Notice of Market Rules Modification

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Mixed Integer Program (MIP)-based regulation constraints were first introduced into the Market Clearing Engine (MCE) in 2007. The use of MIP-based regulation constraints allows a generator to ramp outside of its regulation range if not scheduled for regulation.

As there was initial concern about the impact on solving times, these MIP-based regulation constraints were used only when deemed necessary, i.e. only when it was determined that there were generators trapped at their RegulationMin or RegulationMax during a normal linear programming run.

However, it was observed that if MIP-based regulation constraints are only applied for "trapped" cases, the MCE can produce sub-optimal schedules under certain circumstances. Thus, it is proposed that the MIP-based regulation constraints should be applied for all dispatch periods.

It is also proposed that the existing MIP-based regulation constraints, which currently employ three binary variables and seven constraints, can be re-formulated by using fewer variables and constraints to define the same solution space.

This paper examined the limitations of the existing MIP-based regulation formulation and concludes that the proposed re-formulation of the MIP-based regulation constraints is superior to the existing one.

The TWG and the RCP unanimously supported the proposed rule modifications to in **Annex 1**.

Date considered by Rules Change Panel:	07 November 2013
Date considered by EMC Board:	28 November 2013
Date considered by Energy Market Authority:	11 December 2013

Proposed rule modification:

See attached paper.

Reasons for rejection/referral back to Rules Change Panel (if applicable):

PAPER NO. : **EMC/BD/XX/2013/XX**

RCP PAPER NO. : **EMC/RCP/2013/70/RC319**

SUBJECT : **REMODELLING OF MIXED INTEGER PROGRAM (MIP)-BASED REGULATION CONSTRAINTS**

FOR : **DECISION**

PREPARED BY : **WANG JING**
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SVP, MARKET ADMINISTRATION

DATE OF MEETING : **28 NOVEMBER 2013**

Executive Summary

Mixed Integer Program (MIP)-based regulation constraints were first introduced into the Market Clearing Engine (MCE) in 2007. The use of MIP-based regulation constraints allows a generator to ramp outside of its regulation range if not scheduled for regulation.

As there was initial concern about the impact on solving times, these MIP-based regulation constraints were used only when deemed necessary, i.e. only when it was determined that there were generators trapped at their RegulationMin or RegulationMax during a normal linear programming run.

However, it was observed that if MIP-based regulation constraints are only applied for "trapped" cases, the MCE can produce sub-optimal schedules under certain circumstances. Thus, it is proposed that the MIP-based regulation constraints should be applied for all dispatch periods.

It is also proposed that the existing MIP-based regulation constraints, which currently employ three binary variables and seven constraints, can be re-formulated by using fewer variables and constraints to define the same solution space.

This paper examined the limitations of the existing MIP-based regulation formulation and concludes that the proposed re-formulation of the MIP-based regulation constraints is superior to the existing one.

The Technical Working Group and the Rules Change Panel (RCP) considered the proposed rule modifications to re-formulate the MIP-based regulation constraints and unanimously **supported** the proposed rule modifications as set out in **Annex 1.**

The RCP recommends that the EMC Board adopt this proposal.

1. Introduction

Mixed Integer Program (MIP) is a field of Linear Programming (LP) in which some variables are required to be integers[1], thereby overcoming the limitations of solving non-convex problems using standard linear programming methods. It was first introduced into the Market Clearing Engine (MCE) in 2007 to model regulation constraints, and prevents generation registered facilities (GRFs) from being "trapped", in the sense that energy dispatch levels cannot be set beyond either end of their regulation range, RegulationMin or RegulationMax.

At that time, MIP was a relatively new form of LP. Accordingly, it was implemented as a two-step optimisation process in the MCE to reduce the processing time. In the first step, the MCE will solve only with the LP-based regulation constraints. The MCE then checks if any GRF's scheduled energy is "trapped" at either its RegulationMin or RegulationMax level. If so, then the MCE will activate MIP-based regulation constraints to release such trapped GRFs.

This paper discusses a proposal to remove the LP-based regulation constraints completely, and to simplify the MIP-based regulation constraints, which will enhance the objective function.

2. Background on MCE Processing of MIP-based Regulation Constraints

Regulation is the frequent adjustment of a generating unit's output so that any power system frequency variations or imbalances between load and the output from generation facilities can be corrected.

Currently, the Power System Operator (PSO) prompts GRFs to provide regulation through the Automatic Generation Control (AGC) subsystem. Accordingly, only GRFs that are AGC-responsive are eligible to provide regulation. For the AGC to be able to control a GRF during a dispatch period, the GRF's output must be within a certain range, termed the regulation range. This range is bounded by the RegulationMin and RegulationMax of the GRF i.e. the GRF's output cannot be less than the RegulationMin or greater than RegulationMax, while on regulation duty.

This technical requirement translates into the following qualification pre-checks that are applied to a GRF with a valid regulation offer to determine if it qualifies as a regulation provider.

Table 1: Pre-checks to qualify a GRF with a valid regulation offer for regulation provision

No.	Conditions	Purpose	Relevant Market Rules
1	Regulation offered > 0	The GRF must have offered regulation into the market.	Chapter 6, Section 5.4.6
2	Sum of energy offered>RegulationMin	The GRF must have offered enough energy to be able to operate in its AGC range (i.e. above RegulationMin).	Appendix 6D, D.13A.1.1
3	ExpectedStartGeneration[2] ≥ RegulationMin	The GRF is expected to be generating within its	Appendix 6D, D.13A.1.2

[1] Winston, Wayne (1994) "Operations Research: Applications and Algorithms"

[2] ExpectedStartGeneration takes into account a GRF's output level 10 minutes prior to the start of a dispatch period and its expected output over that 10 minutes, to determine if it is expected to be generating within the regulation range by the start of the dispatch period. Please refer to Appendix 6D, D13A.2 of the Market Rules for a detailed definition of ExpectedStartGeneration.

No.	Conditions	Purpose	Relevant Market Rules
4	ExpectedStartGeneration ≤ RegulationMax	regulation range at the beginning of the dispatch period.	Appendix 6D, D.13A.1.3

Thus, an AGC-responsive GRF can only qualify as a regulation provider for a given dispatch period if it meets the above conditions. If so, the MCE then applies the following constraints (LP based regulation constraints), as set out in Appendix 6D, D.18.1.3 and D.18.1.4 of the Market Rules, to the qualified GRF when determining its schedules.

