RCP PAPER NO.	:	**EMC/RCP/69/2013/CP47**
SUBJECT	:	**PROPOSED NEW CONSTRAINT FOR HANDLING NON-PHYSICAL LOSSES**
FOR	:	**DECISION**
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Executive Summary

To serve a given level of forecast demand, the Market Clearing Engine (MCE) will schedule generation such that the overall production cost is minimised, thus maximising Net Benefit (which is the benefit of serving the forecast demand less the production cost). To minimise production cost, generation output and transmission losses have to be correspondingly minimised.

The MCE models transmission line losses that are non-linear (specifically, quadratic) in nature, using piecewise linear segments. When energy prices are positive, the MCE seeks to reduce losses and uses linear segments that are good approximations of actual losses. Lower losses would minimise the amount of generation required and hence minimise production cost, thereby maximising Net Benefit.

However, when energy prices are negative, the MCE increases the modelled losses as higher losses increase the amount of generation required, leading to a lower production cost and higher Net Benefit. To do so, the MCE uses linear segments that are poor approximations of actual losses. The differential between the good and poor approximations is termed Non Physical Losses (NPL), which is essentially a modelling error that compromises accuracy in transmission modelling and energy dispatch. Currently, the MCE adopts an iterative process to reduce the NPL to below an acceptable threshold prior to publishing the dispatch schedules.

This paper assesses the proposal to implement an enhancement, namely the “Loss Ceiling Method”, to accelerate the convergence of the iterative procedure by capping the total loss (physical loss and NPL) by an estimated value.

An incident occurred on 14 February 2013, which triggered an MCE procedural change.

Although the performance of the iterative process has since improved, there is still room for further enhancement (both in terms of performance and optimality) through the implementation of a three-step modified loss ceiling constraint.

Simulation results show that the three-step modified loss ceiling method achieves a lower final NPL level (close to zero) in fewer iterations (fixed at 3) than the current handling of NPL. This means that we can achieve a more accurate modelling of actual losses in a shorter amount of time when there is NPL in the system. In addition, the three-step modified loss ceiling method achieves a more robust outcome of determining the flow concurrently with a low NPL. The improved optimality of the three-step modified loss ceiling method over the current NPL handling is verified through a comparison of Net Benefit values, where the former shows a small (maximum of $0.36) and consistent deviation from the true global optimum, while the latter shows an inconsistent deviation, with a deviation of as large as $109.24 for the periods simulated.

The above factors show that the three-step modified loss ceiling method minimises NPL with fewer iterations, while also achieving better optimality.

Nevertheless, periods with negative prices/NPL processing usually occur during forecast runs and rarely in RTDS runs. As such, the enhancement should be weighed against the system implementation costs.

At the 21st TWG meeting, the TWG discussed the benefits and costs of the three-step modified loss ceiling method. While the TWG recognised the merits of the three-step modified loss ceiling proposal, they noted that the actual number of real-time dispatch periods that will be affected by NPL is limited, given the low frequency of negative prices in real-time dispatch periods. Therefore, the TWG by majority vote recommends that the RCP **<u>do not support</u>** implementing the three-step modified loss ceiling method to handle NPL.

At the 69th RCP meeting, the RCP considered the benefits and costs of the three-step modified loss ceiling method. There was general consensus with the TWG that while the proposal was sound and had its merits, the low frequency of negative prices in real-time dispatch periods would mean that the benefits would be limited and not justify the costs of implementation. Therefore, the RCP unanimously decided **<u>not to support</u>** the implementation of the three-step modified loss ceiling method to handle NPL.

1. INTRODUCTION

To serve a given level of forecast demand, the Market Clearing Engine (MCE) will schedule generation[1] such that the overall production cost is minimised, thus maximising Net Benefit[2] (which is the benefit of serving the forecast demand less the production cost)[3]. To minimise production cost, generation output and transmission losses have to be correspondingly minimised.

The MCE models transmission line losses that are non-linear (specifically, quadratic) in nature, using piecewise linear segments. When energy prices are positive, the MCE seeks to reduce losses and uses linear segments that are good approximations of actual losses. Lower losses would minimise the amount of generation required and hence minimise production cost, thereby maximising Net Benefit.

However, when energy prices are negative, the MCE increases the modelled losses as higher losses increase the amount of generation required, leading to a lower production cost[4] and higher Net Benefit. To do so, the MCE uses linear segments that are poor approximations of actual losses. The differential between the good and poor approximations is termed Non Physical Losses (NPL), and it is essentially a modelling error that compromises accuracy in transmission modelling and energy dispatch.

Currently, the MCE adopts an iterative process to reduce the NPL to below an acceptable threshold[5]. To further refine the current handling of NPL, a proposer suggested implementing a heuristic enhancement, namely the “Loss Ceiling Method”, which accelerates the convergence of this iterative procedure by capping the total losses by an estimated value.

2. BACKGROUND

2.1 Transmission Loss Model

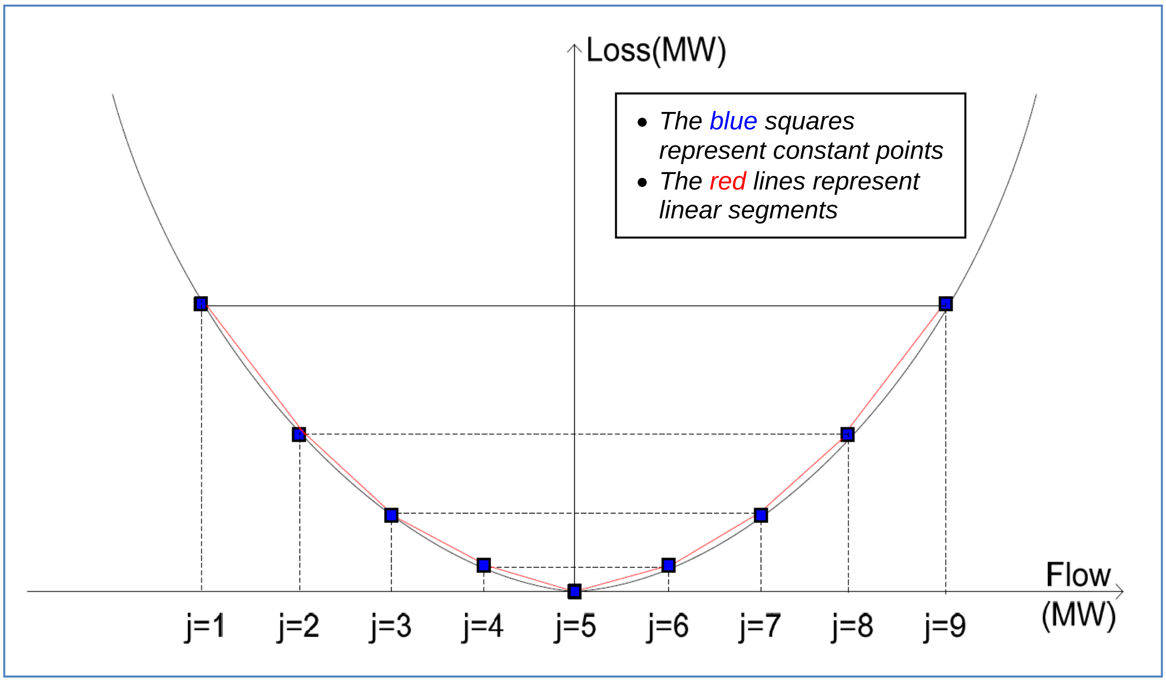
The transmission loss model in the NEMS can be described by the formula:

$$L = F^2 * R,$$

where L is the transmission loss, F is the flow in the transmission line and R is a constant proportion to the resistance of the said line. The MCE approximates this quadratic loss function using a piece-wise linear approximation, which is graphically illustrated in Figure 1 below.

[1] Including reserve and regulation
[2] Please refer to Appendix 6D.14.1.1 of the Market Rules.
[3] Plus violation costs if any
[4] With negative prices, producers pay to produce; therefore increasing production will reduce production cost.
[5] This threshold is currently set at 10MW in the MCE.

Figure 1: Piece-wise Linear Approximation of the Transmission Loss Model (Positive Energy Prices)

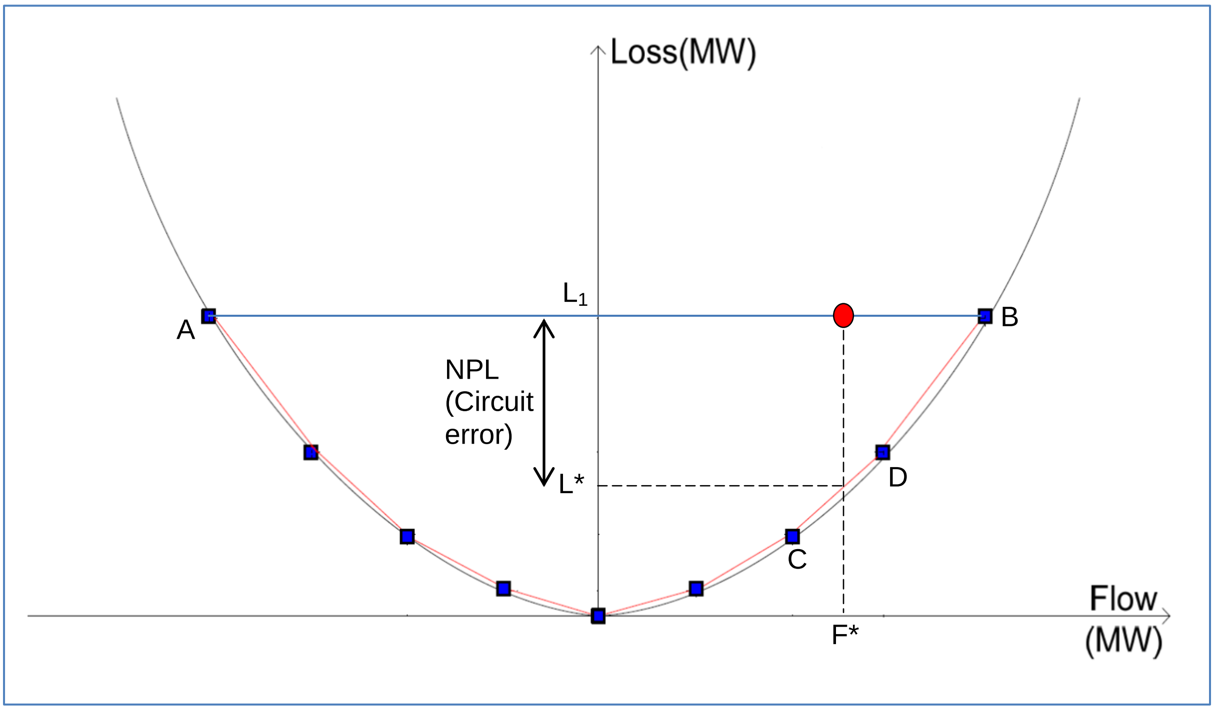


The true transmission loss curve, which is shown in black, cannot be perfectly modelled in the MCE's linear program. The MCE thus uses linear approximation by fixing 9 constant points (j= 1 to 9 above) and decomposes the curve into 8 linear segments. When energy prices are positive, the MCE seeks to minimise losses. In doing so, it uses the linear segments interpolating between adjacent points (e.g. j=5 and j=6, as shown in red above) to estimate losses. This results in a relatively good approximation of actual losses.

However, during periods of excess capacity in the system, energy prices are usually negative and the MCE seeks to increase the losses[6] that can be incurred. Instead of interpolating the linear loss segment from two adjacent points, the MCE will select two non-adjacent points as shown in Figure 2 below.

[6] The MCE seeks to minimise generation cost, which entails maximising generation when energy prices are negative, and this can be achieved by increasing (modelled) losses.

Figure 2: Non-Physical Loss and Circuit Error (Negative Energy Prices)



In Figure 2 above, the energy prices are negative, and the MCE seeks to increase losses. To calculate the expected transmission loss corresponding to a line flow of F*, instead of using line segment CD (which best models the underlying loss curve), line segment AB might be used instead. Hence, the modelled loss will be L_1 instead of L*, with the gap (L_1-L*) representing the NPL, also referred to as the Circuit Error.[7] Although the higher estimated loss L_1 leads to a better net benefit when prices are negative, this enhancement is artificial and the outcome of misestimating losses at L_1 leads to the problems as discussed in the next section.

