Energy Market Company

RCP PAPER NO.	:	**EMC/RCP/23/2005/CP10**
SUBJECT	:	**REVIEW OF CONSTRAINT VIOLATION PENALTY STRUCTURE**
FOR	:	**DECISION**
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Executive Summary

In some cases, the current constraint violation penalty structure has resulted in the order of the constraint violation undertaken by the MCE not matching the intended order. Identified problems include: (1) energy being shed before reserve, (2) line flow limits being violated before load being shed and (3) excess generation being scheduled before load is shed.

EMC has investigated three options to address the identified problems. The first option was abandoned because it would require significant downward revisions to reserve price caps which may reduce the amount of reserve available to the market. Alternatively, it would require a significant increase in VoLL which cannot be justified under the current calculation methodology.

The second option would solve Problems 2 and 3, but would result in more extreme negative prices under a spring washer scenario. The third option solves Problem 2, which is the problem with the most significant practical implications, without a significant effect on prices. This is the option recommended by EMC.

On 18 October 2005, the TWG considered the EMC's review and the results of the testing. The TWG considered that the problems experienced were not significant enough to warrant changes to the CVP structure. Accordingly, the TWG recommends that the CVP structure remain unchanged. However, in the event VoLL is increased, for example to incentivise sufficient generation investment, then EMC will review whether the Deficit Reserve CVPs should be revised to solve Problem 1.

1. Introduction

The RCP's workplan contains a workstream which involves a review of the Constraint Violation Penalty (CVP) structure used in the Market Clearing Engine (MCE).

This paper presents the results of the EMC's review and outlines the TWG's views and conclusions.

2. Background

The relative size of the CVPs for the different types of violations are important in that they determine how the MCE makes trade-offs to produce the optimal schedule for a dispatch period. EMC has observed that, in some cases, the current CVP structure has resulted in the order of the constraint violation undertaken by the MCE not matching the intended order.

EMC has investigated the identified occurrences and tested possible solutions. The purpose of this paper is to present the results obtained to the TWG, and to recommend that TWG consider that two of the CVPs (referred to as Option 3) be increased.

3. The Role of Constraint Violation Penalties

The MCE produces schedules of prices and quantities with the aim of maximising the objective function (net benefit), subject to a number of constraints. The constraints represent the physical limits of transmission lines, transformers and other equipment, amongst other things. Applying the constraints ensures that the schedule is physically feasible, and complies with the applicable security limits to ensure the reliability and security of the system. The process used by the MCE involves finding the optimal solution (maximising the objective function or net benefit) from multiple possible solutions. In some cases, there is no solution that does not involve the violation of at least one constraint, i.e. the MCE is not able to find a feasible solution within the set of constraints.

To ensure that the MCE can always arrive at a solution, a number of the constraints in the model are defined as *soft* – meaning that they can be violated at the cost of incurring a penalty (Constraint Violation Penalty, or CVP) for the constraint(s) that are violated. Different CVPs are applied in respect of different types of these *soft* constraints.

The relative importance of constraints is reflected in the CVP structure where constraints that may be violated in the physical system (such as shedding reserve, regulation or load) have much lower CVPs compared to constraints that should never be violated, such as facility limits, line flow limits or security constraints.

For example, under the current CVP structure, the CVP associated with a deficit in generation (requiring load to be shed) is set at $5,000 (1* Value of Lost Load[1], or VoLL) whereas the CVP associated with the violation of a facility limit is set at $100,000 (20*VoLL).

The relative values of CVPs determine the trade-offs that the MCE will make when facing the situation of having to violate at least one constraint. The aim of maximising the objective function should drive the MCE to violate the constraints with the lowest CVPs first.

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[1] When load is shed, the value of another MWh of power equals the cost imposed on those customers who have not been supplied that MWh of electricity. This is the value of lost load or VoLL. The value of lost load is defined as the average value that consumers place on an unsupplied MWh of electricity.

4. Current Constraint Violation Penalty Structure

Currently, the following CVPs are used. The structure reflects the desire to shed regulation, followed by reserve and then energy if necessary. Other penalties are multiples of VoLL to reflect that the relevant constraints should not be violated physically.

