Energy Market Company

RCP PAPER NO.	:	**EMC/RCP/74/2014/CP49**
SUBJECT	**:**	**INTRODUCTION OF REGULATION EFFECTIVENESS FACTOR**
FOR	:	**DECISION**
PREPARED BY	:	**TAN LIANG CHING** **VP, MARKET ADMINISTRATION**
REVIEWED BY	:	**PAUL POH LEE KONG** **HEAD OF MARKET DEVELOPMENT AND POLICY**
DATE OF MEETING	:	**08 July 2014**

Executive Summary

This paper examines the implementation of the Regulation Effectiveness Factor, which measures the responsiveness of a given regulation provider and in turn translates into share of regulation payments. This ensures that these providers are provided with the correct incentives to be responsive to regulation signals.

EMC had in a 2010 RCP paper found that while there was no evidence of excess regulation provision on a system-wide level, some Generation Registered Facilities (GRFs) were more responsive and correspondingly provided regulation in excess of their schedules. However, given the challenges involved with implementing a comprehensive regulation responsiveness assessment, the RCP unanimously agreed not to pursue it.

At the recent workplan prioritisation exercise, a proposal was received to re-evaluate the Regulation Effectiveness Factor proposal. It was also observed that markets such as PJM and NYISO already have such a mechanism in place, whereby regulation resources with the highest value to system control are given the highest payments. In this round of review, the focus will be on coming up with an <u>assessment scheme that minimises implementation costs</u>.

In October 2011, the US Federal Energy Regulatory Commission (FERC) issued Order No. 755 to require a <u>two-part payment, including both a capacity and a performance payment</u>, for frequency regulation service provided in organized wholesale electric markets, in order to ensure just and reasonable and not unduly discriminatory or

preferential frequency regulation rates. To comply with FERC Order 755, PJM implemented a revised regulation scheduling and payment framework that accounts for the regulation providers' historical and actual period performance.

This paper outlines in detail PJM's treatment of regulation providers in both performance assessment and subsequently regulation payments. As PJM's implementation is relatively comprehensive but resource intensive, EMC does not recommend a wholesale implementation of PJM's algorithm given the consideration to differentiate regulation providers without incurring significant costs. Instead, one possible enhancement could be to solely measure the Correlation scores of units during periods of actual response, which will then form its Regulation Effectiveness Factor.

The concept paper was published for industry consultation on 02 April 2014, and comments were received from PSO, YTL PowerSeraya, Tuas Power Supply and Keppel Merlimau Cogen. Although feedback from the industry was mixed on whether to adopt more features of PJM's implementation, PSO's simulations show that the Correlation factor alone achieves a good distribution in regulation effectiveness among existing units. Thus, EMC recommends that the RCP:

1) **Support** the proposal to implement the Regulation Effectiveness Factor based on solely the Correlation Factor, and
2) **Task** EMC to work with PSO to come up with the operational details of the proposal.

At the 76th RCP meeting, the Panel commented that there is not enough evidence to support the requirement to implement the proposal, in view of the significant costs involved. If a handful of generating units were found not to behave properly, the PSO can approach them and work with them directly to improve their performance.

The Panel by majority vote decided **not to support** the proposal to implement the Regulation Effectiveness Proposal.

1. Introduction

This paper examines the implementation of the Regulation Effectiveness Factor, which measures the responsiveness of a given regulation provider and in turn translates into share of regulation payments. This ensures that these providers are provided with the correct incentives to be responsive to regulation signals.

2. Background

Earlier Study in 2010

In a 2010 RCP paper[1], EMC studied the trends in regulation provision and found that excess regulation provision on a system-wide level was insignificant, representing only 0.89% of total regulation payments or 4.04% of periods over a six-month period. However, at the facility level, some Generation Registered Facilities (GRFs) were found to be more responsive and correspondingly provided regulation in excess of their schedules.

As the total regulation quantities procured were generally adequate, EMC thus proposed redistributing regulation payments collected to GRFs in relation to their responsiveness. This redistribution could be based on a Regulation Effectiveness Factor (REF), determined based on either

a) The Power System Operator's (PSO) technical assessment of each individual GRF's effectiveness in responding to regulation needs, or;
b) a historical assessment of each individual GRF's regulation provision pattern relative to their respective offers.

At the 50th RCP meeting, PSO responded with the following key points:

a) It is difficult for the PSO to determine the regulation effectiveness of a GRF from a technical perspective. This is because a generator's output is influenced by both primary and secondary control systems; the primary system refers to a GRF's governor response to frequency changes while the secondary system refers to PSO's Automatic Governor Control (AGC) commands and the generator's internal control system. As such, it is difficult to apportion the GRF's output according to each of these controls with reasonable accuracy.
b) The actual workings of AGC are rather complex. A GRF's primary control typically reacts first, with the AGC kicking in only after it measures the system frequency and calculates the output required (in MW terms) to bring system frequency deviations back to acceptable levels. The total output adjustment required is then allocated to all GRFs that are participating in regulation provision, with corrections made over time rather than instantly.
c) PSO already conducts regular checks on whether GRFs are responding to regulation, failing which the PSO could request these units to cease offering regulation.

Given the above responses from the PSO, the RCP unanimously agreed not to pursue refining the proposed REF methodology.

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[1] *Compensation for Excess Regulation*, as presented at the 50th RCP meeting on 06 July 2010

2013/2014 Workplan Prioritisation Exercise

At the recent workplan prioritisation exercise, a proposal was received to re-evaluate the Regulation Effectiveness Factor proposal, given concerns from Market Participants (MPs) that their units were called upon to provide more regulation than their schedules. It was also observed that markets such as PJM and NYISO already have such a mechanism in place, whereby regulation resources with the highest value to system control are given the highest payments.

In this round of review, the focus will be on coming up with an assessment scheme that minimises implementation costs. For example, it could mirror PSO's current historical assessment of reserve providers (i.e. assess once a year), rather than a dynamic assessment of a given regulation provider's performance for that given period. However, adjustments would have to be made given that the potential number of data points to compute the REF is significantly more than that for Reserve Provider Groups[2].

During the consultation exercise, many stakeholders were supportive of the proposal because it could "drive regulation providers to be faster and more effective in response" and "be consistent with the treatment of Reserve". However, PSO reiterated their reservations over this proposal and made the following points:

a) There are already regular checks by the PSO on whether GRFs are able to provide regulation based on dispatch instructions, which ensures that GRFs can effectively provide regulation when called upon.

b) It is not possible for PSO to conduct a technical assessment of a GRF's regulation effectiveness during actual operation as it is impossible to separate GRF's responses to its internal control system and to AGC commands.

c) Further refinements would have to be made to the proposed REF methodology using historical data given that it is not possible to use the technical assessment approach. The RCP recognises that this is one of the many approaches and it is hard to assess the accuracy of the methodology.

This paper assesses the feasibility of implementing an REF regime, taking into account the above comments and the experience from other markets.

3. Experience from the United States

PJM's Regulation Providers Eligibility/Testing Critera (prior FERC Order 755)

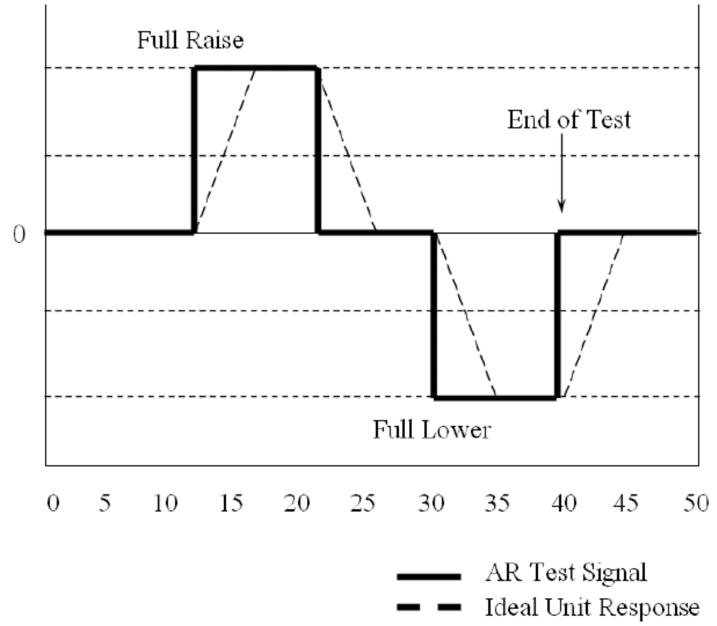
Prior to FERC Order No. 755 (see below), PJM had an assessment framework in place to qualify regulation resources, although this does not translate into differentiation in settlement payments. This assessment is termed an Area Regulation (AR) test, which is run during a continuous 40-minute period when, in the judgment of the PJM test administrator, economic or other conditions do not otherwise change the base loading of the resources that are being tested.

