Regulation Market Review

OC Reg

July 7, 2015

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Monitoring Analytics

Regulation: Efficient, least cost market design requirements

- **Market design intended to minimize the cost to provide regulation using two different products but clearing the resources in a single market requires:**
  - **An accurate marginal rate of substitution (marginal benefit factor) in the optimization**
  - **A single price (or a single two part price pair) for settlement**
  - **That the two products be defined, cleared and settled in equivalent units throughout**

Current Design

- **Incorrectly defined marginal benefit factor function (MBF)**
  - **Incorrectly valuing RegD as a substitute for RegA**
- **Incorrectly applying the MBF in the optimization**
  - **Undercounting the contribution of RegD to total effective regulation**
- **MBF not consistently used in pricing and settlement**
  - **Assumes MBF in price but not settlement**

Effect of Current Design

- **Incorrectly defined marginal benefit factor function (MBF)**
  - **Current MBF function does not reflect KEMA study findings regarding feasible combinations of RegA and RegD**
  - **Current MBF does not properly account for diminishing returns of RegD as a substitute for RegA**
  - **Causing incorrect/inefficient combinations of RegA and RegD to clear the market**
  - **Adversely affecting ACE control in some hours**

Effect of Current Design

- **Incorrectly applying the MBF in the optimization**
  - **Current market design incorrectly accounting for the amount of RegD it is acquiring in the market solution**
  - **Undercounting the contribution of RegD to total effective regulation**
  - **Contributes to optimization acquiring too much RegD in all hours**
  - **Inefficient squeezing out of RegA**
  - **Lowers regulation price per MW of RegA**

Effect of Current Design

- **MBF not consistently used in pricing and settlement**
  - **Current market model assumes MBF in price but not settlement**
  - **Result in incorrect compensation of RegD in all hours**

Effect of Current Design

- **MBF not consistently used in pricing and settlement**
  - **When MBF is <1 (RegD MW < RegA MW)**
  - **RegD overcompensated on a $/effective MW basis**
  - **Creates incentives to self schedule/price at $0.00**
  - **Long term investment signals incorrect for RegA and RegD**

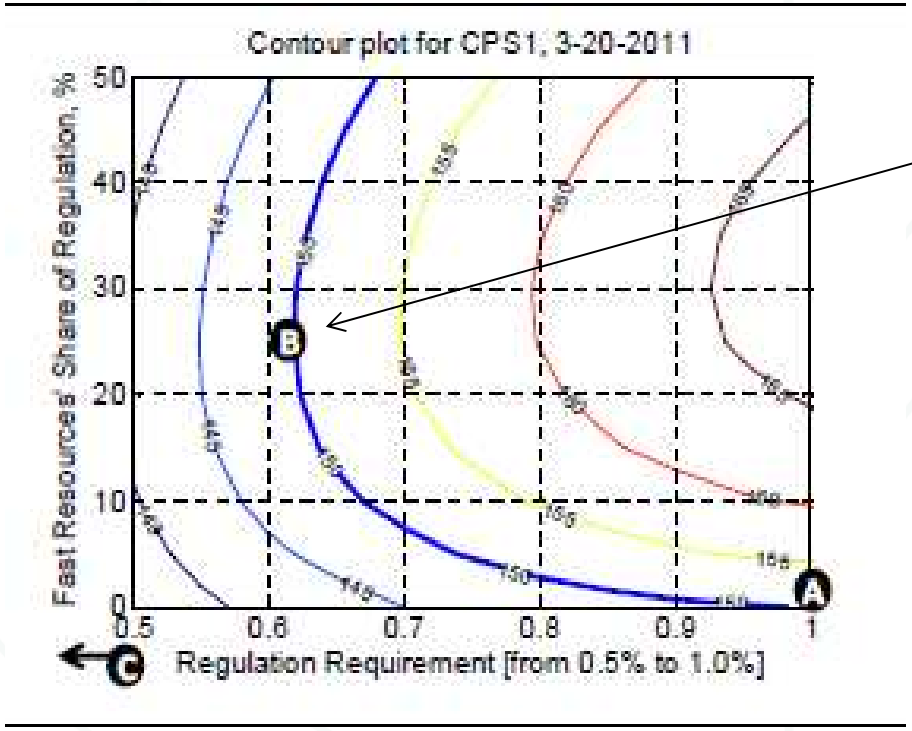
KEMA Study

- **KEMA study of RegA/RegD interactions indicated that there were diminishing returns to RegD as a substitute for RegA in providing regulation service.**
- **KEMA study showed that the marginal rate of substitution could go to zero or be negative.**
- **KEMA study showed that MRS function (curve) varies with system conditions.**

Issue with current design: MBF not correctly defined

- **PJM experience indicates market is operating, in some hours, where MBF is zero or negative.**
- **PJM experience indicates that MBF does vary with system conditions.**
- **The current assumed MBF is not sensitive to changes in system conditions.**

Issue with current design: MBF not correctly defined



RegD MW as Percent of Regulation MW

Combinations of RegA and RegD that provide the same CPS1 Scores

Slope of curve at any point describes marginal rate of substitution between RegA and RegD for a given CPS1 Score.

Slope is the Marginal Rate of Technical Substitution (MRTS) or the marginal benefit factor (MBF)

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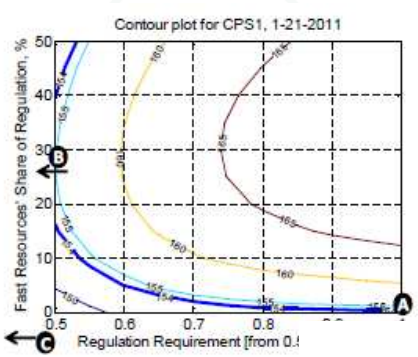
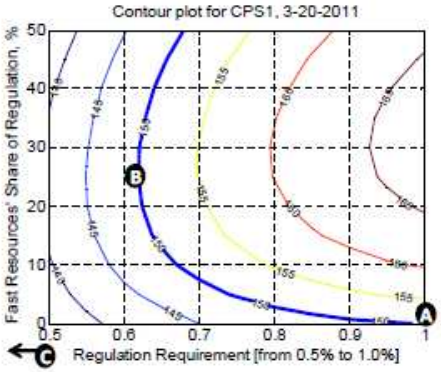
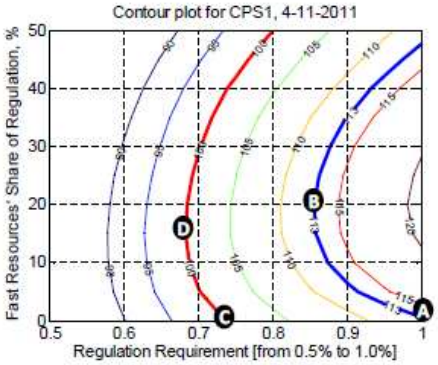
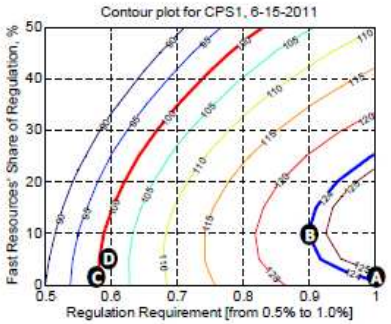
MBF varies with system conditions









Combinations of RegA and RegD that provide the same CPS1 Scores

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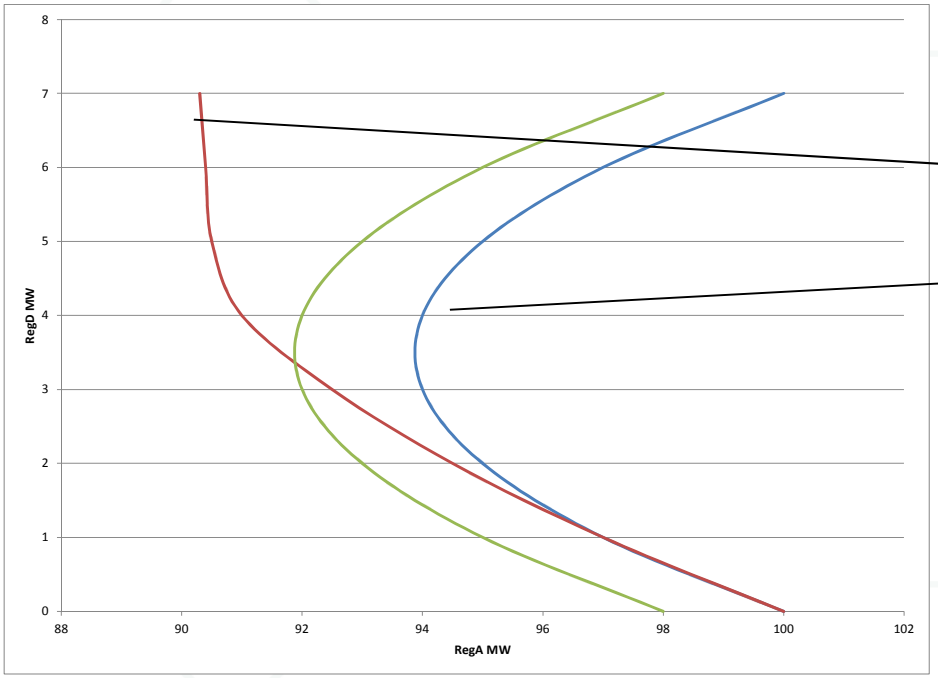
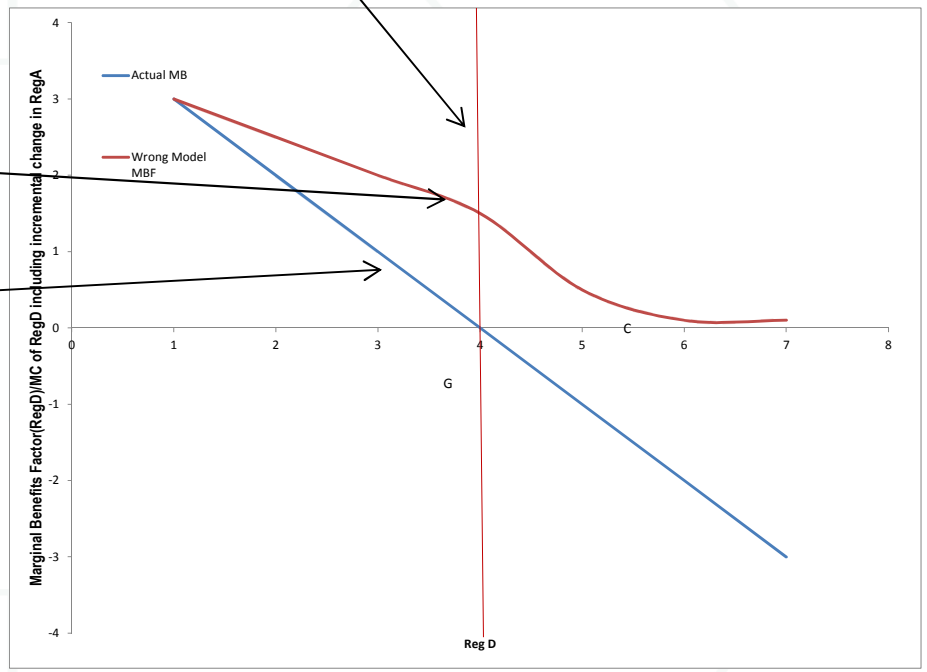
Example of RegA/RegD Combination Assumptions

Actual saturation (Actual MBF = 0)





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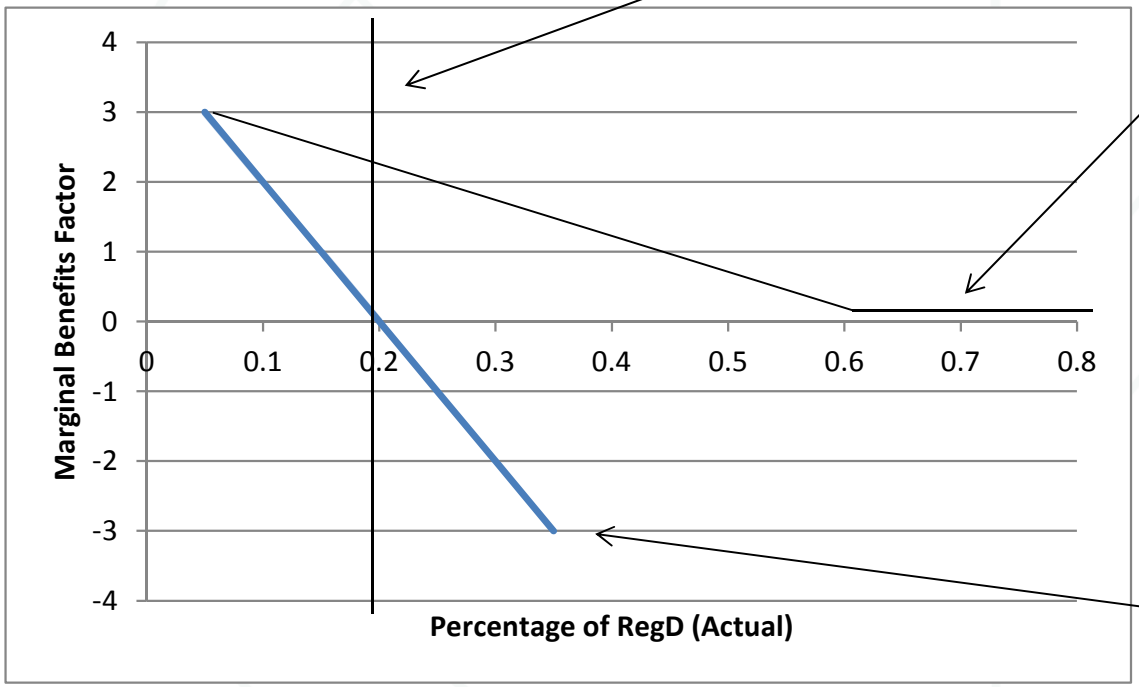
MBF varies with system conditions

