Congestion management technical working group

Working paper for the congestion relief market 21 July 2022

Purpose of paper

The Energy Security Board (**ESB**) issued a consultation paper in May 2022 that shortlisted four model options to address congestion issues.[1] On 23 June 2022, the ESB shared with the congestion management technical working group (**TWG**) a list of outstanding questions to resolve as part of the next stage of detailed design.

This paper is designed to provide a base level of understanding for the congestion relief market (**CRM**), which is one of the model options addressing operational timeframes.

This paper will be shared with:

- NERA to develop its approach to model outcomes of the CRM for different market participants
- TWG (operational subgroup) to understand the fundamental elements of the CRM and explore detailed design questions in separate working papers.

The ESB has issued a companion paper for the congestion management model (**CMM**). Where appropriate, the terminology is consistent between the papers.

Context

The CRM was originally proposed by Edify Energy in June 2021.[2] The model design has evolved and was submitted in a modified form by the Clean Energy Council (**CEC**) in June 2022.[3] The ESB is reviewing the modified version and has identified a number of policy and design questions to be considered.

This reference paper covers the following:

1. Reference scenario
2. Status quo arrangements
3. Overview of the CRM
4. How will the CRM lead to efficient dispatch?
5. Incentives and operation of the CRM with storage
6. Conclusions

The reference scenario and status quo arrangements are consistent with the worked examples provided for the companion paper on the CMM.

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[1] ESB, https://esb-post2025-market-design.aemc.gov.au/transmission-and-access consultation paper, May 2022

[2] Edify Energy, Edify Energy Response to Post 2025 Market Design Options, initially submitted June 2021 and re-submitted January 2022

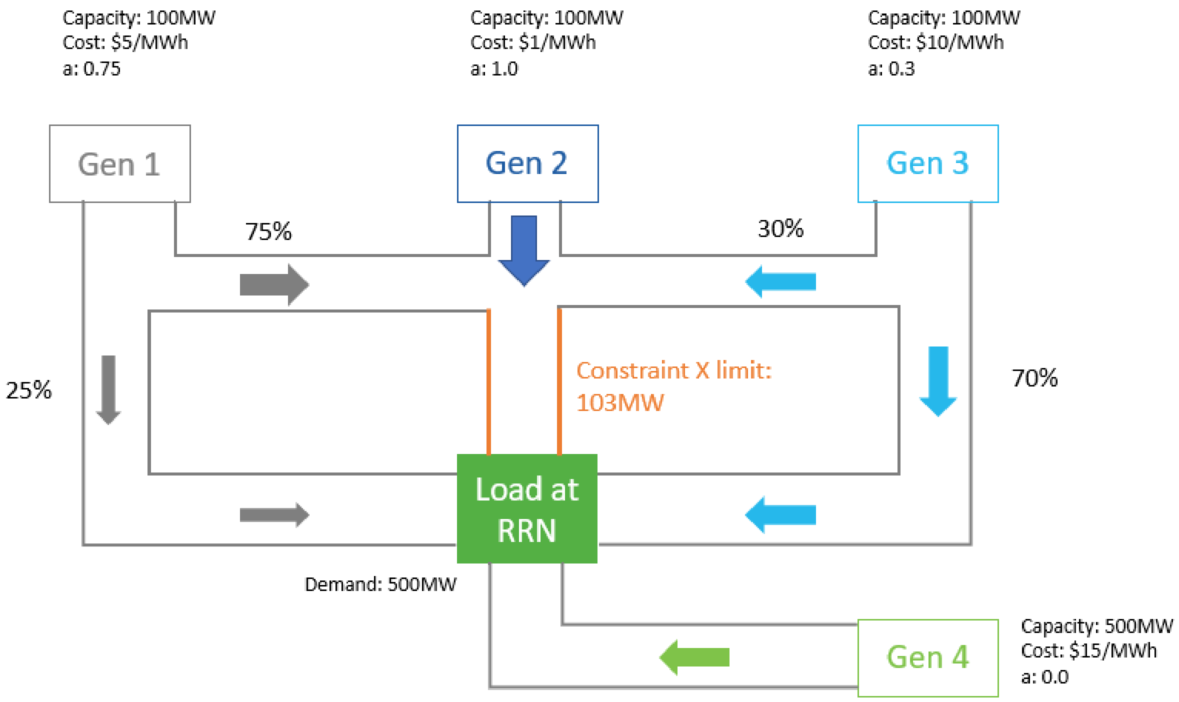
[3] CEC, https://www.energy.gov.au/government-priorities/energy-ministers/priorities/national-electricity-market-reforms/transmission/transmission-access-reform-consultation-paper-may-2022, June 2022

