BONNEVILLE POWER ADMINISTRATION

BP-20 Solar Study

Frank Puyleart, BPA TOOC Libby Kirby, BPA TOOC

Attachment 2 – BP-20 Partial Rates Settlement Agreement

Solar Technical Work. As part of the workshop phase of the BP-22 rate case, and starting no later than January, 2020, Bonneville will:

- i. Present to customers and stakeholders the costs and impacts of holding reserves in a non-flat shape, such as planned shaped diurnal reserve amounts. This presentation(s) will use the BP-18 Solar Integration Study with Solar modeling updates identified and implemented during BP-20 workshops to provide:
 - a) Up to two shaped balancing reserve forecasts for all Generation Input customer classes (Wind, Solar, DERBS and Load).
 - b) Forecasts for the different thresholds of installed solar generation in order to identify any meaningful thresholds where a shaped diurnal balancing reserve forecast or other form of planned shaped reserve operation becomes impactful and cost-effective.
- ii. Analyze and present to customers any Generation Inputs variable and embedded cost allocation differences associated with a shaped balancing reserve operation, including the associated impact on Ancillary and Control Area Service rates. This analysis and presentation will:
 - a) Assume that shaped balancing reserve held on Bonneville's system is physically possible.
 - b) Use a variation of the Generation And Reserves Dispatch (GARD) model or other balancing reserve variable cost estimation method to estimate any material change in Bonneville's cost of providing balancing reserves associated with a planned shaped balancing reserves operation. If, following these deliverables, Bonneville staff, customers and stakeholders agree that a shaped balancing reserve operation provides material value, Bonneville will provide customers a list highlighting the workload necessary with approximate completion timelines that would need to occur for Bonneville to be able to implement such an operation.

Disclaimer: INCs and DECs

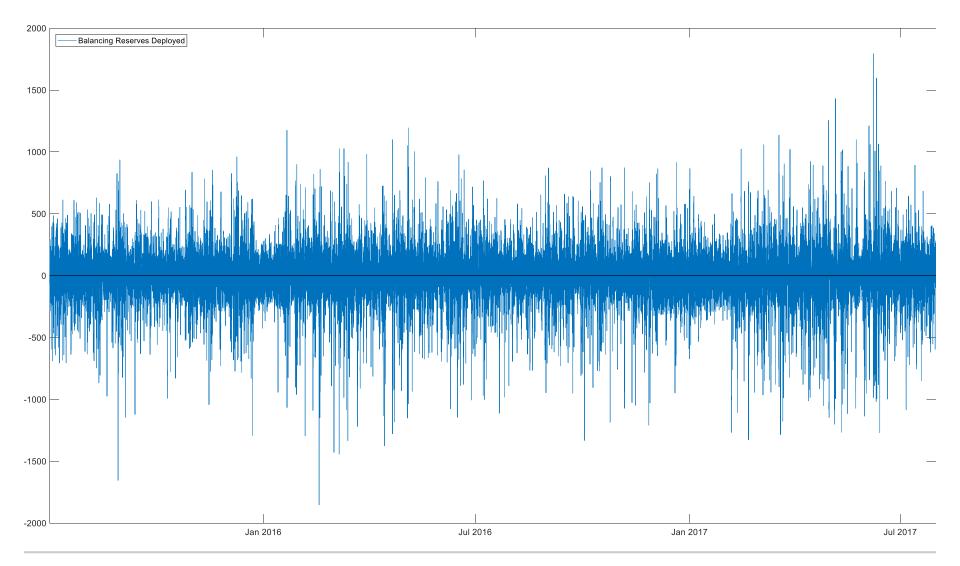
Concepts in these slides will all be demonstrated for INC reserves.

DEC reserves operate under the same principles and are only excluded from this presentation for the purposes of simplification.

CURRENT BPA METHODOLOGY

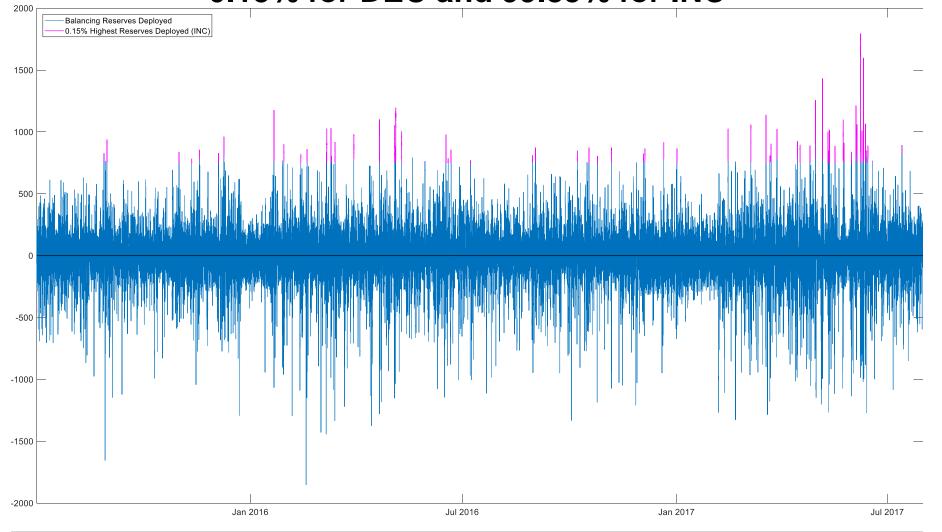
- Consider all generation and load data over the study period (two years for this study).
- Determine Balancing Reserves Deployed for those two years
 - (BA Load Actual BA Load Forecast) (BA Generation Actuals BA Generation Schedules)
- Determine tail events of Balancing Reserves Deployed over those two years at 0.15% for DEC and 99.85% for INC for all hours and all days.
 - Which sets Balancing Reserves at the level that encompasses the remaining 99.7% of Balancing Reserves Deployed
- Balancing Reserves held constant 24/7 with adjustments only for changes in Generation Installed Capacity in the BA.

Determine Balancing Reserves Deployed over two year period



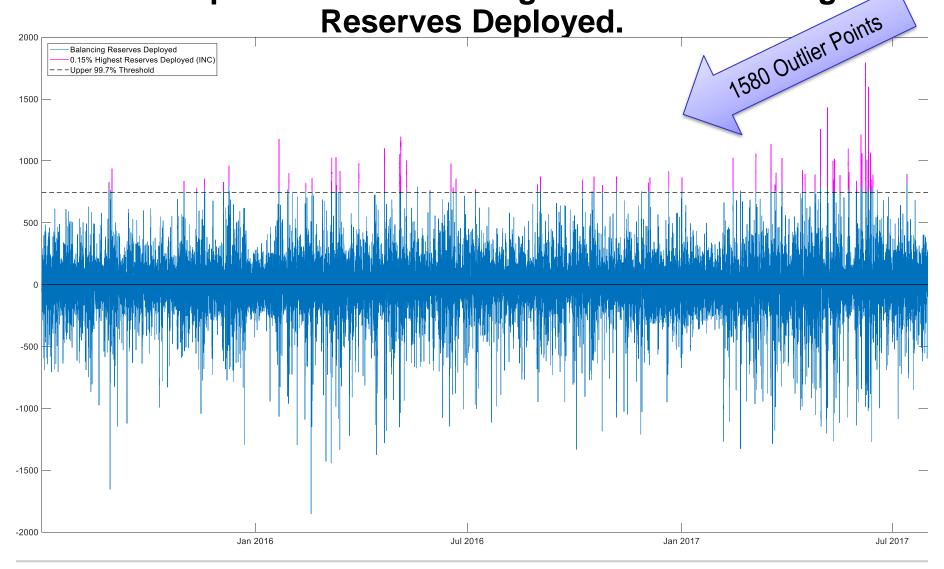


Determine tail events of Balancing Reserves Deployed over those two years at 0.15% for DEC and 99.85% for INC





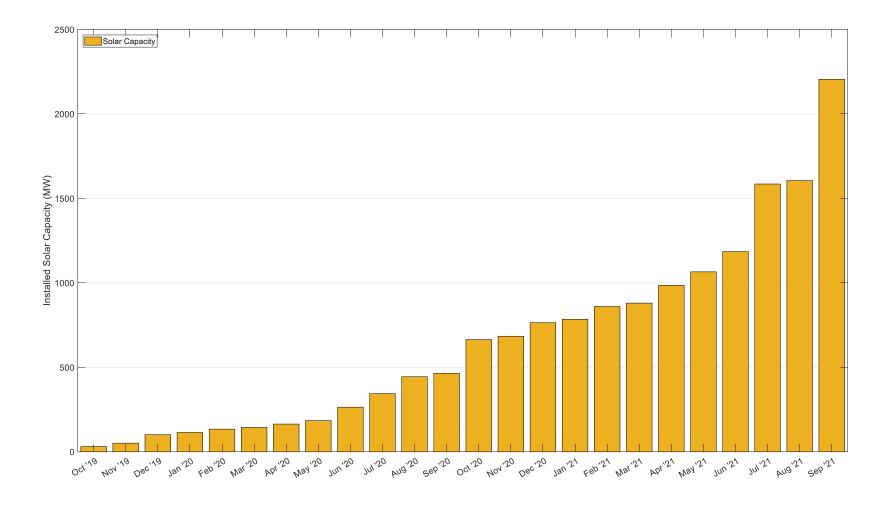
Balancing Reserves are set at the level that encompasses the remaining 99.7% of Balancing Reserves Deployed.



Shaped Reserve Options in BP-20 Settlement

- As part of the settlement for BP-20, BPA committed to further Solar integration study work from the BP-18 settlement by investigating a "shaped" reserve option that would set reserve levels by time of day and year.
- Load and non-solar generation are held constant at the post-BP-18 level (a 10/1/2019 snapshot).
- Per the BPA Balancing Reserve Forecast methodology, load and generation are analyzed as a whole for diversity and ISD is used to separate out the individual requirements (Solar, Wind, Load, etc.).

