Congestion Management Technical Working Group
Summary of current thinking: Transmission queue model as a stand-alone option

Introduction

In its submission to the transmission access reform consultation paper, the Clean Energy Investor Group (CEIG) has affirmed and clarified its Transmission Queue Model (TQM).[1] CEIG explained its preference for this model over alternative model options, including a version of the TQM modified by the Energy Security Board (ESB).

The CEIG provided some clarifications and amendments to its model through its consultants Castalia and stated that it would support further investigation of the introduction of a hybrid model combining the CEIG's TQM and the congestion relief market (CRM). The CEIG also supported further work and close engagement with industry stakeholders on the proposal. This working paper aims to support that engagement.

The TQM contains both investment and operational elements; the former describes how queue numbers are assigned to generators and the latter explains how these numbers are used in dispatch. This paper focusses on the operational aspect of the TWG and does not consider the detailed design of the model in investment timeframes. The impact of the model in investment timeframes is arguably more important, as this is the timeframe that the TQM is designed for.

Context

The ESB has been considering access reforms in which the allocation of access is separated from physical dispatch, with differences settled at the locational marginal price (LMP). With generators paid LMP at the margin, they have a stronger incentive to bid close to cost, compared to the current market where constrained off generators will bid at the market price floor (MPF) to maximise dispatch. Cost-reflective bidding results in more efficient dispatch.

Both the congestion management model (CMM) and CRM have this core attribute. In contrast, the TQM doesn't separate access from dispatch but rather changes the dispatch algorithm itself, to incorporate and reflect queue numbers. For that reason, there is no equivalent prima facie expectation that it will improve dispatch efficiency. This is what this paper examines.

1. Background

Today, the dispatch algorithm finds the cheapest feasible dispatch, based on bids and offers subject to the network loadings resulting from a particular dispatch pattern maintain the system within safe and secure operating limits. The maintenance of system security is delivered by applying constraints to the dispatch. There are a large number of constraints within AEMO's constraint library which represent the many different network limits which could be binding under some dispatch patterns. Constraint equations in the NEM Dispatch Engine (NEMDE) are linear equations containing terms for each centrally dispatched network user including generators, storage and inter-connectors. The relative impact of each network user on each constraint is measured by its contribution factor (CF) in the relevant constraint equation. The constraint equation to manage the thermal limit on a simple radial network with one or two generators is simple as both generators would have a CF of 1.00.

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[1] CEIG, https://www.energy.gov.au/sites/default/files/2022-06/CEIG%20Response%20to%20transmission%20access%20reform%20consultation%20paper%20May%202022.pdf, 10 June 2022

However on a meshed network constraints become more complex as generators will often have two or more flowpaths to the load at the regional reference node (RRN). This leads to each generator having its own CF and in the NEM each would be represented in a number of constraint equations and would have a specific contribution factor in each of them.

In principle, the preference to dispatch one generator over another depends upon:

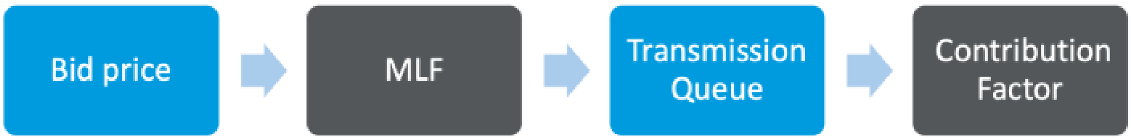
- their relative bid prices (adjusted for MLF); and
- their relative CF in any/all binding constraints.

Where constrained generators all bid at the same price, bid price is no longer a factor and so dispatch differentiates solely on the basis of CF(s). In a simple scenario, with a single binding constraint, generators will be dispatched in order of ascending CF.