1. Reference scenario

Figure 1 provides an illustrative example of a looped network with a flowgate constraint of 103MW. This paper continues to apply this reference scenario to create worked examples of physical and financial outcomes under the status quo and the CRM.

To understand the theory, we have simplified the worked examples and ignored marginal loss factors from the calculations.

Figure 1 Flowgate capacity of 103MW (constraint RHS)



Note a = contribution factor of a generator in the constraint

A flowgate is a transmission element by which electricity power flows. The constraint limit (or flowgate capacity) reflects the capacity of the associated transmission element or the transmission network more generally.

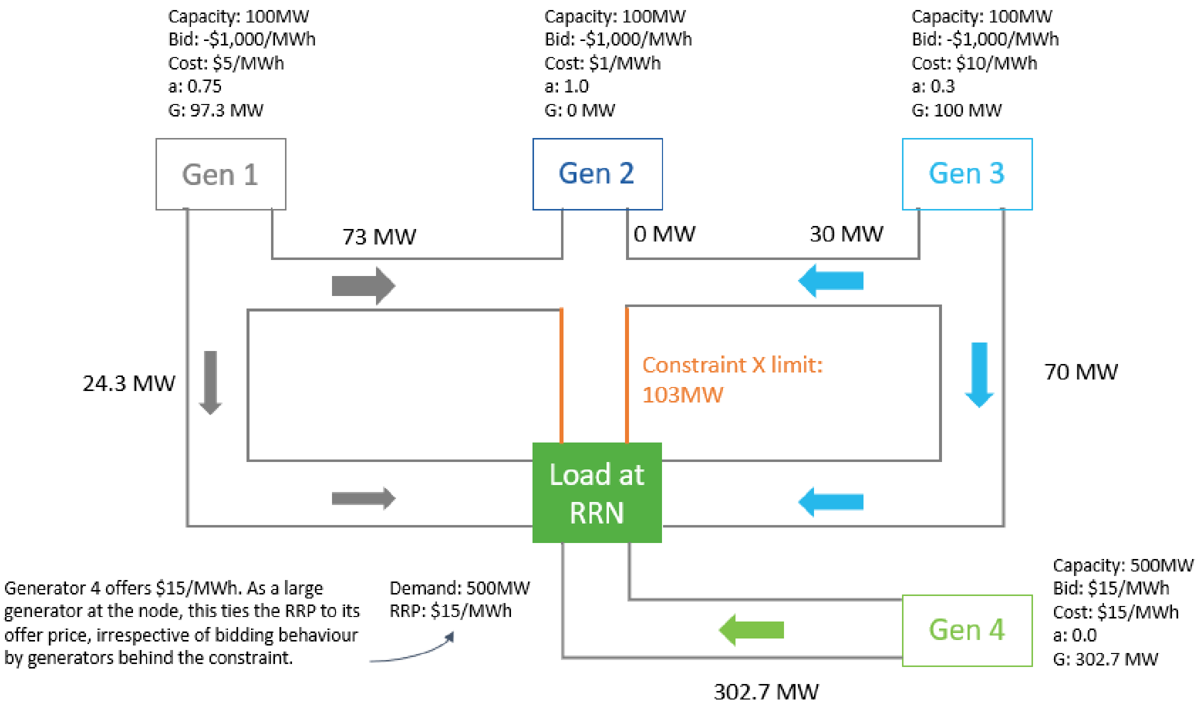
2. Status quo arrangements

The CMM paper includes a fuller explanation of the status quo arrangements. Key figures and tables are replicated in this paper to compare dispatch, cost and profit outcomes against the CRM.