Solar Capacity Modeled in the Study





Shaped Solar Reserve Options

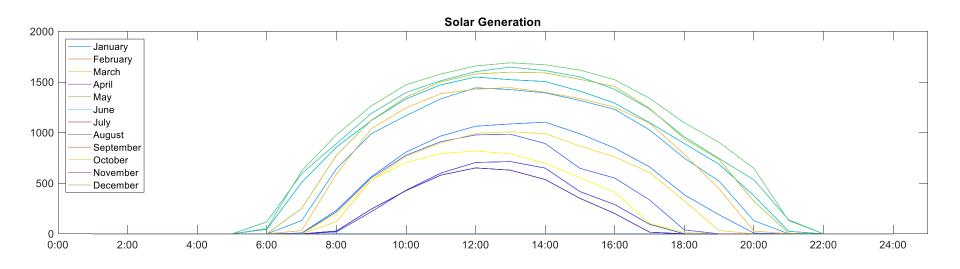
1. Rolling Monthly

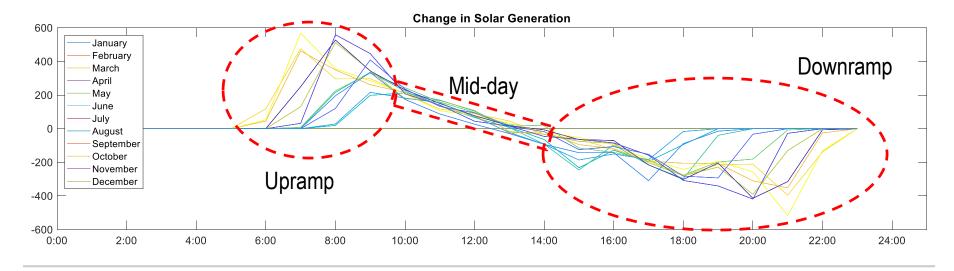
- In each month, reserves are calculated based on historical data from four time of day periods: night, upramp, mid-day, and downramp.
- Reserves are calculated with data from the preceding month, the target month and the following month, effectively tripling the dataset from the target month.

2. Shaped Seasonal

- In each month, reserves are calculated based on historical data from four time of day periods: night, upramp, mid-day, and downramp.
- Reserves are calculated with time periods from sets of months based on the seasons (i.e. Autumn: September, October, November; Summer: June, July, August; etc.)

Solar Time of Day Period Definitions



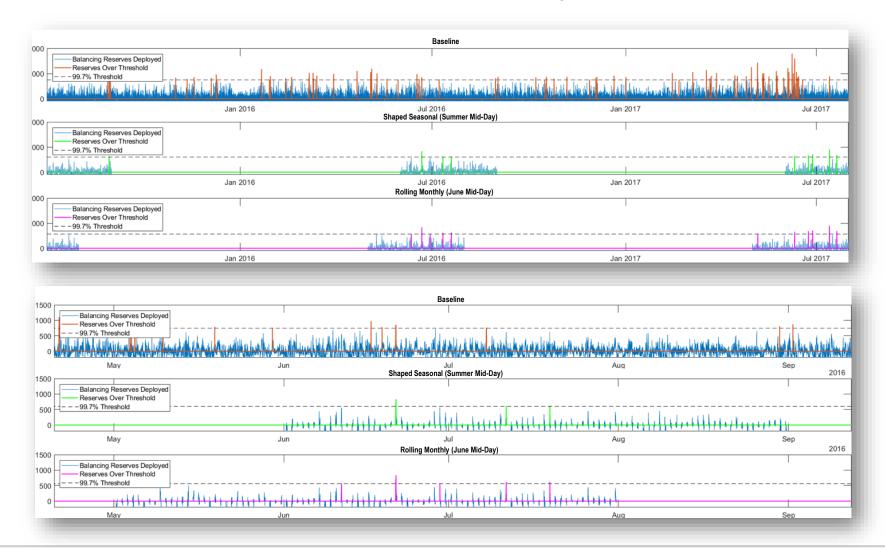


Impacts of Reduced Datapoints in the Studies Datapoint Totals

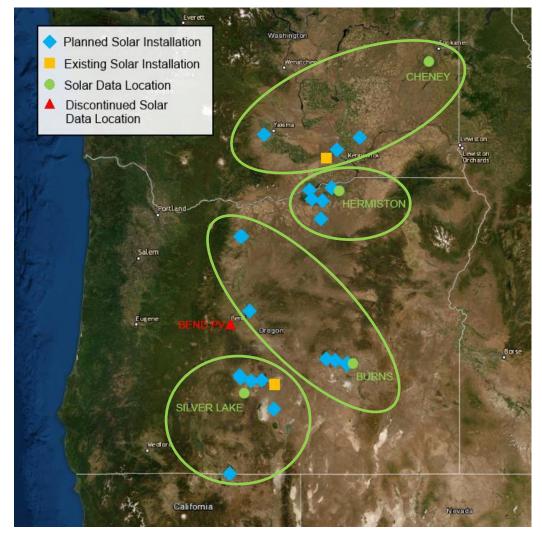
Reserve Method	Max Evaluated Total	Average Evaluated Total	Min Evaluated Total	99.7 % Max Tails	99.7% Average Tails	99.7% Min Tails	highest data point period	lowest data point period
Current Methodology	1053120	1053120	1053120	1580	1580	1580	N/A	N/A
Rolling Monthly	143700	65730	28860	215	99	43	Dec- Night	January- Mid-Day
Shaped Seasonal	141480	65730	28860	212	99	43	Winter- Night	Winter- Mid-Day

- Datapoints in "evaluated" columns represent total number of datapoints considered when generating the reserve number for a given period (Rolling Monthly: June-Upramp; Shaped Seasonal: Night, etc.).
- Datapoints in "99.7" columns represent datapoints that are discarded in the tails of the distribution.

Impacts of Reduced Datapoints in the Studies: Visual Comparison for Daytime Data



Proposed Solar Plant and University of Oregon Data Locations



1. Rolling Monthly

In each month, reserve levels are calculated for four different times of the day for the current, preceding, and following months.