Name of CVP	**When Invoked**	**Value**	**$Value**
Deficit Regulation	Where less than the required amount of regulation is scheduled	0.6*VoLL	$3,000
Deficit Reserve 10 Minute (Contingency Reserve)	Where less than the required amount of contingency reserve is scheduled	0.7*VoLL	$3,500
Deficit Reserve 30 Second (Secondary Reserve)	Where less than the required amount of secondary reserve is scheduled	0.8*VoLL	$4,000
Deficit Reserve 8 Second (Primary Reserve)	Where less than the required amount of primary reserve is scheduled	0.9*VoLL	$4,500
Deficit Generation	Where generation is insufficient to meet demand and load must be shed	VoLL	$5,000
Line Flow	Where the scheduled flow of energy across a line is higher than the line's rated capacity	2.2*VoLL	$11,000
Deficit Security	Where a security constraint applied by PSO (in respect of a line or a facility) is violated	6*VoLL	$30,000
Facility (various)	Where a facility is scheduled beyond its approved standing capability data	20*VoLL	$100,000
Excess Generation	Where scheduled generation is higher than actual load and artificial load is scheduled	CDC[2]	-$5,000

The current CVPs used may result in bus prices between -$5,000 and $5,000 and observed nodal energy prices of between -$5,000 and $5,000. However, price caps are then applied in post-processing which limit observed energy prices to between -$4,500 and $4,500.

[2] CDC is the Cost of Decommitment and represents the cost of having to remove a generator from service in order to reduce generation output to match demand.

5. Observed Problems

Under the current CVP structure, EMC has observed the following problems. For each of the identified problems, examples of affected trading periods and a description of the practical impact are provided. In all of the examples provided, the problem occurred in the Real-Time Schedule. Settlement was not affected because the problems were removed subsequently in re-runs. None of the problems listed below occurred on 29 June 2004.

Problem 1: The Deficit Reserve Penalties are too high relative to the Deficit Generation Penalty

<u>Problem Definition</u>

Sometimes, the total offered capacity of energy and reserve will be lower than the total quantity of energy and reserve that is demanded. The desired outcome is that reserve is shed before energy. This is reflected in the CVP structure where the deficit reserve penalties are all lower than the deficit generation penalty.

Where a unit offers both energy and reserve, the MCE needs to decide whether to use the available capacity to schedule energy or reserve. It has been observed that when the unit is offering all three classes of reserve, the MCE may then shed energy before reserve is shed. This is due to the fact that reducing the amount by which a unit is scheduled for energy potentially allows the unit to be scheduled higher for all three classes of reserve. The total avoided CVP for shedding 1MW of energy is potentially 2.4*VoLL[3], the sum of the CVPs for all three classes of reserve.

<u>Practical Impact</u>

Examples of affected trading periods	Impact
Trading periods 28, 29 and 30 on 14 August 2003	Consequence observed due to this problem (not due to a physical event): • Load shedding was scheduled (deficit generation) even though full reserves were still being scheduled.

Problem 2: The Line Flow Penalty is set too low relative to the Deficit Generation Penalty

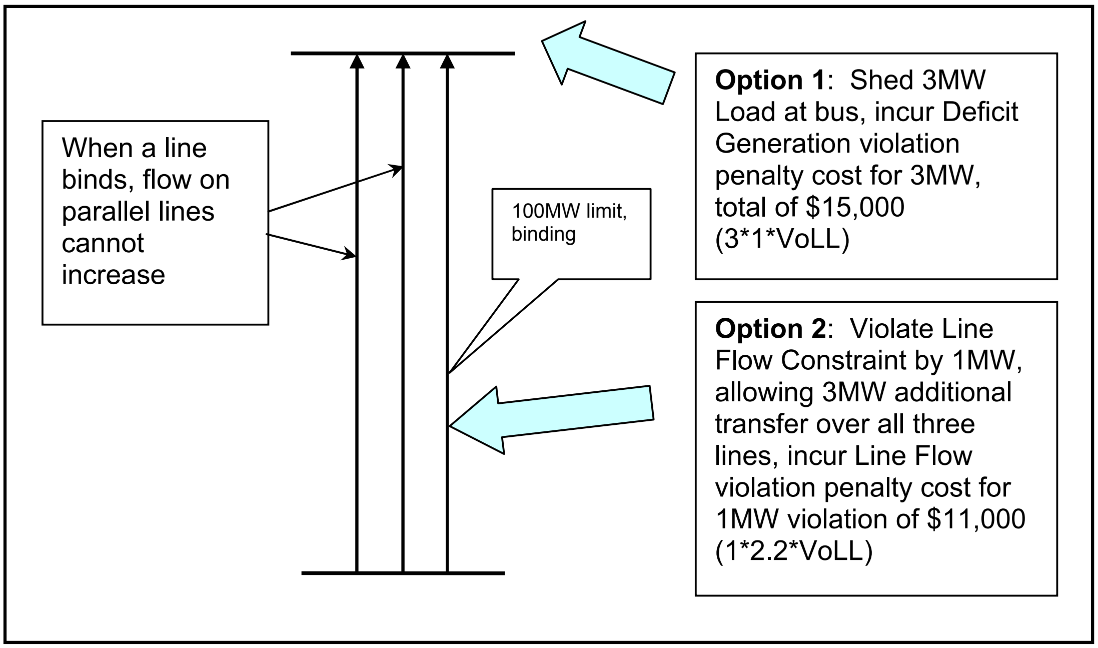
<u>Problem Definition</u>

The Line Flow Penalty is set at 2.2*VoLL while the Deficit Generation Penalty is set at VoLL. The intent is that load shedding (deficit generation) should always occur before a line flow constraint is violated. However, currently a line flow constraint can be violated before load is shed.