D.18.1.3 Regulation Max Constraint:

$$\text{Generation}_{g(l)} + \text{Regulation}_{l} - \text{ExcessRegGen}_{l} \leq \text{RegulationMax}_{g(l)} \quad \{l \in \text{REGULATIONOFFERS}\}$$

D.18.1.4 Regulation Min Constraint:

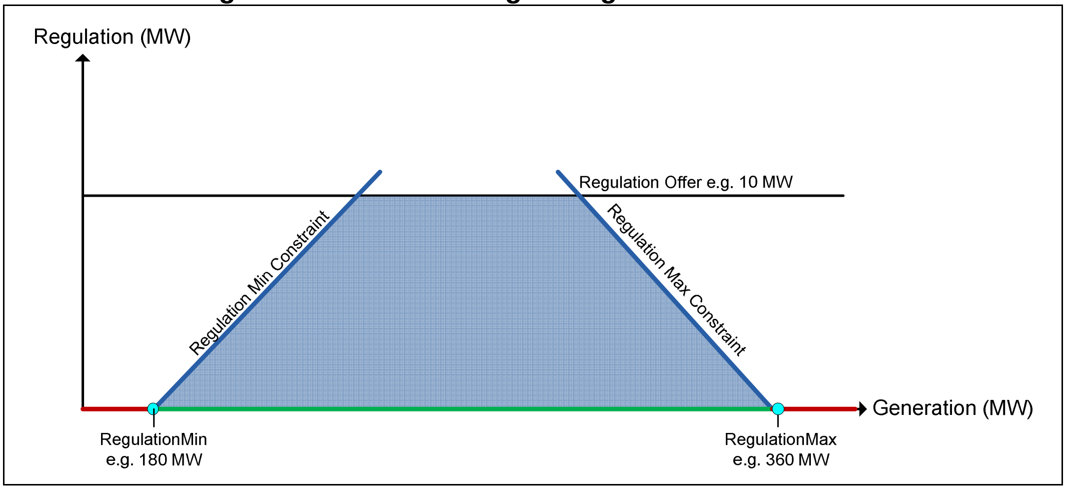
$$\text{Generation}_{g(l)} - \text{Regulation}_{l} + \text{DeficitRegGen}_{l} \geq \text{RegulationMin}_{g(l)} \quad \{l \in \text{REGULATIONOFFERS}\}$$

D.18.1.3 and D.18.1.4 ensure that the GRF's output when providing both scheduled energy and scheduled regulation is within its regulation range, RegulationMin to RegulationMax, such that it is able to respond readily to AGC signals to provide regulation. These constraints, together with the regulation offer constraints, define the feasible solution space for any qualified regulation provider, in the initial LP solve.

2.1 Purpose of MIP-Based Regulation Constraints

Figure 1 below illustrates how the regulation constraints are applied in the MCE to determine the LP feasible solution space, which represents all possible regulation and energy dispatch combinations that a qualified regulation provider may be scheduled for, in the initial LP solve.

Figure 1: MCE modelling of Regulation Constraints



Prior to the implementation of MIP-based regulation constraints, a qualified regulation provider's feasible solution space for regulation provision was solely and always represented by the blue trapezium in Figure 1 above. Under that regime, a qualified regulation provider may occasionally be "trapped", in the sense that its energy dispatch could not move beyond either RegulationMin or RegulationMax, despite not being scheduled for regulation. These trapped points are represented by the light blue dots in Figure 1 above. This scenario gave rise to market inefficiencies and uneconomic outcomes, for two reasons:

(i) A GRF with a relatively more expensive energy offer, but trapped at its RegulationMin level, would not be allowed to generate below that level (i.e. scheduled for less energy), despite the availability of other cheaper energy offers. Similarly, a GRF with a relatively cheaper energy offer, but trapped at its RegulationMax level, would not be able to generate above that level (i.e. scheduled for more energy).

(ii) It is also inappropriate to apply the RegulationMax/RegulationMin constraints to GRFs that are not scheduled to provide regulation. Since such GRFs will not be required to provide regulation, they should not be bounded by any regulation-related constraints.

To address this situation, MIP-based regulation constraints were implemented in 2007 to extend the solution space to include the two red lines on the x-axis in Figure 1. This extension enables a GRF that is not scheduled for regulation to be scheduled for energy at levels represented by the two red lines. As this modified solution space is non-convex, MIP was then employed to solve this optimisation problem.

2.2 Current Modelling of Non-Convex Solution Space using MIP-based Regulation Constraints

To model this non-convex solution space in the MCE, EMC introduced seven MIP-based regulation constraints under Appendix 6D, D.18.3 of the Market Rules in 2007[3], as reflected in Table 2 below.

Table 2: List of MIP-based Regulation Constraints Introduced in 2007

D.18.3.1 Mixed Integer Program Based Regulation Max Constraint
$\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector2}_l \leq \text{RegulationMax}_{g(l)}$
D.18.3.2 Mixed Integer Program Based Regulation Min Constraint
$\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l + \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector2}_l \geq \text{RegulationMin}_{g(l)}$
D.18.3.3 Regulation Availability Determination at Regulation Max
$\text{Regulation}_l - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector3}_l \leq 0$
D.18.3.4 Regulation Availability Determination at Regulation Min
$\text{Regulation}_l - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector1}_l \leq 0$
D.18.3.5 Generation Switch at Regulation Max
$\text{Generation}_{g(l)} + \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector3}_l \geq \text{RegulationMax}_{g(l)}$
D.18.3.6 Generation Switch at Regulation Min
$\text{Generation}_{g(l)} - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector1}_l \leq \text{RegulationMin}_{g(l)}$
D.18.3.7 Regulation Segment Selectors Restrictions
$\text{RegulationSegmentSelector1}_l + \text{RegulationSegmentSelector2}_l + \text{RegulationSegmentSelector3}_l = 2$

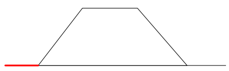
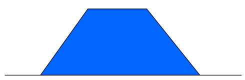
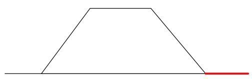
[3] Details can be found in Rule Change paper "RC263 Mixed Integer Program Based Modeling of Regulation Constraints", which is published on EMC website.

Where: InfinitePositiveValue: a big positive constant number

RegulationSegmentSelectors 1, 2 and 3: binary integer variables of value 0 or 1.

These regulation constraints model the non-convex solution space (the blue trapezium area, plus the two red lines in Figure 1) by dividing it into 3 segments. Different binary values are then assigned to the RegulationSegmentSelectors to determine the applicable MIP-based regulation constraints, and in turn, applicable sub-set of the feasible region, as shown in Table 3.

