Regulation Market Issues

RMISTF

October 16, 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

- **Potentially incorrectly defined marginal benefit factor function (MBF)**
  - **Evidence that MBF between RegA and RegD is incorrectly defined.**
- **Incorrectly applying the MBF in the optimization**
  - **MBF use not consistent with derivation.**
  - **Inefficient displacement of RegA MW.**
  - **Incorrect calculation of contribution of RegD to total effective regulation.**
- **MBF inconsistently used in pricing and settlement**
  - **Assumes MBF in offers/price but not settlement**

Effect of Current Design

- **Incorrectly defined marginal benefit factor function (MBF)**
  - **Causing incorrect/inefficient combinations of RegA and RegD to clear the market**
  - **Adversely affecting ACE control in some hours**

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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**
  - **Too much total regulation MW clearing**

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**

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Effect of Current Design

- **MBF not consistently used in pricing and settlement**
  - **When MBF is <1 (RegD MW contribution per incremental MW < RegA MW contribution per incremental 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**

Effect of Current Design

- **LOC calculated on the lower of price or cost schedule, not the operational schedule.**
  - **Marginal costs for lost energy to provide regulation not consistent with marginal costs to provide energy**
  - **Inefficient market result (price <> actual incremental offers)**

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Correcting Current Market Design

- Determine correct BF/MBF function
  - Determine correct BF (RTS) between RegA and RegD.
- Align BF/MBF definition with application in optimization
  - Correct RegD/RegA amount and proportions in market solution
- Consistent application of BF/MBF throughout construct: optimization to settlement
  - Price and compensate on equivalent terms

Correcting Current Market Design

- **Address LOC issue.**

Benefit Factor (MBF/BF) Derivation/Definition/Issues

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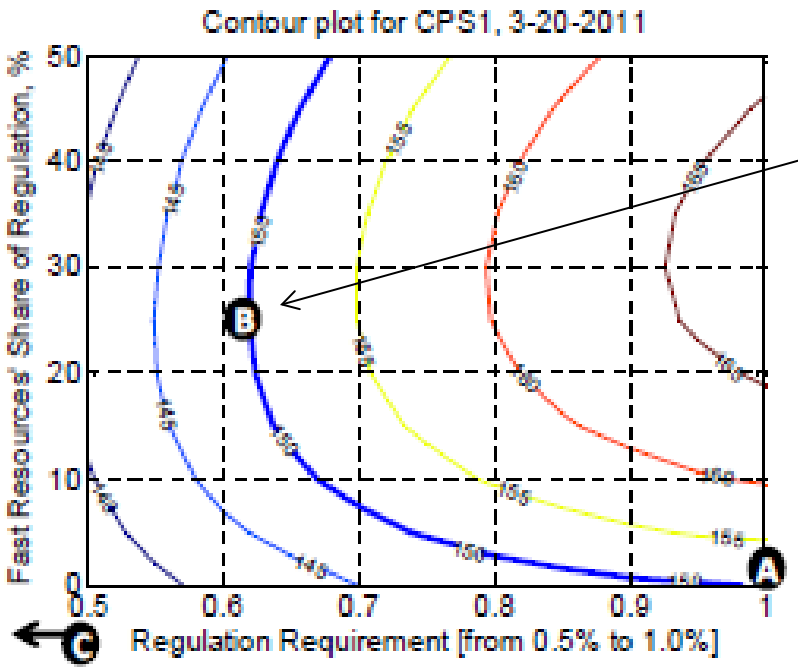
KEMA Study

- **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.**
- **Evidence that a single curve is not optimal.**
- **Related Issue: Use within optimization inconsistent with derivation/definition.**

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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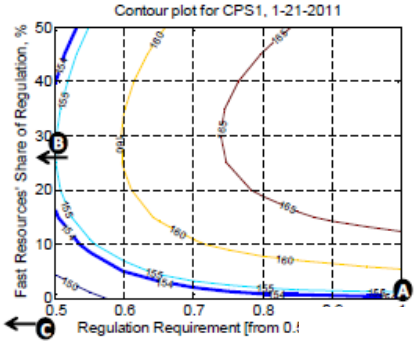
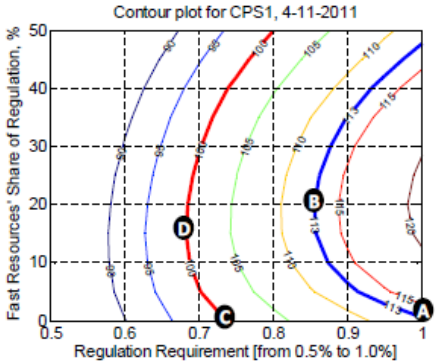
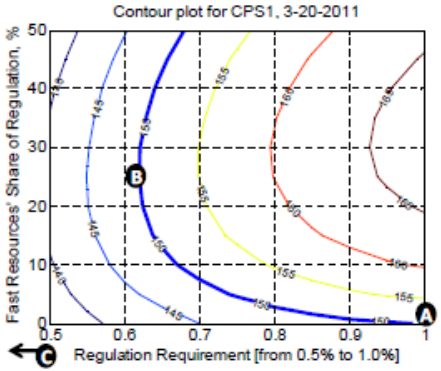
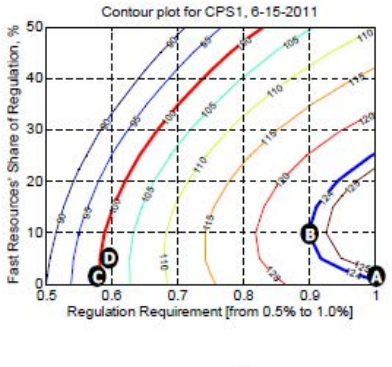
MBF varies with system conditions









Combinations of RegA and RegD that provide the same CPS1 Scores

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Benefit Factor (MBF/BF) Implementation Issues: Optimization/Market Clearing

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Current Design

- **Incorrectly applying the MBF in the optimization**
  - **Incorrect calculation of contribution of RegD to total effective regulation.**
- **BF of the last MW (of the last unit) of a price block assigned to every MW of every unit of that price block for purposes of effective MW calculations.**
  - **Under estimates effective MW from RegD assigned.**
- **BF of the last MW of a unit assigned to every MW of every unit of that unit for purposes of effective MW calculations.**
  - **Under estimates effective MW from RegD assigned.**

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Benefit Factor (MBF/BF) Implementation Issues: 1. Incorrect Calculation of Effective MW (assuming BF curve properly defined)

Monitoring Analytics

Current Design

- **Issue 1: MBF of the last MW (of the last unit) of a price block is assigned to every MW of every unit of that price block for purposes of effective MW calculations.**
  - **Addressed (in part) in current proposal before the MRC.**
  - **Break block up into discrete unit MW.**
- **Issue 2: MBF of the last MW of a unit assigned to every MW of every unit of that unit for purposes of effective MW calculations.**
  - **Not addressed yet.**

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Current Design

- **Issue 1: MBF of the last MW (of the last unit) of a price block is assigned to every MW of every unit of that price block for purposes of effective MW calculations.**

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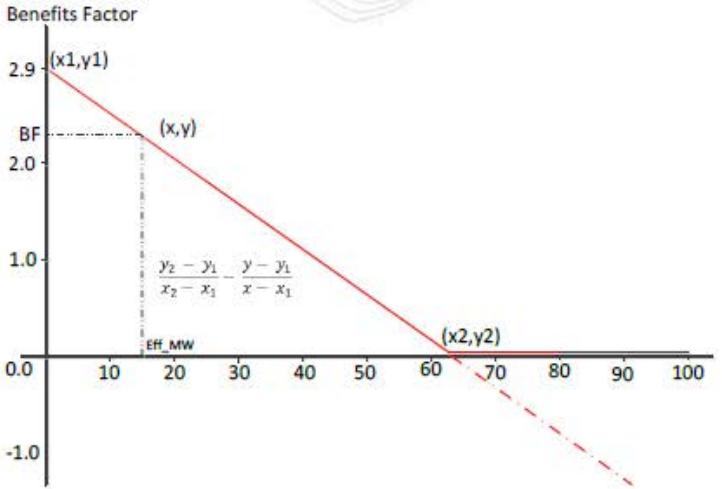
PJM Current Approach

- Resource specific benefits factor determination
  - The BF is the intersection on the Y (BF) axis of the corresponding rolling effective MW on the X (percentage RegD) axis
  - The slope equation is:



$$BF_i = \frac{EffMW_i * (0.0001 - 2.9)}{Percentage\ RegD * RegReq} + 2.9$$

BF=2.9-((rise)/(run))*RegDMW

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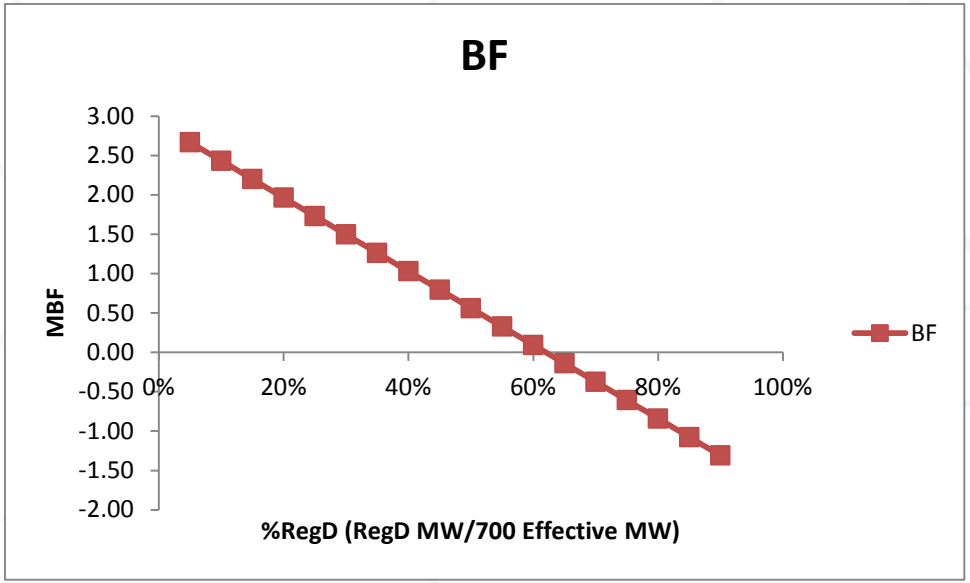
PJM current approach effective MW calculations

RegD% /700	RegD MW	BF
5%	35	2.67
10%	70	2.43
15%	105	2.20
20%	140	1.96
25%	175	1.73
30%	210	1.50
35%	245	1.26
40%	280	1.03
45%	315	0.80



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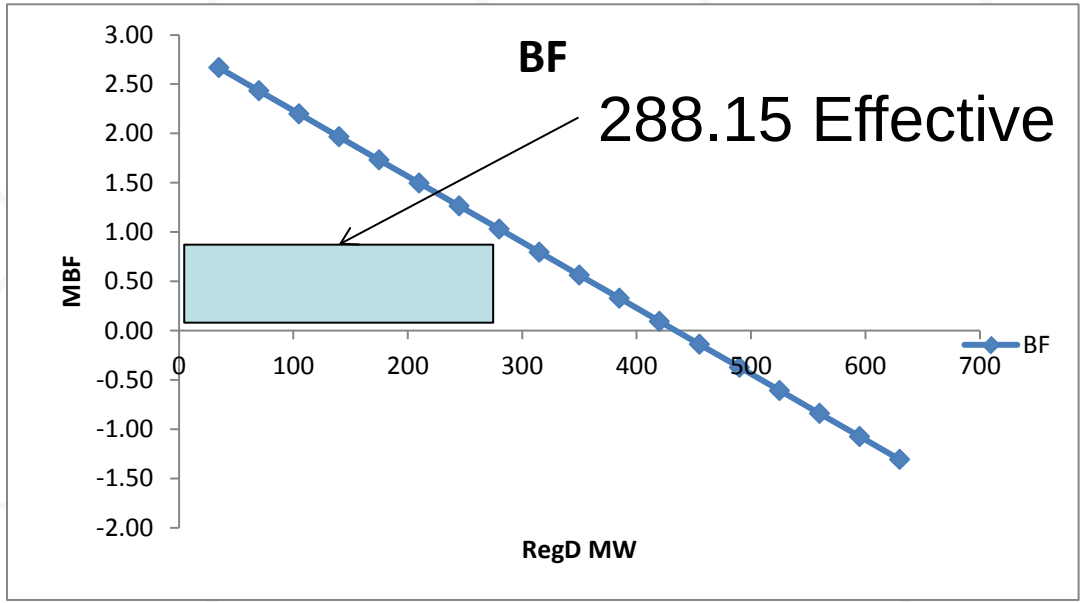
PJM current approach effective MW calculations

RegD% /700	RegD MW	BF	PJM Effective Calculation (1 unit at each point)
5%	35	2.67	93.31
10%	70	2.43	170.26
15%	105	2.20	230.83
20%	140	1.96	275.04
25%	175	1.73	302.87
30%	210	1.50	314.33
35%	245	1.26	309.43
40%	280	1.03	288.15
45%	315	0.80	250.50



280 MW from 8 units offered at $0 treated as 1 unit for BF assignment

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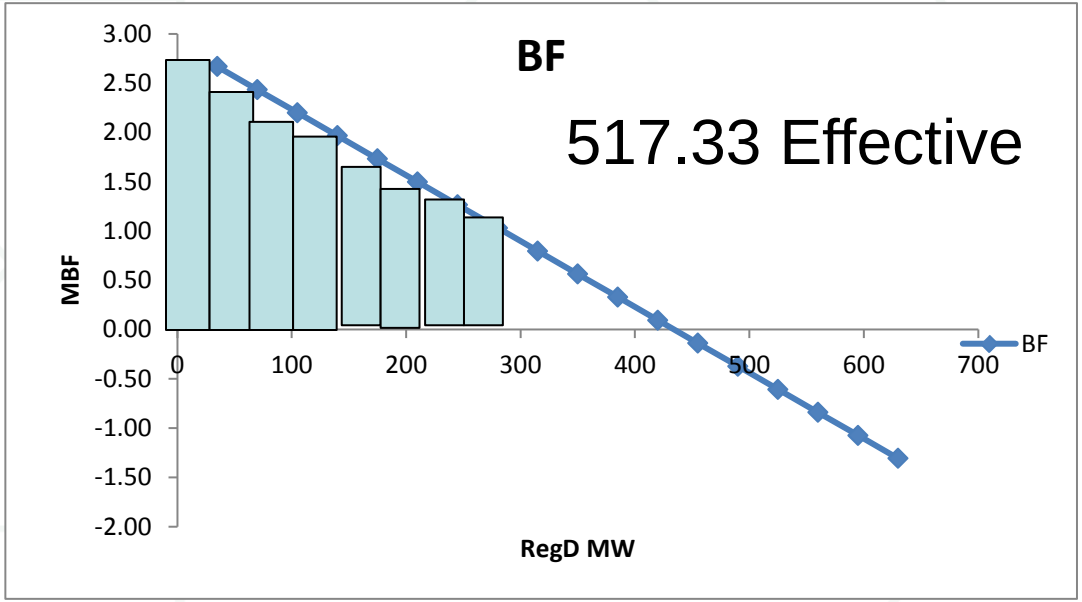
MRC Proposed approach for effective MW calculations

RegD% /700	RegD MW	BF	MW by Unit	PJM Effective Calculation (1 unit at each point)	Unit Specific Effective MW (PJM)	Cumulative Effective MW (PJM)
5%	35	2.67	35	93.31	93.31	93.31
10%	70	2.43	35	170.26	85.13	178.44
15%	105	2.20	35	230.83	76.94	255.39
20%	140	1.96	35	275.04	68.76	324.15
25%	175	1.73	35	302.87	60.57	384.72
30%	210	1.50	35	314.33	52.39	437.11
35%	245	1.26	35	309.43	44.20	481.31
40%	280	1.03	35	288.15	36.02	517.33
45%	315	0.80	35	250.50	27.83	545.17



280 MW from 8 units (35 MW blocks) offered at $0 treated as 8 unit for BF assignment

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Current Design

- **Note, as more units added, closer to approximating the area under the curve.**
  - **Getting closer to correctly calculating the contribution of RegD to total effective regulation.**

- **Properly defined, the area under the MBF function defines effective MW for a set of MW.**

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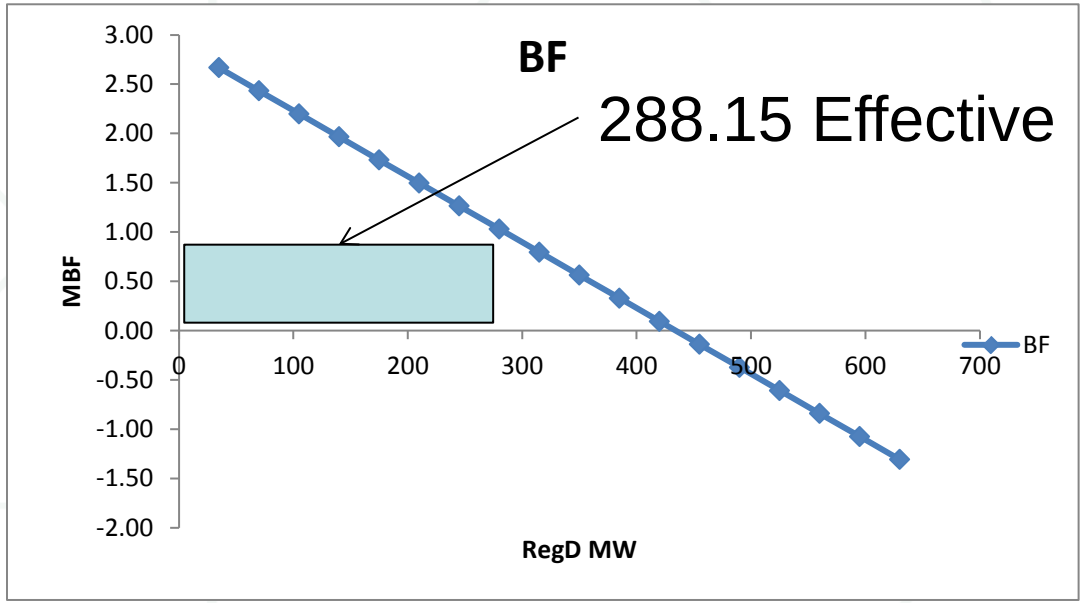
Issues with the Current Design

- **Issue 2: BF of the last MW of a unit assigned to every MW of every unit of that unit for purposes of effective MW calculations.**
  - **Underestimates effective MW from RegD MW assigned.**

Monitoring Analytics

PJM current approach to effective MW calculations

RegD% /700	RegD MW	BF	PJM Effective Calculation (1 unit at each point)
5%	35	2.67	93.31
10%	70	2.43	170.26
15%	105	2.20	230.83
20%	140	1.96	275.04
25%	175	1.73	302.87
30%	210	1.50	314.33
35%	245	1.26	309.43
40%	280	1.03	288.15
45%	315	0.80	250.50