The Transmission Queue Model (TQM)

The TQM would change the dispatch order via the dispatch algorithm. The TQM assigns a queue number to each generator with “0” representing the front of the queue and the highest number the back. In the original TQM, the queue number only came into effect to “tie-break” between two generators with identical loss-adjusted bids and contribution factors.[2] However, the latest CEIG submission has clarified that queue number will *always* take priority: e.g. generator with queue number zero will *always* be given preference over a generator with identical bid but higher queue number, irrespective of CFs. Under the TQM, the dispatch algorithm would favour generators with lower queue numbers. The CEIG acknowledge that this could jeopardise security and could increase the price paid by customers. They therefore propose that dispatch would occur in accordance with the transmission queue prioritisation subject to maintaining system security and to the extent that it does not increase the regional reference price (RRP).

Figure 1 Proposed placement of the queue in the NEMDE dispatch algorithm



> *The figure above shows that the NEMDE should first determine the bid-stack by assessing all MLF weighted bids to determine the least cost generation mix to meet demand in a given five-minute interval.*
>
> *Next, where there are binding constraints within the NEM that NEMDE must resolve, NEMDE should curtail generators in descending order of the queue. This means that NEMDE would seek to resolve binding constraints by curtailing generators with a high queue number and then proceed down the generators in the queue until the constraint is resolved. If NEMDE cannot resolve the binding constraint using queue order, then NEMDE should resolve the constraint using contribution factors as it currently does. Thus, if NEMDE reaches generators with queue number 0 without resolving the constraint then it should resolve the constraint using contribution factors as it does now.*

Source: CEIG, CEIG response to the TAR consultation paper released May 2022, 10 June 2022, p.8

> *We acknowledge it is possible that there is no way to relieve a constraint without changing the marginal generator and thus the RRP. As a result, to eliminate this possibility we propose a limit on the transmission queue such that NEMDE should only curtail generators in order of the queue to the point where it would require changing the marginal generator. If using the queue to resolve a constraint would result in increasing*

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[2] Castalia Ltd, on behalf of the CEIG, https://ceig.org.au/wp-content/uploads/2022/02/2022-02-23-Report-on-Transmission-Access-Reform.pdf, February 2024, p.24

> *the cost of the RRP, then we propose that NEMDE revert to the use of contribution factors to resolve a binding constraint. This safeguard will ensure that customers do not pay extra due to the queue.*

Source: CEIG, CEIG response to the TAR consultation paper released May 2022, 10 June 2022, p.8

The ESB welcomes this aspect of the model. We agree that any reforms to the access model should maintain system security and should not result in changes to dispatch that increase the RRP.

2. The theoretical problem with providing physical access

Physical access regimes are used with some infra-structure and have been considered in electricity from the commencement of liberalised markets. Where usage of one link in a network has minimal or no impact on usage of others, these regimes can work effectively. This might apply to radial pipelines for example. However, the electricity network is not a radial network and there are numerous parts of the network where the network is "meshed", meaning that there is more than one path over which electricity can flow from point A to point B. In this situation, an injection of electricity at one node will have an impact on all paths that the electrons flow over between point A and point B. This is because electricity flows are governed by Kirchhoff's laws, resulting in electricity flow "splitting" at every junction in the network and flows on each link related to the voltage difference across the link and its impedance. Each node on a network must comply with Kirchoff's first Law (what goes in must come out) and voltages across the network comply with Kirchhoff's second law.

Dispatch in a network therefore needs to manage the pattern of generation across the whole grid. Given that, we can interpret Figure 1 as seeking to prioritise dispatch of generators based on their priority in the queue, but any dispatch pattern must be consistent with Kirkoff's Law and flows on all elements of the grid must be maintained within their secure operating range. The CEIG submission recognised that and the need to ensure dispatch delivered secure outcomes.