Table 3: Decomposition of MIP-based Regulation Constraints

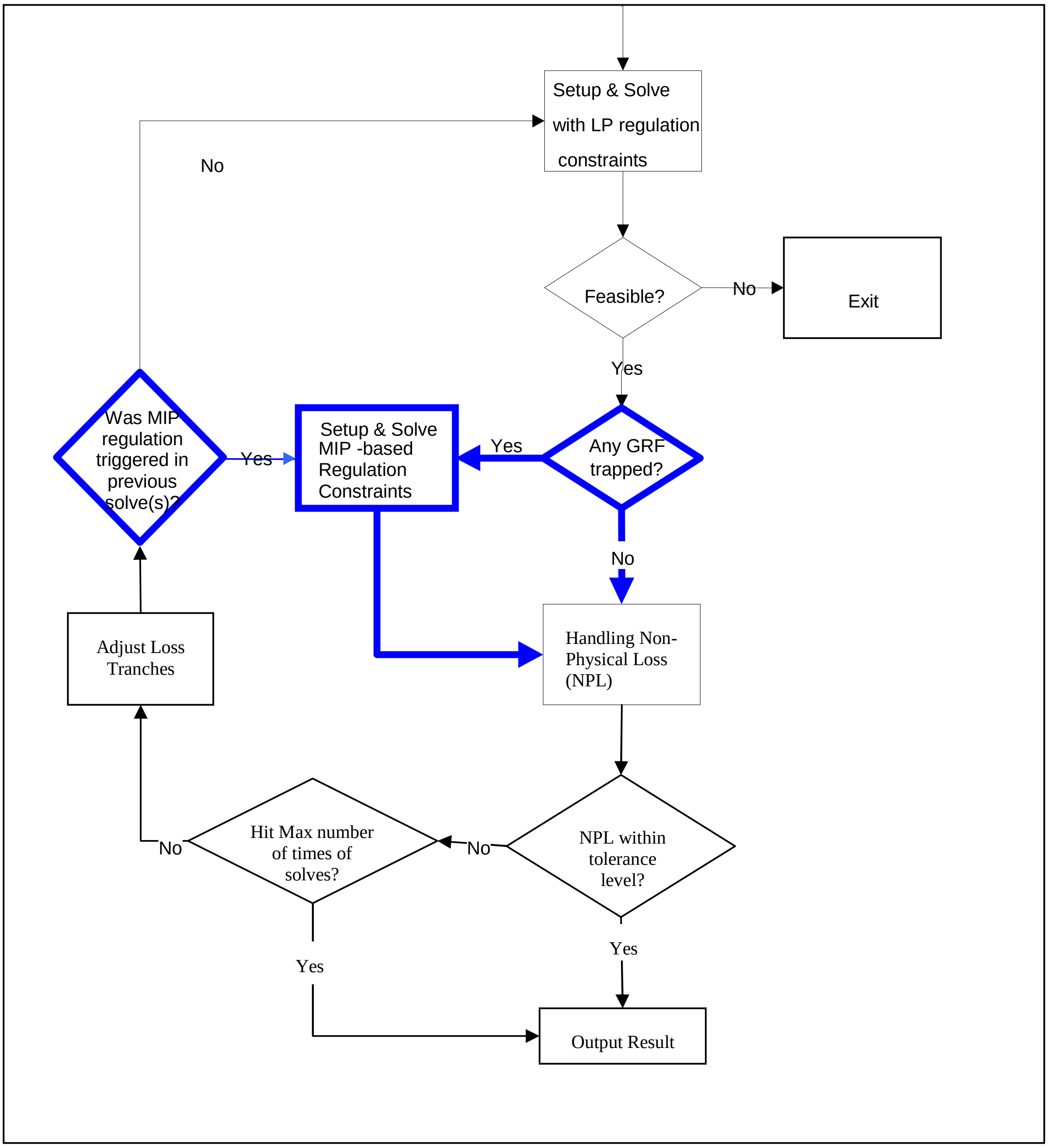
Section of Solution Space Modeled	**Regulation Segment Selector Value**	**Applicable MIP-based Regulation Constraints**
	RegSegmentSelector 1= 0 RegSegmentSelector 2 = 1 RegSegmentSelector 3 = 1	Regulation = 0 Generation ≤ RegulationMin
	RegSegmentSelector 1= 1 RegSegmentSelector 2 = 0 RegSegmentSelector 3 = 1	Generation- Regulation + DeficitReg ≥ RegulationMin Generation + Regulation – ExcessRegGen ≤ RegulationMax
	RegSegmentSelector 1= 1 RegSegmentSelector 2 = 1 RegSegmentSelector 3 = 0	Regulation = 0 Generation ≥ RegulationMax

2.3 Approach to Implementing MIP-based Regulation Constraints

As solvers were relatively less efficient in 2007, the decision then was to invoke these MIP-based constraints only when GRFs were found to be “trapped” at either their RegulationMin or RegulationMax levels. This was expected to reduce the total time required to solve the optimization problem in the MCE.

The current procedure is thus that the MCE will first run with LP-based regulation constraints (D.18.1.3 and D.18.1.4). If “trapped”, GRFs are found following the LP run using a check stated in D.21.A.2, the entire optimisation problem will be re-solved using the MIP-based regulation constraints (D.18.3) instead of the constraints set out in D.18.1.3 and D.18.1.4. The flow chart in Figure 2 summarises this current two-step optimisation process.

Figure 2: Process for Application of MIP-based Regulation Constraints



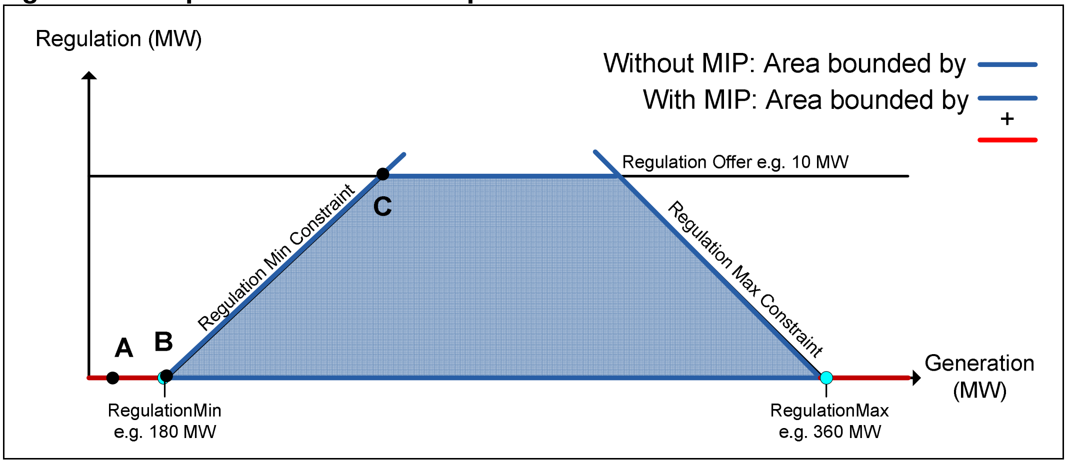
2.4 Limitations of Current Approach

While the two-step optimisation process has worked well for the MCE, there are still limitations to the current MIP-based regulation constraints process. These are identified below:

2.4.1 Sub-Optimal Solution

Figure 3 below compares the solution space available to a GRF with and without MIP-based regulation constraints. Without any “trapped” GRFs for a given period, MIP will not be triggered, and the available solution space for a GRF qualified to provide regulation will be given by the trapezium (blue shaded area). It is only when “trapped” GRFs are identified that the MIP will be invoked, and the solution space for a GRF qualified to provide regulation thus extended to include the area below RegulationMin and above RegulationMax (blue shaded area + red line).

Figure 3: Comparison of Solution Space with and without MIP-based Constraints



Applying the MIP-based regulation constraints only when trapped GRFs are identified may result in the MCE selecting a lower net benefit than applying the constraints under all scenarios. For example, suppose it would be optimal for the MCE to schedule a GRF only for energy, marked by point A in Figure 3, since the solution space is restricted to the trapezium area in the first LP run, the MCE, in most cases, will try to minimise its energy schedule and reach point B. The GRF is then recognisably trapped at RegulationMin, so MIP will be triggered to find the optimal solution (solution A).

However, under certain circumstances, the MCE may choose to schedule the unit strictly within the trapezium (at point C for example) in the LP run. In that case, the unit is not recognised as being trapped at either RegulationMin or RegulationMax, and the MIP-based regulation constraints will thus not be triggered to find the solution A.