280 MW from 1 unit provides 288.15 Effective MW

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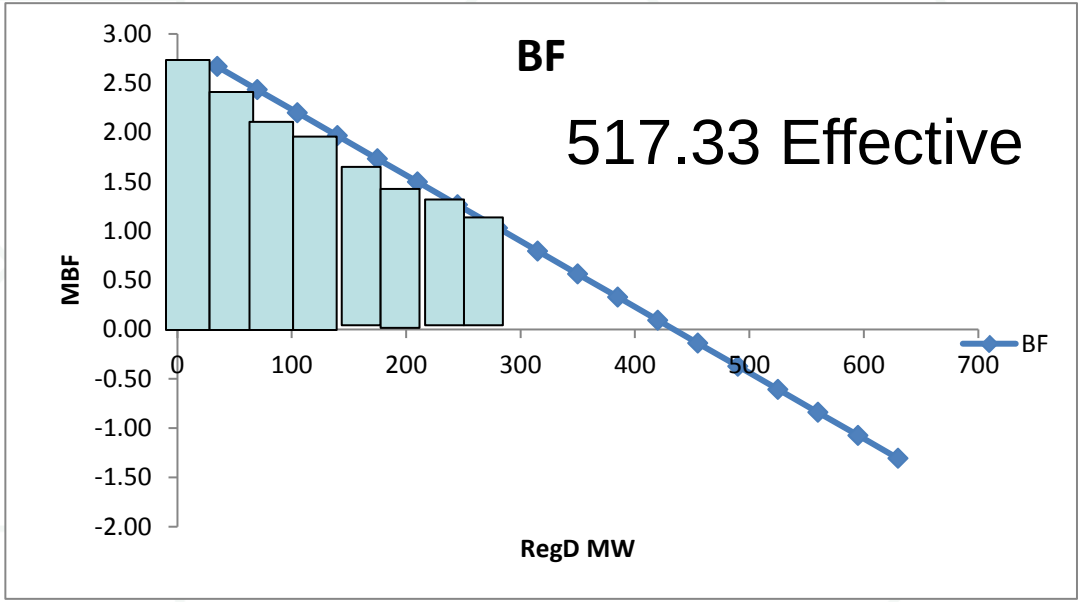
PJM current approach: The smaller the unit size, the closer effective equals area under curve

RegD% /700	RegD MW	BF	MW by Unit	PJM Effective Calculation (1 unit at each point)	Unit Specific Effective MW (PJM)	Cumulative Effective MW (PJM)
5%	35	2.67	35	93.31	93.31	93.31
10%	70	2.43	35	170.26	85.13	178.44
15%	105	2.20	35	230.83	76.94	255.39
20%	140	1.96	35	275.04	68.76	324.15
25%	175	1.73	35	302.87	60.57	384.72
30%	210	1.50	35	314.33	52.39	437.11
35%	245	1.26	35	309.43	44.20	481.31
40%	280	1.03	35	288.15	36.02	517.33
45%	315	0.80	35	250.50	27.83	545.17



280 MW from 8 units (35 MW blocks) treated as 8 unit for BF assignment

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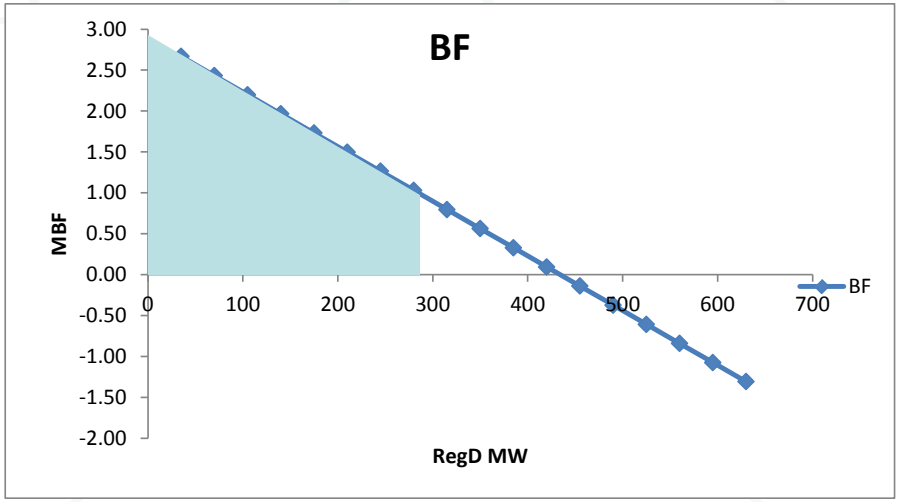
Should be area under curve

RegD% /700	RegD MW	BF	MW by Unit	PJM Effective Calculation (1 unit at each point)	Unit Specific Effective MW (PJM)	Cumulative Effective MW (PJM)	Area Under the Curve Effective MW
5%	35	2.67	35	93.31	93.31	93.31	97.41
10%	70	2.43	35	170.26	85.13	178.44	186.63
15%	105	2.20	35	230.83	76.94	255.39	267.67
20%	140	1.96	35	275.04	68.76	324.15	340.52
25%	175	1.73	35	302.87	60.57	384.72	405.18
30%	210	1.50	35	314.33	52.39	437.11	461.67
35%	245	1.26	35	309.43	44.20	481.31	509.96
40%	280	1.03	35	288.15	36.02	517.33	550.07
45%	315	0.80	35	250.50	27.83	545.17	582.00



Area under curve = 550.07 MW

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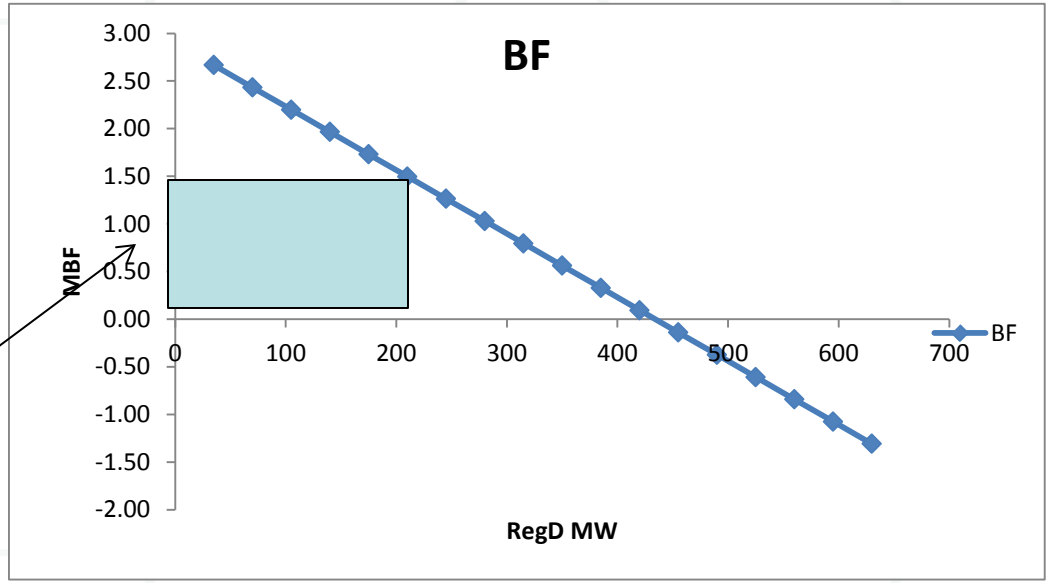
Current Design

- As unit size shrinks (and more units added), calculation gets closer to approximating the area under the curve.
  - Getting closer to correctly calculating the contribution of RegD to total effective regulation.
- Current approach causes effective MW to vary with the size of units cleared, not the cumulative MW (of all unit) cleared.
- Properly defined, effective MW calculated as area under the MBF function.

PJM current approach to RegA/RegD combinations

RegD% /700	RegD MW	BF	PJM Effective Calculation (1 unit at each point)	Unit
5%	35	2.67	93.31	Unit 1
10%	70	2.43	170.26	Unit 1
15%	105	2.20	230.83	Unit 1
20%	140	1.96	275.04	Unit 1
25%	175	1.73	302.87	Unit 1
30%	210	1.50	314.33	Unit 1
35%	245	1.26	309.43	Unit 1
40%	280	1.03	288.15	Unit 1
45%	315	0.80	250.50	Unit 1



Example: 1 Unit with 210 MW = 314 Effective

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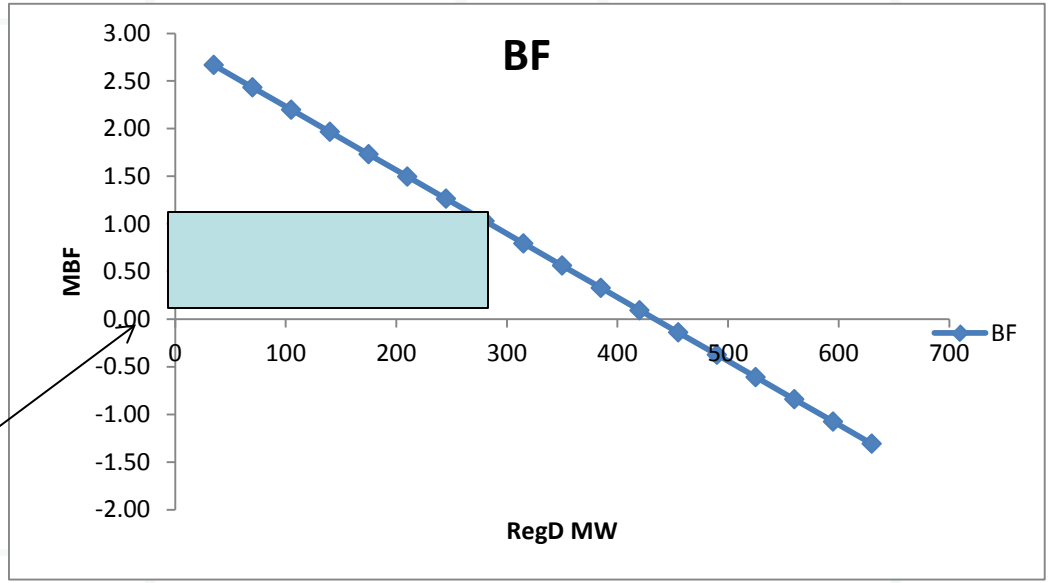
PJM current approach to RegA/RegD combinations

RegD% /700	RegD MW	BF	PJM Effective Calculation (1 unit at each point)	Unit
5%	35	2.67	93.31	Unit 1
10%	70	2.43	170.26	Unit 1
15%	105	2.20	230.83	Unit 1
20%	140	1.96	275.04	Unit 1
25%	175	1.73	302.87	Unit 1
30%	210	1.50	314.33	Unit 1
35%	245	1.26	309.43	Unit 1
40%	280	1.03	288.15	Unit 1
45%	315	0.80	250.50	Unit 1



Example: 1 Unit with 280 MW = 288.15 Effective

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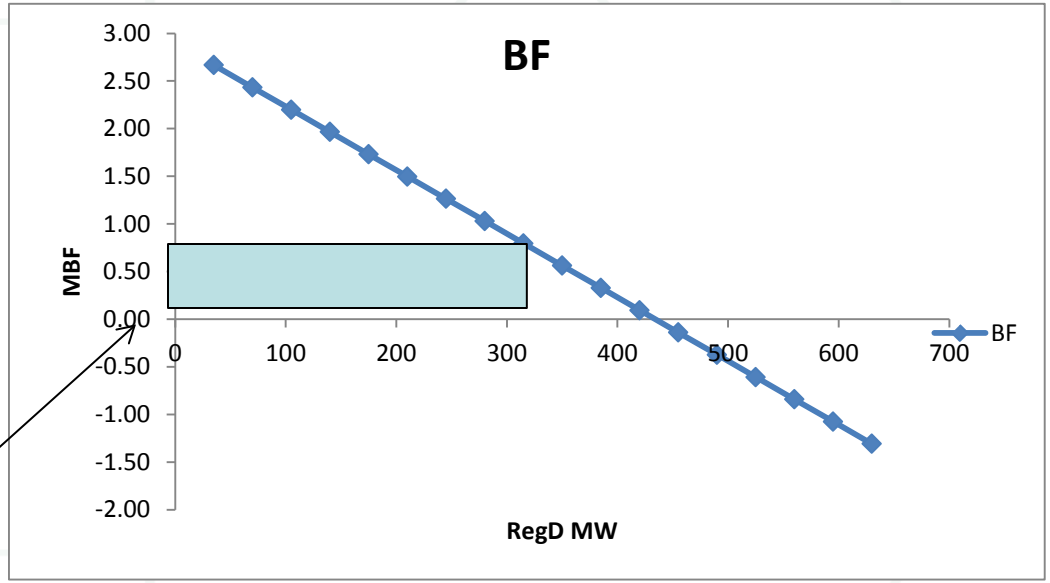
PJM current approach to RegA/RegD combinations

RegD% /700	RegD MW	BF	PJM Effective Calculation (1 unit at each point)	Unit
5%	35	2.67	93.31	Unit 1
10%	70	2.43	170.26	Unit 1
15%	105	2.20	230.83	Unit 1
20%	140	1.96	275.04	Unit 1
25%	175	1.73	302.87	Unit 1
30%	210	1.50	314.33	Unit 1
35%	245	1.26	309.43	Unit 1
40%	280	1.03	288.15	Unit 1
45%	315	0.80	250.50	Unit 1



Example: 1 Unit with 315 MW = 250.50 Effective

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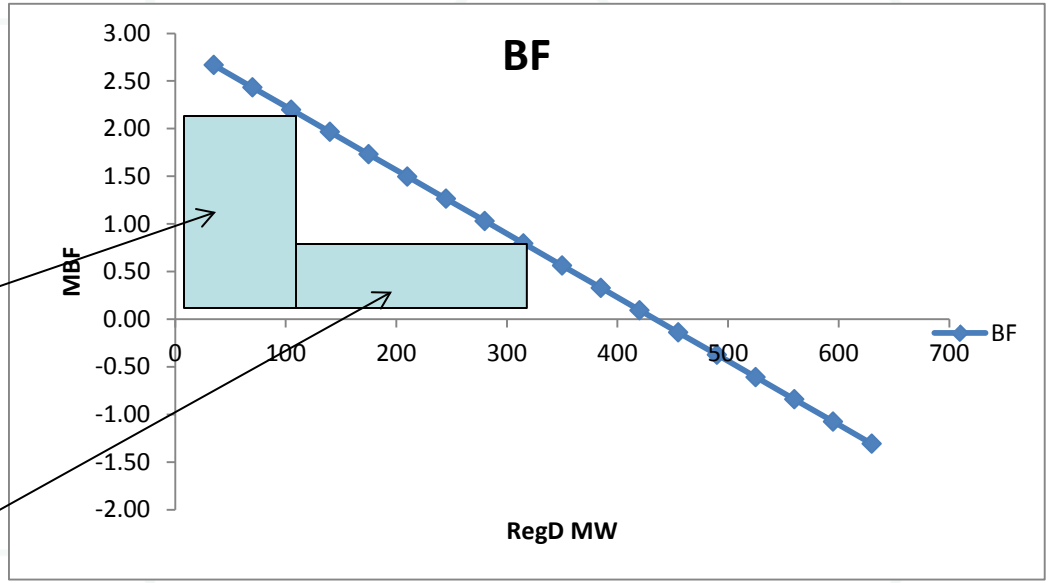
PJM current approach to RegA/RegD combinations

RegD% /700	RegD MW	BF	Two Units	Two Unit Cumulative Effective MW
5%	35	2.67	Unit 1	
10%	70	2.43	Unit 1	
15%	105	2.20	Unit 1	230.83
20%	140	1.96	Unit 2	
25%	175	1.73	Unit 2	
30%	210	1.50	Unit 2	
35%	245	1.26	Unit 2	
40%	280	1.03	Unit 2	
45%	315	0.80	Unit 2	167.00
			Sum	397.83



Example: 2 Units 105 and 210= 315 MW = 397.83 Effective

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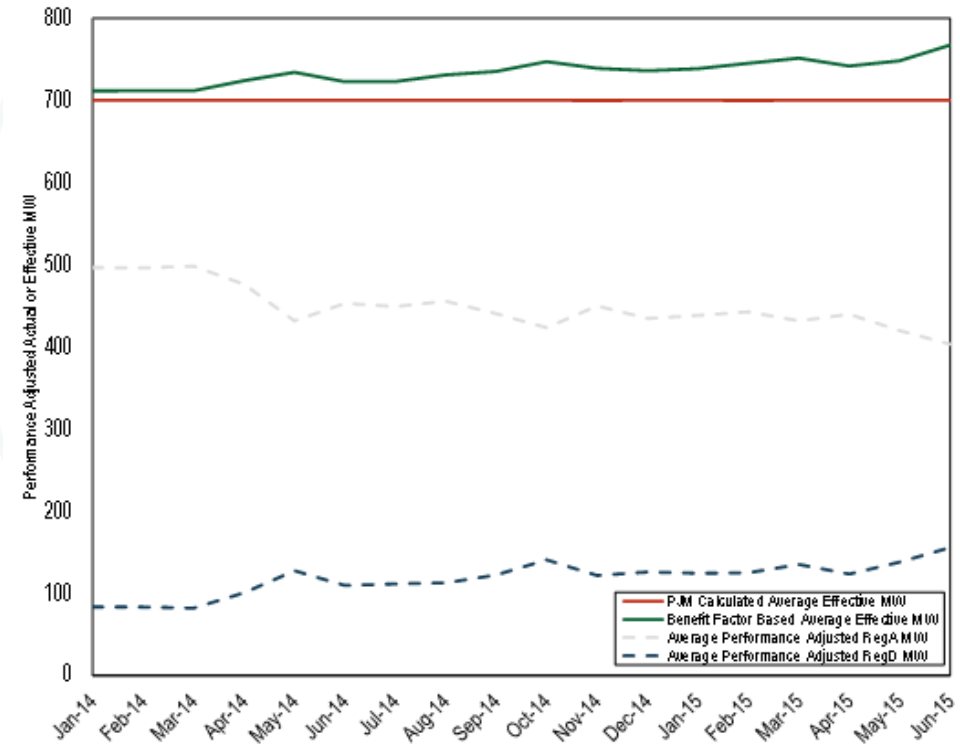
Average monthly peak effective MW: PJM market calculated versus benefit factor based



← Includes both effects

Effect growing due to increase in $0 effective offers

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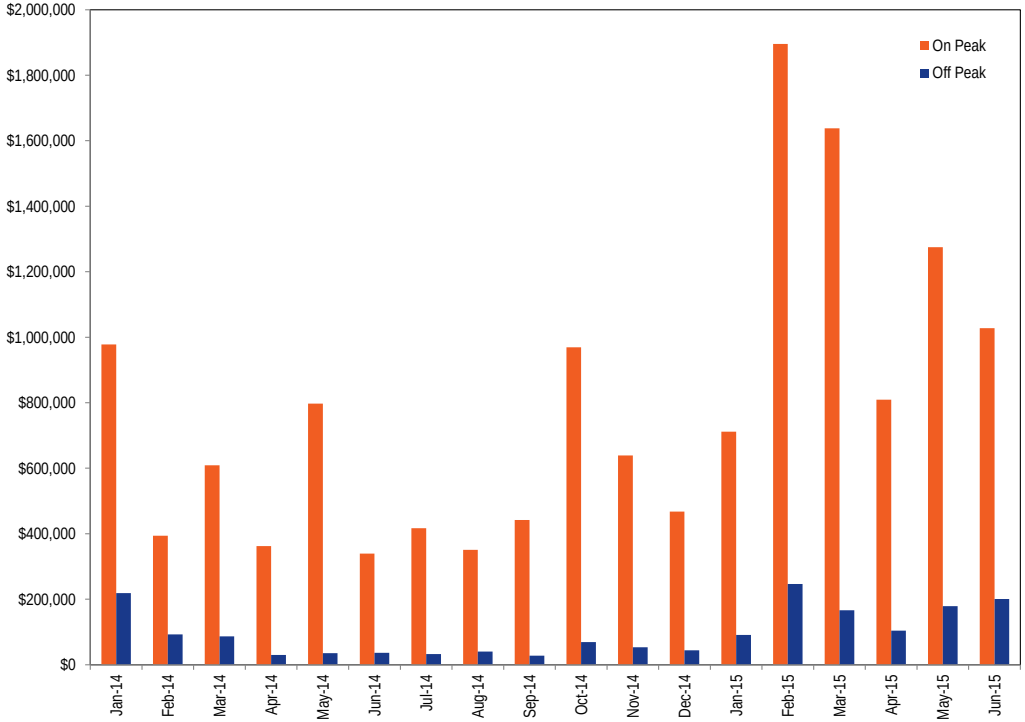
Cost of excess effective MW cleared by month, peak and off peak: January 1, 2014 through June 30, 2015



- Assumes MBF function correctly implemented.
- Assumes no change in price.
- Upper bound estimate.