Disorderly bidding

Figure 2 shows the dispatch outcomes when constrained generators bid at the market price floor (**MPF**). Table 1 summarises the financial outcomes.

Figure 2 Status quo dispatch outcomes bidding at MPF



Generator 4 offers $15/MWh. As a large generator at the node, this ties the RRP to its offer price, irrespective of bidding behaviour by generators behind the constraint.

a = contribution factor of a generator in the constraint, G = dispatch MW

Table 1 Status quo financial outcomes (constrained generators bidding at MPF)

Unit	a	G	RRP	Cost	Revenue $	Cost $	Profit $
	coefficient	MW	$/MWh	$/MWh	G x RRP	G x Cost	Revenue – Cost
Gen 1	0.75	97.3	15	5	1,460	487	973
Gen 2	1.0	0	15	1	0	0	0
Gen 3	0.3	100	15	10	1,500	1,000	500
Gen 4	0.0	302.7	15	15	4,540	4,540	0
Total		**500**			**7,500**	**6,027**	**1,473**

Cost reflective bidding

If the generators bid at their SRMC, Figure 3 shows the updated physical outcomes and Table 2 the financial outcomes.

Figure 3 Dispatch outcomes with cost-reflective bidding

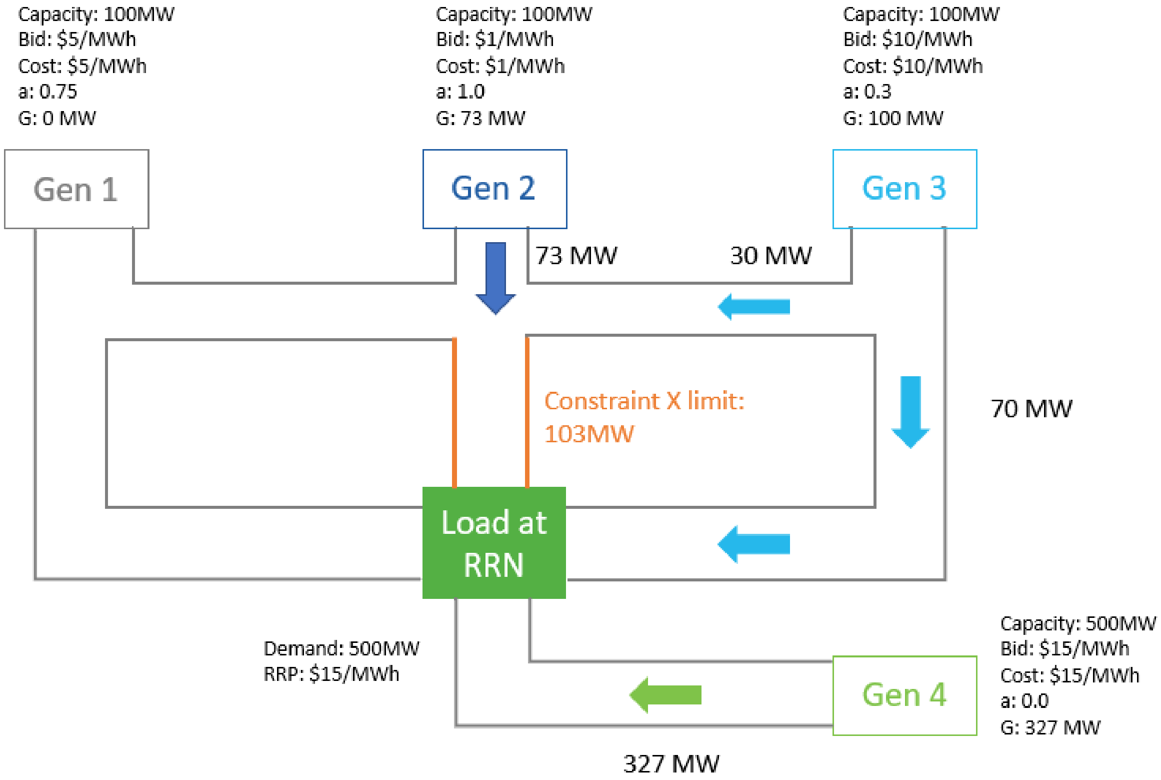


Table 2 Status quo financial outcomes (cost reflective bidding)

