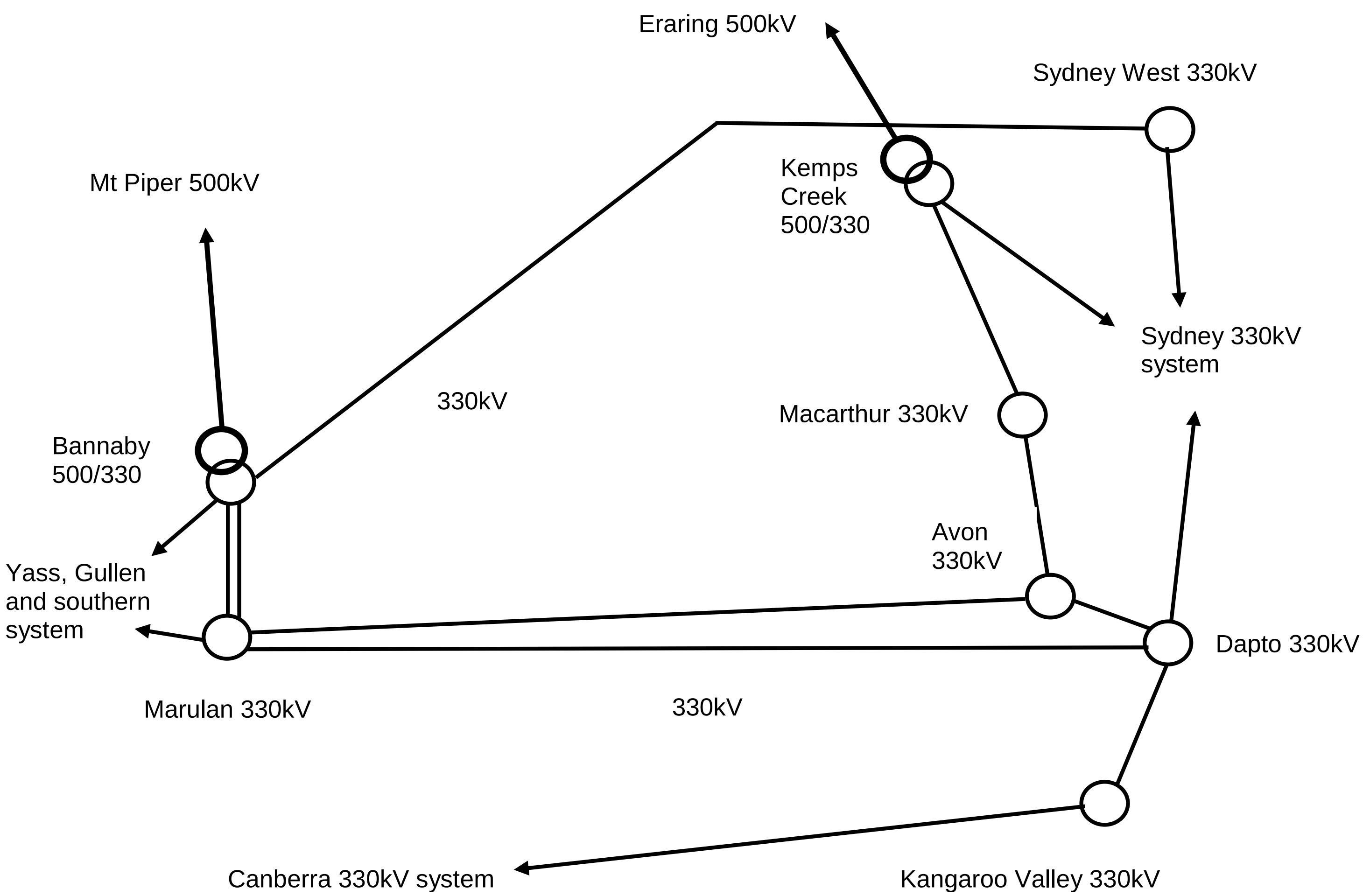
2. Provide the capability for replacement of a line by a higher capacity line, perhaps by identifying a line as relatively low in capacity compared to the ultimate power flow required.

3. Break or remove parallel low voltage network paths so that the LRIC reflects the cost of major augmentations on the major transmission path between the generator and the RRN.

