2020 Study of the Levels of Flex Reserve and Regulating Reserve Necessary for Reliable System Operation while Accommodating the Uncertainty of Wind and Solar Generation at Varying Levels of Installed Wind and Solar Generation Capacity within the Public Service Company of Colorado Balancing Area Authority

Public Service Company of Colorado

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Executive Summary

With its Electric Resource Planning process, Public Service Company of Colorado ("Company") meets the multiple objectives of (1) maintaining a safe, reliable electric system while (2) reducing carbon emissions by 80% from 2005 levels by 2030 and (3) keeping costs low for our customers. In order to achieve the 2030 carbon emissions mandate, the Company could replace a substantial portion of annual energy sourced from fossil-fueled generation with energy sourced from renewables such as wind and solar. Energy from wind and solar plants is dependent on the weather, which adds uncertainty to the economic generation dispatch process. Utilities address generation uncertainty by carrying reserves which can replace expected generation that is not available. This Study determines the volume of reserves necessary to maintain system reliability given the volume of wind and solar generation within the Company's Balancing Authority Area ("BAA"). In Phase 2 of the Electric Resource Planning process, the Company will evaluate various portfolios of generators to determine a preferred portfolio which meets the 2030 carbon reduction mandate while maintaining sufficient reserves to address the uncertainty of the portfolio of renewable generation and while keeping costs low for our customers.

A Technical Review Committee ("TRC") of experts in the integration of renewable generation into the electric system informed and reviewed the Company's Study. The Company used historic renewable generation data, where available, and synthesized generation profiles to represent future wind and solar generation additions.

The Company determined, and the TRC agreed, that the uncertainty of wind generation occurs during all seasons of the year and during all hours of the day. To determine the volume of Flex Reserve necessary to maintain reliable system dispatch given portfolios with varying volumes of wind generation, the Company determined the largest volume of wind generation that could be lost over a 30-minute period given the volume of wind generation at the start of the 30-minute ramp event. Table 1 shows the maximum Flex Reserve for the portfolios of installed wind generation capacity that were studied.

Table 1: Maximum Flex Reserve for wind portfolios

Portfolio	Base	Base + 500	Base + 1000	Base + 1500
Wind Capacity (MW)	4,962	5,462	5,962	6,462
Maximum Flex Reserve (MW)	1,391	1,494	1,553	1,691
Wind Gen at Max Flex (MW)	2,500	3,300	3,400	4,193

In contrast to wind generation, electric load and solar generation have moderately predictable patterns that are influenced by the season of year and the time of day. As such, Net Load (calculated as electric load minus solar generation) is also moderately predictable. Much of the movement in Net Load can be addressed through economic system dispatch based on Net Load forecasts and a relatively small volume of uncertainty must then be addressed through Regulating Reserve. Regulating Reserve is comprised of two components: (1) the Fast-Moving component addresses the minute-to-minute uncertainty in the Net Load; and the Following component addresses the 10-minute uncertainty in the Net Load trend. To determine the volume of Regulating Reserve necessary to maintain reliable system dispatch given portfolios with varying volumes of solar generation, the Company first adjusted the data to account for the expected Net Load movement for the relevant season-of-year and hour-of-day. The Company then summed the largest values from the Fast-Moving and Following components of Regulating Reserve for each season-of-year and hour-of-day category after eliminating the top 5% of volumes from each component. Table 2 shows the range in hourly Regulating Reserve for the portfolios of installed solar generation capacity that were studied.

Table 2: Range of hourly Regulating Reserve for solar portfolios

Portfolio	Base	Base + 500	Base + 1000	Base + 1500	Base + 2000
Solar Capacity	**2,366 MW**	**2,866 MW**	**3,366 MW**	**3,866 MW**	**4,366 MW**
Minimum Regulating Reserve	**82 MW**	**82 MW**	**82 MW**	**82 MW**	**82 MW**
Maximum Regulating Reserve	**170 MW**	**192 MW**	**221 MW**	**250 MW**	**264 MW**

Introduction

Public Service Company of Colorado ("PSCo" or the "Company") must comply with reliability standards established and enforced by the North American Reliability Corporation ("NERC"). NERC BAL-002-3, the Disturbance Control Standard, requires that a Balancing Authority ("BA") carry sufficient Operating Reserve to respond to and recover from contingency events such as the loss of a large generator or transmission element. The Company realized that large, sustained loss-of-generation wind ramps could deplete the BA's Operating Reserve and potentially cause the Company to fail compliance with the Disturbance Control Standard. To address this concern, the Company studied the nature of large loss-of-generation wind ramps and developed a 30-minute Flexibility Reserve ("Flex Reserve") held in addition to Operating Reserve and designed specifically to address large wind ramps.

NERC Standard BAL-001-2, the Real Power Balancing Control Performance Standard, is intended to control the electric system interconnection frequency within defined limits and requires that Balancing Authorities comply with: (1) Control Performance Standard 1 ("CPS1"); and (2) the Balancing Authority ACE Limit ("BAAL") [1]. The Company has found that increasing levels of wind and solar generation has made compliance with NERC Standard BAL-001-2 more challenging. The Company addressed this concern by adding a 10-minute component to Flex Reserve and by studying the combined contribution of load and solar generation to the Fast-Moving and Following components of Regulating Reserve.

In CPUC Decision No. C17-0316, the Colorado Public Utilities Commission ("the Commission") ordered the Company to complete an updated Flex Reserve Study[2] to be filed with the Company's next Electric Resource Plan ("ERP") filing. The Commission also ordered the Company to conduct a backcast of

[1] The Balancing Authority balance between supply and demand is measure by its Area Control Error ("ACE"). Because supply and demand change unpredictably, there will often be a mismatch between them, resulting in non-zero ACE. CPS1 and BAAL establish the statistical boundaries for ACE magnitudes, ensuring that steady-state frequency is statistically bounded around its scheduled value.

[2] During the last ERP proceeding, the Company used Flex Reserve to address the uncertainty of wind generation. The Company believes, and the TRC agrees, that Flex Reserve should only address the uncertainty of wind generation and that Regulating Reserve should address the combined uncertainty of load and solar generation.

modeled wind data for verification and modification of the results to ensure the accuracy of or improve the accuracy of modeled wind data for use in the next Flex Reserve study and to work with the Commission's Trial Staff ("Staff") to form a panel of industry experts to help guide the updated study.

During the last ERP proceeding, Flex Reserve capacity was represented as a determinant for a reliability ceiling on renewable generation additions. The Company now believes that the Flex Reserve and Regulating Reserve requirements should not be used to limit the potential addition of renewable generation; but rather those requirements should be an input to production cost and capacity expansion models. For example, high volumes of renewable generation paired with sources of flexible, dispatchable generation capacity may result in lower cost model runs relative to the same volumes of renewable generation paired with generation capacity with less flexibility. Accordingly, this study will: (1) determine how much Flex Reserve is needed to address potential wind generation ramps; and (2) determine how much Regulating Reserve is needed to address solar uncertainty. The Resource Planning model runs will then determine what dispatchable generation capacity should be used to meet these requirements. While this study will determine the appropriate levels of reserve to reliably address resource uncertainty for wind (Flex Reserve) and load and resource uncertainty for solar (Regulating Reserve), the Company will continue to refer to the study as the Flex Reserve Study for ease of presentation.

<u>Technical Review Committee</u>

With the input and agreement of Staff, the Company invited the following individuals to participate on the Technical Review Committee ("TRC") for the Flex Reserve Study:

- Paul Denholm – Principal Energy Analyst at the National Renewable Energy Laboratory ("NREL")
- Debra Lew – Private Energy Consultant[3]
- Clyde Loutan – Principal, Renewable Energy Integration at the California ISO
- Julia Matevosyan – Lead Planning Engineer at the Electric Reliability Council of Texas
- Charlie Smith – Executive Director at the Energy Systems Integrations Group

All five individuals agreed to participate on the TRC and the TRC met four times.[4]

<u>Technical Review Committee inputs into Flex Reserve Study</u>

The TRC advised the Company on data sources, data validity, modeling approaches, improvements to modeling and modeling results analysis. Below is a listing of key TRC input into the study and study modeling:

1.) **<u>Clarification between uncertainty[5] and variability</u>**[6]: The Company previously claimed that Flex Reserve is a form of contingency reserve necessary to address the variability of wind generation

[3] Debra Lew is currently a private energy consultant. For several years she was a Senior Technical Director at General Electric Consulting and prior to working at GE she was a Senior Engineer at the National Renewable Energy Laboratory.
[4] The TRC met on October 4, 2018, June 3, 2019, November 20, 2019, and March 9, 2020.

rather than uncertainty. For example, the Company maintained that even if it had a perfect forecast of hourly wind generation, there can be considerable intra-hour generation variability that must be addressed. A TRC member noted that contingency reserves are typically carried to address *uncertainty* (i.e., sudden loss of transmission or generating unit or sudden restoration of demand). The Company concedes that Flex Reserve would not be necessary if, for instance, the Company had a perfect 5-minute wind generation forecast and, therefore, the Company and the TRC agree that Flex Reserve addresses wind generation uncertainty.

2.) **Time granularity of study data:** A TRC member expressed a concern that 5-minute data was not sufficiently granular to capture the uncertainty in solar generation. The Company proposed the use of 1-minute data and the TRC agreed that 1-minute data was sufficiently granular.

3.) **Preferred method to construct generation profiles for future wind plants:** A TRC member inquired how the study would assess renewable generation uncertainty with new wind additions that aren't in the same geographic location as existing resources, since that uncertainty is a direct driver of Flex Reserve need. The Company explained that while the Company cannot specify the location of new renewable resources, PSCo will disclose injection capability at various locations on the PSCo transmission system to prospective bidders during Phase 2 of the ERP process. The bidder is responsible for delivering generation to those injection points. The cost of building transmission to connect to the PSCo Bulk Power System is very expensive, so successful bidders typically bid projects located fairly closely to the injection points. The Company confirmed with the Xcel Energy Resource Planning and Transmission Planning groups that future injection capability is likely to be located along the recently built Pawnee-Daniels Park 345 kV backbone. Accordingly, much of capacity of future wind generation projects is likely to be located fairly closely to existing wind generation.