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Benefit Factor (MBF/BF) Implementation Issues: Optimization/Market Clearing Issues

2. Implementation inconsistent with MBF/BF Definition

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Current Design

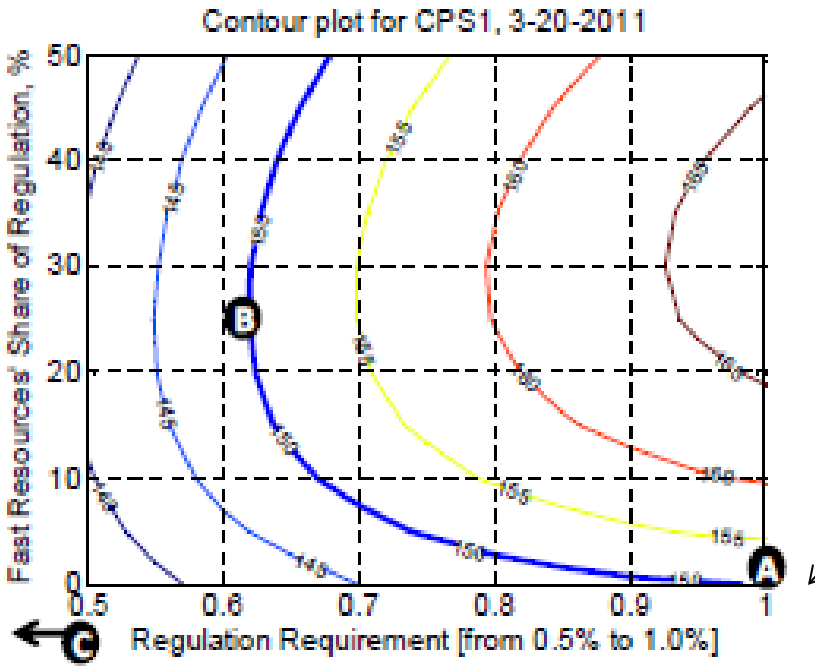
- **Potentially incorrectly defined marginal benefit factor function (MBF)**
  - **Evidence that MBF between RegA and RegD may be incorrectly defined.**
- **Incorrectly applying the MBF in the optimization**
  - **MBF use not consistent with derivation.**
  - **Inefficient displacement of RegA MW.**

Optimization Issues

- **Basis for BF function presumes set combinations of RegA and RegD holding "ACE control" constant.**
- **Current optimization engine does not presume set combination of RegA and RegD.**
- **Use of BF in optimization is therefore not consistent with concept of BF function.**

KEMA: Assumed Relationship

RegD MW as Percent of Regulation MW



Reg requirement in terms of total Reg MW (RegA + RegD)

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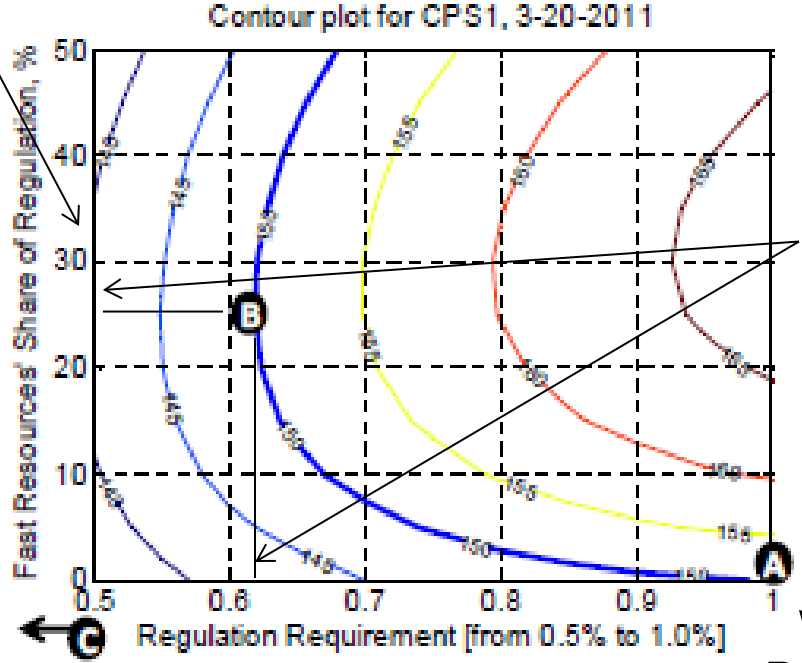
KEMA: Assumed Relationship

RegD MW as Percent of Regulation MW



	RegA	RegD	Total Reg Cleared	RegD % of Reg	RegMW/Regbase Point
Point A	1,000.0	-	1,000.0	0%	100%
	644.0	56.0	700.0	8%	70%
Point B	468.8	156.3	625.0	25%	63%

62.5% of Reg%, 25% RegD

62.5% of 1000 MW = 625 MW Reg

25% of 625 = 156.3 MW of RegD

75% made up of RegA

Reg requirement in terms of total Reg MW (RegA + RegD)

Average of all (12) KEMA Maps

CPS1	Reg Requirement %											
RegD%	0.50%	0.55%	0.60%	0.65%	0.70%	0.75%	0.80%	0.85%	0.90%	0.95%	1.00%	RegD%
50%	120%	125%	129%	132%	135%	138%	**140%**	142%	144%	146%	147%	50%
45%	122%	127%	131%	134%	137%	**140%**	142%	144%	146%	148%	149%	45%
40%	124%	129%	132%	136%	139%	**142%**	144%	146%	148%	149%	151%	40%
35%	126%	130%	134%	137%	**140%**	143%	145%	147%	149%	151%	152%	35%
30%	127%	131%	135%	138.6%	**142%**	144%	146%	148%	150%	152%	153%	30%
25%	128%	132%	136%	139%	**142%**	145%	147%	149%	151%	152%	153%	25%
20%	128%	133%	136%	**140%**	142%	145%	147%	149%	151%	152%	153%	20%
15%	128%	132%	136%	139.3%	**142%**	144%	146%	148%	150%	151%	152%	15%
10%	128%	132%	135%	138%	**141%**	143%	145%	147%	148%	149%	150%	10%
5%	127%	131%	134%	136%	139%	**141%**	142%	144%	145%	146%	147%	5%
0%	125%	129%	131%	134%	135%	137%	138%	139%	**140%**	141%	142%	0%
	0.50%	0.55%	0.60%	0.65%	0.70%	0.75%	0.80%	0.85%	0.90%	0.95%	1.00%	

Reg D as a percent of regulation MW

Reg D as a percent of regulation MW

Reg Requirement %

Monitoring Analytics

Average of all (12) KEMA Maps

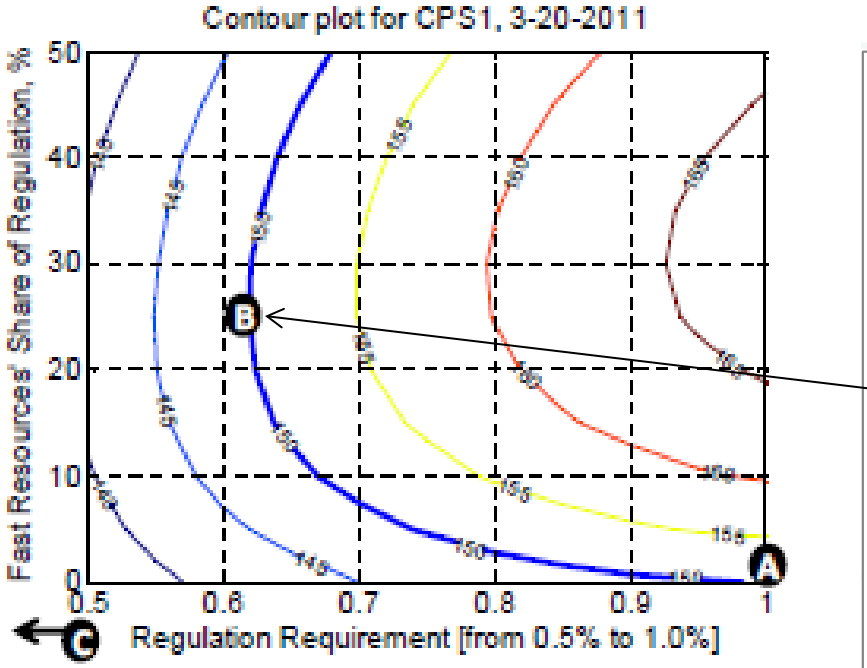
Reg D as a percent of regulation MW	RegD MW	Total Regulation MW: 500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1,000.00	RegD MW	Reg D as a percent of regulation MW
	50%	250	275	300	325	350	375	400	425	450	475	500	50%	
	45%	225	248	270	293	315	338	360	383	405	428	450	45%	
	40%	200	220	240	260	280	300	320	340	360	380	400	40%	
	35%	175	193	210	228	245	263	280	298	315	333	350	35%	
	30%	150	165	180	195	210	225	240	255	270	285	300	30%	
	25%	125	138	150	163	175	188	200	213	225	238	250	25%	
	20%	100	110	120	130	140	150	160	170	180	190	200	20%	
	15%	75	83	90	98	105	113	120	128	135	143	150	15%	
	10%	50	55	60	65	70	75	80	85	90	95	100	10%	
	5%	25	28	30	33	35	38	40	43	45	48	50	5%	
	0%	-	-	-	-	-	-	-	-	-	-	-	0%	
		500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1,000.00		
		Total Regiulation MW												

Total Reg MW

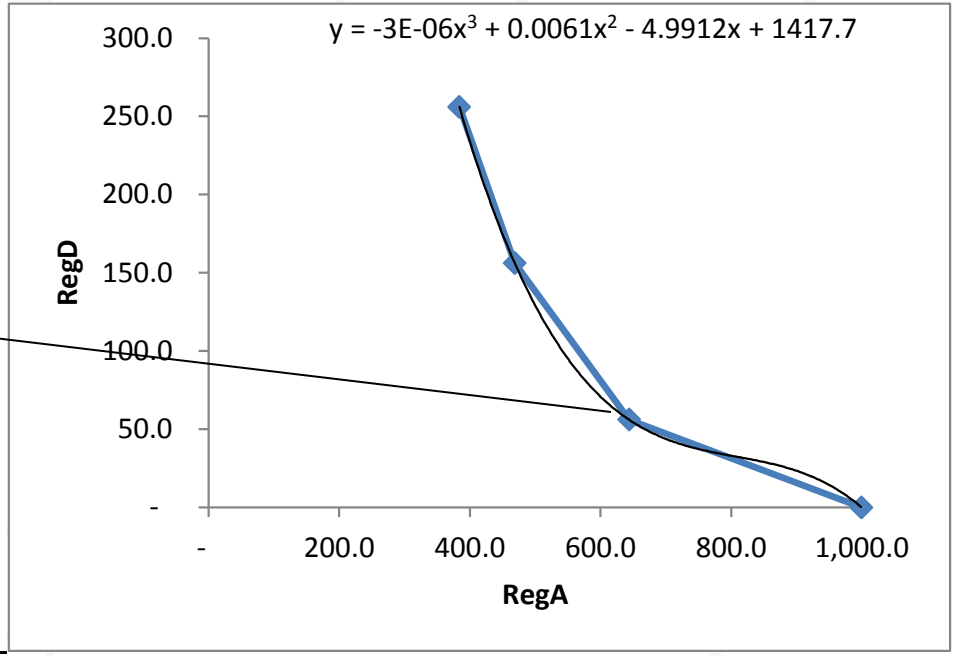
RegD MW

Monitoring Analytics

KEMA: Assumed Relationship



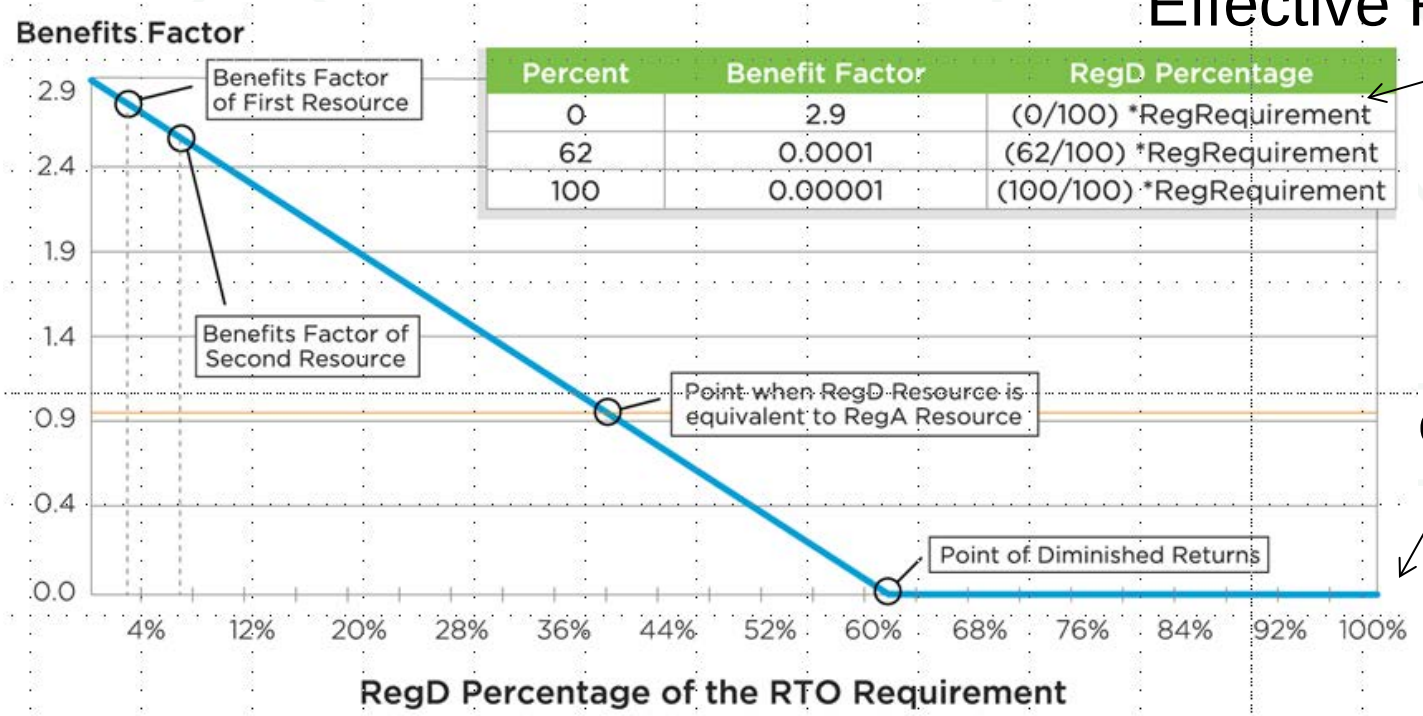
Example curve in terms of MW



Monitoring Analytics

PJM Current Approach

Effective Reg Requirement



Percent	Benefit Factor	RegD Percentage
0	2.9	(0/100) *RegRequirement
62	0.0001	(62/100) *RegRequirement
100	0.00001	(100/100) *RegRequirement

% of 700 if peak

Not % of RegMW, % of 700 MW

Monitoring Analytics

PJM current approach to RegA/RegD combinations

BF with another logic

Perf_Adj_MW	BF	Eff_MW
10	2.8332	28.3
9	2.773	2.05
8	2.7196	21.8
7	2.6728	18.7
5	2.6394	13.2
5	2.6060	13.0
Total Eff_MW		**120**

Source: PJM Presentation 08/11/2015

$$BF_i = \frac{EffMW_i * (0.0001 - 2.9)}{Percentage\ RegD * RegReq} + 2.9$$

RegA is set as residual requirement:
700 MW – RegD Effective = RegA Needed

Assumed proportion of RegA from underlying curve ignored.

Monitoring Analytics

Current approach to RegA/RegD combinations

Performance adjusted MW

%RegD = Performance adjusted MW/ Effective MW Target

MBF of the last unit of RegD MW listed

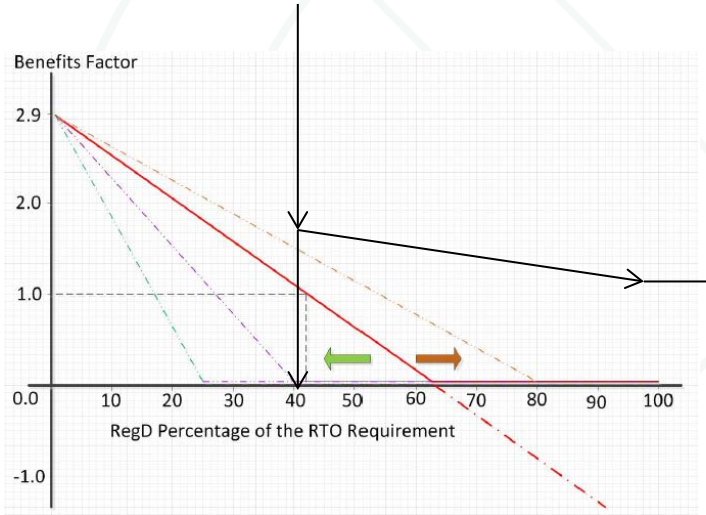
Cumulative effective MW for the cleared RegD listed

Effective MW Requirement – Effective MW = Residual A cleared

RegD% /700	RegD MW	Effective BF	Effective MW	Residual A	RegD/(RegA +RegD)	RegD% of Effective MW
5%	35	2.67	97.41	602.59	5%	14%
10%	70	2.43	186.63	513.37	12%	27%
15%	105	2.20	267.67	432.33	20%	38%
20%	140	1.96	340.52	359.48	28%	49%
25%	175	1.73	405.18	294.82	37%	58%
30%	210	1.50	461.67	238.33	47%	66%
35%	245	1.26	509.96	190.04	56%	73%
40%	280	1.03	550.07	149.93	65%	79%
45%	315	0.80	582.00	118.00	73%	83%
50%	350	0.56	605.74	94.26	79%	87%
55%	385	0.33	621.30	78.70	83%	89%
60%	420	0.09	628.67	71.33	85%	90%
65%	455	-0.14	627.85	72.15	86%	90%
70%	490	-0.37	618.85	81.15	86%	88%
75%	525	-0.61	601.66	98.34	84%	86%
80%	560	-0.84	576.29	123.71	82%	82%
85%	595	-1.08	542.74	157.26	79%	78%
90%	630	-1.31	501.00	199.00	76%	72%