As shown in Figure 1 below, a fixed AR test signal (in bold) is sent to the resource for four ten-minute periods during the test. The Ideal Unit Response is shown in as the dotted

[2] Assuming a GRF is scheduled to provide regulation consistently in a quarter, there would be at least 43,000 data points which have to be captured by the EMS (sampling rate at least 1 minute) and subsequently retrieved and analysed by PSO to derive the REF. And that is only for 1 GRF. Typically in the system, there are about 20 GRFs providing regulation reserve.

line, whereby the unit is expected to reach the target “Full Raise” or “Full Lower” 5 minutes after the signal, rather than immediately.

Figure 1: Test Signal and Expected Response of PJM’s Area Regulation Test



The testing unit is then scored based on its compliance with two measurements:

- **Rate of Response Compliance** — The rate of response compliance is a measure of a resource‘s ability to achieve its Regulation assignment within five minutes.
- **Regulation Mismatch Compliance** — The Regulation mismatch compliance is a measure of a resource‘s ability to maintain its actual loading at a constant desired level for five minutes.

The AR test score is determined based on the aggregate of both measurements, and a resource is certified only after it achieves three consecutive AR scores of 75% or above.

Please refer to **Annex 1** for the detailed equations to compute the AR test score.

FERC Order No. 755

In October 2011, the US Federal Energy Regulatory Commission (FERC) issued Order No. 755[3] to require a two-part payment, including both a capacity and a performance payment, for frequency regulation service provided in organized wholesale electric markets, in order to ensure just and reasonable and not unduly discriminatory or preferential frequency regulation rates. Specifically, current compensation methods fail to acknowledge the inherently greater amount of frequency regulation service being provided by faster-ramping resources.

This order required Regional Transmission Organisations (RTOs) and Independent system operators (ISOs) to compensate frequency regulation based on the actual amount of frequency regulation service provided in responding to the system operator’s AGC signal. Their rationale is that compensating resources at the same level regardless of the

[3] Frequency Regulation Compensation in the Organized Wholesale Power Markets, Order No. 755, http://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

different amounts of frequency regulation service provided is unjust and unreasonable. However, Order No. 755 recognizes that an individual RTO or ISO is in the best position to design a method for measuring such accuracy within its system; accordingly, RTOs and ISOs were directed to determine their own technical specifications for measuring accuracy in following the AGC dispatch signal, with the caveat that the same accuracy measurement must apply to all resources.

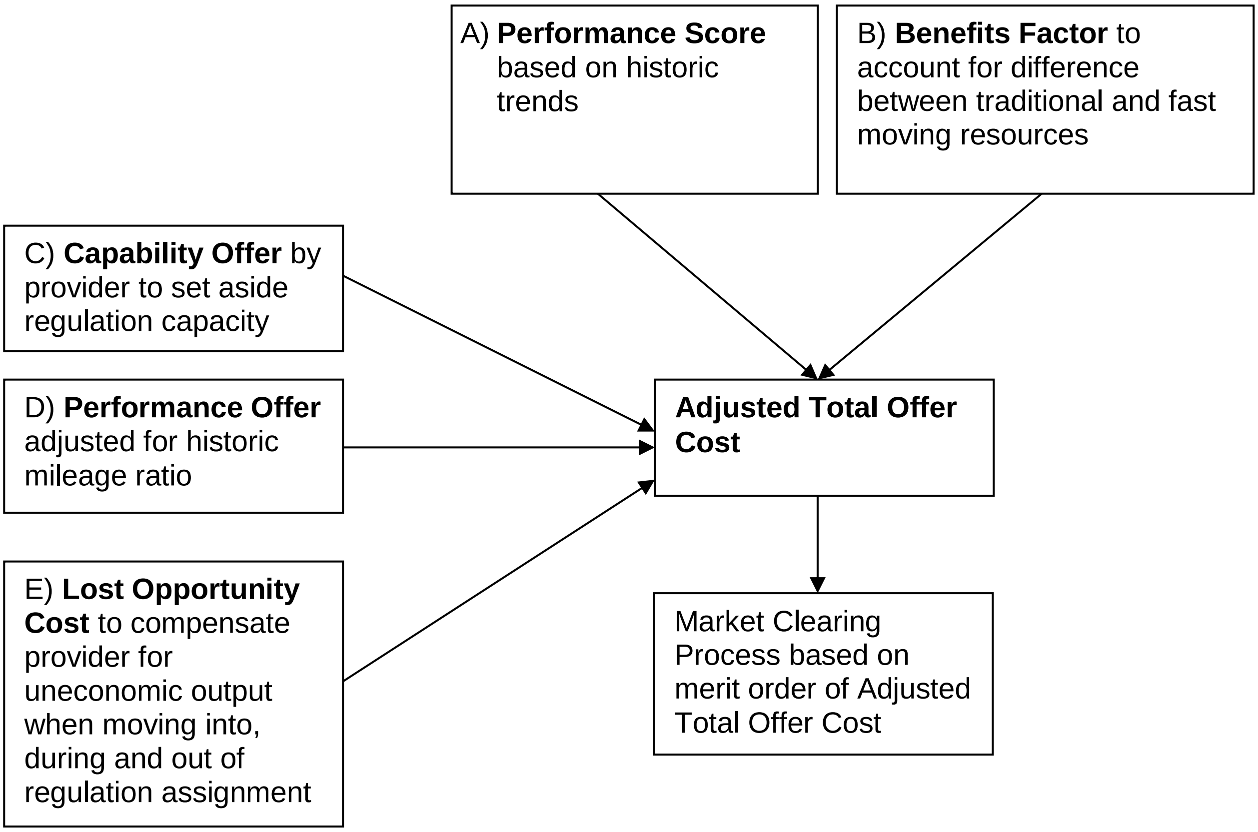
PJM's Regulation Providers Performance Assessment (post FERC Order 755)

To comply with FERC Order 755, PJM implemented a revised regulation scheduling and payment framework that accounts for the regulation providers' historical and actual period performance.

I) Scheduling Framework

An overview of PJM's scheduling framework is shown in the figure below:

Figure 2: Scheduling Framework by PJM



Essentially, a regulation provider submits Capability and Performance Offers, and the system further computes a Lost Opportunity Cost component. These three cost components are further adjusted by the historic Performance Score of the provider and the Benefits Factor (which accounts for the technology type of the resource, either traditional or fast-moving) to derive the Adjusted Total Offer Cost. The merit-order scheduling of regulation providers will subsequently be based on this Adjusted Total Offer Cost, rather than their raw Capability or Performance Offers.

A description of the above components is given in the table below, with the detailed equations provided in Annex 2:

Table 1: Description of Factors used in PJM's Scheduling Framework

Factor	Description	Computed Using
A) Performance Score	To reflect the regulation resource's accuracy in varying its output in response to PJM's dispatch signal	3 separate components, namely: • **Correlation score**: measures goodness-of-fit between regulation and response signals • **Delay score**: measures time delay between regulation and response signals • **Precision score**: Absolute difference between the energy provided versus energy requested by regulation signal
B) Benefits Factor	PJM sends out 2 separate regulation signals to traditional resources (slower response units like steam plants) and fast moving resources (e.g. energy storage). The Benefits Factor is used to translate fast moving resource's MWs into traditional MWs.	Both fast-moving and traditional resources are critical to system stability, and PJM has a downward sloping function that reflects the rate of substitution of fast-moving to traditional resources. Depending on the amount of fast-moving resources, 1MW of fast-moving resource could be valued at 3MW of traditional resource (when there are few fast-moving resources) or 0MW (when there is too much fast-moving resource that it cannot substitute traditional resource)[4].
C) Capability Cost	Capacity offer by resource owner to set aside capacity for regulation provision	Adjusted by Benefits Factor and Performance Score (average of last 100 hours of performance score)
D) Performance Cost	Performance offer by resource owner for resource's movement (i.e. change in output) when providing regulation.	In addition to the Benefits Factor and Performance Score, the Performance Cost is further adjusted by the mileage trends over past 30 days for the respective resource type (i.e. either traditional or fast-moving resource).
E) Lost Opportunity Cost	The Lost Opportunity Cost is computed by the MCE rather than being an explicit offer by the resource owner. It accounts for the lost	The detailed computations involve integrations that encapsulate the lost opportunity cost energy schedule, the points on that curve corresponding to the resource's desired economic dispatch, and the set-point necessary

[4] If the benefits factor is zero, then any additional quantities of fast-moving resource cannot be used to provide regulation and thus will not be scheduled.