Given the assumption that future wind generation would likely be proximate to existing wind generation, the TRC members agreed that generation profiles for future wind projects could be constructed using wind speed data from existing wind plants with a time-offset to represent geographic diversity and scaled to account for differences in generation capacity between the existing and future plants. Further, the TRC acknowledged that weather model reanalysis data would not be available in the 1-minute granularity proposed for this study. The TRC requested that the Company perform a correlation analysis to compare wind speed model data against actual plant generation data as well as time-shifted empirical generation profiles against actual plant generation data to verify that the time-shifted empirical generation profiles are a reasonable proxy for future generation.

The Company gathered 5-minute wind speed and generation data from wind plants as well as from the NREL Wind Integration National Dataset ("WIND") Toolkit. Using these data sets, the Company compared actual wind generation profiles against synthesized profiles using:

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[5] Uncertainty typically means forecast error, but can also include unexpected events such as a generator trip.
[6] The generation output from renewable resources such as wind and solar is dependent on the weather, which is inherently variable. Periods of higher variability are harder to accurately predict than periods with low variability, thus uncertainty and variability are related, but separate concepts.

(1) wind speed data from a nearby wind plant converted to generation using an empirical power conversion from the target wind plant;
(2) wind generation data from a nearby wind plant scaled to match the generation capacity of the target wind plant;
(3) WIND Toolkit wind speeds for the target wind plant converted to generation using an empirical power curve from the target wind plant; and
(4) WIND Toolkit generation data for the target wind plant scaled to match the generation capacity of the target wind plant.

Based on the analysis of the results, the Company concluded that:

(1) The WIND Toolkit profiles were much less variable[7] than the wind speeds and generation data from the wind plants which makes the use of wind plant data superior for the purpose of the Flex Reserve Study;
(2) The WIND Toolkit profiles produced significantly more data points at very high generation levels which resulted in higher capacity factors than the actual plant data and proxy plant data;
(3) Profiles based on wind speed data from a plant within ~50 miles of the target plant were more highly correlated with actual plant generation than profiles based on the WIND Toolkit data;
(4) Based on the data, it seemed appropriate to use an offset of approximately one minute per mile of separation between an existing plant and a proposed plant when using data from the existing plant to create a profile for the proposed plant; and
(5) Using a power conversion appropriate for the proposed plant to convert wind speed data results in a more realistic capacity factor than using scaled generation data.

4.) **<u>The interaction between the uncertainty of load and the uncertainty of renewable generation</u>:** A TRC member questioned the Company's proposal to only study wind/solar generation ramps, as opposed to studying customer load net of renewable generation (hereafter referred to as *net load*). In the member's experience, with the addition of behind-the-meter solar generation, electric vehicle charging, and demand side management, net load exhibits greater variability than generation alone. Another member pointed out that forecast errors in load, wind, and solar could at times "pancake", and that a study of generation only might be less effective. The questioning TRC member further clarified that there can be offsetting diversity between load and renewable generation and that carrying reserves separately to address load uncertainty and renewable generation uncertainty may result in carrying excessive reserves. To address the TRC's concerns, the Company agreed to compare its current process of separately calculating load following reserve to address load uncertainty and Flex Reserve to address renewable generation uncertainty against a process of calculating Flex Reserve as a function of Net Load ramps which include the contribution of load, wind generation and solar generation.

[7] A less variable profile results in lower 30-minute ramp amplitudes than are actually experienced at the wind plants.

The Company gathered a years' worth of 5-minute load and renewable generation data and supplemented these data sets with a profile of behind-the-meter solar generation expected in 2023 in addition to all renewable generation approved in Phase 2 of the 2016 ERP as well as the solar facilities associated with the Renewable Connect program and the EVRAZ steel plant. Analysis of the data showed significantly higher levels of reserve required to cover the largest 30-minute and 10-minute Net Load (load minus wind and solar generation) ramps compared to the combined reserve necessary to cover (1) the largest 30-minute and 10-minute wind generation ramps and (2) a 10-minute Regulating Reserve to cover the combined uncertainty of load and solar generation. The Company concluded that there are predictably higher levels of load and solar variability during specific time-of-day and season-of-year combinations[8] whereas wind generation ramps can and do occur during any time-of-day and season-of-year combinations. Accordingly, the Company decided and the TRC approved basing the Flex Reserve requirement solely on wind generation data and basing the Regulating Reserve requirement on the combined uncertainty of load and solar generation data.

Backcast of the Expanded Study of 30-Minute Flex Reserve's modeled wind data using historical wind data

In the Company's previous Flex Reserve study, the Expanded Study of 30-Minute Flex Reserve on the Public Service Company of Colorado System[9] ("Expanded Flex Reserve Study"), the Company used wind speed data from geographically proximate wind plants to derive wind generation profiles for the Golden West and Rush Creek wind plants. The Commission ordered the Company to conduct a backcast of modeled wind data for verification and modification of the results to ensure the accuracy of or improve the accuracy of modeled wind data for use in the next Flex Reserve study.

Golden West

The Company gathered actual Golden West wind generation data and Cedar Point wind speed data for the time period June, 2016 through June, 2018 and performed a backcast and verification of the Golden West wind generation profile used in the Expanded Flex Reserve Study. In the Expanded Flex Reserve Study, Scenario 1 represented a portfolio with 2,566 MW of wind generation capacity; the capacity of the Company's wind generation portfolio including Golden West but not including Rush Creek. For the time period June, 2016 through June, 2018, the largest ramp for Scenario 1, which determines the maximum Flex Reserve requirement, was 824 MW when using Cedar Point wind speed data with a 5-hour offset compared to 850 MW when using actual Golden West generation data. For the same time period, the largest ramp for Scenario 1 was 855 MW when using Cedar Point wind speed data with a 1-hour offset.

The Company concludes that the Golden West profile derived from Cedar Point wind speed data with a 5-hour offset and converted to generation using an empirical Golden West power conversion, the methodology the Company used in the Expanded Flex Reserve Study, was a reasonably accurate proxy;

[8] For example, the evening lighting load ramp and coincident loss of solar generation during winter months make Hour Ending 16 and Hour Ending 17 much more variable and uncertain than the immediately preceding or succeeding hours.
[9] Hearing Exhibit 106, Attachment DTB-1, in Proceeding No. 16A-0396E.

however, a profile derived from Cedar Point wind speed data with a 1-hour offset would have been superior. Actual Golden West generation data was used for the current Flex Reserve Study.

Rush Creek

The Company gathered actual Rush Creek wind generation data as well as Limon 3 and Golden West wind speed data for the time period June, 2019 through February 19, 2020 and performed a backcast and verification of the Rush Creek wind generation profile used in the Expanded Flex Reserve Study. For this time period, the largest 30-minute loss-of-generation ramp based on metered Rush Creek generation was 422 MW. The largest 30-minute ramp for the Rush Creek generation profile based only on Limon 3 wind speed data was 525 MW and the largest combined 30-minute ramp for Rush Creek 1[10] generation based on Golden West wind speed data and Rush Creek 2[11] generation based on Limon 3 wind speed data was 425 MW.

The Company concludes that the Rush Creek wind generation profile based solely on Limon 3 wind speed data is inferior to a Rush Creek wind generation profile based on Golden West wind speed data for Rush Creek 1 generation and Limon 3 wind speed data for Rush Creek 2 generation. For time periods prior to December, 2018[12] in this Flex Reserve Study, the Company derived the Rush Creek 1 generation profile using Golden West wind speed data with a -20-minute offset[13] and the Rush Creek 2 generation profile using Limon 3 wind speed data with a +20-minute[14] offset.