CASE 2 – BANNABY – SYDNEY LINE DEVELOPMENT

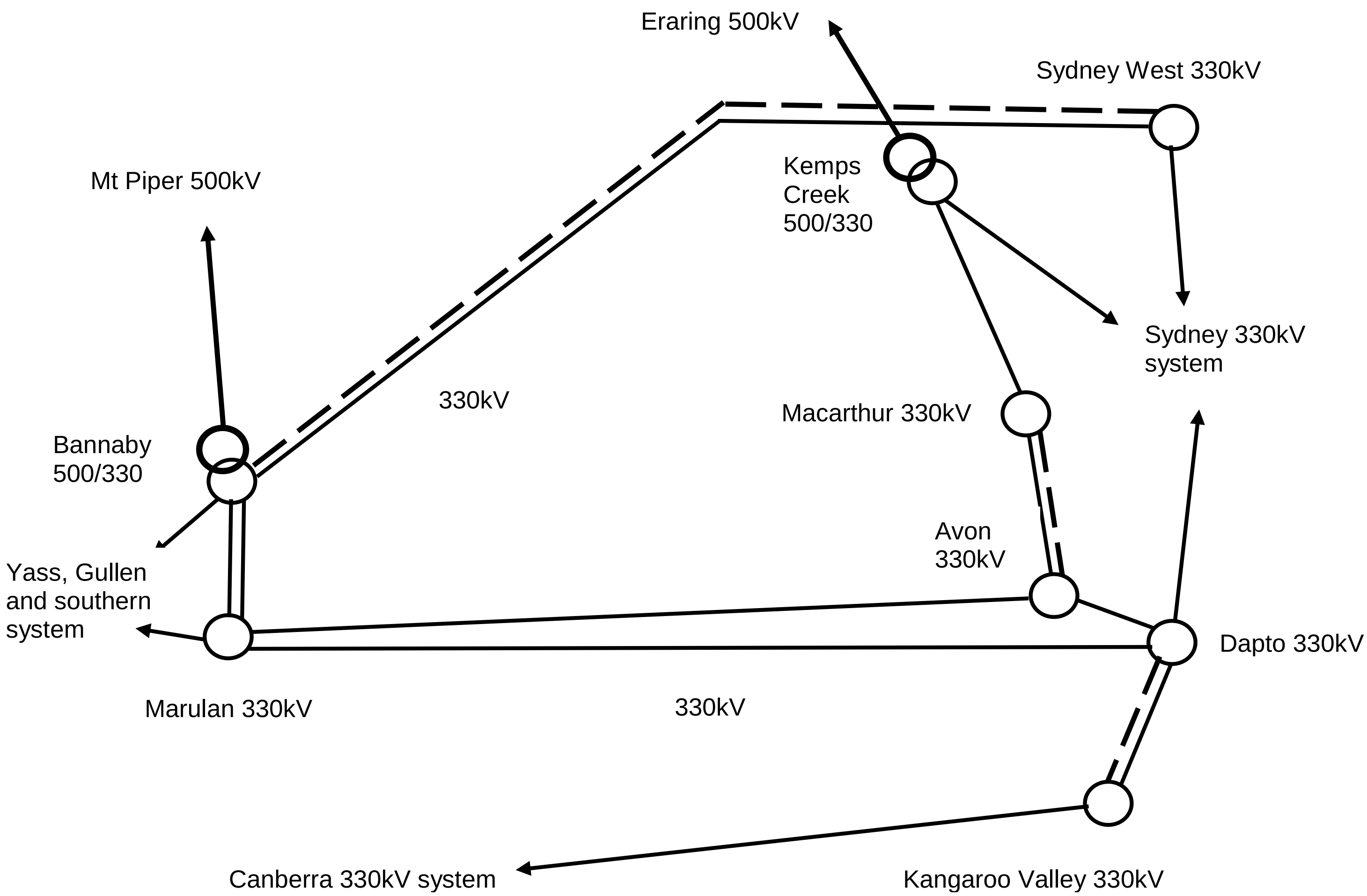
This case considers the access for a 1000MW generator at Yass. It is assumed that a 400MW generator is in service at Gullen Range. The purpose is to stress the network north of Bannaby towards Sydney.