[3] Sum of 0.7*VoLL for Deficit Reserve - Contingency, 0.8*VoLL for Deficit Reserve - Secondary, 0.9*VoLL for Deficit Reserve – Primary

This problem occurs because the violation on a single line constraint can allow increased flows to occur across multiple parallel lines. For example, if a binding line flow constraint on one of three parallel lines results in a total of 3MW of load being shed, the total violation penalty cost will be $15,000 (3*VoLL). However violating the line flow constraint on the binding line by 1MW will incur a penalty of only $11,000, but allow an additional 3MW of energy to flow into the constrained area. Therefore, the MCE will prefer to violate the line flow constraint, rather than shedding load.

Figure 1: Illustration of Problem 2



<u>Practical Impact</u>

Examples of affected trading periods	Impact
Trading periods 18-32 on 22 September 2003	The consequences observed are: • The MCE scheduled a line overload (load shedding should have been scheduled). • Violation penalties for line flow violation were incurred. • No effect on reserve/regulation prices. • USEP was higher due to violation penalties incurred, but lower than it should have been.

Problem 3: The Excess Generation Penalty is set too low relative to the Deficit Generation Penalty

<u>Problem Definition</u>

The Excess Generation Penalty may be incurred before the Deficit Generation Penalty. Where a spring washer[4] effect occurs, the price at the low-price side of the spring washer can drop to a level where the Excess Generation Penalty is incurred before the Deficit Generation Penalty on the high price side of the spring washer is incurred.

When this occurs, the MCE schedules artificial load, and the solution shows an energy surplus instead of an energy shortfall, incurring the Generation Excess Penalty. The correct outcome should be for an energy shortfall to occur instead. This is preferable because it is physically feasible to shed load whereas it is physically impossible to create artificial load to compensate for an energy surplus.

<u>Practical Impact</u>

Examples of affected trading periods	Impact
Trading Period 35 on 7 July 2004	• Fictitious load was scheduled instead of load shedding. • No effect on reserve/regulation prices. • USEP was higher due to violation penalties incurred, but lower than it should have been. • Energy quantity scheduled was slightly higher to meet the fictitious load, meaning that the scheduled outcome differed from the physical outcome.

6. Options Considered and Results of Testing

The EMC considered three potential solutions to the problems identified in Section 5 above:

<u>Option 1</u>: Lowering the Deficit Reserve Penalties so their combined total is less than the Deficit Generation Penalty

This option is designed to solve Problem 1 outlined above. EMC abandoned this option without testing because reducing the Deficit Reserve Penalties to ensure that they add up to less than VoLL would also require that the current price caps for the three classes of reserve and regulation be reduced significantly, for example to $1,700, $1,600, $1,500 and $1,400 from current values of $4,250, $3,750, $3,250 and $2,750 respectively. This significant reduction in price caps could run the risk of reducing the amount of reserve and regulation available to the market.

The only other alternative would be to increase VoLL to $12,000 or above (to at least the sum of the CVPs for the three classes of reserve) so that the current price cap for the three classes of reserve and regulation need not be reduced. EMC re-calculated VoLL using current GDP and energy consumption data (see Annex 1). VoLL was found to be only $5,250/MWh in 2004. This VoLL level does not justify raising the value of VoLL in the MCE to a level of more than $12,000.

[4] When the spring washer effect occurs around a binding line constraint, one end (the high-side) has its prices pushed up, while the other end (the low-side) is pushed down below the normal prices.

On balance, the consequences of implementing a solution to this problem would be more severe than the consequences of the problem which is rarely observed and only occurs at times when the system is under stress and when the model is unlikely to precisely reflect the physical situation in any case.

Option 2: Increasing Line Flow to 18*VoLL, Deficit Security to 19*VoLL and decreasing Excess Generation to -21*VoLL

Under this option, the upper penalties are anchored around the facility violation penalty which remains unchanged at 20*VoLL. The values are set such that the difference between these penalties and the Deficit Generation Penalty is sufficiently large to ensure that the Deficit Generation Penalty is always incurred first. The Line Flow Penalty is lowest because line flow constraints can be violated to some degree for limited amounts of time. Placing the Deficit Security Penalty between the Line Flow and Facility Penalties means that the current relative ranking of the Line Flow and Facility Penalties is preserved. The Excess Generation Penalty is highest in absolute terms because it is physically impossible to implement.