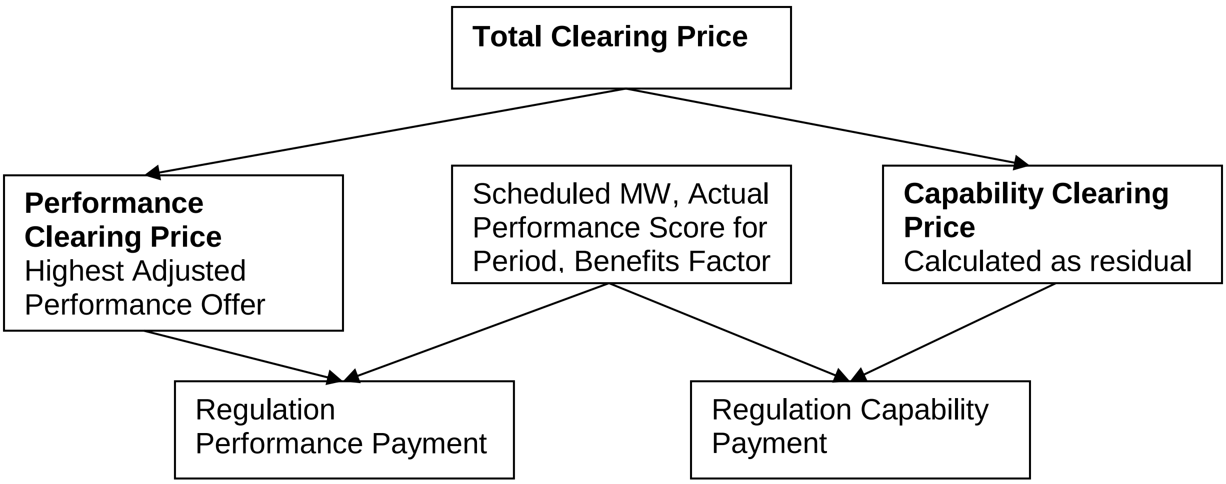
Factor	Description	Computed Using
	opportunity costs: • Before regulating hour – Unit moves uneconomically into its regulating band • During regulating hour – Unit reduces/raises output uneconomically when providing regulation • After regulating hour – Unit moves uneconomically from regulating band back to economic set point	to provide the full amount of regulation, and the LMP. Further adjusted by Benefits Factor and Performance Score (average of last 100 hours of performance score)

After adjusting the Capability, Performance and Lost Opportunity Costs by their respective factors, these 3 components are added up to derive the Adjusted Total Offer Cost. The Adjusted Total Offer Costs from various providers will then be sorted based on merit-order and correspondingly scheduled.

II) Payment Framework

After scheduling, PJM adopts the following framework for payment to regulation providers based on their actual performance for the period:

Figure 3: Payment Framework by PJM



The merit order ranking for Adjusted Total Offer Cost discussed earlier determines the clearing price for regulation as a whole (inclusive of both performance and capability). However, this needs to be further separated into the Performance and Capability component prices. This section covers an overview of the payment framework, with details included in **Annex 3**.

i) Payment for Performance

PJM computes the real-time performance score for each regulation resource. Resources with a score of 25% or lower will not receive any regulation payments for the hour. For resources that qualify, the clearing price for performance, the Regulation Market Performance Clearing Price (RMPCP) is calculated by taking the highest adjusted performance offer equivalent (this time using the actual mileage rather than the 30-day historical average earlier) among all scheduled regulation units. The payment for individual units will then be based on:

Regulation Performance Payment = Scheduled Regulation (MW) x Actual Performance Score x Benefits Factor x RMPCP ($/MW)

ii) Payment for Capability

The Regulation Market Capability Clearing Price (RMCCP) is determined as the residual between the Regulation Market Total Clearing Price and the RMPCP:

$$\begin{matrix} Regulation\ Market\ Capability \\ Clearing\ Price \\ \$/MW \end{matrix} = \begin{pmatrix} Total\ Regulation\ Market \\ Total\ Clearing\ Price \\ \$/MW \end{pmatrix} - \begin{pmatrix} RM\ Performance \\ Clearing\ Price \\ \$/MW \end{pmatrix}$$

The capability payment is then computed as:

Regulation Capability Payment = Scheduled Regulation (MW) x Actual Performance Score x Benefits Factor x RMCCP ($/MW)

The implications of the above algorithm for Performance and Capability payments are that when units are called upon to provide more regulation, the RMPCP (performance price) will be higher and payment weightage will shift towards performance over capability. Furthermore, the actual Performance and Capability payments for individual units are adjusted for their actual Performance Score and respective Benefits Factor.

4. Takeaways for SWEM

PJM’s treatment of regulation providers in both performance assessment and subsequently regulation payments is relatively comprehensive but resource intensive. EMC does not recommend a wholesale implementation of PJM’s algorithm given the main thrust of this proposal is to generally differentiate regulation providers without significant costs. Nevertheless, there are certain features that could be adapted to Singapore’s context, as discussed below:

Features	Recommended	Comments
Static assessment of response to PJM’s test signal (Figure 1)	No	It is inaccurate to use the artificial test signal to assess unit’s responsiveness to regulation signals during actual system conditions. Would be appropriate to test for eligibility/commissioning purposes but not suitable for payment determination.
Historical Performance Score Calculation	Yes	It is not overly resource intensive to assess the Correlation/Delay/Precision

Features	Recommended	Comments
(Correlation, Delay and Precision Scores) to adjust offers		scores of units during periods of actual response.
Benefits Factor (account for traditional/fast-moving units)	No	Not necessary, since SWEM's generation technology spread is relatively uniform (mostly CCGTs, no energy storage nor hydro)
Segregation to Capability and Performance Offer/Payments	No	Conceptually sound, but likely complicated and inconsistent with the current paradigm of reserve payments based on standby capacity rather than actual response.
Real-Time tracking of Actual Mileage Ratio for Performance Pricing	No	Likely to be too resource intensive to track real-time mileage ratio
Lost Opportunity Cost	No	Conceptually sound, but likely complicated and inconsistent with the current paradigm where there is no opportunity cost compensation for reserve response.
Real-Time Performance Score Calculation (Correlation, Delay and Precision Scores) to determine payments	No	Likely to be too resource intensive to track real-time performance score

Based on the above assessment, EMC recommends the implementation of the Historical Performance Score calculation, <u>comprising solely the Correlation Score</u>.

One possible implementation option would be to sample a given unit's actual response to regulation signals every 6 to 12 months[5]. A simple correlation function will be run between the expected response to actual response, based on which the unit will be assigned a corresponding REF. This REF will determine its share of the overall regulation revenues (which is unchanged from current way based on scheduling and pricing), and the assessed REF will apply to the unit until the next test. Since there is no real-time, actual period performance tracking, the resources required for implementation should be significantly reduced.

We would like to seek the views of any interested party on this proposal, specifically on the following issues:

1) Is the Correlation score a reasonable reflection of the unit's responsiveness to regulation signals?
2) Are there additional measures (e.g. from the PJM implementation) that should be incorporated into the Regulation Effectiveness Factor?

[5] The AGC command is used to ramp the GRF to its target output and regulate the system frequency. As system condition is dynamic, it may be difficult to select a period of relative stability to assess the performance of the unit in providing regulation reserves.

5. Conclusion

This paper examines the implementation of the Regulation Effectiveness Factor, which measures the responsiveness of a given regulation provider and in turn translates into settlement payments. Although this proposal was earlier turned down at an earlier RCP meeting, it resurfaced at the recent workplan prioritisation exercise given concerns from MPs that their units were called upon to provide more regulation than their schedules.

It was also observed that markets such as PJM and NYISO already have such a mechanism in place, whereby regulation resources with the highest value to system control are given the highest payments. Specifically, in Oct 2011, the US Federal Energy Regulatory Commission (FERC) issued Order No. 755[6] to require a two-part payment, including both a capacity and a performance payment, for frequency regulation service provided in organized wholesale electric markets, in order to ensure just and reasonable and not unduly discriminatory or preferential frequency regulation rates.