RegD saturation (Actual MBF = 0)



Current MBF

System will over procure and overpay RegD:

1. MBF in optimization > than actual MBF (Make RegD look less expensive than it is)

2. Will clear more RegD than is efficient (total cost not minimized)
3. Procure less RegA than is efficient

Potential MBF

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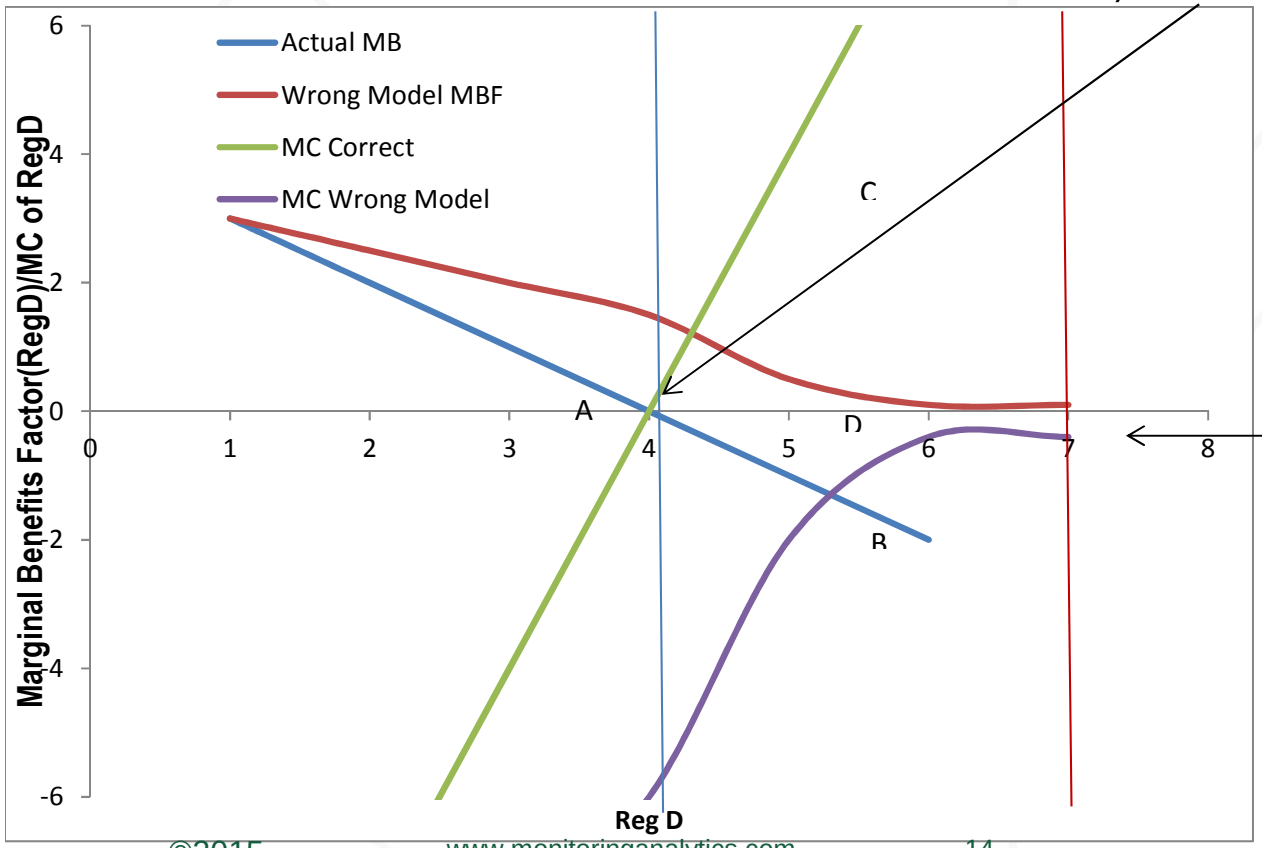
Example of RegA/RegD Combination Assumptions

Correct, with PA=$4, PD=$0, MBF = MC



Current MBF results in no limit to RegD purchase if RegD price = $0.00

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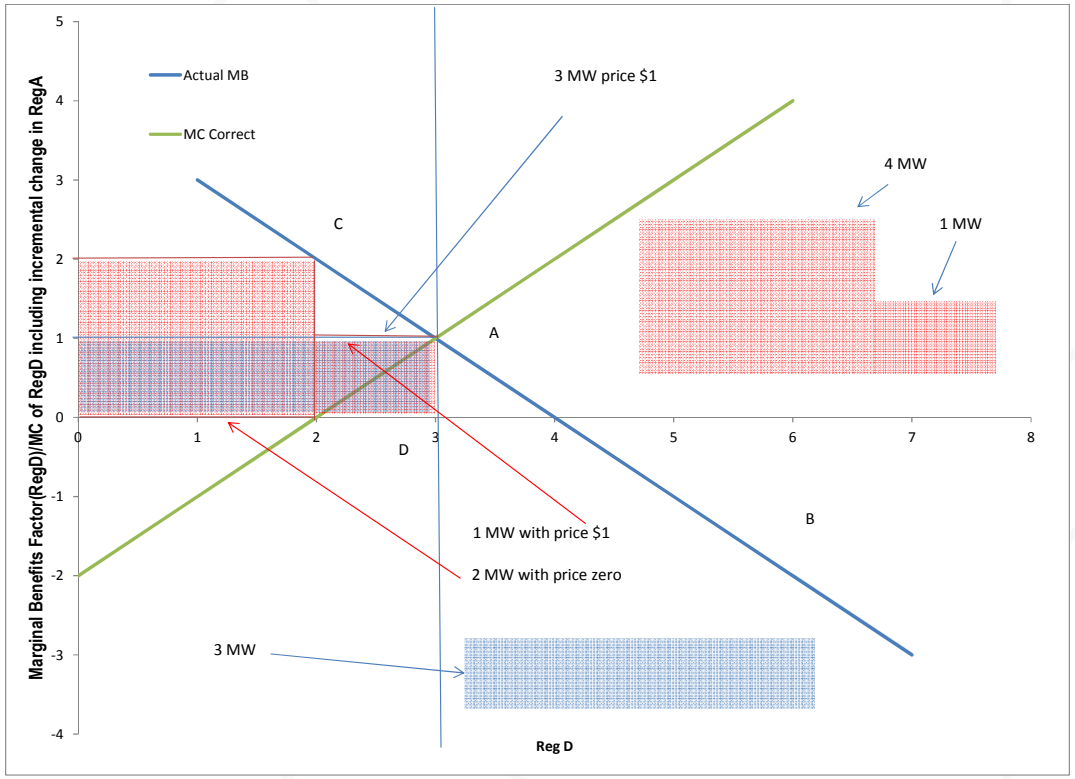
Optimization Flawed

- **Current market solution/optimization does not consistently account for the amount of effective MW provided by RegD**
- **Current market solution requires a specific amount of total effective MW to clear**
- **Amount of effective MW attributed to a given amount of cleared RegD depends on the number of price steps that exist in the supply stack, not the proportion of RegD MW cleared.**

Other issue (assuming MBF function is corrected)



Effective MW = MBFstep1*Mwstep1+MBFstep22+ ….
Red lines show two price steps:
Effective MW = 5 = 2*2MW+1*1MW

Blue line show one price step:
Effective MW = 3 = 3*1MW

Result is different effective MW based on number of price steps in supply stack for the same RegD actual MW. Results in different levels of total effective Reg clearing.

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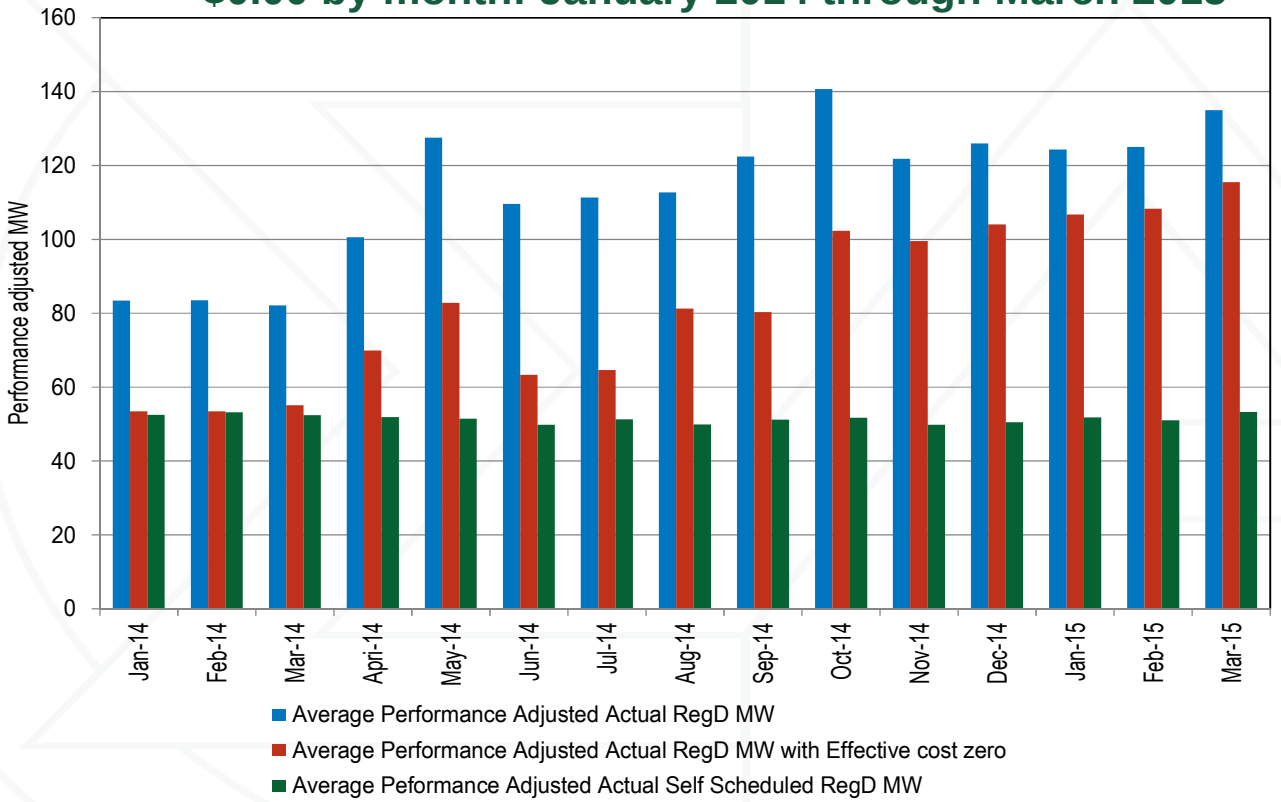
Average cleared RegD MW and average cleared RegD with an effective price of $0.00 by month: January 2014 through March 2015



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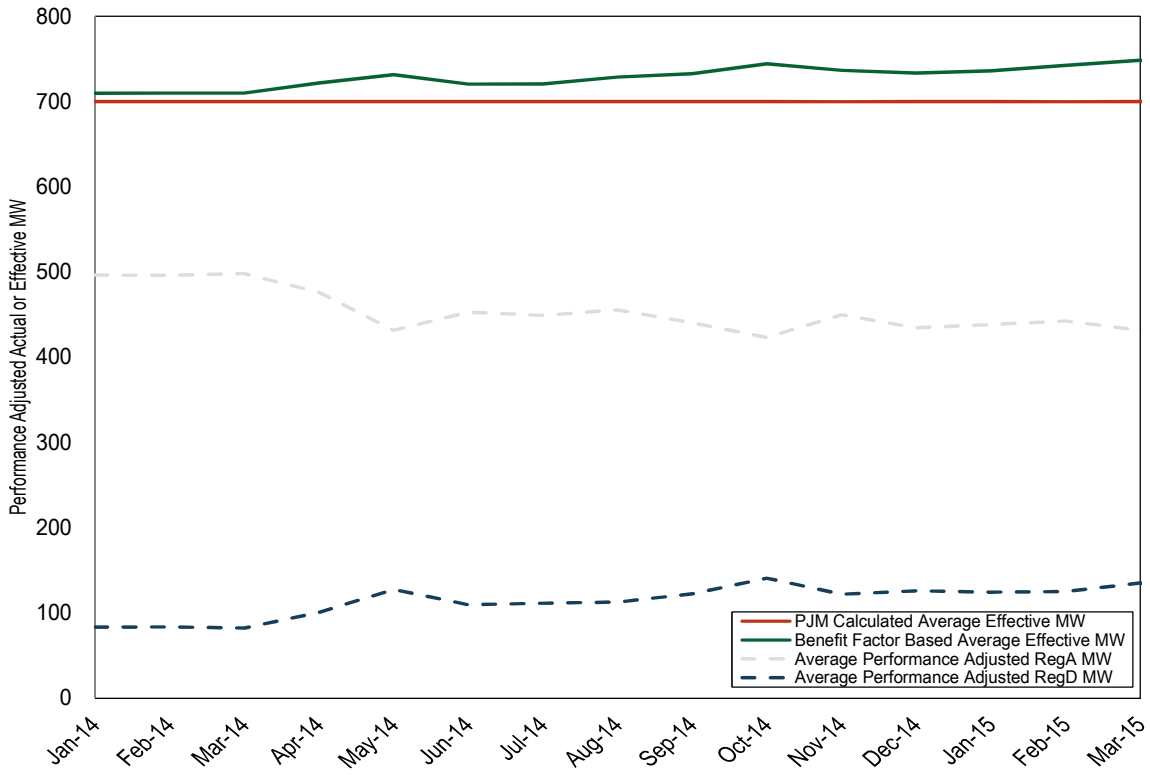
Average monthly peak effective MW: PJM market calculated versus benefit factor based