3. How will physical prioritisation affect dispatch? – illustrative scenario

The ESB has previously provided the TWG with an illustrative scenario where three generators have meshed access to the load, each with differing CFs. A fourth generator located at the RRN provided the balance of the load, viz:

Figure 2 Reference scenario

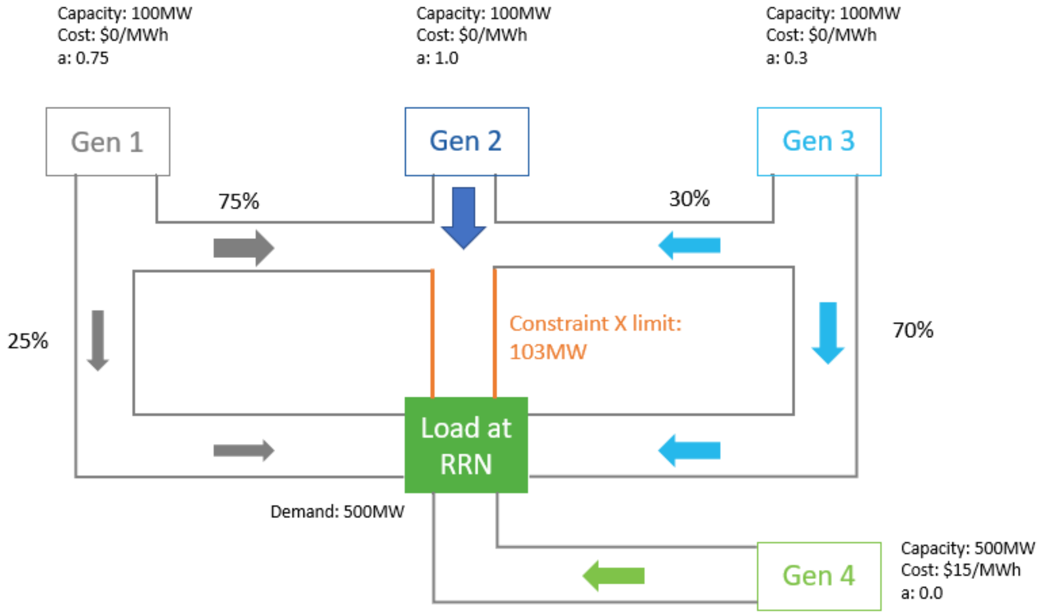

Figure 1 illustrates the impact of the CFs on dispatch outcomes. For example:

- Gen 3 has the lowest CF of 0.3. For every 1 MW flowing through the constraint, 2.33 MW is dispatched around the constraint.
- Gen 2 has the highest CF of 1.0. For every 1 MW flowing through the constraint, 0 MW is dispatched around the constraint.

Every MW dispatched by Generators 1 to 3 displaces the higher cost marginal generator being Generator 4. In this case, maximising the dispatch of low cost energy from Generators 1 to 3 will minimise the higher cost generation from Generator 4. Table 1 shows the dispatch outcome based on tsking into account both the bid price **and** CF.

Table 1 Optimal dispatch and cost

	Unit	**Efficient dispatch**	
Gen 1	MW	97	} Total of 197 MW of low cost generation dispatched
Gen 2	MW	0	
Gen 3	MW	100	
Gen 4	MW	303	
Dispatch Cost	*$*	*4,540*	

Generator 4 is not constrained and is not directly affected by the access models. But the dispatch has an implied priority order for generators. In the efficient dispatch, the order is "312" ie Gen 3 is dispatched first, Gen 1 next and Gen 2 last, with each generator dispatched up to full output in sequence, until the constraint binds.

The TQM would return an identical dispatch if queue positions happened to be assigned in order of this priority: ie Gen 3 at the front of the queue, Gen 1 in the middle, Gen 2 at the back. Table 2 calculates dispatch for the six possible queueing permutations.

Table 2 Dispatch costs under different queue permutations

Generator	***Unit***	***Queue Order***					
		123	***132***	***213***	***231***	***312^{+}***	***321***
Gen 1	MW	100	100	4	0	97	0
Gen 2	MW	28	0	100	100	0	73
Gen 3	MW	0	93	0	10	100	100
Gen 4	MW	372	307	396	390	303	327
Cost	*$*	*5580*	*4600*	*5940*	*5850*	*4540*	*4905*

This demonstrates that any alternative queue order dispatched the same or less low cost generation. This would mean a higher underlying cost of supply on the majority of cases. In a market context, whether it means a higher customer price or not would depend upon the bid profile of Generator 4. How much TQM worsens dispatch efficiency compared with the status quo in reality is not straightforward to answer.