EMC studied PJM's regulation mechanism, which is relatively comprehensive but resource intensive. EMC does not recommend a wholesale implementation of PJM's algorithm given the main thrust of this proposal is to generally differentiate regulation providers without significant costs. Rather, EMC recommends the implementation of the Correlation Score, which would determine a unit's REF and correspondingly share of overall regulation payments (which is unchanged from current scheduling and pricing).

6. Industry Consultation

The concept paper was published for industry consultation on 02 April 2014, and comments were received from PSO, YTL PowerSeraya, Tuas Power Supply and Keppel Merlimau Cogen.

Comments from PSO

The Correlation score is a reasonable reflection of the units' responsiveness as it takes into consideration both the magnitude and direction of the actual power output with reference to the expected response. We could also consider incorporating the Benefits factor to take into account the additional mileage that a battery can provide as compared with the traditional units.

EMC's Response

PSO's comments are noted. We can keep in view the option of introducing the Benefits factor if and when batteries are introduced as regulation providers in future.

Comments from YTL PowerSeraya

If the Regulation Effectiveness is implemented,

- *will there still be price capped (currently at $300)?*
- *will the first 5MW of regulation charges be removed?*
- *will be applicable to all Regulation providers or just the Gencos?*

[6] Frequency Regulation Compensation in the Organized Wholesale Power Markets, Order No. 755, http://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

When assessing the Correlation/Delay/Precision score during periods of actual response,

- *will we be informed of the assessment date, time and duration (before or after commencement of assessment)?*
- *the responsiveness of the Regulation is subjective to the loading of the GRF at that point of time which might be disadvantages to that provider*
- *what is the likely sample frequency and sample size?*
- *what if the Provider's machine responded more via GOV control then AGC, will the assessment able to take into account responses via GOV control?*
- *will the implementation disincentivize the market to offer more Regulation?*

Lastly, what would be the proportion of the Performance Score Calculation against the Regulation Market Clearing Price i.e. will it exceed the limit of $300 or below $0?

<u>EMC/PSO's Response</u>

If the Regulation Effectiveness Factor (REF) proposal were implemented, it would not affect other aspects of regulation including the price cap of $300/MW and the regulation cost allocation methodology. It should also apply evenly to all Regulation providers; if batteries were introduced to provide regulation, they would be similarly subjected to the REF assessment.

All periods that a GRF is scheduled to provide regulation will be subjected to assessment. As such, since the REF is not derived from just a few instances but rather from all periods that a GRF is scheduled to provide regulation, periods that are advantageous or disadvantageous to the provider should average out. The new methodology will also recognise positive contribution of GRF in aiding frequency regulation regardless of whether it is in response to GOV control or AGC commands.

As this proposal is still at the concept paper stage, there will be further operational details to be worked out, which will be under the purview of the PSO. However, the implementation should <u>not</u> discourage the market from offering more Regulation, since there would not be any changes to the procurement quantity nor clearing price of Regulation.

The Performance Score Calculation serves as a multiplier/discount to the regulation payments, depending on whether the regulation provider is more/less responsive relative to other scheduled regulation providers. Therefore, it is possible for some regulation providers to receive more than $300, but not below $0. We are essentially changing the allocation of the regulation revenue pie; neither the regulation price produced by the MCE nor the price cap of $300 will be affected by the proposal. It is thus possible that even when the regulation price cap reaches $300, some generators may receive an effective price above $300 if they are more responsive than other scheduled regulation providers.

<u>Comments from Tuas Power Supply</u>

We agree not to follow PJM model where the amount of regulation provision are much bigger than Singapore hence may justify the resources to do so.

Question is: If the proposal has been turned down in 2010, why should it be resurfaced? Are there any significant changes in the regulation market since 2010 e.g. percent of excess regulation provision?

Also, for better understanding, can EMC work out a sample calculation of REF and Correlation Score for a Genco?

EMC/PSO's Response

We agree with Tuas' point on not following the PJM model completely.

As mentioned, the proposal was resurfaced given concerns from Market Participants (MPs) that their units were called upon to provide more regulation than scheduled, and other markets such as PJM already have similar mechanisms in place. Also, the new methodology recognises positive contribution of GRF in aiding frequency regulation, regardless if it is in response to GOV control or AGC commands. This contrasts with the previous proposed technical assessment where it is almost impossible to differentiate responses due to GOV or AGC.

Based on PSO's simulations conducted using data from 19 Feb to 18 May 2014 for all periods that they were scheduled to provide regulation, the Correlation/REF Scores of existing regulation providers are shown below:

Correlation/REF Score	Number of Units	Percentage
1.0 to 0.9	15	65.2%
0.9 to 0.8	4	17.4%
0.8 to 0.7	1	4.3%
Below 0.7	3	13.0%
Total	**23**	**100.0%**

Comments from Keppel Merlimau Cogen

Keppel does not believe that the Correlation score based on historical performance is a reasonable reflection of the unit's responsiveness to regulation signals. As highlighted by PSO at the 50th RCP meeting, from a technical perspective, it is difficult to apportion a generator's output that is influenced by both primary and secondary control systems accurately. Hence, Keppel is not supportive of the introduction of Regulation Effectiveness Factor due to the complexity and accuracy of retrieving the actual unit's regulation output.

Keppel is not for the idea of introducing Regulation Effectiveness Factor unless GRF's regulation output can be accurately measured. Historical Performance Score calculation comprising solely on the Correlation Score is inadequate in achieving the aim of redistributing regulation payments in relation to GRF's responsiveness. Delay and Precision Score should be taken into consideration otherwise it loses meaning to the proposal of differentiating regulation providers. Features from PJM implementation like Segregation to Capability and Performance Offer/Payments, Lost Opportunity Cost and Real-Time Performance Score Calculation to determine payments will be relevant in Singapore context and should be incorporated into the Regulation Effectiveness Factor in time as the market progresses.

EMC's Response

While it may not be possible to perfectly isolate the effects of both the primary and secondary control systems, the number of samples used to compute the Regulation Effectiveness Factor should be sufficient to meaningfully represent the units' responsiveness to regulation by "averaging out" any secondary effects. Also, the new methodology recognises positive contribution of GRF in aiding frequency regulation regardless if it is in response to GOV control or AGC commands. This contrasts with the previous proposed technical assessment where it is almost impossible to differentiate responses due to GOV or AGC.

Keppel's suggestion of taking into account the Delay and Precision Scores, and other PJM features is noted. As a start, so as not to overcomplicate the proposal, EMC suggests to use only the Correlation Score, and the other features can be incorporated over time as finetunes.

7. Deliberation at the 74th RCP Meeting

At the 74th RCP meeting, the panel suggested using both the Delay and Precision scores to assess regulation providers, in addition to the Correlation score as recommended by the RCP. They requested for further studies to be conducted with the PSO on the effectiveness of incorporating all 3 scores in the REF. They further tasked EMC to work with the PSO on (a) the implementation cost and time, and (b) the effectiveness, of implementing the REF based on

- Option A: Correlation score only;
- Option B: Correlation, Delay and Precision scores

8. Deliberation at the 75th RCP Meeting

At the 75th RCP meeting, EMC informed the panel that the PSO felt that the inclusion of the Delay score was not relevant in SWEM's context. However, the PSO did conduct simulations incorporating the Precision score which measures the absolute differential between actual and the required response.

To derive the combined rating, PSO calculated the Precision score for all regulation providers, and nominally gave equal weightage to both the Correlation and Precision Scores. The ratings of 23 units that were scheduled to provide regulation during the test period were tabulated.

Score	Correl Score only	Correl and Precision Scores
A	17	20
B	3	1
C	0	2
D	2	0
E	1	0
Total	**23**	**23**

There were 6 units that did not make the "A" grading when only the Correlation score was used, compared to 3 units when the combined score (for Correlation and Precision) was used.

EMC highlighted the following points for the Panel to note:

1) Using only Correlation score shows up greater differentiation among units.
2) As the results only comprise those that were actually scheduled for regulation during the test period, the 23 units that were graded forms only a subset of all providers. Going forward, there could be more regulation providers and the introduction of REF could encourage better behaviour and performance.
3) If a wider distribution of grades is desired, the grading thresholds that are used to classify providers could be adjusted.