Unit	G MW	RRP $/MWh	Cost $/MWh	Revenue $	Cost $	Profit $
				G x RRP	G x Cost	Revenue – Cost
Gen 1	0	15	5	0	0	0
Gen 2	73	15	1	1,095	73	1,022
Gen 3	100	15	10	1,500	1,000	500
Gen 4	327	15	15	4,905	4,905	0
Total	**500**			**7,500**	**5,978**	**1,522**

With all generators bidding reflective of their marginal cost, the overall cost of dispatch has decreased from $6,027 (Table 1) to $5,978 (Table 2).

3. Overview of the CRM

The CRM is based on two dispatch runs. The participants' initial dispatch of energy is determined as per the status quo arrangements. The second CRM dispatch enables market participants to pay or receive additional money to adjust their dispatch up or down. Buyers and sellers would bid/offer into the energy market and the CRM:

- Prospective sellers in CRM: Generators (loads) that participate in a constraint and are initially dispatched (not consuming).
- Prospective buyers in CRM: Generators that participate in a constraint and are initially constrained off (fully or partially).

The quantity bid/offered is adjusted by each participant’s contribution factor in the constraint. The market clearing determines a clearing price and quantity of congestion relief traded.

Participation in the CRM is optional. But the combined energy and CRM deviations must result in a secure dispatch by ensuring it meets the NEM’s security constraints and the technical limits of all plant.

The revenue earned from the energy market and CRM markets can be expressed as follows:

		Energy market Access dispatch		CRM Physical dispatch
Revenue$	=	A x RRP	+	ΔA x LMP[4]
	=	A x RRP	+	(G – A) x LMP

Where:

A = access MW (initial dispatch as per energy market)

ΔA = change in dispatch as a result of the CRM (CRM deviations)

G = *A + ΔA* = actual generation (dispatch MW)

LMP = locational marginal price (also referred to as the congestion relief price, CRP)

RRP = regional reference price

The terminology and expression *Revenue = A x RRP + (G-A) x LMP* are consistent with the CMM which is the alternative shortlisted model in operational timeframes.

Access dispatch

- In the CRM, access dispatch *A* determines the quantity on which generators are paid RRP.
- In the CMM, *A* determines the quantity of rebates awarded to the generator to offset the congestion charge.

Physical dispatch

- Physical dispatch determines the quantity that the generator must physically produce.
- In both the CMM and CRM, generators are paid LMP for any unders and overs between access and physical dispatch.

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[4] Consistent with MarketWise Solutions, prepared for the CEC, CEC The Modified CRM model, 10 June 2022, p.18 “Total settlement outcome = Energy and CRM revenue = x_i x RRP + Δx_i x CRP” CRP refers to the nodal CRM price or CRM LMP. Equivalent formulation provided in Note on CRM Demonstration Model, SW Advisory, 7-Jun-2022, p.28, “Revenue = Q_n x RRP + (G_n - Q_n) x LMP_n where $Q_n = x_n$ and $G_n = x_n + \Delta x_n$”

4. How will the CRM lead to efficient dispatch?

The trading of congestion relief enables low-cost participants to be dispatched over higher cost participants through a compensation process. This would lead to more efficient dispatch with lower cost generation being dispatched.

As a worked example, Table 3 retains the market price floor bids in the energy market (access dispatch) but introduces cost-efficient bids for the CRM (physical dispatch). The generators bid at their SRMC to capture additional value in the CRM.

Table 3 Energy and CRM bids

Unit	Cost $/MWh	Energy market (access dispatch) $/MWh	CRM (physical dispatch) $/MWh
Gen 1	5	-1000	5
Gen 2	1	-1000	1
Gen 3	10	-1000	10
Gen 4	15	15	15

Note: Cells in grey are consistent with the worked example provided for status quo arrangements in Figure 2.

The RRP remains $15/MWh which is determined by the marginal cost at the regional reference node (**RRN**). Gen 4 remains the marginal generator with its cost of $15/MWh.

