Regulation Up/Down Opportunity Cost Calculation Review in LPC Pricing

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1. Background

The purpose of this document is to give an overview of the calculation of Regulation Up Lost Opportunity Cost (RegUp LOC) and Regulation Down Lost Opportunity Cost (RegDn LOC) in Locational Pricing Calculator (LPC) pricing for the Regulation Redesign Phase 2. The formulation and calculation methodology differ separately for the eligible non-hydro and hydro resources. This document describes RegUp/RegDn LOC for non-hydro in section 2 and RegUp/RegDn LOC for hydro in section 3.

In general, Regulation Lost Opportunity Cost (RegLOC) represents the Energy Market profit a resource gives up, or the additional cost it incurs, when it is held uneconomically to provide Regulation instead of following its economic energy dispatch. The five-minute regulation clearing price includes the marginal resource's RegLOC, making it financially indifferent between energy and Regulation; other cleared resources may earn above their opportunity costs.

RegLOC is evaluated for the eligible resources at three different stages:

- **Commitment:** ASO in its half-hourly regulation clearing and commitment estimates RegLOC using forecast prices and expected resource output based on the forecasted system conditions and includes them in the resources' expected Regulation cost when selecting resources.

- **Pricing:** LPC recalculates RegLOC for the currently regulating resources in real time every five minutes using real-time prices and tracking ramp-limited desired (TRLD) megawatt output, so it can affect the Regulation clearing price.

- **Settlement:** Settlement calculates any eligible lost opportunity cost credit after comparing the resource's Regulation offer and opportunity costs with its clearing price credits.

This document covers RegLOC in the commitment and pricing. Throughout the document, the resource performance score (PS) is assumed to be 1 for simplicity.

Regulation Set Point

The Regulation set point of a regulating resource is determined by the forecasted or actual LMP at its bus, together with its operating parameters such as ramp rates, validated Regulation range, and regulation offer or assigned megawatt. Regulation set point establishes the megawatt headroom and/or foot room the resource must hold to provide regulation service. There is a potential non-zero RegLOC if the eligible resource's regulation set point is anywhere other than its TRLD output.

RegLOC calculation is described pictorially thus:

Figure 1.1 RegLOC – Opportunity Cost Scenario

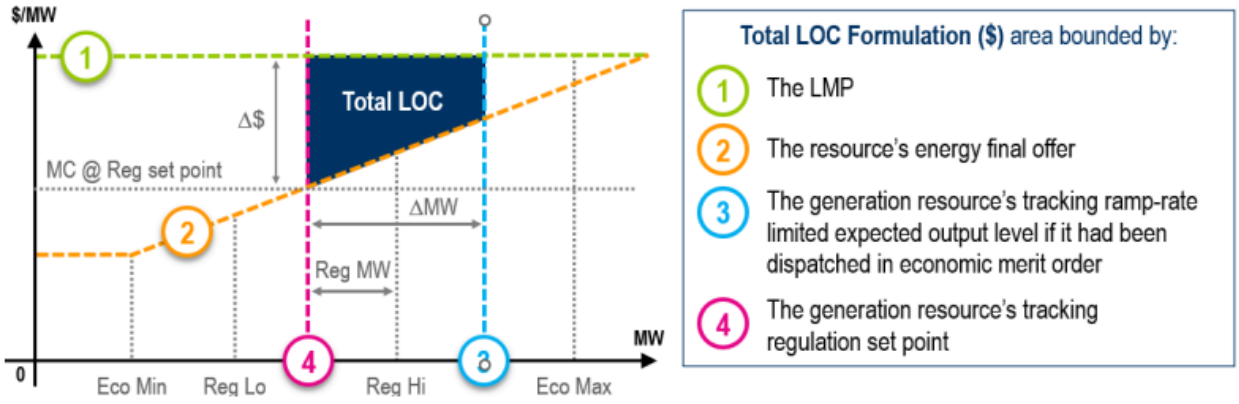
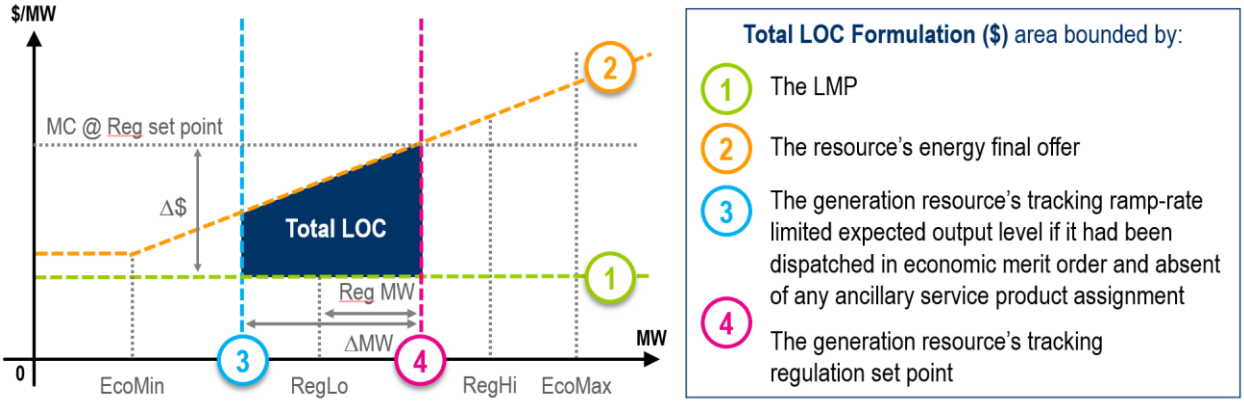