The tests (with findings outlined below) involved analysing a number of distinct cases to assess whether the revised Option 2 CVPs would fix Problems 2 and 3 outlined above and provide a better overall outcome.

Findings

The tests carried out and the results obtained are summarized in Annex 2. The MNN prices, USEP, Reserve and Regulation prices of each test case are presented in Annex 3.

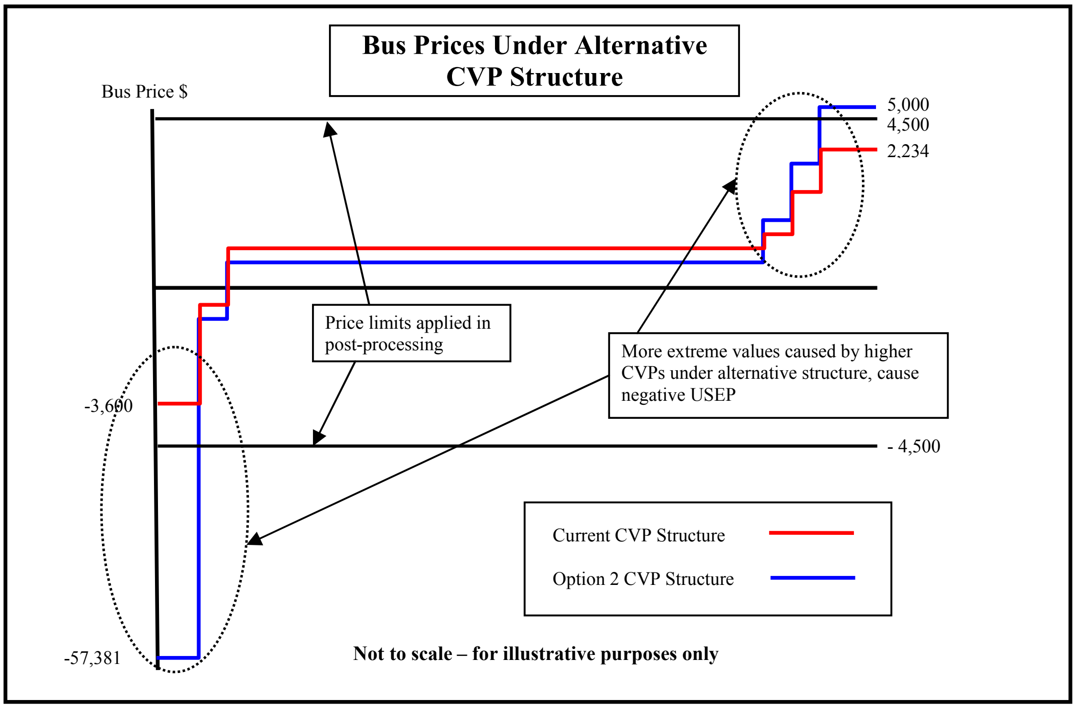
Test Cases 1 to 4 demonstrate that the modified penalty structure achieves the desired results and that the constraints are violated in the correct order. Test Cases 5 to 9 investigate the more extreme case where generation is constrained within an area, and where scheduling a bus deficit does not address the problem. These tests are used to confirm that the priority order reflected in the penalty structure is reflected in the test results.

The tests demonstrated that the modified penalty structure achieves the objectives, but in some cases results in more extreme prices. For example, where generation is constrained in an area, the existing penalties result in a line violation. The proposed new penalty structure would reduce the line violation, but some bus deficit arises from the spring-washer effect. This in itself is not of concern and is expected.

What is cause for concern under the Test Case 5 is that the more negative value of -21*VoLL for the Excess Generation Penalty creates more extreme bus prices, which then result in a negative USEP.

The graph in Figure 2, which is not to scale, shows how bus prices are more extreme under the alternative CVP structure. Even with the price cap and price floor applied in post-processing, the result is more widespread extreme nodal prices in the area affected by the spring washer effect.

Figure 2: Bus Prices Under Alternative CVP Structure



As a result of the findings obtained with the CVP structure proposed under Option 2, EMC decided to test an alternative CVP structure, with only the Line Flow and Deficit Security Penalties increased.

Option 3: Increase Line flow to 18*VoLL and Deficit Security to 19*VoLL

Option 3 was considered as an alternative to Option 2 due to the more extreme prices produced by Option 2 under testing. Under Option 3, only the Line Flow and Deficit Security Penalties are increased, with the Excess Generation Penalty remaining unchanged. The Line Flow Penalty is increased to ensure that load is always shed before a line constraint is violated.

The tests (with findings outlined below) involved analysing a number of distinct cases to assess whether the revised Option 3 CVPs would fix Problems 2 and 3 outlined above and provide a better overall outcome.