Current approach to RegA/RegD combinations

Assume % <> realized %



Too much RegD%

RegD% /700	RegD MW	Effective BF	Effective MW	Residual A	RegD/(RegA +RegD)	RegD% of Effective MW
5%	35	2.67	97.41	602.59	5%	14%
10%	70	2.43	186.63	513.37	12%	27%
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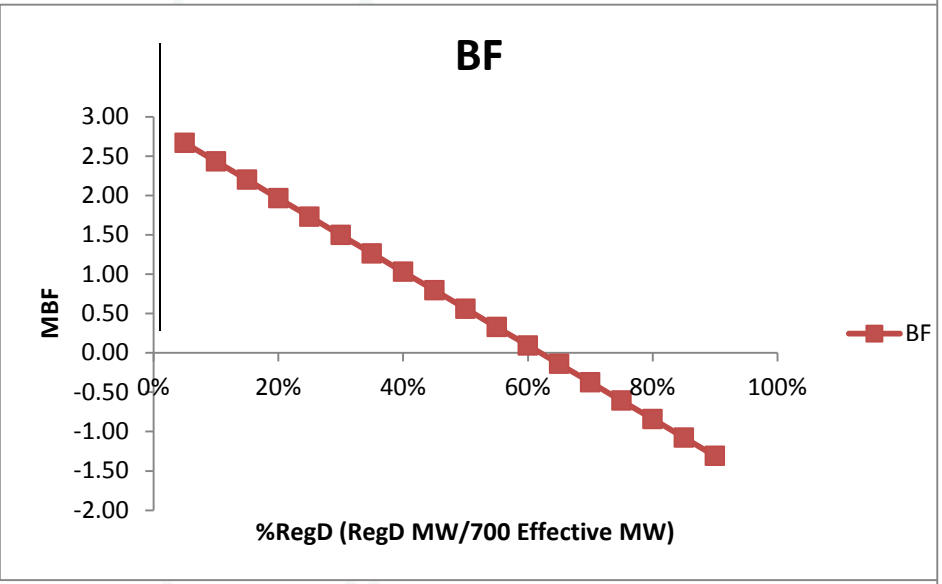
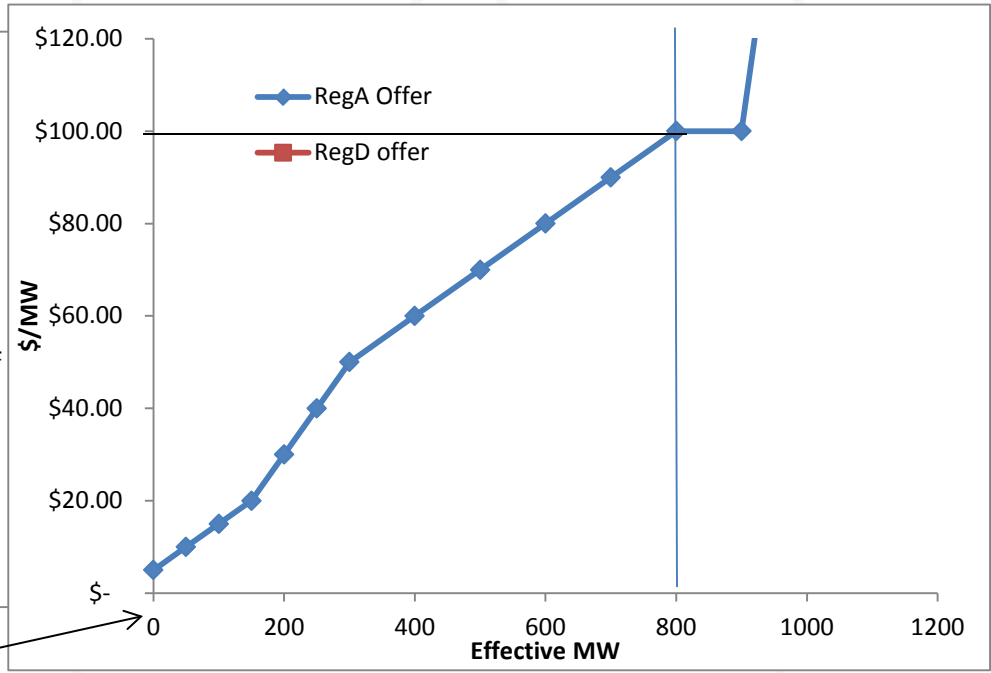
55%	385	0.33	621.30	78.70	83%	89%
60%	420	0.09	628.67	71.33	85%	90%
65%	455	-0.14	627.85	72.15	86%	90%
70%	490	-0.37	618.85	81.15	86%	88%
75%	525	-0.61	601.66	98.34	84%	86%
80%	560	-0.84	576.29	123.71	82%	82%
85%	595	-1.08	542.74	157.26	79%	78%
90%	630	-1.31	501.00	199.00	76%	72%

PJM current approach to RegA/RegD combinations



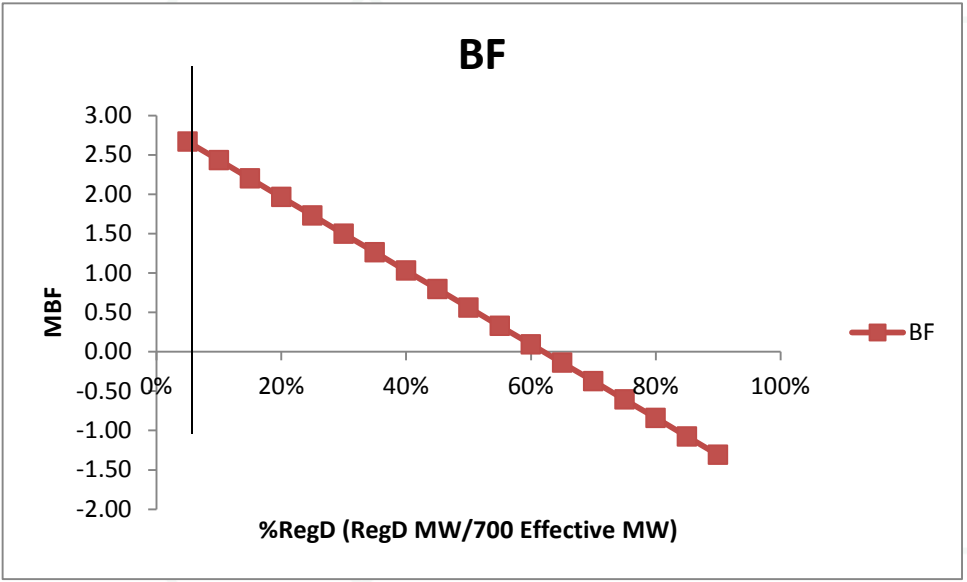


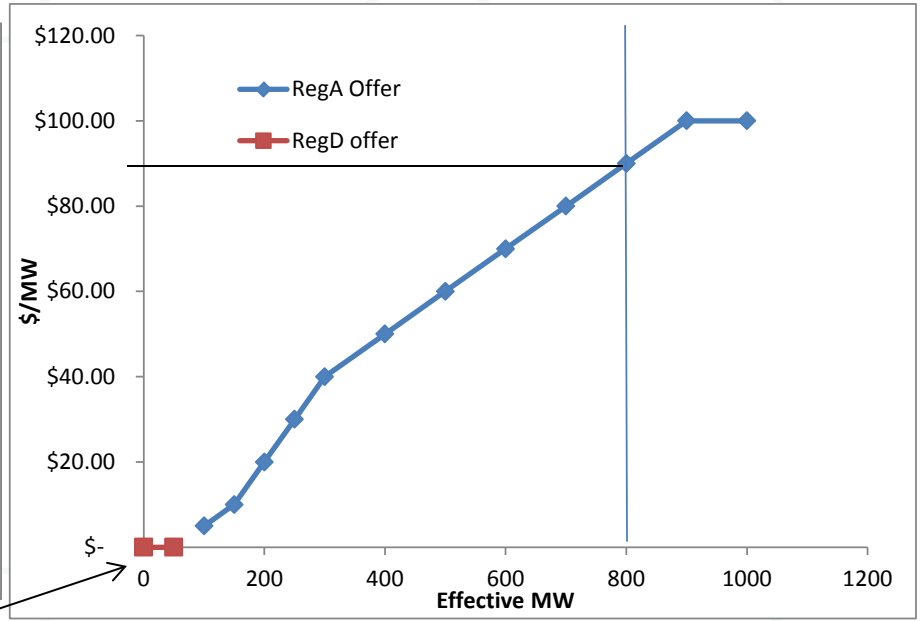
Zero RegD

Monitoring Analytics

PJM current approach to RegA/RegD combinations

5% of 700 MW

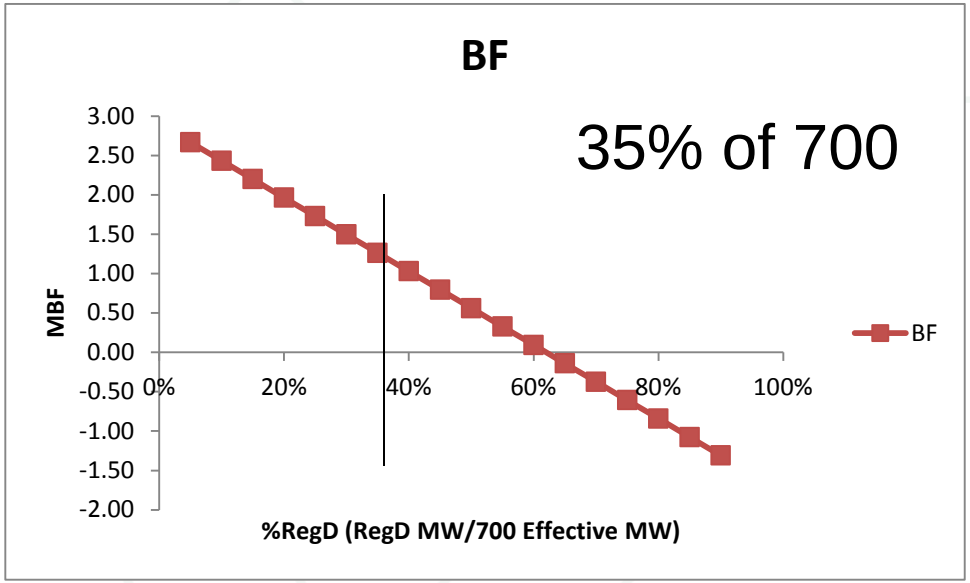


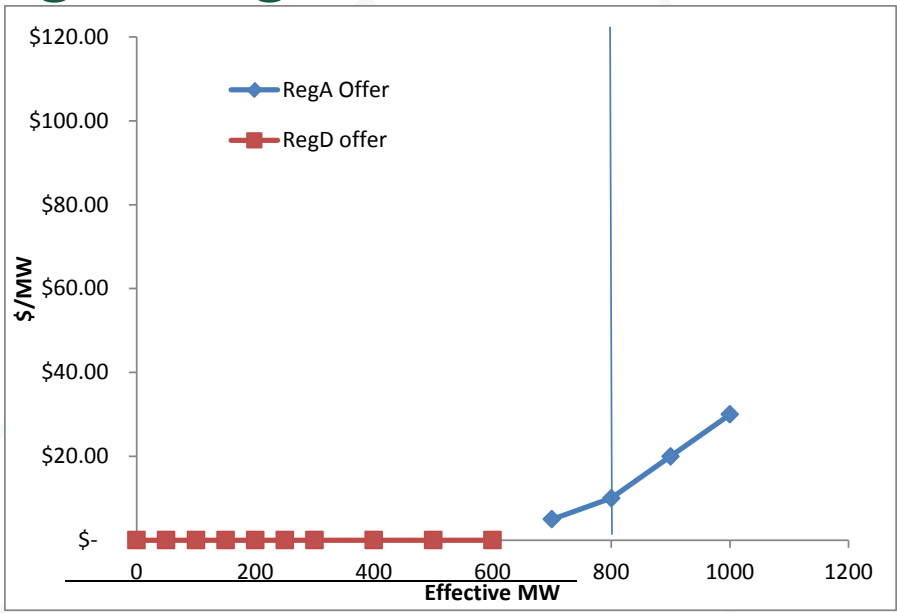


Effective MW from Reg D displaces Reg A. 5% of Reg, 14% of Effective

Monitoring Analytics

PJM current approach to RegA/RegD combinations



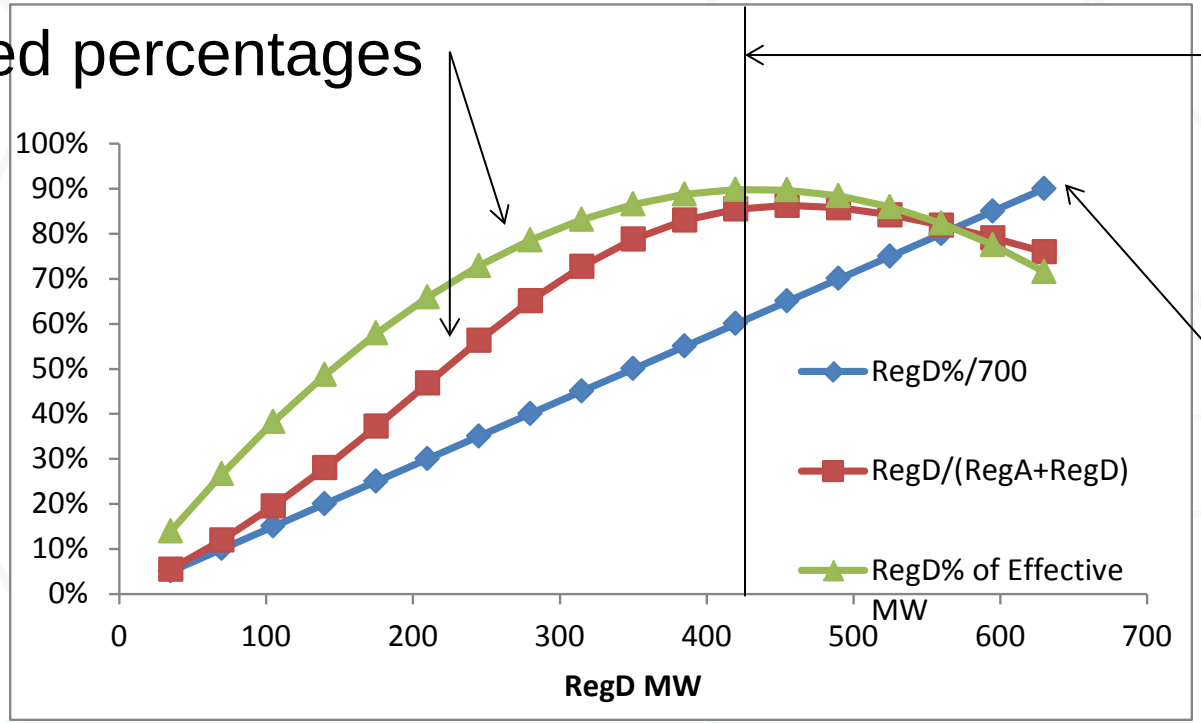


Realized proportion of RegD and RegA not consistent. 56% of Reg, 73% of effective.

Monitoring Analytics

PJM current approach to RegA/RegD combinations

Realized percentages



Where MBF = zero

BF assumed percentages

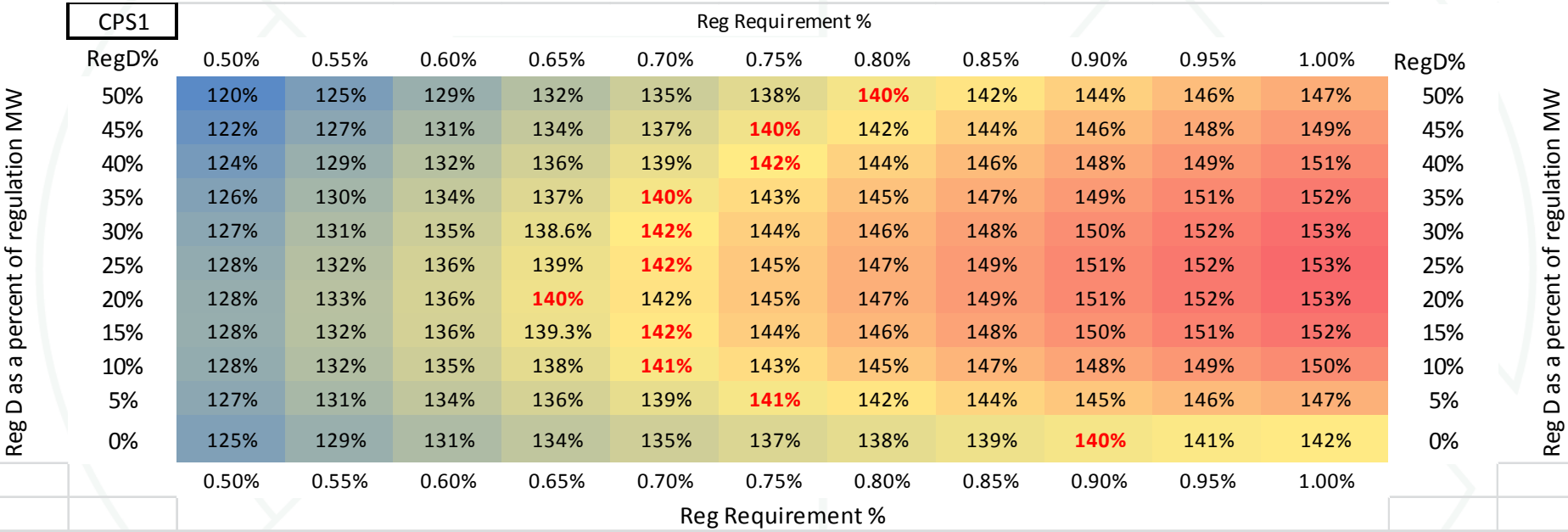
Realized proportion <> assumed RegD proportion

Monitoring Analytics

Ideally engine should produce relevant combinations

- **If defined relationship based on RegD/RegA combinations that meet operational requirements.**
- **Then axis should be in terms of RegD MW cleared, not on some percentage of RegD MW cleared.**

Average of all (12) KEMA Maps



Monitoring Analytics

Average of all (12) KEMA Maps

Reg D as a percent of regulation MW	RegD MW	Total Regulation MW: 500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1,000.00	RegD MW	Reg D as a percent of regulation MW
	50%	250	275	300	325	350	375	400	425	450	475	500	50%	
	45%	225	248	270	293	315	338	360	383	405	428	450	45%	
	40%	200	220	240	260	280	300	320	340	360	380	400	40%	
	35%	175	193	210	228	245	263	280	298	315	333	350	35%	
	30%	150	165	180	195	210	225	240	255	270	285	300	30%	
	25%	125	138	150	163	175	188	200	213	225	238	250	25%	
	20%	100	110	120	130	140	150	160	170	180	190	200	20%	
	15%	75	83	90	98	105	113	120	128	135	143	150	15%	
	10%	50	55	60	65	70	75	80	85	90	95	100	10%	
	5%	25	28	30	33	35	38	40	43	45	48	50	5%	
	0%	-	-	-	-	-	-	-	-	-	-	-	0%	
		500.00	550.00	600.00	650.00	700.00	750.00	800.00	850.00	900.00	950.00	1,000.00		
		Total Regiulation MW												

Total Reg MW

RegD MW

Monitoring Analytics

KEMA provided RegA/RegD combinations

Reg MW at 100%					
1,000					
Reg%	Total Reg MW	RegD %	REGD MW	REGA MW	Score
90.0%	900	0%	0	900	140%
75.0%	750	5%	37.5	712.5	140%
70.0%	700	10%	70	630	140%
70.0%	700	15%	105	595	140%
65.0%	650	20%	130	520	140%
70.0%	700	25%	175	525	140%
70.0%	700	30%	210	490	140%
70.0%	700	40%	280	420	140%
80.0%	800	50%	400	400	140%
90.0%	900	55%	495	405	140%

RegD MW = Reg% x Total RegMW

- Constant regulation service from combination
- Each combination equivalent to 900 MW of RegA (and 0 MW RegD)

RegA MW = Total RegMW – RegD MW

Example assumes all MW are performance adjusted

Monitoring Analytics

KEMA provided RegA/RegD combinations

Reg MW at 100%					
1,000					
Reg%	Total Reg MW	RegD %	REGD MW	REGA MW	Score
90.0%	900	0%	0	900	140%
75.0%	750	5%	37.5	712.5	140%
70.0%	700	10%	70	630	140%
70.0%	700	15%	105	595	140%
65.0%	650	20%	130	520	140%
70.0%	700	25%	175	525	140%
70.0%	700	30%	210	490	140%
70.0%	700	40%	280	420	140%
80.0%	800	50%	400	400	140%
90.0%	900	55%	495	405	140%

Note, total Reg MW not constant

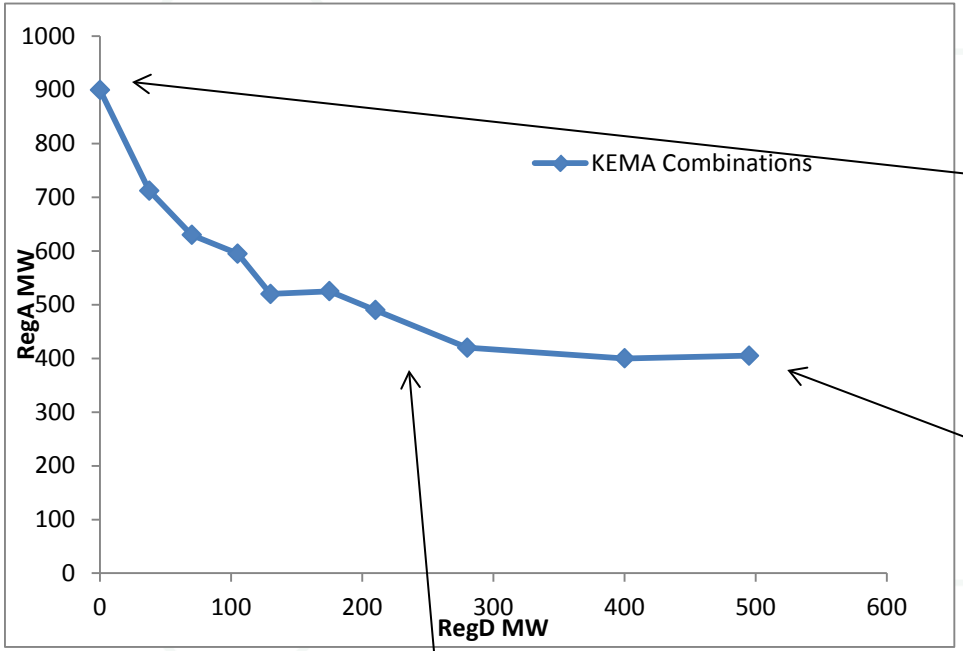
%D is correct here, with assumed pair.