Figure 1.2 RegLOC – Uplift Scenario



Resource's opportunity cost equal to the area bounded by:

- The Locational Marginal Price (LMP) at the generation bus for the regulating resource
- The resource's energy Final Offer
- The resource's tracking ramp-rate limited expected output level if it had been dispatched for energy in economic merit order (TRLD)
- The generation resource's tracking regulation set point on the energy schedule curve on which the resource is running in the PJM Interchange Energy Market (TRLDAS)

Equation 1

$$RegLOC = \frac{\Delta\$}{PS} \times \frac{\Delta MW}{RegMW}$$

Where:

- *ΔS is the difference between LMP and Marginal Cost at the Regulation set point.*
- *ΔMW is the difference between TRLD and TRLDAS.*

The Total LOC in dollar is converted to RegLOC in $/MWh by dividing by the resource's historic performance score and RegMW.

There are four scenarios that determine if a RegLOC of an eligible resource is zero or above zero. RegLOC cannot be negative:

1 | If Δ$ is positive, and ΔMW is positive, then RegLOC is greater than zero.

2 | If Δ$ is negative, and ΔMW is negative, then RegLOC is greater than zero.

3 | If Δ$ is positive, and ΔMW is negative, then RegLOC is zero.

4 | If Δ$ is negative, and ΔMW is positive, then RegLOC is zero.

In Phase 2, the bidirectional regulation is split into Regulation Up (RegUp) and Regulation Down (RegDn) products. Therefore, there is Regulation resource lost opportunity cost calculation separately for RegUp and RegDn.

As described in equation 2, it is expected that for the same resource and under the same conditions, parameters, and equal RegUp and RegDn megawatt.

Equation 2

RegLOC (bidirectional) = RegUp LOC + RegDn LOC

For non-hydro units, it is not common that the ratio of ΔMW/RegMW is not 1:1; therefore, equation 1 persists for the RegLOC calculation. However, for resource type hydro, RegLOC formula may be further simplified as in equation 3 below. This is because the ratio of ΔMW/RegMW is 1:1.

Equation 3

$$\text{RegLOC (hydro)} = \frac{\Delta\$}{PS}$$

2. Non-Hydro Lost Opportunity Cost Calculation for RegUp and RegDn in Phase 2

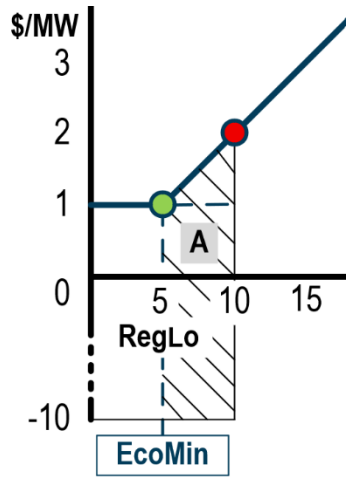
For the non-hydro LOC analysis, we will use the energy incremental curve described in **Table 1**

Table 1. Energy Incremental Curve

MW	5	10	15	20	25	30	35	40	45	50
Price ($/MWh)	1	2	3	4	5	6	7	8	9	10
Use Bid Slope										

Case Study 1: Single LPC Interval Review: EcoMin = RegLo, LMP ≤ Price @ EcoMin

Figure 2.1 Uplift Graphic



LMP at $-10 (below marginal cost at EcoMin), and RegLo = EcoMin.

1. To provide 5 MW of Reg bidirectional, Reg set point (Reg SP) is at 10. Since the resource is held uneconomically above cost at EcoMin, RegLOC in area A is incurred.
2. To provide 5 MW of RegUp only, Reg SP is at 5. Since the resource can provide regulation at its expected energy output, there is no RegUpLOC associated.
3. To provide 5 MW of RegDn only, Reg SP is at 10. Since the resource is held uneconomically above cost, RegDnLOC in area A is incurred.

Scenario 1.1 – Reg Bidirectional (control calculation)

LMP = **-10**	EcoMin = RegLo = **5**	Energy expected output = **5**	Unit on Reg Bi for **5 MW**	Reg SP = **10**

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLDAS > TRLD and LMP < MC at RegSP. That is, roughly (-10-2) x (5-10) is positive. So, yes.