9. Decision at the 76th RCP Meeting

At the 76th RCP meeting, EMC presented the time and cost estimates for EMC and PSO respectively as follows:

EMC's Resource Estimates

Time Estimates	Man week(s)	Calendar week(s)
1. Change Requirement Scoping and Analysis	8	3
2. Standing Data/ Settlement Engine Development/ Testing/ Deployment/ Documentation	34.6	13
3. User Acceptance Testing (UAT)	5	6
4. Audit	2	3
Total Effort Required	49.6	25
Total Project Time	N.A	25
Cost		
1. Internal EMC Manpower	$50,360	
2. External resource to change Settlement Engine/SD	$141,560	
3. Audit	$20,000	
Total Additional Cost Required	$211,920	

PSO's Resource Estimate

- The cost of implementing the proposal is setup cost of $70,000 and annual recurring cost of $50,000
- It will take at least 1 year to implement this proposal

The Panel commented that there is not enough evidence to support the requirement to implement the proposal, in view of the significant costs involved. If a handful of generating units were found not to behave properly, the PSO can approach them and work with them directly to improve their performance.

The Panel by majority vote decided **not to support** the proposal to implement the Regulation Effectiveness Proposal.

Those who voted not to support the proposal:
1. Mr. Daniel Lee Representative of Generation Licensee

2. Mr. Luke Peacocke	Representative of Generation Licensee
3. Mr. Pak-Juan Koe	Representative of Generation Licensee
4. Mr. Phillip Tan	Person experienced in Financial Matters
5. Mr. Sean Chan	Representative of Retail Electricity Licensee
6. Mr. Chan Hung Kwan	Representative of Transmission Licensee
7. Mr. Dallon Kay	Representative of Wholesale Electricity Market Trader
8. Mr. Michael Wong	Representative of Retail Electricity Licensee
9. Dr. Toh Mun Heng	Representative of Consumers of Electricity in Singapore

Those who abstained:

1. Mr. Toh Seong Wah	Representative of the EMC
2. Ms. Frances Chang	Representative of Consumers of Electricity in Singapore

ANNEX 1

PJM's Regulation Capability Test (Before Oct 2012)

In order to qualify as a regulation resource, an Area Regulation (AR) test is conducted. The AR test is run during a continuous 40-minute period when, in the judgment of PJM test administrator, economic or other conditions do not otherwise change the base loading of the resources that are being tested.

During the test, a fixed AR signal is sent to the resource for four ten-minute periods, as follows (and illustrated below):

- T0-T10 — To initiate the test, the AR signal is equal to zero for the first ten minutes so that the regulating resource settles at its base loading. At T10, the actual loading is sampled and the resulting value defines the base loading for that resource.
- T10-T20 — During this 10 minute period, the AR signal is set to full raise (or full lower).
- T20-T30 — During this 10 minute period, the AR signal is set to zero.
- T30-T40 — During this 10 minute period, the AR signal is set to full lower (or full raise).
- T40 — At this time, the AR signal is set to zero to terminate the test.

Figure A1: Test Signal and Expected Response of PJM's Area Regulation Test

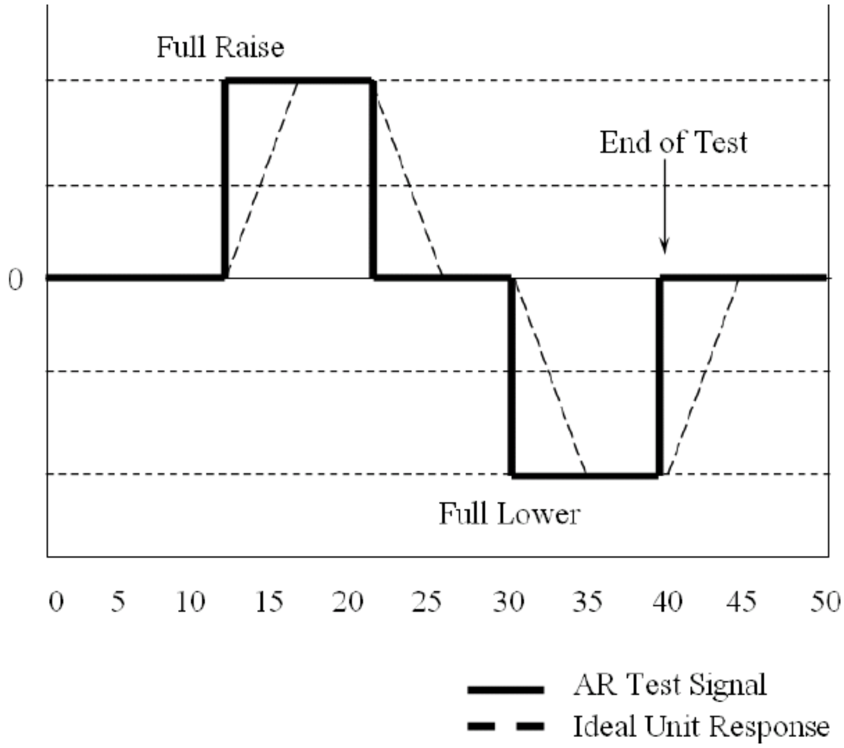


Figure 1 above shows the AR Test Signal (in bold) and the corresponding Ideal Unit Response. As shown, the Ideal Unit Response is expected to reach the target "Full Raise" or "Full Lower" 5 minutes after the signal, rather than immediately.

Scoring the AR test is based on compliance with two measurements:

- **Rate of Response Compliance** — The rate of response compliance is a measure of a resource‘s ability to achieve its Regulation assignment within five minutes.
- **Regulation Mismatch Compliance** — The Regulation mismatch compliance is a measure of a resource‘s ability to maintain its actual loading at a constant desired level for five minutes.

The Rate of Response Compliance is an average of three compliance calculations corresponding to the end of each of the three five-minute ramping periods (T15, T25, and T35) during the test, determined as follows:

- At T15, the actual loading of the resource is sampled. This value is called AG15.

The Rate of Response Compliance at time T15 (RORC15) is:

$$RORC15 = 100 - \left[\left(\frac{ABS\ (Base\ Loading + AR\ Signal - AG15)}{Resource's\ Assigned\ AR}\right) \times 100\right]$$

- This calculation is repeated at T25 and T35, yielding RORC25 and RORC35.
- The Rate of Response Compliance is:

$$Rate\ of\ Response\ Compliance = \frac{RORC15 + RORC25 + RORC35}{3}$$

The Regulation Mismatch Compliance is an average of three mismatch calculations, corresponding to samples taken during three, five-minute periods when the resource response yields an actual loading equal to the base loading, plus the AR signal. These time periods are T15-T20, T25-T30, and T35-T40. During these time periods, the actual loading is sampled.

- During the time period T15-T20, a number of samples, n, of actual loading, AG1, AG2,, AGn, are taken. The mismatch for the M20 period is:

$$M20 = \frac{\sum_{i=1}^{n}\left[100 - \left(\left(\frac{\mathrm{ABS}(\mathrm{Base\ Loading} + \mathrm{AR} - \mathrm{AG_i})}{\mathrm{Resource's\ Assigned\ AR}}\right) \times 100\right)\right]}{n}$$

$$where\ \mathrm{AG_i} = \mathrm{AG1}, \mathrm{AG2}, \ldots, \mathrm{AGn}$$

- This calculation is repeated for T25-T30 and T35-T40, yielding M30 and M40.
- The Regulation Mismatch Compliance is:

$$Regulation\ Mismatch\ Compliance = \frac{M20 + M30 + M40}{3}$$

The AR test score is determined by averaging the two compliance values:

$$Test\ Score = \frac{Rate\ of\ Response\ Compliance + Regulation\ Mismatch\ Compliance}{2}$$

The range for a valid test score is zero to one hundred percent. Test score results that are equal to 100% indicate the perfect, idealized response. All non-ideal responses yield positive values that decrease as the responses deviate from 100%. Any negative test results default to zero. A resource may be certified only after it achieves three consecutive AR scores of 75% or above.