The LMP is determined by the marginal cost of the capacity constraint. Gen 2 is the marginal generator with an LMP of $1.00/MWh.

Table 4 shows the LMP outcomes for each generator. The LMPs are calculated with reference to the contribution factor and congestion price (**CP**) (the shadow price of the constraint).

Table 4 LMP calculation for the generators

Unit	Cost $/MWh	RRP $/MWh	a ratio	CP $/MWh	LMP $/MWh RRP – a x CP
Gen 1	5	15	0.75	14	4.50
Gen 2	1	15	1.0	14	1.00
Gen 3	10	15	0.3	14	10.80
Gen 4	15	15	0.0	14	15.00

Note: CP = congestion price is calculated by the algorithm of the NEM dispatch engine (NEMDE).

Table 5 summarises the CRM dispatch outcomes as a consequence of the generators' LMP relative to their costs (assuming they bid at cost).

Table 5 Dispatch outcomes as a result of LMP vs costs

Unit	Relative prices	Outcome	Note
Gen 1	LMP < costs	Lower dispatch	
Gen 2	LMP = costs	Partially raise dispatch	Marginal generator
Gen 3	LMP > costs	[Raise] dispatch	Gen 3 has already been fully dispatched in the energy market and cannot increase its generation output
Gen 4	LMP = costs	Partially raise dispatch	Marignal generator. Given the physical construct of this looped flow, Gen 4 (or an equivalent generator outside the constraint) must participate in the CRM to enable the CRM trades to be executed.

Figure 4 Illustrates the dispatch outcomes of the RRP and LMP.