RegLOC = (Δ$ x ΔMW) / (RegMW x PS) = $\frac{\text{Area A}}{PS*RegMW}$ = $\frac{[(11*5)+(0.5*1*5)]}{(1*5)}$ = $11.5/MWh

Scenario 1.2 – RegUp Only

LMP = -10	EcoMin = RegLo = 5	Energy expected output = 5	Unit on RegUp for 5 MW	Reg SP = 5

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLDAS = TRLD and LMP < MC at RegSP. That is, roughly (-10-2) x (5-5) is zero. So, no.

RegUp LOC = (Δ$ x ΔMW) / (RegUpMW x PS) = $0/MWh

Scenario 1.3 – RegDn Only

LMP = -10	EcoMin = RegLo = 5	Energy expected output = 5	Unit on RegDn for 5 MW	Reg SP = 10

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLDAS > TRLD and LMP < MC at RegSP. That is, roughly (-10-2) x (5-10) is positive. So, yes.

RegDn LOC = (Δ$ x ΔMW) / (RegDnMW x PS) = $\frac{\text{Area A}}{PS*RegDnMW}$ = $\frac{[(11*5)+(0.5*1*5)]}{(1*5)}$ = $11.5/MWh

Scenario 1.4 – RegUp and RegDn

LMP = -10	EcoMin = RegLo = 5	Energy expected output = 5	Unit on RegDn for 5 MW and RegUp for 5 MW	Reg SP = 10

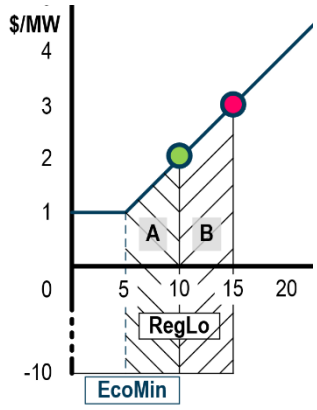
As described in scenario 1.2, if RegUp only, then Reg set point would have been at the 5 MW limit and the RegUp LOC of $0/MWh. However, since the resource is assigned RegDn at the same time, the Reg set point must then be at the 10 MW limit, and RegDn LOC of $11.5/MWh as described in scenario 1.3.

Remark: RegLOC = RegUp LOC + RegDn LOC ⟶ $11.5MWh = $0/MWh + $11.5/MWh

Conclusion: In a scenario where LMP is at or below price at EcoMin, and EcoMin = RegLo, then RegUp LOC = $0/MWh, and RegDn LOC is calculated as in scenario 1.3.

Case Study 2: Single LPC Interval Review: EcoMin < RegLo, LMP ≤ Price @ EcoMin

Figure 2.2 Uplift Graphic



LMP at $-10 (below marginal cost at EcoMin), and RegLo at 10 > EcoMin at 5.

1. To provide 5 MW of Reg bidirectional, Reg SP is at 15. Since the resource is held uneconomically above cost, RegLOC is the summation of Area A and Area B.
2. To provide 5 MW of RegUp only, Reg SP is at 10. Since the resource is held uneconomically above cost, RegUpLOC in area A is incurred.
3. To provide 5 MW of RegDn only, Reg SP is at 15. Since the resource is held uneconomically above cost, RegLOC is the summation of Area A and Area B.
4. For the resource to provide RegUp and RegDn in the same market interval, it should incur similar RegLOC as in Reg bidirectional.
5. **RegLOC bidirectional = RegUpLOC + RegDnLOC**
6. That is, Area A should not be counted twice. Rather, Area A should be commonly shared between RegUp and RegDn.

Scenario 2.1 – Reg Bidirectional (control calculation)

LMP = -10	EcoMin < (RegLo = 10)	Energy expected output = 5	Unit on Reg Bi for 5 MW	Reg SP = 15

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLDAS > TRLD and LMP < MC at RegSP. That is, roughly (-10-3) x (5-15) is positive. So, yes.

RegLOC = (Δ$ x ΔMW) / (RegMW x PS) = $\frac{\text{Area A \& B}}{PS*RegMW}$ = $\frac{[(11*10)+(0.5*2*10)]}{(1*5)}$ = $24/MWh

Scenario 2.2 – RegUp Only

LMP = -10	EcoMin < (RegLo = 10)	Energy expected output = 5	Unit on RegUp for 5 MW	Reg SP = 10

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLDAS > TRLD and LMP < MC at RegSP. That is, roughly (-10-2) x (5-10) is positive. So, yes.

RegUp LOC = abs (Δ$ x ΔMW) / (RegUpMW x PS) = $\frac{\text{Area A}}{PS*RegUpMW}$ = $\frac{[(11*5)+(0.5*1*5)]}{(1*5)}$ = $11.5/MWh

Scenario 2.3 – RegDn Only

LMP = -10	EcoMin < (RegLo = 10)	Energy expected output = 5	Unit on RegDn for 5 MW	Reg SP = 15

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLDAS > TRLD and LMP < MC at RegSP. That is, roughly (-10-3) x (5-15) is positive. So, yes.