280 RegD / (280 + 420) = 40%

Higher proportions of RegD require a greater amount of total Regulation MW (Balance from RegA) to provide effective MW target (750 MW of RegA)

Need to operationalize the curve.

KEMA based combinations with the same CPS1 Scores, Resulting BF Function

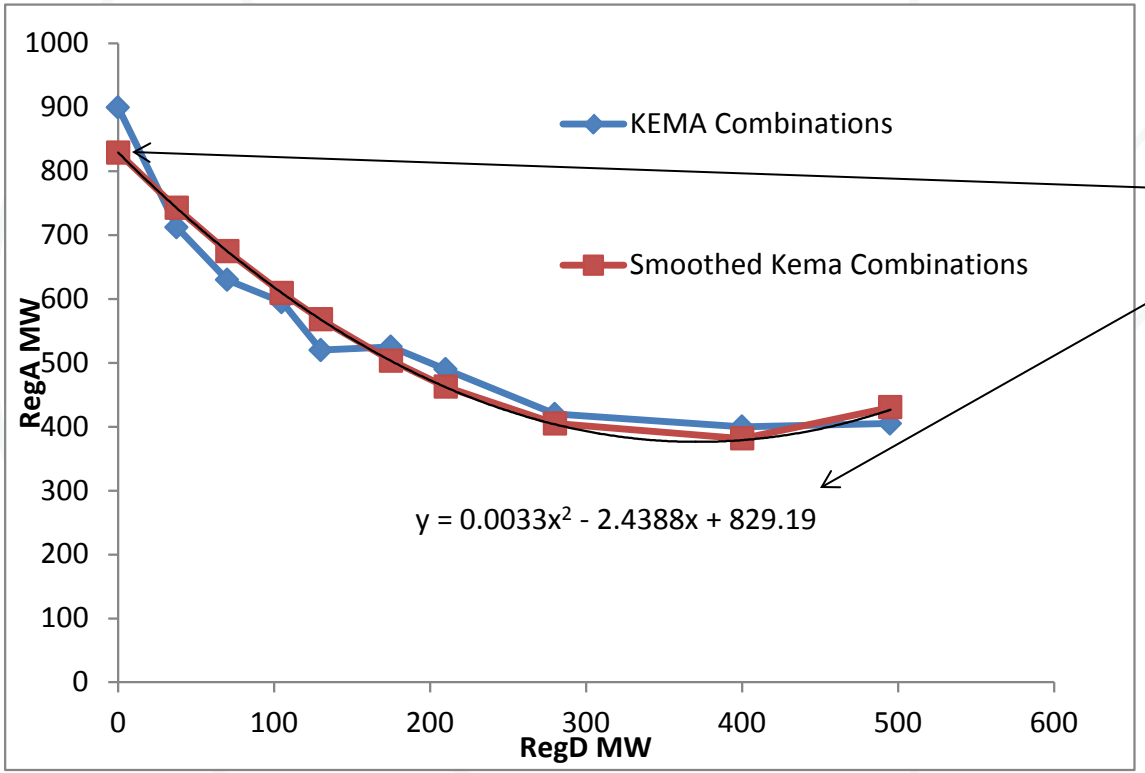


Reg MW at 100%					
1,000					
Reg%	Total Reg MW	RegD %	REGD MW	REGA MW	Score
90.0%	900	0%	0	900	140%
75.0%	750	5%	37.5	712.5	140%
70.0%	700	10%	70	630	140%
70.0%	700	15%	105	595	140%
65.0%	650	20%	130	520	140%
70.0%	700	25%	175	525	140%
70.0%	700	30%	210	490	140%
70.0%	700	40%	280	420	140%
80.0%	800	50%	400	400	140%
90.0%	900	55%	495	405	140%

Relevant RegA/RegD MW Combinations

Monitoring Analytics

KEMA based combinations: Smooth the curve

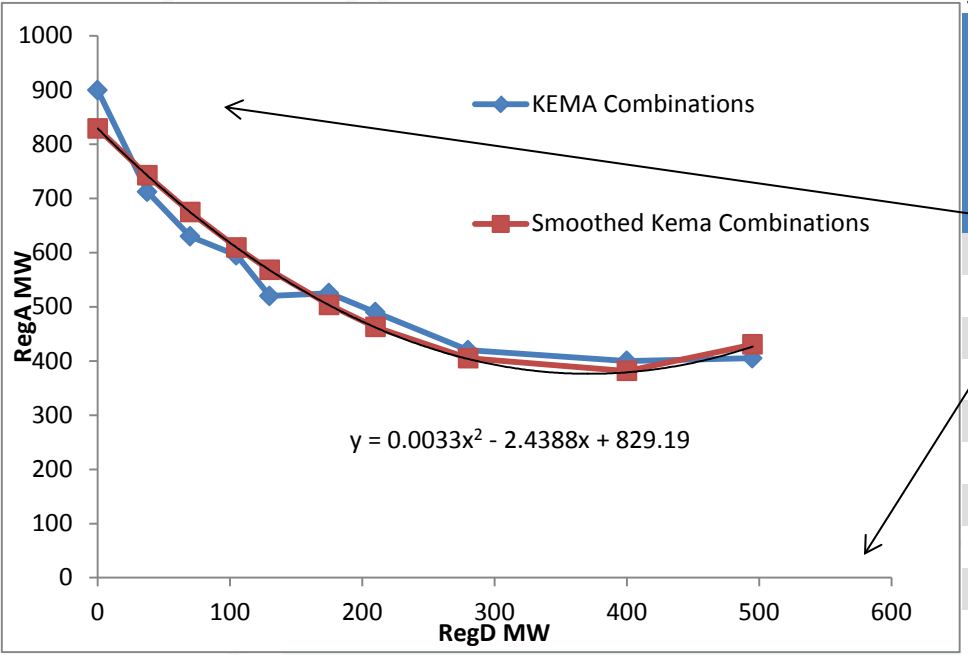


Smoothed curve intercept = 829.19 RegA MW

All figures in terms of performance adjusted MW

Monitoring Analytics

KEMA based combinations: Smooth the curve

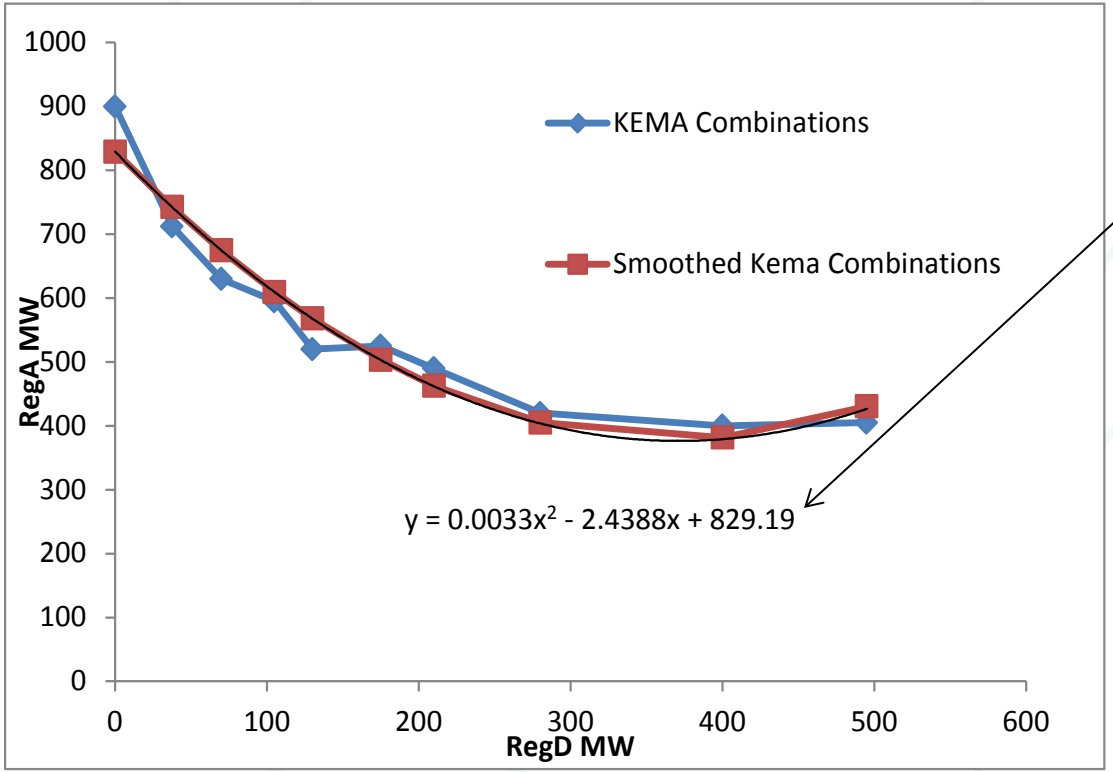


Smoothed MW relationship

RegD MW	Smoothed Kema Combinations RegA	Total MW	Perecentage RegD	Percentage RegA	Total Reg%
0	829.19	829.19	0%	100%	83%
37.5	742.38	779.88	5%	95%	78%
70	674.64	744.64	9%	91%	74%
105	609.50	714.50	15%	85%	71%
130	567.92	697.92	19%	81%	70%
175	503.46	678.46	26%	74%	68%
210	462.57	672.57	31%	69%	67%
280	405.05	685.05	41%	59%	69%
400	381.67	781.67	51%	49%	78%
495	430.57	925.57	53%	47%	93%

Monitoring Analytics

KEMA based combinations: Smooth the curve

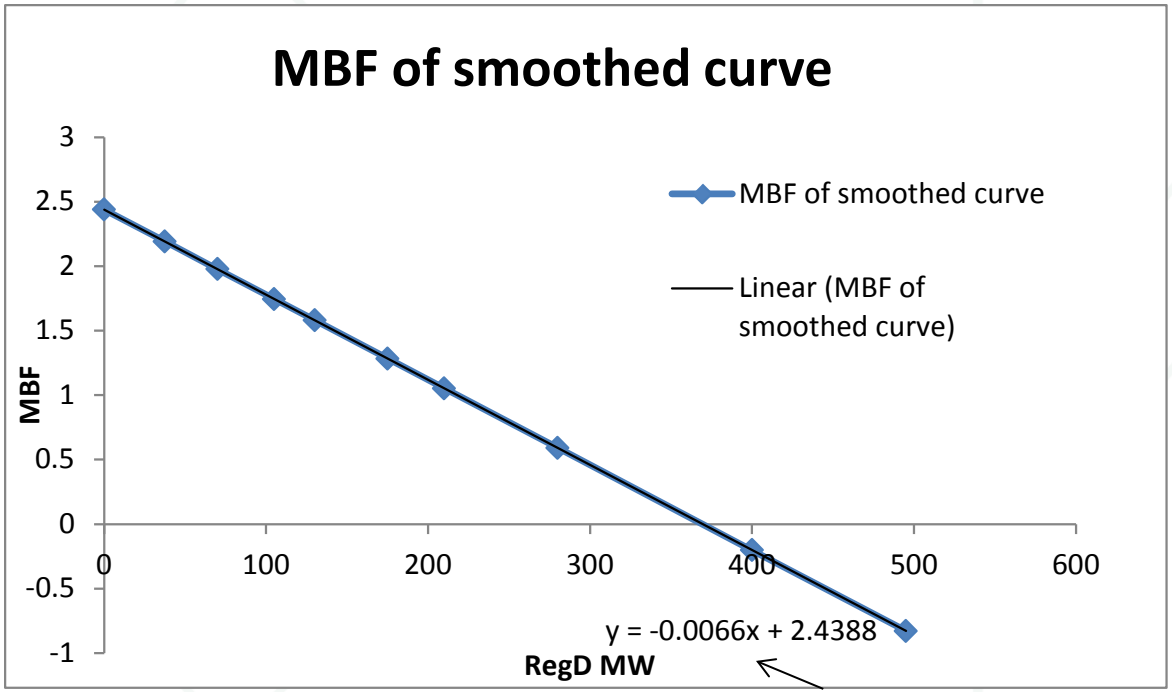


Derivative of this function is MRTS = MBF Function

Change in RegA for Change in RegD

Monitoring Analytics

KEMA based combinations: MBF

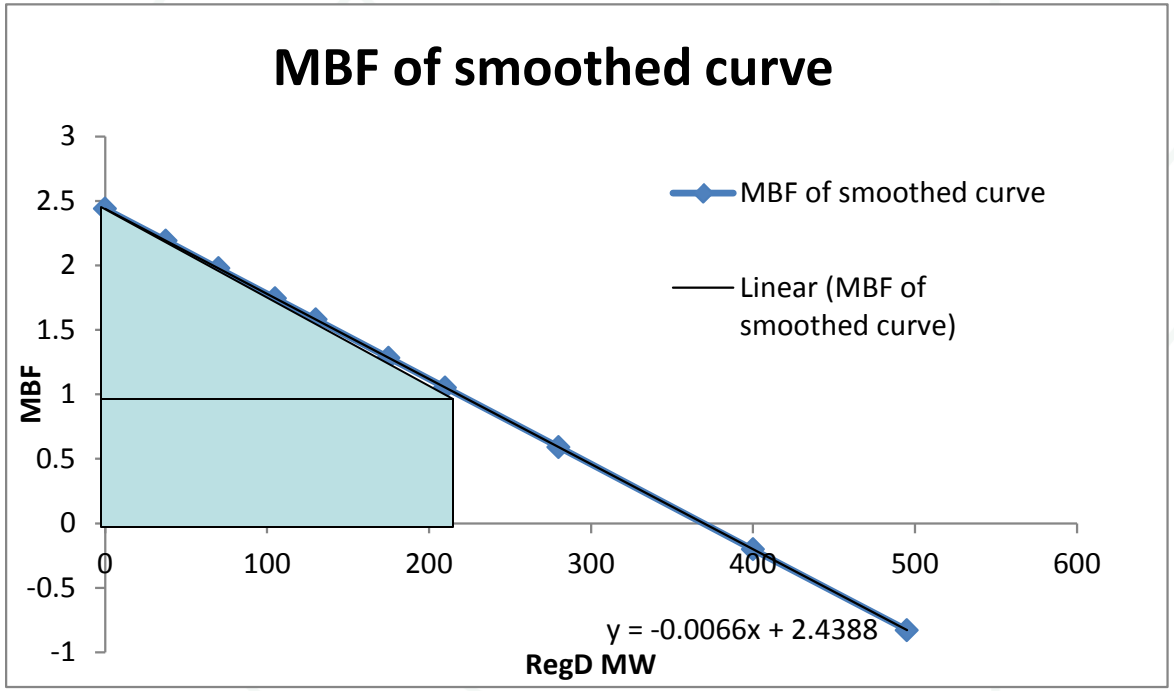


Area under *this* curve = total effective MW from D.

Derivative of curve defining combinations of RegA/RegD

Monitoring Analytics

KEMA based combinations: MBF

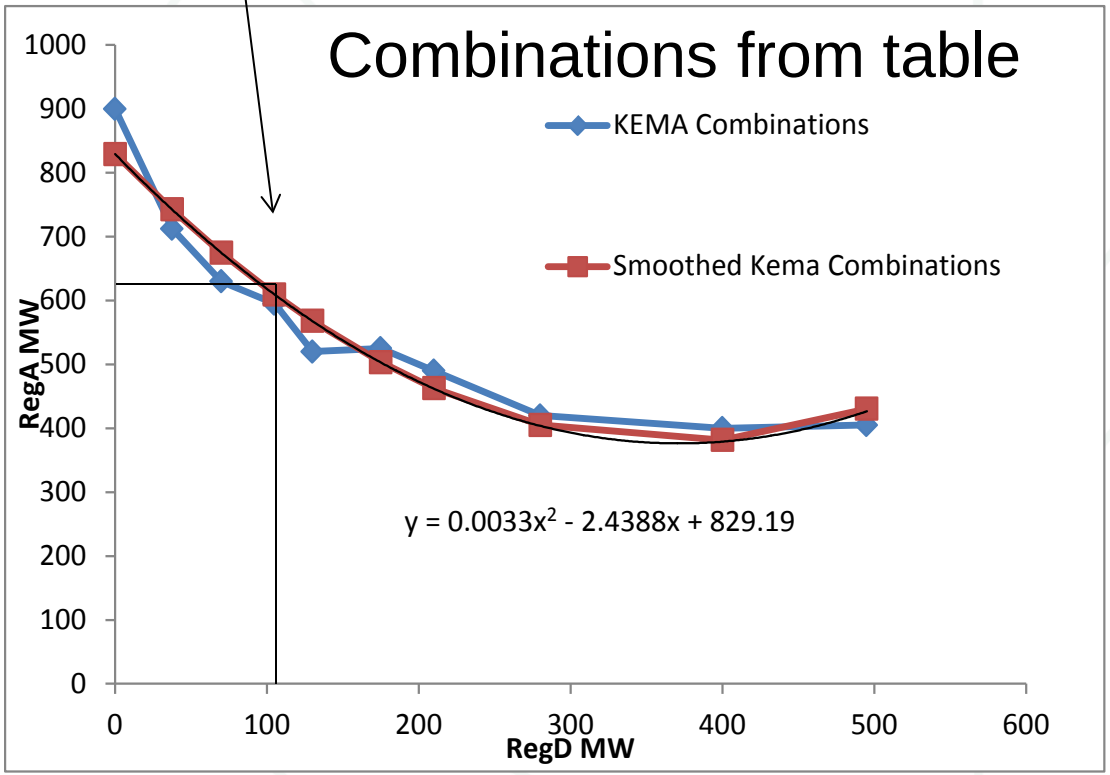


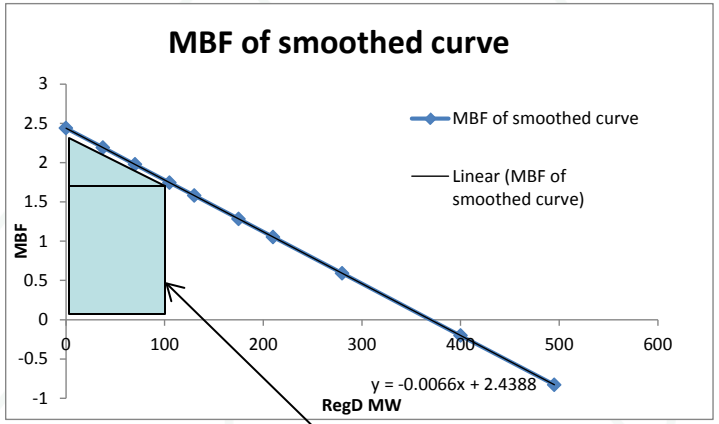
- Effective MW from RegD = Area Under MBF Curve
- Works so long as MBF function defined in terms of discrete MW, not percentage.