Table 4: Illustration of a Sub-Optimal Case

<u>System Wide Requirement</u>

Load forecast = 500MW

Regulation Requirement = 12MW

<u>Unit 1</u>:

Energy offer 200MW @ $200/MW

Regulation offer: 10MW@$20/MW

Regulation Min/Max= 180MW/360MW

<u>Other units</u>

Energy offer: 400MW@$170/MW

Regulation offer: 50MW@$60/MW

	Solution A		**Solution B**		**Solution C**	
Energy	Unit 1	100MW	Unit 1	180MW	Unit 1	190MW
	Others	400MW	Others	320MW	Others	310MW

Regulation	Unit 1	0MW	Unit 1	0MW	Unit 1	10MW
	Others	12MW	Others	12MW	Others	2MW
Total Cost		**$88,720**		**$91,120**		**$91,020**

Table 4 gives a numerical example of how this could happen. Unit 1 has relatively cheap regulation offers and expensive generation offers. In the first solve, the MCE only considers the trapezium area as the feasible solution space. The MCE may then choose to schedule it to provide some regulation (solution C), rather than trap it at RegulationMin and not provide any regulation (solution B), as solution B is more costly. In this case, MIP-based regulation constraints will not be triggered and solution C will be the final schedule from the MCE.

On the other hand, if the full solution space (including the red line area) is available to the MCE by triggering the MIP-based regulation constraints under all scenarios, the MCE will choose to reduce the energy output from unit 1 to below its RegulationMin and reach the most optimal solution A.

Solution C, the “optimal" solution found within the restricted solution space, is a sub-optimal solution. Compared with the optimal solution A that is found with the full solution space, the sub-optimal solution incurs higher generation cost, and correspondingly lower net benefit. Thus, this proposal aims to eliminate the occurrence of such sub-optimal cases.

<u>2.4.2 Number of Binary Variables in MIP-based regulation constraints</u>

The current MIP-based regulation constraints employ three binary variables and seven constraints to define the three sectors of solution space. The same solution space can be defined by using only one binary variable and three constraints, which would make the MCE formulation easier to understand, and reduce the time the MCE uses to formulate and solve the optimisation problem. Details of the proposed formulation can be found in Section 3.2.

3. Proposed Changes to MIP-based Regulation Constraints

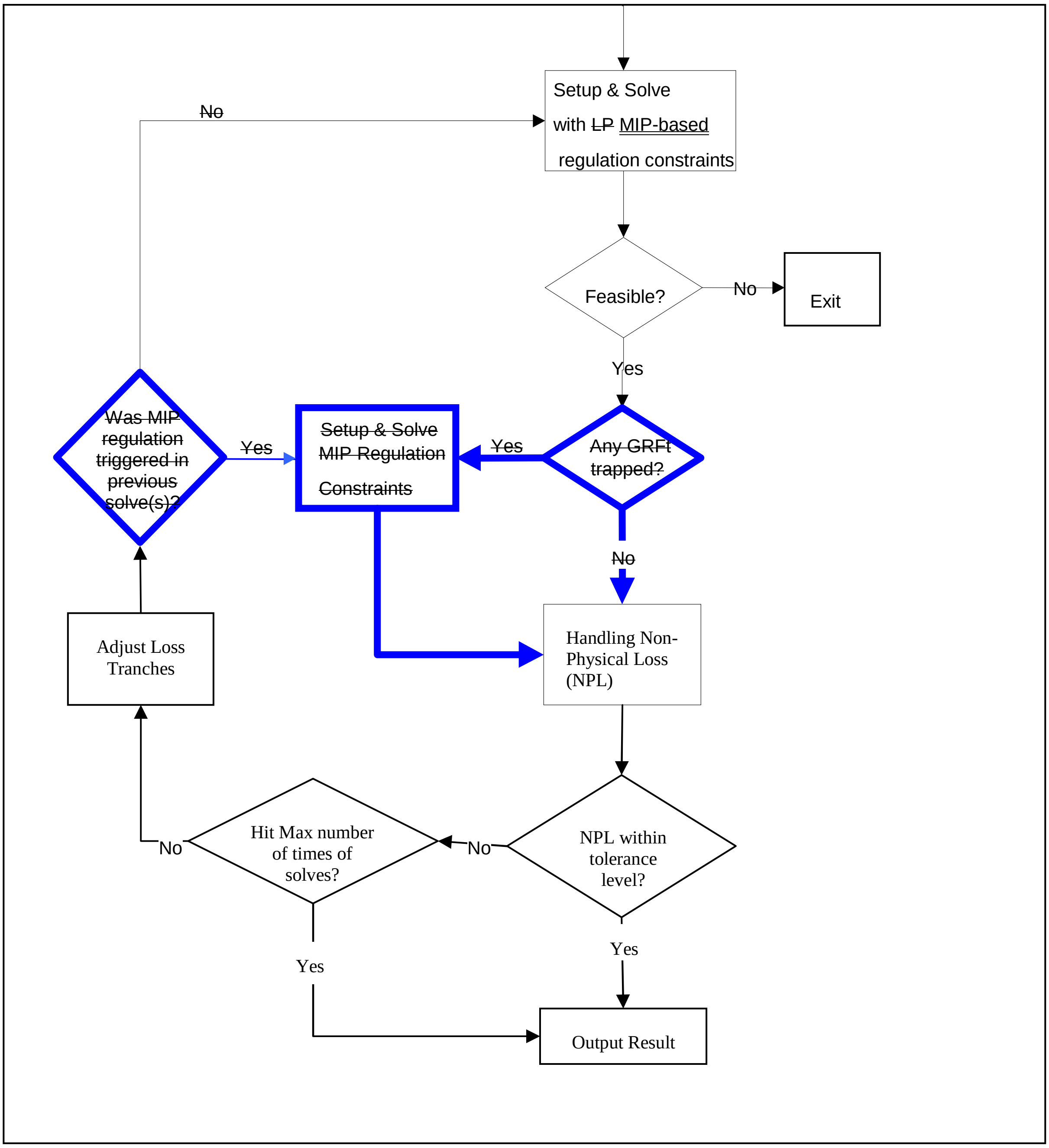
As a result of the limitations described in Section 2.4, this paper suggests two proposed changes to the current modelling of regulation constraints:

3.1 Two-Step Process to One-Step Process

It is proposed that MIP-based regulation constraints be applied for all MCE solves, without having to first solve with LP-based regulation constraints then check if any GRF is trapped at its RegulationMin/RegulationMax. This would make the full solution space available to the MCE to find the most optimal solution from and remove possible sub-optimal solutions that could occur with the current formulation.

The changes to the process for application of MIP-based regulation constraints are shown in Figure 4 below, and detailed in Annex 1.

Figure 4: Proposed Process for Application of MIP-based Regulation Constraints



3.2. Re-formulation of Regulation Constraints

The three Regulation Segment Selectors under the existing MIP-based regulation constraints can be replaced by one Regulation Segment Selector, which is defined to have a value of 1 for a unit that is within its regulation range, and otherwise 0. Table 5 shows the proposed re-formulated MIP-based regulation constraints, which require only one binary variable (namely, RegulationEligibilitySwitch) and three constraints. These three constraints shall replace the existing seven MIP-based regulation constraints.