RegDn LOC = abs (Δ$ x ΔMW) / (RegDnMW x PS) = $\frac{\text{Area A \& B}}{PS*RegDnMW}$ = $\frac{[(11*10)+(0.5*2*10)]}{(1*5)}$) = $24/MWh

Scenario 2.4 – RegUp and RegDn

LMP = -10	EcoMin < (RegLo = 10)	Energy expected output = 5	Unit on RegDn for 5 MW and RegUp for 5 MW	Reg SP = 15

As described in scenario 2.2, if RegUp only, then Reg set point would have been at 10 MW limit and RegUp LOC of $11.5/MWh. However, since the unit is assigned RegDn at the same time, the Reg set point must then be at the 15 MW limit, and RegDn LOC of $24/MWh as described in scenario 2.3.

It is desirable that the summation of RegUp LOC and RegDn LOC does not exceed RegLOC bidirectional of $24/MWh as in scenario 2.1. Otherwise, the sum LOCs are exaggerated.

*Remark**: In the scenario where RegLo > EcoMin, and LMP <= cost at EcoMin**, as described in Fig. 2.2, a common-cost-sharing, Area A, should be applied to both RegUpLOC and RegDnLOC, since the cost between EcoMin and RegLo is common to both products.*

- Allocate $\frac{Area\ A}{PS_{up}*\ RegUp\ MW + PS_{dn}*RegDn\ MW}$ to both RegUp and RegDn.
- Allocate $\frac{Area\ B}{PS_{dn}\ *\ RegDn\ MW}$ to RegDn.

Equation 4

$$\text{RegUp LOC} = \frac{Area\ A}{PS_{up}*\ RegUp\ MW + PS_{dn}*RegDn\ MW}$$

Equation 5

$$\text{RegDn LOC} = \frac{Area\ A}{PS_{up}*\ RegUp\ MW + PS_{dn}*RegDn\ MW} + \frac{Area\ B}{PS_{dn}\ *\ RegDn\ MW}$$

Equation 6

Total RegLOC payment to resource = RegUp LOC * RegUp MW + RegDn LOC * RegDn MW =

$$\frac{Area\ A}{PS_{up} * RegUp\ MW + PS_{dn} * RegDn\ MW} * RegUp\ MW + \frac{Area\ A}{PS_{up} * RegUp\ MW + PS_{dn} * RegDn\ MW} * RegDn\ MW + \frac{Area\ B}{PS_{dn} * RegDn\ MW} * RegDn\ MW = \textbf{(Area A + Area B)/PS}$$

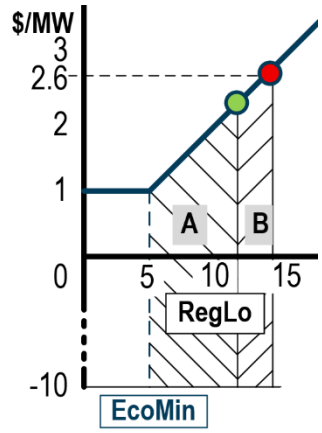
As such, in scenario 2.4, where a resource is assigned both RegUp and RegDn at the same time, and where RegLo > EcoMin, and LMP <= cost at EcoMin.

- RegUpLOC = $\frac{57.5}{1*5+1*5} = \$5.75/MWh$
- RegDnLOC = $\frac{57.5}{1*5+1*5} + \frac{[(12*5)+(0.5*1*5)]}{(1*5)}$ = $18.25/MWh
- RegUpLOC + RegDnLOC = $5.75 + $18.25 = $24/MWh = RegLOC

Scenario 2.5 – RegUp and RegDn (RegUp <> RegDn)

LMP = -10	EcoMin < (RegLo = 10)	Energy expected output = 5	Unit on RegDn for 3 MW and RegUp for 7 MW	Reg SP = RegLo + RegDn = 13

Figure 2.3 Uplift Graphic



LMP at $-10 (below marginal cost at EcoMin), and RegLo at 10 > EcoMin at 5.

For a resource to provide RegUp of 7 MW and RegDn of 3 MW, Reg SP will be at 13. That is, RegLo plus RegDn.

- Area A = (11*5) + (0.5*5*1) = 55 + 2.5 = 57.5
- Area B = (12*3) + (0.5*3*0.6) = 36 + 0.9 = 36.9

RegUp > RegDn

RegUp LOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} = \frac{57.5}{7+3} = 5.75$

RegDn LOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} + \frac{Area\ B}{PS * RegDn\ MW} = \frac{57.5}{7+3} + \frac{36.9}{3} = 5.75 + 12.3 = 18.05$

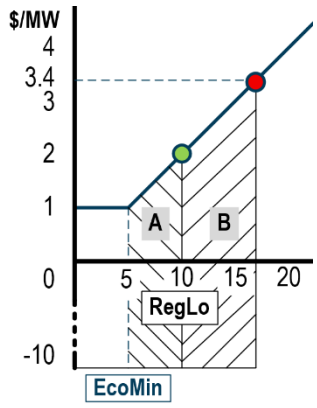
RegUpLOC + RegDnLOC = 5.75+18.05 = $23.8/MWh

Remarks: Note the reduction in RegDnLOC. It is because of the reduced Reg SP from 15 to 13; a reduced uneconomic Regulation set point.