Monitoring Analytics

609.5 A, 105 D

KEMA based combinations





105 MW regD = 219.69 MW effective

829 MW – 219.69 = 609.5 RegA

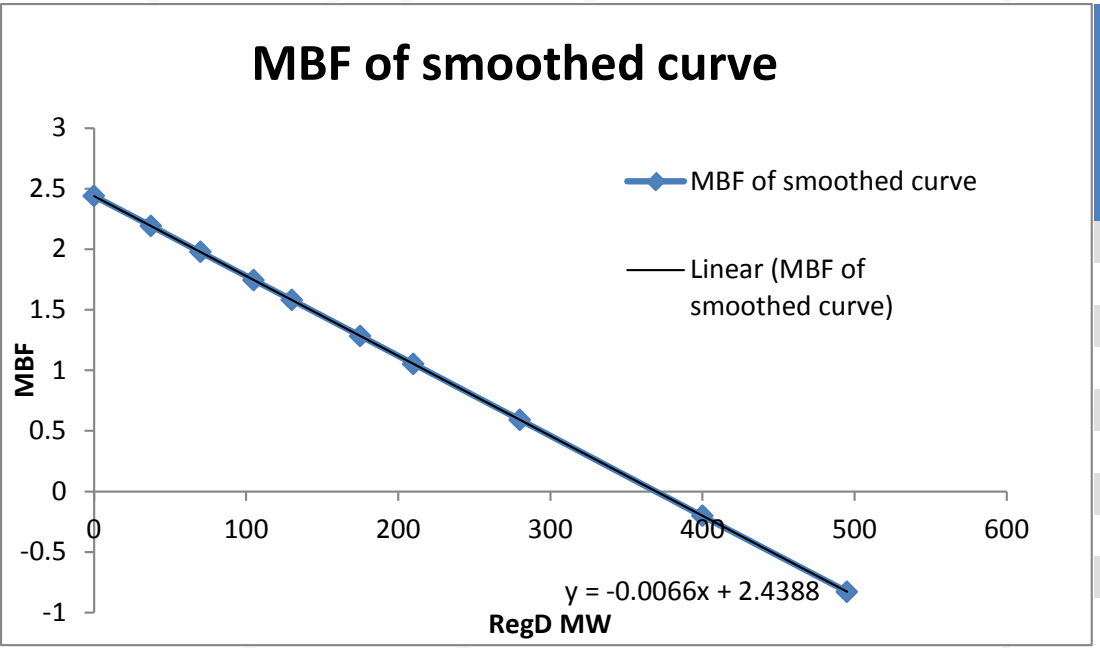
RegA as residual now works.

Monitoring Analytics

KEMA based combinations: MBF

Area under curve calculation

Results match curve



RegD MW	Smoothed Kema Combinations RegA	MBF of smoothed curve	Effective MW from RegD	Total effective MW
0	829.19	2.44	0.00	829.19
37.5	742.38	2.19	86.81	829.19
70	674.64	1.98	154.55	829.19
105	609.50	1.75	219.69	829.19
130	567.92	1.58	261.27	829.19
175	503.46	1.28	325.73	829.19
210	462.57	1.05	366.62	829.19
280	405.05	0.59	424.14	829.19
400	381.67	-0.20	447.52	829.19
495	430.57	-0.83	398.62	829.19

Monitoring Analytics

Compare to Current Approach

- **What if current clearing approach was applied to this MBF curve?**
- **Current approach defines relationship based on percentage of RegD relative to fixed number, not RegD/RegA combinations.**
- **Misinterprets axis (the relationship between RegD and RegA)**
- **Failure to correct interpretation of the axis would result combinations inconsistent with MBF.**

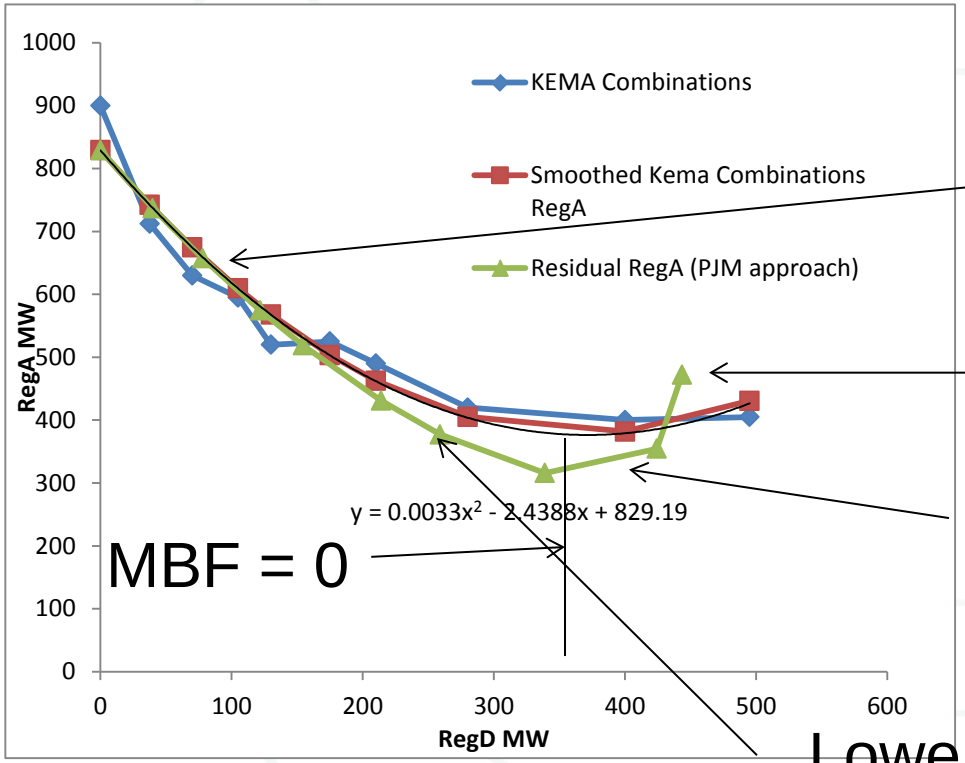
Monitoring Analytics

PJM current approach to RegA/RegD combinations

KEMA Combination Approach					Current Approach				
RegD MW	Smoothed Kema Combinations RegA	Percentage RegD	Percentage RegA	Total Reg%	RegD MW	Residual RegA (PJM approach)	Actual Percentage RegD	Actual Percentage RegA	MW Cleared relative to 1000 MW target
0.0	829.2	0%	100%	83%	0.0	829.2	0%	100%	83%
37.5	742.4	5%	95%	78%	39.9	736.9	5%	95%	78%
70.0	674.6	9%	91%	74%	77.9	657.1	11%	89%	74%
105.0	609.5	15%	85%	71%	121.9	574.2	18%	82%	70%
130.0	567.9	19%	81%	70%	154.5	518.8	23%	77%	67%
175.0	503.5	26%	74%	68%	213.9	431.1	33%	67%	64%
210.0	462.6	31%	69%	67%	258.9	377.2	41%	59%	64%
280.0	405.0	41%	59%	69%	338.9	315.8	52%	48%	65%
400.0	381.7	51%	49%	78%	424.3	354.5	54%	46%	78%
495.0	430.6	53%	47%	93%	443.5	472.1	48%	52%	92%

Note different resulting percentages of RegD.

PJM current approach to RegA/RegD combinations



CPS1 Score constant, Effective MW constant

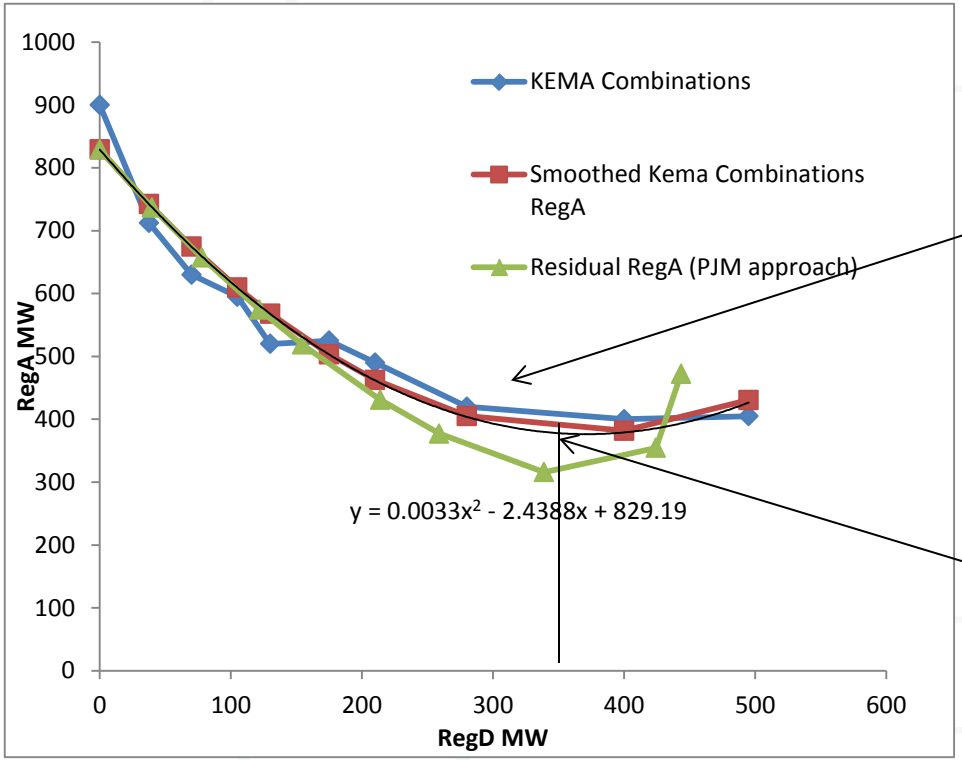
Combinations not consistent with MBF

CPS1 Score not constant, Effective MW not constant

Lower regulation control scores

Monitoring Analytics

Ideal Approach

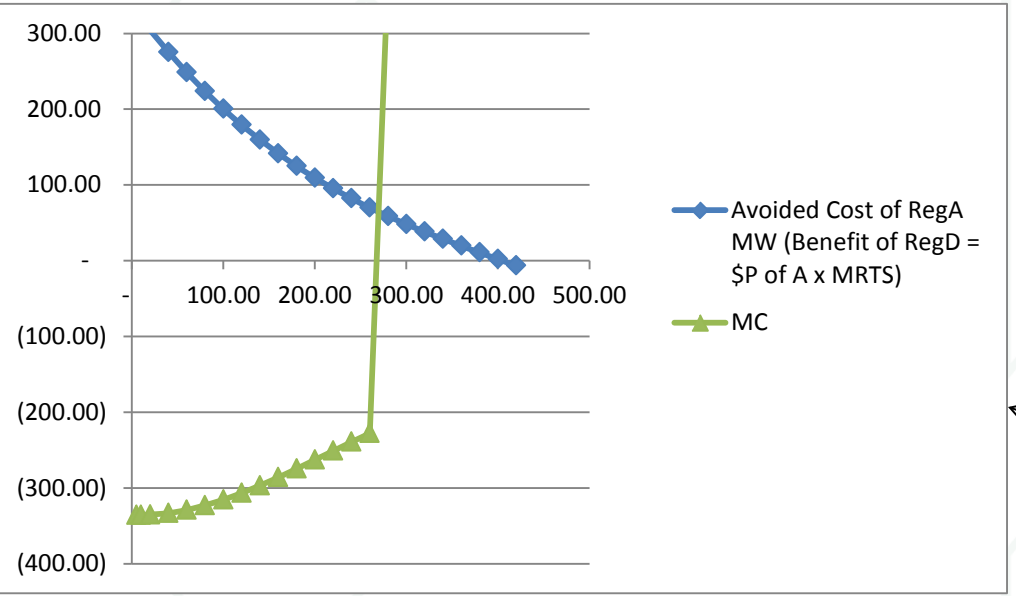


Least cost combination on this line provides is least cost provision of regulation target effective MW

MBF = 0

Monitoring Analytics

Ideal Approach: Least Cost Combination



RegA MW	RegD MW	Price Paid per MW of RegA Equivalent	MRTS	Price paid per MW of RegD
439.144	260	$ 109.79	0.6376	$ 70.00

Computed solution limited in example to the listed combinations. Actual curve is smooth and continuous, would solve were MB/MC ratios constant across resource types (point of intersection of D and S).

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Benefit Factor (MBF/BF): Consistent Application

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Marginal Benefit Factor is not uniformly applied in price and settlement

- **The Marginal Benefit Factor (MBF/BF) is not uniformly applied so that the valuation used in optimization process is consistent with the valuation used in settlement.**
- **MBF/BF used in price/offer conversion but not used in settlement.**
- **MBF/BF used to convert all offers to effective MW of RegA MW and $/effective MW of RegA.**

Effect of Current Design

- **Incorrectly compensating RegD in all hours**
  - **Sometimes too little (when MBF is >1)**
  - **Sometimes too much (when MBF is <1)**
- **Mileage multiplier distorts signal in all hours**
  - **RegD payment per MW slightly higher than RegA payments per MW**
    - Incentives to self schedule/price at zero
    - Inefficient squeezing out of RegA
      - Lowers regulation price per MW of RegA
    - Long term investment signals incorrect for RegA and RegD

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Ideal Design

- **Clearing price in terms of $/Effective MW RegA**
- **Objective is to pay each resource for $/effective MW provided**
- **Price realized should be the same for each effective MW provided**

Components of Offers

- **Offers are composed of**
  - **Capability ($/MW)**
  - **PJM estimated LOC ($/MW)**
  - **performance ($/mile that is converted into $/MW)**
    - **$/Mile x historic mile/MW = $/MW**

- **Sum is $/MW reg offer.**
  - **Reg offer ($/MW) =capability ($/MW)+LOC ($/MW) + performance ($/MW)**

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Example Offers

- **Sum is $/MW reg offer.**
  - **Reg offer ($/MW) =capability ($/MW)+LOC ($/MW) + performance ($/MW)**
- **Example offers:**
- **RegA offer:**
  - **$8/MW capability + ($1/mile) x 2mile/MW**
  - **= $8/MW + $2/MW = $10/MW**
- **RegD offer:**
  - **$6/MW capability +$1/mile x 4mile/MW**
  - **=$6/MW + $4/MW = $10/MW**

Example Offers: Conversion to Effective MW

- **Offers are converted into $/Effective MW**
- $\$/EffectiveMW = \frac{Offer}{Performance\%xBenefitFactor}$
- **$10 offer, 50% performance, 1 BF**
  - **1 MW offered providing 0.5 MW effective**
    - **$10/MW offer = $10/(50%x1)= $20/MW effective**
- **$10 offer, 100% performance, .5 BF**
  - **1 MW offered providing 0.5 effective**
  - **$10/MW offer = $10/(100% x 0.5) = $20/MW effective**

Conversion to offers to $/Effective MW

- **Prices in stack are provided in $/Effective MW**
- **Market Prices are set on the basis of $/Effective MW (marginal offer)**
- $$\$/EffectiveMW = \frac{Offer}{Performance\%xBenefitFactor}$$

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Two Basic Components of Price

- **Marginal offer price is divided into two component pieces:**
- **Performance in $/effective MW**
  - **Set by most expensive effective MW based performance offer, whether part of the marginal offer or not**
- **Capability in $/effective MW**
  - **Capability price is determined as a residual (difference between total price and max performance price cleared stack)**

Settlement: Effect of Current Design

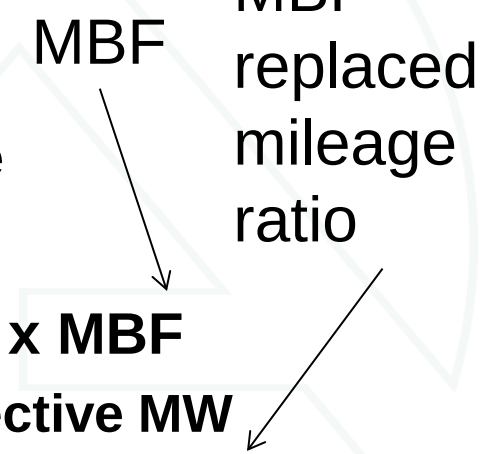
- **Clearing price in terms of $/Effective MW RegA**
- **Reg A Resource paid**
  - **$/Effective MW RegA for Capability**
  - **$/Effective MW RegA for Performance**
- **RegD Resources paid**
  - **RegA price for Capability x RegD MW**
  - **RegA price for Performance x RegD MW x Mile Ratio**

Depending on mileage rate, slight increase in payment to RegD, relative to RegA per MW.

Note: Performance piece relative small portion of total price.

Ideal Design

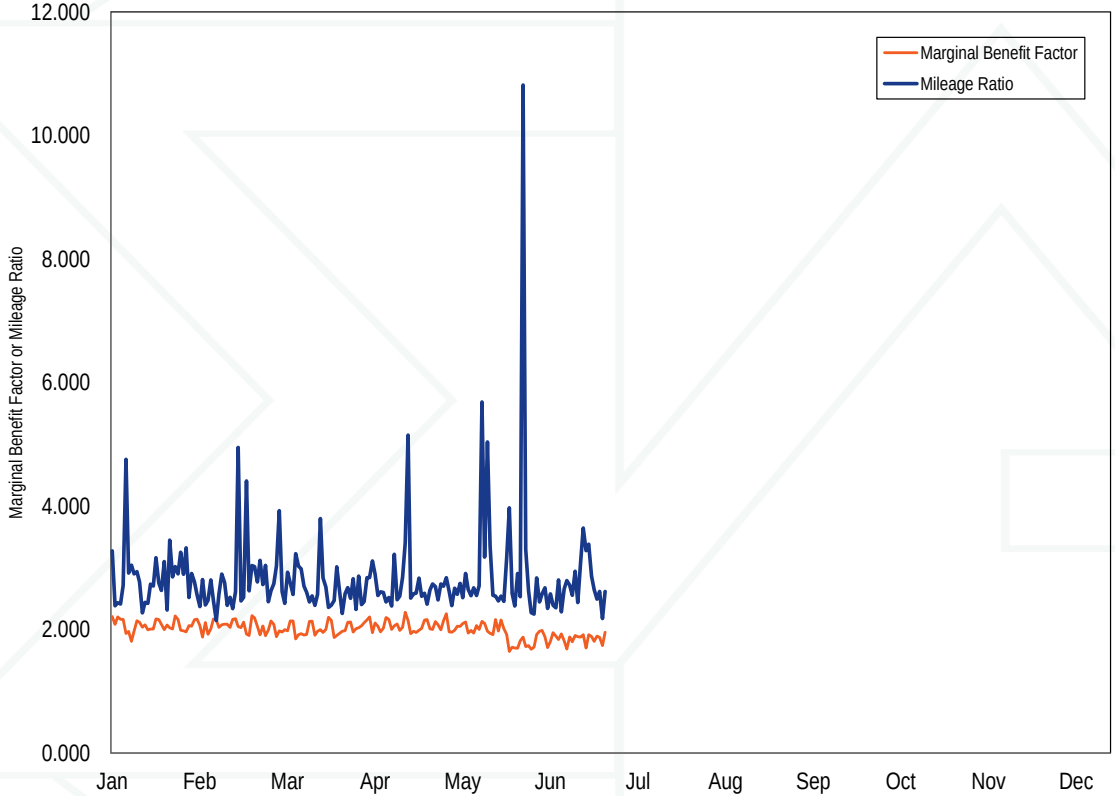
- **Clearing price in terms of $/Effective MW RegA**
- **Reg A Resource paid**
  - **$/Effective MW RegA for Capability**
  - **$/Effective MW RegA for Performance**
- **RegD Resources paid**
  - **RegA price for Capability x RegD MW x MBF**
    - **Results in RegD paid in terms of $/Effective MW**
  - **RegA price for Performance x RegD MW x MBF**
    - **Results in RegD paid in terms of $/Effective MW**