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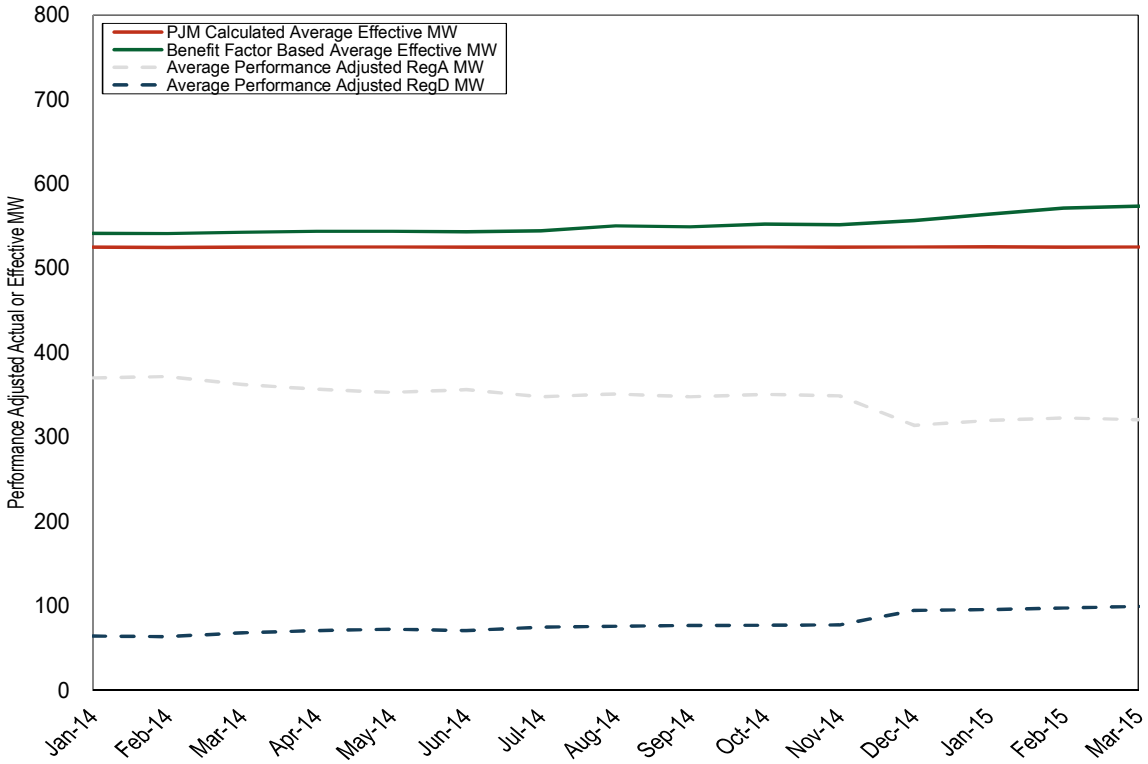
Average monthly off peak effective MW: PJM market calculated versus benefit factor based



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Marginal Benefit Factor should be uniformly applied in price and settlement

- **The Marginal Benefit Factor (MBF) should be uniformly applied so that the valuation used in optimization process is consistent with the valuation used in settlement.**
- **MBF used in price and the same MBF should be used in settlement**
- **MBF used to convert all offers to effective MW of RegA MW and $/effective MW of RegA.**

Marginal Benefit Factor should be uniformly applied

- **RegA resources have a MBF of one (base unit of measure).**
- **RegD resource MBF varies with the amount of RegD used as a percentage of total effective MW**
- **Use of MBF allows comparison of offers on the basis of equivalent units (effective MW of RegA)**

Marginal Benefit Factor should be uniformly applied in price and settlement

- **MBF used in price to convert all offers to effective MW of RegA MW and $/effective MW of RegA.**
- $$Capability(\$/EffectiveMW) = \frac{CapabilityOffer(\$/MW)}{BenefitFactor * HistoricPerformanceScore}$$

$$Performance(\$/EffectiveMW) = \frac{PerformanceOffer(\$/\Delta MW) * (ExpectedMW/MW)}{BenefitFactor * HistoricPerformanceScore}$$

Marginal Benefit Factor should be uniformly applied in price and settlement

- **MBF used in price to convert all offers to effective MW of RegA MW and $/effective MW of RegA.**

$$LOC(\$ / EffectiveMW) = \frac{ExpectedLOC(\$/MW)}{BenefitFactor*HistoricPerformanceScore}$$

Marginal Benefit Factor should be uniformly applied in price and settlement

- **MBF used in price to convert all offers to effective MW of RegA MW and $/effective MW of RegA.**

$$TotalIOffer(\$ / EffectiveMW) = Capability(\$ / effectiveMW) + ...$$

$$.. + Performance(\$ / effectiveMW) + ...$$

$$... + LOC(\$ / effectiveMW)$$

Marginal Benefit Factor should be uniformly applied in price and settlement

- **MBF used in price to convert all offers to effective MW of RegA MW and $/effective MW of RegA.**

$$TotalIOffer(\$ / EffectiveMW) = Capability(\$ / effectiveMW) + ...$$

$$.. + Performance(\$ / effectiveMW) + ...$$

$$... + LOC(\$ / effectiveMW)$$

All resources should be paid the same $/effective MW

$$EffectiveMW = Perf\%_i * MW\_D_i * MB$$

$$EffectiveMW = Perf\%_i * MW\_A_i$$

Effect of Current Design

- **Incorrectly compensating RegD in all hours**
  - **Sometimes too little (when MBF is >1)**
  - **Sometimes too much (when MBF is <1)**
    - Incentives to self schedule/price at $0.00
      - Inefficient squeezing out of RegA
      - Lowers regulation price per MW of RegA
    - Long term investment signals incorrect for RegA and RegD

Correct Current Design

- **Correct solution to both issues is related**
  - **Benefits factor needs to correctly reflect the trade off between RegA and RegD in providing regulation service**
  - **Least cost solution requires that:** $\frac{MB_A}{P_A} = \frac{MB_D}{P_D}$
  - **Short term and long term efficiency requires same marginal valuation used in optimization is realized in market signals**

Marginal Benefit Factor should be uniformly applied in price and settlement

- **For example, Resource 1 with a historic performance score of 0.7 and an assigned benefit factor of 1.0 (it is a RegA resource), makes an offer of $10 per MW for its capability. The capability offer, in terms of effective MW of RegA, would be $14.26/MW.**

- **Resource with a historic performance score of 1.0 and an assigned benefit factor of 0.5 based on its place in the supply stack, makes an offer of $10 per MW for its capability. The capability offer, in terms of effective MW of RegA, would be $20.00/MW**

Marginal Benefit Factor should be uniformly applied in price and settlement

- **For example, a resource with a historic performance score of 0.7 and an assigned benefit factor of 1.0 (it is a RegA resource), makes an offer of $1 per mile ($1 per delta MW per MW) for its regulation movement. The expected delta MW per MW for RegA is 5. The performance offer, in terms of effective MW of RegA, would be $7.14/MW.**
- **For example, a resource with a historic performance score of 1.0 and an assigned benefit factor of 0.5 (it is a RegD resource), makes an offer of $1 per mile ($1 per delta MW per MW) for its regulation movement. The expected delta MW per MW for RegA is 10. The performance offer, in terms of effective MW of RegA, would be $20/MW.**

Marginal Benefit Factor should be uniformly applied in price and settlement

- **Total offer unit 1 = $14.26/MW+ $7.14/MW = $21.40/MW of RegA**
- **Total offer unit 2 = $20/MW+$20/MW=$40/MW of RegA**
- **Both offer 1MW (not adjusted)**
- **In terms of effective MW, Unit 1 provides 1 MW RegA x 0.7 performance = 0.7 effective MW of RegA**
- **In terms of effective MW, Unit 2 provides 1 MW RegD x 1.0 performance x 0.5 MBF = 0.5 effective MW of RegA**
- **Marginal Price $40 per effective MW of RegA**

Marginal Benefit Factor should be uniformly applied in price and settlement

- **Price per MW of RegA = $40**
- **Unit 1 should be paid a total of $28 (0.7 effective MW of RegA x $40), as it provided 0.7 MW of RegA.**
  - **Equal to $40 per effective MW of RegA.**
- **Unit 2 should be paid $20 (0.5 effective MW of RegA x $40), as it provided 0.5 MW of RegA.**
  - **Equal to $40 per effective MW of RegA.**

Marginal Benefit Factor should be uniformly applied in price and settlement

- **Current rules however:**
- **Price per MW of RegA = $40**
- **Unit 1 is paid $28 (0.7 effective MW of RegA x $40), as it provided 0.7 MW of RegA.**
  - **Equal to $40 per effective MW of RegA.**
- **Unit 2 is paid $60 (1 MW of RegD x $20 for capability + 1MW of RegD x miles ratio (2) x $20 performance), despite providing only 0.5 MW of RegA.**
  - **Equal to $120 per effective MW of RegA.**

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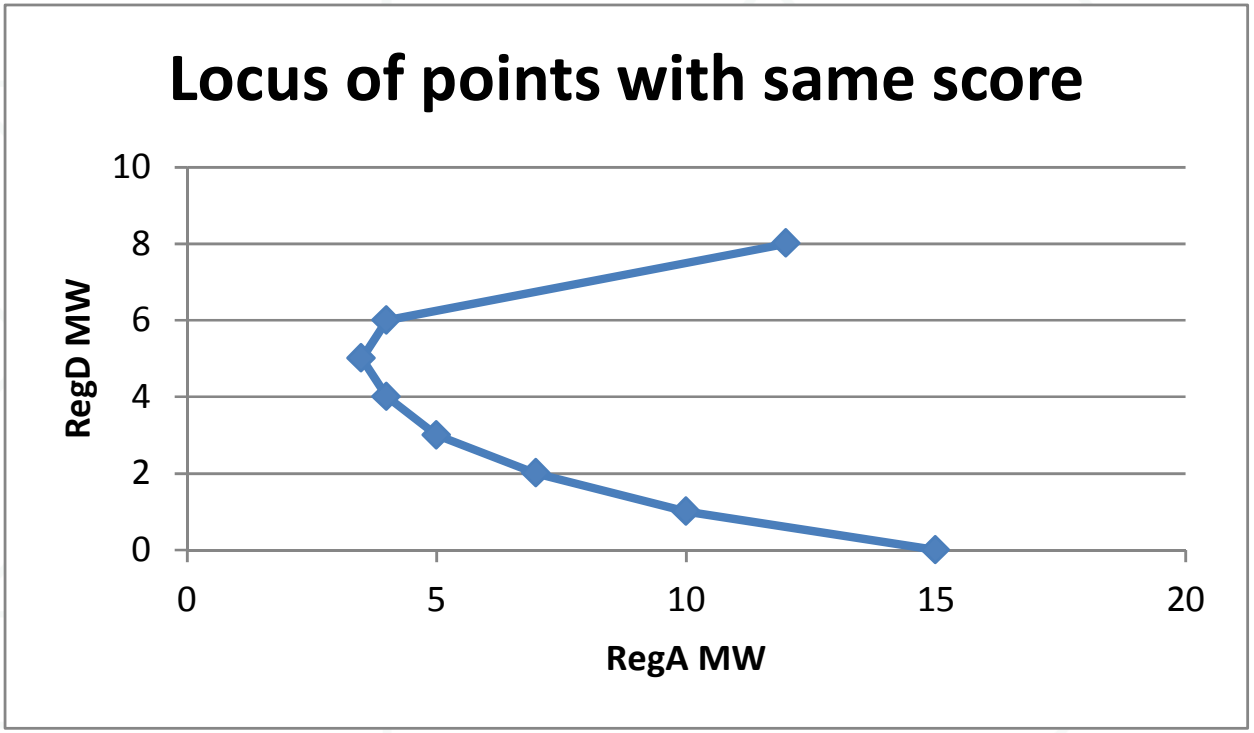
Example

Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor	Price of RegA ($/MW)	Price of RegD ($/MW)	RegD %	Reg %	Ratio PA/MBF of A	Ratio PD/MBF of D	Least Cost	TC (as optimized dual market)	MB in terms of Avoided $ of MW A	TC Using $/Effective MW	Min cost point
15	15	0		$15.00		0%	100%	$15.00		-	$225.00		$ 225.00	$55.00
15	10	1	5	$10.00	$10.00	9%	73%	$10.00	$ 2.00	-	$110.00	$ 50.00	$ 150.00	
15	7	2	3	$ 7.00	$10.00	22%	60%	$ 7.00	$ 3.33	-	$ 69.00	$ 21.00	$ 91.00	
15	5	3	2	$ 5.00	$10.00	38%	53%	$ 5.00	$ 5.00	yes	$ 55.00	$ 10.00	$ 55.00	
15	4	4	1	$ 4.00	$10.00	50%	53%	$ 4.00	$ 10.00	-	$ 56.00	$ 4.00	$ 80.00	
15	3.5	5	0.5	$ 3.50	$10.00	59%	57%	$ 3.50	$ 20.00	-	$ 62.25	$ 1.75	$ 120.00	
15	4	6	-0.5	$ 4.00	$10.00	60%	67%	$ 4.00	$ (20.00)	-	$ 76.00	$ (2.00)	$ 256.00	
15	12	8	-4	$12.00	$10.00	40%	133%	$12.00	$ (2.50)	-	$224.00	$(48.00)	$ 1,104.00	

How it works

Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor
15	15	0	
15	10	1	5
15	7	2	3
15	5	3	2
15	4	4	1
15	3.5	5	0.5
15	4	6	-0.5
15	12	8	-4



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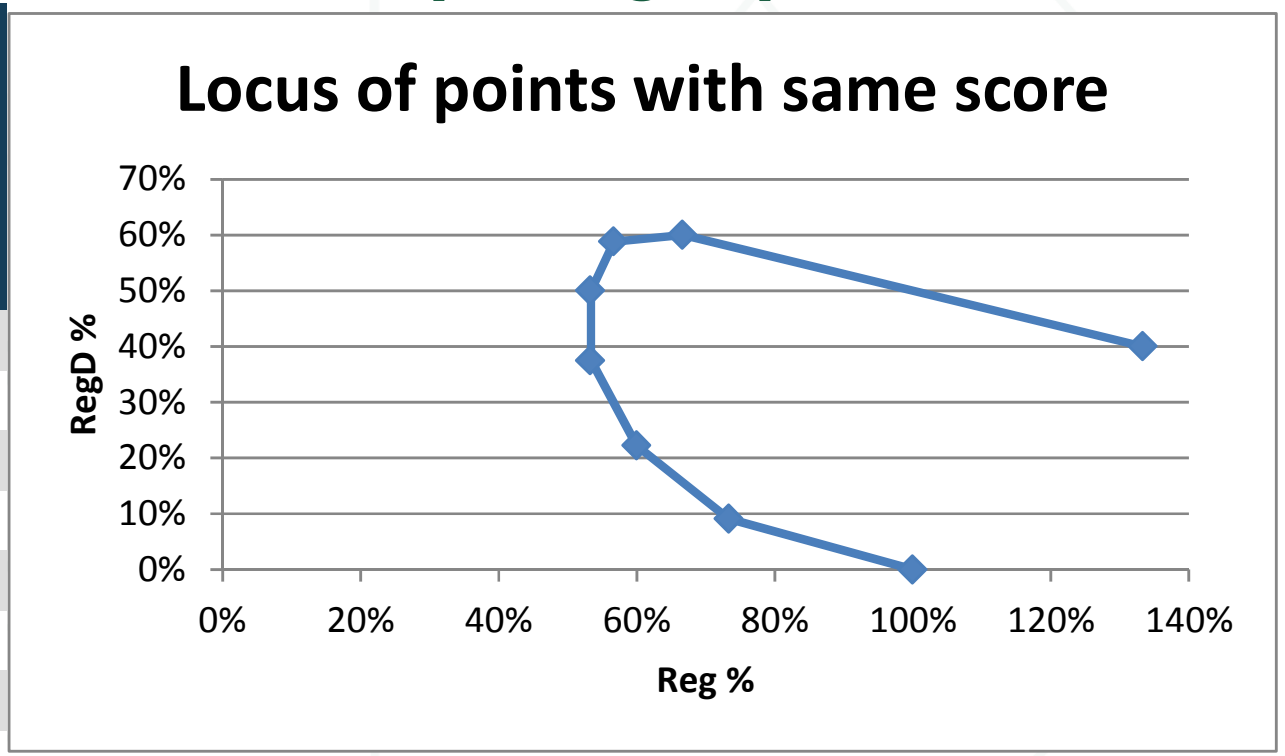
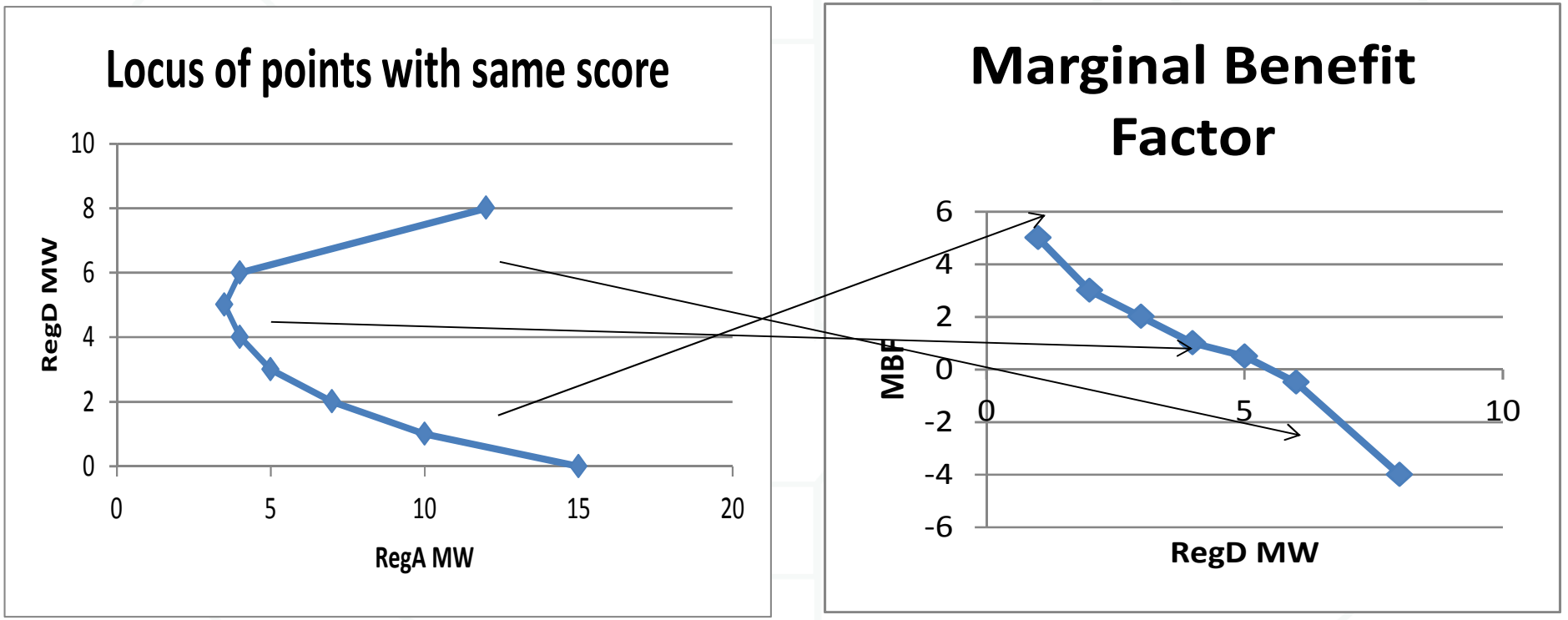
How it works (Using %)

Total Reg A Equivalent MW	RegD %	Reg %
15	0%	100%
15	9%	73%
15	22%	60%
15	38%	53%
15	50%	53%
15	59%	57%
15	60%	67%
15	40%	133%



Monitoring Analytics

Slope of curve = MBF at every point



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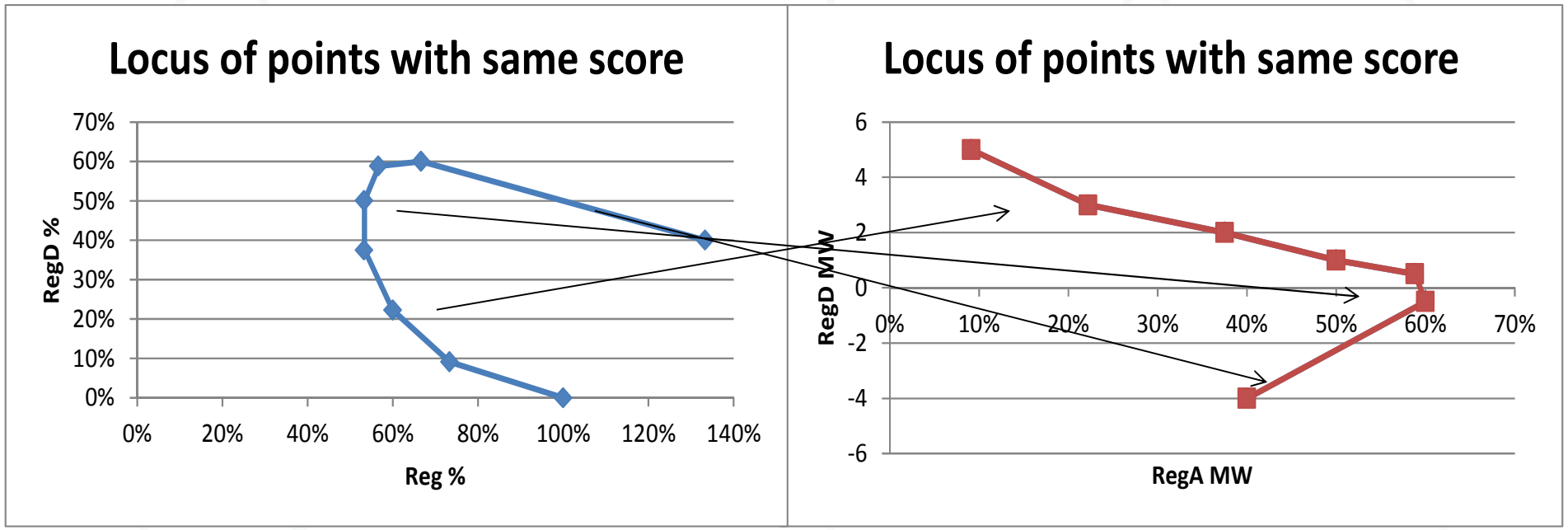

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How it works

Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor	Price of RegA ($/MW)	Price of RegD ($/MW)	RegD %	Reg %	Ratio PA/MBF of A	Ratio PD/MBF of D	Least Cost	TC (as optimized dual market)	MB in terms of Avoided $ of MW A	TC Using $/Effective MW	Min cost point
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15	7	2	3	$ 7.00	$10.00	22%	60%	$ 7.00	$ 3.33	-	$ 69.00	$ 21.00	$ 91.00	
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15	4	4	1	$ 4.00	$10.00	50%	53%	$ 4.00	$ 10.00	-	$ 56.00	$ 4.00	$ 80.00	
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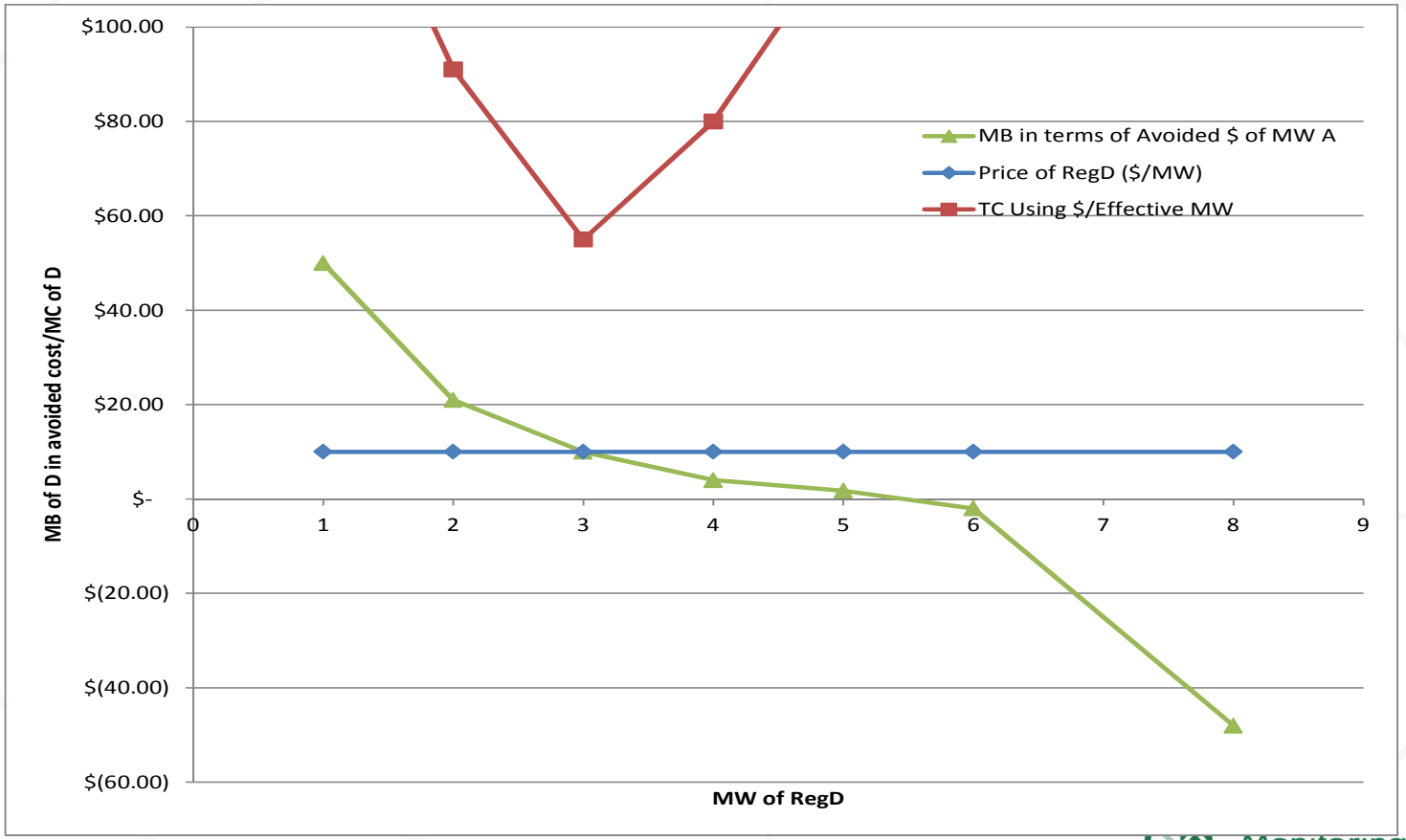
15	4	6	-0.5	$ 4.00	$10.00	60%	67%	$ 4.00	$ (20.00)	-	$ 76.00	$ (2.00)	$ 256.00	
15	12	8	-4	$12.00	$10.00	40%	133%	$12.00	$ (2.50)	-	$224.00	$(48.00)	$ 1,104.00	