2.2 Problems with NPL

The presence of NPL poses various problems for the system:

- **Scheduling more generation than is required** - In an attempt to minimise the cost of generation (hence maximising the net benefit) during periods of negative prices, the MCE schedules more generation than is required by increasing modelled losses and hence creating NPL. Since losses are overestimated, regulation resources need to respond by backing off excess generation.
- **Incorrect pricing** – By increasing the amount of generation scheduled, the total number of Generation Blocks[8] dispatched could increase (by moving up the merit order), resulting in the scheduling of more expensive (albeit still negatively-priced) offer stacks.
- **Inaccuracy in transmission modelling** – Since losses are over-estimated and excess generation is scheduled, the resulting modelled transmission flow will also be unreflective of the physical reality (where NPL does not exist).

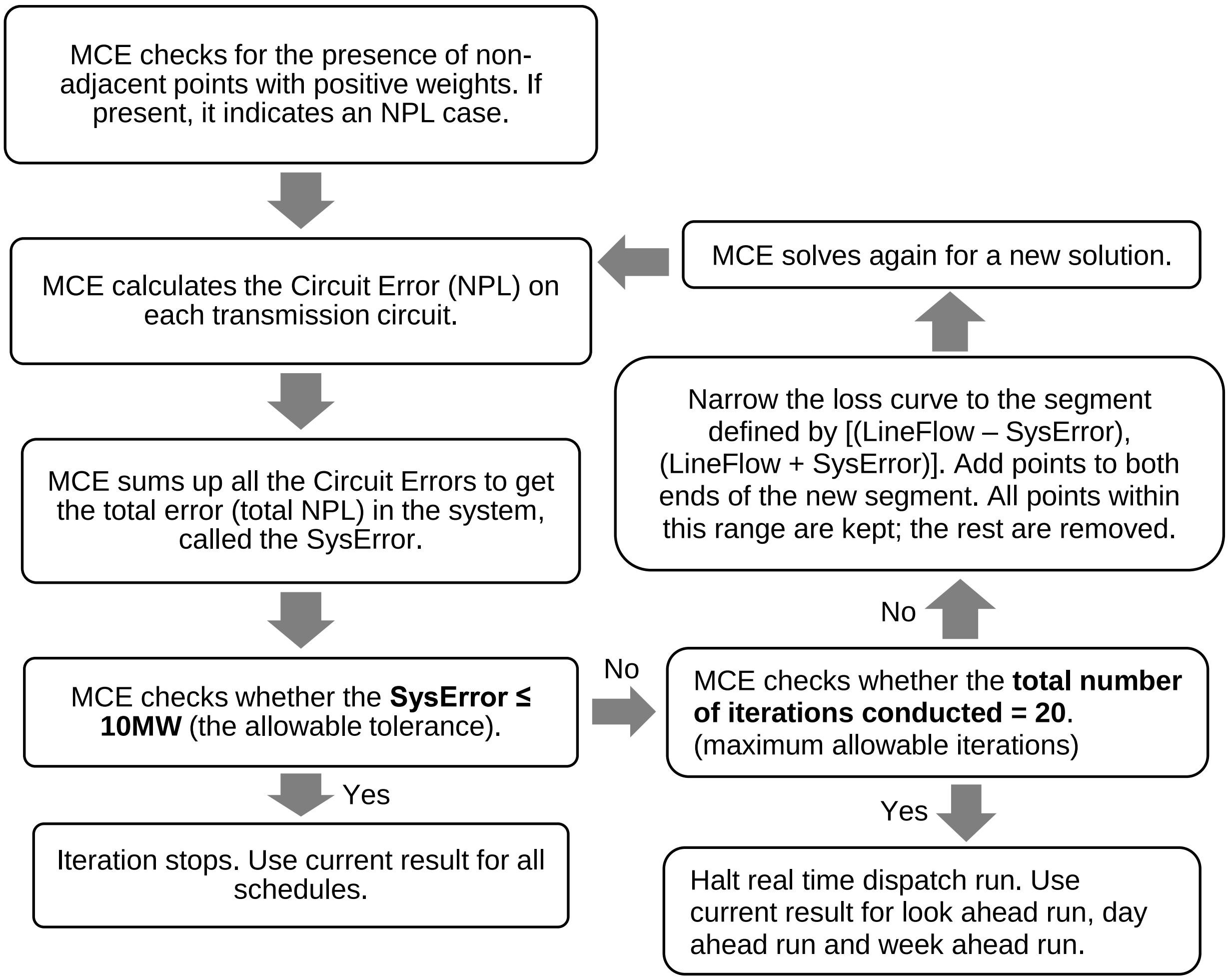
Therefore, our market rules and design currently provide for the treatment (specifically, reduction) of NPL when it exists.

[7] Please refer to Appendix 6D.22.4 of the Market Rules.
[8] Please refer to Appendix 6D.14.1.1 of the Market Rules.

2.3 Current Treatment of NPL: The Iterative Process

The root cause of NPL lies in the selection of non-adjacent points when calculating the loss. Currently, the MCE mitigates this problem by iteratively reducing the solution range, as described below.

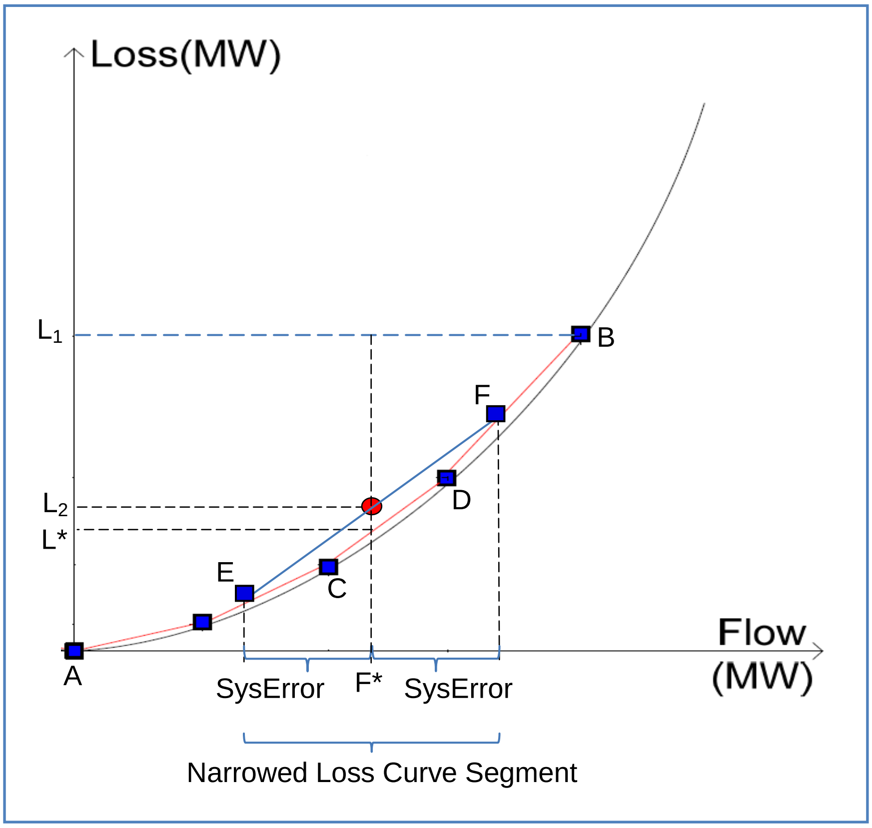
Figure 3: Current Iterative Handling of Non-Physical Losses



The NPL can be progressively reduced to within the allowable tolerance through the above iterative process. The iterative process ends when either the total NPL has been reduced to within the accepted threshold of 10MW, or the number of iterations[9] has reached 20, whichever comes first. This iterative process is further illustrated in Figure 4.

[9] For the threshold of 20 iterations, the first run that produces the initial results is treated as the first iteration.

Figure 4: Reducing NPL through an Iterative Process



In the earlier Figure 2, the MCE overestimated the transmission losses at L_1, much higher than the correct level of L*. Figure 4 above illustrates the iterative process that moves the loss level towards L*.

Essentially, after deriving the estimated flow, F*, across a given transmission line in the first solve, the MCE is re-run, restricting the flow on that same line to between F*± SysError (predetermined factor). Two additional points, E and F, are added at these ends, and losses are correspondingly restricted to the linear loss segment interpolated between F*+SysError and F*-SysError. The benefit of this approach can be seen from the example in both Figures 2 and 4, where the loss curve segment is narrowed such that the maximum loss that can be incurred for a flow of F* is lowered from L_1 to L_2, as determined by interpolation on the new solution range (i.e. F*± SysError).

However, the downside is that it is possible for the optimal line flow in the second run to fall outside the range of F*± SysError, which is in itself an artificial constraint. Due to the above method of narrowing the loss curve after each iteration (referred to herein as the "SysError-cutting method"), the estimated flow will be unnecessarily constrained at the boundaries (i.e. either F*+SysError or F*-SysError), leading to non-physical line binding ("NPLB") which is sub-optimal. Thus the choice of SysError has to be a careful balance between speed of convergence and NPLB[10].

2.4 Proposal Received

A proposal was received for an enhancement, named the "Loss Ceiling Method", to streamline the current iterative treatment of NPL. The proposer noted that the iterative process significantly increases the amount of time required for an MCE run, particularly for Market Outlook Scenario

[10] The smaller the SysError is, the greater the speed of convergence but at the same time, also the greater the problem of non-physical line binding.

(MOS) runs that cover 288 periods in a single run. In addition, the increasing generation capacity in the market could lead to more frequent periods of negative energy prices (especially in the forecast runs), and correspondingly the likelihood of NPL processing. It is thus crucial to improve the overall efficiency of the MCE in handling NPLs.

The proposed Loss Ceiling Method accelerates the convergence of the iterative procedure by capping the total loss (sum of physical and non-physical losses) in the system at an estimated upper limit value. This can be done by adding a new constraint (hereinafter called the "loss ceiling constraint") as part of the MCE formulation. The estimated total loss ceiling is calculated using the load forecast multiplied by a loss ratio, which is empirically determined based on historical data.

3. ANALYSIS OF PROPOSAL

3.1 NPL Incident on 14 February 2013

On 14 February 2013, EMC was unable to publish real-time schedules for Periods 6, 8, 9 and 10 of 14 Feb and Period 4 of 15 Feb, stemming from the MCE's failure to reduce the NPL to below the threshold of 10MW by the 20th iteration. During offline processing, despite removing the 20-iteration limit, the NPL level still persisted at around 10.5MW.