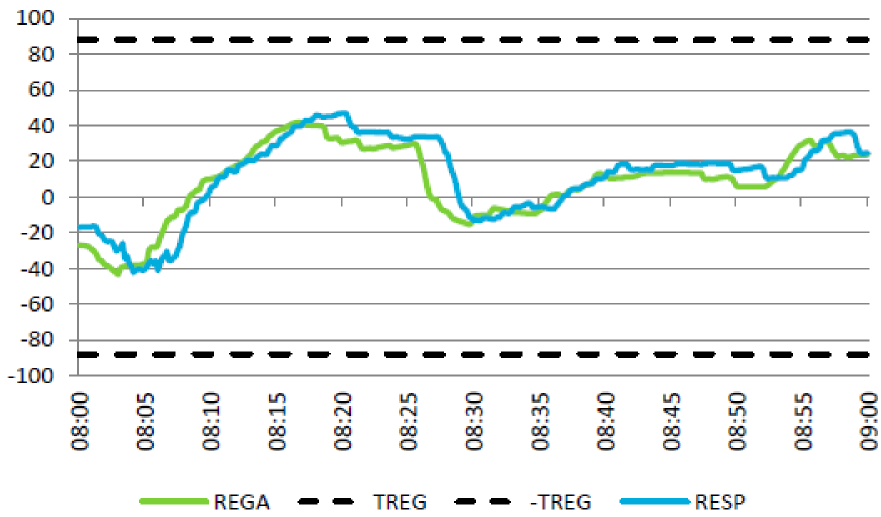
ANNEX 2

Details of PJM's Scheduling Framework

A) Performance Score Calculation

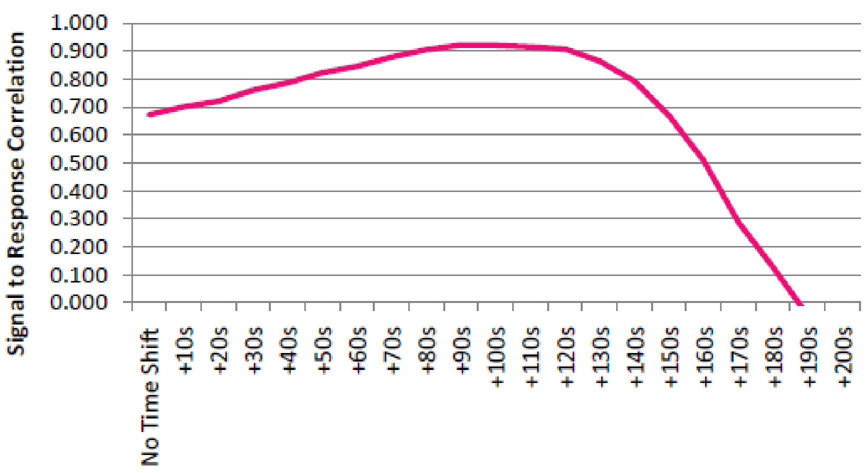
PJM calculates an hourly performance score which reflects a regulation resource's accuracy in varying its output in response to PJM's dispatch signal. At a frequency of 10 seconds, PJM tracks the regulation signal sent (in green below) together with the actual response of the unit (in blue below):

Figure A2: Regulating Resource Response vs. Regulation Signal[7]



PJM will then measure the correlation between the regulation signal (green) and response (blue), corresponding to different time delays. For example, for a time delay of 10s (i.e. shift green line 10s to the right), one correlation value will be calculated. Then for a time delay of 20s, another correlation value will be calculated. The corresponding relationship between the "time delay" and "correlation" can then be found, as shown in Figure 2 below:

Figure A3: Shifted Response Correlation to Regulation Signal[8]



[7] Source: Regulation Market Clearing for Performance and Mileage, PJM
[8] Ibid

PJM then computes the Correlation and Delay scores for each 10s interval up to a total time delay of 5 mins (i.e. total of 30 Correlation-Delay score pairs) as follows:

$$\underset{\delta=0 \text{ to } 5 \text{ Min}}{\begin{matrix} Correlation \\ Score \end{matrix}} = r_{Signal\ ,Response\ (\delta,\delta+5\text{Min})}$$

$$\begin{matrix} Delay \\ Score \end{matrix} = Abs\left|\frac{\delta - 5\ Minutes}{5\ Minutes}\right|$$

where r represents the statistical correlation function between the regulation signal and response (y-axis value in Figure 2) and δ is the time delay (x-axis value in Figure 2). Essentially, the Correlation and Delay scores are higher when the statistical correlation is higher, and the time delay is smaller respectively.

The effective Correlation and Delay scores applicable to the unit for the given period are determined together by finding the 10s interval with the highest coincident Correlation and Delay score. In other words, the 10s interval that will determine Correlation and Delay for each scoring period is:

$$\max_{\delta = 0 \text{ to } 5 \text{ Min}} (Delay\ Score + Correlation\ Score)$$

To illustrate, suppose a given regulation provider has the Delay-Correlation profile in Figure A3. It would then have the following Delay-Correlation Score pairs:

Table A1: Representative Delay-Correlation Score for Given Provider

S/N	Time Delay (s)	Delay Score	Correlation Score	Delay Score + Correlation Score
1	0	1.00	0.69	**1.69**
2	20	0.93	0.71	1.64
3	40	0.87	0.80	1.67
4	60	0.80	0.85	1.65

Note: The table above contains only 4 data points for illustrative purposes. Since PJM samples the scores at 10s intervals over a period of 5 minutes, there will be a total of 30 data points in reality.

As shown above, the time delay for each point translates into a corresponding delay score based on the above equation. This is then summed up with the Correlation Score (determined based on the curve in Figure A3) to derive a combined Delay-Correlation Score. The highest combined value over the 5-min period will then be used as its representative Delay-Correlation Score. In the reduced sample above, this would be the score of 1.69, corresponding to a Delay and Correlation Score of 1.00 and 0.69 respectively.

Furthermore, for each 10s interval, PJM will calculate a Precision Score as a function of the difference in the energy provided versus the energy requested by the regulation signal while scaling for the number of samples. For each 10s sample averaged over an hourly basis, PJM calculates the Precision Score as the absolute error (ε) as a function of the resource's regulation capacity, as:

$$Error = Avg\ of\ Abs \left| \frac{Response - \ Regulation\ Signal}{Hourly\ Average\ Regulation\ Signal} \right|$$

$$\begin{matrix} Precision \\ Score \end{matrix} = 1 - \frac{1}{n} \sum Abs(\,Error)$$

Where n is the number of samples in the hour.

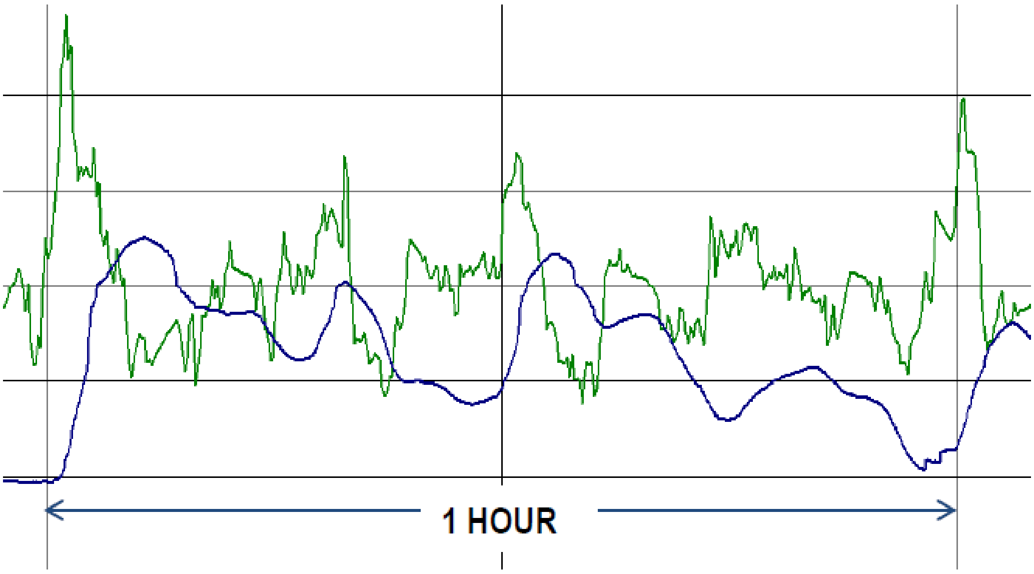
The Precision score is then combined with the maximum Delay and Correlation scores derived earlier, with each score given a 1/3 weight, to derive the aggregate Performance Score.