The existing 330kV network in the area north of Bannaby is shown below. With high generation in the south and a 1000MW generator at Yass it would be expected that the network between Bananby and Sydney, and / or between Kangaroo Valley / Dapto and Sydney would need augmentation.



The pricing model indicates the following 330kV augmentations to this system, as shown below.

Year	Issue	Pricing Model Remedy
2023	Bannaby – Sydney West line requires augmentation	Second Bannaby – Sydney 330kV line installed
2025	Kangaroo Valley - Dapto line requires augmentation	Second Kangaroo Valley – Dapto line installed
2032	Avon - Macarthur line requires augmentation	Second Avon – Macarthur line installed

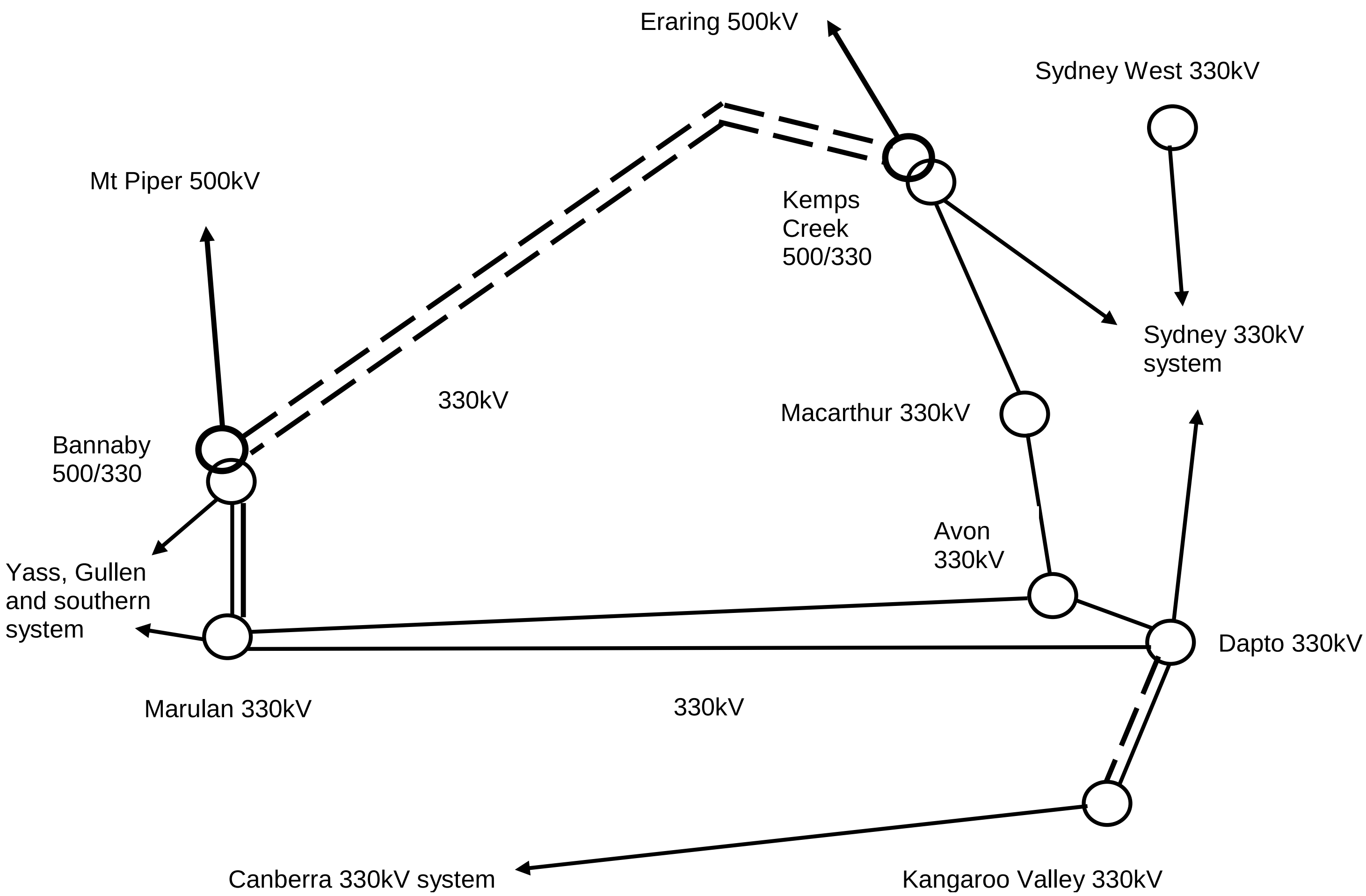


TransGrid has a long term strategy for addressing constraints between the Bannaby area and the Sydney area by rebuilding the Bannaby – Sydney West 330kV line as a 500kV double circuit line, largely on the existing easement[11]. It would be terminated at Bannaby and a 500kV terminal in Sydney. A 500kV double circuit line on the existing easement is preferred due to constraints on the ability to build new lines into the greater Sydney area.

[11] TransGrid Network Development Strategy 2014.

If this network development is adopted instead of the pricing model option the outcome is shown below[12]. The 500kV line has been terminated at Kemps Creek but other options for termination in the Sydney area are possible.