Data for Flex Reserve and Regulating Reserve analysis

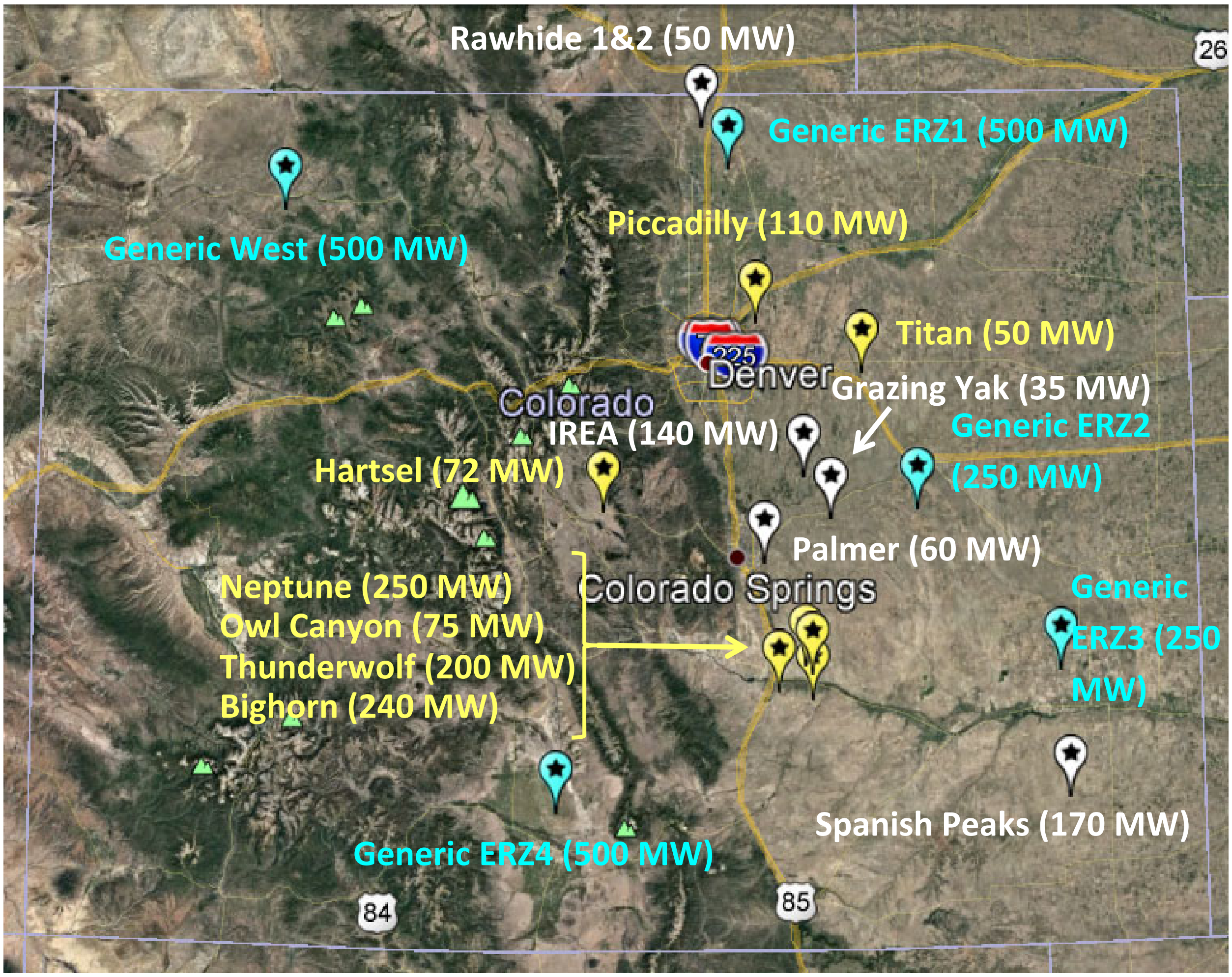
The Company gathered the following information to determine wind Flex Reserve and solar Regulating Reserve:

- 1-minute wind generation data for the time period November, 2015 through May, 2019.
- 1-minute wind speed data for the time period November, 2015 through May, 2019 for the following wind plants:
    - Cedar Creek 2
    - Limon 3
    - Golden West
    - Cedar Point
    - Colorado Green/Twin Buttes
- 1-minute solar generation data downscaled from 5-minute 2018[15] solar irradiance data from the NREL National Solar Radiation Database converted to solar generation using the NREL System Advisory Model ("SAM"). In Figure 1, the yellow data points represent solar plants controlled by

[10] Rush Creek 1 has generation capacity of 380 MW and is located approximately 20 miles NE of the Golden West wind plant.
[11] Rush Creek 2 has generation capacity of 220 MW and is located approximately 20 miles SE of Limon 3.
[12] Rush Creek had a Commercial Operation Date of December 9, 2018.
[13] The wind speed data from Golden West was assumed to occur 20 minutes earlier at Rush Creek 1.
[14] The wind speed data from Limon 3 was assumed to occur 20 minutes later at Rush Creek 2.
[15] Grant Buster from NREL provided the 1-minute solar generation data downscaled from the 5-minute 2018 solar irradiance data. 2018 is the only year for which NREL has 5-minute data granularity.

the Company[16], the white data points represent solar plants within the BAA not controlled by the Company, and the blue data points represent generic locations for potential future solar plants[17].

Figure 1: Solar plants with generation profiles derived from NREL irradiation data



- 1-minute distributed solar generation data from 2018 and scaled to 658 MW to represent the expected installed capacity of distributed solar generation in the Company's service territory in 2023.
- 1-minute data from 2018 for load and utility-scale solar generation controlled by the Company.

[16] Note that the solar plants controlled by the Company that are displayed on the map are those for which the Company constructed generation profiles using NREL irradiation data. There are other solar plants controlled by the Company which are not displayed and for which the Company used historic generation data.
[17] The Owl Canyon and Picadilly solar plants were selected projects under the Colorado Energy Plan; however, the Company did not reach a contractual agreement with these projects. Replacement projects are being considered under Proceeding 19A-0530E.

Wind Generation Profiles for Flex Reserve

The Company gathered or modeled the following information to determine wind Flex Reserve:

1. Base Case (Colorado Energy Plan portfolio + other wind generation within the BAA[18], 4,962 MW)
    a. Colorado Energy Plan wind generation portfolio (4,095 MW)
        i. Generation data from existing wind plants
        ii. Rush Creek 1 prior to COD – Golden West wind speed with -20 minute offset
        iii. Rush Creek 2 prior to COD – Limon 3 wind speed with +20 minute offset
        iv. Bronco Plains – Limon 3 wind speed with +20 minute offset
        v. Cheyenne Ridge – Limon 3 wind speed with +30 minute offset
        vi. Mountain Breeze – Cedar Creek 2 wind speed with -15 minute offset
    b. Round House (150 MW) – Cedar Creek 2 wind speed with -63 minute offset
    c. Peak View (61 MW) – Twin Buttes wind speed with -89 minute offset
    d. Busch Ranch 1&2 (88 MW) – Twin Buttes wind speed with -89 minute offset
    e. Crossing Trails (104 MW) – Limon 3 wind speed with -4 minute offset
    f. Spring Canyon 2&3 (63 MW) – Cedar Creek 2 wind speed with +37 minute offset
    g. Kit Carson (51 MW) – Limon 3 wind speed with +63 minute offset
    h. Carousel (150 MW) – Limon 3 wind speed with +63 minute offset
    i. Arriba (200 MW) – Limon 3 wind speed with +10 minute offset

Figure 2 shows the locations of the wind plants in the Base Case which have derived generation profiles and the existing wind plants from which wind speed data was used in the derivation. In Figure 2, the yellow data points represent wind plants controlled by the Company and white data points represent wind plants within the BAA that are not controlled by the Company.

[18] The Company has the responsibility for maintaining reliability for the entire Balancing Authority Area, so it must maintain sufficient Flex Reserve to cover the uncertainty of all wind generation within the BAA despite the fact that some of the wind generation is not controlled by the Company.

Figure 2: Base Case Wind Plants

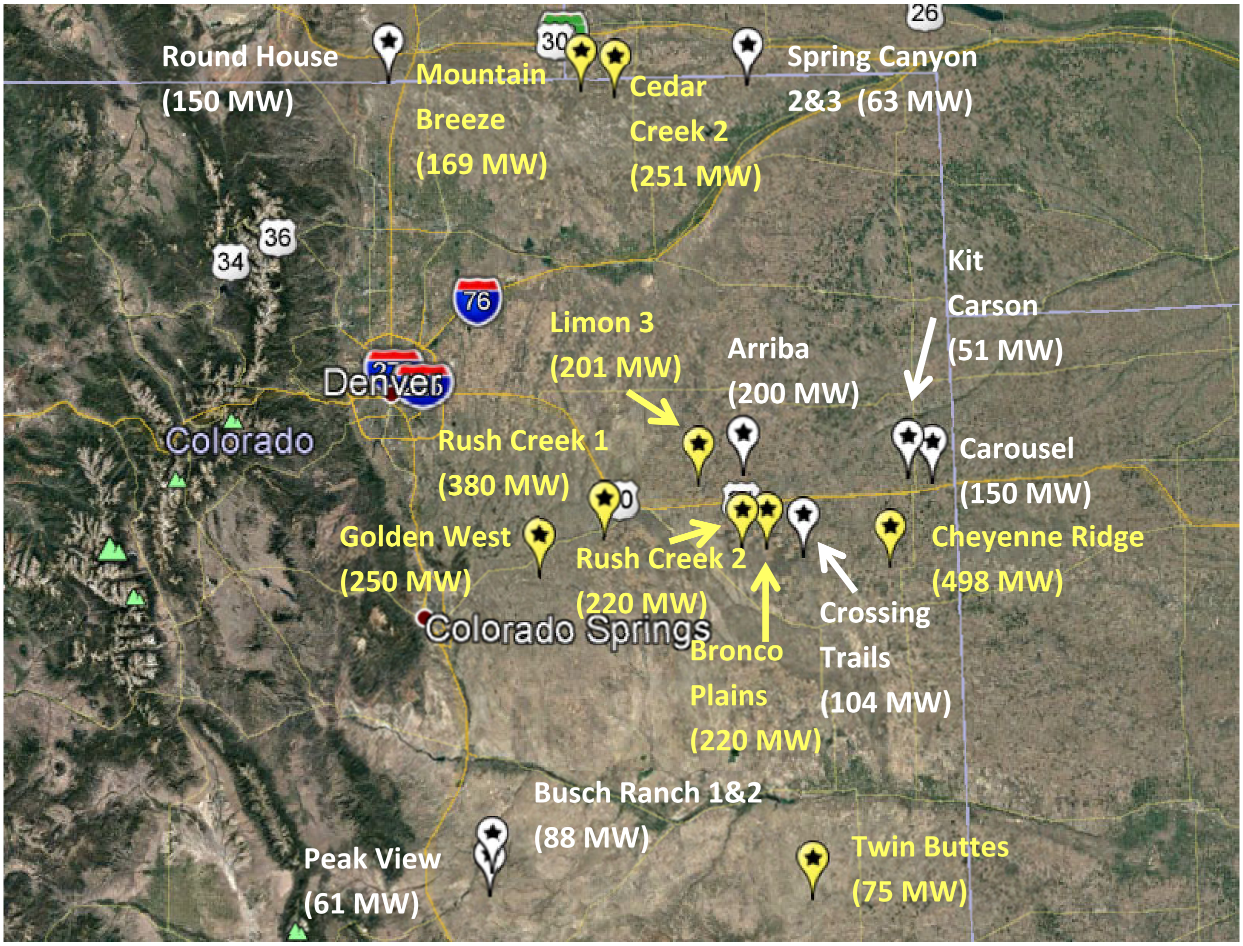
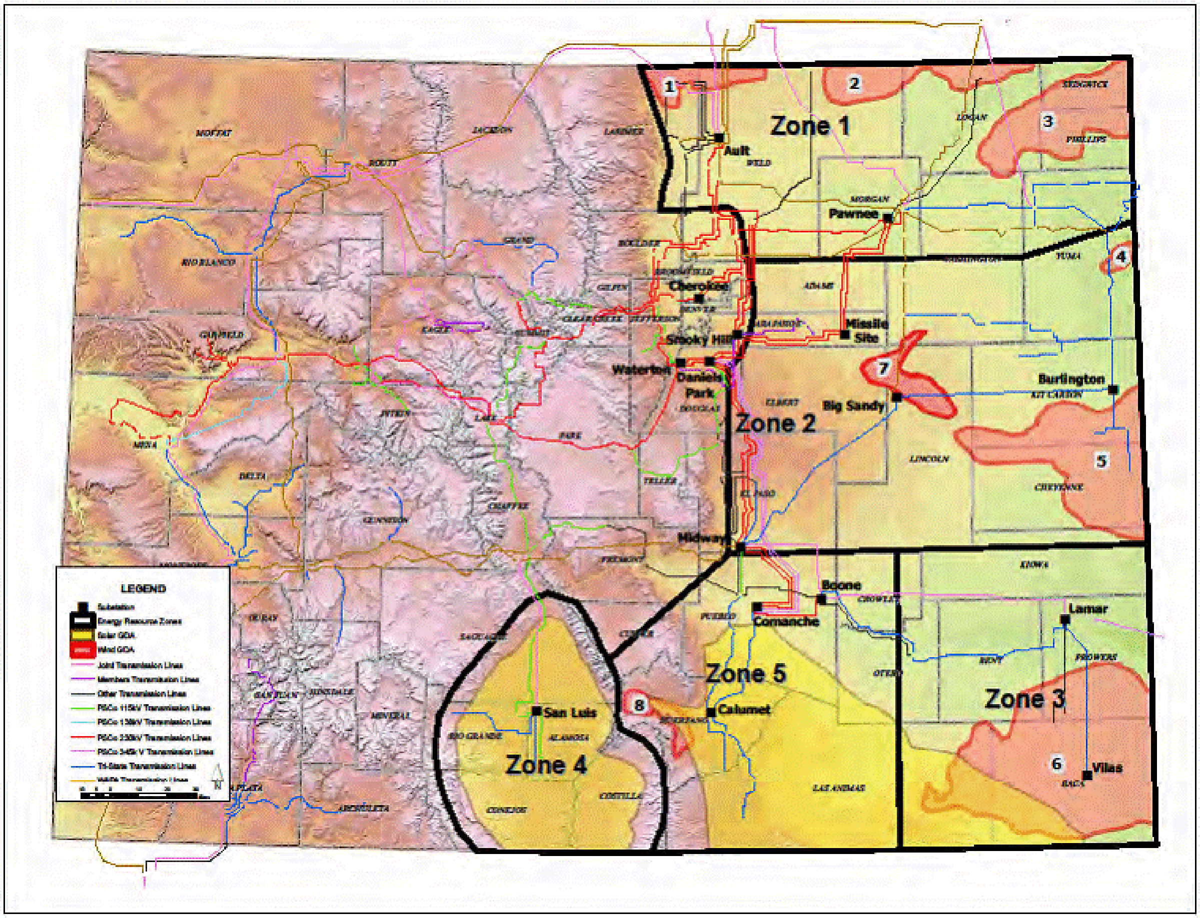