B) Benefits Factor

In PJM, there are two types of fleet level regulation signals sent out by PJM:

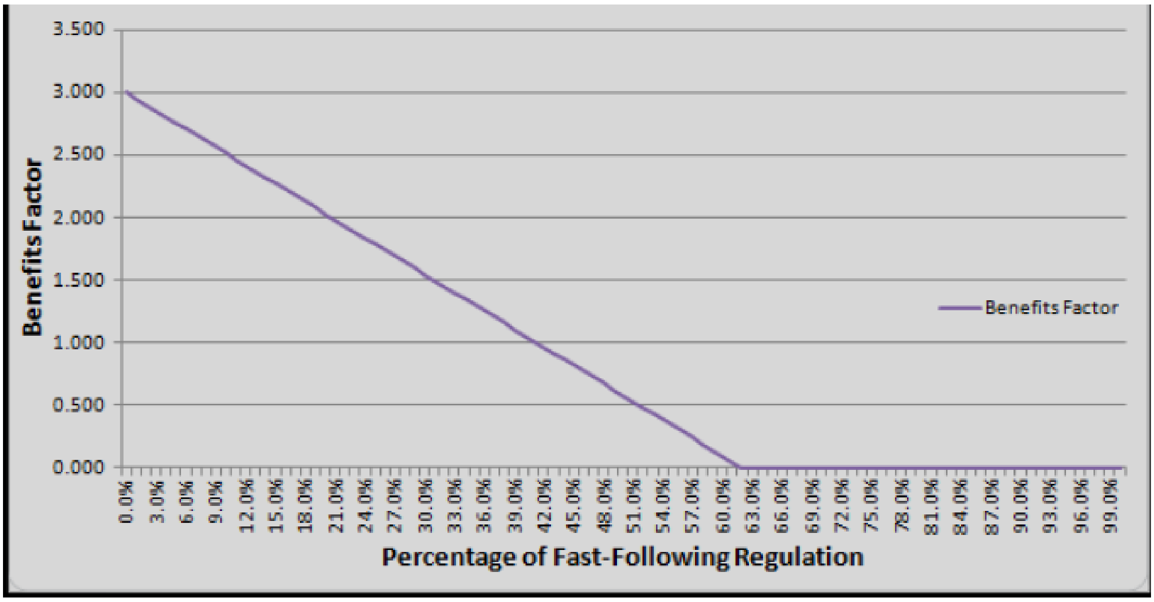
- **RegA** – traditional units (Some CTs, CCs, Steam)
- **RegD** – fast moving units (Some CTs, energy storage, hydro)

Figure A4: Regulation Signals sent to RegA (blue) and RegD (green)



Regulating resources can follow either a RegA (traditional) or RegD (dynamic) signal based on their resources' limitation and business practices. The regulating resources cleared in any hour can be any set of or mix of both traditional and dynamic resources, with the mix determined by Benefits Factor, which translates fast moving resource's MWs into traditional MWs or Effective MWs. This Benefits Factor is shown in Figure 4 overleaf:

Figure A5: Benefits Function Adopted to Translate RegD to RegA Resources

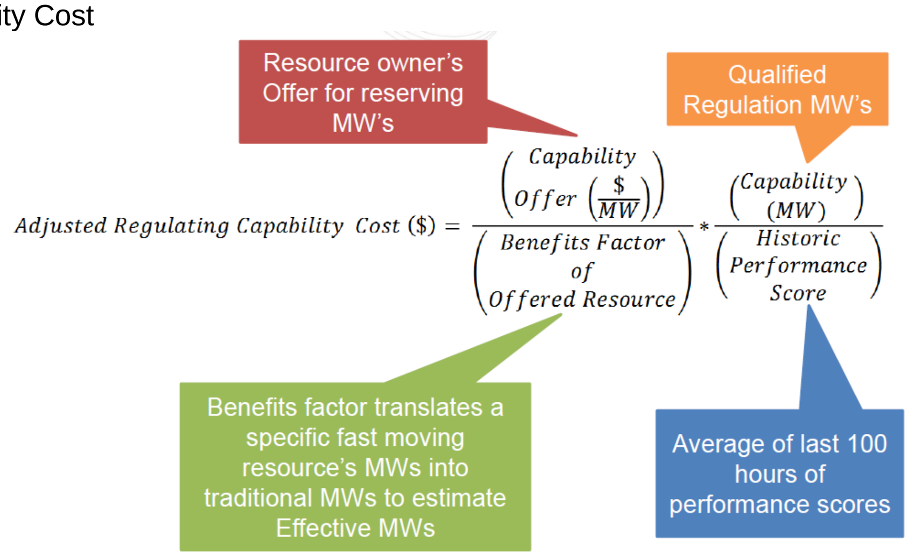


The Benefits factor (y-axis) reflects the rate of substitution of RegD into RegA resources. To illustrate, when there is only 9% of RegD (Fast-Following Regulation) in the system, 1 unit of RegD is equivalent to 2.5 units of RegA (Traditional Regulation). With expected diminishing returns, when the proportion of RegD resources reaches about 40%, 1 unit of RegD is treated similarly to 1 unit of RegA. PJM will review the benefits factor over time, taking into account changes to the regulation signal tuning parameters, set of resources providing regulation service, and the regulation requirement.

C) Adjusted Total Offer Cost

After calculating the Performance Score and Benefits Factor of a given resource, the resource owner will then make a two-part offer for specifically the capacity and performance of the regulation resource. These 2 offers are combined with a 3rd component which estimates the lost opportunity cost of the unit in responding to regulation signals, to derive the Adjusted Total Offer Cost. This is illustrated as follows:

i) Capability Cost



$$Adjusted\ Regulating\ Capability\ Cost\ (\$) = \frac{\left(\begin{matrix} Capability \\ Offer\ \left(\frac{\$}{MW}\right)\end{matrix}\right)}{\left(\begin{matrix} Benefits\ Factor \\ of \\ Offered\ Resource\end{matrix}\right)} * \frac{\left(\begin{matrix} Capability \\ (MW)\end{matrix}\right)}{\left(\begin{matrix} Historic \\ Performance \\ Score\end{matrix}\right)}$$

The resource owner makes an explicit Capability (i.e. capacity) Offer, which is multiplied by the total MW capacity and further adjusted by the Benefits Factor and Historic Performance to derive the Adjusted Regulating Capability Cost

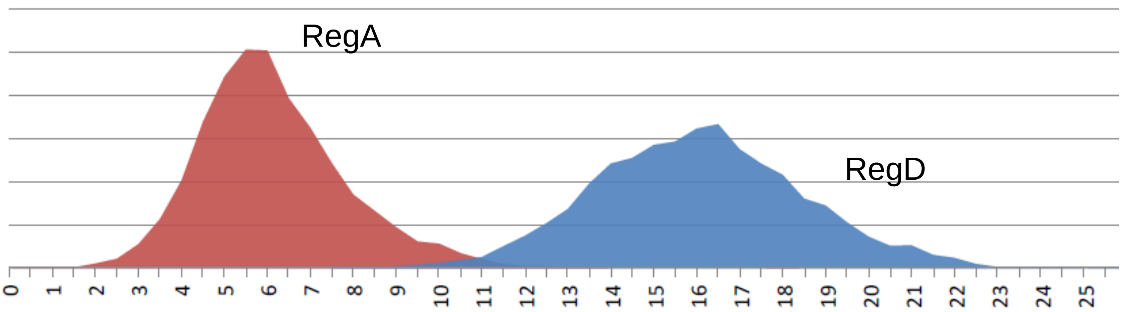
ii) Performance Cost

PJM first computes the mileage for a given resource type (e.g. RegD), which is the change in output for the resource at discrete 10s frequency, over a 5 minute interval as follows:

$$Mileage_{RegD} = \sum_{i=0}^{n} |RegD_i - RegD_{i-1}|$$

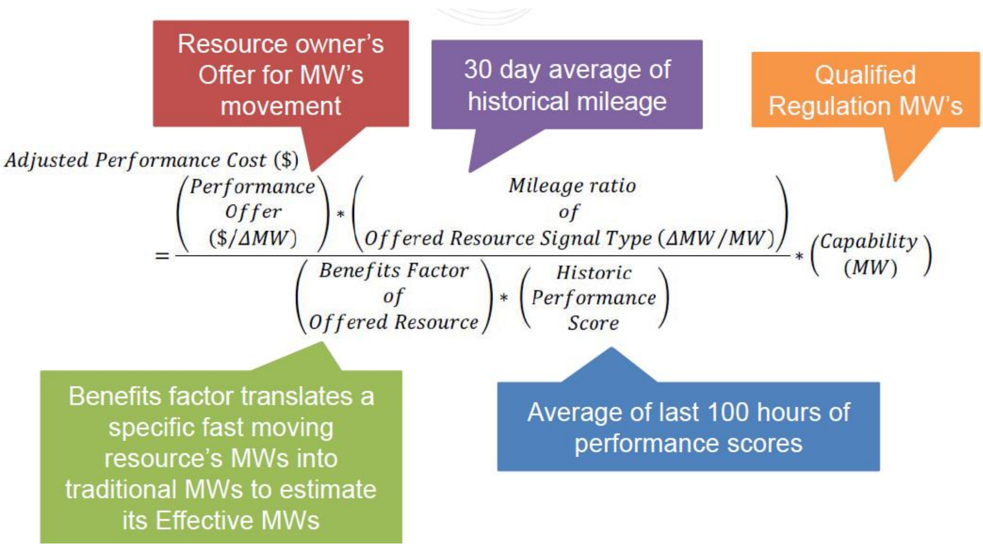
As expected, RegD resources would have greater mileage compared to RegA resources, as shown below:

Figure A6: Historical Jan-Jun 2012 Signal Mileage, PJM



Note: The X-axis represents the mileage ratio for the respective resource type. In other words, 1MW of RegA and RegD resource are expected to chalk up an average mileage of 6MW and 16MW respectively.