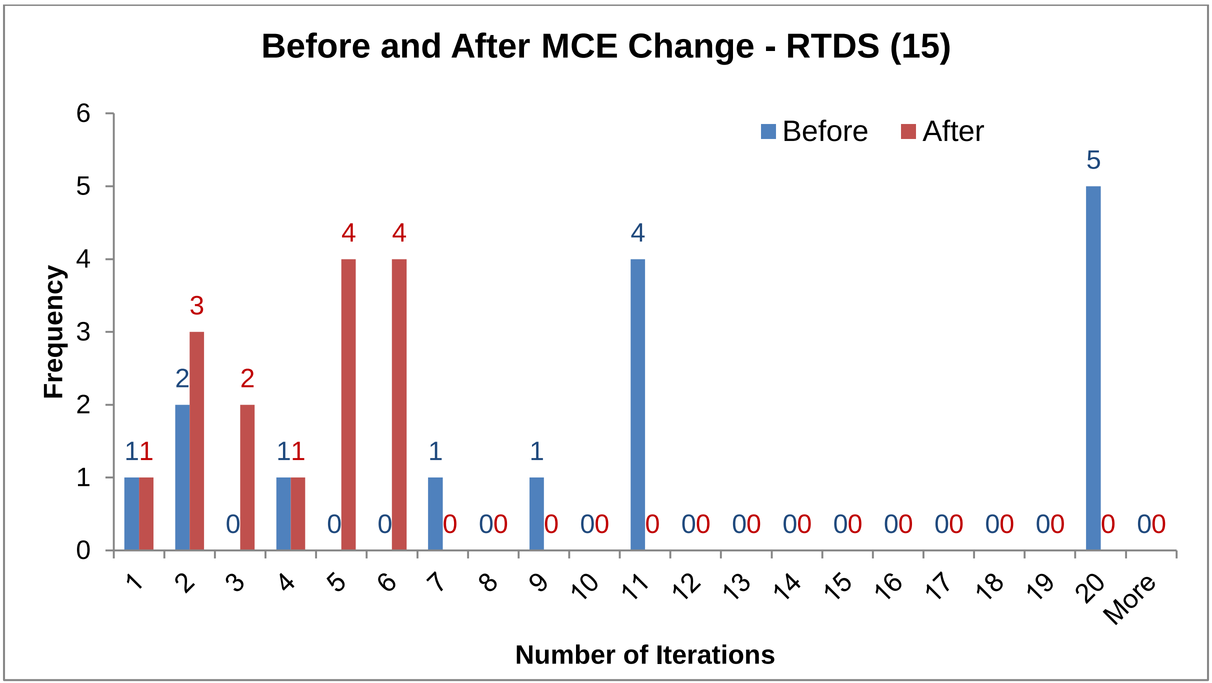
Upon investigation, it was found that the NPL levels for Type 2[11] artificial lines remained high even after 20 iterations, accounting for around 80% of overall NPL. This was because the MCE did not include Type 2 artificial lines in the iterative NPL reduction process. To address this problem, a procedural change to the MCE was implemented to <u>include all artificial lines</u>[12] in the NPL processing. EMC conducted re-runs in an offline environment, which showed that this change successfully brought the NPL down to below 10MW within 6 iterations for all affected periods.

Simulations were conducted on Real Time Dispatch Schedule (RTDS) runs for periods with zero and negative prices. Using 15 periods of actual RTDS with zero/negative prices from 14-15 February 2013, we observe a significant reduction in the number of iterations required after the MCE change, as shown in Figure 5 below.

[11] A physically disconnected unit (or node in the MCE) is modelled in the MCE as 'connected' to the grid via an artificial line (known as a "Type 2 artificial line"). This is to represent the fact that they are likely to be connected to the grid in future periods.

[12] In line with the Market Rules, the MCE now includes all artificial lines (Types 1, 2 and 3) for NPL processing. However, the MCE will first assess these lines for losses before treating them for NPL, and only Type 2 artificial lines are lossy. Thus, effectively only Type 2 artificial lines are treated for NPL.

Figure 5: Number of iterations before and after MCE change (15 RTDS periods, 14-15 Feb 2013)



To expand the scope of testing, 100 periods of RTDS were selected from 9-20 February 2013, with their offers replaced by standing offers[13] to generate zero/negative prices. The same outcome of a significant reduction in the number of iterations required after the MCE change was obtained. Please refer to **Annex 1** for details.

3.2 Proposed Loss Ceiling Constraint

The earlier sections found that after the MCE procedural change stemming from the 14 February 2013 incident, the number of iterations (and correspondingly the MCE run time required) has since been greatly reduced. Notwithstanding, there is merit in considering the proposed loss ceiling constraint as part of the continual enhancements to the MCE.

Specifically, the proposed loss ceiling constraint to be added into the MCE is

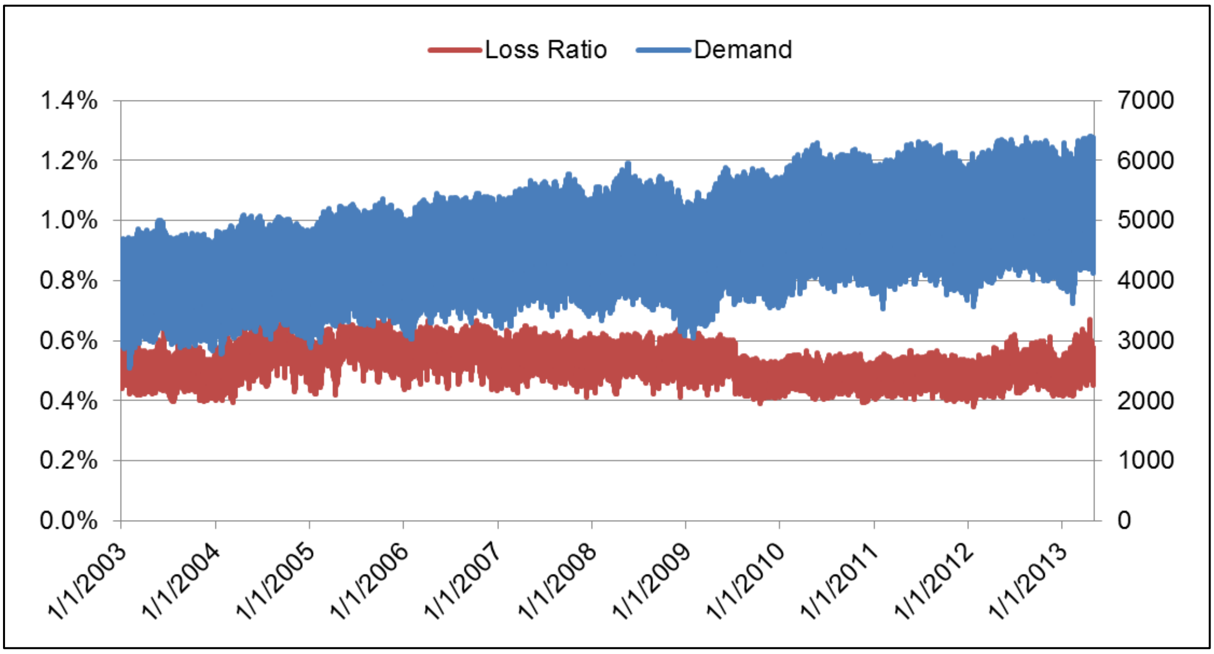
$$\sum_k \mathrm{LineLoss}_k \leq \text{Estimated total loss}, k \in \mathrm{LINES};$$

Estimated total loss[14] = Loss ratio * Forecast demand

Essentially, the loss ceiling constraint caps the maximum allowable loss across all transmission lines ($\sum_k \mathrm{LineLoss}_k$) at a proportion (i.e. the loss ratio) of overall forecast demand. As a result, at the very first iteration where the loss ceiling constraint is applied, the MCE already comes up with a solution with a relatively low NPL. The current SysError-cutting method is still used in subsequent iterations to reduce NPL further if the NPL in the first iteration is above the threshold of 10MW.

[13] Generally, standing offers are offered at lower prices, leading to a greater likelihood of negative prices.
[14] Also referred to as the total loss ceiling.

Figure 6: Loss Ratio (Left) and Demand (Right), Jan 2003 – Apr 2013



To derive a reasonable loss ratio, we observe the historical trends of forecast demand and total losses as shown in Figure 6. Although the average electricity demand steadily increased from 2003 to 2013, the loss ratio held steady within the range of 0.4-0.7%. Simulations were thus conducted based on loss ratios[15] of **0.7% and 1.0%,** given the need to set a buffer between the actual physical loss and the loss ceiling. Please refer to **Annex 2** for detailed results of the simulations.

The results show that the proposed loss ceiling does indeed reduce the number of iterations. However, since the loss ratio is determined in a static manner (e.g. 1%) regardless of the actual loss conditions, there are times when it varies significantly from the actual loss ratio (e.g. as low as 0.4% as shown above) such that its effectiveness is compromised. Specifically, when the difference between the actual loss ratio and the static loss ratio is *large*, the NPL obtained in the first run would be high and the SysError-cutting method would need to be applied in subsequent iterations to reduce the NPL. This increases the risk of NPLB which is sub-optimal. More iterations (and hence longer CPLEX solve-time) may also be required to bring the NPL level to within the acceptable threshold if the NPL in the first run is higher.

On the other hand, when the difference between the actual loss ratio and the static loss ratio is *small*, there is a risk of over-constraining the Physical Loss (PL) by setting the loss ceiling below the PL level. This is especially so because the proposed loss ceiling applies to both periods with positive and negative prices, even though NPL exists only during periods with negative prices.

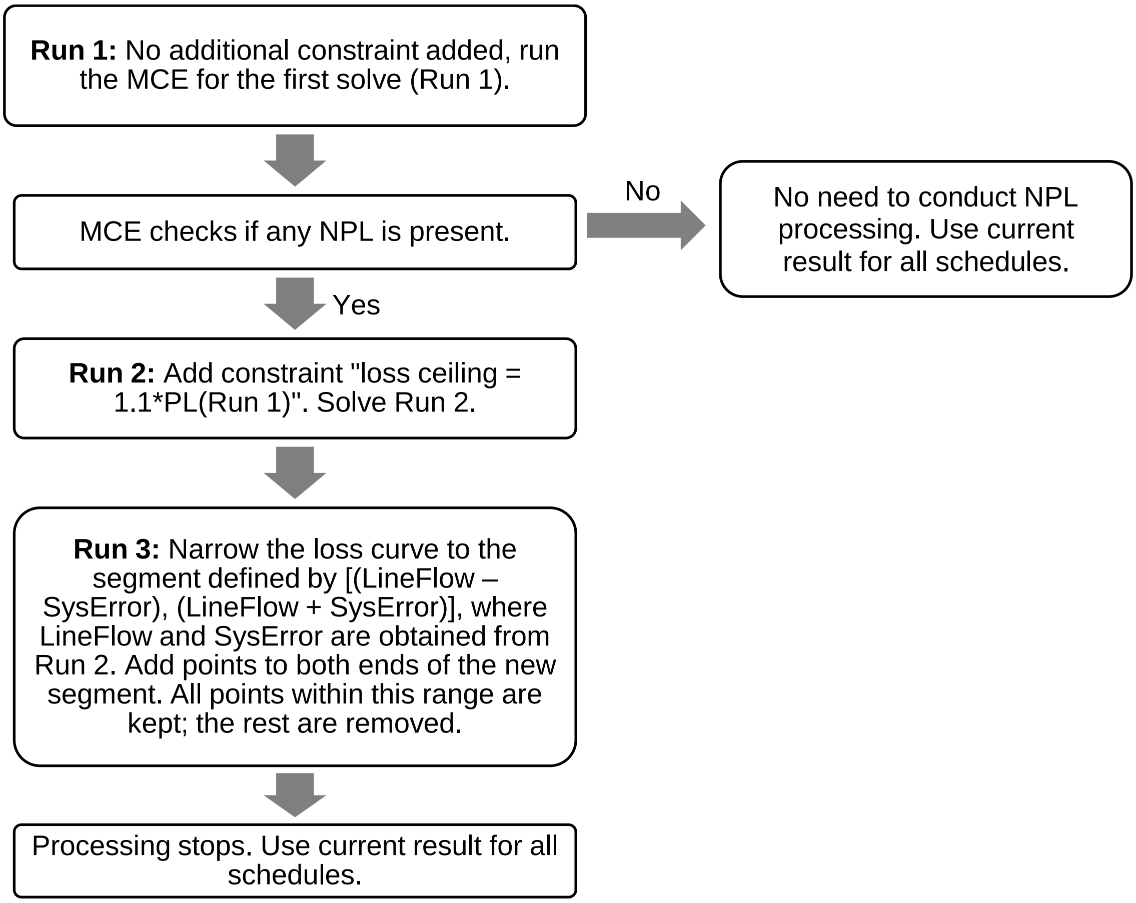
The upshot of this is that the loss ratio should be set such that the total loss ceiling is just above PL during periods of negative prices. This keeps NPL at a minimum and leads to faster convergence, without sub-optimally constraining PL[16]. Given the above issues of determining the loss ratio in a static manner, an alternative method termed the Modified Loss Ceiling constraint is analysed in the subsequent section.

[15] Loss Ratio = (Total Loss/Total Demand), where Total Loss=Sum of physical and non-physical losses.
[16] Please refer to Section 3.3.2 of this paper on the substitution between PL and NPL.

3.3 Three-Step Modified Loss Ceiling Constraint[17]

The three-step modified loss ceiling constraint dynamically sets the loss ceiling as a ratio (1+X%) of the Physical Loss (PL) where X is proposed to be 10. This implies that the loss ceiling is set at 1.1x of the PL, and the proposed method is shown in Figure 7 below.