Year	Issue	Remedy
2023	Bannaby – Sydney West line requires augmentation	Bannaby – Kemps Creek double circuit 500kV line installed
2029	Kangaroo Valley - Dapto line requires augmentation	Second Kangaroo Valley – Dapto line installed



[12] Note that the pricing model generation dispatch and other data have been applied in this study to preserve consistency between a pricing model outcome and a planning outcome. In practice a planning study could involve a different set of dispatches and scenarios.

It may also be possible to defer the cost of the 500kV terminations for the new line by initially operating it at 330kV. Fault level constraints in Sydney may need to be resolved in this case. The following is the set of augmentations:

Year	Issue	Remedy
2023	Bannaby – Sydney West line requires augmentation	Bannaby – Sydney double circuit 500kV line, operating at 330kV, installed
2025	Kangaroo Valley - Dapto line requires augmentation	Second Kangaroo Valley – Dapto line installed
2030	Avon - Macarthur line requires augmentation	Second Avon – Macarthur line installed

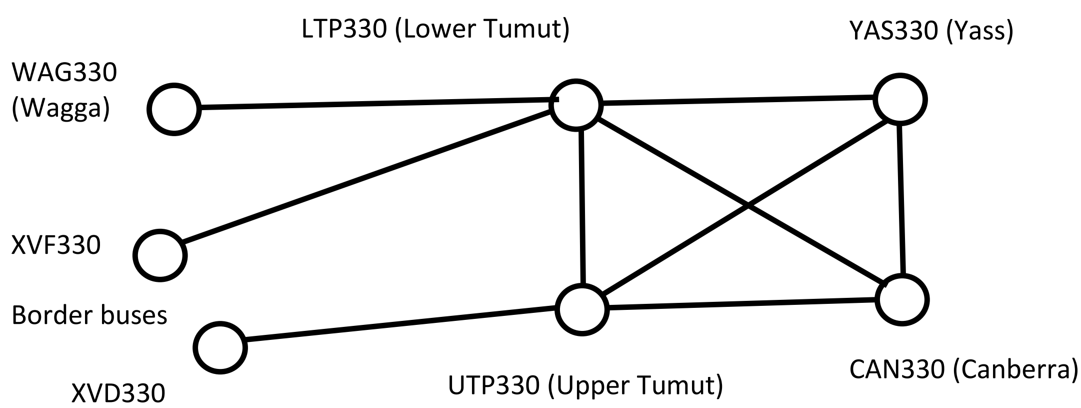
The approximate LRIC for the 3 augmentation options are:

Network development	LRIC
Pricing model developments	$89.9M or $89.9/kW
New 500kV double circuit line	$124M or $124/kW
500kV double circuit line operates at 330kV	$99M or $99/kW

Hence it is possible for a planning approach to yield a higher LRIC, for a given generation dispatch.