Figure 3: Energy Resource Zones



2. Base Case + 500 MW (5,462 MW)
    a. 500 MW Energy Resource Zone 1 ("ERZ1")
        i. 250 MW wind plant using Cedar Creek 2 wind speed with +15 minute offset
        ii. 250 MW wind plant using Cedar Creek 2 wind speed with +30 minute offset
    b. 500 MW Energy Resource Zone 2 ("ERZ2")
        i. 250 MW wind plant using Cedar Point wind speed with +15 minute offset
        ii. 250 MW wind plant using Golden West wind speed with +30 minute offset
    c. 500 MW Energy Resource Zone 3 ("ERZ3")
        i. 250 MW wind plant using Twin Buttes wind speed data with +15 minute offset
        ii. 250 MW wind plant using Twin Buttes wind speed data with +30 minute offset
3. Base Case + 1,000 MW (5,962 MW)
    a. ERZ1 + ERZ2
    b. ERZ2 + ERZ3
    c. ERZ1 + ERZ3
4. Base Case + 1,500 MW (6,462 MW)
    a. ERZ1 + ERZ2 + ERZ3

   b. ERZ1 + ERZ2 + ERZ2
   c. ERZ1 + ERZ3 + ERZ3
   d. ERZ2 + ERZ1 + ERZ1
   e. ERZ2 + ERZ3 + ERZ3
   f. ERZ3 + ERZ1 + ERZ1
   g. ERZ3 + ERZ2 + ERZ2

Load + Solar Generation Profiles for Regulating Reserve

The Company gathered the following information to determine solar Regulating Reserve:

1. Base Case (Colorado Energy Plan portfolio + other solar generation within the PSCo BAA, 2,366 MW)
   a. Colorado Energy Plan solar portfolio
      i. Generation data from existing plants (306 MW)
      ii. Hartsel Solar Plant (72 MW)
      iii. Neptune Solar Plant (250 MW)
      iv. ThunderWolf Solar Plant (200 MW)
      v. Owl Canyon Solar Plant (75 MW)
      vi. Picadilly Solar Plant (110 MW)
      vii. Bighorn Solar Plant (240 MW)
      viii. 2023 Distributed Solar generation (658 MW)
   b. Rawhide Solar Plants (50 MW)
   c. Palmer Solar Plant (60 MW)
   d. IREA Solar Plant (140 MW)
   e. Grazing Yak Solar Plant (35 MW)
   f. Spanish Peaks 1&2/San Isabel (170 MW)
2. 500 MW East (250 MW ERZ2 + 250 MW ERZ3), 2,866 MW
   a. 125 MW solar plant (ERZ2+ERZ3 profile with +3 minute offset[19])
   b. 125 MW solar plant (ERZ2+ERZ3 profile with +1 minute offset)
   c. 125 MW solar plant (ERZ2+ERZ3 profile with -1 minute offset)
   d. 125 MW solar plant (ERZ2+ERZ3 profile with -3 minute offset)
3. 500 MW ERZ1, 2,866 MW
   a. 125 MW solar plant (Generic ERZ1 profile with +3 minute offset)
   b. 125 MW solar plant (Generic ERZ1 profile with +1 minute offset)
   c. 125 MW solar plant (Generic ERZ1 profile with -1 minute offset)
   d. 125 MW solar plant (Generic ERZ1 profile with -3 minute offset)

[19] The Company analyzed 1-minute generation data from the Comanche solar plant and noted that the very largest 1-minute solar generation down ramps were almost always followed by a commensurately large up-ramp in the following minute. The Company concluded that these dramatic ramping events were the result of passing cloud shading on the PV panels and that applying a 2-minute time offset between the generation profiles for generic solar plants within an Energy Resource Zone would mimic sufficient geographic diversity to account for intermittent cloud cover.

4. 500 MW ERZ4, 2,866 MW
   a. 125 MW solar plant (Generic ERZ4 profile with +3 minute offset)
   b. 125 MW solar plant (Generic ERZ4 profile with +1 minute offset)
   c. 125 MW solar plant (Generic ERZ4 profile with -1 minute offset)
   d. 125 MW solar plant (Generic ERZ4 profile with -3 minute offset)
5. 500 MW West, 2,866 MW
   a. 125 MW solar plant (Generic West profile with +3 minute offset)
   b. 125 MW solar plant (Generic West profile with +1 minute offset)
   c. 125 MW solar plant (Generic West profile with -1 minute offset)
   d. 125 MW solar plant (Generic West profile with -3 minute offset)
6. ERZ4 + West (3,366 MW)
7. ERZ4 + West + ERZ1 (3,866 MW)
8. ERZ4 + West + ERZ1 + East (4,366 MW)

Flex Reserve Study Methodology

For each wind generation portfolio, the Company used the 1-minute data to determine the 30-minute change in wind generation given the starting level of generation. For each time period, the starting generation value was rounded up to the next 100 MW generation bin.

Example data:

- 2,015 MW at time T
- 1,970 MW at time T+1
- 1,695 MW at time T+30
- 1,705 MW at time T+31