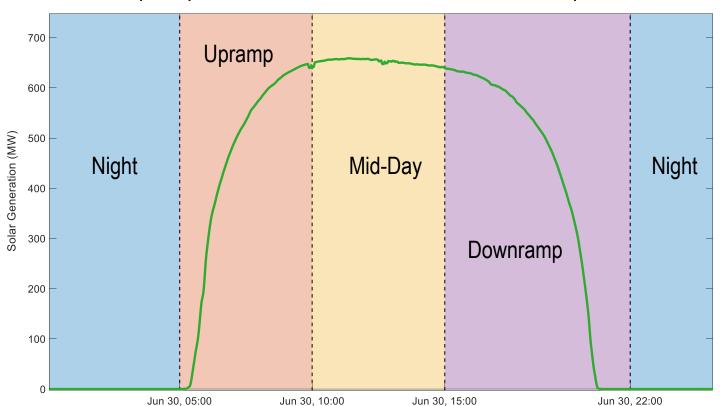
Times of Day



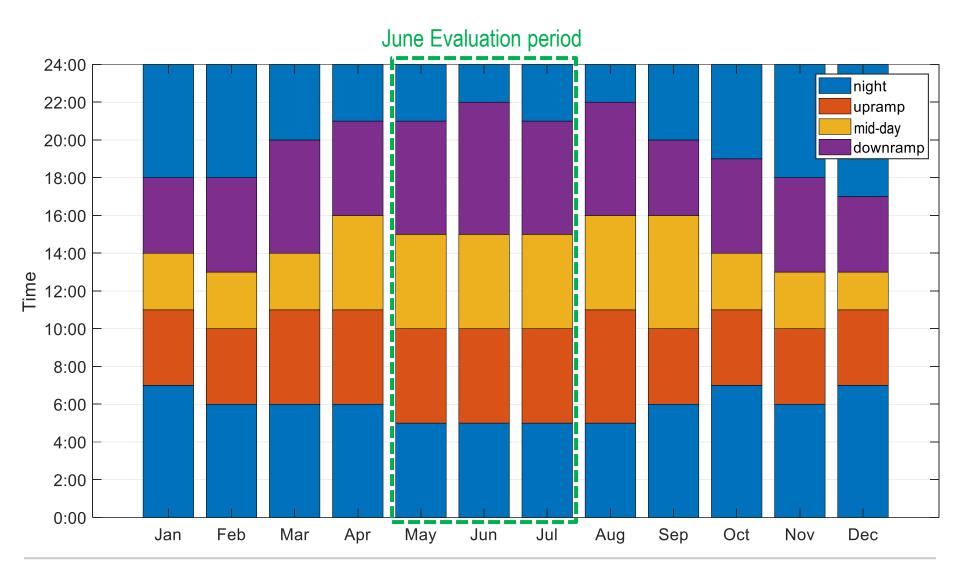
Upramp

Mid-day

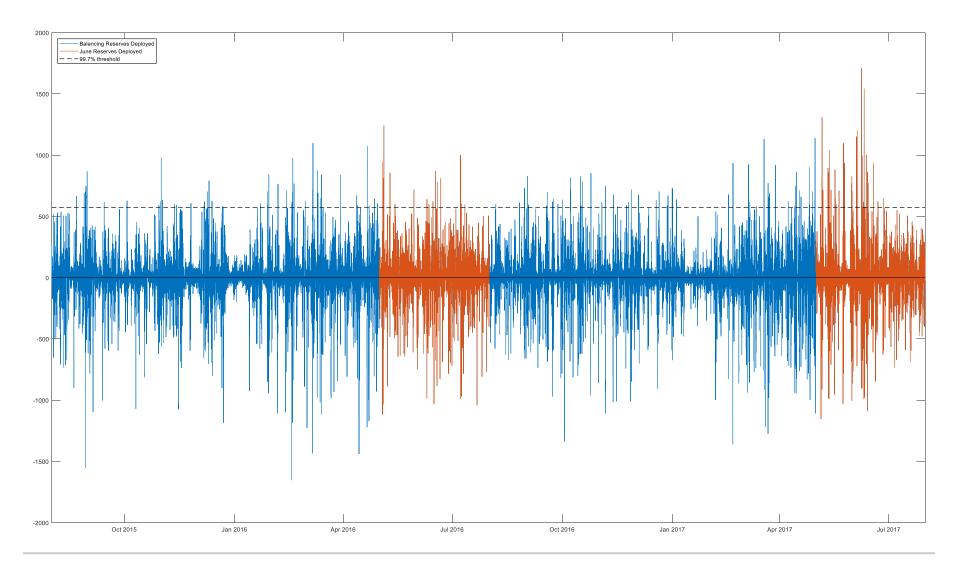
Downramp



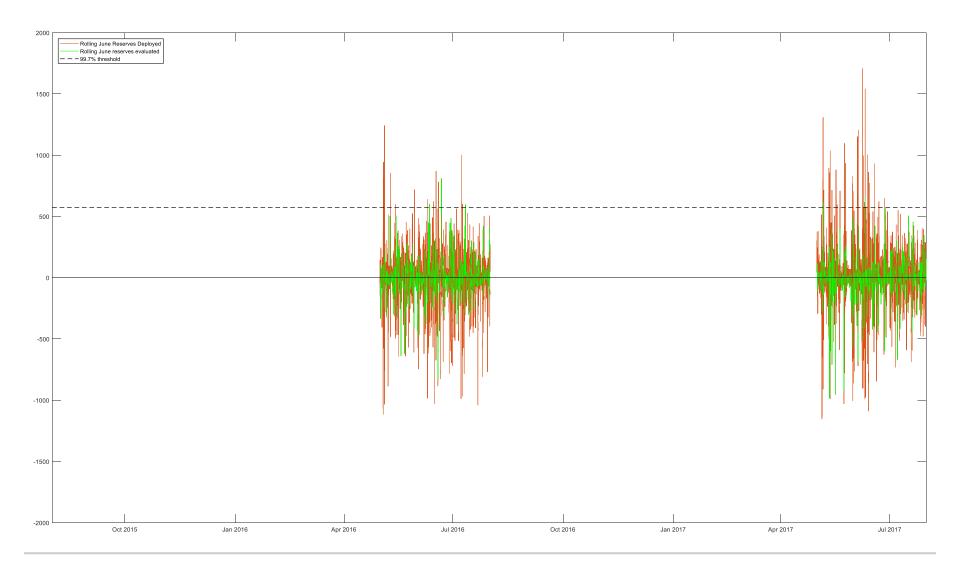
Rolling Monthly Period Definitions



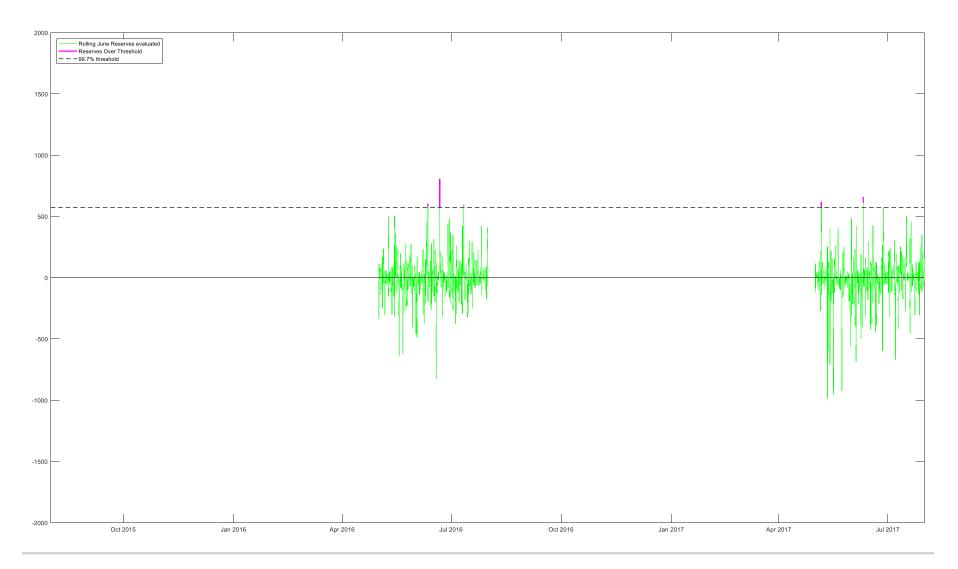
June Subset



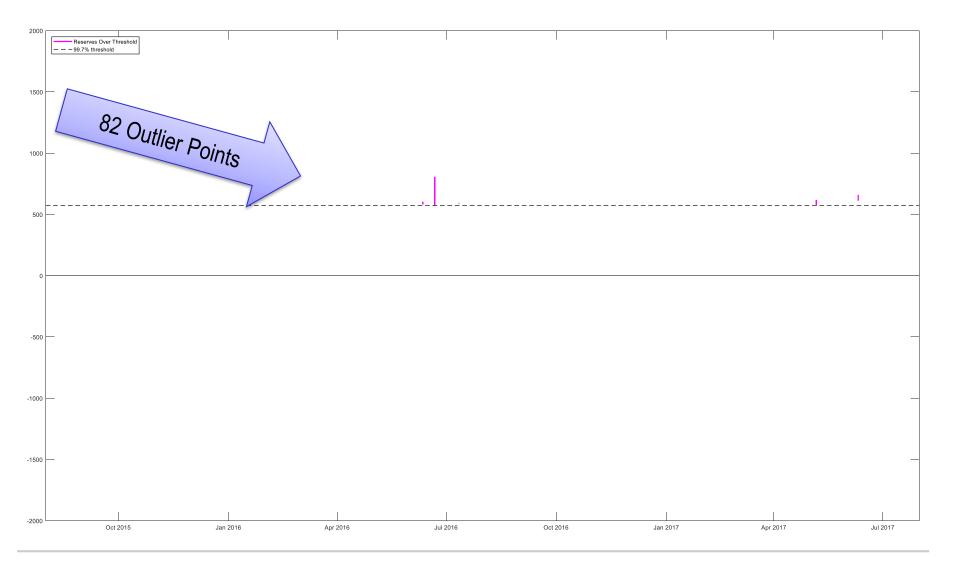
June Mid-Day Reserves



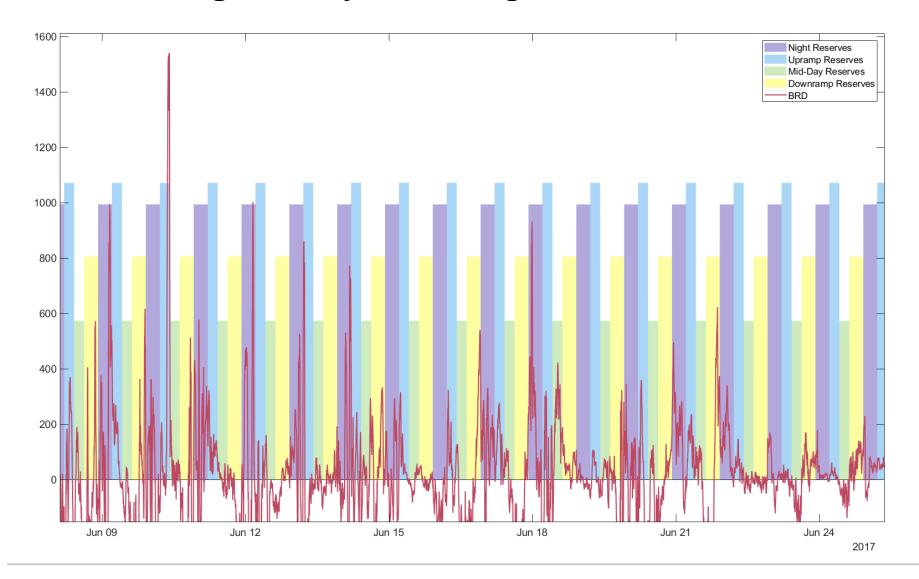
June Mid-Day Reserves Deployed Subset



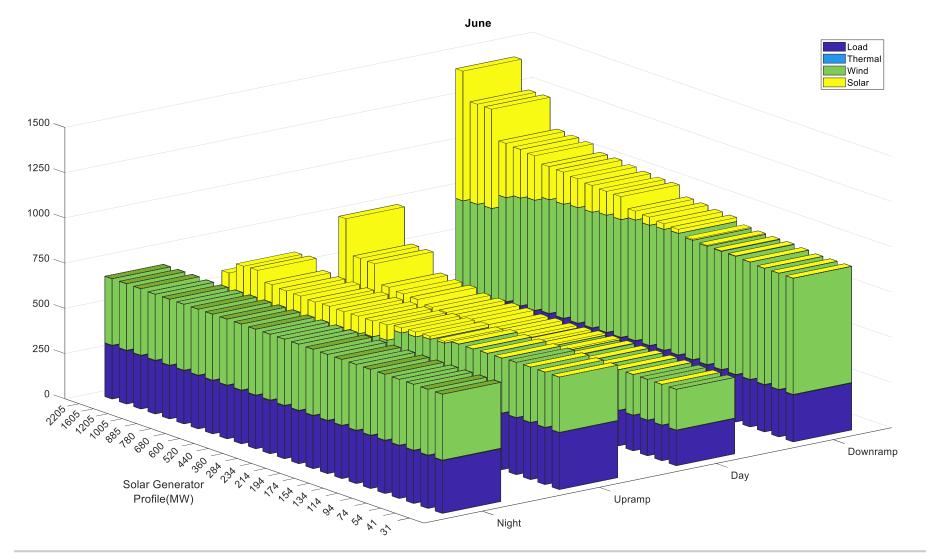
June Mid-Day Reserves Deployed Subset



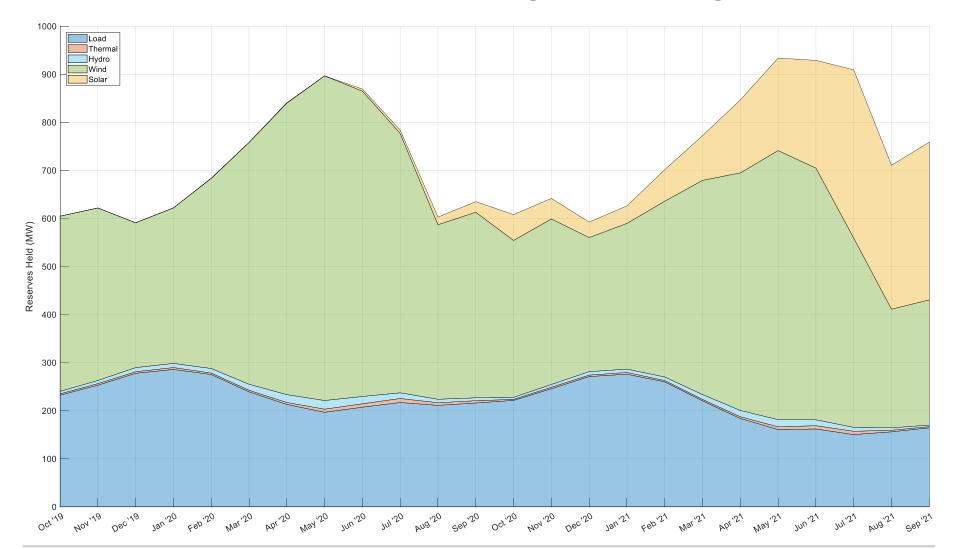
Rolling Monthly Balancing Reserves vs. BRD