Table 5: List of Proposed Re-formulated MIP-based Regulation Constraints

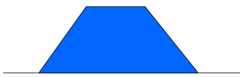
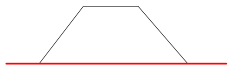
Mixed Integer Program Based Regulation Max Constraint $\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l$ $- \text{InfinitePositiveValue} \times (1\text{-RegulationEligibilitySwitch}_l) \leq \text{RegulationMax}_{g(l)}$ $\{l \in \text{REGULATION OFFERS}\}$
Mixed Integer Program Based Regulation Min Constraint $\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l$ $+ \text{InfinitePositiveValue} \times (1\text{-RegulationEligibilitySwitch}_l) \geq \text{RegulationMin}_{g(l)}$ $\{l \in \text{REGULATION OFFERS}\}$
Mixed Integer Program Based Zero Regulation Constraint (New) $\text{Regulation}_l - \text{InfinitePositiveValue} \times \text{RegulationEligibilitySwitch}_l \leq 0$ $\{l \in \text{REGULATION OFFERS}\}$

Table 6 below shows the solution space that will apply when the RegulationEligibilitySwitch takes on either a value of 1 or 0. When the optimal schedule for a generator is to provide both regulation and energy, the MCE will set the value of RegulationEligibilitySwitch to 1 for this generator and the solution space for this generator will be the blue trapezium area. Likewise, when it is more optimal to schedule a generator to provide energy only, the MCE will set the value of RegulationEligibilitySwitch to 0 and the solution space will become the red line.

It can be seen that the effective solution space is the same as the solution space defined by the current MIP-based regulation constraints as shown in Table 3.

Table 6: Illustration of Solution Space When RegulationEligibilitySwitch is 1 or 0

	Scenario 1	**Scenario 2**
Binary Integer Value	RegulationEligibilitySwitch = 1	RegulationEligibilitySwitch = 0
(New D.18.1.3) Mixed Integer Program Based Regulation Max Constraint	D.18.1.3 collapses to: $\text{Generation}_{g(l)} + \text{Regulation}_l$ $- \text{ExcessRegGen}_l$ $\leq \text{RegulationMax}_{g(l)}$	D.18.1.3 collapses to: $\text{Generation}_{g(l)} + \text{Regulation}_l$ $- \text{ExcessRegGen}_l$ $- \text{InfinitePositiveValue}$ $\leq \text{RegulationMax}_{g(l)}$ Thus, D.18.1.3 becomes non-binding since the inequality will always hold regardless of the level of Generation and Regulation.
(New D.18.1.4) Mixed Integer Program Based Regulation Min Constraint	D.18.1.4 collapses to: $\text{Generation}_{g(l)} - \text{Regulation}_l$ $+ \text{DeficitRegGen}_l$ $\geq \text{RegulationMin}_{g(l)}$	D.18.1.4 collapses to: $\text{Generation}_{g(l)} - \text{Regulation}_l$ $+ \text{DeficitRegGen}_l$ $+ \text{InfinitePositiveValue}$ $\geq \text{RegulationMin}_{g(l)}$

	Scenario 1	Scenario 2
		Thus, D.18.1.4 becomes non-binding since the inequality will always hold regardless of the level of Regulation.
(New D.18.1.5) Mixed Integer Program Based Zero Regulation Constraint	D.18.1.5 collapses to: $\text{Regulation}_l - \text{InfinitePositiveValue} \times 1 \leq 0$ Thus, D.18.1.5 becomes non-binding since the inequality will hold regardless of the level of Regulation.	D.18.1.5 collapses to: $\text{Regulation}_l \leq 0$
Resulting Effect	The original (LP) RegulationMin/RegulationMax constraints are binding. Thus generation and regulation can be scheduled at any combination of levels within the trapezium.	The regulation range constraints no longer apply, but regulation supply is constrained to zero.
Applicable Solution Space		

3.3. Impact Analysis

3.3.1 Impact on the MCE performance

Currently, with the two-step process, there are only about 10.4%[4] in the real-time dispatch runs where MIP-based regulation constraints are triggered after the first run with LP-based regulation constraints. For 89.6% of the dispatch periods, no generator is found trapped at its RegulationMin or RegulationMax in the real-time dispatch runs, and MIP-based regulation constraints are correspondingly not triggered.

Compared with LP-based regulation constraints, it will take the MCE longer to solve MIP-based regulation constraints. With the proposed one-step process where MIP-based regulation constraints are applied all the time, it is expected that:

1) The MCE solving time will increase for those periods where the MCE currently finishes the solve without triggering the MIP-based regulation constraints.

2) The MCE solving time will reduce for those periods where the MCE currently triggers MIP-based regulation constraints after the first run.

Simulations were conducted to evaluate the impact of the proposal. A prototype MCE, which adopts the one-step process and the re-formulated MIP-based regulation constraints, was built to evaluate the impact on the MCE's performance.

[4] Statistics for calendar year 2012.

Parallel runs of the current MCE that is used in the production system and the prototype MCE were conducted to compare their performance. It was observed that, on average, the prototype MCE will take slightly longer to solve. Table 7 below shows the increase in solve time across different types of runs.

Table 7: Impact to MCE performance

Run Type	Max Solve Time available[5]	Average solve time under existing MCE	Additional average solve time under re-formulated MIP- based MCE
Real-Time Dispatch	270s	13 s	0.29 s
Short-Term Schedule	540s	66 s	3.39 s
Pre-Dispatch Schedule	7,200s	302s	7.51 s
Market Outlook Scenario	43,200s	1728s	0[6]

We consider that the impact on the MCE's performance is minimal and the MCE solving time remains well within the acceptable threshold.

3.3.2 Impact on the MCE outcomes

With the proposed one-step process, where MIP-based regulation constraints are applied straightaway, it is expected that the MCE would not produce any sub-optimal solutions and so achieve more efficient scheduling outcomes.

A simulation was conducted to evaluate the impact to the schedules and prices. During the one-month study period (1 April 2013 - 30 April 2013), the prototype MCE produced the same schedules and objective values as the current MCE, except for two dispatch periods which were later both confirmed to have been sub-optimal cases, under the status quo. For the two sub-optimal cases, the schedules produced by the prototype MCE were better, with a higher net benefit value. Please refer to Annex 2 for a detailed study of the two sub-optimal cases.

3.4 Rule Changes Required

Rule modifications, as summarised in Table 8, are proposed to be made to Appendix 6D (Market Clearing formulation) of the market rules to give effect to the changes proposed in section 3.3.1 and 3.3.2 of this paper. Details of the rule modifications can be found in Annex 1.

Table 8 Summary of Rules Changes

Section	Rules Changes	Reasons for change
Appendix 6D, D.3 Parameters	To replace the reference to section D.18.3 with the reference to D.18.1.	To update the reference to the correct section as existing section D.18.3 is removed.
Appendix 6D, D.4 Variables	To replace the three existing RegulationSegmentSelector variable with a new RegulationEligibilitySwitch variable.	The proposed new formulation only requires one binary variable instead of three.