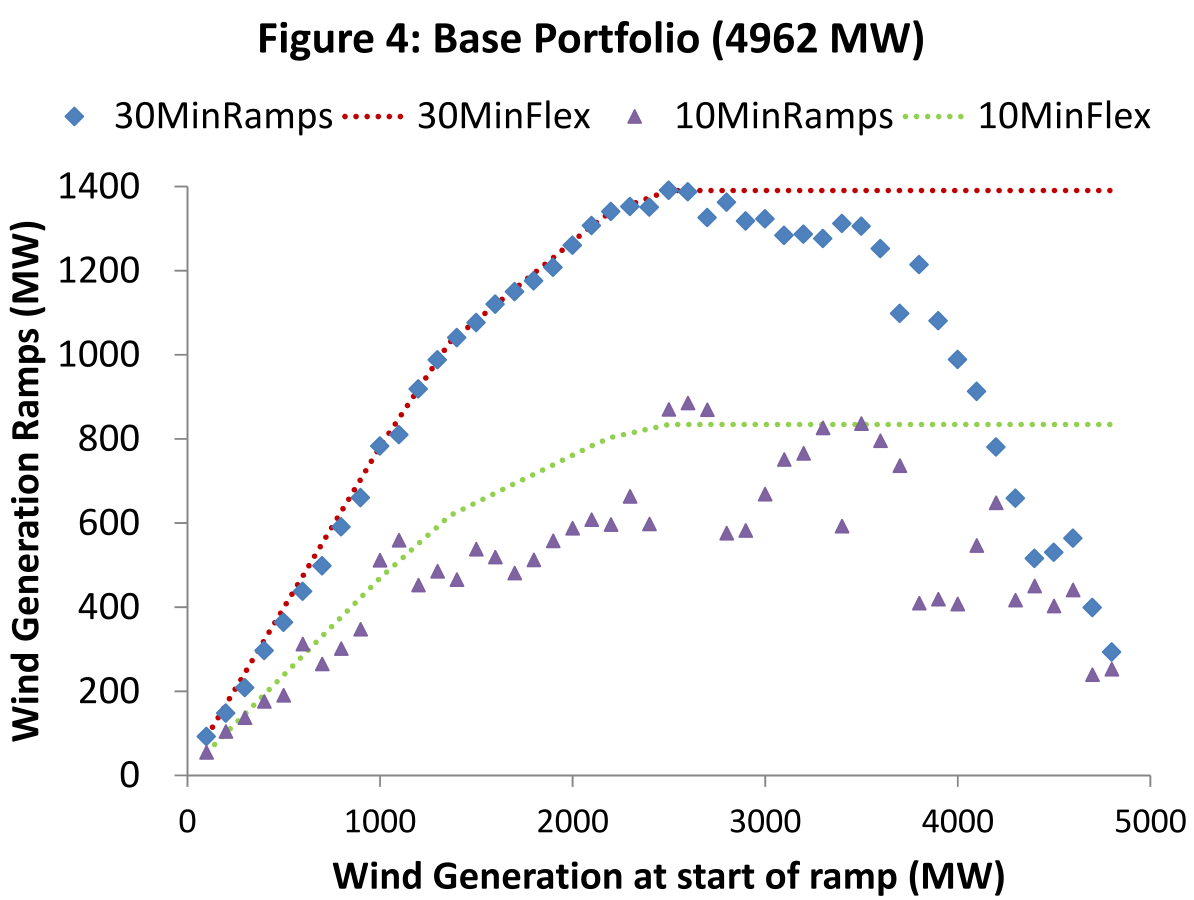
Using the example data above, time T is included in the 2,100 MW starting generation bin (2,015 MW rounded up to the next higher 100 MW generation bin) and has a 30-minute ramp of -320 MW (1,695 MW at time T+30 minus 2015 MW at time T). Time T+1 is included in the 2,000 MW starting generation bin and has a 30-minute ramp of -265 MW.

The Company created a scatterplot of the largest 30-minute loss of wind generation ramps for each 100 MW starting generation bin, and then used linear equations along the outer edge of the data points to create a Flex Reserve value that was at least as large as the largest ramp for each 100 MW starting generation bin.

For each portfolio, the Company also created a scatterplot of the largest 10-minute loss of wind generation ramps for each 100 MW starting generation bin, and then used linear equations along the outer edge of the data points to create a 10-minute Flex Reserve value that was at least as large as the largest 10-minute ramps for each 100 MW starting generation bin. On average across the portfolios for each 100 MW starting generation bin, the 10-minute Flex Reserve value was approximately 60% of the 30-minute Flex Reserve value. The Company decided to calculate the 10-minute Flex Reserve value as 60% of the 30-minute Flex Reserve value because: (1) 60% of the 30-minute Flex Reserve value is an accurate representation of the largest 10-minute wind ramps; and (2) 60% of the 30-minute Flex Reserve volume is easier to program in the Company's Energy Management System than a completely separate set of formulas for the 30-minute and 10-minute components.

The final Flex Reserve requirements for the Base + 500 MW, Base + 1000 MW, and Base + 1500 MW profiles is the average of the largest 30-minute ramps, given the wind generation at the start of the ramp, from the underlying profiles. For example, the Base + 500 MW Flex Reserve value at 100 MW of wind generation is derived from the average of the largest ramps from the 100 MW generation bin from the Base + ERZ1, Base + ERZ2, and Base + ERZ3 profiles.

Figure 4 depicts the 30-minute ramps and the derived 30-minute Flex Reserve requirement for the Base Portfolio. The 10-minute Flex Reserve requirement is 60% of the 30-minute Flex Reserve requirement for each starting generation value. As can be seen in Figure 4, the 10-minute Flex Reserve requirement is representative of the largest 10-minute ramps realized for each 100 MW starting generation bin.

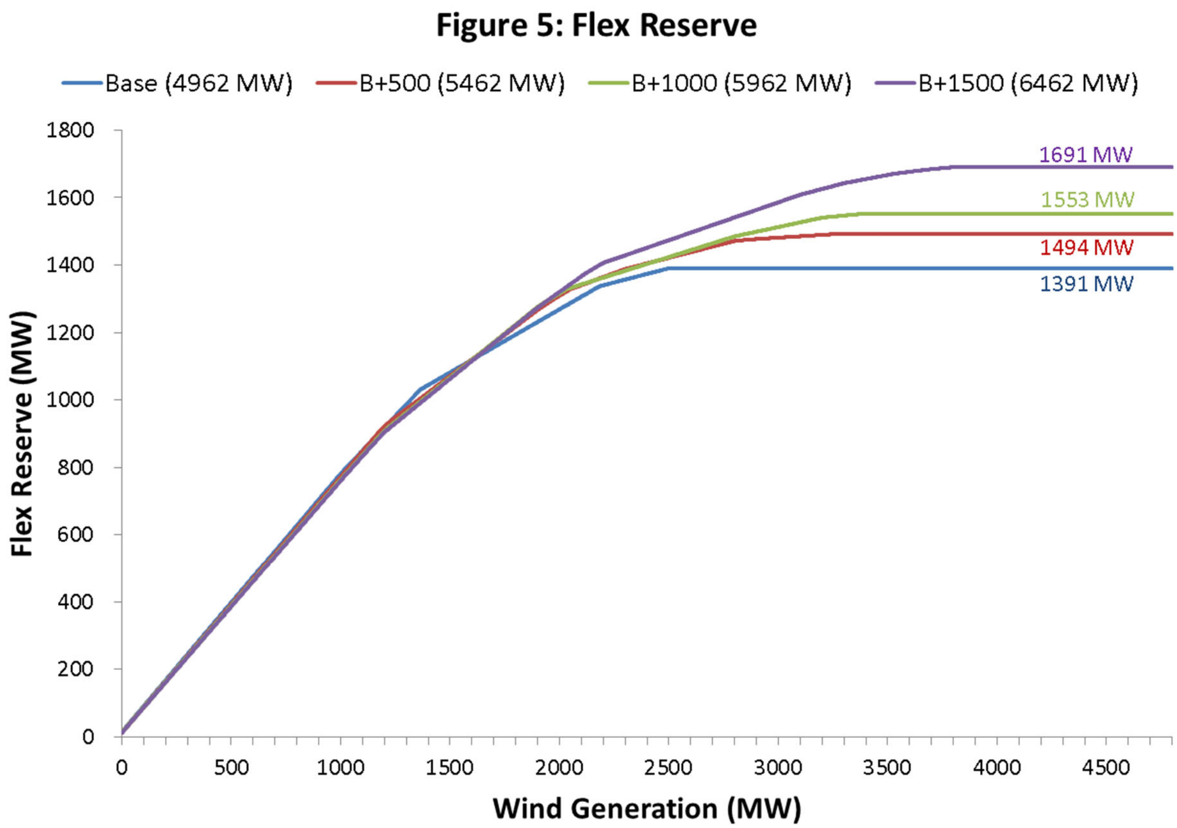


Flex Reserve Study Results

Table 3 lists the maximum levels of Flex Reserve required to account for wind resource uncertainty and to reliably operate the Company's system. Figure 5 shows the relationship between current levels of wind generation and the required volume of Flex Reserve for the various portfolios.

Table 3: Maximum 10-minute and 30-minute Flex Reserve requirements for wind generation portfolios

Portfolio	Maximum Flex Reserve	Maximum 10-min Flex Reserve
Base Case (4,962 MW)	1,391 MW	834 MW
Base + 500 (5,462 MW)	1,494 MW	896 MW
Base + 1000 (5,962 MW)	1,553 MW	932 MW
Base + 1500 (6,462 MW)	1,691 MW	1,015 MW



The Base Case portfolio represents the volume of wind generation within the BAA that has already been committed to by the Company and others. Note that the addition of 1.5 GW of wind generation results in virtually no increase in Flex Reserve for wind generation up to ~2000 MW and only a 300 MW increase in Flex Reserve at the highest levels of wind generation.