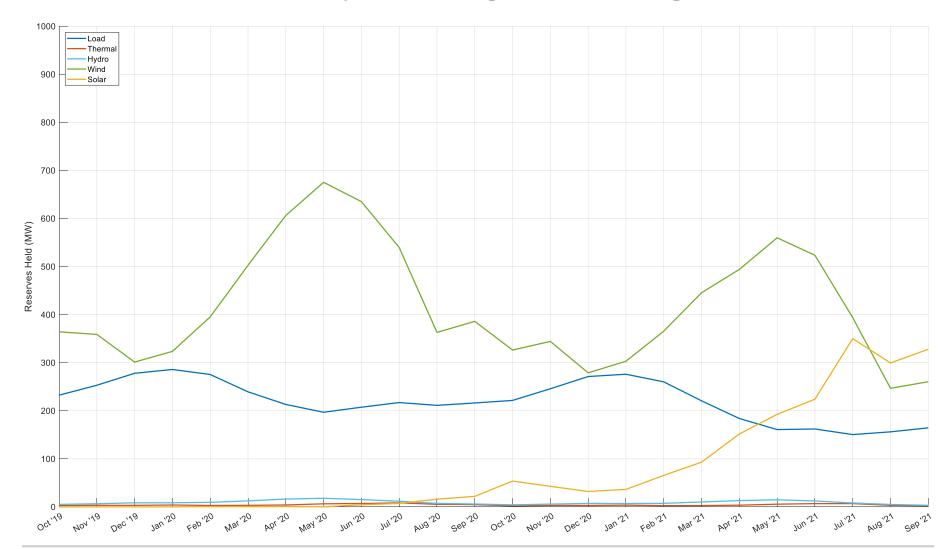
Rolling Monthly Balancing Reserve Over Different Solar Profiles



Rolling Monthly Balancing Reserve Stacked Totals - Weighted Average



Rolling Monthly Balancing Reserve Gen Type - Weighted Average



2. Shaped Seasonal

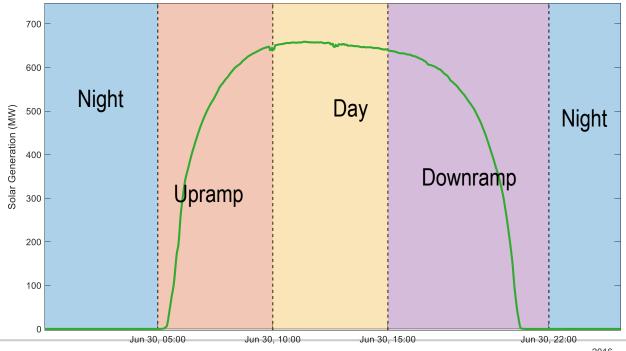
In each of four seasons, reserve levels are calculated for four different times of the day.