[5] Max solve time available is the interval between the time that computation of the schedules begins and the time that the schedules are required to be released or published, as specified in Appendix 6A of market rules.
[6] For market outlook scenarios, the prototype MCE always took less time to solve for the dispatch periods simulated.

Appendix 6D, D.18 Regulation	To revise existing Regulation Max (D.18.3) and Regulation Min (D.18.4) constraints.	To reflect the new MIP-based Regulation Max and Regulation Min constraints as proposed in the reformulation.
	To add a MIP-based Zero Regulation Constraint (new D.18.5).	To include the new MIP-based zero Regulation constraint as proposed in the reformulation.
	To delete existing section D.18.3 MIP-based Regulation Constraints.	Existing section D.18.3 is used only when MIP-based regulation constraints are required to be activated. With the new MIP-based regulation constraints (D.18.1.3-D.18.1.5), which will be applied throughout the optimisation process, this section is no longer required.
Appendix 6D, D.21A Regulation Anomaly Correction	To remove section D.21A Regulation Anomaly Correction.	To remove the regulation anomaly correction procedure to reflect the changes as shown in the flowchart.
Appendix 6D, D.22 Loss Calculation Correction	To remove the reference to section D.21A.	Section D.21A is removed.
	To remove the requirement for MCE to check if MIP-based regulation constraints should be applied before conducting a re-solve for loss calculation correction.	To revise the loss calculation correction procedures to reflect the changes in the flowchart.

4 Conclusion

We conclude that the proposed re-modelling of regulation constraints would enable the MCE to produce more optimal market outcomes that increase economic efficiency.

5 Implementation

Based on EMC's estimate, the implementation will take 21 calendar weeks and the cost would be $49,700. Please refer to Table 9 for the breakdown of the effort estimation.

Table 9: Effort Estimation

Time Estimates	Man week(s)	Calendar week(s)
1. Change Requirement Scoping and Analysis	2	2
2. MCE Development	2	2
3. System Tests and Performance	2	3
4. User Acceptance Testing (UAT)	4	6
5. Audit	2	5
6. Parallel MCE runs & detailed daily check analysis/investigation*	4	8
Total Effort Required	16	26

Total Project Time	N.A	21 (Audit overlapping with Parallel Run
Cost Estimates		
1. Internal Power Systems Consultant Resource	4 man weeks	
2. External resource to support parallel MCE Runs	$29,700.00	
3. Audit	$20,000.00	
Total Additional Cost Required (on RCP budget)	$49,700.00	

6. Consultation

We have published the rule modification proposal on the EMC website for comments. No comments have been received for consideration.

7. Legal sign off

EMC's external legal counsel has indicated that because of the technical nature of the rule modification proposal he is not able to provide a legal signoff.

8 TWG's Decision at the 22nd TWG Meeting

The proposed rule modifications were discussed at the 22nd TWG meeting held on 17th October 2013. The TWG unanimously supported the proposed rule modifications set out in Annex 1.

9 Recommendations

The RCP unanimously recommends that the EMC Board

a) **adopt** the rule modification proposal to amend Appendix D of Chapter 6 as set out in the Annex 1;

b) **seek** EMA's approval of the rule modification proposal; and

c) **recommend** that the rule modification proposal come into force **six months** after the date on which the approval of the Authority is published by the EMC.

Existing Rules (Release 1 Jul 2013)	**Proposed Rules** (Deletions represented by strikethrough text and additions represented by double-underlined text)	Reason for Modification
APPENDIX 6D MARKET CLEARING FORMULATION **D.3 PARAMETERS** InfinitePositiveValue: A relatively large positive value applied in section D.17.2.8 and section D.18.3 as a selector variable coefficient.	**APPENDIX 6D MARKET CLEARING FORMULATION** **D.3 PARAMETERS** InfinitePositiveValue: A relatively large positive value applied in section D.17.2.8 and section D.18.1~~3~~ as a selector variable coefficient.	To delete the reference to section D.18.3 and replace with a reference to section D.18.1.
D.4 VARIABLES RegulationSegmentSelector1$_l$ RegulationSegmentSelector2$_l$ RegulationSegmentSelector3$_l$ Binary integer variables associated with *regulation offer l*, used for modeling of regulation-generation constraints in section D.18.3.	**D.4 VARIABLES** ~~RegulationSegmentSelector1$_l$~~ ~~RegulationSegmentSelector2$_l$~~ ~~RegulationSegmentSelector3$_l$~~ RegulationEligibilitySwitch$_l$ Binary integer variable~~s~~ associated with *regulation offer l*, used for ~~modeling~~ modelling of regulation-generation constraints in section D.18.1~~3~~.	To replace the 3 existing RegulationSegmentSelector variables with a new RegulationEligibilitySwitch variable for simplification of the MIP-based regulation constraints. To amend a typographical error. To delete the reference to section D.18.3 and replace with a reference to section D.18.1.

Existing Rules (Release 1 Jul 2013)	**Proposed Rules** (Deletions represented by strikethrough text and additions represented by double-underlined text)	Reason for Modification
D.18 REGULATION D.18.1 Supply of Regulation ... D.18.1.3 Regulation Max Constraint: $\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l \le \text{RegulationMax}_{g(l)}$ $\{l \in \text{REGULATIONOFFERS}\}$ D.18.1.4 Regulation Min Constraint: $\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l \ge \text{RegulationMin}_{g(l)}$ $\{l \in \text{REGULATION OFFERS}\}$	**D.18 REGULATION** D.18.1 Supply of Regulation ... D.18.1.3 Mixed Integer Program Based Regulation Max Constraint: ~~$\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l \le \text{RegulationMax}_{g(l)}$~~ $\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l - \text{InfinitePositiveValue} \times (1 - \text{RegulationEligibilitySwitch}_l) \le \text{RegulationMax}_{g(l)}$ $\{l \in \text{REGULATIONOFFERS}\}$ D.18.1.4 Mixed Integer Program Based Regulation Min Constraint: ~~$\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l \ge \text{RegulationMin}_{g(l)}$~~ $\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l + \text{InfinitePositiveValue} \times (1 - \text{RegulationEligibilitySwitch}_l) \ge \text{RegulationMin}_{g(l)}$ $\{l \in \text{REGULATION OFFERS}\}$	To revise the existing Regulation Max Constraint set out in section D.18.1.3 and the existing Regulation Min Constraint set out in section D.18.1.4 to reflect the new Mixed Integer Program Based Regulation Max Constraint and the Mixed Integer Program Based Regulation Min Constraint respectively.