CASE 3 – SNOWY 330kV SYSTEM

The 330kV connections in the AEMC data for the Snowy system are shown below:

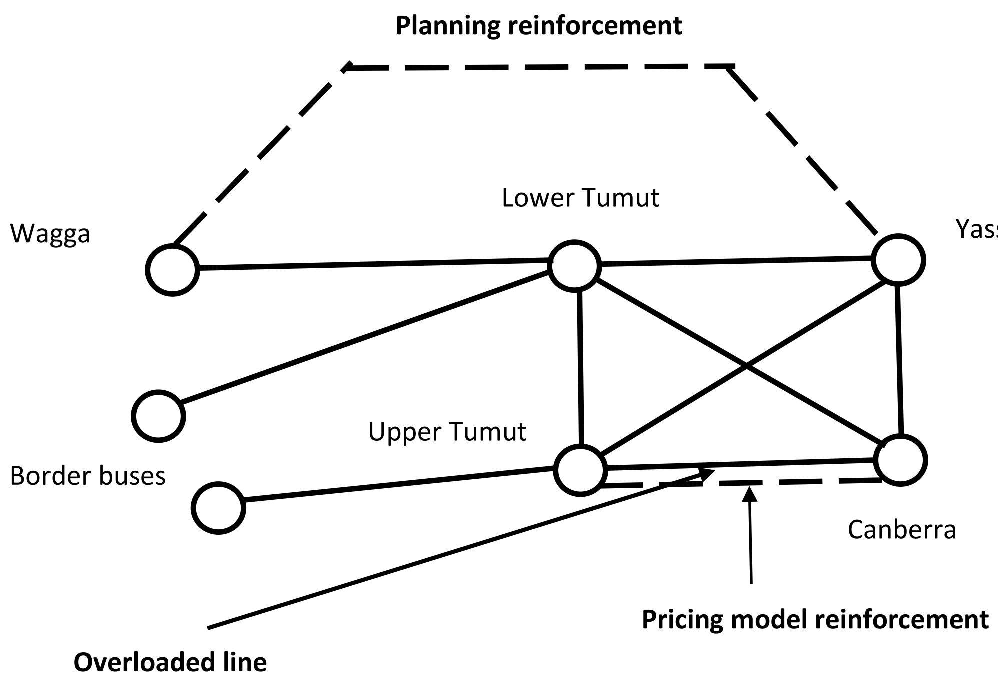


Case 2 is continued with access for a 1000MW generator at Upper Tumut instead of Yass. This is intended to represent an increase in Snowy generation in combination with increased export from Victoria. Owing to the lack of a Murray bus and interconnections to Victoria the pricing model will not provide a reliable LRIC (an issue with the network model rather than the approach) but attention is focused instead on the augmentation selected.

The pricing model identifies an overload of the Upper Tumut – Canberra line and adds a duplicate line with a contribution of $33.7M to the LRIC.

The construction of a new line through the national park in the area is not feasible. An alternative is the construction of a 330kV line from Wagga to Yass, with associated power flow control. The total LRIC would be much higher as a result.

The pricing model augmentation and the possible planning alternative are shown in the figure below.



In such cases as this it may be possible to arrange for a set of feasible reinforcement options to be developed with appropriate costs. The pricing model may be able to be modified to select from the set of feasible options, rather than duplicating the line.

4. NETWORK MODEL AND DATA

This section covers some observations and comments regarding the line data and network configuration used by the pricing model.

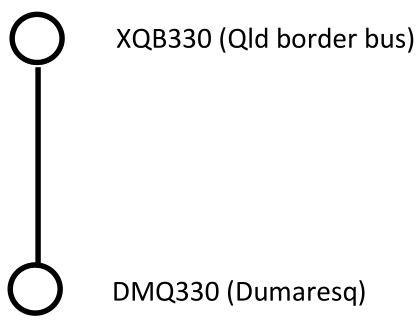
The line electrical characteristic used in the program is the line admittance. This is stated as being the inverse of reactance (page 10 of the User Guide). Lines are treated as lossless hence to allow continued checking of the data could the AEMC please clarify if the line admittance quoted is the inverse of the reactance or the magnitude of the inverse of the complex impedance.

It would be preferred to see the line resistance and reactance (on a 100MVA base) to be shown in the dataset. This would facilitate the checking of data against standard system models.