Figure 7: Three-Step Modified Loss Ceiling Method



As shown in Figure 7, this modified version conducts the first MCE run without any additional constraints. If NPL is present in the first run, the loss ceiling is dynamically set at 1.1x of the PL in Run 1 and the MCE is run again. Given that PL is typically below 30MW during periods of negative prices[18], the loss ceiling of 1.1xPL translates to a maximum total loss of around 33MW or an NPL of at most 3MW (provided PL remains relatively steady across runs). Since 3MW is well within the threshold of 10MW, there is no longer a need to explicitly set this threshold, and the processing can possibly end here (after Run 2). Please refer to Figure A7 in **Annex 3** for the illustration of the two-step modified loss ceiling method.

However, if the processing were to end here, nodal prices will have a tendency to equalise (i.e. the prices at all nodes are the same). Under normal circumstances, nodal prices vary because the marginal load at various nodes causes differing losses[19] depending on their location on the grid, which contributes to their shadow price. However, after Run 2 of the modified loss ceiling method, this ceiling will be **binding** such that any marginal load that increases PL creates an

[17] To retain the principal of nodal price differential, a three-step modified loss ceiling method is proposed. This is similar to the two-step modified loss ceiling method proposed in the earlier published concept paper, except that a third run will be conducted with the SysError-cutting method to remove the effects of nodal price equalisation and further reduce the NPL obtained in the second run.
[18] This is because total demand is usually low in such situations, at about 4000MW.
[19] To be precise, transmission congestion effects also contribute to nodal price differential.

equal reduction in NPL and vice versa. Since there is no net change in total losses regardless of location, the nodal prices are the same throughout the grid.

To remove this effect of nodal price equalisation, the SysError-cutting method is used in the third run to relieve the binding loss-ceiling constraint obtained in Run 2. This causes the loss ceiling to be non-binding in the final round of iteration (Run 3), such that the nodal price differential is retained when prices are determined. This method is referred to as the Three-Step Modified Loss Ceiling method.

3.3.1 Simulations Using the Three-Step Modified Loss Ceiling Method

In the earlier concept paper published for consultation, the simulation results of the two-step modified loss ceiling method were compared with the current handling of NPL and the original loss ceiling method. This can be found in Table A1 of **Annex 3**.

To test the feasibility and effects of the Three-Step Modified Loss Ceiling method, it was applied to the same 15 periods of actual RTDS with zero/negative prices from 14-15 February 2013. The results are shown in Table 1 below.

Table 1: Simulation Results Using the Three-Step Modified Loss Ceiling Method (15 RTDS periods, 14-15 Feb 2013)

NPL Processing	Number of Iterations/Runs	Range of NPL	Average Final NPL	Range of Nodal Prices	Average Nodal Price
Current	6 (maximum)	0.2 to 7.2 MW	3.4 MW	-$10.19 to $0	-3.35
Three-Step Modified Loss Ceiling	3 (fixed)	0 to 0.08 MW	0.05 MW	-$10.19 to $0	-$3.70

As shown, with only half the number of iterations required compared to the current NPL handling, the three-step modified loss ceiling method significantly reduces the NPL level to below 0.08MW. The range of nodal prices across the 15 periods remains the same, while the average nodal price is slightly lower under the three-step modified loss ceiling method. This is expected because NPL is reduced and hence the amount of generation scheduled is reduced too. The detailed simulation results of the individual periods' nodal prices can be found in Annex 4.

3.3.2 Non-Physical Line Binding (NPLB)

As described in **Annex 3**, the two-step modified loss ceiling method removes the need for the SysError-cutting method (used in the current NPL handling and the original proposed loss ceiling method), and the corresponding risk of NPLB. Given that this three-step modified loss ceiling method reintroduces the SysError-cutting method (albeit in a different order and frequency), it is important to assess the risk (proxied by the frequency) of NPLB.

Simulation 1 (Frequency of NPLB under the three-step modified loss ceiling method):

Simulations using the three-step modified loss ceiling method were conducted for the same 15 RTDS periods on 14 and 15 Feb 2013, and the results are tabulated below.

Table 2: Simulation results of frequency of NPLB (three-step modified loss ceiling method)

Date	Period	Total number of transmission lines	Number of lines with NPLB	% of lines with NPLB
14/2/2013	6	602	0	0%

14/2/2013	7	602	0	0%
14/2/2013	8	602	1	0.17%
14/2/2013	9	602	0	0%
14/2/2013	10	602	1	0.17%
14/2/2013	11	602	0	0%
15/2/2013	3	598	0	0%
15/2/2013	4	599	1	0.17%
15/2/2013	5	598	0	0%
15/2/2013	6	598	0	0%
15/2/2013	7	598	0	0%
15/2/2013	8	598	2	0.33%
15/2/2013	9	598	0	0%
15/2/2013	10	598	0	0%
15/2/2013	11	598	0	0%
	Total =	**8995**	**5**	**0.06%**

Table 2 shows that when the SysError-cutting method was applied to Run 3 of the three-step modified loss ceiling method, NPLB exists in 4 out of the 15 periods simulated, with only 5 cases out of a total of 8995 line-iterations (0.06%).

Simulation 2 (Frequency of NPLB under the current NPL handling):

Simulations were also conducted using the current NPL handling, for the 15 RTDS periods on 14 and 15 Feb 2013. The results are shown in Table 3.

Table 3: Simulation results of frequency of NPLB (current NPL handling

Date	Period	Total number of transmission lines (A)	Number of iterations applying SysError-cutting (B)	Number of lines with NPLB (C)	% of lines with NPLB [=C/(A*B)]
14/2/2013	6	602	1	0	0.00%
14/2/2013	7	602	1	1	0.17%
14/2/2013	8	602	4	0	0.00%
14/2/2013	9	602	4	0	0.00%
14/2/2013	10	602	4	0	0.00%
14/2/2013	11	602	1	0	0.00%
15/2/2013	3	598	1	1	0.17%
15/2/2013	4	599	4	0	0.00%
15/2/2013	5	598	5	0	0.00%
15/2/2013	6	598	5	0	0.00%
15/2/2013	7	598	5	0	0.00%
15/2/2013	8	598	5	0	0.00%
15/2/2013	9	598	3	0	0.00%
15/2/2013	10	598	2	0	0.00%
15/2/2013	11	598	0	0	0.00%
	Total =	**8397 (excluding P11 of 15 Feb)**	**45**	**2**	**0.00%**

Table 3 shows that NPLB were found in 2 out of the 15 periods used. Given that there can be multiple iterations per period under the current NPL handling, of which each iteration is subjected to the sys-error cutting method (and hence the likelihood of NPLB), the percentage of lines with NPLB is found by taking into account the number of iterations in the period too.

Although NPLB occurs more frequently under the three-step modified loss ceiling method, it is because the SysError used (around 1.7 to 2.3MW) is much narrower than that in the current method (26.9 to 157.1MW). This is because the SysError used is the NPL level, and the NPL under the current method is much higher because it is not initially "trimmed" by the loss ceiling". With a narrower SysError under the three-step modified loss ceiling method, there is greater restriction on the flow boundaries and more NPLB is expected. However, based on the figures in Table 2, the extent of NPLB is not high enough to be a concern.

3.3.3 Further Considerations

Substitution between PL and NPL

One main concern regarding the loss ceiling constraints is that when there are both positive and negative prices in the system, the MCE, when constrained by the total loss ceiling, may hypothetically choose to reduce PL (by scheduling generation nearer to load) rather than reduce NPL[20]. This could lead to a double whammy of having NPL still at high levels, while scheduling in a more inefficient manner (intentionally scheduling out-of-merit generation nearer to load simply because this would reduce losses).

However, this is unlikely to pose a significant problem for two reasons:

1. Situations where there are both positive and negative prices in the system at the same time are very rare and require very significant price separation arising from serious transmission congestion. In recent cases of negative prices, there were only negative prices throughout the system without any price separation.
2. More importantly, the cost of reducing PL should outweigh the cost of reducing NPL, which implies that the MCE, when facing a loss ceiling, should almost always prefer to reduce NPL rather than PL. This is because to reduce 1MW of PL, the MCE would need to significantly reshuffle generation flow in the order of hundreds of MW, hence correspondingly penalising the net benefit function due to out-of-merit dispatch. In contrast, the cost of reducing NPL is the negative nodal price, which is likely to be only slightly negative.

To verify point 2 above, simulations were conducted as described below.

Simulation 3 (Forcing real loss reduction of 1MW):

To assess the cost of reducing 1MW of PL, five random periods with positive prices[21] were selected, and the MCE was run for two scenarios: 1) Normal scenario, and 2) "Force Loss Reduction" scenario where a hard constraint is set to limit the loss in this scenario to <u>1MW less</u> than the loss found in the normal scenario.

[20] When there are positive and negative prices, it could be more attractive for the MCE to reduce PL at positive price nodes (which increases the net benefit) rather than reduce NPL at negative nodes (which reduces the net benefit); this incentive may be strong enough for the MCE to schedule more expensive generation nearer to load. However, when there are negative prices throughout, MCE is neutral between reducing PL and NPL. Since the former involves scheduling more expensive generation nearer to load, the MCE will always choose to reduce NPL instead.

[21] Periods with positive prices were used so that there would not be NPL. This allows us to set the hard constraint of 1MW reduction of real loss (PL).

Essentially, the results show that by forcing a real loss reduction of 1MW, the selected five periods' net benefit values suffered a decrease of between $2,684 and $27,777 as a result of out-of-merit dispatch (i.e. scheduling more expensive energy and ancillary services). This implies that unless negative prices in the system are of the magnitude of thousands of dollars, the substitution effect (of reducing PL instead of NPL) should not exist.

Stability of Physical Loss Level

It was mentioned earlier in Section 3.3 that the final NPL level will be below 3MW (the 10% buffer allowance for NPL), provided PL is relatively stable across the two runs[22]. The results of Simulation 3 above, showing that the MCE is unlikely to reduce PL over NPL, lends weight to the stability of PL across runs.

Notwithstanding this, when total loss is reduced in Run 2 due to the imposition of the loss ceiling, there could be correspondingly slight reductions in PL; with the significant reductions in NPL, generation schedule is reduced (since fewer MWs are required in the system), which resultantly reduces PL slightly.

It is therefore important to verify that the ratio of the change in PL to the change in total loss (that is, $\frac{\Delta PL}{\Delta TotalLoss}$) is low, which implies that the loss ceiling is effective in reducing NPL rather than PL. Simulations were conducted that found that the final NPL level achieved in Run 2 falls below 3MW, and the change in PL relative to the change in total loss is small (less than 1%). Please refer to **Annex 5** for the detailed results.

3.4 Finding the Global Optimum

There were concerns raised on how the proposal may affect the net benefit function. Given the earlier discussion on how NPL would perversely improve the net benefit function, adjustments had to be made before there could be a logical basis for comparison. Specifically, we needed to strip away the effects of NPL, so that the resulting net benefit function is comparable across different methods as a true reflection of optimality.

Essentially, NPL arises because given a line flow value, the MCE had to interpolate between 9 different points to derive the modelled line loss. An alternative algorithm was implemented whereby given that line flow value, it was directly matched to the correct line loss segment[23] (red linear segment in Figure 1) using Mixed Integer Programming (MIP). This effectively strips away any possible NPL but is computationally intensive[24].

Using this revised algorithm, simulations were conducted on 6 periods from 14-15 Feb 2013 to find the global optimum (without NPL), and outcomes under the current NPL handling and three-step modified loss ceiling method:

Simulation 4 (MIP-based Net Benefit values):

We define Options A, B and C as follows:

- **Option A:** Apply MIP from the start to find the global optimum for each period. This gives us a theoretical "best" net benefit value to compare other results against.

[22] Specifically, it refers to the change in PL from Run 1 (without loss ceiling constraint) to Run 2 (with the modified loss ceiling constraint).
[23] The MIP was programmed to require that only adjacent points can be selected in the modeling of losses, thus ensuring that no NPL can be formed.
[24] Given the computational complexity of MIP, it takes a few hours for a single run. It is thus suitable only for offline simulations, but not for actual scheduling runs whereby MCE has to complete the computations within a matter of minutes.