Times of Day

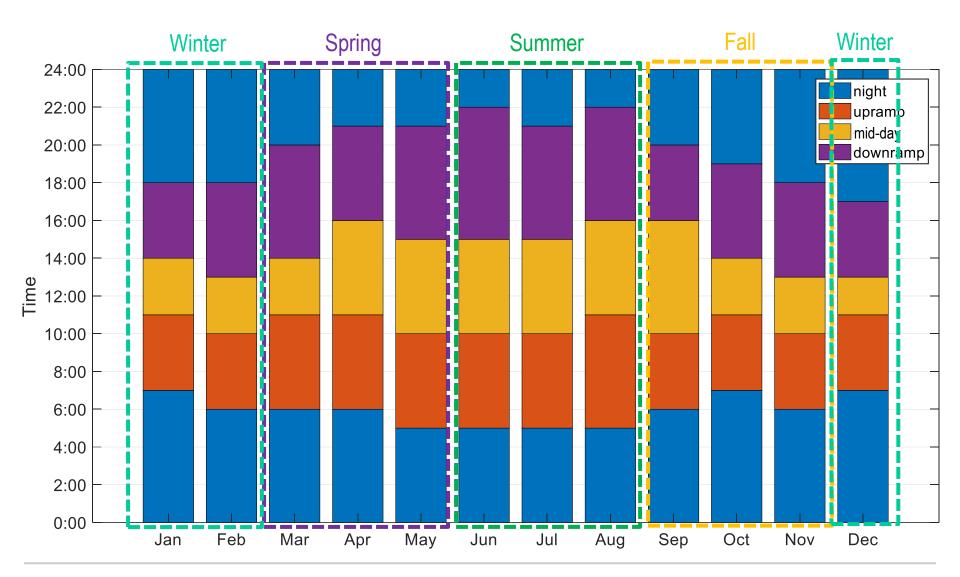
- Night
- Upramp
- Mid-day
- Downramp

Seasons

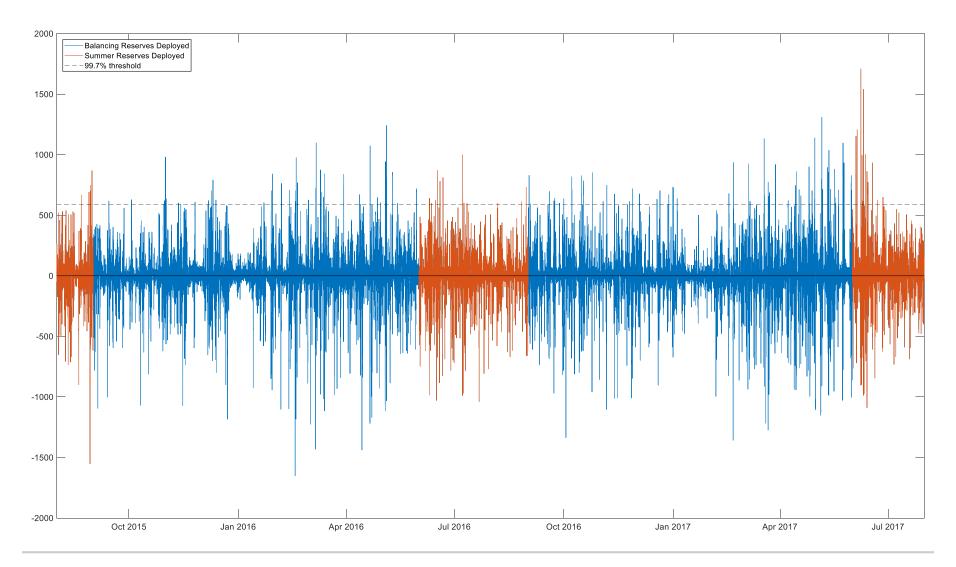
- Winter
- Spring
- Summer
- Fall



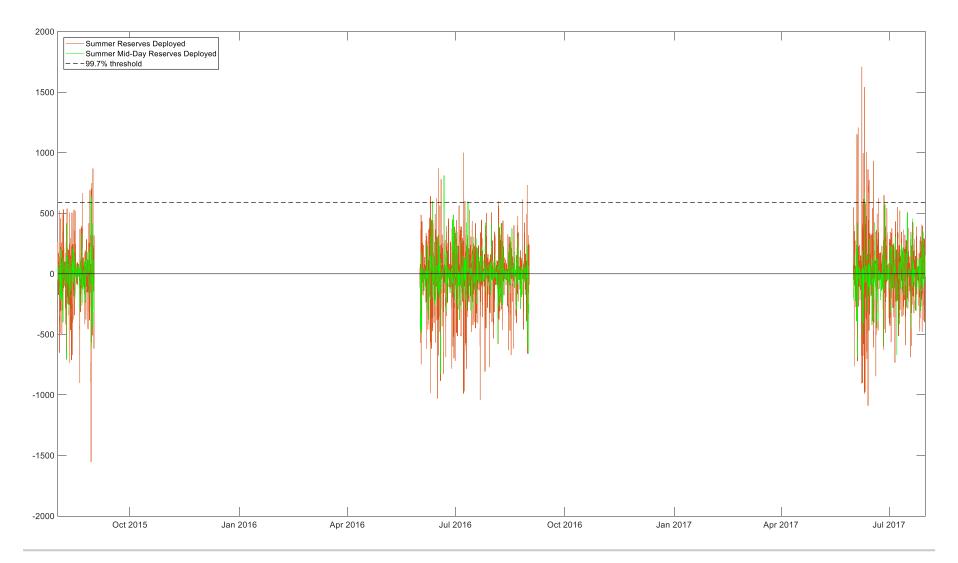
Shaped Seasonal Period Definitions



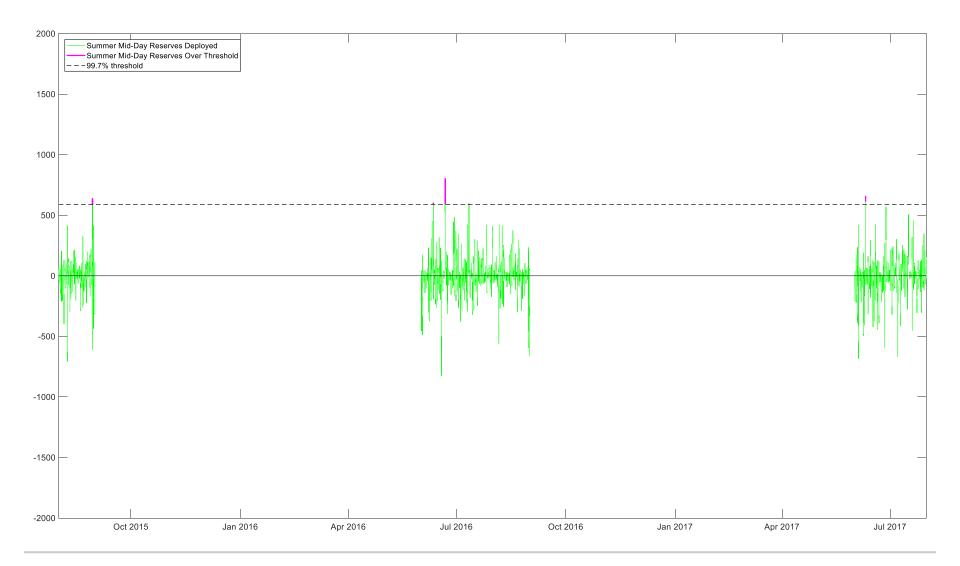
Summer Subset



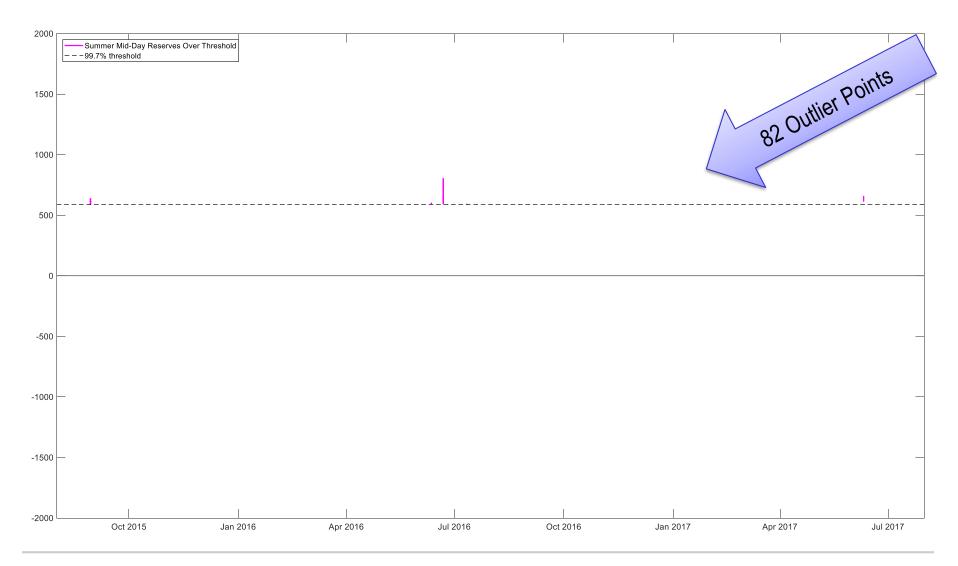
Summer Mid-Day Subset



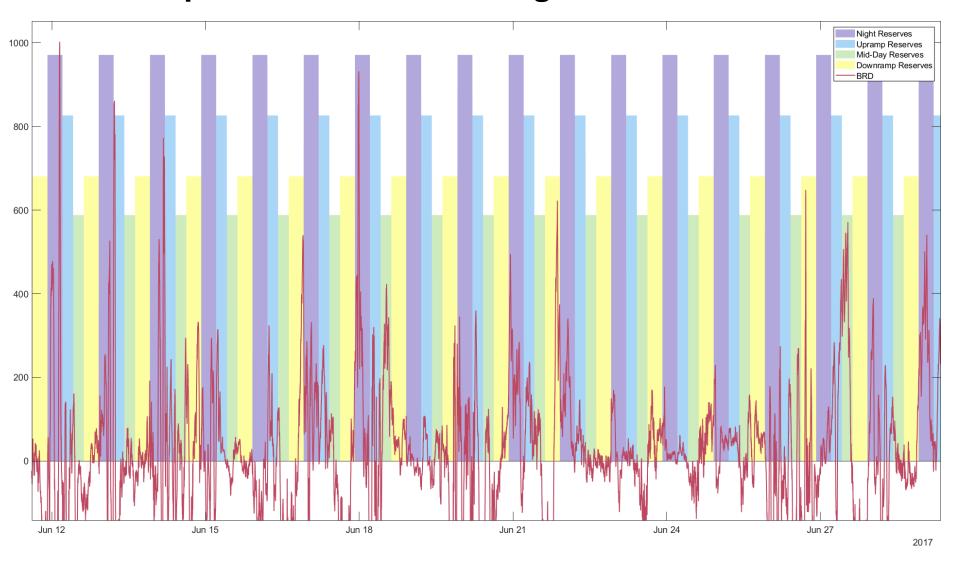
Summer Mid-Day Reserves Deployed Subset



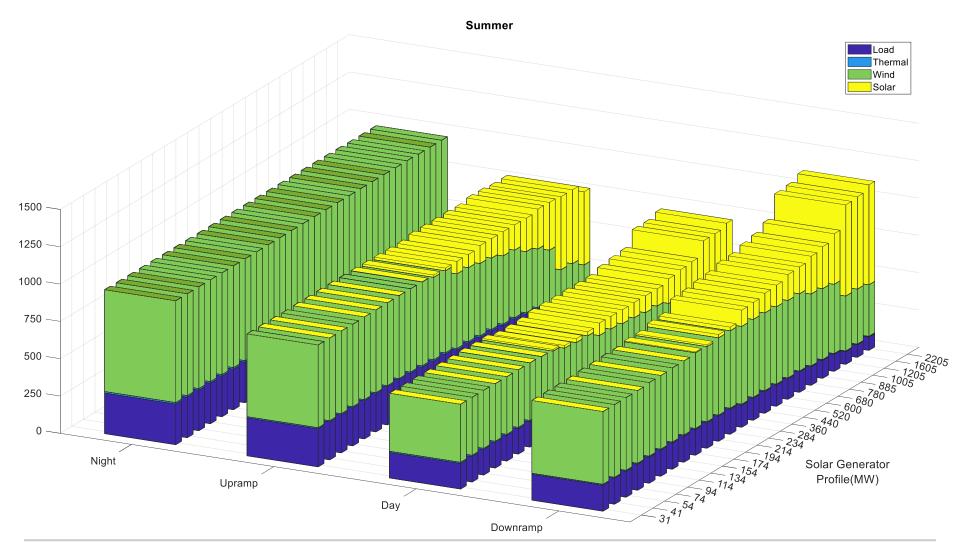
Summer Mid-Day Reserves Deployed Subset



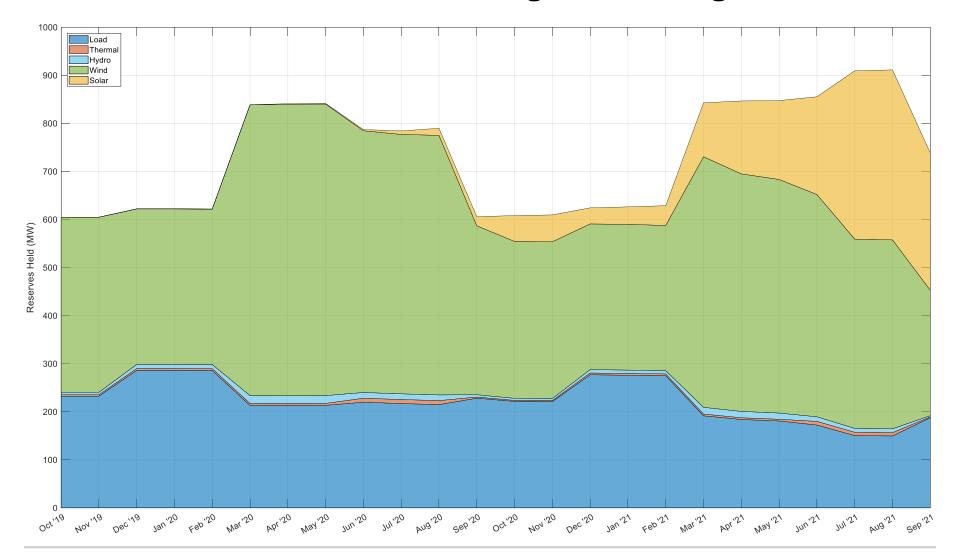
Shaped Seasonal Balancing Reserves vs. BRD



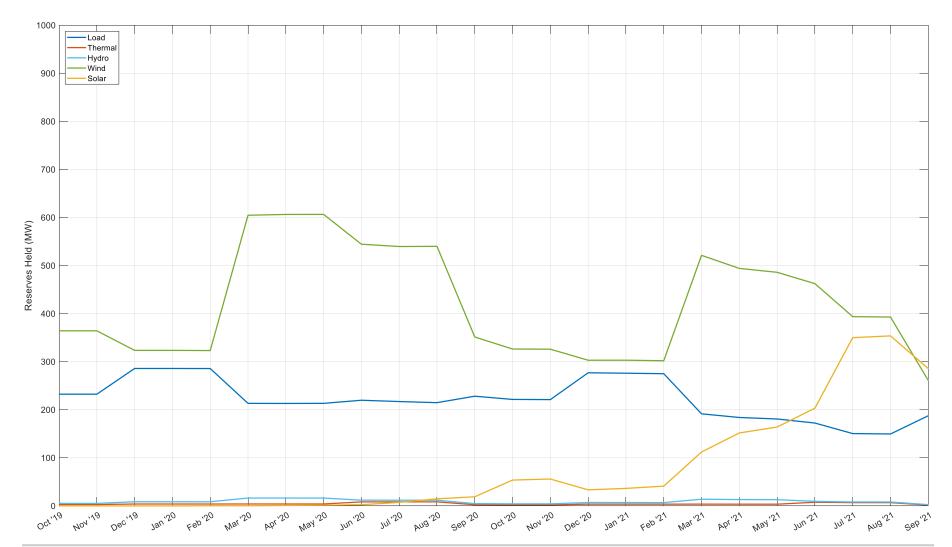
Shaped Seasonal Balancing Reserves Over Different Solar Profiles