Least Cost Solution



Price of $0

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15	7	2	3	$ 7.00	$ -	22%	60%	$ 7.00	$ -	-	$ 49.00	$ 21.00	$ 91.00	
15	5	3	2	$ 5.00	$ -	38%	53%	$ 5.00	$ -	-	$ 25.00	$ 10.00	$ 55.00	
15	4	4	1	$ 4.00	$ -	50%	53%	$ 4.00	$ -	-	$ 16.00	$ 4.00	$ 32.00	
15	3.5	5	0.5	$ 3.50	$ -	59%	57%	$ 3.50	$ -	-	$ 12.25	$ 1.75	$ 21.00	
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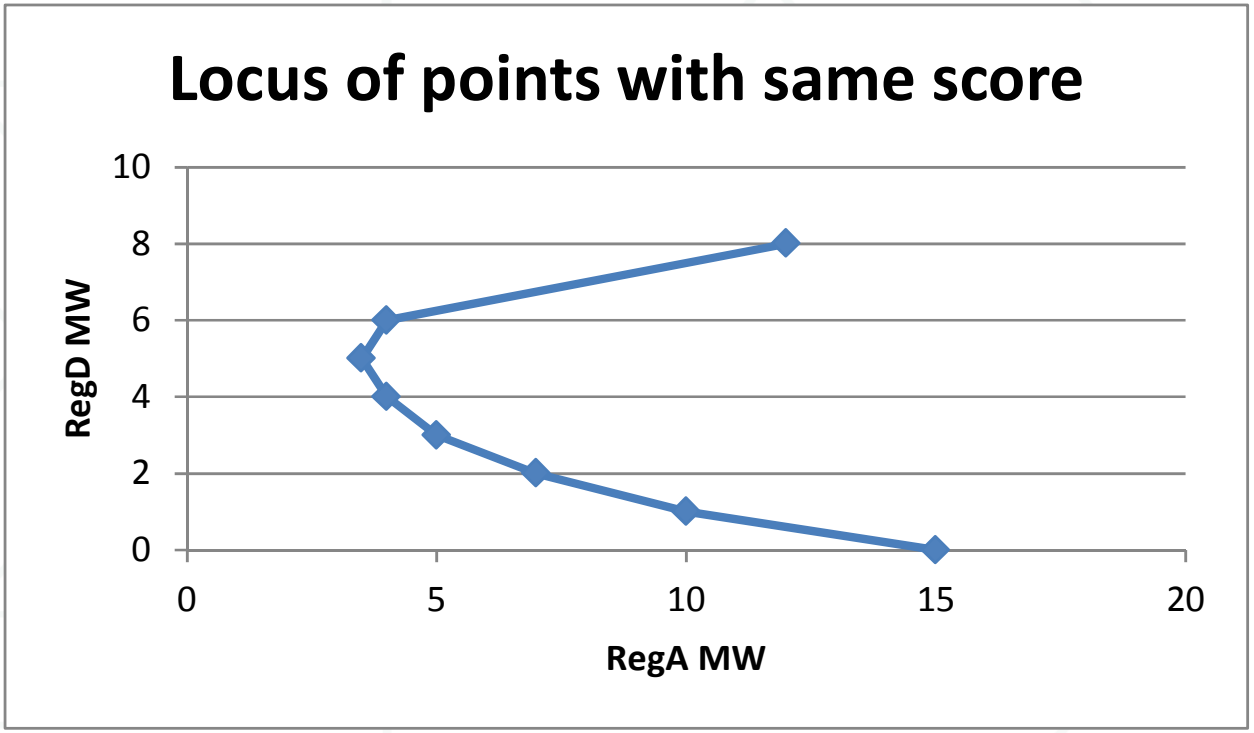

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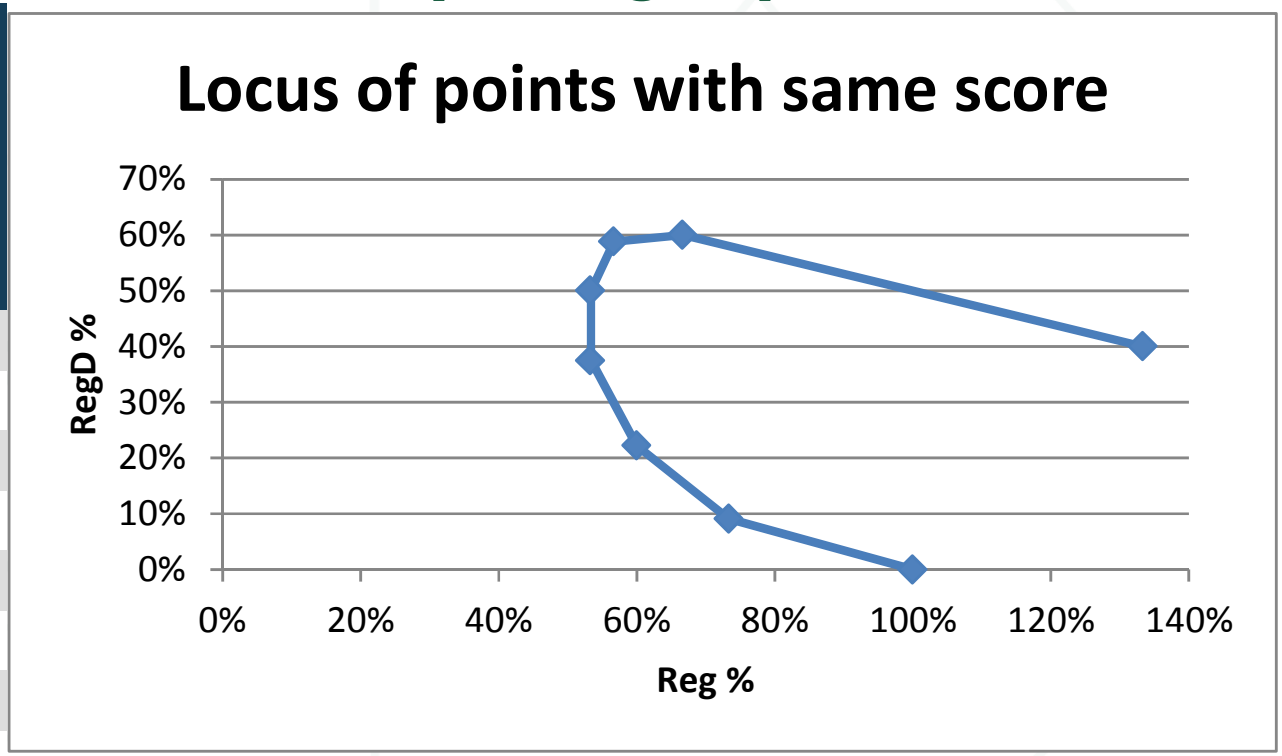

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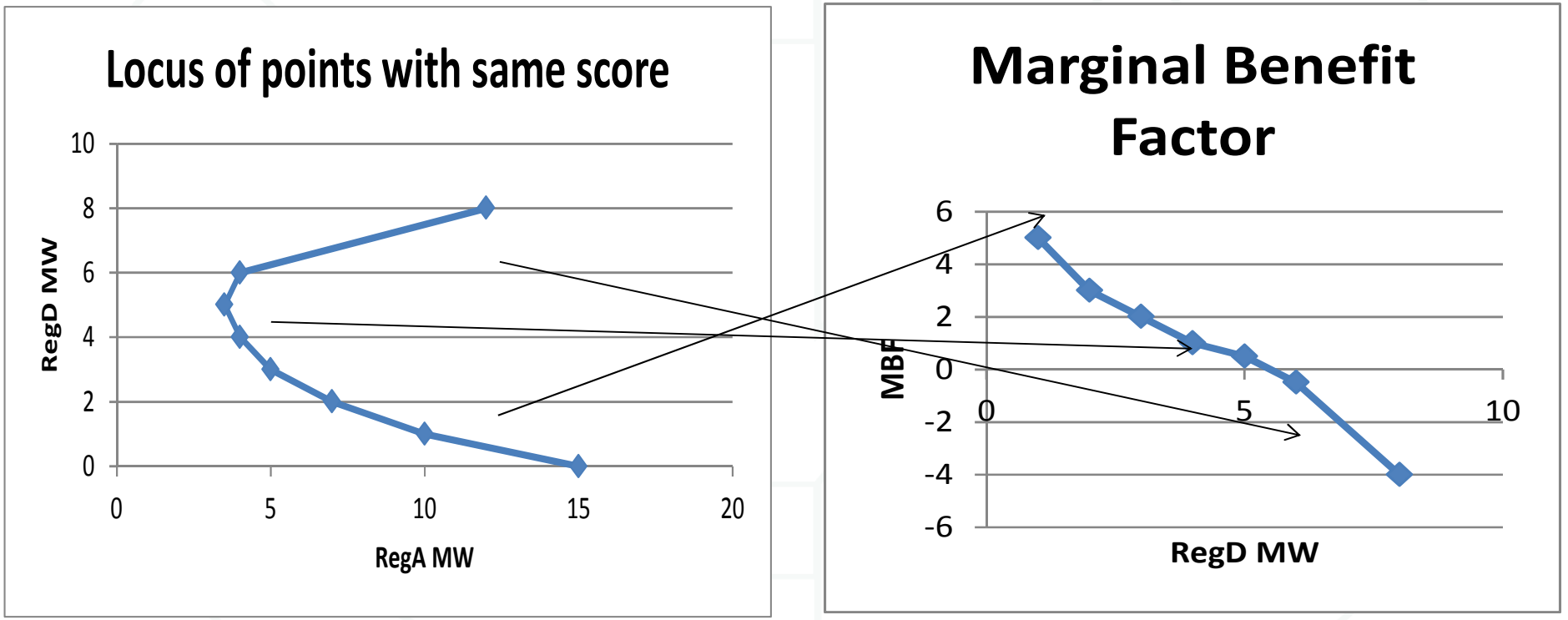

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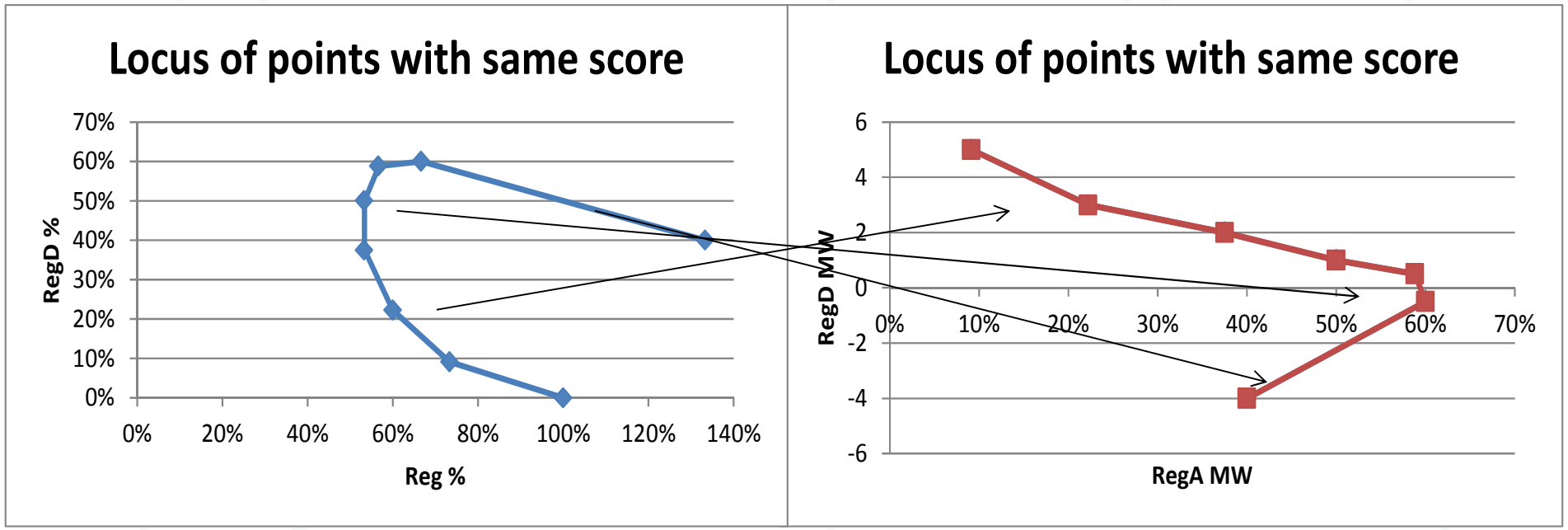