MBF vs Mileage Ratio

	Marginal Benefit Factor			Mileage Ratio		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Jan	0.915	2.441	2.065	1.113	43.184	2.834
Feb	0.911	2.361	2.058	1.160	54.340	2.747
Mar	0.895	2.389	2.001	1.249	20.818	2.692
Apr	1.188	2.424	2.066	1.402	60.054	2.722
May	0.589	2.452	1.978	1.298	200.672	3.099
Jun	0.784	2.375	1.840	1.243	15.155	2.666
Jul	0.745	2.237	1.867	1.107	45.156	2.817
Aug	0.757	2.272	1.875	1.186	19.904	2.617
Sep	0.910	2.222	1.794	1.274	24.975	2.752

MBF vs Mileage Ratio



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Effect of Current Design

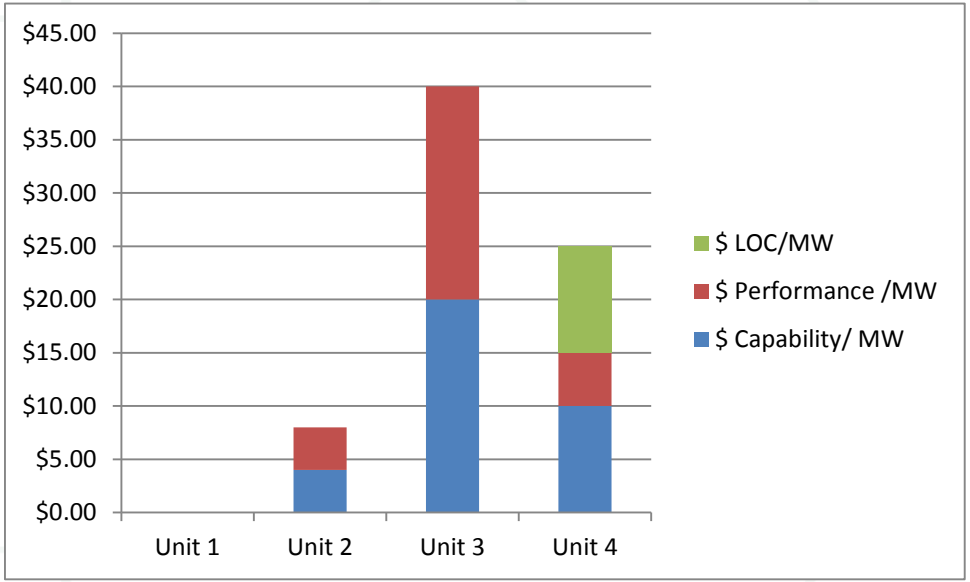
	Miles/MW
RegA	5
RegD	10
Mileage Ratio	2

Offer	$ Capability/ MW	$ Performance /MW	$ LOC/MW	Total Offer (Raw $/MW)	MW	RegA/RegD	BF	Modified Total Offer (Offer/BF)	Modified Performance Offer (offer/BF)	Effective MW	Regulation Requirement
Unit 1	$0.00	$0.00	$0.00	$0.00	10	RegD	2.8	$0.00	$0.00	29	300
Unit 2	$4.00	$4.00	$0.00	$8.00	10	RegD	2.6	$3.08	$1.54	28	300
Unit 3	$20.00	$20.00	$0.00	$40.00	10	RegD	2.5	$16.00	$8.00	27.5	300
Unit 4	$10.00	$5.00	$10.00	$25.00	300	RegA	1	$25.00	$5.00	300	300
									Total MW	384.5	300

Effect of Current Design

Offers

Offer	$ Capability/ MW	$ Performance /MW	$ LOC/MW	Total Offer (Raw $/MW)
Unit 1	$0.00	$0.00	$0.00	$0.00
Unit 2	$4.00	$4.00	$0.00	$8.00
Unit 3	$20.00	$20.00	$0.00	$40.00
Unit 4	$10.00	$5.00	$10.00	$25.00



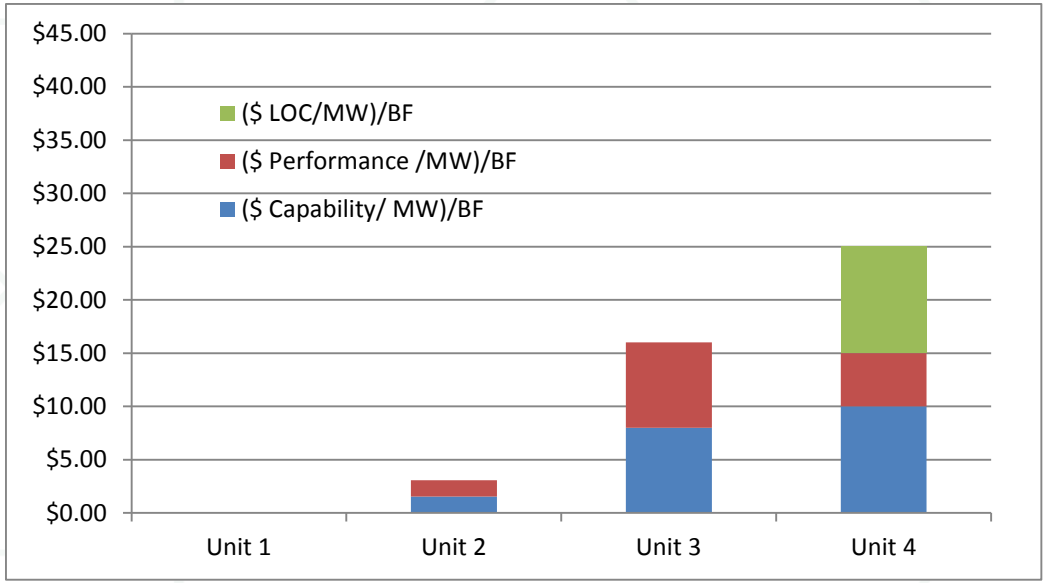
Monitoring Analytics

Effect of Current Design

BF Adjusted offers

Offer	$ Capability/ MW	$ Performance /MW	$ LOC/MW
Unit 1	$0.00	$0.00	$0.00
Unit 2	$4.00	$4.00	$0.00
Unit 3	$20.00	$20.00	$0.00
Unit 4	$10.00	$5.00	$10.00

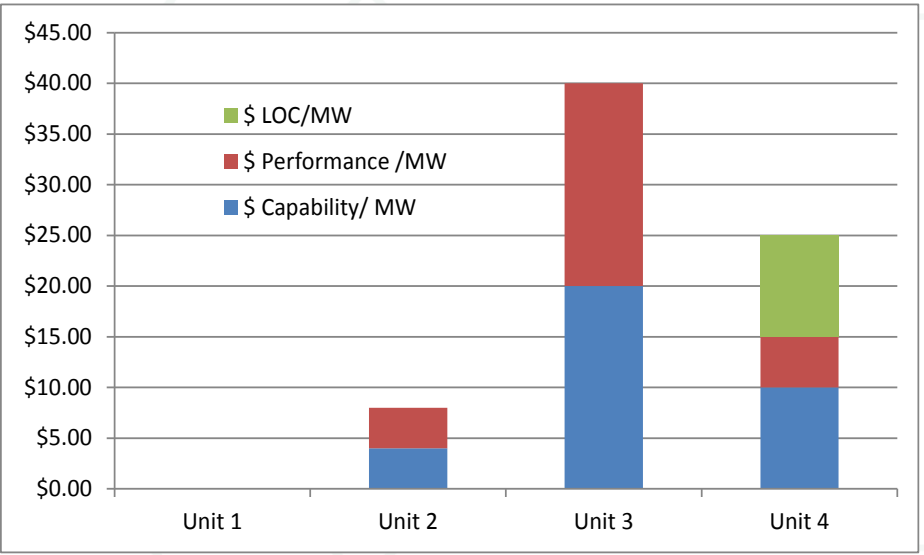
Offer	($ Capability/ MW)/BF	($ Performance /MW)/BF	($ LOC/MW) /BF
Unit 1	$0.00	$0.00	$0.00
Unit 2	$1.54	$1.54	$0.00
Unit 3	$8.00	$8.00	$0.00
Unit 4	$10.00	$5.00	$10.00



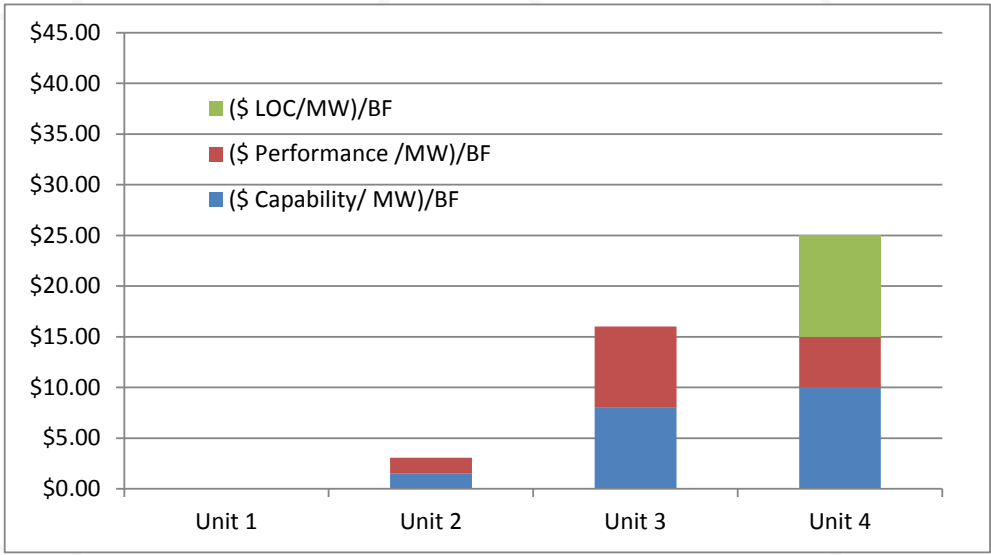
Monitoring Analytics

Effect of Current Design

No BF adjustment



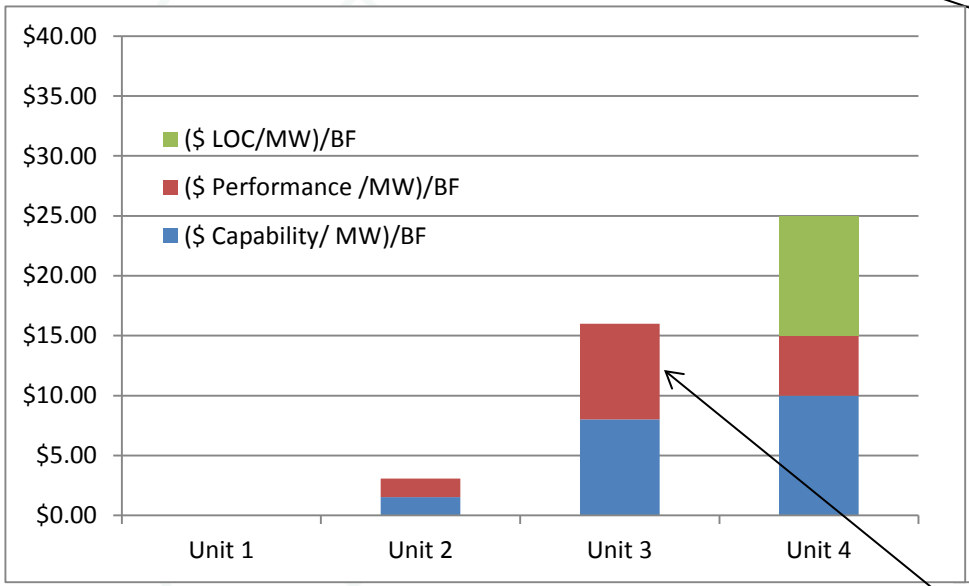
BF Adjusted

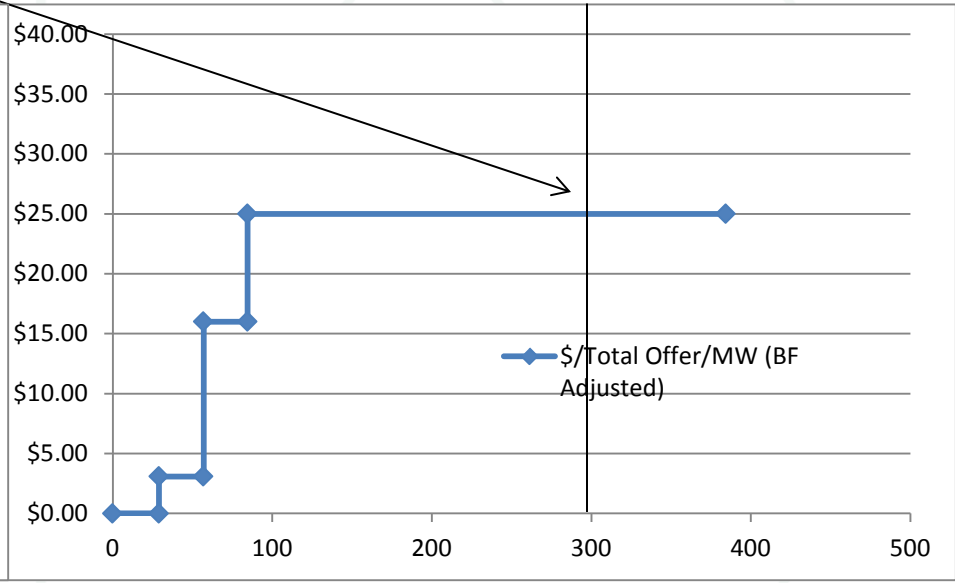


Monitoring Analytics

Effect of Current Design

Clearing price $/MW





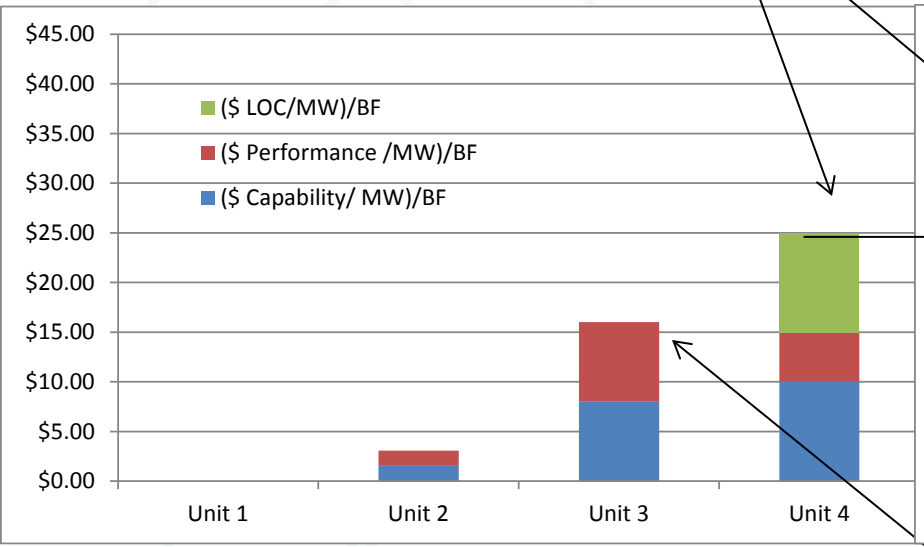
Performance price (biggest)

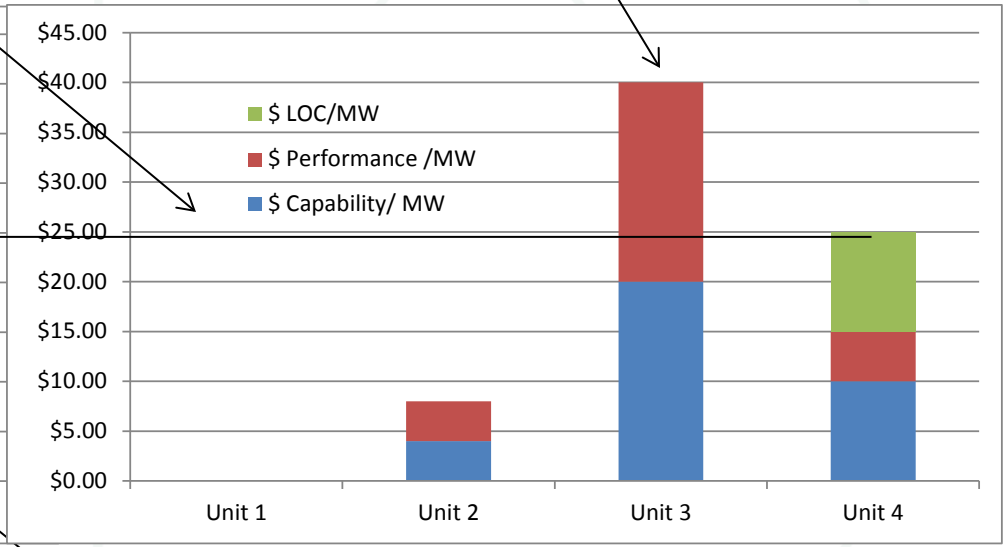
Monitoring Analytics

Settlement

Clearing price $/MW

Clearing price will not cover





Performance price (biggest)

Monitoring Analytics

Current Settlement: Mileage Ratio

Offer	$ Capability/ MW	$ Performance /MW	$ LOC/MW	Total Offer/MW	MW cleared	Total Cost of Offer
Unit 1	$0.00	$0.00	$0.00	$0.00	10.0	$0.00
Unit 2	$4.00	$4.00	$0.00	$8.00	10.0	$80.00
Unit 3	$20.00	$20.00	$0.00	$40.00	10.0	$400.00
Unit 4	$10.00	$5.00	$10.00	$25.00	215.5	$5,387.50

Offer	($ Capability/ MW)/BF	($ Performance /MW)/BF	($ LOC/MW) /BF	Clearing Price $/MW	Performance Clearing Price $/MW	Capability Price $/MW	Mileage Ratio	Capability Payment/ MW	Performance Payment/MW	Total Payment/MW	Total Payment	Total Profit
Unit 1	$0.00	$0.00	$0.00	$25.00	$8.00	$17.00	2.00	$17.00	$16.00	$33.00	$330.00	$330.00
Unit 2	$1.54	$1.54	$0.00	$25.00	$8.00	$17.00	2.00	$17.00	$16.00	$33.00	$330.00	$250.00
Unit 3	$8.00	$8.00	$0.00	$25.00	$8.00	$17.00	2.00	$17.00	$16.00	$33.00	$330.00	-$70.00
Unit 4	$10.00	$5.00	$10.00	$25.00	$8.00	$17.00	1.00	$17.00	$8.00	$25.00	$5,387.50	$0.00

- Higher payment for RegD per MW
- But payment inconsistent on effective MW basis.

Current Settlement: Mileage Ratio

Offer	($ Capability/ MW)/BF	($ Performance /MW)/BF	($ LOC/MW) /BF	Clearing Price $/MW	Performance Clearing Price $/MW	Capability Price $/MW	Total Payment/ MW	Total Payment	MBF	MW Cleared	Total Effective MW (at margin)	Effective Payment per Effective MW of RegA
Unit 1	$0.00	$0.00	$0.00	$25.00	$8.00	$17.00	$33.00	$330.00	2.50	10.00	25.00	$13.20
Unit 2	$1.54	$1.54	$0.00	$25.00	$8.00	$17.00	$33.00	$330.00	2.50	10.00	25.00	$13.20
Unit 3	$8.00	$8.00	$0.00	$25.00	$8.00	$17.00	$33.00	$330.00	2.50	10.00	25.00	$13.20
Unit 4	$10.00	$5.00	$10.00	$25.00	$8.00	$17.00	$25.00	$5,387.50	1.00	215.50	215.50	$25.00

- $/effective MW not equal across resource types
- Caused by failure to use BF/MBF consistently in market.
- Price provided in terms of $/Effective MW, needs to be settled in same terms.