4. How will physical prioritisation affect dispatch? – example based on X5 constraint

The paper on constraints from WattClarity referenced by the CEIG outlines how the X5 constraint operates. The X5 constraint is a complex constraint which includes generator, storage and interconnector terms. It is oriented to the New South Wales RRN but includes generation in Victoria.

If participants bid their costs, we could expect that the generation from all solar plant would be bid at zero. The short run cost of wind generation is low but higher than that of solar so those have been removed for the purposes of this analysis. While the constraint is written as a feedback constraint, for the purposes of illustration, it could be simplified as having a left hand side (or terms to be optimised) consisting of 12 solar farms each with their own CF. The sum of the product of each generators output and CF must be equal or less than the right hand side to ensure security is maintained. Looking at the data from WattClarity, the RHS is approximately 400MW.

If this constraint is binding, we would expect an efficient dispatch would be as outlined in Table 3.

Table 3 Security constrained, optimal dispatch against X5 limitation only

Contribution factor	Generator	Capacity MW	Dispatch %	Dispatch MW	Contribution to constraint LHS
1.0000	Limondale1	220	47%	102.3	102.3
1.0000	Limondale 2	29	47%	13.5	13.5
1.0000	Sunraysia	200	47%	93.0	93.0
0.6665	BrokenHill	53	100%	53.0	35.3
0.5197	Yatpool	81	100%	81.0	42.1
0.4487	Bannerton	88	100%	88.0	39.5
0.4467	Wemen	88	100%	88.0	39.3
0.3952	Kiamal	200	100%	200.0	79.0
0.2544	Gannawarra	50	100%	50.0	12.7
0.2544	Cohuna	34	100%	34.0	8.6
-0.1507	Coleambally	150	100%	150.0	-22.6
-0.1566	Darlington Point	275	100%	275.0	-43.1
	Total			**1227.8**	**399.7**

Generators with the lowest contribution factor would be dispatched first until power transfer is constrained. When constrained, tiebreaking would share dispatch between the marginal generators as those have the same contribution factor. Dispatching in this way maximises the generation from these generators under this constraint. It should be noted though that this only considers one constraint and individual generators may in one or more other binding constraints in the same dispatch interval.

When a group of generators who are all affected by congestion bid the same price, the least cost solution is to dispatch generators in ascending order of their contribution factor until the constraint binds. Alternative formulations would have the result that NEMDE dispatches less low cost, renewable energy than possible, with the additional MW unable to reach load due to congestion.

This can be illustrated in the extreme case where the generators with the higher contribution factors had the highest priority for dispatch. Table 4 shows the outcomes in this case.

Table 4 Physical priority to Limondale and Sunraysia in dispatch of X5 constraint

Contribution factor	Generator	Capacity MW	Dispatch %	Dispatch MW	Contribution to constraint LHS
1.0000	Limondale1	220	89%	196.0	196.0
1.0000	Limondale 2	29	89%	25.8	25.8
1.0000	Sunraysia	200	89%	178.2	178.2
0.6665	Broken Hill	53	0%	0.0	0.0
0.5197	Yatpool	81	0%	0.0	0.0
0.4487	Bannerton	88	0%	0.0	0.0
0.4467	Wemen	88	0%	0.0	0.0
0.3952	Kiamal	200	0%	0.0	0.0
0.2544	Gannawarra	50	0%	0.0	0.0
0.2544	Cohuna	34	0%	0.0	0.0
-0.1507	Coleambally	150	0%	0.0	0.0
-0.1566	Darlington Point	275	0%	0.0	0.0
	Total			**400.1**	**400.1**

In this case, the limitation on dispatch would be binding with only 400MWs of low cost solar energy being dispatched, or only one third of that in the optimal case. With both optimal and priority physical dispatch other generation that was not constrained from the NSW RRN would be needed to meet demand and the bid of the marginal generator would set the price. However in the case where physical priority was applied, three times the generation would need to be sourced from unconstrained generators. This increases the total cost of dispatch.