Scenario 2.6 – RegUp and RegDn (RegUp <> RegDn)

LMP = -10	EcoMin < (RegLo = 10)	Energy expected output = 5	Unit on RegDn for 7 MW and RegUp for 3 MW	Reg SP = RegLo + RegDn = 17

Figure 2.4 Uplift Graphic



LMP at $-10 (below marginal cost at EcoMin), and RegLo at 10 > EcoMin at 5.

For a resource to provide RegUp of 3 MW and RegDn of 7 MW, Reg SP will be at 17. That is, RegLo plus RegDn\

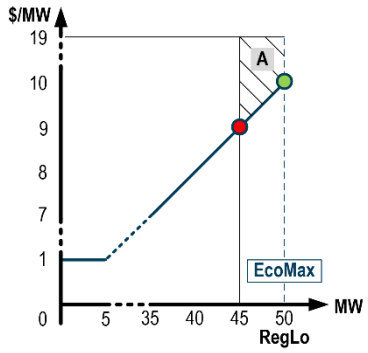
- Area A = (11*5) + (0.5*5*1) = 55 + 2.5 = 57.5
- Area B = (12*7) + (0.5*7*1.4) = 84 + 4.9 = 88.9

- RegUp < RegDn
- RegUp LOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} = \frac{57.5}{3+7} = 5.75$
- RegDn LOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} + \frac{Area\ B}{PS * RegDn\ MW} = \frac{57.5}{3+7} + \frac{88.9}{7} = 5.75 + 12.7 = 18.45$
- RegUpLOC + RegDnLOC = 5.75+18.45 = $24.2/MWh

Remarks: Note the increase in RegDnLOC. It is because of the increased Reg SP to 17; an increase in the uneconomic Regulation set point.

Case Study 3: Single LPC Interval Review: EcoMax = RegHi, LMP ≥ Price @ EcoMax

Figure 2.5 Uplift Graphic



LMP at $19 (above marginal cost at EcoMax), and RegHi = EcoMax.

1. To provide 5 MW of Reg bidirectional, Reg set point (Reg SP) is at 45. Since the resource is held uneconomically below the economic desired output, RegLOC in area A is incurred.
2. To provide 5 MW of RegUp only, Reg SP is at 45. Since the resource is held uneconomically below the economic desired output, RegUpLOC in area A is incurred.
3. To provide 5 MW of RegDn only, Reg SP is at 50. Since the resource is operating at its expected energy output, there is no RegDnLOC associated.

Scenario 3.1 – Reg Bidirectional (control calculation)

LMP = 19	EcoMax = RegHi = 50	Energy expected output = 50	Unit on Reg Bi for 5 MW	Reg SP = 45

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLD > TRLDAS and LMP > MC at RegSP. That is, roughly (19-9) x (50-45) is positive. So, yes.

RegLOC = (Δ$ x ΔMW) / (RegMW x PS) = $\frac{\text{Area A}}{PS*RegMW} = \frac{[(9*5)+(0.5*1*5)]}{(1*5)} = \frac{47.5}{5}$ = $9.5/MWh

Scenario 3.2 – RegUp Only

LMP = 19	EcoMax = RegHi = 50	Energy expected output = 50	Unit on RegUp for 5 MW	Reg SP = 45

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLD > TRLDAS and LMP > MC at RegSP. That is, roughly (19-9) x (50-45) is positive. So, yes.

RegUp LOC = abs (Δ$ x ΔMW) / (RegUpMW x PS) = $\frac{\text{Area A}}{PS*RegUpMW} = \frac{[(9*5)+(0.5*1*5)]}{(1*5)} = \frac{47.5}{5}$ = $9.5/MWh

Scenario 3.3 – RegDn

LMP = 19	EcoMax = RegHi = 50	Energy expected output = 50	Unit on RegDn for 5 MW	Reg SP = 50

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLD = TRLDAS and LMP > MC at RegSP. That is, roughly (19-9) x (50-50) is zero. So, no.

RegDn LOC = abs (Δ$ x ΔMW) / (RegDnMW x PS) = $0/MWh

Scenario 3.4 – RegUp and RegDn

LMP = 19	EcoMax = RegHi = 50	Energy expected output = 50	Unit on RegDn for 5 MW and RegUp for 5 MW	Reg SP = 45

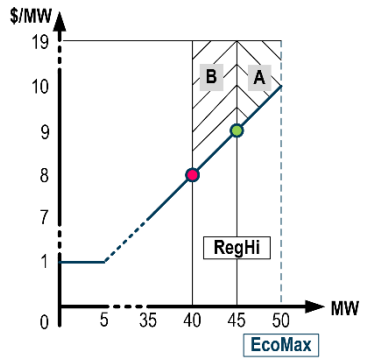
As described in scenario 3.3, if RegDn only, then, Reg set point would have been at 50 MW limit and the RegDn LOC of $0/MWh. However, since the unit is assigned RegUp at the same time, the Reg set point must then be at the 45 MW limit, and RegUp LOC of $9.5/MWh as described in scenario 3.2.