- **Option B:** Apply the three-step modified loss ceiling method to each period, and then apply MIP on the reduced solution space following the last iteration (3rd Run).
- **Option C:** Apply the current NPL handling to each period, and then apply MIP to the reduced solution space following the last iteration whereby the 10MW threshold was met.

Since both Options B and C use different methods to reduce the solution space, the optimal solution could have been 'cut out' in the process, and the resulting net benefit value would have a greater discrepancy from that of Option A (the global optimum). The method that is better in terms of optimality (that is, low degree of sub-optimality) should have net benefit values closest to Option A's net benefit value.

Table 4: Simulation Results of Net Benefit Values using MIP

	Net Benefit Value ($)			Deviation from Optimal Net Benefit Value	
Date	**Option A: Global Optimum**	**Option B: Three-Step Modified Loss Ceiling**	**Option C: Current**	**Absolute Difference (A, B)**	**Absolute Difference (A, C)**
14/2/2013 P6	193405601.061	193405601.355	193405601.354	$0.29	$0.29
14/2/2013 P7	196469280.145	196469280.503	196469280.500	$0.36	$0.36
14/2/2013 P8	196167747.069	196167747.208	196167637.824	$0.14	**$109.24**
14/2/2013 P9	196338484.540	196338484.517	196338484.540	$0.02	$0.00
14/2/2013 P10	197440058.866	197440058.855	197440058.866	$0.01	$0.00
15/2/2013 P4	196886975.088	196886975.088	196886975.088	$0.00	$0.00

Table 4 above shows the simulation results of the three options using MIP. The absolute differences between Options A and B, and Options A and C, are generally small, which suggests that both methods are sound and do not compromise optimality. However, Period 8 of 14 Feb 2013 showed **a large discrepancy of $109.24** between both Options A and C, suggesting that the current NPL handling method may not consistently provide a solution close to the global optimum, and hence could be a less accurate modelling method than the three-step modified loss ceiling method.

3.5 Comparison of the Three-Step Modified Loss Ceiling Method with the Current NPL Handling

Table 5 below summarises the differences between the current NPL handling and the three-step modified loss ceiling method, based on the above analysis.

Table 5: Comparison of the Three-Step Modified Loss Ceiling Method with the Current NPL Handling

Method	Performance	Optimality			
	Number of Iterations[25]	Final NPL Level[26]	Non-Physical Line Binding (NPLB)	Determination of Optimal Flow	Deviation from Global Optimum
Current	≤7 (variable though; could be greater than 7 depending on the period)	~3.4MW	NPLB is negligible given large SysError ranges	Flow determined in first few runs could be sub-optimal due to presence of high NPL. Flow determined in subsequent runs may not contain optimal flow due to SysError cutting in each iteration.	Inconsistent deviation from global optimum. Maximum deviation of $109.24 for 6 periods simulated.
Three-Step Modified Loss Ceiling Method	3 (fixed)	~0.05MW	More NPLB than current method given tighter SysError ranges, but still insignificant	Flow determined in Run 2 is closer to optimum, since loss ceiling constraint greatly reduces NPL already.	Consistently small deviation from global optimum. Maximum deviation of $0.36 for 6 periods simulated.

As shown above, the three-step modified loss ceiling method achieves a lower final NPL level (close to zero) through fewer iterations (fixed at 3) than the current handling of NPL. This ensures a more accurate modelling of actual losses/transmission flow in a shorter amount of time when NPL exists in the system.

In addition, although the three-step modified loss ceiling could lead to more frequent NPLB, this is because its SysError ranges are much tighter. If anything, its modelled flow in Run 2 should be much closer to the optimum, given that the NPL has already been greatly reduced to below 3MW. This shows up in the comparison with the global optimum, whereby it consistently achieves only a small deviation (maximum of $0.36) for the 6 periods simulated.

Taken together, the results show that the three-step modified loss ceiling method achieves both better performance and optimality than the current NPL handling.

4. SYSTEM IMPLEMENTATION TIME AND COSTS

The table below shows the breakdown of the estimated time and costs for the implementation of the three-step modified loss ceiling method.

[25] The lower the number of iterations/runs, the lesser the amount of CPLEX-solve time required.
[26] Average final NPL level for 15 RTDS periods.

Table 6: Estimated Implementation Time and Costs

Time Estimates		
1. Change Requirement Scoping and Analysis	1 man-week	3 calendar-weeks
2. MCE Development	5 man-weeks	5 calendar-weeks
3. System Tests and Performance	2 man-weeks	4 calendar-weeks
4. User Acceptance Testing (UAT)	4 man-weeks	5 calendar-weeks
5. Audit	2 man-weeks	4 calendar-weeks
6. Parallel MCE runs & detailed daily check analysis/investigation	4 man-weeks	8 calendar-weeks
Total Effort Required	18 man-weeks	29 calendar-weeks
Total Time Required	**27 calendar-weeks** (Audit overlapping with Parallel Runs)	
Cost Estimates		
1. Internal Power Systems Consultant Resource	Within EMC's Budget	
2. External resource to support parallel MCE Runs	$29,700	
3. Audit	$20,000	
Total Additional Cost Required	**$49,700** (To be funded from the RCP Contingency Budget)	

5. CONCLUSION

The original proposal to implement a loss ceiling constraint aims to reduce the number of iterations and CPLEX solve-time required in the iterative process used to handle NPL. Although an MCE procedural change made after the proposal was received has already improved the iterative process, there is still room for further enhancement (both in terms of performance and optimality) through the implementation of a three-step modified loss ceiling constraint.

Simulation results show that the three-step modified loss ceiling method achieves a lower final NPL level (close to zero) in fewer iterations (fixed at 3) than the current handling of NPL. This means that we can achieve a more accurate modelling of actual losses in a shorter amount of time when there is NPL in the system.

In addition, the three-step modified loss ceiling method is able to achieve a more robust outcome of determining the flow concurrently with a low NPL. Comparing net benefit values, the same result is obtained verifying the improved optimality of the three-step modified loss ceiling method over the current NPL handling, where the former shows a small (maximum of $0.36) and consistent deviation from the true global optimum, while the latter shows an inconsistent deviation, with a deviation of as large as $109.24 for the periods simulated.

The above factors show that the three-step modified loss ceiling method minimises NPL with fewer iterations while also achieving better optimality.

Nevertheless, periods with negative prices/NPL processing usually occur during forecast runs and rarely in RTDS runs. As such, the enhancement should be weighed against the system implementation costs.

6. INDUSTRY CONSULTATION

The concept paper was published for industry consultation on 16 July 2013, and the following comments were received from Tuas Power Supply and Senoko Energy.

Comments from Tuas Power Supply

1. *Tuas Power does not support the equalization of nodal prices because it works against the economic optimality which should be the prime objective of MCE run;*
2. *It is not clear from the paper that adopting the modified loss ceiling method is superior in achieving better optimization. If the objective is only to minimize NPL, the easiest solution would be to adopt actual loss L* calculated from the flow F* instead of applying a 10% range to L*. If the objective is also to achieve better optimization, it would be helpful if the objective function resulting from applying the different methods are worked out and compared to each other;*
3. *Re the cost-benefit of applying the proposed change, if the benefit is only to reduce the number of iterations from 6 to 2, it may not worth the cost which includes the side effects such as equalization of nodal prices.*

EMC's Response

EMC recognises the concerns about the equalisation of nodal prices under the two-step modified loss ceiling method (published in the original concept paper), and has proposed a three-step modified loss ceiling method to address this. Table 5 of this paper compares the three-step modified loss ceiling method with the current NPL handling. Our simulation results found that the three-step modified loss ceiling method achieves a lower final NPL level (close to zero) in fewer iterations (fixed at 3) than the current handling of NPL. This means that we can achieve a more accurate modelling of actual losses in a shorter amount of time when there is NPL in the system.

In addition, the three-step modified loss ceiling method is able to achieve a more robust outcome of determining the flow concurrently with a low NPL. Comparing net benefit values, the same result is obtained verifying the improved optimality of the three-step modified loss ceiling method over the current NPL handling, where the former shows a small (maximum of $0.36) and consistent deviation from the true global optimum, while the latter shows an inconsistent deviation, with a deviation of as large as $109.24 for the periods simulated.

The above factors show that the three-step modified loss ceiling method minimises NPL with fewer iterations while also achieving better optimality.

Comments from Senoko Energy

We request that further analysis is undertaken and provided comparing the 3 methods in Table 4 [current NPL handling; original proposed loss ceiling method with 1% loss ratio; modified loss ceiling method]*. In particular, it would be useful to consider the costs of implementation for the new methods and the potential impact of whether nodal price equalisation in the presence of NPL is consistent with the market design (i.e., nodal prices reflect localised differences in the demand and supply balance).*

EMC's Response

The proposed three-step modified loss ceiling method removes concerns over nodal price equalisation, and the cost of implementation is detailed in Table 6 of this paper.

7. TWG'S DECISION AT THE 21ST TWG MEETING

The paper was presented at the 21st TWG meeting held on 21 August 2013. EMC recommended that the TWG discuss the benefits and costs of the three-step modified loss ceiling method, and decide whether or not to implement the three-step modified loss ceiling method.

While the TWG recognised the merits of the three-step modified loss ceiling proposal and agreed that it was theoretically sound, they noted that the actual number of real-time dispatch periods that will be affected by NPL is limited, given the low frequency of negative prices in real-time dispatch periods. In view of other higher priority issues in our market currently, the TWG reckoned that this proposal could be put on hold until a time when NPL becomes a more pressing issue.

Therefore, the TWG by majority vote **did not support** implementing the three-step modified loss ceiling method.

The member who supported the proposal was:
1. Mr. Yong Thi Yen (PSO)

The members who did not support the proposal were:
1. Mr. Chua Gwen Heng (Sembcorp Cogen)
2. Mr. Tung Ho Kok (PacificLight Power)
3. Mr. Lionel Lee (SP PowerGrid)
4. Ms. Tini Mulyawati (Keppel Energy)
5. Ms. Lin Nan (Seraya Energy)
6. Ms. Bai Jie (EMC)

8. DECISION AT THE 69TH RCP MEETING

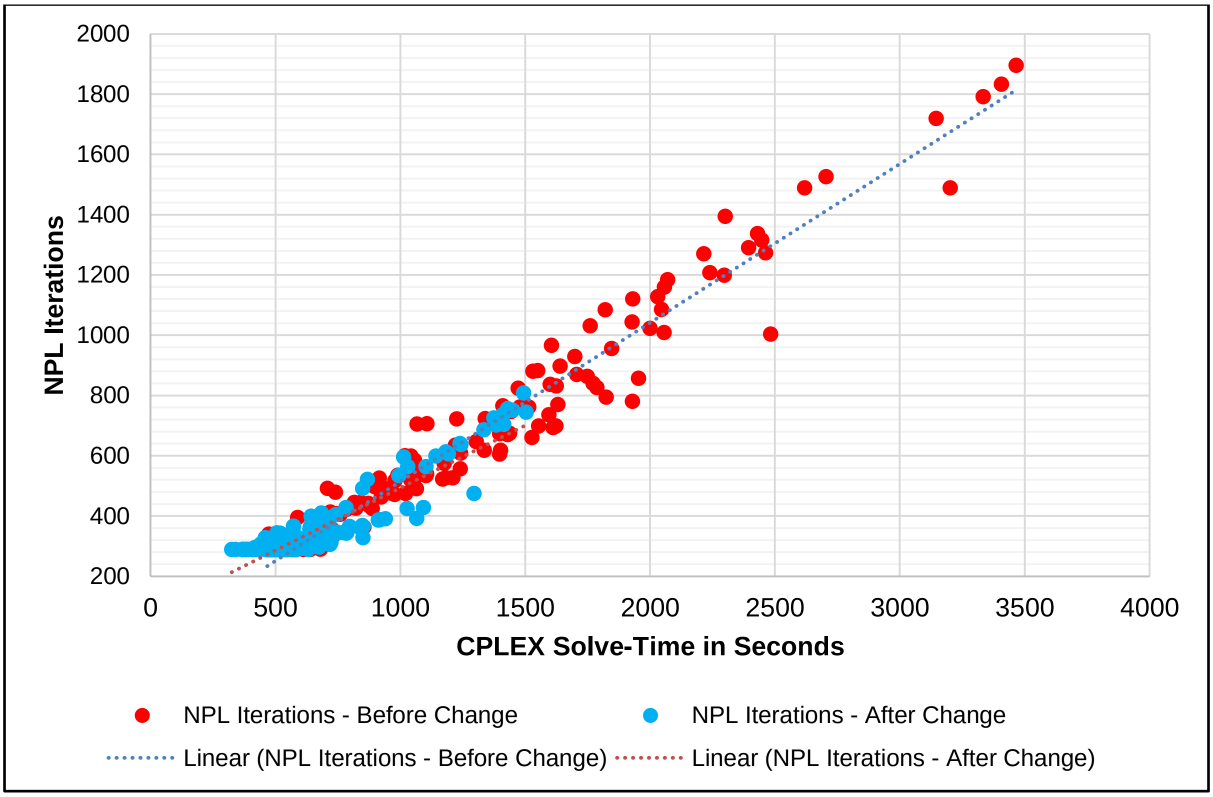
At the 69th RCP meeting, the RCP considered the benefits and costs of the three-step modified loss ceiling method. There was general consensus with the TWG that while the proposal was sound and had its merits, the low frequency of negative prices in real-time dispatch periods would mean that the benefits would be limited and not justify the costs of implementation. Therefore, the RCP unanimously decided **not to support** the implementation of the three-step modified loss ceiling method to handle non-physical losses.