Table 4 shows a worst case but, as illustrated in Table 2, any dispatch profile other than security constrained, optimised dispatch can only be the same or higher cost. Again we need to bear in mind that each generator is affected by a number of constraints and several may be binding at the same time. This could lead to a number of overlapping priorities to be resolved and drive further inefficiencies in dispatch.

5. Price outcomes with physical prioritisation of dispatch

While prioritisation of physical dispatch based on a scheme to allocate ranking to each generator would increase the underlying cost of supply, it is unclear the extent to which it would increase the price to customers. The price paid by customers would be set by the marginal bid block of unconstrained generation. In the worst case shown in Table 4, a very significant increase in output from unconstrained generators is required and this would almost certainly increase the RRP, possibly significantly. In the case of the NEM, it would also likely increase emissions.

The CEIG proposal recognised this as a possibility and have proposed that physical priority only be provided to the extent that the RRP was not affected.[3] In the optimal dispatch case, tie breaking shares the marginal 208.8 MW of transfer capacity pro-rata across the three marginal generators. Physical priority could be applied between those generators without changing the total volume of generation dispatched against the X5 limit and hence would have no effect on RRP. Beyond this, any other prioritisation will reduce the total solar generation dispatched from these sources behind the X5 constraint. This would then increase the dispatch of higher priced, unconstrained plant and at some point, depending upon the supply-demand bid stack at the RRN in that dispatch interval, would increase the RRP.

In practice we could expect that it is likely that only limited prioritisation could be provided without increasing the regional price paid by customers. The overall impact of that would be unpredictable. The mathematical approach to prioritising physical dispatch based on ranking of generators but capping of price outcomes is unclear at this stage.

6. How will the TQM affect bidding?

The change to dispatch proposed under TQM would change the incentives on participants and their bidding behaviour. The exact method of implementation would be critical to any changed bidding. Based on our current understanding, generators may still have an incentive to disorderly bidding. In the illustrative example in Figure 1, if Generators 1 to 3 each have a different queue number, their bidding is irrelevant so long as their bid is below Gen 4, which sets the RRP. In reality, bidding to the price floor may then maximise their dispatch against other generators with the same queue priority in any binding constraints. In these circumstances, bidding at the MPF is likely to be the safest bidding strategy for in-merit, constrained generators.

In an ideal market (auction) design, dispatch is consistent with bids and prices; i.e. a generator could expect to be dispatched if their bid is below the clearing price and not dispatched if above it. The regional design of the NEM and the complexity of constraints means that this is not currently delivered. With a TQM, that difference could be exacerbated. However participants would need to take care that their bids did not lead to price capping and redispatch.

7. Implementing TQM in dispatch

The CEIG submission describes a method for implementing the TQM dispatch as follows:

> "NEMDE should first determine the bid-stack by assessing all MLF weighted bids to determine the least cost generation mix to meet demand in a given five-minute interval. Next, where there are binding constraints within the NEM that NEMDE must resolve, NEMDE should curtail generators in descending order of the queue."

One can see how this could work in our simple example. The "least cost generation mix" would involve dispatching Gens 1-3 at their full output, with Gen 4 contributing the remainder. Since this would violate the constraint, generators would then be curtailed in reverse queue order: e.g. under a 123 permutation, Gen 3 would be fully curtailed and then Gen 2 partially curtailed, with Gen 4

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[3] CEIG, CEIG response to the TAR consultation paper released May 2022, 10 June 2022, p.8

dispatch increasing to offset the curtailed generation. This gives the dispatch shown in table 2, above.