Interconnector Data

The network model, derived from AEMO data, is divided into regions. Hence the connections between NSW and Queensland and between NSW and Victoria and have been represented as below:

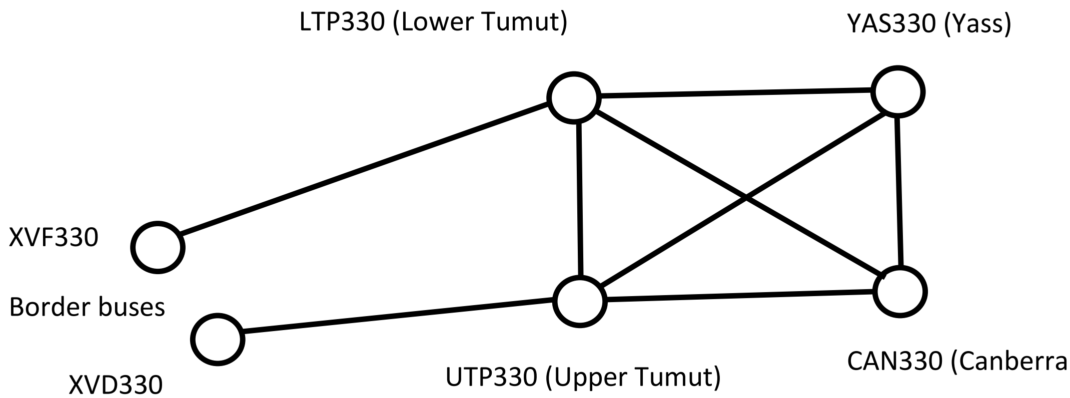
<u>NSW - Queensland</u>



The representation of the Queensland – NSW interconnector is adequate for the LRIC process, providing attention is given to the assumed power transfer across the interconnector, as part of the overall generation dispatch.

<u>NSW – Victoria</u>

The NSW – Victoria 330kV interconnections, via the Snowy system and Jindera, and the western 220kV interconnection are shown below:



Ideally the Murray bus (connected to Upper Tumut and Lower Tumut) and the connections between Murray – Dederang and Wodonga, and connections in the Victorian 220kV network may need to be represented.

The Snowy – Victoria connections may be important in reasonably representing the impact of additional generation in the Snowy – Wagga area.

The development of an LRIC for any new generation in the NSW western 220kV system should take into account power transfers between NSW and Victoria and flows in the Victorian 220kV system.

The AEMC will also need to decide whether the Directlink and Murraylink power transfers are to be represented.

Other Data

The following are some possible data anomalies observed in this investigation:

AEMC-lines	Bayswater – Mt Piper 500kV line: there is 1 circuit, the dataset has 3 Bannaby – Marulan 330kV – these are 500kV lines operating at 330kV and have a high conductor rating – see discussion in Section 6.
AEMC-access	The generation at Bayswater and Eraring is connected to the 330kV buses but needs to be distributed across the 500kV and 330kV buses.
Demand forecast	Load data for a number of 132kV nodes seems to be missing. Perhaps the loads are represented at nearby buses.

5. LINE AND TRANSFORMER COST DATA

The AEMC has noted the possible need for improvements to the line/transformer cost data. The following are some comments:

500kV line	In NSW there is a preference for the construction of double circuit 500kV lines for various reasons including maximizing the use of an easement and to avoid the proliferation of lines. The rating of each circuit is in the order of 3500MVA (continuous) to 4500MVA (emergency).[13] The AEMC data quotes for a 4250MW line a cost of $400/MWkm, implying $1.7M per km for a line rated at 3500MVA. This is for one circuit only. This cost seems lower than for a double circuit line but if doubled seems too high for a double circuit line. Data is also provided for a 7000MW line, which presumably is a double circuit line. With a cost of $240/MW/km this implies $1.68M per km which seems low.
330kV line	Single circuit lines in NSW tend to be rated from the order 1000MVA to 1500MVA. The AEMC data indicates $480/MWkm for a 1450MW line. A 1000MVA line would thus cost $0.48M/km and a 1500MW line about $0.64M/km per km. These values seem low.
330/132kV transformer	The AEMC data shows $24000/MW for a 400MW transformer or about $9.6M. This seems very high for a new transformer where there is no requirement for significant substation augmentation. However it may not be high enough to

[13] TransGrid TAPRs and past TAPR presentations

	cover the cost of installation where significant substation augmentation is required[14].
Cable costs	The inner Sydney area is served predominantly by underground cables, some of which are directly buried and some have required tunneling. The recently commissioned Haymarket 330/132kV substation is underground. Hence the cost of cable options can be very high and variable. It may not be feasible to duplicate a cable that is stressed by high power flows and other options may need to be examined, for example the Sydney West – Holroyd – Rookwood 330kV development, which is in the western Sydney area, effectively supports the inner Sydney area.