The tests carried out and the results obtained are summarized in Annex 1. The MNN prices, USEP, Reserve and Regulation prices associated with each test case are presented in Annex 2.

Findings

The test cases demonstrate that increasing the Line Flow Penalty prevents the line flow violation from occurring ahead of load being shed. Increasing the Deficit Security Penalty does not affect the way the security constraint functions.

The tests performed under Test Case 14 confirmed that prices are less extreme if the existing Excess Generation Penalty is retained rather than decreased to -21*VoLL. Test Case 14b shows that USEP under the Option 3 CVP structure is relatively close to the USEP experienced with the current CVP structure (-$57.13 compared to -$54.98). Under the Option 3 CVP structure, MNN Prices at the SAKRA nodes decrease to -$4,500 from -$4,416.83 whereas the other MNN prices increase on average by $3.96 from an average of $106.14 to $110.10. Under the Option 2 CVP Structure, USEP would be -$81.26. This demonstrates that the Option 3 CVP structure achieves the desired results without creating the more extreme prices that would occur under the Option 2 CVP structure.

It is useful to note here that the MNN prices and USEP obtained under these test scenarios would only be used for settlement if prices are not subsequently revised under Section 9.3.2C of Chapter 6 of the Market Rules. This means that such prices are not likely to be used for settlement often as load shedding is likely to be rare and prices will generally be revised if load had not actually been shed in the relevant dispatch period.

7. EMC's Conclusions

The MCE formulation is, by necessity, a simplified approximation of an extremely complex physical system. As such, modeled outcomes of the MCE will never perfectly match all physical outcomes in all extreme situations. Therefore, the aim must be to design the MCE formulation such that it works best under most reasonable scenarios. It is undesirable to modify the MCE so that it correctly models an outcome that very rarely occurs while compromising how the MCE works in other scenarios that are more likely to occur. These are the principles underpinning EMC's recommendation.

Option 1 was dismissed without testing because implementation would either require that the price limits for reserve and regulation be decreased significantly, or that VoLL is increased significantly. Decreasing price limits for reserve and regulation significantly is undesirable because it could result in less reserve being offered into the market, potentially undermining system security.

EMC re-calculated VoLL using the latest GDP and electricity consumption data and found that VoLL had not changed significantly from the current level of $5,000. Therefore, EMC recommends that the Deficit Reserve Penalties remain unchanged. In this case, the solution to a rare problem is likely to have more severe consequences than the identified problem itself.

Option 2 achieved the desired outcomes in that load would be shed before a line flow limit is violated. Also, in theory, the Excess Generation Penalty should be higher to reflect the fact that it is impossible to physically schedule fictitious load. However, this effectively lowers the price floor, leading to more extreme prices and a more complex interaction of CVPs.

Option 3 ensures that load is shed before line flow limits are violated, without the more extreme results experienced under Option 2. Testing has also shown that the increased Security Deficit Penalty does not affect the functionality of the security constraint.

On balance, EMC recommended that the TWG consider whether Option 3 should be implemented.

8. Consideration by the TWG

The RCP considered the evaluation of Options 1 to 3 presented in this paper. In respect of Option 1, the TWG agreed that reducing the three Deficit Reserve CVPs would be undesirable and have consequences more severe than the identified problem. In terms of the alternative approach of increasing VoLL above $12,000, the TWG noted that there may be other reasons that support an increase in VoLL above its current level. However, this is outside the scope of this review and an increase in VoLL of such magnitude cannot be justified on the basis that it will solve Problem 1. However, in the event that VoLL is increased, for example to incentivise sufficient generation investment, then EMC will review whether the Deficit Reserve CVPs should be revised to solve Problem 1.

The TWG also considered that the negative consequences of Option 2, in the form of more extreme prices, would outweigh the potential benefits. In respect of Option 3, the TWG recognised that this option had performed better under testing and had not resulted in the more extreme prices that were experienced under Option 2.

Nevertheless, the TWG considered that changing the CVP structure is currently not justified given the relatively infrequent and minor nature of the problems experienced. The fact that there would only be an impact on settlement prices if load is actually shed was taken into account by the TWG in forming this view.

Consequently, the TWG recommends that the CVP structure be left unchanged.

9. Recommendations

The TWG recommends that the RCP:

a. **endorse** the TWG's recommendation that the CVP structure should remain unchanged.

Annex 1: Updated Value for Value of Lost Load

The Economic Estimate method was used by PA Consulting to calculate VoLL and then cross checked with the results of a survey of other jurisdictions. The estimate of VoLL used by PA consulting is as follows:

Singapore GDP (2000)	=	S$159.0 Billion
Electricity Production (2000)	=	31,665 GWh
Therefore, VoLL	=	S$5,021/MWh

The following table shows re-calculated estimates for VoLL for the years 2000 to 2004 using the Economic Estimate method. The quantity of energy consumed (i.e. WEQ) in a year is used for these calculations. The GDP figures are taken from the Economic Survey of Singapore Second Quarter 2005 published by the Singapore Department of Statistics[5].