Regulating Reserve Study Methodology

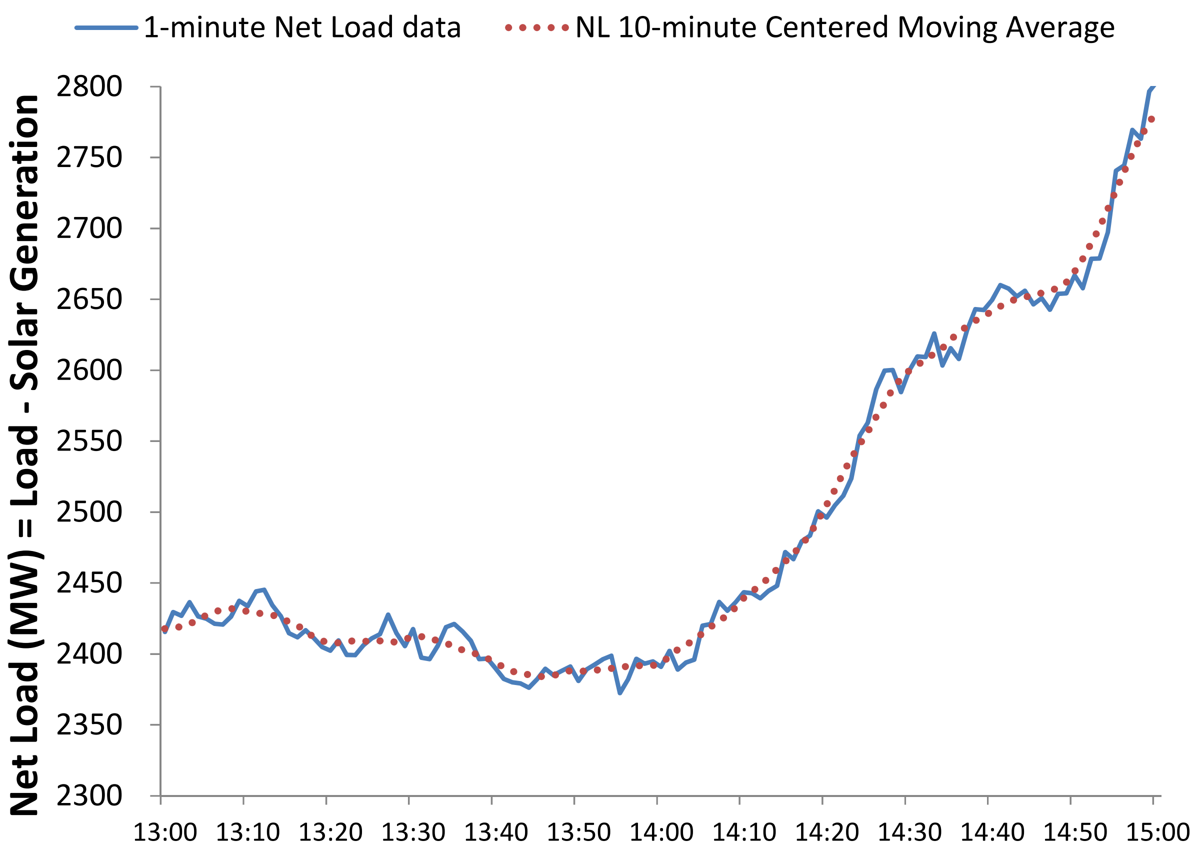
The methods for determining the incremental Regulating Reserve quantities required to support additional solar generation within the BAA are based on work performed by Brendan Kirby and Eric Hirst.[20] Regulating Reserve is comprised of Following and Fast-Moving components. The distinction

[20] Brendan Kirby and Eric Hirst, Pricing Ancillary Services so Customers Pay for What They Use, EPRI, (July, 2000) http://www.consultkirby.com/files/EPRI_Price_2000.PDF
And

between the Following component and the Fast-Moving component is the time period over which these fluctuations occur. The Fast-Moving component responds to one-minute load and generation fluctuations and the Following component responds to 10-minute changes.

For each solar generation portfolio, the Company used 1-minute load and solar generation data from 2018[21] to determine the 1-minute and 10-minute changes in load, solar generation, and Net Load[22]. In Figure 6, the blue line represents 1-minute Net Load data and the Net Load trend is represented by the pink dotted line which is calculated as the 10-minute centered moving average of the 1-minute Net Load data[23]. The uncertainty in the 10-minute Net Load trend, represented by the pink dotted line, is addressed by the Following component of Regulating Reserve and the minute-to-minute uncertainty is addressed by the Fast-Moving component.

Figure 6: Fast-moving and Following components



Brendan Kirby and Eric Hirst, *Customer-Specific Metrics for the Regulation and Load-following Ancillary Services*, Oak Ridge National Laboratory, https://certs.lbl.gov/sites/all/files/ornl-con-474.pdf.pdf (January, 2000).

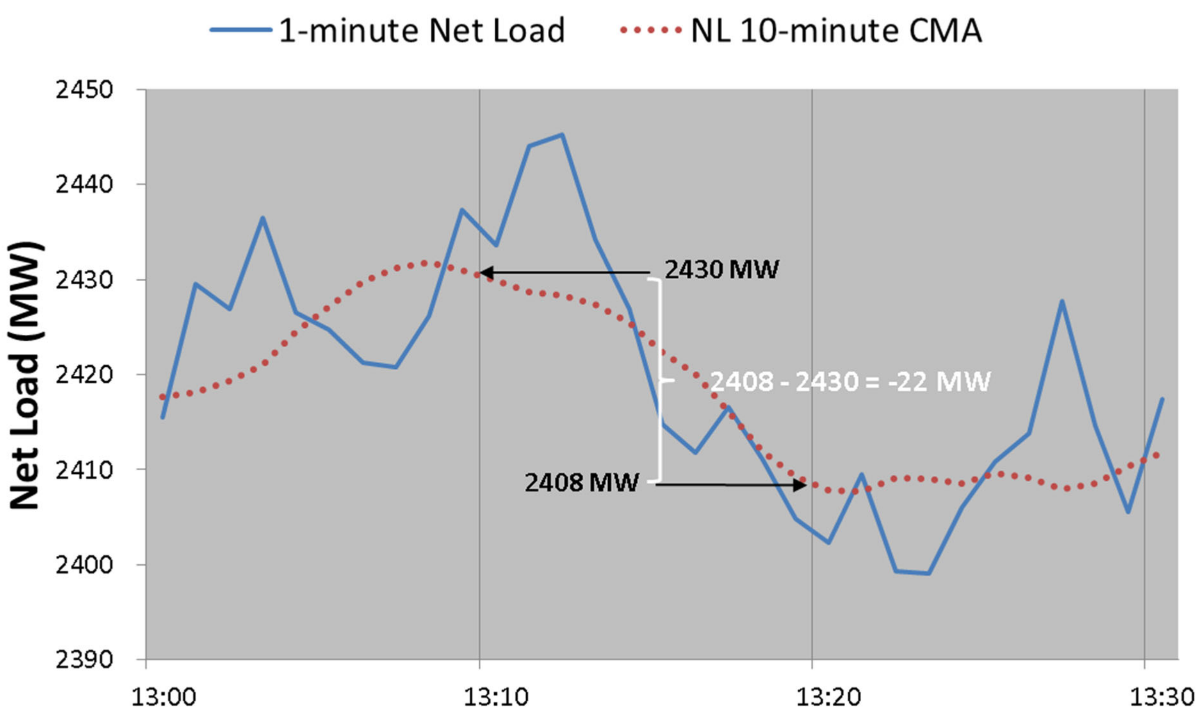
[21] NREL provided solar generation profiles for multiple locations in Colorado using 5-minute irradiance data that was downscaled to 1-minute granularity. The NREL irradiance dataset had 5-minute granularity only for 2018, so the Company limited the study period to 2018 to temporally match the solar generation change cases.

[22] In this case, Net Load is load less solar generation.

[23] For each 1-minute time period, the Company calculated the 10-minute centered moving average of the Net Load; in other words, the average of the eleven Net Load values centered on time T, from T-5 minutes to T+5 minutes.

Figure 7 shows the initial calculation of the Following component of Regulating Reserve. At time 13:10, the Net Load trend value is 2,430 MW, which is the average of the 1-minute Net Load values from 13:05 to 13:15, inclusive. At time 13:20, the Net Load trend value is 2,408 MW, which is the average of the 1-minute Net Load values from 13:15 to 13:25, inclusive. The maximum change in the Following component for this 10-minute time period from 13:10 to 13:20 is -22 MW, which the Company derived by subtracting the Net Load trend value at time 13:10 from the Net Load trend value at time 13:20. Note that there is a directional component to the calculation. If the Net Load is rising over the 10-minute time period, then the Following component is positive and if the Net Load is falling over the 10-minute time period, then the Following component is negative. Also note that the Company calculated the Following component for each clock 10-minute period; however, the maximum and minimum Net Load trend value does not need to coincide with the beginning or end of the clock 10-minute period. For example, during the clock 10-minute period from 13:00 to 13:10 in Figure 7, the maximum Net Load trend value occurs at 13:08.

Figure 7: Following component calculation



The Company divided the year into three seasons: summer, winter, and shoulder. The summer season includes the months June through September, the winter season includes the months November through February, and the shoulder season includes the remaining months of March through May and October. As stated earlier, the Company sorted the data by season-of-year and hour-of-day. For each season-of-year and hour-of-day data category, there were approximately 732 data values (~122 days per season * 6 clock 10-minute periods per hour = 732 data points per season-of-year and hour-of-day category).

The Company covers a significant portion of the Following component of Regulating Reserve with economic dispatch based on the forecasts of load and renewable generation. The Company determined the economic dispatch portion of Following by taking the average of the ~732 Following values for each season-of-year and hour-of-day category. The Company subtracted this averaged value from each Following value in the season-of-year and hour-of-day category. Then the Company excluded the top 5% of data values for each category (732 data points * 0.05 = ~37 largest Following values excluded for each season-of-year and hour-of-day category). The remaining largest Following value is the Following component of Regulating Reserve for that season-of-year and hour-of-day category.

The Company used the same process to determine the Following component of Regulating Reserve for load and solar generation separately. For example, for hour ending 8 during the Winter season for the Base Portfolio the Following component of Regulating Reserve based solely on load data is 59 MW[24], the Following component based solely on solar generation data is 65 MW, and the Following component based on Net Load data (load data net of solar generation) is 110 MW. Note that there is offsetting uncertainty in the load and solar generation data resulting in a lower reserve requirement for the Net Load than would be realized by summing the Following reserve requirements for load and solar generation calculated separately.

The Fast-Moving component of Regulating Reserve is calculated for each minute by taking the difference between the 1-minute Net Load value and the Net Load trend calculated as the 10-minute centered moving average value. Note that the Fast-Moving component can be positive if the 1-minute Net Load value is larger than the Net Load trend value or negative if the 1-minute Net Load value is smaller than the Net Load trend value. The Company excluded the top 5% of data values for each season-of-year and hour-of-day category. The remaining largest Fast-Moving value is the Fast-Moving component of Regulating Reserve for that season-of-year and hour-of-day category. The Company used the same process to determine the Fast-Moving component of Regulating Reserve for load and solar generation separately. For example, for hour ending 8 during the Winter season for the Base Portfolio the Fast-Moving component of Regulating Reserve based solely on load data is 33 MW, the Following component based solely on solar generation data is 14 MW, and the Following component based on Net Load data (load data net of solar generation) is 35 MW.