Remark: RegLOC = RegUp LOC + RegDn LOC → $9.5/MWh = $9.5/MWh + $0/MWh

Conclusion: In a scenario where LMP is at or above cost at EcoMax, and EcoMax = RegHi, then RegDn LOC = $0/MWh, and RegUp LOC is calculated as in scenario 3.2.

Case Study 4: Single LPC Interval Review: EcoMax > RegHi, LMP ≥ Price @ EcoMax

Figure 2.6 Uplift Graphic



LMP at $19 (above marginal cost at EcoMax), and RegHi at 45 < EcoMax at 50.

1. To provide 5 MW of Reg bidirectional, Reg set point (Reg SP) is at 40. Since the resource is held uneconomically below the economic desired output, RegLOC is the summation of Area A and Area B.
2. To provide 5 MW of RegUp only, Reg SP is at 40. Since the resource is held uneconomically below the economic desired output, RegLOC is the summation of Area A and Area B.
3. To provide 5 MW of RegDn only, Reg SP is at 45. Since the resource is operating below economic desired output, RegLOC is Area A.

   For the resource to provide RegUp and RegDn in the same market interval, it should incur similar RegLOC as in Reg bidirectional.

   RegLOC bidirectional = RegUpLOC + RegDnLOC

   That is, Area A should not be counted twice. Rather, Area A should be commonly shared between RegUp and RegDn.

Scenario 4.1 – Reg Bidirectional (control calculation)

LMP = 19	EcoMax > (RegHi = 45)	Energy expected output = 50	Unit on Reg Bi for 5 MW	Reg SP = 40

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLD > TRLDAS and LMP > MC at RegSP. That is, roughly (19-8) x (50-40) is positive. So, yes.

RegLOC = abs (Δ$ x ΔMW) / (RegMW x PS) = $\frac{\text{Area A \& B}}{PS*RegMW} = \frac{[(9*10)+(0.5*2*10)]}{(1*5)}$ = $20/MWh

Scenario 4.2 – RegUp Only

LMP = 19	EcoMax > (RegHi = 45)	Energy expected output = 50	Unit on RegUp for 5 MW	Reg SP = 40

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLD > TRLDAS and LMP > MC at RegSP. That is, roughly (19-8) x (50-40) is positive. So, yes.

RegUp LOC = abs (Δ$ x ΔMW) / (RegUpMW x PS) = $\frac{\text{Area A \& B}}{PS*RegUpMW} = \frac{[(9*10)+(0.5*2*10)]}{(1*5)}$ = $20/MWh

Scenario 4.3 – RegDn Only

LMP = 19	EcoMax > (RegHi = 45)	Energy expected output = 50	Unit on RegDn for 5 MW	Reg SP = 45

Eligibility: Must this resource be held uneconomically to provide the needed regulation? TRLD > TRLDAS and LMP > MC at RegSP. That is, roughly (19-9) x (50-45) is positive. So, yes.

RegDn LOC = abs (Δ$ x ΔMW) / (RegDnMW x PS) = $\frac{\text{Area A}}{PS*RegDnMW} = \frac{[(9*5) + (0.5*1*5)]}{(1*5)}$ = $9.4/MWh

Scenario 4.4 – RegUp and RegDn

LMP = 19	EcoMax > (RegHi = 45)	Energy expected output = 50	Unit on RegDn for 5 MW and RegUp for 5 MW	Reg SP = 40

As described in scenario 4.3, if RegDn only, then Reg set point would have been at 45 MW limit and RegDn LOC of $9.4/MWh. However, since the unit is assigned RegUp at the same time, the Reg set point must then be at the 40 MW limit, and RegUp LOC of $20/MWh as described in scenario 4.2.

It is desirable that the summation of RegUp LOC and RegDn LOC does not exceed RegLOC bidirectional of $20/MWh as in scenario 4.1. Otherwise, the sum LOCs are exaggerated.

*Remark: **In the scenario where RegHi < EcoMax, and LMP >= cost at EcoMax**, as described in **Fig. 4.1**, a common-cost-sharing, Area A, should be applied to both RegUpLOC and RegDnLOC, since the cost between EcoMax and RegHi is common to both products.*

- Allocate $\frac{Area\ A}{PS_{up} * RegUp\ MW + PS_{dn}RegDn\ MW}$ to both RegUp and RegDn.
- Allocate $\frac{Area\ B}{PS_{up} * RegUp\ MW}$ to RegUp.