Figure 4 Energy and CRM dispatch outcomes

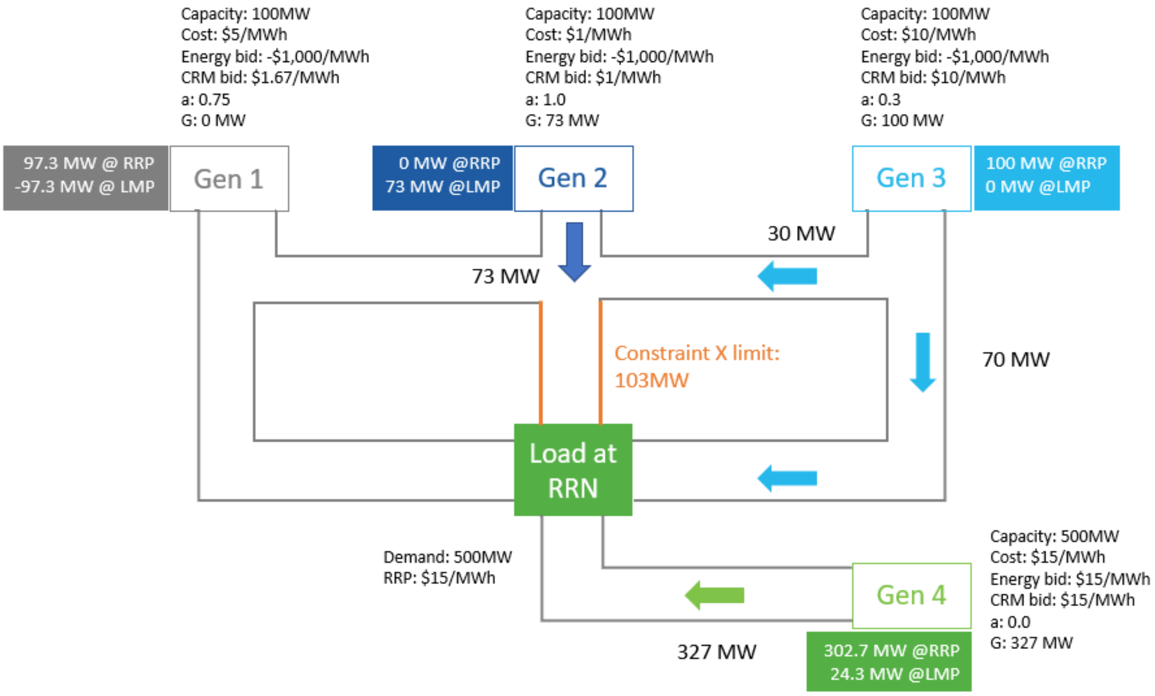

Table 6 Financial outcomes of the energy market and CRM

Unit	A	CRM	G	RRP	LMP	Cost	A x RRP	(G-A) x LMP	G x Cost	Profit
	MW	MW	MW	$/MWh	$/MWh	$/MWh	$	$	$	$
Gen 1	97.3	-97	0	15	4.50	5	1,460	-438	0	1,022
Gen 2	0	73	73	15	1.00	1	0	73	73	0
Gen 3	100	0	100	15	10.80	10	1,500	0	1,000	500
Gen 4	302.7	24.3	327	15	15.00	15	4,540	365	4,905	0
Total	**500**	**0**	**500**				**7,500**	**0**	**5,978**	**1,522**

Note: 'CRM MW' represents the deviations in access dispatch (*ΔA*) as a result of the CRM.

The total energy generated by a generator (*G*) is the sum of the access dispatch and CRM deviations.

The initial access dispatch *A* is identical to disorderly bidding under the status quo.

The CRM provides an opportunity for mutually beneficial trades that achieve a more efficient outcome. Table 6 shows that total costs have reduced from $6,027 (status quo Table 1) to $5,978. The aggregate profit for the market participants has increased from $1,473 to $1,522.

Table 7 Summary of cost and profit outcomes

Unit	Cost			Profit		
	Energy $	CRM $	Total $	Energy $	CRM $	Total $
Gen 1	487	-487	**0**	973	49	**1,022**
Gen 2	0	73	**73**	0	0	**0**
Gen 3	1,000	0	**1,000**	500	0	**500**
Gen 4	4,540	365	**4,905**	0	0	**0**
Total	**6,027**	**-49**	**5,978**	**1,473**	**49**	**1,522**

Note: Profit calculations; Energy profit = A x (RRP – cost), CRM profit = (G-A) x (LMP – cost)

In aggregate, the cost outcomes are equivalent to cost-reflective bidding under status quo arrangements (Table 2). An efficient outcome is achieved with the CRM irrespective of whether the constrained generators bid in the energy market at cost or with disorderly bidding. An efficient outcome is dependent on the total costs of the actual physical dispatch rather than access dispatch. Trading opportunities in the CRM align the incentives of generators with an overall least-cost dispatch.

In aggregate, profit has increased compared to status quo disorderly bidding (Table 1). The generators share the savings in dispatch costs. At an individual level, the gain accrues to Gen 1 where its profit increases from $973 (status quo disorderly bidding) to $1,022 (disorderly bidding with CRM). Gen 2 benefits from increased dispatch (from 0MW to 73MW) with a neutral profit outcome because it is the marginal generator and its costs of $1/MWh match the LMP of $1/MWh.

The CRM allows for generators to opt out.

In this simplified example with only four generators:

- CRM dispatch outcomes are unaffected if Gen 3 opts out. The access dispatch for Gen 3 also represents the efficient physical dispatch so there is no opportunity in the CRM to optimise from this initial access dispatch.
- The CRM would not have cleared if any of the other three generators opted out.
- However, the generators had an incentive to participate:
  - Gen 1 could have opted out but it would have lost potential profits achieved via the CRM.
  - Gen 2 and Gen 4 benefited from uplifts to their physical dispatch with a neutral profit outcome given they were the marginal generators in this case.

In general, assuming zero transaction costs and ignoring separate contract arrangements:

- All generators under the CRM have an incentive to participate/bid cost reflectively in order to maximise their profits. This results in efficient dispatch.
- Assuming that generators bid cost effectively in the CRM, they will not adversely affect their net profit outcomes compared to status quo.
- Trading is viable in the CRM even with a subset of generators opting out. The simplified scenario is designed to show the financial incentives to participate.

5. Incentives and operation of the CRM with storage

This section introduces a storage unit BESS 1 to the reference scenario. It has a discharge bid of $30/MWh (50MW) and load/charging bid of $4/MWh (-50MW).