A Fair Allocation to Solar Generation of the Regulating Reserve Requirement

The Company's intent is to determine the incremental Regulating Reserve required supporting various volumes of future solar generation. Assuming no correlation between the uncertainty of load and solar generators allows us to use the square root of the sum of the squares approach to determine the contribution from the two separate contributors of the Following component of Regulating Reserves. Similarly, an assumption of non-correlation allows the same approach to determine the relative contribution from load and solar generators to the Fast-Moving component of Regulating Reserves.

While working at Oak Ridge National Laboratory, Brendan Kirby developed a formula[25] for the fair allocation of reserves that is independent of the correlation between the separate contributors to the

[24] 59 MW represents the largest load Following value after eliminating the top 5% of load Following values for that season-of-year and time-of-day.

[25] $$\sigma_{i\_allocation} = \frac{\left(\sigma_{Total}^2 + \sigma_i^2 - \sigma_{Total-i}^2\right)}{2 * \sigma_{Total}}$$

Regulating Reserve components of Following and Fast-Moving. We used a variation[26] of the Kirby formula to calculate an allocation for the Following and Fast-Moving components of Regulation Reserves.

For example, for the Following component of the Regulating Reserves during HE8 in the Winter season, we calculated the allocation to solar generation Following by summing the square of the 95th percentile for solar generation Following values (65 MW) and the square of the 95th percentile for Net Load Following (110 MW) and then subtracting the square of the 95th percentile for load Following (59 MW). This value was then divided by twice the value of the 95th percentile for Net Load Following (2 * 110 = 220). Specifically for HE 8 during the Winter season:

Solar generation Following share = $[(65)^2 + (110)^2 – (59)^2] / (2 * 110) = 58.4$ MW

Regulating Reserve Study Results

Table 4 shows the solar contribution to hourly Regulating Reserve values for the Base Portfolio by season-of-year and hour-of-day. The Base Portfolio includes all solar generation included in the Colorado Energy Plan plus other solar generation within the PSCo BAA with dispatch not controlled by the Company. The hourly solar Regulating Reserve volume is the sum of the solar allocation of the Fast-Moving and Following components. For example, the hourly solar Regulating Reserve volume of 63.1 MW during HE8 in the Winter season is comprised of 4.7 MW from the Fast-Moving component and 58.4 MW from the Following component. Figure 8 is a graph of the data found in Table 4.

[26] We used 95th percentile values rather than standard deviations. Approximately 95% of values fall within two standard deviations (“σ”) of the mean. Eliminating the top and bottom 2.5% of data from the data set would approximate the application of two standard deviations. Some participants in the TRC felt that it would be more appropriate to eliminate the largest 5% of Regulating Reserve values rather than the largest 2.5% of values, so the Company used the standard of the 95th percentile of the values.

Table 4: Solar Contribution to Regulating Reserve for Base Portfolio (2,366 MW)

	Winter			Shoulder			Summer		
MST	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating
HE1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE5	0.0	0.0	0.0	0.0	1.0	1.0	0.0	1.1	1.1
HE6	0.0	0.0	0.0	0.3	23.2	23.5	0.6	45.5	46.0
HE7	0.0	4.0	4.0	9.2	73.5	82.7	10.3	65.9	76.2
HE8	4.7	58.4	63.1	17.9	89.9	107.7	14.4	62.8	77.2
HE9	17.2	86.9	104.0	15.8	62.2	78.0	11.9	49.4	61.3
HE10	12.3	51.5	63.7	12.9	52.9	65.8	9.2	35.9	45.1
HE11	8.6	30.8	39.3	10.1	37.8	47.8	7.5	31.9	39.5
HE12	3.0	19.8	22.9	8.7	40.5	49.1	7.8	30.8	38.6
HE13	4.6	30.7	35.2	11.6	45.8	57.4	12.0	59.1	71.1
HE14	8.1	37.5	45.6	14.2	64.0	78.2	14.8	82.6	97.4
HE15	10.9	54.0	64.9	19.3	76.2	95.5	19.2	82.0	101.2
HE16	12.0	59.9	71.9	21.6	84.1	105.7	20.4	92.2	112.6
HE17	2.4	44.9	47.3	16.1	80.4	96.5	18.8	81.2	100.0
HE18	0.0	66.7	66.7	6.5	62.4	68.9	11.1	45.1	56.1
HE19	0.0	1.0	1.0	0.1	53.0	53.2	0.6	28.7	29.3
HE20	0.0	0.0	0.0	0.0	1.0	1.0	0.0	28.4	28.4
HE21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 8: Base Portfolio (2366 MW) Solar Regulating Reserve

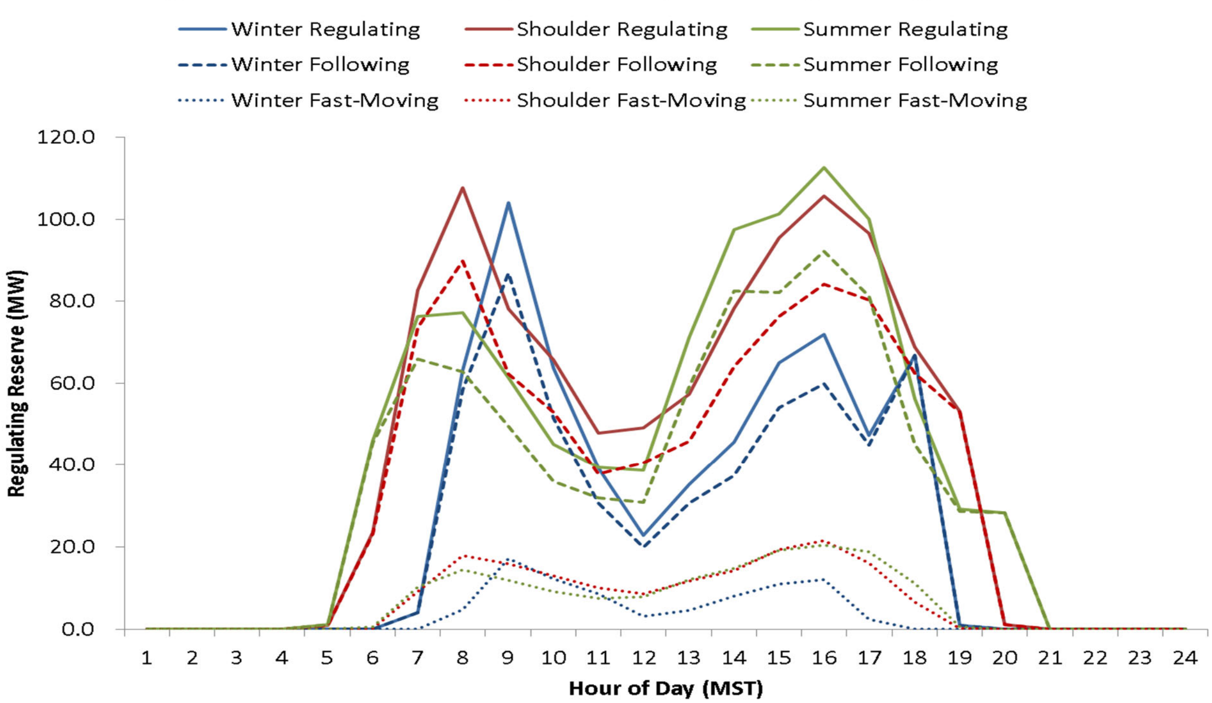


Table 5 shows the solar generation allocation of the hourly Regulating Reserve values for the Base + 500 Portfolio by season-of-year and hour-of-day. The Company studied four separate Base + 500 Portfolios by adding to the Base Portfolio 500 MW of generic solar generation resource in either the West, ERZ1, East, or ERZ4. The values in Table 5 are the average of the values for the four separate Base + 500 portfolios.

Table 6 shows the solar generation allocation of the hourly Regulating Reserve values for the Base + 1,000 Portfolio by season-of-year and hour-of-day. The Base + 1,000 Portfolio added to the Base Portfolio 500 MW each of generic solar generation resource from the West and ERZ4.

Table 7 shows the solar generation allocation of the hourly Regulating Reserve values for the Base + 1,500 Portfolio by season-of-year and hour-of-day. The Base + 1,500 Portfolio added to the Base Portfolio 500 MW each of generic solar generation resource from the West, ERZ4, and ERZ1.

Table 8 shows the solar generation allocation of the hourly Regulating Reserve values for the Base + 2,000 Portfolio by season-of-year and hour-of-day. The Base + 2,000 Portfolio added to the Base Portfolio 500 MW each of generic solar generation resource from the West, ERZ4, ERZ1, and East.

Figures 9-11 are graphs of the solar generation allocation of the Regulating Reserve values for the Winter, Shoulder, and Summer seasons, respectively, for each of the following portfolios: Base (2,366 MW), Base + 500 (2,866 MW), Base + 1,000 (3,366 MW), Base + 1,500 (3,866 MW), and Base + 2,000 (4,366 MW).