The 30-day average historical mileage is then divided by the total capacity to derive the "mileage ratio" and used to derive the Adjusted Performance Cost:



As shown above, the Adjusted Performance Cost is derived by applying the Performance offer from the resource owner, applied onto the mileage ratio of the relevant type (e.g. RegD) and capability, and adjusted by the Benefits Factor and Historic Performance Score.

iii) Lost Opportunity Cost

The final Lost Opportunity Cost component is not an explicit offer by the resource owner, but is automatically computed by the MCE to account for the lost opportunity cost:

- Before regulating hour – Unit moves uneconomically into its regulating band
- During regulating hour – Unit reduces/raises output uneconomically when providing regulation
- After regulating hour – Unit moves uneconomically from regulating band back to economic set point

The detailed computations involve integrations that encapsulate the lost opportunity cost energy schedule, the points on that curve corresponding to the resource's desired economic dispatch, and the setpoint necessary to provide the full amount of regulation, and the LMP.

The estimated lost opportunity cost is similarly adjusted by the Benefits Factor and Historic Performance to derive the Adjusted Lost Opportunity Cost

Estimated Lost Opportunity Cost

Qualified Regulation MW's

$$Adjusted\ Lost\ Opportunity\ Cost\ (\$) = \frac{\left(\begin{matrix} Estimated\ Lost\ Opportunity \\ \left(\frac{\$}{MW}\right) \end{matrix}\right)}{\left(\begin{matrix} Benefits\ Factor \\ of \\ Offered\ Resource \end{matrix}\right)} * \frac{\left(\begin{matrix} Capability \\ (MW) \end{matrix}\right)}{\left(\begin{matrix} Historic \\ Performance \\ Score \end{matrix}\right)}$$

Benefits factor translates a specific fast moving resource's MWs into traditional MWs to estimate its Effective MWs

Average of last 100 hours of performance scores

iv) Merit Order Ranking for Scheduling

After individually determining the Adjusted Regulation Capability Cost, Adjusted Lost Opportunity Cost and Adjusted Performance Cost, they are summed up to derive the Adjusted Total Offer Cost as follows:

$$Adjusted\ Total\ Offer\ Cost\ (\$) = \underbrace{\left(\begin{matrix} Adjusted \\ Regulation \\ Capability \\ Cost \\ (\$) \end{matrix}\right) + \left(\begin{matrix} Adjusted \\ Lost \\ Opportunity \\ Cost \\ (\$) \end{matrix}\right)}_{\text{Capability Payment}} + \underbrace{\left(\begin{matrix} Adjusted \\ Performance \\ Cost \\ (\$) \end{matrix}\right)}_{\text{Performance Payment}}$$

$$Rank\ Price = \frac{Adjusted\ Total\ Offer\ Cost\ (\$)}{Capability\ \ (MW)}$$

The Adjusted Total Offer Cost is then normalised by the offer Capability to derive the Rank Price, which is used in merit-order ranking to determine which units are scheduled. Essentially, the lower Rank Price units are scheduled first, until total regulation requirements are met.

ANNEX 3

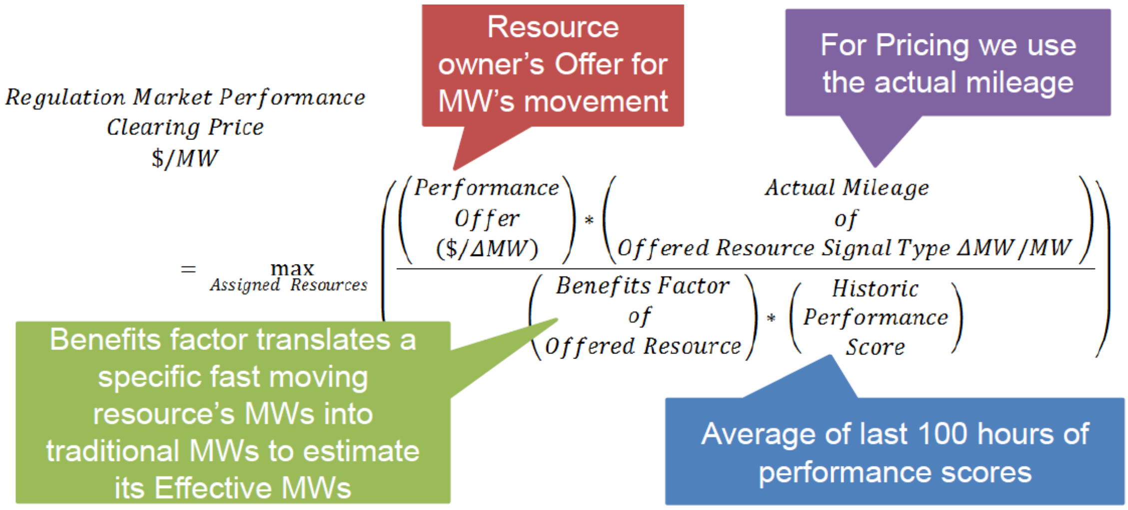
PJM Payment Framework

The merit order ranking for Adjusted Total Offer Cost discussed earlier determines the clearing price for regulation as a whole (inclusive of both performance and capability). However, the Total Clearing Price needs to be further separated into the Performance and Capability component prices.

A) Payment for Performance

PJM computes the real-time performance score for each regulation resource. Resources with a score of 25% or lower will not receive any regulation payments for the hour. For resources that qualify, the clearing price for performance is determined as follows:

$$\begin{matrix} Regulation\ Market\ Performance \\ Clearing\ Price \\ \$/MW \end{matrix} = \max_{Assigned\ Resources} \left(\frac{\begin{pmatrix} Performance \\ Offer \\ (\$/\Delta MW) \end{pmatrix} * \begin{pmatrix} Actual\ Mileage \\ of \\ Offered\ Resource\ Signal\ Type\ \Delta MW/MW \end{pmatrix}}{\begin{pmatrix} Benefits\ Factor \\ of \\ Offered\ Resource \end{pmatrix} * \begin{pmatrix} Historic \\ Performance \\ Score \end{pmatrix}} \right)$$



The Regulation Market Performance Clearing Price (RMPCP) is calculated by taking the highest adjusted performance offer equivalent (this time using the actual mileage during the period rather than the 30-day historical average earlier) among all scheduled regulation units. The payment for individual units will then be based on:

Regulation Performance Payment = Scheduled Regulation (MW) x Actual Performance Score x Benefits Factor x RMPCP ($/MW)

B) Payment for Capability

The Regulation Market Capability Clearing Price (RMCCP) is determined as the residual between the Regulation Market Total Clearing Price and the RMPCP:

$$\begin{matrix} Regulation\ Market\ Capability \\ Clearing\ Price \\ \$/MW \end{matrix} = \begin{pmatrix} Total\ Regulation\ Market \\ Total\ Clearing\ Price \\ \$/MW \end{pmatrix} - \begin{pmatrix} RM\ Performance \\ Clearing\ Price \\ \$/MW \end{pmatrix}$$

The capability payment for each unit is then computed as:

Regulation Capability Payment = Scheduled Regulation (MW) x Actual Performance Score x Benefits Factor x RMCCP ($/MW)

The implications of the above algorithm for Performance and Capability payments are that when units are called upon to provide more regulation, the RMPCP (performance price) will be higher and payment weightage will shift towards performance over capability. Furthermore, the actual Performance and Capability payments for individual units are adjusted for their actual Performance Score and respective Benefits Factor.