Ideal Design

- Clearing price in terms of $/Effective MW RegA
- Objective is to pay each resource for $/effective MW provided
- Price realized should be the same for each effective MW provided
- Clearing price was $25 per effective MW
- RegA resources should realize $25 per effective MW
- RegD resources should realize $25 per effective MW

Ideal Design

- Clearing price in terms of $/Effective MW RegA
- Reg A Resource paid
  - $/Effective MW RegA for Capability
  - $/Effective MW RegA for Performance
- RegD Resources paid
  - RegA price for Capability x RegD MW x MBF
    - Results in RegD paid in terms of $/Effective MW
  - RegA price for Performance x RegD MW x MBF
    - Results in RegD paid in terms of $/Effective MW

Settlement

Current approach

Offer	$ Capability/ MW	$ Performance /MW	$ LOC/MW	Total Offer/MW	MW cleared	Total Cost of Offer
Unit 1	$0.00	$0.00	$0.00	$0.00	10.0	$0.00
Unit 2	$4.00	$4.00	$0.00	$8.00	10.0	$80.00
Unit 3	$20.00	$20.00	$0.00	$40.00	10.0	$400.00
Unit 4	$10.00	$5.00	$10.00	$25.00	215.5	$5,387.50

Ideal

Offer	($ Capability/ MW)/BF	($ Performance /MW)/BF	($ LOC/MW) /BF	Clearing Price $/MW	Performance Clearing Price $/MW	Capability Price $/MW	Mileage Ratio	Capability Payment/ MW	Performance Payment/MW	Total Payment/MW	Total Payment	Total Profit
Unit 1	$0.00	$0.00	$0.00	$25.00	$8.00	$17.00	2.00	$17.00	$16.00	$33.00	$330.00	$330.00
Unit 2	$1.54	$1.54	$0.00	$25.00	$8.00	$17.00	2.00	$17.00	$16.00	$33.00	$330.00	$250.00
Unit 3	$8.00	$8.00	$0.00	$25.00	$8.00	$17.00	2.00	$17.00	$16.00	$33.00	$330.00	-$70.00
Unit 4	$10.00	$5.00	$10.00	$25.00	$8.00	$17.00	1.00	$17.00	$8.00	$25.00	$5,387.50	$0.00

Offer	($ Capability/ MW)/BF	($ Performance /MW)/BF	($ LOC/MW) /BF	Clearing Price $/MW	Performance Clearing Price $/MW	Capability Price $/MW	MBF	Capability Payment/ MW	Performance Payment/MW	Total Payment/MW	Total Payment	Total Profit
Unit 1	$0.00	$0.00	$0.00	$25.00	$8.00	$17.00	2.50	$42.50	$20.00	$62.50	$625.00	$625.00
Unit 2	$1.54	$1.54	$0.00	$25.00	$8.00	$17.00	2.50	$42.50	$20.00	$62.50	$625.00	$545.00
Unit 3	$8.00	$8.00	$0.00	$25.00	$8.00	$17.00	2.50	$42.50	$20.00	$62.50	$625.00	$225.00
Unit 4	$10.00	$5.00	$10.00	$25.00	$8.00	$17.00	1.00	$17.00	$8.00	$25.00	$5,387.50	$0.00

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Current vs Proposed

Offer	($ Capability/ MW)/BF	($ Performance /MW)/BF	($ LOC/MW) /BF	Clearing Price $/MW	MW Provided	MBF	Effective MW provided at Margin	Total Payment Current Method	$/Effective MW Using Current Mileage Ratio Method	Total Payment MBF Adjusted Method	$/Effective MW Using Consistent Application of MBF
Unit 1	$0.00	$0.00	$0.00	$25.00	10.00	2.50	25.00	$330.00	$13.20	$625.00	$25.00
Unit 2	$1.54	$1.54	$0.00	$25.00	10.00	2.50	25.00	$330.00	$13.20	$625.00	$25.00
Unit 3	$8.00	$8.00	$0.00	$25.00	10.00	2.50	25.00	$330.00	$13.20	$625.00	$25.00
Unit 4	$10.00	$5.00	$10.00	$25.00	215.50	1.00	215.50	$5,387.50	$25.00	$5,387.50	$25.00

Current approach (payment varies on $/Effective MW basis)

Proposed Approach (same $/Effective)

LOC: Optimization/Market Clearing Issues

Monitoring Analytics

Lost Opportunity Cost: LOC

- **LOC is intended to reflect:**
  - **The lost opportunity associated with foregone energy sales incurred when providing regulation service**
  - **Costs associated with operating uneconomically to provide regulation (regulation set point above economic point for energy)**
  - **Real costs from not following economic dispatch signal**

Lost Opportunity Cost: LOC

- **LOC is intended to make participant indifferent to providing regulation (outside of regulation related costs/offer)**
- **In optimization, intended to reflect incremental cost to using resource to provide regulation rather than energy.**
- **To align incremental cost to provide regulation and incremental cost in terms of energy, need to base off the operational offer in use.**

Lost Opportunity Cost: LOC

- Regulation market does not use the operational energy offer.
- Uses the lower of cost or price.
- Where lower of price or cost <> operational offer
  - Internalized opportunity cost to provide regulation > actual opportunity cost to provide regulation.
  - Reduced efficiency to market solution.
  - Artificial increase to regulation price when marginal.

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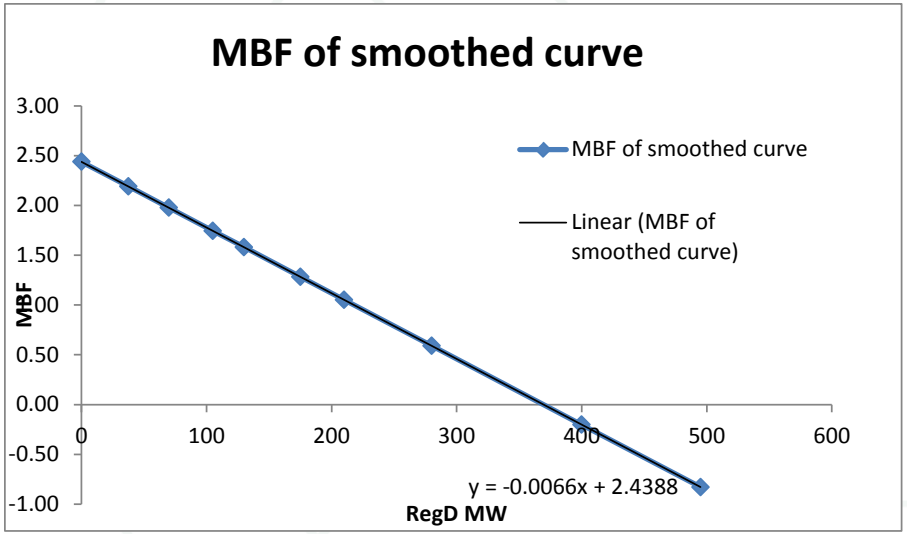
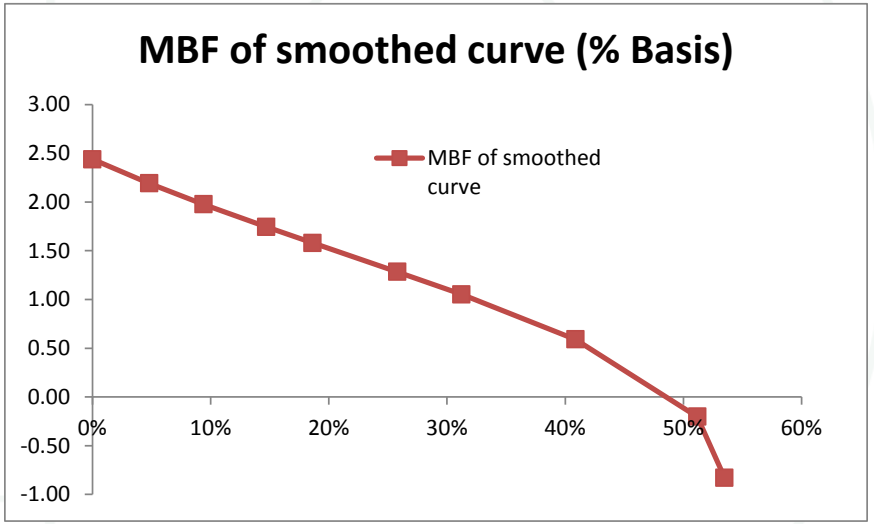
Appendix: MBF based on MW vs. MBF based on %Reg D.

Monitoring Analytics

KEMA based combinations with the same CPS1 Scores, Resulting BF Function





Monitoring Analytics

PJM Current Approach

- **RTO Regulation MW target for effective MW (829 MW for example).**
- **Reg requirement can be met with X MW of RegA (829 MW for example).**
- **RegD%, for purposes of determining resource specific BF, is Reg MW (*actual*) as a percent of X *effective* MW target (829 MW for example).**

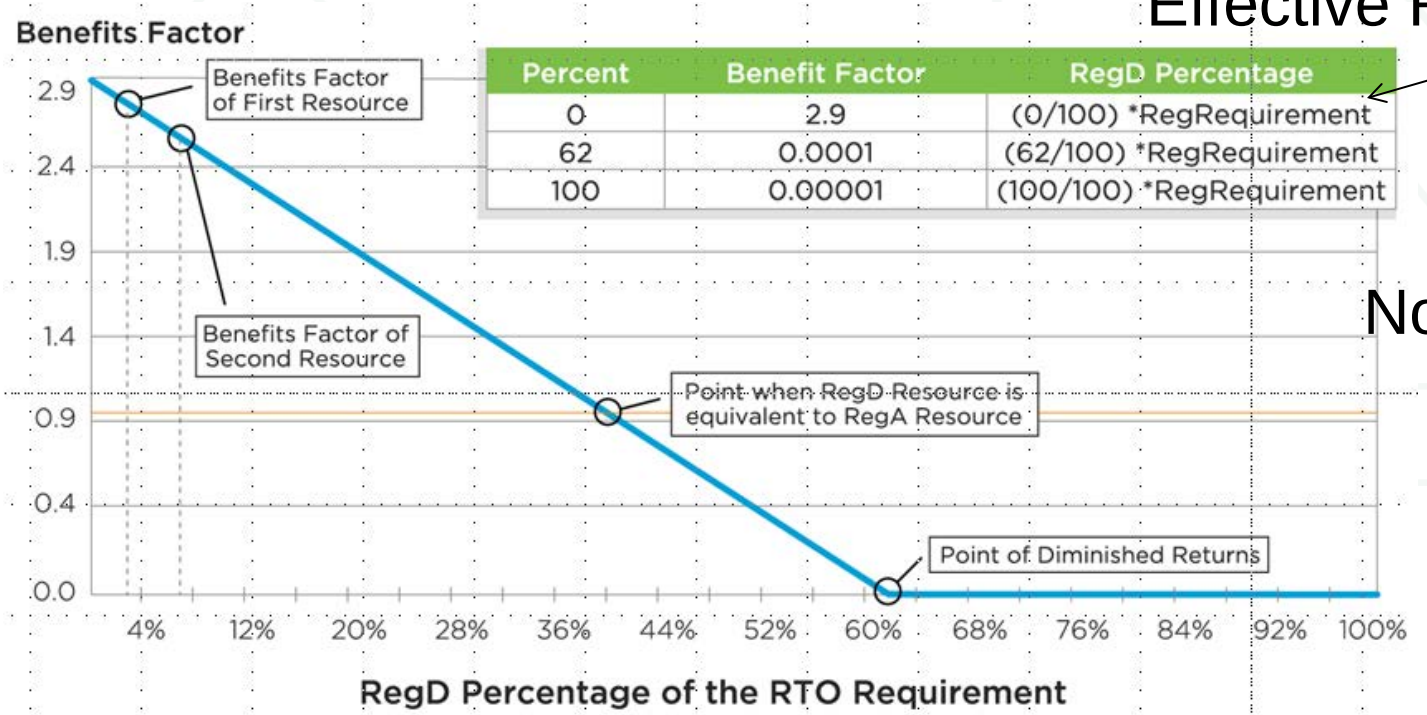
Monitoring Analytics

PJM Current Approach

Effective Reg Requirement

Percent	Benefit Factor	RegD Percentage
0	2.9	(0/100) *RegRequirement
62	0.0001	(62/100) *RegRequirement
100	0.00001	(100/100) *RegRequirement

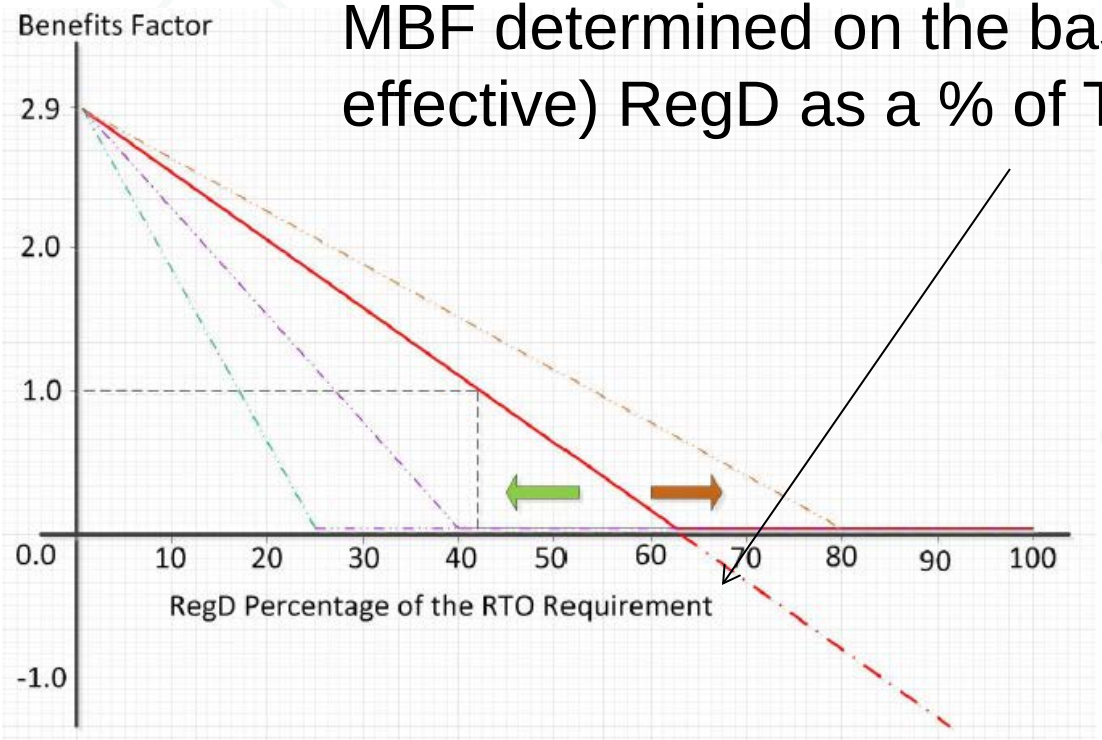
Not % of RegMW



Monitoring Analytics

PJM Current Approach

MBF determined on the basis of actual (not effective) RegD as a % of Total Reg MW



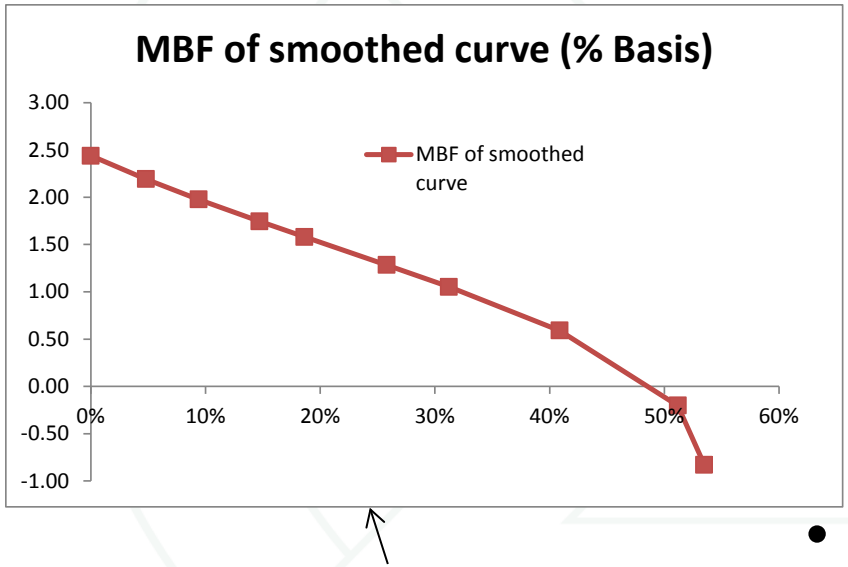
Not consistent with RegD% of fixed MW amount (here 829 MW)

Monitoring Analytics

PJM Current Approach: Applied to Current Example

- **RTO Regulation MW target for effective MW (829 MW for example).**
- **Reg requirement can be met with X MW of RegA (829 MW for example).**
- **RegD%, for purposes of determining resource specific BF, is Reg MW as a percent of X MW target (829 MW for example).**

PJM current approach to RegA/RegD combinations



RegD/Effective MW Target

- Same BF function, different axis interpretation (inconsistent with derivation).

  BF determined/assigned as a function of RegD MW as a percent of Effective MW target.

- BF not determined/assigned as RegD MW as a percent of total MW of regulation.

PJM current approach to RegA/RegD combinations

MW Requirement (Baseline for PJM	Percentage RegD	Assigned MBF to %
829.19	0%	2.4388
829.19	5%	2.1913
829.19	9%	1.9768
829.19	15%	1.7458
829.19	19%	1.5808
829.19	26%	1.2838
829.19	31%	1.0528
829.19	41%	0.5908
829.19	51%	-0.2012
829.19	53%	-0.8282

- Same BF function, different axis interpretation (inconsistent with derivation).
- BF determined/assigned as a function of RegD MW as a percent of Effective MW target.
- BF not determined/assigned as RegD MW as a percent of total MW of regulation.

PJM current approach to RegA/RegD combinations

MW Requirement (Baseline for PJM	Percentage RegD	Assigned MBF to %	RegD MW
829.19	0%	2.4388	0.00
829.19	5%	2.1913	39.87
829.19	9%	1.9768	77.95
829.19	15%	1.7458	121.85
829.19	19%	1.5808	154.45
829.19	26%	1.2838	213.88
829.19	31%	1.0528	258.90
829.19	41%	0.5908	338.92
829.19	51%	-0.2012	424.32
829.19	53%	-0.8282	443.46

- BF determined/assigned as a function of RegD MW as a percent of Effective MW target.
- RegA MW cleared determined as a residual= (assuming all the RegD priced at zero)
- Total Effective MW Needed – Effective MW from RegD cleared

PJM current approach to RegA/RegD combinations

BF with another logic

Perf_Adj_MW	BF	Eff_MW
10	2.8332	28.3
9	2.773	2.05
8	2.7196	21.8
7	2.6728	18.7
5	2.6394	13.2
5	2.6060	13.0
Total Eff_MW		**120**

$$BF_i = \frac{EffMW_i * (0.0001 - 2.9)}{Percentage\ RegD * RegReq} + 2.9$$

Source: PJM Presentation 08/11/2015

Note: proportion of RegD to total Reg clearing not being used.

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PJM current approach to RegA/RegD combinations

MW Requirement (Baseline for PJM	Percentage RegD	Assigned MBF to %	RegD MW	Calculated Effective MW RegD	Residual RegA (PJM approach)	PJM Calculated Effective MW
829.19	0%	2.4388	0.00	0.00	829.19	829.19
829.19	5%	2.1913	39.87	92.30	736.89	829.19
829.19	9%	1.9768	77.95	172.09	657.10	829.19
829.19	15%	1.7458	121.85	254.96	574.23	829.19
829.19	19%	1.5808	154.45	310.42	518.77	829.19
829.19	26%	1.2838	213.88	398.09	431.10	829.19
829.19	31%	1.0528	258.90	451.99	377.20	829.19
829.19	41%	0.5908	338.92	513.39	315.80	829.19
829.19	51%	-0.2012	424.32	474.73	354.46	829.19
829.19	53%	-0.8282	443.46	357.12	472.07	829.19

Effective MW from RegD cleared = Cumulative effective MW from RegD.

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