Shaped Seasonal Balancing Reserves Stacked Totals - Weighted Average

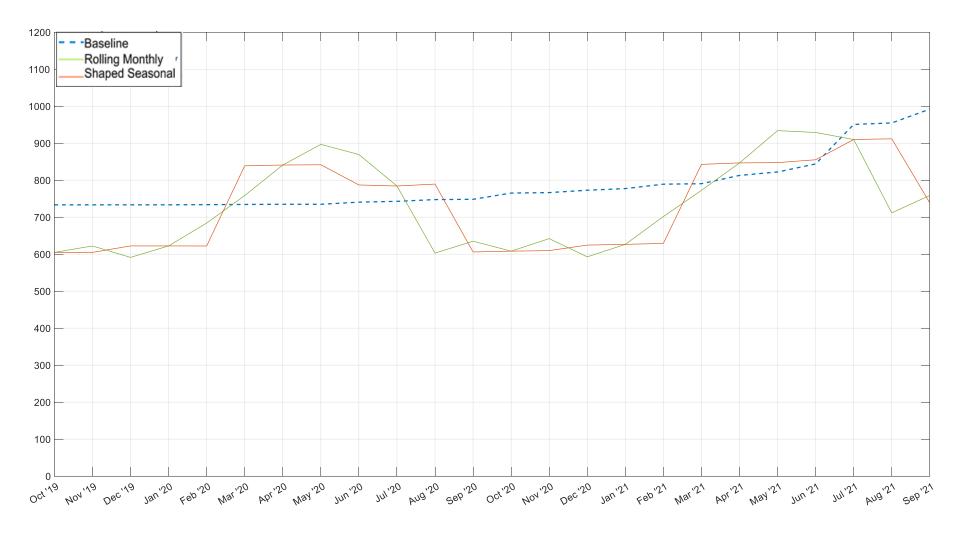


Shaped Seasonal Balancing Reserves by Type - Weighted Average

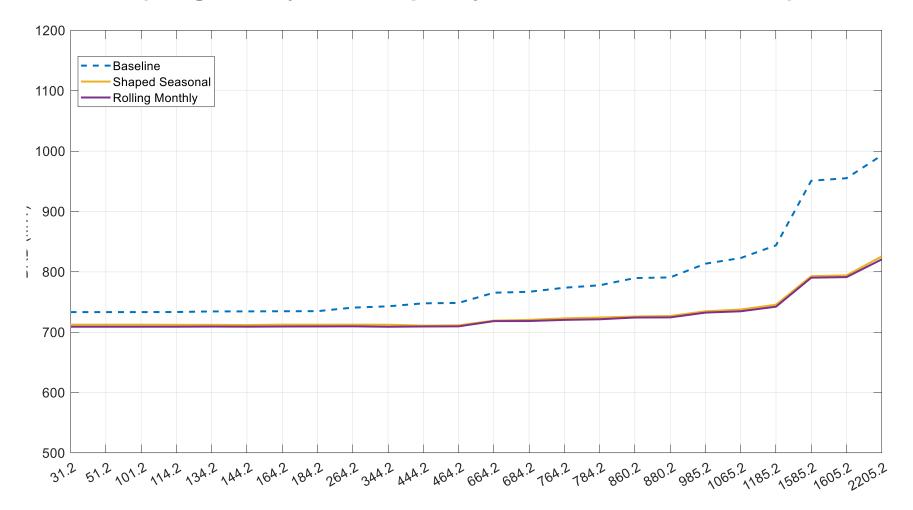


Comparisons and Results

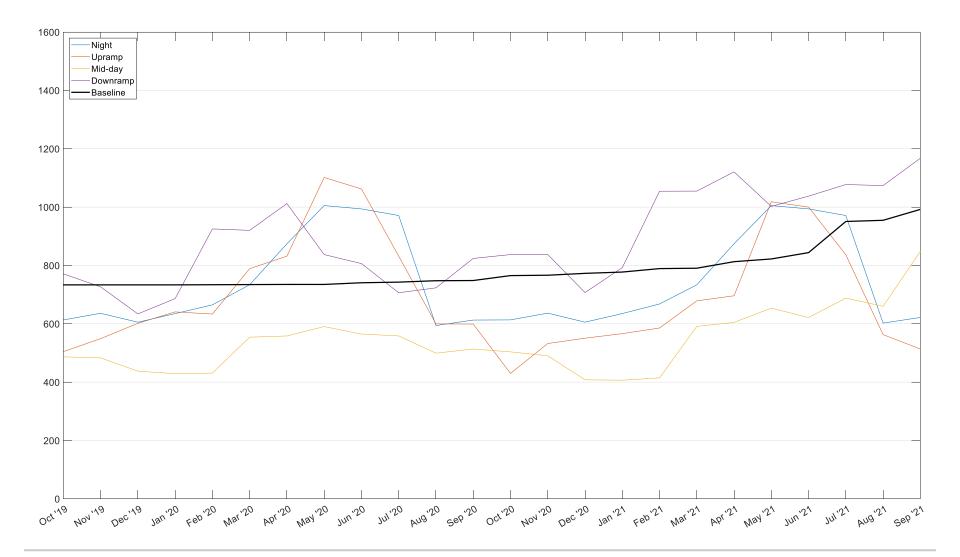
Weighted Average Comparison by Date (weighted by each shaped period)



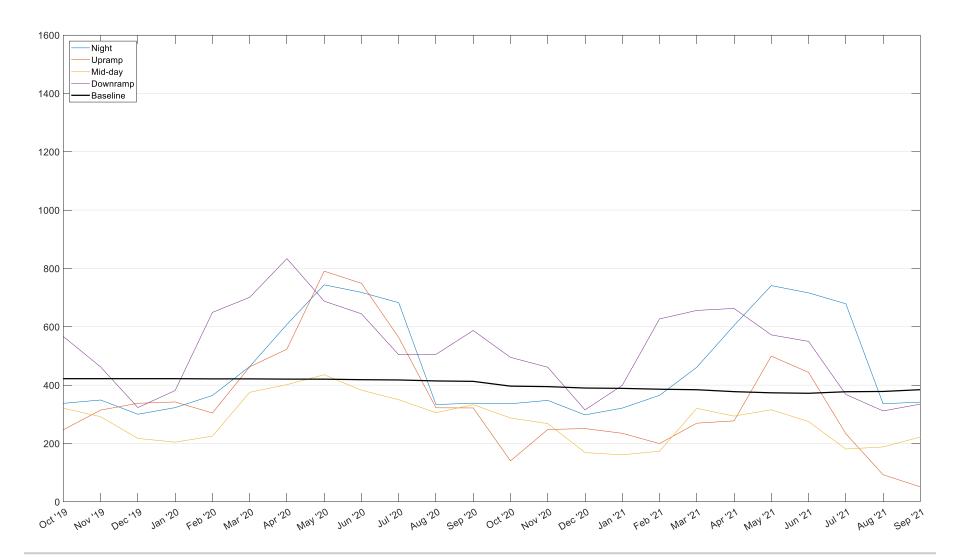
Weighted Average Comparison by Solar Profile (weighted by solar capacity level across all months)



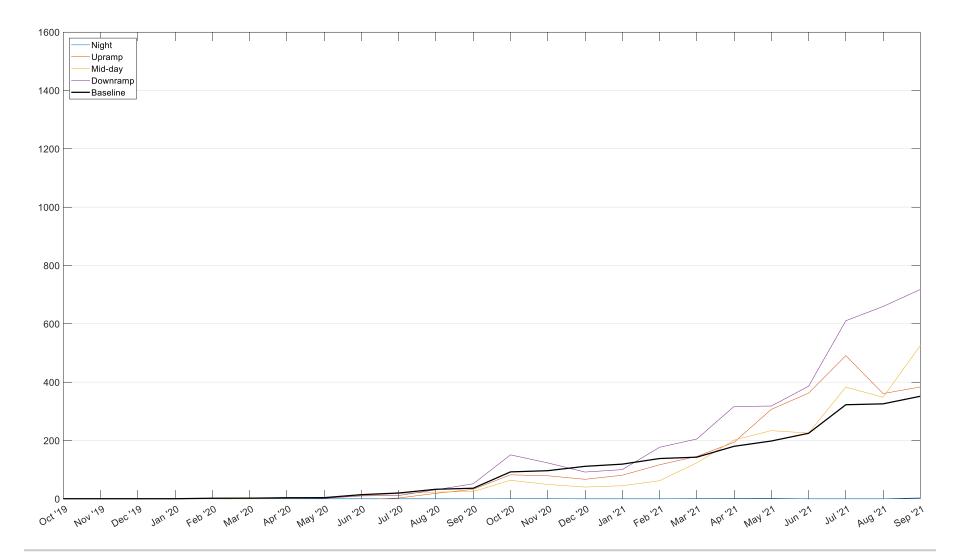
1. Rolling Monthly – Total Balancing Reserves



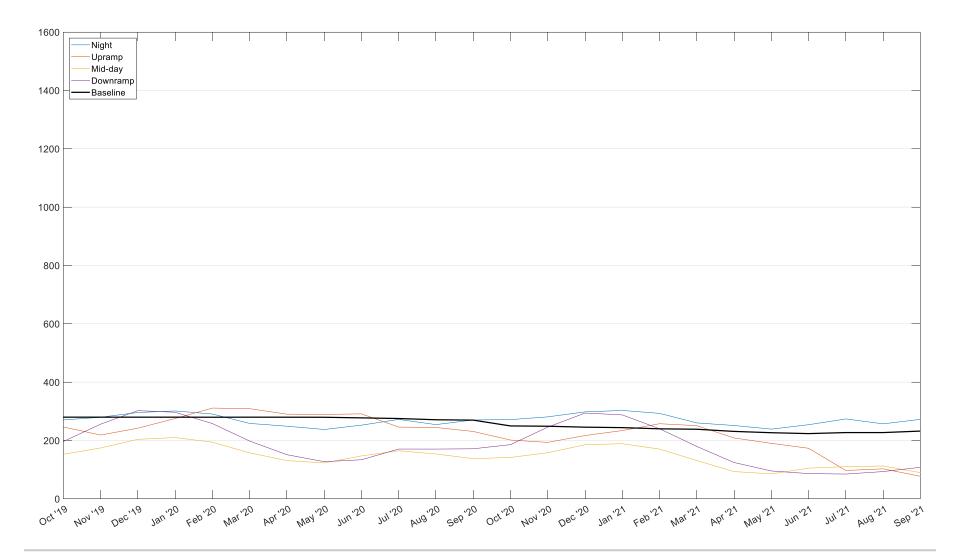
1. Rolling Monthly - Wind Balancing Reserves



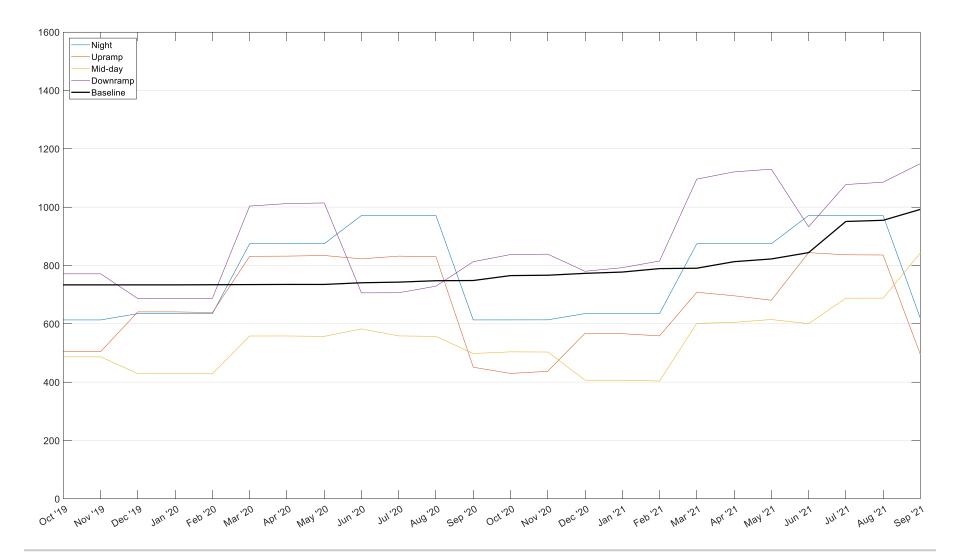
1. Rolling Monthly - Solar Balancing Reserves