Under status quo arrangements, BESS1 charging would relieve constraint X by 1.0 MW for every MW dispatched. But BESS 1 does not charge or discharge given the RRP of $15/MWh is higher than its cost to charge of $4/MWh and lower than its cost to discharge of $30/MWh.

Table 8 retains energy bids at MPF and CRM bids at SRMC but introduces new bids for BESS 1. In this example, BESS 1 bids unavailable to avoid a negative mis-pricing event[5] and optimises its participation in the CRM.

Table 8 Energy and CRM bids including BESS 1

Unit	**Cost** $/MWh	**Energy bid (access dispatch)** $/MWh	**CRM bid (physical dispatch)** $/MWh
Gen 1	5	-1,000	5
Gen 2	0	-1,000	1
Gen 3	10	-1,000	10
Gen 4	15	15	15
BESS 1 - discharge	30	unavailable	30
BESS 1 – charge	4	unavailable	4

Note: Cells in grey are consistent with the worked example provided for status quo arrangements in Figure 2.

Table 9 RRP and LMPs including BESS 1

Unit	**Cost** $/MWh	**RRP** $/MWh	**a** ratio	**CP** $/MWh	**LMP $/MWh** RRP – a x CP
Gen 1	5	15	0.75	13	5.00
Gen 2	1	15	1.0	13	1.67
Gen 3	10	15	0.3	13	11.00
Gen 4	15	15	0.0	13	15.00
BESS 1 – charge	4	15	1.0	13	1.67

Note: CP = congestion price is calculated by the algorithm of NEMDE. Gen 1 is the marginal generator and sets the LMP at $5/MWh.

With a cost to discharge of $30/MWh, BESS 1 is out of merit to dispatch. But with a cost to charge of $4/MWh and LMP of $1.67/MWh, it is incentivised to charge and relieve the congestion.

Gen 1 is now the marginal generator with *LMP = costs = $5/MWh* and it is partially dispatched.

Gen 2 has *LMP > costs* and is fully dispatched at 100MW. Gen 2 benefits from the change in marginal generator (vs CRM scenario without storage). The LMP has increased from $4.50/MWh (Gen 2 marginal, CRM scenario without storage) to $5.00/MWh (Gen 1 marginal, CRM with storage).

Gen 3 remains unaffected by the CRM scenario with storage. It has already achieved an optimal and cost efficient outcome in the access dispatch.

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[5] Refer to AEMO's Guide to mis-pricing information, November 2021

Gen 4’s LMP remains $15/MWh. Its physical dispatch decreases with BESS 1 because Gen 1’s output includes 23MW to charge BESS 1 and 7.7MW around the constraint.

Figure 4 Illustrates the physical dispatch outcomes of the RRP and LMP.