Existing Rules (Release 1 Jul 2013)	**Proposed Rules** (Deletions represented by strikethrough text and additions represented by double-underlined text)	Reason for Modification
[New section D.18.1.5]	D.18.1.5 Mixed Integer Program Based Zero Regulation Constraint $\text{Regulation}_l - \text{InfinitePositiveValue} \times \text{RegulationEligibilitySwitch}_l \leq 0$ $\{ l \in \text{REGULATION OFFERS} \}$	To add a new simplified Mixed Integer Program Based Zero Regulation constraint that can restrict regulation to zero, by using the RegulationEligibilitySwitch. The revised sections D.18.1.3 and D.18.1.4 and the new section D.18.1.5, together with the rest of section D.18.1, shall be applied throughout the MCE optimisation process.
D.18.3 Mixed Integer Program Based Regulation Constraints The provisions of this section shall apply only to a re-solve of the linear program under section D.21A.2 or section D.22.7 where applicable. In such a re-solve, sections D.18.3.1 to D.18.3.7 shall replace sections D.18.1.3 and D.18.1.4.	~~D.18.3 Mixed Integer Program Based Regulation Constraints~~ ~~The provisions of this section shall apply only to a re-solve of the linear program under section D.21A.2 or section D.22.7 where applicable. In such a re-solve, sections D.18.3.1 to D.18.3.7 shall replace sections D.18.1.3 and D.18.1.4.~~	To delete the header of the existing section D.18.3 and the introductory note since the new Mixed Integer Program Based regulation constraints in the amended/new sections D.18.1.3 to D.18.1.5 will now be applied throughout the MCE optimisation process.

Existing Rules (Release 1 Jul 2013)	**Proposed Rules** (Deletions represented by strikethrough text and additions represented by double-underlined text)	Reason for Modification
D.18.3.1 Mixed Integer Program Based Regulation Max Constraint $\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector2}_l \leq \text{RegulationMax}_{g(l)}$ $\{l \in \text{REGULATION OFFERS}\}$	~~D.18.3.1 Mixed Integer Program Based Regulation Max Constraint~~ ~~$\text{Generation}_{g(l)} + \text{Regulation}_l - \text{ExcessRegGen}_l - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector2}_l \leq \text{RegulationMax}_{g(l)}$~~ ~~$\{l \in \text{REGULATION OFFERS}\}$~~	To delete the existing MIP-based regulation constraints set out in sections D.18.3.1 to D.18.3.7 as these regulation constraints will be replaced by the amended/new MIP-based regulation constraints set out in sections D.18.1.3 to D.18.1.5 above.
D.18.3.2 Mixed Integer Program Based Regulation Min Constraint $\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l + \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector2}_l \geq \text{RegulationMin}_{g(l)}$ $\{l \in \text{REGULATION OFFERS}\}$	~~D.18.3.2 Mixed Integer Program Based Regulation Min Constraint~~ ~~$\text{Generation}_{g(l)} - \text{Regulation}_l + \text{DeficitRegGen}_l + \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector2}_l \geq \text{RegulationMin}_{g(l)}$~~ ~~$\{l \in \text{REGULATION OFFERS}\}$~~	
D.18.3.3 Regulation Availability Determination at Regulation Max $\text{Regulation}_l - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector3}_l \leq 0$ $\{l \in \text{REGULATION OFFERS}\}$	~~D.18.3.3 Regulation Availability Determination at Regulation Max~~ ~~$\text{Regulation}_l - \text{InfinitePositiveValue} \times \text{RegulationSegmentSelector3}_l \leq 0$~~ ~~$\{l \in \text{REGULATION OFFERS}\}$~~	

Existing Rules (Release 1 Jul 2013)	**Proposed Rules** (Deletions represented by strikethrough text and additions represented by double-underlined text)	Reason for Modification
D.18.3.4 Regulation Availability Determination at Regulation Min $Regulation_l - InfinitePositiveValue \times RegulationSegmentSelector1_l \leq 0$ $\{l \in REGULATIONOFFERS\}$ D.18.3.5 Generation Switch at Regulation Max $Generation_{g(l)} + InfinitePositiveValue \times RegulationSegmentSelector3_l \geq RegulationMax_{g(l)}$ $\{l \in REGULATIONOFFERS\}$ D.18.3.6 Generation Switch at Regulation Min $Generation_{g(l)} - InfinitePositiveValue \times RegulationSegmentSelector1_l \leq RegulationMin_{g(l)}$ $\{l \in REGULATIONOFFERS\}$	~~D.18.3.4 Regulation Availability Determination at Regulation Min~~ ~~$Regulation_l - InfinitePositiveValue \times RegulationSegmentSelector1_l \leq 0$~~ ~~$\{l \in REGULATIONOFFERS\}$~~ ~~D.18.3.5 Generation Switch at Regulation Max~~ ~~$Generation_{g(l)} + InfinitePositiveValue \times RegulationSegmentSelector3_l \geq RegulationMax_{g(l)}$~~ ~~$\{l \in REGULATIONOFFERS\}$~~ ~~D.18.3.6 Generation Switch at Regulation Min~~ ~~$Generation_{g(l)} - InfinitePositiveValue \times RegulationSegmentSelector1_l \leq RegulationMin_{g(l)}$~~ ~~$\{l \in REGULATIONOFFERS\}$~~	

Existing Rules (Release 1 Jul 2013)	Proposed Rules (Deletions represented by strikethrough text and additions represented by double-underlined text)	Reason for Modification
D.18.3.7 Regulation Segment Selectors Restrictions $\text{RegulationSegmentSelector1}_l + \text{RegulationSegmentSelector2}_l + \text{RegulationSegmentSelector3}_l = 2$ $\{l \in \text{REGULATIONOFFERS}\}$	~~D.18.3.7 Regulation Segment Selectors Restrictions~~ ~~$\text{RegulationSegmentSelector1}_l + \text{RegulationSegmentSelector2}_l + \text{RegulationSegmentSelector3}_l = 2$~~ ~~$\{l \in \text{REGULATIONOFFERS}\}$~~	
D.21A REGULATION ANOMALY CORRECTION D.21A.1 After each solution of the linear program which did not involve the use of the constraints set out in sections D.18.3.1 to D.18.3.7, the *EMC* shall carry out the procedures in section D.21A.2 to the extent provided in this section D.21A. D.21A.2 If the following condition: $\text{Generation}_{g(l)} = \text{RegulationMin}_{g(l)}$ or $\text{Generation}_{g(l)} = \text{RegulationMax}_{g(l)}$ $\{l \in \text{REGULATIONOFFERS}\}$ is true for any *generation registered facility*, then the linear program shall be re-solved with the constraints set out in sections D.18.3.1 to D.18.3.7 in lieu of the constraints set out in sections D.18.1.3 and D.18.1.4.	~~**D.21A REGULATION ANOMALY CORRECTION**~~ ~~D.21A.1 After each solution of the linear program which did not involve the use of the constraints set out in sections D.18.3.1 to D.18.3.7, the *EMC* shall carry out the procedures in section D.21A.2 to the extent provided in this section D.21A.~~ ~~D.21A.2 If the following condition:~~ ~~$\text{Generation}_{g(l)} = \text{RegulationMin}_{g(l)}$ or~~ ~~$\text{Generation}_{g(l)} = \text{RegulationMax}_{g(l)}$~~ ~~$\{l \in \text{REGULATIONOFFERS}\}$~~ ~~is true for any *generation registered facility*, then the linear program shall be re-solved with the constraints set out in sections D.18.3.1 to D.18.3.7 in lieu of the constraints set out in sections D.18.1.3 and D.18.1.4.~~	This section describes the checking criteria currently used to trigger the MIP-based regulation constraints in the existing sections D.18.3.1 to D.18.3.7. This section is no longer required as the new regulation constraints in the amended/new sections D.18.1.3 to D.18.1.5 above will be applied regardless of whether there are any regulation anomalies or trapped GRFs.