Annex 1: Simulations on Effect of MCE Procedural Change

Simulations Before and After MCE Procedural Change (Using Week Ahead Runs)

To rigorously test the impact of the MCE procedural change, simulations were conducted on Week Ahead Runs (WAR) from 1 January 2013 to 30 April 2013[27]. WARs were chosen as they comprise 288 periods each, which amplifies the effect of multiple iterations. As the NPL incident occurred on 14 February 2013, and the MCE procedural change was successfully implemented on 15 February 2013, data before and after the MCE change were compared in Figure A1.

Figure A1: Number of iterations and CPLEX solve-time for WAR from 1 Jan to 30 Apr 2013



Note: In this figure, the first run that produces the initial results is counted as an iteration. Hence periods with positive prices will show up as 288 iterations (representing the first run for each of the 288 periods in a WAR), as there is no need for further iterations since there is no NPL. Periods with negative prices will entail more than 288 iterations per WAR.

As shown in Figure A1, the number of iterations required and the total CPLEX solve-time for each WAR were reduced significantly after the change (from red dots to blue dots). Specifically, the maximum and average CPLEX solve-times for WAR were reduced by 57%[28] and 52%[29] respectively.

Figure A1 also shows a direct, linear relationship between the number of iterations and the total CPLEX solve-time (approximately 2 seconds per iteration). This suggests that any reduction in the iterations directly reduces the CPLEX solve-time, which is critical given the MCE's responsibility to produce schedules within deadlines.

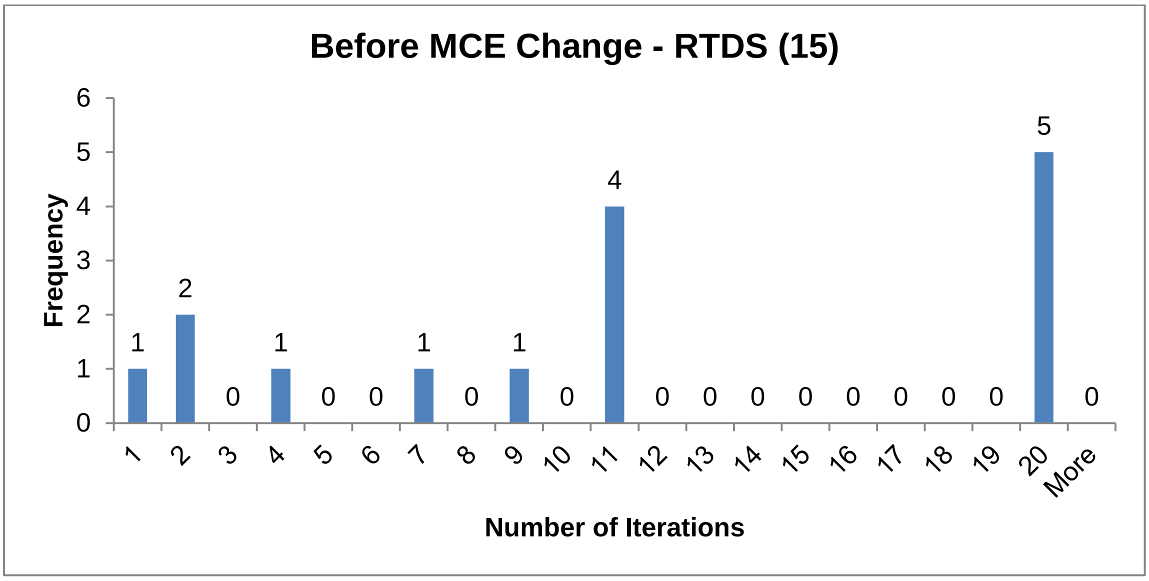
[27] 360 WAR (also known as Market Outlook Scenarios) were used in total.
[28] Based on the raw data, the maximum CPLEX solve time before the MCE change is 3466s, and that after the MCE change is 1504s.
[29] Based on the raw data, the average CPLEX solve time before the MCE change is 1320s, and that after the MCE change is 639s.

Simulations Before and After MCE Change (Using Real Time Dispatch Schedule Runs)

Additional simulations were conducted on Real Time Dispatch Schedule (RTDS) runs for periods with zero and negative prices. Using 15 periods of actual RTDS with zero/negative prices from 14-15 February 2013, we observe a significant reduction in number of iterations required after the MCE change:

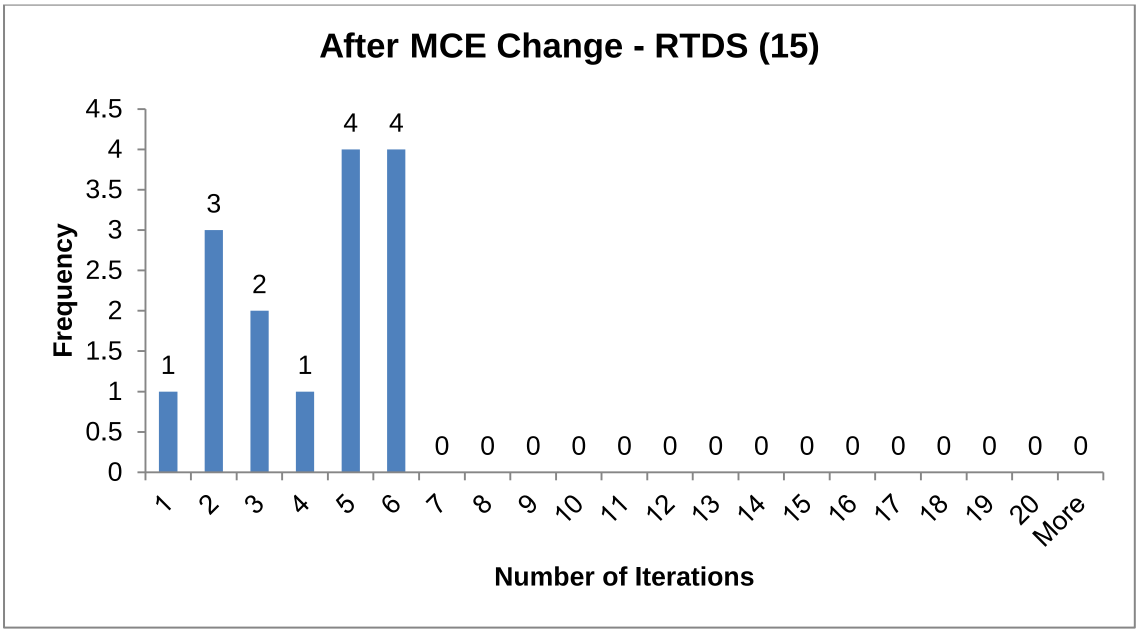
Simulation A1a (15 periods of RTDS with actual offers):

Figure A2a: Number of iterations before MCE change (15 RTDS periods, 14-15 Feb 2013)



Note: In Figures A2a and A2b, the first run that produces the initial results is counted as one iteration. Hence, if the number of iterations is 2, it means that the first iteration discovered negative prices (hence NPL exists), and the second iteration managed to reduce the NPL to within 10MW.

Figure A2b: Number of iterations after MCE change (15 RTDS periods, 14-15 Feb 2013)

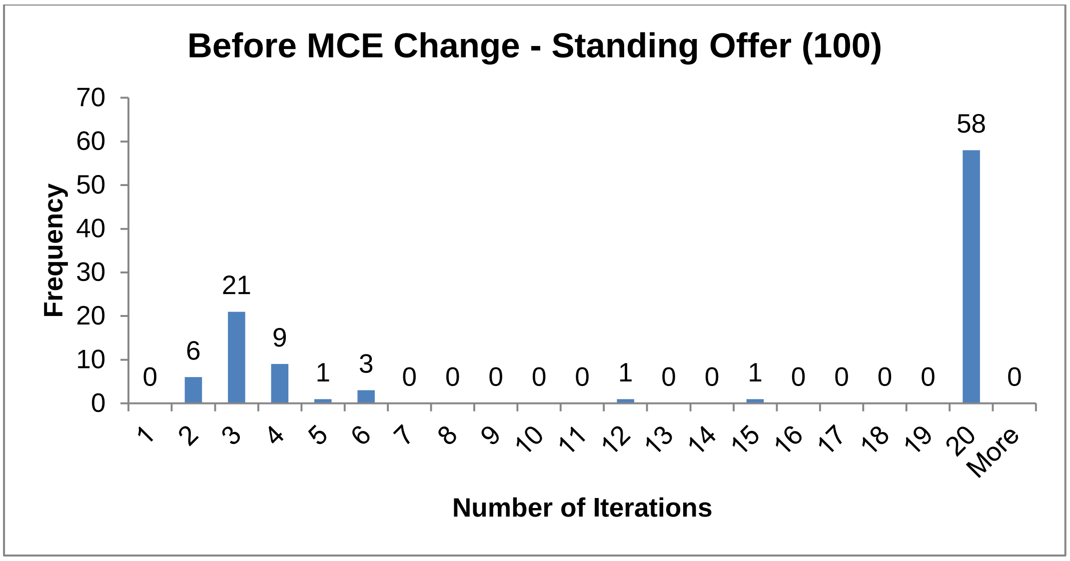


On 14 and 15 February 2013, 15 RTDS exhibited zero or negative prices, of which 5 failed to reduce the NPL to within 10MW even after 20 iterations (see Figure A2a). After the MCE change, the NPL was successfully brought down to within 10MW in 6 iterations or less for all affected periods (see Figure A2b).

Simulation A1b (100 periods of RTDS with offers replaced by standing offers):

To expand the scope of testing, 100 periods of RTDS were selected from 9-20 February 2013, with their offers replaced by standing offers[30] to generate zero/negative prices. The first 10 periods of each day (excluding 14-15 February 2013[31]) were used as they have zero/negative prices.

Figure A3a: Number of iterations <u>before</u> MCE change (100 periods using standing offers)



Note: In Figures A3a and A3b, the first run to produce the initial results is counted as an iteration.