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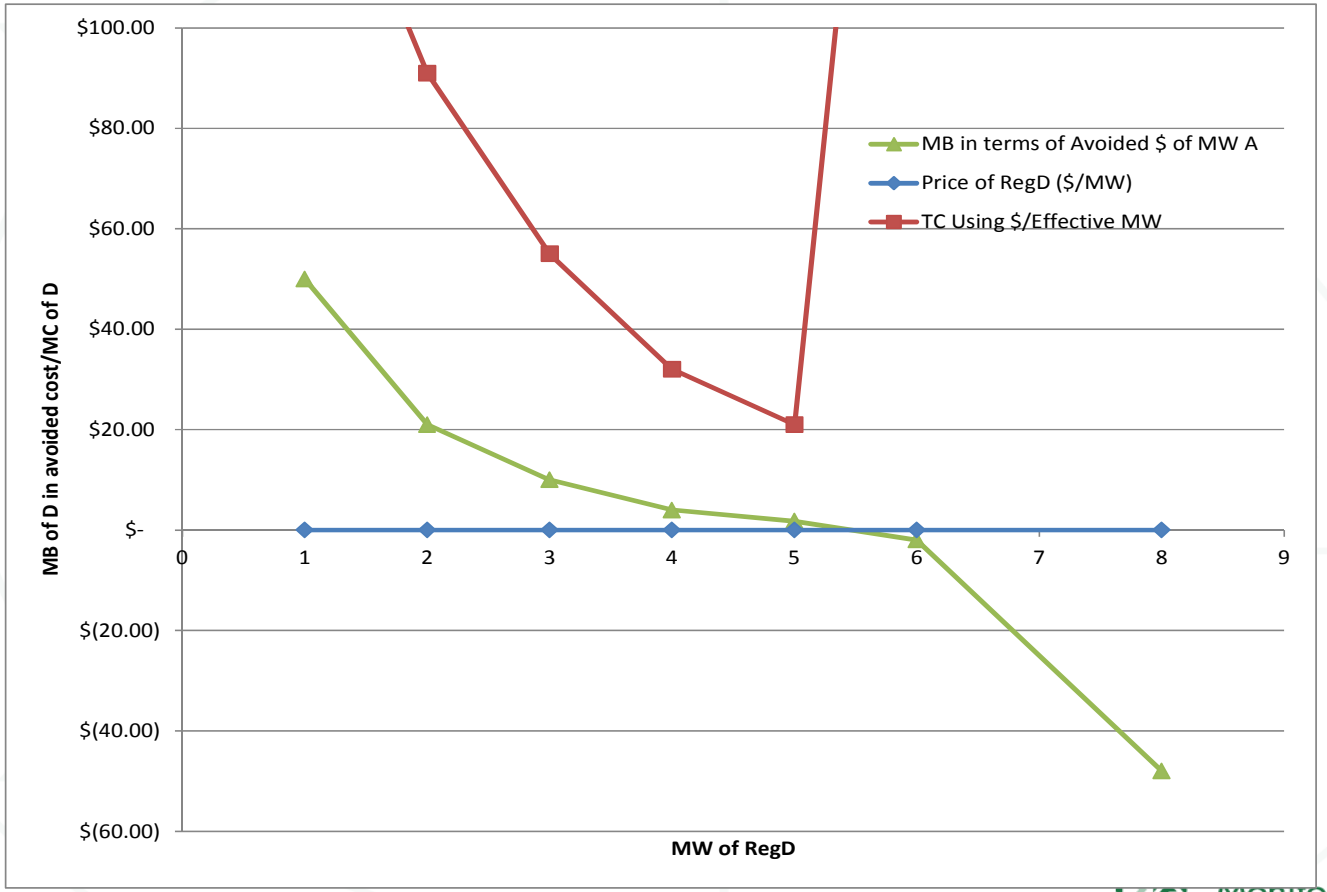
15	10	1	5	$10.00	$ -	9%	73%	$10.00	$ -	-	$100.00	$ 50.00	$ 150.00	
15	7	2	3	$ 7.00	$ -	22%	60%	$ 7.00	$ -	-	$ 49.00	$ 21.00	$ 91.00	
15	5	3	2	$ 5.00	$ -	38%	53%	$ 5.00	$ -	-	$ 25.00	$ 10.00	$ 55.00	
15	4	4	1	$ 4.00	$ -	50%	53%	$ 4.00	$ -	-	$ 16.00	$ 4.00	$ 32.00	
15	3.5	5	0.5	$ 3.50	$ -	59%	57%	$ 3.50	$ -	-	$ 12.25	$ 1.75	$ 21.00	
15	4	6	-0.5	$ 4.00	$ -	60%	67%	$ 4.00	$ -	-	$ 16.00	$ (2.00)	$ 256.00	
15	12	8	-4	$12.00	$ -	40%	133%	$12.00	$ -	-	$144.00	$(48.00)	$ 1,104.00	

Least Cost Solution

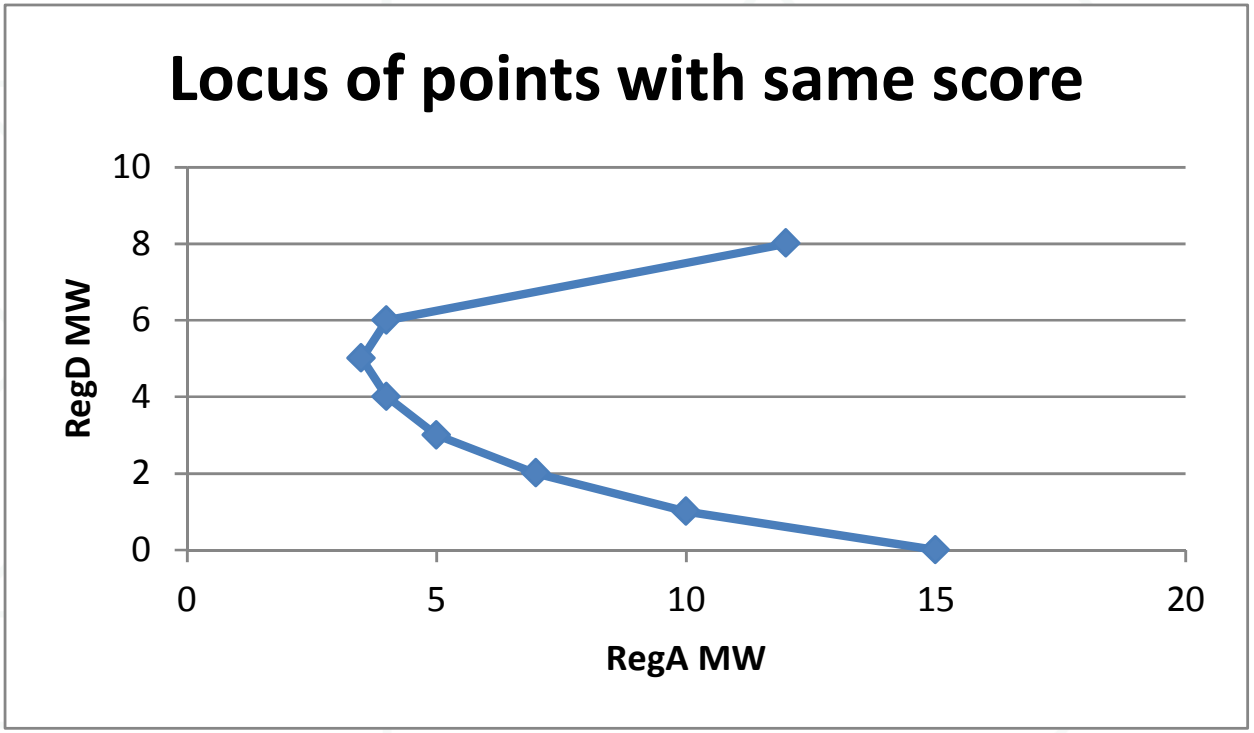


Price of $0 for RegA and RegD

Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor	Price of RegA ($/MW)	Price of RegD ($/MW)	RegD %	Reg %	Ratio PA/MBF of A	Ratio PD/MBF of D	Least Cost	TC (as optimized dual market)	MB in terms of Avoided $ of MW A	TC Using $/Effective MW	Min cost point
15	15	0		$ -		0%	100%	$ -		yes	$ -		$ -	$ -
15	10	1	5	$ -	$ -	9%	73%	$ -	$ -	yes	$ -	$ -	$ -	
15	7	2	3	$ -	$ -	22%	60%	$ -	$ -	yes	$ -	$ -	$ -	
15	5	3	2	$ -	$ -	38%	53%	$ -	$ -	yes	$ -	$ -	$ -	
15	4	4	1	$ -	$ -	50%	53%	$ -	$ -	yes	$ -	$ -	$ -	
15	3.5	5	0.5	$ -	$ -	59%	57%	$ -	$ -	yes	$ -	$ -	$ -	
15	4	6	-0.5	$ -	$ -	60%	67%	$ -	$ -	yes	$ -	$ -	$ -	
15	12	8	-4	$ -	$ -	40%	133%	$ -	$ -	yes	$ -	$ -	$ -	

How it works

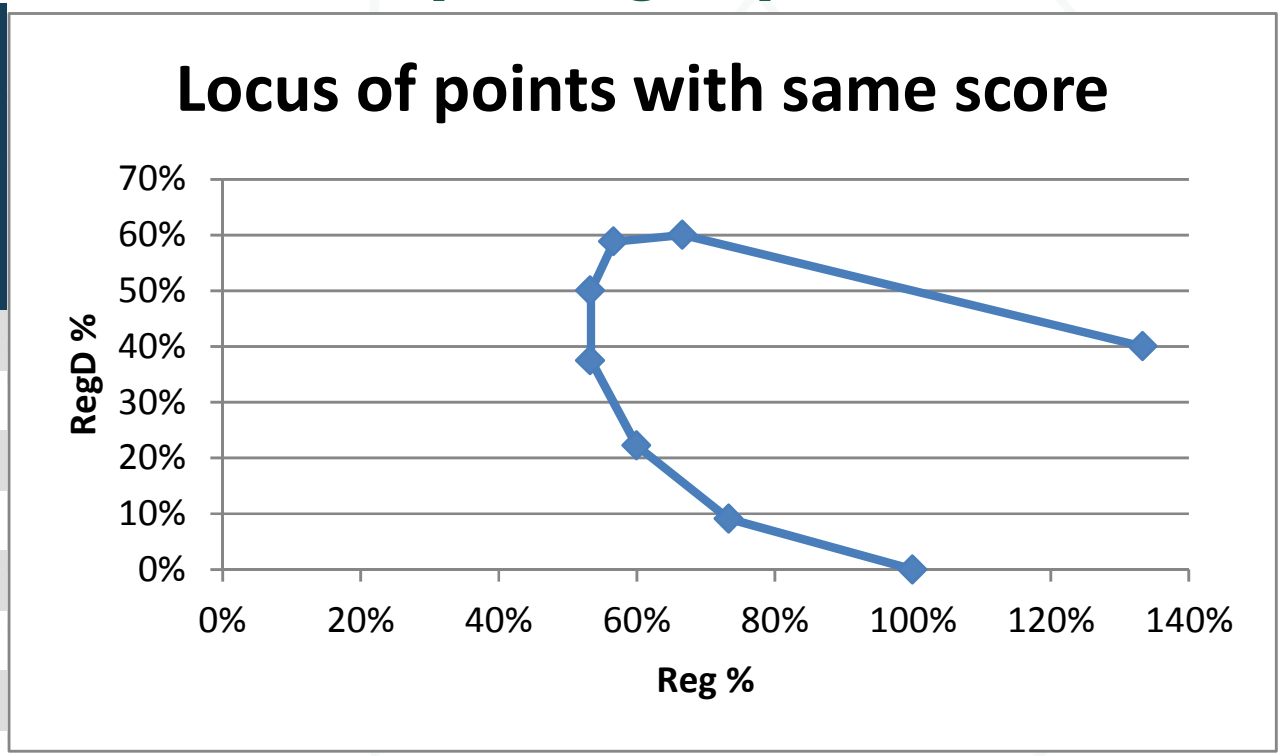
Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor
15	15	0	
15	10	1	5
15	7	2	3
15	5	3	2
15	4	4	1
15	3.5	5	0.5
15	4	6	-0.5
15	12	8	-4