Year	Calculation	Additional Embedded Load[6]	VoLL Value	VoLL Value Including Embedded Load
2000	$159.596 Billion/ 29,448 GWh	-	$ 5,420/MWh	$ 5,420/MWh
2001	$153.771 Billion/ 30,465 GWh	-	$ 5,047/MWh	$ 5,047/MWh
2002	$158.388 Billion/ 31,816 GWh	-	$ 4,978/MWh	$ 4,978/MWh
2003	$160.924 Billion/ 32,578 GWh	1,586.961 GWh	$ 4,940/MWh	$ 4,710/MWh
2004	$180.554 Billion/ 32,805 GWh	1,586.961 GWh	$ 5,504/MWh	$ 5,250/MWh
Average			***$ 5,178/MWh***	***$ 5,081/MWh***

Conclusion

The average value of VoLL over last five years is $ 5,178/MWh ($5,081/MWh if embedded load is accounted for). This represents a slight increase in the VoLL value compared to the year 2000 figure calculated by PA ($5,021/MWh). Hence, there is no strong justification to increase VoLL significantly above its current level.

[5] See: http://www.singstat.gov.sg/keystats/mqstats/ess/essa11.pdf

[6] 452.9 MW of installed embedded generation is currently exempt from participating in the wholesale maket of the NEMS and hence not settled through the market. The annual load figures here assume that these plants were generating only 40% of the time. Such generation would result in an increase in the total system demand thus reducing VoLL. For years 2000 to 2002 (i.e. in the SEP), such load was already accounted for in the metered data.

Annex 2: Tests Performed, Purpose and Outcomes Recorded

Option 2

No	Description	Purpose	Outcome
1	Line Flow Case One line is de-rated to create line violation. The Option 2 CVP structure is then applied and results are compared.	Show that increasing the Line Flow Penalty to 18*VoLL will result in load being shed (deficit generation violation) instead of a line overload (line flow violation) even when they are parallel flows, thus resolving Problem 2.	Results as expected. Under the existing penalty structure, there is an overload (line flow violation) on the line. No deficit generation is scheduled. Under the Option 2 penalty structure, load is shed (deficit generation is scheduled). No line overload (line flow violation) occurs.
2	Bus Excess Case Two lines are de-rated to create spring washer. The Option 2 CVP structure is then applied and results are compared.	Show that decreasing the Excess Generation Penalty to -21*VoLL will result in load shedding (deficit generation violation) to occur before excess generation, solving Problem 3.	Results as expected. Under the existing penalty structure, a bus excess (excess generation) is scheduled and a line overload (line flow violation) is also scheduled. Under the Option 2 penalty structure, load is shed. There is no bus excess (excess generation) and no line overload (line flow violation). However, negative prices are more widespread.
3	Bus Excess Case (ramp rate) Two branches are removed to create a situation where the facility cannot ramp down immediately without violating the facility constraint. The Option 2 CVP structure is then applied and results are compared.	Show that decreasing the Excess Generation Penalty to -21*VoLL will result in the unit ramping down to match the load before excess generation occurs, reflecting the physical reality.	Results as expected. Under the existing penalty structure, generation at ENV Tuas South stops at ramp rate minimum. A bus excess takes up the difference between generation and real load. Under the Option 2 penalty structure, the generation at ENV Tuas South violates its ramp-rate minimum and ramps down to match real load. No bus excess is scheduled. The price of -$100,000.01 at ENV Tuas South represents the cost of a 1MW increase in load at the bus (consisting of violation cost of $100,000 and offer price of generation at -$0.01).

4	Security Constraint Case (security constraint applied) A binding security constraint is applied to two parallel lines, requiring the MCE to schedule deficit generation at the bus where demand cannot be satisfied. The Option 2 CVP structure is then applied and results are compared.	Show whether the MCE still correctly schedules deficit generation where a binding security constraint is applied to two parallel lines.	Results as expected. Under the existing penalty structure, a bus deficit (deficit generation) is scheduled. The result is identical under the Option 2 penalty structure.
5	Priority Order Test Part 1 (Lines 1 and 2 removed) With the 230kV circuits removed, SAKRA needs to ramp down to prevent overloading the 66kV circuits. Because the SAKRA units have regulation offers and are above regulation minimum, they are constrained to minimum = generation + regulation. The Option 2 CVP structure is then applied.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	Under the existing penalty structure, SKRA is prevented from reducing below regulation Minimum, the line is violated (line flow violation) in order to remove the SKRA generation from the constrained area. Bus excess (excess generation) and bus deficit (deficit generation) are not used because violation of the line enables flow on parallel lines before the bus prices rise to VoLL or fall to -VoLL. Under the Option 2 violation penalty structure, the line is violated (line flow violation) in order to remove the SKRA generation from the constrained area. However, in this case, the MCE also schedules deficit generation at the high price end of the constraint. The line violation is 10% less than with the existing violation penalty structure. The higher line flow violation penalty which allows the bus price to rise to VoLL also causes other bus prices in the constrained area to reach large negative values. Although these will be capped at -$4,500, but in combination they are sufficient to reduce USEP to -$41.02.