Figure A3b: Number of iterations <u>after</u> MCE change (100 periods using standing offers)

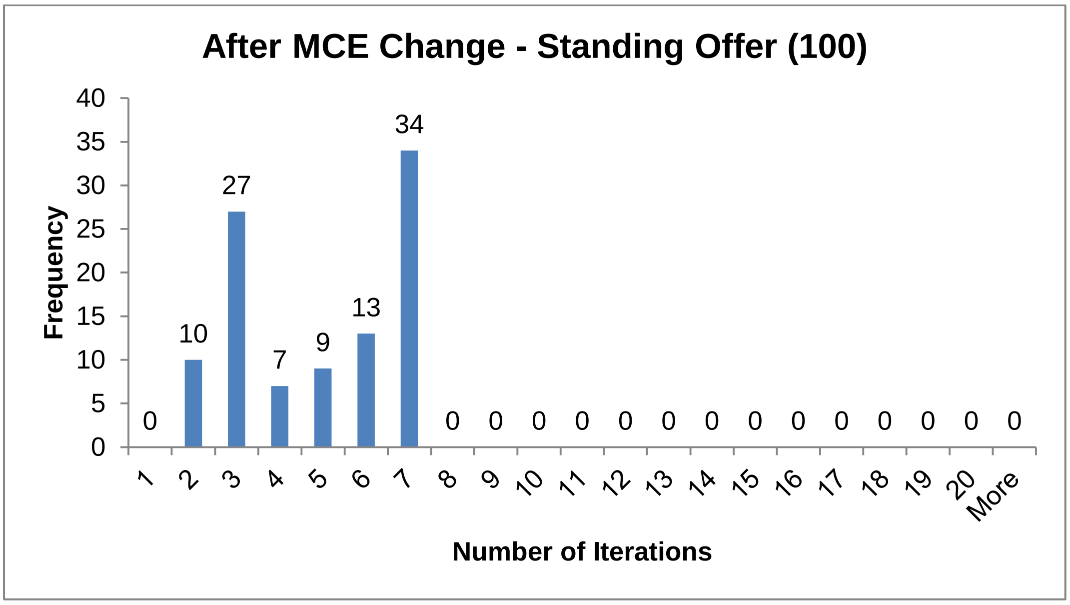
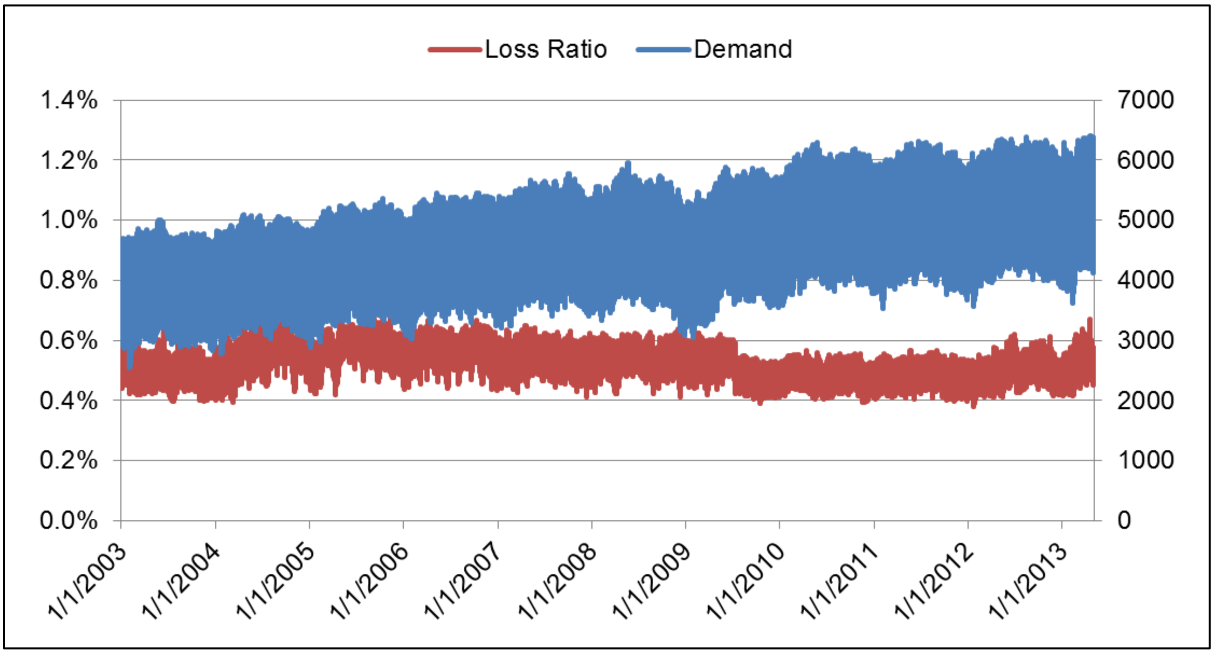


Figure A3a shows that, under this stress test, the MCE was unable to reduce the NPL to below 10MW, even after 20 iterations, in 58 out of 100 periods. However, after the MCE change in Figure A3b, the MCE could reduce the NPL to acceptable levels within 7 iterations, for all 100 periods.

[30] Generally, standing offers are offered at lower prices, leading to a greater likelihood of negative prices.
[31] There are real DPR runs with zero/negative prices for 14 and 15 February 2013. These 15 periods on those two dates are simulated separately in Simulation 1a earlier, without replacing offers with standing offers. Recall that the NPL incident leading to the MCE change occurred on 14 February 2013.

Annex 2: Detailed Results of Proposed Loss Ceiling Constraint

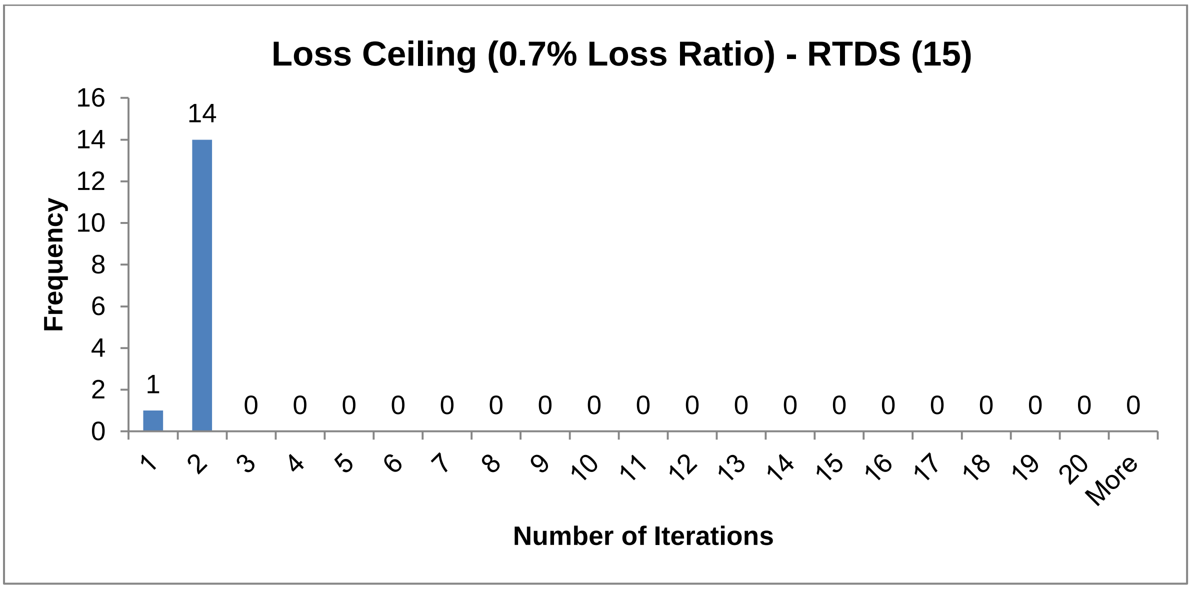
Figure A4: Loss Ratio (Left) and Demand (Right), Jan 2003 – Apr 2013



Since Figure A4 shows that the loss ratio has been steady within the range of 0.4-0.7% over the past decade, we conducted simulations based on a loss ratio[32] of **0.7%**.

Simulation A2a (Loss Ceiling, 15 periods of RTDS with actual offers):

Figure A5a: Number of iterations with Proposed Loss Ceiling Constraint (0.7% Loss Ratio, 15 RTDS periods, 14-15 Feb 2013)

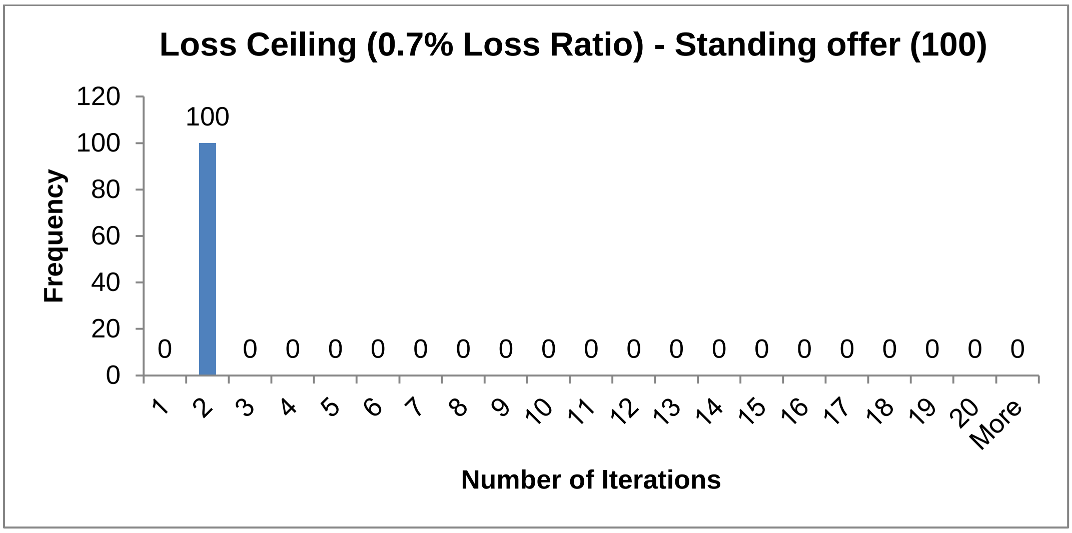


Note: In Figures A5a and A5b, the first run to produce the initial results is counted as an iteration.

[32] Loss Ratio = (Total Loss/Total Demand), where Total Loss=Sum of physical and non-physical losses.

Simulation A2b (Loss Ceiling, 100 periods of RTDS with offers replaced by standing offers):

Figure A5b: Number of iterations with Proposed Loss Ceiling Constraint (0.7% Loss Ratio, 100 periods using standing offers)



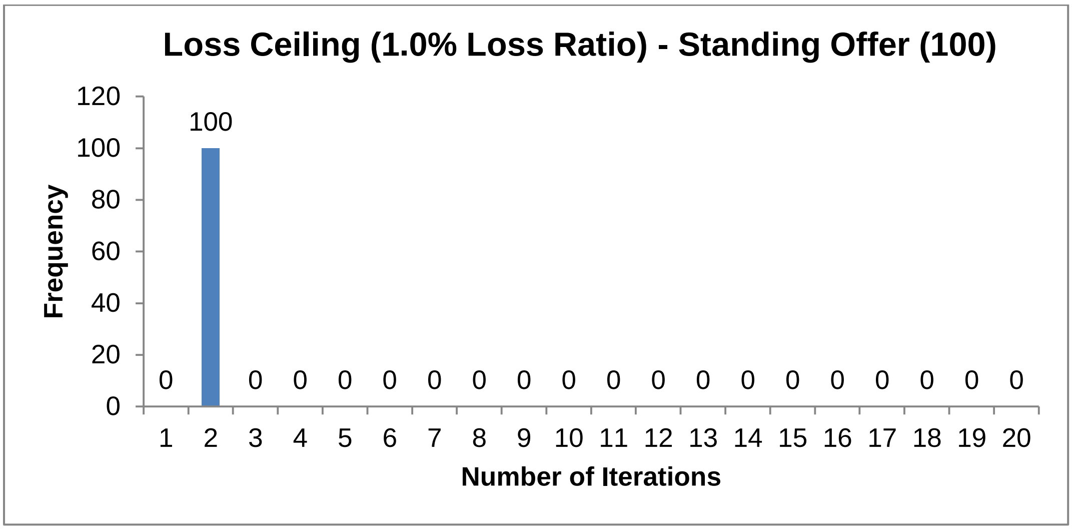
With the proposed loss ceiling constraint added, the maximum number of iterations required reduced from 6-7 (Figures A2b and A3b) to 2 (Figures A5a and A5b), under both sets of data (15 periods using RTDS and 100 periods using standing offers). It accelerated the convergence of the iterative process, leading to fewer iterations and correspondingly shorter CPLEX solve-time.