Monitoring Analytics

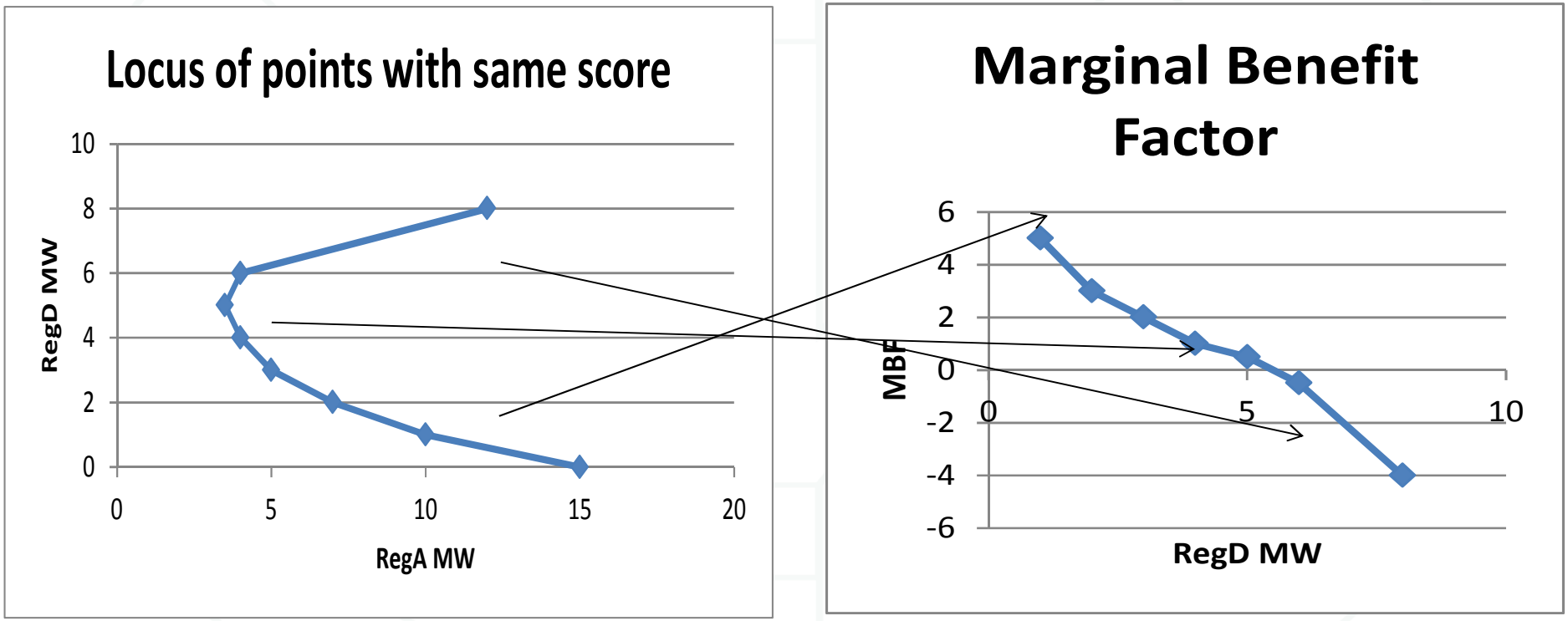
How it works (Using %)

Total Reg A Equivalent MW	RegD %	Reg %
15	0%	100%
15	9%	73%
15	22%	60%
15	38%	53%
15	50%	53%
15	59%	57%
15	60%	67%
15	40%	133%



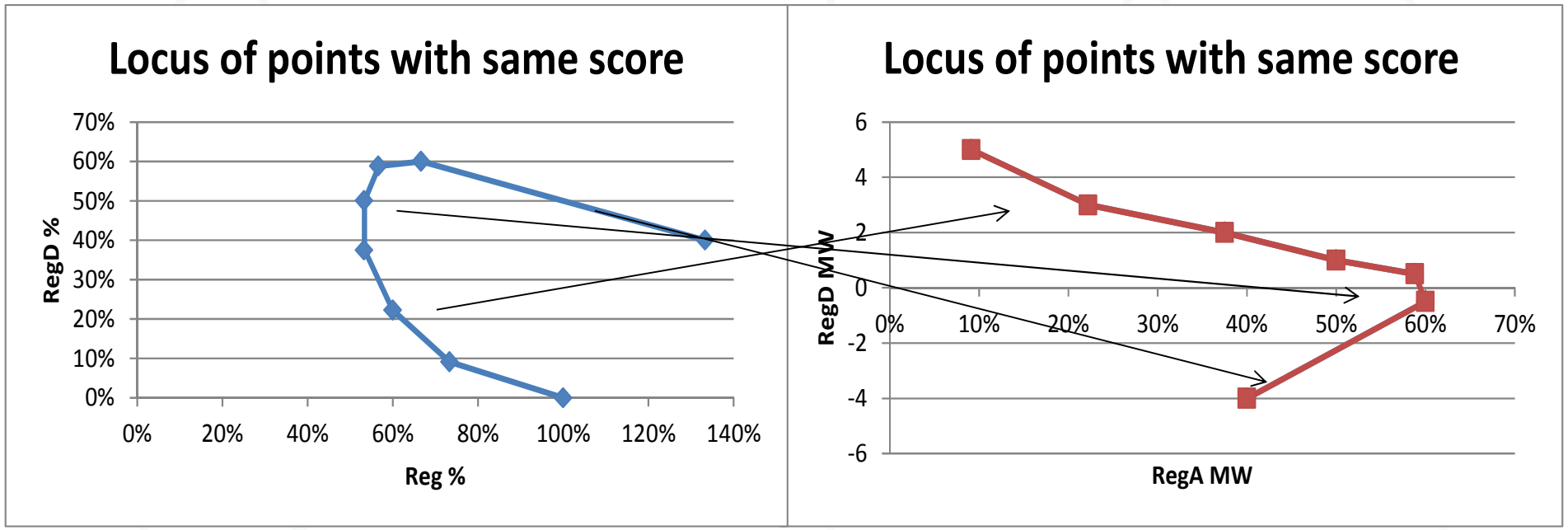
Monitoring Analytics

Slope of curve = MBF at every point



Monitoring Analytics

Slope of curve = MBF at every point

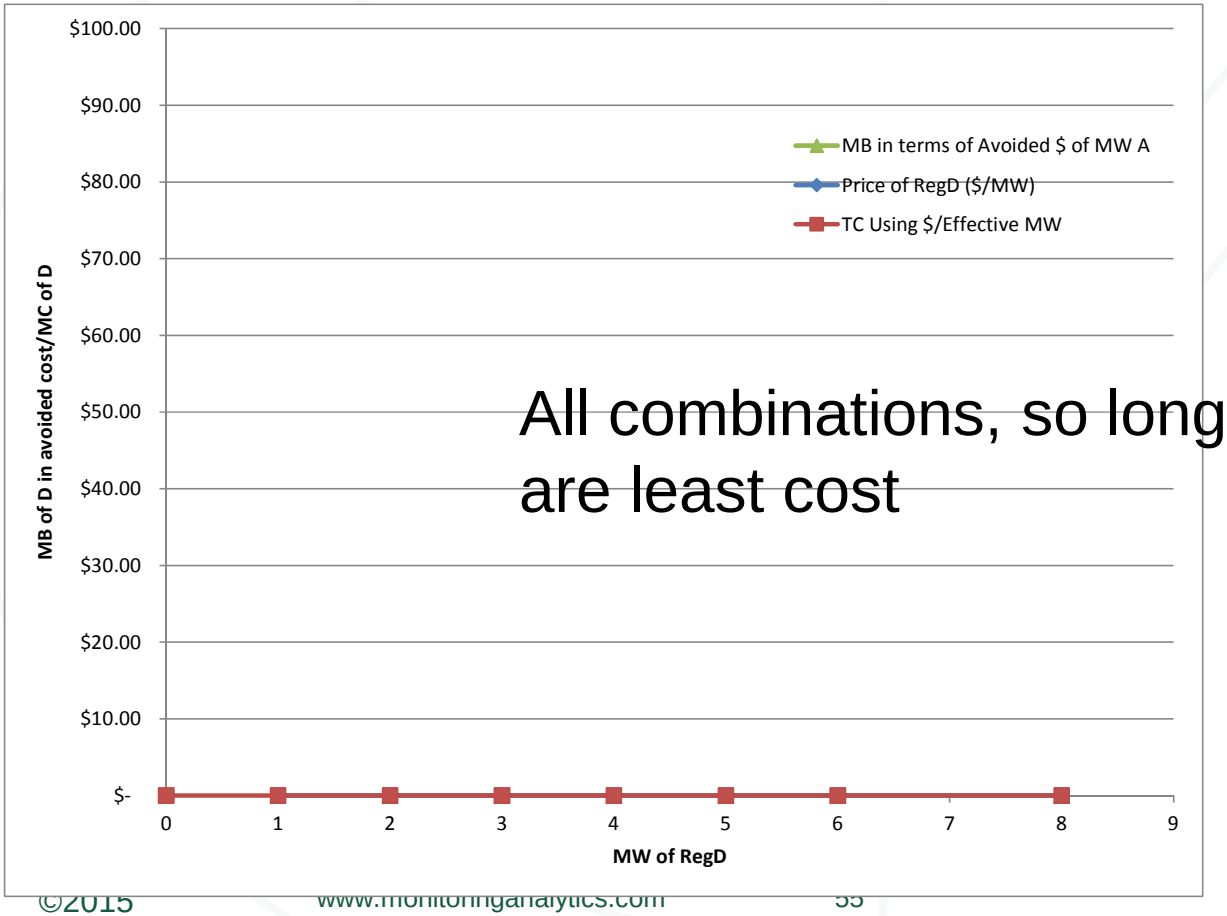


Monitoring Analytics

How it works

Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor	Price of RegA ($/MW)	Price of RegD ($/MW)	RegD %	Reg %	Ratio PA/MBF of A	Ratio PD/MBF of D	Least Cost	TC (as optimized dual market)	MB in terms of Avoided $ of MW A	TC Using $/Effective MW	Min cost point
15	15	0		$ -		0%	100%	$ -		yes	$ -		$ -	$ -
15	10	1	5	$ -	$ -	9%	73%	$ -	$ -	yes	$ -	$ -	$ -	
15	7	2	3	$ -	$ -	22%	60%	$ -	$ -	yes	$ -	$ -	$ -	
15	5	3	2	$ -	$ -	38%	53%	$ -	$ -	yes	$ -	$ -	$ -	
15	4	4	1	$ -	$ -	50%	53%	$ -	$ -	yes	$ -	$ -	$ -	
15	3.5	5	0.5	$ -	$ -	59%	57%	$ -	$ -	yes	$ -	$ -	$ -	
15	4	6	-0.5	$ -	$ -	60%	67%	$ -	$ -	yes	$ -	$ -	$ -	
15	12	8	-4	$ -	$ -	40%	133%	$ -	$ -	yes	$ -	$ -	$ -	