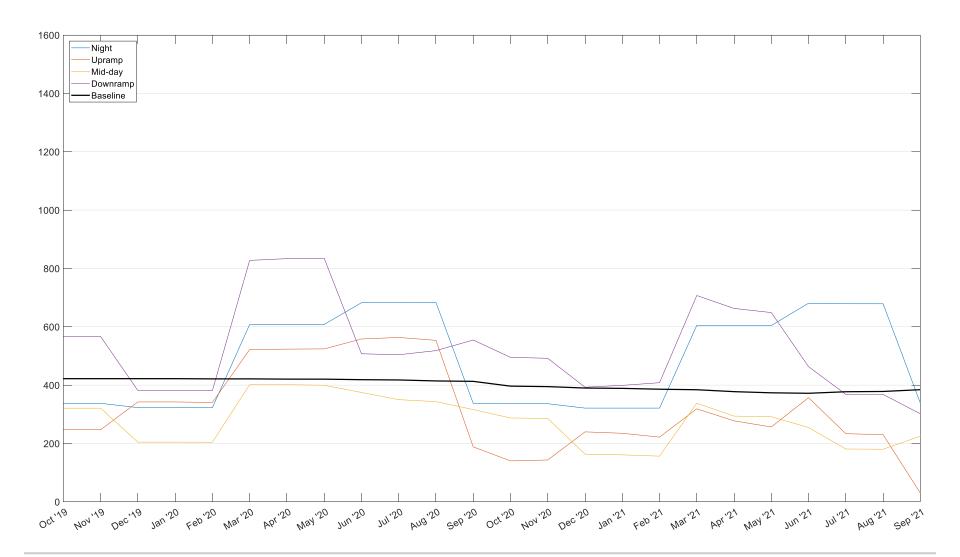
1. Rolling Monthly - Load Balancing Reserves



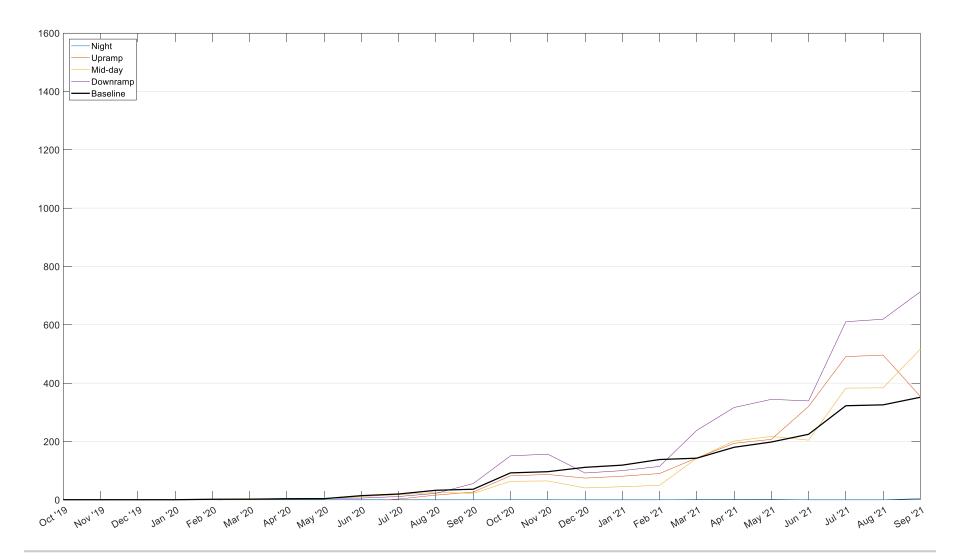
2. Shaped Seasonal - Total Balancing Reserves



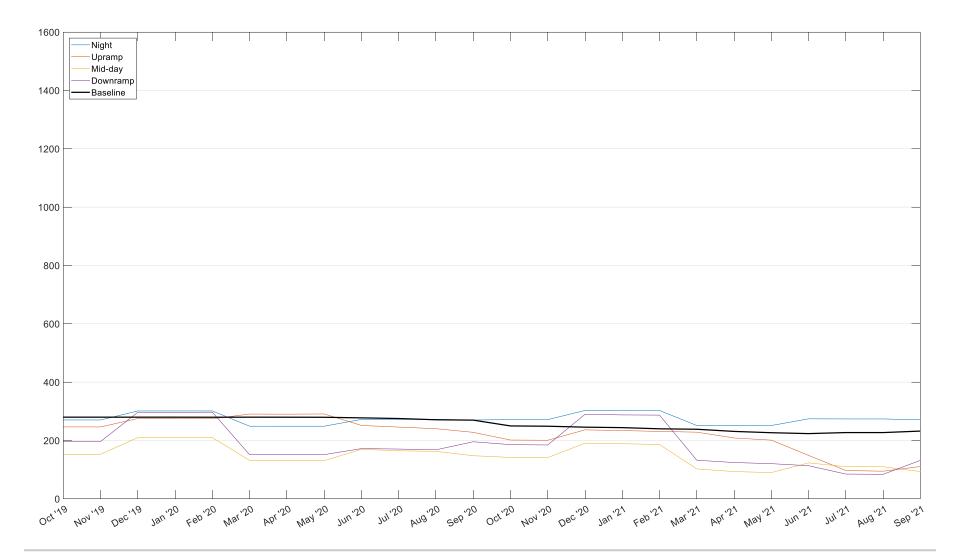
2. Shaped Seasonal - Wind Balancing Reserves



2. Shaped Seasonal - Solar Balancing Reserves



2. Shaped Seasonal - Load Balancing Reserves



BONNEVILLE POWER ADMINISTRATION

Reserve Capacity Costs & Rates

Jarek Hunger - PSR

Reserve Capacity Cost Background

- Used the same embedded cost value calculated via the proposed method in the BP-20 workshops in 2018
 - Fixed costs: \$1.016B
 - 1-hour capacity: 14,335MW
 - Embedded cost of capacity: \$5.91/kW/mo
- This embedded cost increased by the variable costs (next slide) to determine the reserve capacity cost

GARD Model Update

- The GARD model was redesigned (in R instead of Excel) to calculate the cost of holding reserves in a non-flat shape
- Quick refresher on what GARD does:
 - It determines the optimal way to commit the turbines at the Big 4 if there was no reserve requirement
 - It then imposes the reserve constraint (i.e., the reserve requirement) and calculates the lost value to federal generation caused by holding reserves
 - Hydro Shift is responsible for the vast majority of the cost
 - This is due to either an inc requirement in high value times reducing generation below ideal; or a dec requirement increasing generation in low value times
 - Additional Spill is another significant cost
 - This is caused when there is enough water that the inc requirement causes a need to spill in order to generate at a low enough level

Results

- Overall shaped reserve operations did allow holding less reserves on average
 - ~787 MW in base case; and
 - ~735 MW in both of the shaped cases
- However, shaped reserve operations resulted in holding more reserves at times when they negatively impact the system – resulting in a higher variable cost.

Variable Cost:

Base Case: \$12.80 million

Rolling Monthly: \$26.62 million

Seasonal: \$27.54 million

Comparison of Methods

Reve	nue Forecast (in t	thousands of do	ollars)				
Reserve Forecast	В	asecase		Rolling		Seasonal	
Balancing for Load	\$	21,900	\$	22,600	\$	22,900	
Balancing for Non-Fed Generation	\$	43,500	\$	50,200	\$	51,100	
Balancing for Federal Generation	\$	(1,300)	\$	(1,600)	\$	(1,600)	
Balancing for All Generation	\$	44,800	\$	51,800	\$	52,700	
Operating Reserves	\$	35,900	\$	35,800	\$	35,900	
Reserves Total	\$	101,200	\$	108,600	\$	109,900	
Small Fry Forecast							
Synchronous Condensing	\$	800	\$	800	\$	800	
Generation Dropping	\$	500	\$	500	\$	500	
Redispatch	\$	300	\$	300	\$	300	
Segmentation of COE/BOR	\$	8,800	\$	8,800	\$	8,800	
Station Service	\$	1,700	\$	1,700	\$	1,700	
Small Fry Total	\$	12,000	\$	12,000	\$	12,000	
Total Gen Inputs Credit Forecast	\$	113,300	\$	120,600	\$	122,000	

Allocation Of Costs

- Holding reserves in a shape shifts the allocation of reserve costs between customer groups:
 - DERBS allocation goes from about 1.6% to 0.5%
 - Solar allocation goes from about 13% to 10%
 - Wind allocation goes from about 52% to 57%
 - Load allocation goes from about 34% to 33%

ACS Rates

	Unit	Base	eline	Rol	ling	Seasonal	
	Oilit	Incs	Incs Decs		Incs Decs		Decs
DERBS Reg							
DERBS Following	mills/kWh	19.25	2.06	7.58	1.73	6.22	1.4
DERBS Imbalance							
Solar Reg	\$/kW-mo	0.18		0.21		0.23	
Solar Following	\$/kW-mo	0.36		0.48		0.48	
Solar Imbalance	\$/kW-mo	0.55		0.38		0.30	
Wind Reg	\$/kW-mo	0.11		0.13		0.16	
Wind Following	\$/kW-mo	0.35		0.39		0.44	
Wind Imbalance	\$/kW-mo	0.57		0.76		0.70	
Load Reg		0.42		0.44		0.48	
Load Following	mills/kWh						
Load Imbalance	<u> </u>						

Total Rate \$/kW-Nameplate	Baseline	Rolling	Seasonal	
Solar	1.09	1.07	1.01	
Wind	1.02	1.28	1.30	
Load	0.42	0.44	0.48	

Example Annual Cost			
100 MW Solar Plant	\$ 1,310,400	\$ 1,287,600	\$ 1,215,600
100 MW Wind Plant	\$ 1,226,400	\$ 1,534,800	\$ 1,556,400

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- i. Present to customers and stakeholders the costs and impacts of holding reserves in a non-flat shape, such as planned shaped diurnal reserve amounts. This presentation(s) will use the BP-18 Solar Integration Study with Solar modeling updates identified and implemented during BP-20 workshops to provide:
 - a) Up to **two shaped balancing reserve forecasts** for all Generation Input customer classes (Wind, Solar, DERBS and Load).
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- ii. Analyze and present to customers any Generation Inputs variable and embedded cost allocation differences associated with a shaped balancing reserve operation, including the associated impact on Ancillary and Control Area Service rates. This analysis and presentation will:
 - a) Assume that shaped balancing reserve held on Bonneville's system is physically possible.
 - b) Use a variation of the Generation And Reserves Dispatch (GARD) model or other balancing reserve variable cost estimation method to estimate any material change in Bonneville's cost of providing balancing reserves associated with a planned shaped balancing reserves operation. If, following these deliverables, Bonneville staff, customers and stakeholders agree that a shaped balancing reserve operation provides material value, Bonneville will provide customers a list highlighting the workload necessary with approximate completion timelines that would need to occur for Bonneville to be able to implement such an operation.