Figure 5 Energy and CRM dispatch outcomes including BESS 1

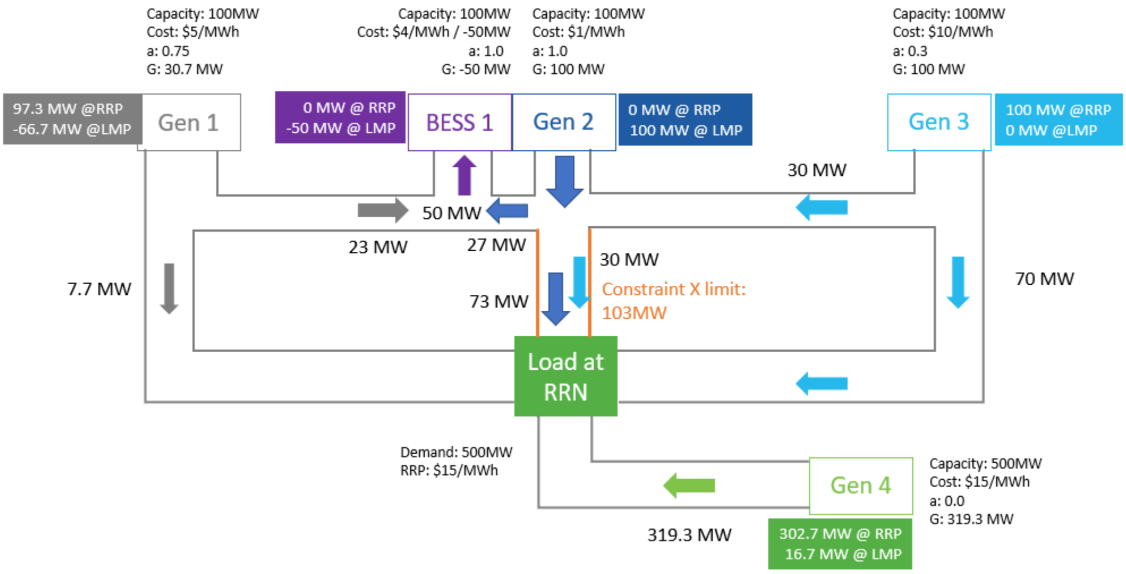

Table 10 Financial outcomes of the energy market and CRM including BESS 1

Unit	A	CRM	G	RRP	LMP	Cost	A x RRP	(G-A) x LMP	G x Cost	Profit
	MW	MW	MW	$/MWh	$/MWh	$/MWh	$	$	$	$
Gen 1	97.3	-66.7	30.7	15	5.00	5	1,460	-333	153	973
Gen 2	0	100	100	15	1.67	1.0	0	167	100	67
Gen 3	100	0	100	15	11.00	10	1,500	0	1,000	500
Gen 4	302.7	16.7	319.3	15	15.00	15	4,540	250	4,790	0
BESS 1	0	-50	-50	15	1.67	4	0	-83	-200	117
Total	**500**	**0**	**500**				**7,500**	**0**	**5,843**	**1,657**

Table 11 Summary of cost and profit outcomes including BESS 1

Unit	Cost			Profit		
	Energy $	CRM $	Total $	Energy $	CRM $	Total $
Gen 1	487	-333.3	**153**	973	0	**973**
Gen 2	0	100	**100**	0	66.7	**67**
Gen 3	1,000	0	**1,000**	500	0	**500**
Gen 4	4,540	250	**4,790**	0	0	**0**
BESS 1	0	-200	**-200**	0	116.7	**117**
Total	**6,027**	**-183**	**5,843**	**1,473**	**183**	**1,657**

Note: Profit calculations; Energy profit = A x (RRP – cost), CRM profit = (G-A) x (LMP – cost)

Table 11 shows that total costs ($5,843) have reduced compared to status quo disorderly bidding ($6,027) and the previous CRM scenario without storage ($5,978). This is despite total dispatch MW increasing from 500MW (demand at RRN) to 550MW (with BESS 1 charging by 50MW).

The cost differential is the result of how costs are quantified for BESS 1.

Table 11 shows BESS 1 with costs of -$200 and profits of $117. The costs and profits relate to the economic value for the differential between its cost to charge ($4/MWh) and its cost incurred ($1.67/MWh).

Table 12 summarises the economic gain (producer surplus) for BESS1.

Table 12 Calculating economic gain for BESS1 under CMM

Scenario	**Price reference**	**Price to charge** $/MWh	**G** MW	**Value** $
Status quo	Cost to dispatch	4.00	50	200
CMM	LMP	1.67	50	83
Economic gain				**117**

The CRM creates incentives for storage and scheduled load to help to alleviate congestion. This addresses the transmission access reform objective to achieve efficient market outcomes in dispatch.

There is potential that the CRM may offer an investment signal to scheduled load and storage to locate in areas of congestion in order to profit from lower costs to charge. An additional working paper will be developed and shared with the TWG to explore the locational signals and impacts for storage as a result of the proposed congestion models in operational timeframes.

6. Conclusions

The theoretical concepts of the CRM and CMM are similar; they both allocate access to generators (paid at RRP) and calculate physical dispatch (paid at LMP for the differences between access and physical dispatch). Stakeholders have expressed a preference for the CRM given it provides optionality to participate and may enable participants to better manage contract positions and basis risk.

The ESB has separately shared a list of outstanding questions to resolve for the detailed design of the CRM. This paper provides a base level of common understanding for the ESB and TWG for that purpose. The ESB will share outcomes of detailed modelling so that market participants can better identify and quantify the impacts of the proposed CRM.