6	<u>Priority Order Test Part 2 (as Part 1, regulation minimum constraint removed)</u> Lines 1 and 2 are removed. SKRA regulation offers are set to zero to allow ramp-down to below regulation minimum.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	With the 230KV circuits out, SKRA needs to ramp down to prevent overloading the 66kV circuits. With the regulation offers set to zero, the unit is scheduled down to match the export capacity. Hence, there is no problem. USEP increases to $110.21.
7	<u>Priority Order Test Part 3 (as Part 1, with violated 66kV line removed)</u> Lines 1 and 2 are removed. SKRA regulation offers prevent ramp-down below regulation minimum. The binding 66kV line has been removed. This case is run with the Option 2 CVP structure only.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	With SKRA unable to ramp down, the lines need to violate in order to remove the generation from the constrained area. Two 66kV lines violate, incurring a violation penalty of $90,000/MWh. USEP reduces to -$41.12.
8	<u>Priority Order Test Part 4 (as part 3, with remaining 66kV lines removed)</u> Lines 1 and 2 removed. SKRA regulation offers prevent ramp down below regulation minimum. Remaining 66kV lines have been removed. This case is run with the Option 2 CVP structure only.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	There are now no lines leaving the constrained area, hence no line flow violation. The result is that the MCE breaks the regulation minimum constraint (facility constraint) allowing it to ramp down below its regulation minimum, incurring a violation penalty of $100,000/MWh. USEP increases to $159.64.

9a	Priority Order Test Part 5a (Lines 1 and 2 re-rated to 5MVA) This case is run with the Option 2 CVP structure only.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	Both line ratings are violated (line flow violation occurs) to allow SKRA generation to be exported. This is the base result. Subsequent results will incorporate security constraints. USEP is -$298.33.
9b	Priority Order Test Part 5b (Line 2 re-rated to 50MVA, Line 1 re-rated and security constrained to limit flow to <=40MW This case is run with the Option 2 CVP structure only.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	The MCE violates the facility (facility violation) and the lines (line flow violation), but not the security constraint. This is because an extra MW of facility violation will prevent the need for 1MW of line violation and 1MW of security constraint violation. The MCE stops increasing the line flow before it would cause the security constraint to also violate. This is not a clear cut case of the line flow violating before the security constraint because the facility is also violated. In order for the MCE to be able to choose between violating the line constraint or the security constraint, the line flows and the security constraint must somehow be linked, which is difficult to achieve. Priority Order Test 9e demonstrates the priority order. USEP is -$281.89.
9c	Priority Order Test Part 5c (Line 2 re-rated to 150MVA, Line 1 re-rated to 150MVA and security constrained to limit flow <=99MW) This case is run with the Option 2 CVP structure only.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	This illustrates the problem of trying to construct a case where the MCE chooses between violating the line limit (line flow violation) and the security constraint. Here, the MCE violates only the security constraint. USEP is -$300.74.

9d	Priority Order Test Part 5d (Line 2 re-rated to 100MVA, Line 1 re-rated to 100MVA and security constrained to limit flow <=20MW) This case is run with the Option 2 CVP structure only.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	In this case, the security constraint is set so low that it is not possible for the generation to leave the area without violating the security constraint. The fact that the MCE chooses to violate the security constraint and not the facility constraint demonstrates that the priority order of the penalties is correctly observed between the facility and security constraints. USEP is -$298.33.
9e	Priority Order Test Part 5e (Line 2 re-rated to 150MVA, Line 1 re-rated to 100MVA and security constrained to limit flow >=110MW) This case is run with the Option 2 CVP structure only.	Confirm whether the MCE violates constraints in the intended order in a scenario where generation is required to ramp down in a constrained area.	The line is violated in order to satisfy the security constraint, demonstrating that the priority order correctly violates the line constraint before the security constraint. USEP is $103.22.