For 330/132kV transformers, costs are provided for ratings of 225, 400 and 700. The unit sizes could be limited to about 200MVA and about 375MVA, to reflect current sizes in NSW. Switchbay costs would need to be added to the transformer costs. An additional cost component could be included to reflect the need for major substation augmentation. It may be reasonable to assume the expansion of rural substations may not involve additional substation work whereas urban substations may have a higher cost.

6. LINE AND TRANSFORMER RATINGS

“Continuous” and “Short Time” ratings are provided in the data for each element associated with the pricing model.

In practice the ratings of lines may be determined by the line conductors or alternatively by the terminal equipment within the substation at each end of the line. The high voltage terminal equipment may have their own ratings or there may be limitations in the line capability as a result of settings applied to the protective systems on the line.

Hence for example the Bayswater – Regentville 330kV line has a “Short Time” rating of 1429MW[15], however the Regentville – Sydney West 330kV line has a rating of only 1143MW. This is actually the same line, with Regenville being cut into the original line when the substation was developed. This line (or circuit) is also actually one circuit of the double circuit 330kV line connecting Bayswater to Sydney West and the other circuit of the line is shown in the data as a direct Bayswater – Sydney West 330kV line, with a rating of 1428MW.

Similarly the Eraring – Kemps Creek 500kV line is shown as having a rating of 1732, which is considerably lower than the actual conductor rating that exceeds 3500MVA for each circuit of this double circuit 500kV line.

In practice it may be possible to relieve the line terminal limitations by replacing terminal plant or protective equipment and this may be at a relatively low cost and generally could be achieved with a short lead-time.

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[14] For example refer to TransGrid’s cost estimate for the replacement of No.1 and No.2 transformers at Beasonsfield – Transmission Annual Planning Report 2014 page 90. This shows an indicative cost of $37M for the replacement of two 375MVA transformers.

[15] As the pricing model uses a DC load flow the ratings are regarded as being in MW.

It is suggested that the ratings applied in the model should reflect the major constraint on the line, such as the conductor rating. This imposes a long-term limitation on line loading and is commensurate with the LRIC approach.

The transformer “Continuous” and “Short Time” rating data tends to show the same value. The asset owner should be able to provide an appropriate overload rating for transformers.

7. APPLICATION OF LINE RATINGS

This section aims to seek clarification on how the “Continuous” line and transformer ratings and “Short Time” ratings are applied.

Both limitations need to be observed in planning the system[16]. A line loading must remain within the “Continuous” rating with all elements in service and must also observe the “Short Time” rating following a contingency. In NSW various levels of the “Short Time” ratings exist, depending on their application which may vary from minutes to much longer periods. It is normally expected that the “Short Time” rating, following a contingency, would be the more onerous limitation that drives the need for augmentation but this may not always be the case.

Transformers similarly would have a continuous rating and an overload capability that may vary with ambient conditions, typically for summer and winter.

Could the AEMC please clarify how the “Continuous” and “Short Time” ratings are applied in the model. It appears that the two ratings are treated separately in the model, according to the user selection in the Settings file (entry for “limit_offset”).

The guide to the file entries indicates that the term “Security Adjustment” in the Results spreadsheet is “The amount by which the initial flow is increased on the line under the worst case single contingency”. However many of the “Security Adjustment” entries are actually the “Continuous” ratings of the lines.

For example the values in the Results sheet for the Bannaby to Gullen Range Wind Farm are:

“Continuous” rating:	915
“Short Time” rating:	995
Initial flow:	109
Initial spare capacity:	995 – 109 - 915 = -29

The logic of this calculation is not clear.