Equation 7

$$\text{RegUp LOC} = \frac{Area\ A}{PS_{up} * RegUp\ MW + PS_{dn}RegDn\ MW} + \frac{Area\ B}{PS_{up} * RegUp\ MW}$$

Equation 8

$$\text{RegDn LOC} = \frac{Area\ A}{PS_{up} * RegUp\ MW + PS_{dn}RegDn\ MW}$$

Equation 9

Total RegLOC payment to resource = RegUp LOC * RegUp MW + RegDn LOC * RegDn MW=

$$\frac{Area\ A}{PS_{up} * RegUp\ MW + PS_{dn}RegDn\ MW} * RegUp\ MW + \frac{Area\ B}{PS_{up} * RegUp\ MW} * RegUp\ MW + \frac{Area\ A}{PS_{up} * RegUp\ MW + PS_{dn}RegDn\ MW} * RegDn\ MW$$

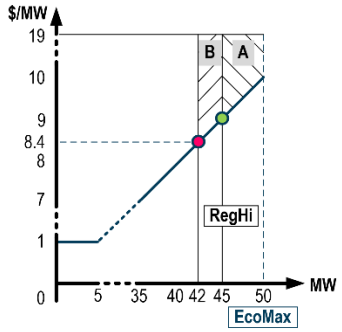
As such, in scenario 4.4, where a resource is assigned both RegUp and RegDn at the same time, and where RegHi < EcoMax, and LMP >= cost at EcoMax.

- RegDnLOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} = \frac{(9*5)+(0.5*5*1)}{1*5+1*5} = \frac{47.5}{1*5+1*5} = \$4.75/MWh$
- RegUpLOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} + \frac{Area\ B}{PS * RegUp\ MW} = \frac{47.5}{1*5+1*5} + \frac{[(10*5) + (0.5*1*5)]}{(1*5)} =$ $15.25/MWh
- RegDnLOC + RegUpLOC = $4.75 + $15.25 = $20/MWh = RegLOC

Scenario 4.5 – RegUp and RegDn (RegUp <> RegDn)

LMP = 19	EcoMax > (RegHi = 45)	Energy expected output = 50	Unit on RegDn for 7 MW and RegUp for 3 MW	Reg SP = RegHi-RegUp = 42

Figure 2.7 Uplift Graphic



LMP at $19 (above marginal cost at EcoMax), and RegHi at 45 < EcoMax at 50.

For a resource to provide RegUp of 3 MW and RegDn of 7 MW, Reg SP will be at 42. That is, RegHi minus RegUp

- Area A = (9*5) + (0.5*1*5) = 45 + 2.5 = 47.5
- Area B = (10*3) + (0.5*0.6*3) = 30 + 0.9 = 30.9

RegUp < RegDn

RegDnLOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} = \frac{47.5}{1*3+1*7} = \$4.75/MWh$

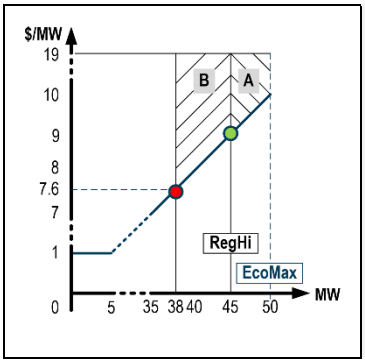
RegUpLOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} + \frac{Area\ B}{PS * RegUp\ MW} = 4.75 + \frac{30.9}{(1*3)}$ = $15.05/MWh

Remarks: Note the decrease in RegUpLOC because of a decrease in the uneconomic Regulation set point.

Scenario 4.6 – RegUp and RegDn (RegUp <> RegDn)

LMP = 19	EcoMax > (RegHi = 45)	Energy expected output = 50	Unit on RegDn for 3 MW and RegUp for 7 MW	Reg SP = RegHi - RegUp = 38

Figure 2.8 Uplift Graphic



LMP at $19 (above marginal cost at EcoMax), and RegHi at 45 < EcoMax at 50.

For a resource to provide RegUp of 7 MW and RegDn of 3 MW, Reg SP will be at 38. That is, RegHi minus RegUp

- Area A = (9*5) + (0.5*1*5) = 45 + 2.5 = 47.5
- Area B = (10*7) + (0.5*1.4*7) = 70 + 0.9 = 74.9

Fig.:

- RegUp > RegDn
- RegDnLOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} = \frac{47.5}{1*7+1*3} = \$4.75/MWh$
- RegUpLOC = $\frac{Area\ A}{PS * (RegUp\ MW + RegDn\ MW)} + \frac{Area\ B}{PS * RegUp\ MW} = 4.75 + \frac{74.9}{(1*7)}$ = $15.45/MWh

Remarks: Note the increase in RegUpLOC because of an increase in the uneconomic Regulation set point.

Case Study 5 – (To be continued)

3. Hydro Lost Opportunity Cost Calculation for RegUp and RegDn in Phase 2

Since hydropower resources operate on a schedule and do not have an energy incremental offer, opportunity cost for these resources is calculated as follows. A hydro resource can only receive a non-zero RegLOC calculation in pricing for the RegUp product as the resource can only be held down to provide this product. Hydro RegLOC for RegDn product is zero because its regulation set point is at its economic output.