However, it is not clear that this approach can be generalised to a situation of multiple binding constraints and regions. For example, in the 123 dispatch above, Gen 2 might plausibly contribute to a *second* binding constraint in which no queue position 3 generators participate. If Gen 2 has to be curtailed anyway to manage this second constraint it might then be unnecessary to also curtail Gen 3 in the original constraint.

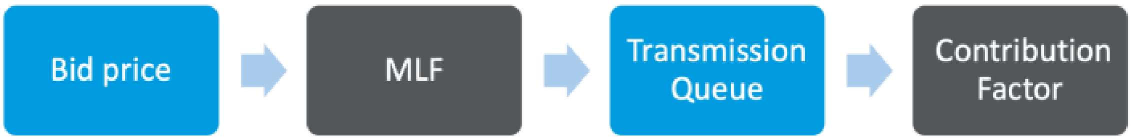
The ESB is considering instead using the reverse approach: dispatching generators at the front of the queue first, and then progressively adding lower priority generators to the dispatch until the constraint is binding. In the two-constraint example above, this would mean:

- Firstly dispatching Gen 1 to full output, which can be done with no constraint violations;
- Next dispatching Gen 2 until the second constraint binds
- Then dispatching Gen 3 until the original constraint binds

Under this approach, each dispatch is a complete, feasible dispatch, calculated using the dispatch algorithm. If there are N queue positions, then N runs of the dispatch algorithm will be required to calculate the TQM dispatch. If the CRM is added, one further run of the dispatch algorithm will be needed to clear this market.

It is not clear that this complies with the full intent of the CEIG's prioritisation, giving highest priority to bid price and MLF; viz:

Figure 3 Proposed placement of the queue in the NEMDE dispatch algorithm



This approach does not address or resolve the CEIG's proposal to unwind the TQM prioritisation if it leads to higher RRP than the status quo. In principle, another, WTA dispatch could be run and the RRPs compared, with WTA dispatch selected if it gives rise to lower RRPs. However, this approach would not identify possibly hybrid dispatches, which follow the TQM prioritisation to some extent whilst still avoiding RRP increases. Finding such hybrid dispatches would appear to be difficult.

8. The potential benefits of TQM to investment certainty

The TQM model is primarily aimed at delivering an improvement in certainty for investors. This is important in the development of renewables where the overall cost of delivered energy is mostly the capital cost. The CEIG highlight this in their submission:

> "A key factor for investors when considering whether to invest in a clean energy project is the relative certainty of future revenue streams associated with the project over the life of the proposed asset. The higher the revenue certainty, the lower the risk, and in turn, the lower the cost of capital for the project, and therefore a lower overall cost for consumers. "

When investing under the TQM regime, an investor would know their relative ranking in the queue and may be able to influence that ranking by their choice of location, funding of additional transmission or participating in a REZ process. Once provided with the ranking, they would be protected from other parties joining the market and increasing congestion on them by those parties having a lower ranking in the queue.

The details of these arrangements need to be worked through, including the methodology for setting queue rankings, the time over which rankings endure and the ability to transfer or trade rankings. These matters will be addressed in a paper to be shared with the TWG shortly. However we need to consider in an operational sense, how effective the TQM would be in actually dispatching by queue ranking. As outlined above, the queue ranking would give priority in dispatch to a participant but only to the extent that overall dispatch remains secure and the price to customers (RRP) is not affected. If additional low cost generation does connect to the grid in the future with a lower dispatch priority, failing to dispatch that plant when it would be efficient to do so would likely increase the RRP. Further work would be required on this aspect if the model proceeds in its current form.

9. Queue-based access with physical dispatch subject to congestion relief market

While the relative cost of the TQM dispatch compared to status quo cannot be determined, the analysis above demonstrates that prioritisation on the basis of a queue rather than security constrained, optimised dispatch can only lead to the same or higher costs against each binding constraint in each dispatch interval. Unless it can be demonstrated that the benefit of increased certainty to investors is greater than the cost of inefficient dispatch, then implementing TQM on the basis proposed would not meet the NEO.