For parallel transformers it is noted that the “Continuous” rating for a single transformer is used in the calculation.

In order to improve the clarity of the calculations it is suggested that the pricing model could instead apply the following two steps:

1. If the line loading exceeds the “Continuous” rating then the line capacity is augmented, and then;
2. If the line loading after a contingency still exceeds the “Short Time” rating then the line capacity would be further augmented.

This would then better match the way the future system is planned. If this two step process is not a practical option for applying in the pricing model at each year then one pass of the model based on “Continuous” ratings may provide a new base network that could then be augmented in a second pass with “Short Time” ratings.

[16] TransGrid NSW Transmission Annual Planning Report 2014 – Appendix 1

8. SHORT CIRCUIT LEVELS

The development of new generation may impact on the short circuit (fault) levels at substations. Remedial action may be required, depending on the headroom available, and the cost may vary from insignificant to large.

Fault levels may also dictate the type of line augmentation selected. At some sites it may not be possible to connect a new line without extensive substation work.

It should be possible to develop an indicative measure of the cost of fault level upgrades for generation in particular geographical areas.

The AEMC may however determine that this level of detail is not warranted in the stylised methodology proposed. Some case studies could be developed to guide the decision process.

9. INCLUSION OF STABILITY CONSTRAINTS

The pricing model presently applies only thermal constraints on lines and transformers and the AEMC is considering the inclusion of stability constraints.

Voltage stability (or voltage control) and transient stability constraints presently impact on the power transfer capability in areas of the system and between the states. These constraints are functions of a number of quantities including load level, generating units in service and the status of reactive plant. Various equations have been derived to represent the constraints in NEMDE.

The constraint equations are revised over time with augmentations to the system and as new generators come on line.

It would be difficult to develop detailed representations of all of the constraints in a form compatible with the pricing model but they may be able to be broadly represented by modelling limitations on the level of power flow across selected cutsets in the network. The constraint limit equations that have been developed for NEMDE could potentially be adapted in the form of appropriate fixed limits or linearized equations using generator output, load and other quantities as variables.

For example the voltage control constraint equation for power transfers north from NSW to Queensland, allowing for a line contingency, is of the form:

Limit = Constant +
Sum of a number of northern loads, each with a constant multiplier +
A factor relating to voltage in the area.

It would be relatively straightforward to represent this linear constraint with a simple linear limit equation within the pricing model.

The corresponding voltage control constraint for the contingent failure of a generator in Queensland is of a similar form but includes a term relating to the largest output of the Queensland generators. In the LRIC study it could be assumed a large generator is operating and hence the limit becomes straightforward to represent.

The transient stability limit equations for the contingent failure of a line or generator, for power flows northward from NSW, are linear functions of the regional loads, inertia of generators in various parts of the system, and generator output. Again these could be broadly represented by simple linear equations.

The voltage control limit equation for the power flow from Snowy to NSW is a linear function of the number of generators at each Snowy power station, their output and area loads. It should be possible to simplify this for the pricing model. The limit could be applied to the total power flow to Yass and Canberra.

The network augmentation that would be appropriate for each stability type of constraint could include:

- A new line; or
- An item of reactive plant, such as a Static Var Compensator.

An appropriate augmentation, with a cost, could be associated with each constraint.

To achieve reasonable accuracy with these constraints it would be necessary to adequately model the power flow conditions in the pricing model. Significant distortions to power flows as a result of the generation dispatch, as discussed in Section 1, may affect the feasibility of including stability constraints.

10. POWER FLOW SOLUTION AND USER INTERFACE

It is suggested that the power flow solver (DC load flow) could be based around existing power system software to ensure that the load flow solution is accurate, without requiring benchmarking tests.

If it is not possible to embed commercial power system software there are open source load flows available[17].

The prototype pricing model software does not have a ready means to ensure that the network connections can be verified. It would be of assistance to have a graphical interface to examine power flows and connectivity. Most modern power flow analysis software packages include a graphical user interface and the pricing model could be added to one of these packages.

[17] F. Milano, An Open Source Power System Analysis Toolbox, IEEE Trans. on Power Systems, Vol. 20, No. 3, pp. 1199-1206, August 2005.