Least Cost Solution



All combinations, so long as feasible, are least cost

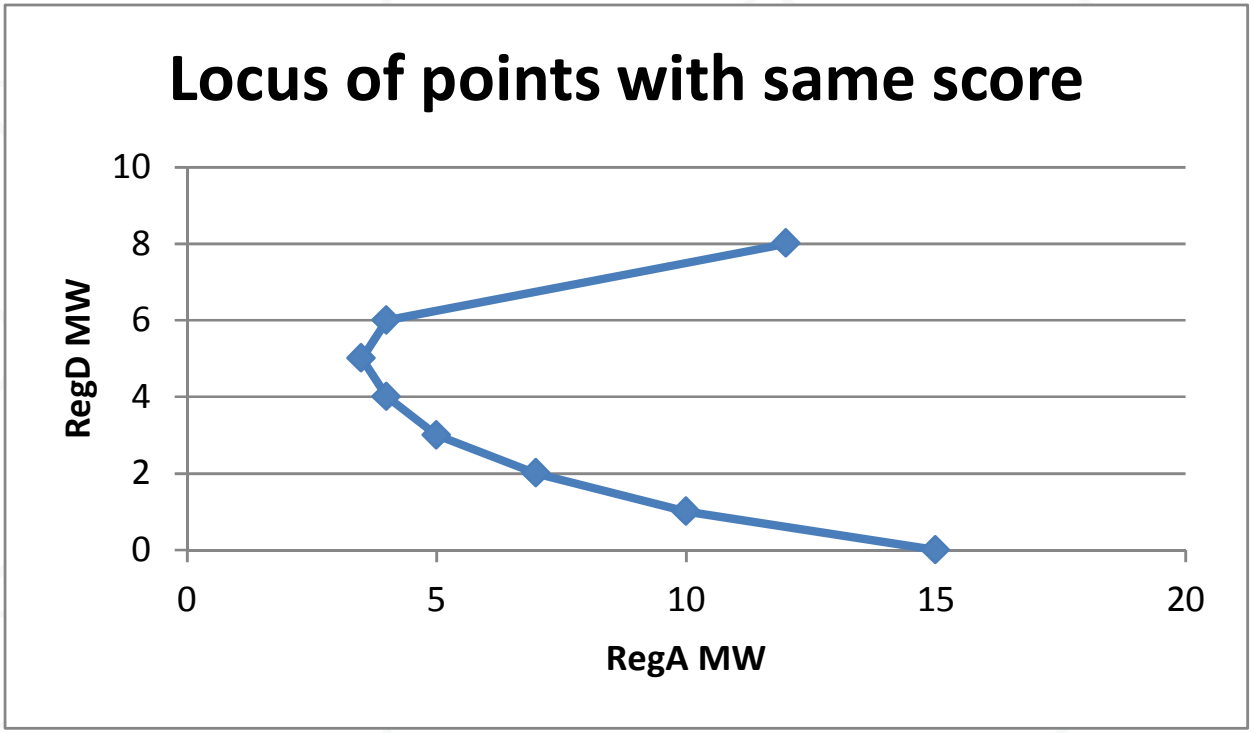
Monitoring Analytics

Price of $10 for RegA and $5 for RegD

Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor	Price of RegA ($/MW)	Price of RegD ($/MW)	RegD %	Reg %	Ratio PA/MBF of A	Ratio PD/MBF of D	Least Cost	TC (as optimized dual market)	MB in terms of Avoided $ of MW A	TC Using $/Effective MW	Min cost point
15	15	0		$10.00		0%	100%	$10.00		-	$150.00		$ 150.00	$60.00
15	10	1	5	$10.00	$ 5.00	9%	73%	$10.00	$ 1.00	-	$105.00	$ 50.00	$ 150.00	
15	7	2	3	$10.00	$ 5.00	22%	60%	$10.00	$ 1.67	-	$ 80.00	$ 30.00	$ 130.00	
15	5	3	2	$10.00	$ 5.00	38%	53%	$10.00	$ 2.50	-	$ 65.00	$ 20.00	$ 110.00	
15	4	4	1	$10.00	$ 5.00	50%	53%	$10.00	$ 5.00	-	$ 60.00	$ 10.00	$ 80.00	
15	3.5	5	0.5	$10.00	$ 5.00	59%	57%	$10.00	$ 10.00	yes	$ 60.00	$ 5.00	$ 60.00	
15	4	6	-0.5	$10.00	$ 5.00	60%	67%	$10.00	$ (10.00)	-	$ 70.00	$ (5.00)	$ 640.00	
15	12	8	-4	$10.00	$ 5.00	40%	133%	$10.00	$ (1.25)	-	$160.00	$(40.00)	$ 920.00	

How it works

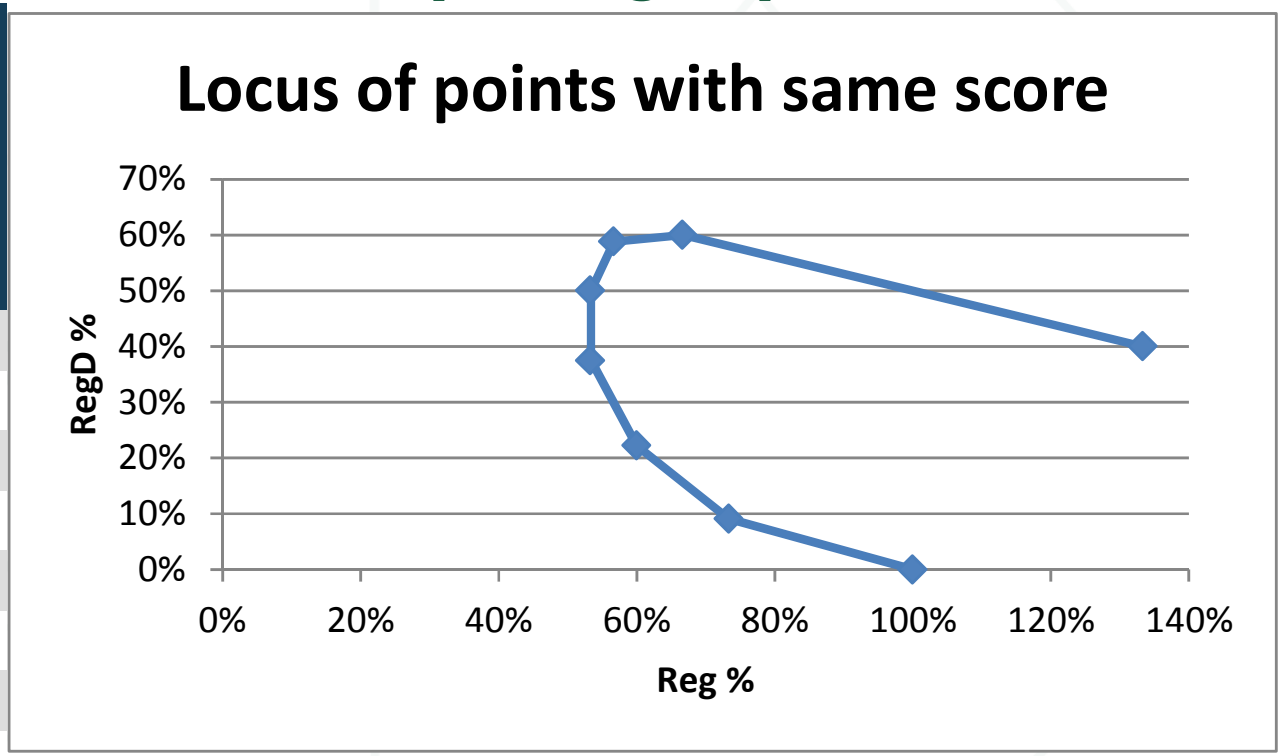
Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor
15	15	0	
15	10	1	5
15	7	2	3
15	5	3	2
15	4	4	1
15	3.5	5	0.5
15	4	6	-0.5
15	12	8	-4



Monitoring Analytics

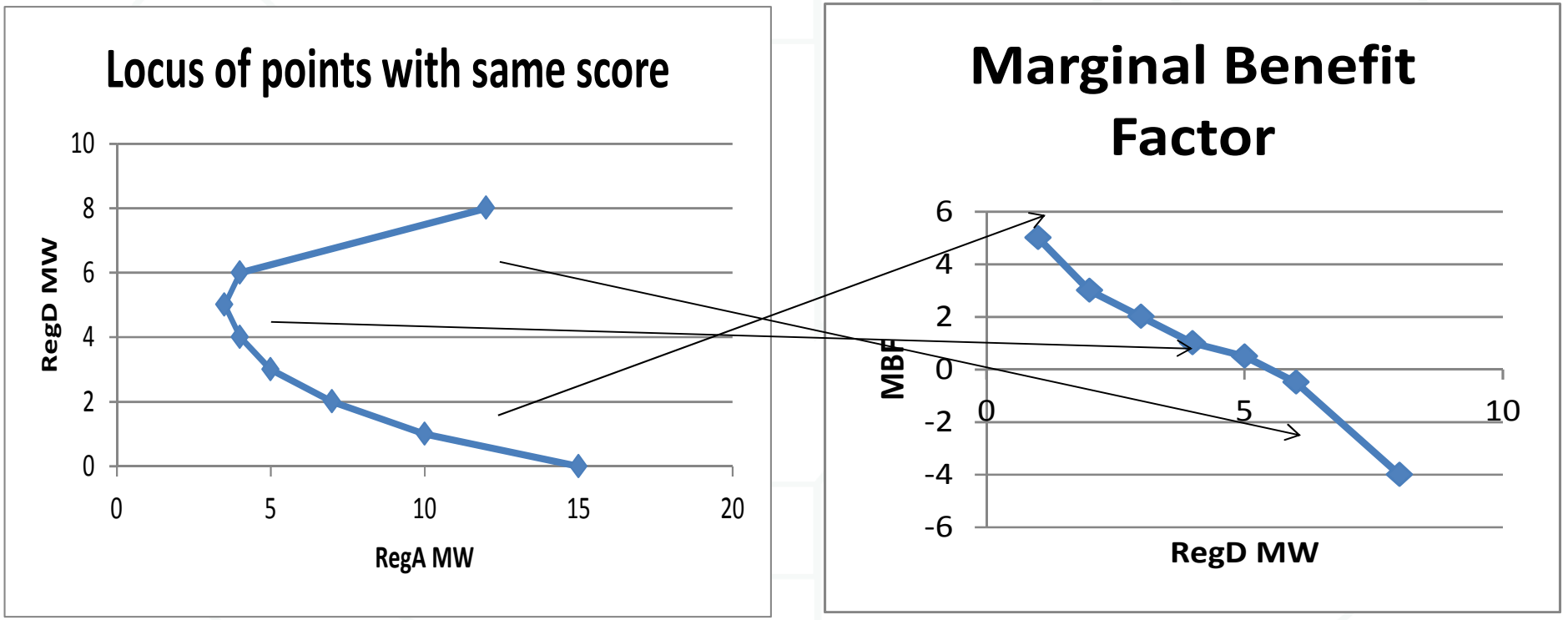
How it works (Using %)

Total Reg A Equivalent MW	RegD %	Reg %
15	0%	100%
15	9%	73%
15	22%	60%
15	38%	53%
15	50%	53%
15	59%	57%
15	60%	67%
15	40%	133%



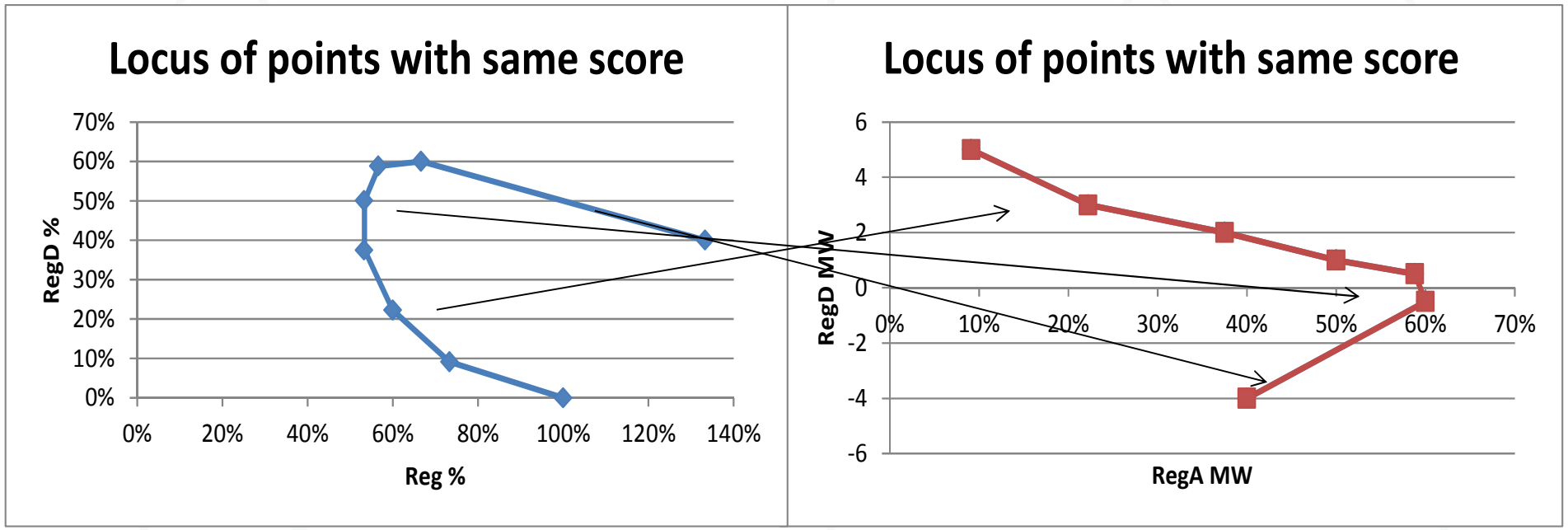
Monitoring Analytics

Slope of curve = MBF at every point



Monitoring Analytics

Slope of curve = MBF at every point



Monitoring Analytics

How it works

Total Reg A Equivalent MW	RegA MW	RegD MW	Marginal Benefit Factor	Price of RegA ($/MW)	Price of RegD ($/MW)	RegD %	Reg %	Ratio PA/MBF of A	Ratio PD/MBF of D	Least Cost	TC (as optimized dual market)	MB in terms of Avoided $ of MW A	TC Using $/Effective MW	Min cost point
15	15	0		$10.00		0%	100%	$10.00		-	$150.00		$ 150.00	$60.00
15	10	1	5	$10.00	$ 5.00	9%	73%	$10.00	$ 1.00	-	$105.00	$ 50.00	$ 150.00	
15	7	2	3	$10.00	$ 5.00	22%	60%	$10.00	$ 1.67	-	$ 80.00	$ 30.00	$ 130.00	
15	5	3	2	$10.00	$ 5.00	38%	53%	$10.00	$ 2.50	-	$ 65.00	$ 20.00	$ 110.00	
15	4	4	1	$10.00	$ 5.00	50%	53%	$10.00	$ 5.00	-	$ 60.00	$ 10.00	$ 80.00	
15	3.5	5	0.5	$10.00	$ 5.00	59%	57%	$10.00	$ 10.00	yes	$ 60.00	$ 5.00	$ 60.00	
15	4	6	-0.5	$10.00	$ 5.00	60%	67%	$10.00	$ (10.00)	-	$ 70.00	$ (5.00)	$ 640.00	
15	12	8	-4	$10.00	$ 5.00	40%	133%	$10.00	$ (1.25)	-	$160.00	$(40.00)	$ 920.00	

Least Cost Solution