An alternative is for the TQM to apply in combination with the CRM, so that market participants have the opportunity to trade to an efficient dispatch outcome. This approach would also provide more certainty for investors than the stand-alone TQM model due to the principle that that physical priority only be provided to the extent that the RRP is not affected.

Under such a model, the TQM would provide the access dispatch component of the CRM. The process for allocating a project’s ranking in the queue would not change but the ranking would give priority in the allocation of access rather than the dispatch of a generator. In this model, a generator who connected after others had made investment would, if they were likely to cause congestion, have a lower ranking. They may still be dispatched if that is the efficient outcome, but would receive little or no access; i.e. they would need to purchase congestion relief from higher ranked generators in order to be dispatched.[4]

The higher ranked generator congested off would not generate but would receive a congestion relief payment. The higher ranked generator would be willing to accept a congestion relief payment in order to not be dispatched if this is more profitable than being dispatched. This would occur, for instance, if the higher ranked generator had higher costs than the lower ranked generator, or if the lower ranked generator had the same cost, but a better participation factor in the relevant constraints.

Similarly, a lower ranked generator would only choose to pay for congestion relief and be dispatched if it was more profitable for them to do so. This would occur if the lower ranked generator had lower costs than the higher ranked generator, or if the lower ranked generator had the same cost, but a better participation factor in the relevant constraints. The alternative faced by the lower ranked

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[4] In theoretical terms, the congestion relief payment is expected to equal the difference between the LMP and the RRP for the amount that the higher ranked generator would have otherwise generated.

generator is that they are not dispatched due to congestion. This model would require new generators to “internalise the externality”; i.e. to take into account the costs they cause when they invest in projects which increase congestion. The revenue that the late-connecting generator would otherwise have received under the winner-takes-all arrangements are instead shared with pre-existing generators via the congestion relief payments.

The ESB’s preliminary preference in operational timeframes is for the CRM, however further work is required to understand its feasibility and cost. If the CRM is found to be unworkable or unduly costly, priority access could be provided by using the queue to determine a participant’s right to rebates under the CMM.

10. Conclusions

The relative cost of the TQM dispatch compared to status quo cannot be determined. Queue positions, or priorities, are delivered by another process and do not relate to the characteristics of the generator. We can though see that any prioritisation on the basis of a queue rather than security constrained optimised dispatch can only lead to the same or higher costs in each dispatch interval.

An objective of the ESB’s access reform is to improve dispatch efficiency; bringing it closer to an idealised optimal efficiency by encouraging generators to bid cost-reflectively even when constrained. The TQM will not achieve this unless, by fortunate coincidence, the queue order happens to align with efficient dispatch.

The CEIG’s proposed approach, of dispatching all generators and then curtailing generators at the back of the queue to remove constraint violations, seems unlikely to be workable in the general situation of multiple regions and binding constraints. But an alternative approach of dispatching generators at the front of the queue first seems to be feasible, although it may require multiple runs of the dispatch algorithm. The ESB’s technical experts are examining this matter. Consistency of this approach with the intent of the CEIG also needs further consideration.

Unless constrained in the manner proposed by the CEIG, TQM would lead to higher prices to customers in at least some dispatch intervals. The process to constrain outcomes to ensure customer prices are not affected would require further work and could erode many of the benefits investors might expect from the priority dispatch under TQM. The TQM dispatch could, in some cases, give rise to higher RRPs than the status quo dispatch, other things being equal. If the CEIG’s proposed approach is adopted, of reverting to WTA dispatch in these situations, this might reduce the value and certainty that is provided to generators at the front of the queue.

Subject to understanding the process for, and impact of, applying a price constraint, the TQM model could offer a major improvement in certainty for investors. Investors have protection against generators unexpectedly connecting to the grid after they have committed funding and reducing their access. This is a benefit worth pursuing and could potentially be delivered by maintaining efficient physical dispatch while allocating access on a queuing basis. This could be done by using a TQM process to allocate access and using a CRM to enable trading around that, or by using a TQM process to allocate residues in a CMM process.