Conclusions

- Dataset has issues/unknowns
 - Only synthetic solar generation data is available at this time
 - Limited number of data points caused through binning the overall data
- Implementation Challenges
 - What extent of system modifications are needed to implement
 - Takes away resources from EIM implementation
- Interaction with EIM Requirements
 - Misalignment with Resource Sufficiency requirements needed for the EIM.
- Does shaped reserves provide Material Value?
 - BPA seeks customer input on how customers stand as to whether or not shaped reserves provide Material Value to them?
 - BPA does not see material value given the current solar penetration



Appendix

BP-18 Solar Study Commitment Summary

Solar Technical Work. By January 2018, Bonneville will study and produce analysis on solar integration in Bonneville's Balancing Authority Area (BAA), though this is not a commitment to conduct a comprehensive integration study. The intent of Bonneville's analytical work will be to enhance Bonneville's current methodology and inform Bonneville and stakeholders prior to workshops leading to the BP-20 Initial Proposal. This analytical work will include:

- a) A focus on the **unique characteristics of integrating solar energy generation** in Bonneville's BAA contrasted to that of wind energy in the Bonneville BAA.
- b) The **creation of a robust synthetic solar generation data set** representative of a prospective geographically diverse build out of solar generation in Bonneville's BAA, forecasted based on the growth of **Bonneville's interconnection queue** through FY2025 as it exists on July 1, 2017 and through utilization of the **University of Oregon's Solar Radiation Monitoring Laboratory datasets**.
- c) Analysis of the **impacts on balancing reserves** necessary to integrate solar energy in Bonneville's BAA with regards to **solar scheduling best practices and geographic diversity benefits** as shown in section 10(b) of this Attachment 1.

Bonneville will also hold stakeholder workshop(s) regarding solar generation prior to the BP-20 Initial Proposal to discuss (1) **potential actions** that can be taken by generators and **Bonneville to reduce the balancing reserve requirement**, (2) solar rate design*, (3) the impact of the variable cost methodology* and the **incremental standard deviation methodology** on balancing reserves held, and (4) the potential impact of **planned reserves held in shaped amounts**.

(Section 10 of "Rate Period Terms" Attachment 1 to the BP-18 Generation Inputs and Transmission Ancillary and Control Area Services Rates Settlement Agreement Page)

*These topics will be dealt with at a subsequent workshop



Solar Requests in Generation Interconnection Queue as of 11/25/2019

Request Number	State	County	Requested In-Service Date	Maximum Output	Generating Facility Type
G0518	OR	Morrow	1-Oct-19	5	Solar
G0540	OR	Morrow	1-Mar-20	10	Solar
G0523	OR	Wasco	1-Jan-20	13	Solar
G0520	OR	Harney	1-Nov-19	20	Solar
G0526	OR	Lake	1-Feb-20	20	Solar
G0536	OR	Harney	1-Apr-20	20	Solar
G0524	OR	Wasco	1-May-20	20	Solar
G0522	OR	Harney	1-Sep-20	20	Solar
G0525	OR	Harney	1-Nov-20	20	Solar
G0521	OR	Lake	1-Jan-21	20	Solar
G0537	OR	Harney	1-Mar-21	20	Solar
G0538	OR	Harney	1-Aug-21	20	Solar
G0529	OR	Morrow	1-Dec-19	50	Solar
G0517	OR	Morrow	1-Feb-21	76	Solar
G0557	OR	Lake	1-Jun-20	80	Solar
G0564	WA	Franklin	1-Jul-20	80	Solar
G0562	WA	Yakima	1-Dec-20	80	Solar
G0563	WA	Yakima	1-May-21	80	Solar
G0532	OR	Morrow	1-Aug-20	100	Solar
G0527	OR	Lake	1-Apr-21	105	Solar
G0550	OR	Umatilla	1-Jun-21	120	Solar
G0545	OR	Klamath	1-Oct-20	200	Solar
G0549	OR	Lake	1-Jul-21	400	Solar
G0539	OR	Deschutes	1-Sep-21	600	Solar

Data Locations

Data Location	Request Number	State	County	Requested In-Service Date	Maximum Output
Burns	G0523	OR	Wasco	12/31/2018	13
Burns	G0520	OR	Harney	6/01/2018	20
Burns	G0536	OR	Harney	4/01/2019	20
Burns	G0524	OR	Wasco	12/31/2018	20
Burns	G0522	OR	Harney	12/31/2018	20
Burns	G0525	OR	Harney	4/30/2019	20
Burns	G0537	OR	Harney	4/01/2019	20
Burns	G0538	OR	Harney	4/01/2019	20
Burns	G0539	OR	Deschutes	4/01/2019	600
Cheney	G0518	WA	Benton	11/13/2017	5
Cheney	G0564	WA	Franklin	6/30/2019	80
Cheney	G0562	WA	Yakima	6/30/2019	80
Cheney	G0563	WA	Yakima	6/30/2019	80
Hermiston	G0540	OR	Morrow	12/31/2018	10
Hermiston	G0529	OR	Morrow	12/31/2017	50
Hermiston	G0517	OR	Morrow	7/01/2018	76
Hermiston	G0532	OR	Morrow	6/30/2017	100
Hermiston	G0550	OR	Umatilla	12/01/2020	120
SilverLake	G0526	OR	Lake	4/01/2019	20
SilverLake	G0521	OR	Lake	1/31/2019	20
SilverLake	G0557	OR	Lake	12/01/2019	80
SilverLake	G0527	OR	Lake	4/01/2019	105
SilverLake	G0545	OR	Klamath	10/01/2019	200
SilverLake	G0549	OR	Lake	12/01/2022	400

Note: Bend PV was removed as a data source from BP-20 Study due to concerns with data quality.



Weighted Minute Rolling Average

- Ex: Under previous definition, minute 3 under a 4 minute rolling average would have:
- T = 240s
- MovingAvg(t) = average(data[t 119:t + 120])

 $minute \ 1: t = [1:60]$ $minute \ 2: t = [61:120]$

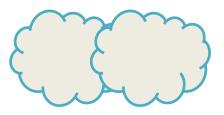
Define: $minute \ 3: t = [121:180]$ $minute \ 4: t = [181:240]$:

	Minute 1 Contribution	Minute 2 Contribution	Minute 3 Contribution	Minute 4 Contribution	Minute 5 Contribution
MovingAverage(121) = $avg(data[2:241])$	59	60	60	60	1
MovingAverage(122) = avg(data[3:242])	58	60	60	60	2
MovingAverage(123) = $avg(data[4:243])$	57	60	60	60	3
:	:	:	:	:	:
MovingAverage(178) = $avg(data[59:298])$	2	60	60	60	58
MovingAverage(179) = $avg(data[60:299])$	1	60	60	60	59
MovingAverage(180) = $avg(data[61:300])$	0	60	60	60	60
Total Contribution of Minute X to Minute 3:	1770	3600	3600	3600	1830

Block average of minute 3 = avg([MovingAverage(121), MovingAverage(122), ... MovingAverage(180)])

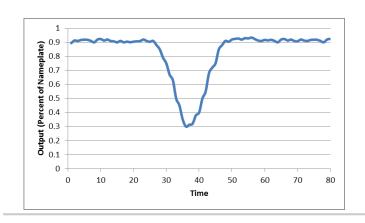


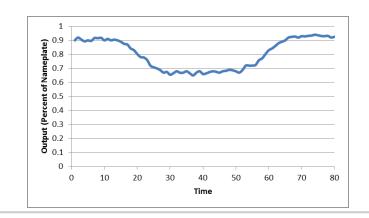
Need for Appropriate Scaling



VS.







Scaling Methodology Development

- University of Oregon data is "point source" - a single irradiance sensor at each location
- We want to represent various sizes of solar farms
- Variability of the signal decreases as size of the plant increases, so we must pay attention to how we scale the data up from the single sensors to the representative plant data

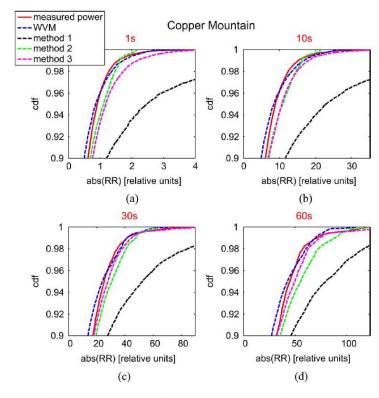
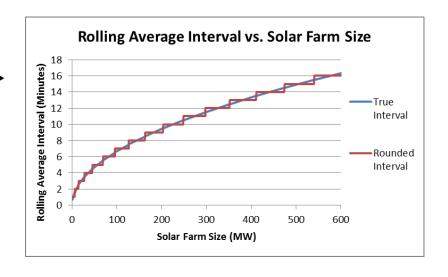


Fig. 9. Extreme (>90th percentile) ramp rate cumulative distribution functions at CM on October 1, 2011 at (a) 1 s, (b) 10 s, (c) 30 s, and (d) 1 min for measured power output (solid red), and for different methods of simulating PV power plant output: WVM (dashed blue), Method 1: linearly scaling from a point sensor (dashed black), Method 2: a moving average of 115 s corresponding to $t_{\rm avg} = Ar^{1/2}/V$ (dashed green line), and Method 3: averaging all 15 reference cells (dashed magenta line).

Adapted from "A Wavelet-Based Variability Model (WVM for Solar PV Power Plants" by Matthew Lave, Jan Kleissl, and Joshua Stein, 2013, IEEE Transactions on Sustainable Energy, Volume 4, No. 2

Lave et al. Rolling Average

- $MovingAvg(t) = average\left(data\left[t \left(\frac{T}{2} 1\right): t + \frac{T}{2}\right]\right)$, where T is the length in seconds of your rolling average interval.
 - Ex: A 2 minute rolling average has an interval size T=120s, and MovingAvg(t) = average(data[t-59:t+60])
- Equation to translate from desired
 plant size to interval length
- Algorithm to translate second-based calculation to minute-based calculation (see appendix)



Scaling Comparison