To refine the proposal, the loss ratio variable was further examined:

- **0.7% Loss Ratio** – The choice of loss ratio is a careful balance. On one hand, setting a high loss ratio dilutes the effect of the proposal, leading to weaker convergence. On the other hand, if the loss ratio were too low, it could lead to infeasible solutions or solutions that were sub-optimal, because they attempt to keep total losses within the loss ceiling (e.g. scheduling very expensive generation just because they are nearer to loads and hence have lower losses).

  The ratio was initially set at 0.7% based on historical trends, but this limit could be binding if losses increase relative to demand in future. Accordingly, further simulations were conducted with the loss ratio set at 1.0%, as shown in Figure A6 below. Since convergence remains strong at 1.0% as observed from the low number of iterations required, while there is a comfortable buffer above current observed loss ratios (as shown in Figure A4), setting the Loss Ratio at 1.0% would be preferred to 0.7%**.**

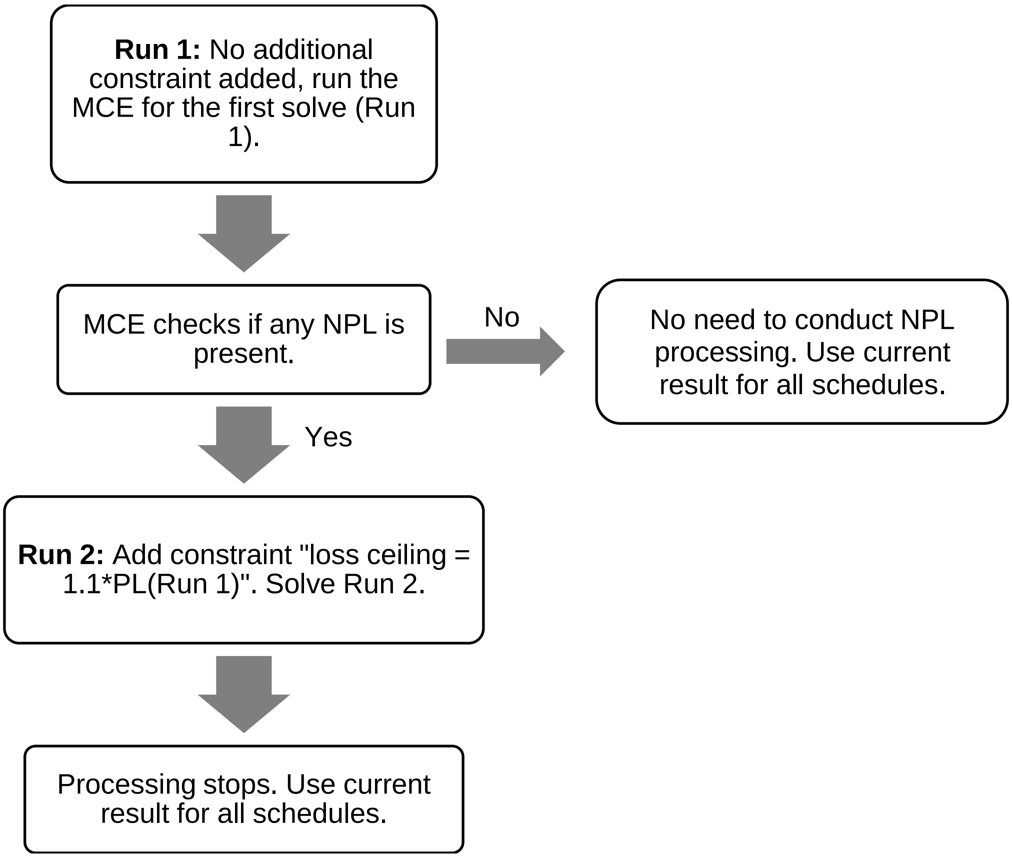
Figure A6: Number of iterations with Proposed Loss Ceiling Constraint (1.0% Loss Ratio, 100 periods using standing offers)



Note: In Figure A6, the first run to produce the initial results is counted as an iteration.

Annex 3: Two-Step Modified Loss Ceiling Constraint (without Run 3 to remove price equalisation)

Figure A7: Two-Step Modified Loss Ceiling Method



As shown in Figure A7, this deterministic[33] process ends after Run 2, without the need for possible additional iterations. This removes the need for the SysError-cutting method described in Section 2.3 (see Figure 4), and the corresponding risk of NPLB. Furthermore, since the final NPL will be at most 3MW, there is no longer a need to explicitly set the thresholds of 10MW and 20 iterations.

Simulations Using the Two-Step Modified Loss Ceiling Method

The Two-Step Modified Loss Ceiling method was applied to the 15 periods of actual RTDS with zero/negative prices from 14-15 February 2013, and 100 RTDS periods using standing offers (with zero/negative prices) from 9-20 February 2013. The results are shown in Table A1 below.

[33] The modified loss ceiling method is deterministic in that it guarantees an outcome with a maximum NPL of 3MW in two runs. In contrast, the enhancement under the original proposed loss ceiling method is heuristic in the sense that the outcomes are empirically observed.

Table A1: Simulation Results Using the Two-Step Modified Loss Ceiling Method

		15 RTDS periods, 14-15 Feb 2013	100 periods standing offers, 9-20 Feb 2013
Number of Iterations/Runs	**Current**	6	7
	Original Loss Ceiling[34]	2	2
	Two-Step Modified Loss Ceiling	2	2
Range of NPL	**Current**	0.2 - 7.2 MW	0.7 - 9.6 MW
	Original Loss Ceiling[35]	0.3 - 6.9 MW	2.0 - 6.4 MW
	Two-Step Modified Loss Ceiling	1.2 - 2.3 MW	2.0 - 2.6 MW
Average Final NPL	**Current**	3.4 MW	3.7 MW
	Original Loss Ceiling[36]	4.8 MW	5.0 MW
	Two-Step Modified Loss Ceiling	1.8 MW	2.0 MW

Table A1 compares the results of the two-step modified loss ceiling method with the current handling of NPL and the original loss ceiling method. Similar to the original loss ceiling method, the modified loss ceiling method requires only two runs before processing stops. However, the resulting NPL level for the latter is lower than that for the former (a maximum of 2.3MW versus 6.9MW, and an average of 1.8MW versus 4.8MW for the 15 periods of RTDS on 14 and 15 February 2013).

[34] The original loss ceiling method here uses a 1% loss ratio.
[35] Ibid.
[36] Ibid.

Annex 4: Detailed Simulation Results of Nodal Prices under the Three-Step Modified Loss Ceiling Method and the Current NPL Handling

Table A2: Simulation Results of Nodal Prices

	Minimum Nodal Price ($)		Maximum Nodal Price ($)		Average Nodal Price ($)	
Date/ Period	**Current**	**Three-Step Modified Loss Ceiling**	**Current**	**Three-Step Modified Loss Ceiling**	**Current**	**Three-Step Modified Loss Ceiling**
14/2/2013 P6	0.00	0.00	0.00	0.00	0.00	0.00
14/2/2013 P7	0.00	0.00	0.00	0.00	0.00	0.00
14/2/2013 P8	-10.12	-10.19	-9.91	-9.95	-9.90	-10.05
14/2/2013 P9	-5.05	-5.07	-4.95	-4.95	-5.00	-5.00
14/2/2013 P10	-5.05	-5.07	-4.95	-4.95	-5.00	-5.00
14/2/2013 P11	0.00	0.00	0.00	0.00	0.00	0.00
15/2/2013 P3	0.00	0.00	0.00	0.00	0.00	0.00
15/2/2013 P4	-5.05	-5.06	-4.93	-4.93	-5.00	-4.99
15/2/2013 P5	-10.19	-10.17	-9.98	-9.94	-10.09	-10.05
15/2/2013 P6	-5.05	-5.06	-4.94	-4.94	-5.00	-5.00
15/2/2013 P7	-5.05	-10.14	-4.95	-9.91	-5.00	-10.01
15/2/2013 P8	-5.05	-5.06	-4.94	-4.94	-5.00	-4.99
15/2/2013 P9	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20
15/2/2013 P10	-0.01	-0.20	-0.01	-0.20	-0.01	-0.20
15/2/2013 P11	0.00	-0.01	0.00	-0.01	0.00	-0.01
Overall	**Min = -$10.19**	**Min = -$10.19**	**Max = $0**	**Max = $0**	**Average = -$3.35**	**Average = -$3.70**

Annex 5: Stability of Physical Loss Level

To verify that the ratio of the change in PL to the change in total loss (that is, $\frac{\Delta PL}{\Delta TotalLoss}$) is low, which implies that the loss ceiling is effective in reducing NPL rather than PL, simulations were conducted to assess this ratio under two types of scenarios – negative price with no price separation, and negative price with price separation.

Simulation A3a (Finding $\frac{\Delta PL}{\Delta TotalLoss}$; negative price with no price separation):

Again using the same 15 periods of actual RTDS with zero/negative prices from 14-15 February 2013, and 100 RTDS periods using standing offers (with zero/negative prices) from 9-20 February 2013, Simulation A3a was conducted to investigate the value of $\frac{\Delta PL}{\Delta TotalLoss}$ under the modified loss ceiling constraint method.

Table A3: Simulation results of $\frac{\Delta PL}{\Delta TotalLoss}$; negative price with no price separation

	ΔPL	$\Delta TotalLoss$	$\frac{\Delta PL}{\Delta TotalLoss}$ %
15 RTDS periods, 14-15 Feb 2013	-0.571MW to -0.006MW	-155.4MW to -5.2MW	0.04% to 0.92%
100 periods standing offers, 9-20 Feb 2013	-1.012MW to -0.015MW	-205.2MW to -22.7MW	0.04% to 0.61%
Overall range =	-1.012MW to -0.006MW	-205.2MW to -5.2MW	**0.04% to 0.92%**

As shown in Table A3, PL does indeed decrease slightly as expected when total loss decreases. However, the change in PL is small compared to the change in total loss, with $\frac{\Delta PL}{\Delta TotalLoss}$ lying between 0.04% and 0.92%, which testifies to the efficiency of the loss ceiling method.

Given that the change in PL relative to the change in total loss is less than 1%, we can see that PL remains relatively stable even when a loss ceiling is introduced in Run 2 (i.e. assume almost no substitution effect). This is consistent with what we found earlier in Section 3.3.3 (Simulation 3), where the MCE would prefer to reduce NPL when forced by a total loss ceiling. Therefore, the modified loss ceiling constraint method effectively reduces NPL to an acceptable level (≤3MW from Table A1) in two runs, without having any significant undesirable effects on PL (and consequently, generation flow patterns[37]).

Simulation A3b (Finding $\frac{\Delta PL}{\Delta TotalLoss}$; negative/negative price separation and positive/negative price separation scenarios):

As mentioned in Section 3.3.3, situations of negative prices with price separation in the system are rare. Nevertheless, there remains a possibility that such situations may arise in future, and hence the modified loss ceiling constraint method should be stress-tested under such situations too. Therefore, negative/negative price separation and positive/negative price separation scenarios were artificially created by reducing demand, adding security constraints to simulate congestion on transmission lines, or both.

[37] Generation flow patterns are unlikely to change much because the cost of reducing 1MW of physical loss is very high.

Table A4: Simulation results of $\frac{\Delta PL}{\Delta TotalLoss}$; negative/negative price separation and positive/negative price separation scenarios

Min Node Price	Max Node Price	Final NPL Level (Run 2's SysError)	$\frac{\Delta PL}{\Delta TotalLoss}$ %
-1.29	3049.27	2.486	0.20%
-1.25	845.04	2.330	0.35%
-2.04	124.15	1.422	0.17%
-46.59	-4.41	1.197	0.13%
-64.58	-28.22	1.486	0.28%
-10	0.6	1.791	0.23%
	Overall range =	**1.2MW to 2.5MW (≤3MW)**	**0.13% to 0.35% (≤1%)**

In Table A4, the six scenarios involving negative/negative price separation and positive/negative price separation all show similar results to those in Tables A1 and A3. Specifically, the final NPL level achieved in Run 2 falls below 3MW, and the change in PL relative to the change in total loss is small (less than 1%).