Option 3

No	Description	Purpose	Outcome
10	Line Flow Case Line rating is lowered to cause a violation of the line flow constraint. The Option 3 CVP structure is then applied and results are compared.	Show that increasing the Line Flow Penalty to 18*VoLL under the Option 3 CVP structure results in load being shed before a line flow violation occurs.	Results as expected. Under the existing penalties an overload on line occurs and no bus deficit is scheduled. Under the Option 3 penalties, load is shed. There is no line overload.
11	Bus Excess Case (spring-washer with resulting bus excess) Two line limits are lowered to cause a spring-washer effect with a bus excess violation being scheduled at the low price side of the spring-washer, and some line flow violation due to the availability of parallel flows. The Option 3 CVP structure is then applied and results are compared.	Show that under the Option 3 CVP structure, the MCE chooses to shed load and/or excess generation rather than violating the line due to the increased Line Flow Penalty of 18*VoLL.	Results as expected. Under the existing penalties, the MCE schedules a bus excess and a line overload. Under the new penalties of Option 3, no line overload is scheduled due to the higher Line Flow Penalty. Load is shed as well as a bus excess occurs.
12	Security Constraint Case (security constraint with resulting bus deficit) A security constraint is created and applied, resulting in a bus deficit. The Option 3 CVP structure is then applied and results are compared.	Show that increasing the Line Flow and Deficit Security Penalties (to 18*VoLL and 19*VoLL respectively) does not affect the way security constraints are applied by the MCE.	Results as expected. Under existing penalties, a bus deficit arises. Under the new penalties, the result is identical. Increasing the deficit security violation penalty does not affect the action of the security constraint.

13	Bus Excess Case (generator islanded by isolation with resulting bus excess) A ramp rate constrained generator is isolated in order to cause a bus excess violation to be scheduled. With the bus excess violation established, the Option 3 CVP structure is then applied and results are compared.	Show that the Option 3 CVP structure does not change how excess generation is scheduled.	Results as expected. Excess generation is scheduled under both violation penalty structures. Prices are identical.
14a	Bus Excess Case Part 1 (binding line with resulting bus excess) Generation from SAKRA is constrained in the Jurong Island area. Both the 230kV circuits are removed from service through loading a modified network status file. SAKRA generation will be constrained on automatically by its regulation. SAKRA area is completely isolated as a 66kV bus split prevents generation from exiting the area via the 66kV line. Both the Option 2 and 3 CVP structures are then applied and results are compared.	Show that the Option 3 penalty structure does not result in more extreme prices, as experienced under Option 2.	The result with the Option 3 penalties is identical to the result achieved with the existing penalty structure. With the area islanded and isolated, the existing penalty structure results in a bus excess being used to remove the SAKRA generation. The Option 3 penalties provide the same result because neither the Line Flow Penalty nor the Security Constraint Penalty has any effect. All bus prices are set at -\$5,000 and capped at -\$4,500. USEP is -\$13.57 under both structures. Under the Option 2 penalty structure, the result is a facility violation to allow SAKRA to ramp down, not a bus excess. All bus prices in the isolated area set at -\$99,999.05. USEP is set at -\$13.54. To properly compare the re-test, need to recreate the 66kV exit path that existed in the original testing of Option 2. This is carried out under Test 14b.

14b	<u>Bus Excess Case Part 2</u> Using the same base case as Test 14a above, Lines 1 and 2 are removed and the area is connected to the rest of the system through the 66kV line. Both the Option 2 and 3 CVP structures are then applied and results are compared.	Show that the result under the Option 3 penalty structure does not result in more extreme prices as experienced under Option 2.	Under the current penalty structure, there is no bus excess because the parallel line flows allow a line violation to clear the generation from the area. Prices in the constrained area range from -$2,354.55 to $4,416.83. USEP is -$54.98. Under Option 3, increasing the Line Flow Penalty to 18*VoLL prevents the line from violating and bus excess is used to clear the excess generation. Prices in the constrained area range from -$5,000 to -$2,669.94. USEP is -$57.13. Prices outside the constrained area are slightly higher as, with no line flow violation, less generation reaches the rest of the system from the constrained area. The MNN Price at the SAKRA nodes has dropped to -$4,500 from -$4,416.83 while the average other MNN prices increased by $3.96 from $106.14 to $110.10. Overall, this is a better result. Under the Option 2 violation penalty structure (with the Excess Generation Penalty at -21*VoLL or -$105,000), it is again cheaper for the MCE to violate the line. Again, parallel flows allow the line to violate before the prices hit the new line violation penalty of $90,000. Within the constrained area, prices range from -$36,899.12 to -$20,025.89. Prices outside the constrained area and the degree of line flow violation are the same as with the existing penalties. This is because both solve the problem by violating the line flow limit. Within the constrained area, the increased bus excess results in a clear example of more extreme prices. Although prices under -$5,000 are capped to -$4,500, there are more instances than with the other violation penalty structures and therefore USEP is lower at -$81.26.