The approximate formula for Hydro unit RegLOC is defined as:

1 | For Hydro where energy scheduled MW > 0

- Pump storage or run-off river

Equation 10

$$RegLOC = max\,[LMP - ED, 0]$$

- Hydro in spill condition

Equation 11

$$RegLOC = max\,[LMP, 0]$$

2 | For Hydro where energy scheduled MW <= 0

- Pump storage or run-off river

Equation 10

$$RegLOC = max[ED - LMP, 0]$$

Where:

- *LMP is the LMP at the hydro unit bus. Forecasted value is used in the hour-ahead regulation clearing in ASO while the actual value is used in the real-time pricing and in settlement.*
- *ED is the average of LMPs at the hydro unit bus for the appropriate on-peak or off-peak period excluding those hours during which all available units at the hydro plant were operating. Off-peak hours are HE1 through HE7, and HE24. On-peak hours are HE8 through HE23. Day-ahead LMPs are used to calculate ED in the hour-ahead regulation clearing in ASO and in real-time pricing while the real-time LMP after the fact is used in settlements.*

Table 1 Hydro Schedule

	Units at Hydro Plant			1	2	3	
Day-Ahead Period	Hour Ending	Day_Ahead LMP	Include in Ave_LMP Calculation	MW	MW	MW	
Off-Peak	1	17.74	N	-200	-200	-200	**Off-Peak Ave_LMP** = (23.14+33.46+30.36)/3 = **28.99**
	2	17.37	N	-200	-200	-200	
	3	16.73	N	-200	-200	-200	
	4	18.78	N	-200	-200	-200	
	5	22.68	N	-200	-200	-200	
	6	**23.14**	**Y**	0	0	0	
	7	**33.46**	**Y**	0	0	0	
On-Peak	8	**35.29**	Y	0	0	0	**On-Peak Ave_LMP** = (35.29+56.77+71.01+75.89 +80.18+56.76+35.79)/7 = **58.81**
	9	**56.77**	Y	0	0	0	
	10	**71.01**	Y	0	0	0	
	11	89.92	N	100	100	100	
	12	89.45	N	100	100	100	
	13	94.58	N	100	100	100	
	14	86.06	N	100	100	100	
	15	**75.89**	Y	0	0	0	
	16	82.48	N	100	100	100	
	17	90.22	N	100	100	100	
	18	96.5	N	100	100	100	
	19	92.98	N	100	100	100	
	20	85.08	N	100	100	100	
	21	**80.18**	Y	0	100	100	
	22	**56.76**	Y	0	0	0	
	23	**35.79**	Y	0	0	0	
Off-Peak	24	**30.36**	Y	0	0	0	

Let's assume a hydro unit with the following parameters:

EcoMax = 100, Regulation Offer MW = 25

Scenario 1:

Unit 1 was pool scheduled for Regulation for HE 11 for 25 MW. The forecasted LMP at the unit bus = $62.10.	• Energy scheduled MW > 0 • The unit is pump storage hydro or a run-off river but not spilling • RegLOC = max[LMP – ED, 0] = max[(62.10 – 58.81), 0] = $3.29/MW

Scenario 2:

Unit 2 was pool scheduled for Regulation for HE 13 for 25 MW. The forecasted LMP at the unit bus = $56.78.	• Energy scheduled MW > 0 • The unit is pump storage hydro or a run-off river but not spilling • RegLOC = max[LMP – ED, 0] = max[(56.78 – 58.81), 0] = 0 • That is, **No RegLOC**

Scenario 3:

Unit 3 was pool scheduled for Regulation for HE 20 for 25 MW. The forecasted LMP at the unit bus = $65.	• Energy scheduled MW > 0 • The unit is a run-off river and spilling • RegLOC = max[LMP, 0] = max[(65, 0] = $65/MW

Scenario 4:

Unit 1 was brought out of schedule to provide regulation by PJM dispatcher in HE 10. Actual LMP at the hydro unit bus = $70.	• Scheduled MW < = 0 • The unit is a pump storage hydro • RegLOC = max[ED – LMP, 0] = max[(58.81 – 70), 0] = 0 • That is, **No RegLOC**

Scenario 5:

Unit 2 was brought out of schedule to provide regulation by PJM dispatcher in HE 09. Actual LMP at the hydro unit bus = $45.	• Scheduled MW < = 0 • The unit is a pump storage hydro • RegLOC = max[ED – LMP, 0] = max[(58.81 – 45), 0] = $13.81/MW

Note: LOC credits for regulation are calculated for the regulation intra-hour and shoulder intervals. Resources supplying pool-scheduled Regulation, PJM sums the resource's Regulation offers and lost opportunity costs, including shoulder intervals' opportunity costs, then compares it to its 5-minute Regulation Clearing Price credits. If the resulting amount is positive, then LOC credits are allocated; however, if the resulting amount is negative, then the credit is $0. Resource supply self-scheduled Regulation are not eligible for LOC credits.

Please send any questions on these examples to PJM Member Relations at custsvc@pjm.com or call 610-666-8980.