Existing Rules (Release 1 Jul 2013)	**Proposed Rules** (Deletions represented by strikethrough text and additions represented by double-underlined text)	Reason for Modification
D.22 LOSS CALCULATION CORRECTION D.22.2 After complying with the procedures in section D.21A, the *EMC* shall carry out the procedures in sections D.22.3 to D.22.7 to the extent provided in those sections. However, the *EMC* shall not do so if any of the line violation variables, ExcessLineFlowForward$_k$, ExcessLineFlowReverse$_k$, DeficitWLineFlow$_k$ or ExcessWLineFlow$_k$, for any *dispatch network line k* is greater than zero.	**D.22 LOSS CALCULATION CORRECTION** D.22.2 ~~After complying with the procedures in section D.21A,~~After each solution of the linear program, the *EMC* shall carry out the procedures in sections D.22.3 to D.22.7 to the extent provided in those sections. However, the *EMC* shall not do so if any of the line violation variables, ExcessLineFlowForward$_k$, ExcessLineFlowReverse$_k$, DeficitWLineFlow$_k$ or ExcessWLineFlow$_k$, for any *dispatch network line k* is greater than zero.	To delete reference to section D.21A, which will no longer exist.
D.22.7 The re-defined set of line flow/line loss points determined in section D.22.6 for each *dispatch network line* shall be used to re-solve the linear program for the given *dispatch period* in the given run of the *market clearing engine*. In so re-solving the linear program under this section D.22.7, if the constraints set out in sections D.18.3.1 to D.18.3.7 had earlier been used in re-solving the linear program for that given *dispatch period* in the given run of the *market clearing engine*, then the constraints set out in sections D.18.3.1 to D.18.3.7 shall be used again in re-solving the linear program (in lieu of the constraints set out in sections D.18.1.3 and D.18.1.4).	D.22.7 The re-defined set of line flow/line loss points determined in section D.22.6 for each *dispatch network line* shall be used to re-solve the linear program for the given *dispatch period* in the given run of the *market clearing engine*. ~~In so re-solving the linear program under this section D.22.7, if the constraints set out in sections D.18.3.1 to D.18.3.7 had earlier been used in re-solving the linear program for that given *dispatch period* in the given run of the *market clearing engine*, then the constraints set out in sections D.18.3.1 to D.18.3.7 shall be used again in re-solving the linear program (in lieu of the constraints set out in sections D.18.1.3 and D.18.1.4).~~	To delete the latter part of this section that is no longer required with the deletions of sections D.18.3.1 to D.18.3.7 and because the amended/new MIP-based regulation constraints in sections D.18.1.3 to D.18.1.5 will apply throughout the MCE optimisation process.

Annex 2: Case Studies of Sub-Optimal Cases

Case 1: Sub-Optimal case at RegulationMin

The table A2.1 shows the differences in generation and regulation schedules between the prototype and production MCE, for this case.

Table A2.1 Comparison of Schedules for Sub-Optimal case at RegulationMin

GRF	RegMin	Prod Schedule MW	Prod Last Cleared Blk Price	Prototype Schedule MW	Prototype Last Cleared Blk Price	Changes in Schedule MW	Diff in Cost $
Energy							
G1	**140**	**143.86**	**270**	**0**	**$0**	**-143.86**	**-38,842.2**
G2		250	$108	267.835	$168	17.835	2,996.31
G3		250	$108	270	$166	20	3,320
G4		250	$108	270	$167	20	3,340
G5		286	$149.53	322	$159.53	36	5,743.08
G6		311.83	$149.31	322	$159.31	10.17	1,619.75
G7		205	$152.98	225	$165.98	20	3,319.6
G8		205	$152.98	225	$165.98	20	3,319.6
					subtotal	0	-15,183.9
Regulation							
G1		**3.86**	**0**	**0**	**0**	**-3.86**	**0**
G9		3	$109.99	3	$109.99	0	0
				3	$119.99	3	359.97
				0.86	$121.99	0.86	104.91
					subtotal	0	464.88
					Total Diff in Cost		-14,718

With the current MCE, in the first iteration, GRF G1 was constrained on and forced to be scheduled energy above its RegulationMin, even though its energy offer price ($270) is much higher than the USEP ($160). The MCE should have minimised G1's energy schedule to RegulationMin (140MW), followed by triggering the MIP-based regulation constraints to further reduce G1's energy schedule to 0. However, G1 has a very cheap regulation offer ($0) compared with the regulation clearing price of $119.99. The difference between the regulation offer and clearing price of 119.99 is more than the difference between G1's energy offer price and the energy clearing price ($110). Therefore, G1's energy schedule is increased to 143.86MW so as to provide 3.86MW of regulation, which is the final schedule for G1.

With the prototype MCE, the MCE considered the option to schedule G1 below its RegulationMin and didn't clear any of its $270 energy offer. This means a saving of $38,842 in generation cost. Instead, the MCE cleared 143.86 MW of extra energy from other units at costs ranging from $159.53 to $168, and 3.86MW of extra regulation at costs ranging from $119.99 to $121.99. Although both regulation and energy are cleared at a slightly higher price, the total cost is still lower by $14,718, if compared with the schedules produced by the current 2-step optimisation MCE.

Case 2: Sub-Optimal case at RegulationMax

The table A2.2 shows the differences in generation and regulation schedules between the prototype and production MCE, for this case.

Table A2.2 Comparison of Schedules for Sub-Optimal case at RegulationMax

GRF	Regmax	Prod Schedule MW	Prod Last Cleared Blk Price	Prototype Schedule MW	Prototype Last Cleared Blk Price	Changes in Schedule MW	Diff in Cost $
Energy							
G1	**205**	**204.11**	**$250**	**220**	**$250**	**15.89**	**3972.5**
G2		337.633	$299.98	330	$249.98	-7.633	-2,289.7
G3		340	$299.93	332.051	$299.93	-7.949	-2,384.1
G4		342.5	$299.93	342.103	$299.93	-0.397	-119
					subtotal	0	-1,000.3
Regulation							
G1		**0.89**	**$0.01**	**0**	**0**	**-0.89**	**-0.089**
G9		4	$21	4.89	$45	0.89	40.25
					subtotal	0	40.16
						Total Diff in Cost	-960.14

GRF G1 has 220MW of relatively cheap energy offered at $250, as the market clearing price is at $300. The optimal solution would be to schedule G1 fully for its 220MW capacity. However, as G1 also has cheap regulation offers, the current MCE chose to schedule 0.89MW of regulation from G1 and scheduled G1's energy below its RegulationMax level, and MIP-based regulation constraints are not triggered. Therefore the MCE will not go outside G1's regulation range and search for better solution and the solution found by the MCE is sub-optimal.

If the full solution space is made available to MCE, as in the proposed MCE, the MCE will schedule G1 to run above its RegulationMax and make full use of its 220MW of cheap energy offer. The additional 15.89MW of energy cleared from G1 displaces some energy offers priced at around $300, and the energy cost is reduced by $1000.3. Although this will require 0.89MW of regulation to be cleared from a more expensive offer, priced at $45, the total cost is still $960.14 lower than the total cost incurred under the sub-optimal solution.