Table 5: Solar Allocation of Regulating Reserve for Base + 500 = 2,866 MW solar									
	Winter			Shoulder			Summer		
MST	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating
HE1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE5	0.0	0.0	0.0	0.0	1.0	1.0	0.0	1.6	1.6
HE6	0.0	0.0	0.0	0.4	30.4	30.7	1.0	61.5	62.5
HE7	0.0	4.3	4.3	10.3	90.2	100.5	12.0	86.7	98.6
HE8	5.5	71.5	77.0	20.2	119.6	139.8	16.2	92.0	108.1
HE9	19.7	109.2	128.9	18.0	83.1	101.0	13.6	63.9	77.5
HE10	15.3	69.7	85.0	15.0	69.0	84.0	10.5	47.1	57.6
HE11	10.1	54.8	64.8	12.2	56.0	68.2	9.1	46.2	55.3
HE12	4.7	33.3	38.0	10.4	61.7	72.1	9.4	54.1	63.5
HE13	5.1	44.8	49.9	13.4	73.2	86.6	13.7	79.4	93.0
HE14	9.9	57.1	67.0	17.2	91.5	108.7	17.9	101.1	119.1
HE15	13.1	80.0	93.0	22.7	102.6	125.3	22.5	112.7	135.2
HE16	13.5	78.8	92.4	24.9	114.1	138.9	24.6	127.5	152.2
HE17	3.1	65.6	68.8	20.1	110.3	130.3	22.1	108.7	130.7
HE18	0.0	92.9	92.9	8.5	87.3	95.7	13.5	68.2	81.7
HE19	0.0	1.5	1.5	0.2	77.3	77.5	1.7	49.1	50.8
HE20	0.0	0.0	0.0	0.0	5.4	5.4	0.0	46.5	46.5
HE21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 6: Solar Allocation of Regulating Reserve for Base + 1000 = 3,366 MW solar									
	Winter			Shoulder			Summer		
MST	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating
HE1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE5	0.0	0.0	0.0	0.0	1.0	1.0	0.0	1.1	1.1
HE6	0.0	0.0	0.0	1.4	37.6	39.0	0.8	74.2	75.0
HE7	0.0	4.0	4.0	10.9	106.0	117.0	13.2	107.9	121.0
HE8	5.6	82.1	87.7	22.2	141.6	163.8	18.1	114.9	133.0
HE9	22.3	115.5	137.8	20.3	106.7	126.9	16.3	79.4	95.7
HE10	18.2	96.5	114.7	17.9	88.1	105.9	12.7	63.6	76.2
HE11	12.0	75.0	87.0	14.4	76.7	91.1	11.7	57.7	69.5
HE12	5.5	47.8	53.3	14.2	93.3	107.5	11.9	76.2	88.1
HE13	6.7	61.5	68.2	16.5	100.2	116.7	15.6	99.9	115.5
HE14	10.9	73.0	83.9	22.3	127.1	149.4	21.8	129.5	151.2
HE15	17.2	102.4	119.5	26.2	141.9	168.0	28.6	132.8	161.3
HE16	17.0	101.5	118.5	29.3	154.1	183.4	30.5	162.0	192.5
HE17	4.6	83.3	87.9	26.2	145.4	171.6	26.4	140.9	167.3
HE18	0.0	125.2	125.2	11.5	114.3	125.8	16.5	92.2	108.7
HE19	0.0	2.0	2.0	0.3	103.7	103.9	2.0	68.4	70.4
HE20	0.0	0.0	0.0	0.0	15.1	15.1	0.0	72.7	72.7
HE21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7: Solar Allocation of Regulating Reserve for Base + 1500 = 3,866 MW solar

	Winter			Shoulder			Summer		
MST	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating
HE1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE5	0.0	0.0	0.0	0.0	1.0	1.0	0.0	3.1	3.1
HE6	0.0	0.0	0.0	1.5	44.7	46.3	2.0	91.2	93.1
HE7	0.0	4.1	4.1	12.7	123.9	136.6	15.0	118.3	133.3
HE8	6.9	95.4	102.3	25.3	160.1	185.5	21.5	147.2	168.7
HE9	24.7	128.2	152.9	23.8	119.8	143.6	18.8	92.7	111.6
HE10	21.5	117.7	139.2	19.8	94.9	114.7	13.9	70.7	84.6
HE11	13.8	85.6	99.4	15.7	98.8	114.4	13.5	73.0	86.6
HE12	6.8	55.7	62.5	15.5	98.9	114.4	13.8	91.6	105.4
HE13	7.6	75.4	83.0	18.4	122.4	140.8	18.1	122.3	140.5
HE14	12.8	85.9	98.6	25.4	141.7	167.1	23.7	144.6	168.3
HE15	19.7	114.2	133.9	30.5	161.2	191.7	32.5	172.3	204.8
HE16	18.9	113.4	132.2	31.3	181.5	212.9	32.9	173.8	206.7
HE17	5.0	99.7	104.7	28.6	172.5	201.1	30.8	166.4	197.2
HE18	0.0	151.0	151.0	13.3	140.6	153.8	18.4	105.4	123.8
HE19	0.0	2.0	2.0	0.4	121.9	122.3	2.2	82.6	84.9
HE20	0.0	0.0	0.0	0.0	16.2	16.2	0.0	86.9	86.9
HE21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 8: Solar Allocation of Regulating Reserve for Base + 2000 = 4,366 MW solar

	Winter			Shoulder			Summer		
MST	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating	Fast-moving	Following	Regulating
HE1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE5	0.0	0.0	0.0	0.0	1.0	1.0	0.0	4.2	4.2
HE6	0.0	0.0	0.0	1.5	53.1	54.6	2.0	107.6	109.6
HE7	0.0	6.0	6.0	13.9	144.5	158.4	16.3	130.1	146.3
HE8	7.4	111.2	118.6	25.3	186.8	212.2	22.7	150.7	173.4
HE9	26.7	159.0	185.7	24.7	129.1	153.8	19.4	99.7	119.1
HE10	22.8	126.2	148.9	21.7	102.1	123.8	14.6	78.6	93.2
HE11	14.4	84.8	99.2	16.3	100.8	117.1	14.1	75.6	89.7
HE12	6.8	61.1	67.8	15.5	101.3	116.8	15.0	94.8	109.8
HE13	8.9	82.4	91.3	19.1	134.7	153.8	18.7	140.6	159.3
HE14	14.0	93.5	107.5	26.2	154.7	180.9	25.4	147.1	172.5
HE15	20.3	134.3	154.6	32.9	166.8	199.7	33.3	171.2	204.5
HE16	20.3	130.7	151.0	33.7	193.4	227.0	35.2	179.4	214.6
HE17	5.0	118.5	123.5	29.7	196.1	225.9	31.1	177.2	208.4
HE18	0.0	171.2	171.2	13.8	157.7	171.5	20.3	115.4	135.7
HE19	0.0	2.0	2.0	0.4	144.3	144.7	2.2	99.0	101.2
HE20	0.0	0.0	0.0	0.0	15.0	15.0	0.0	108.5	108.5
HE21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HE24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

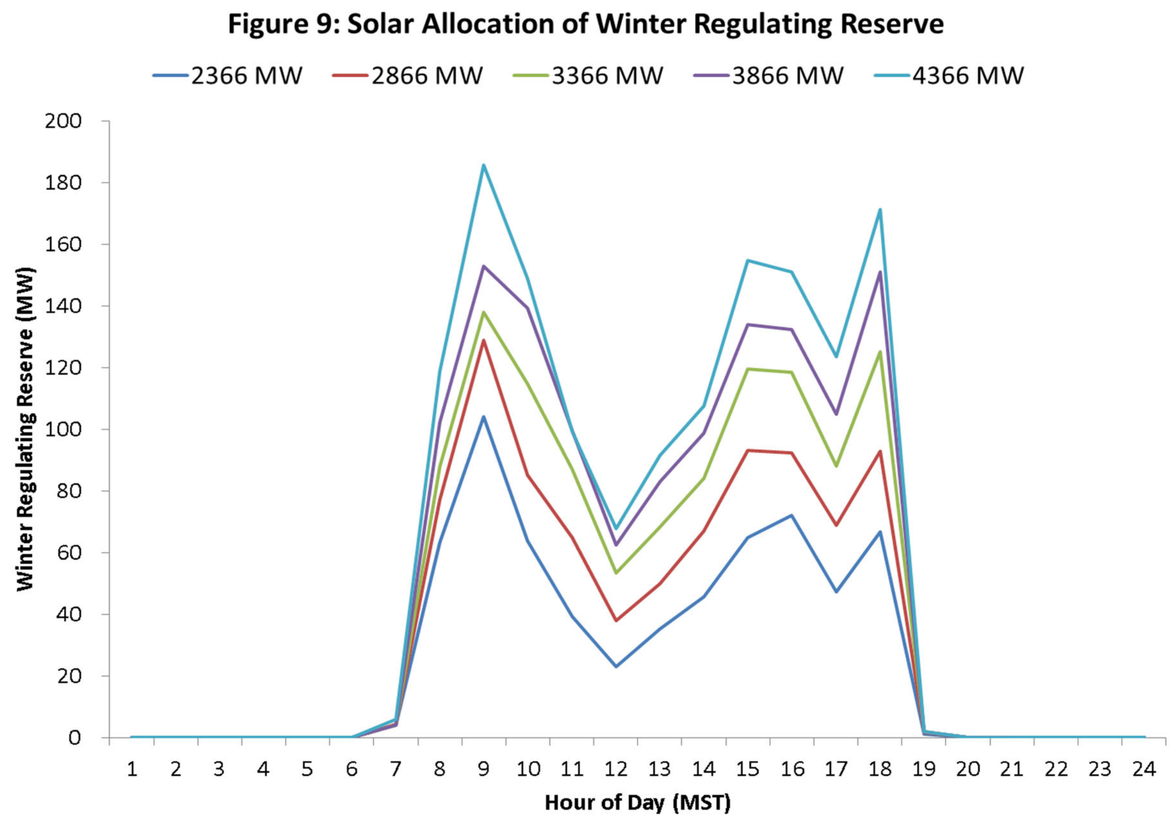


Figure 9: Solar Allocation of Winter Regulating Reserve
2366 MW
2866 MW
3366 MW
3866 MW
4366 MW
Winter Regulating Reserve (MW)
0
20
40
60
80
100
120
140
160
180
200
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (MST)

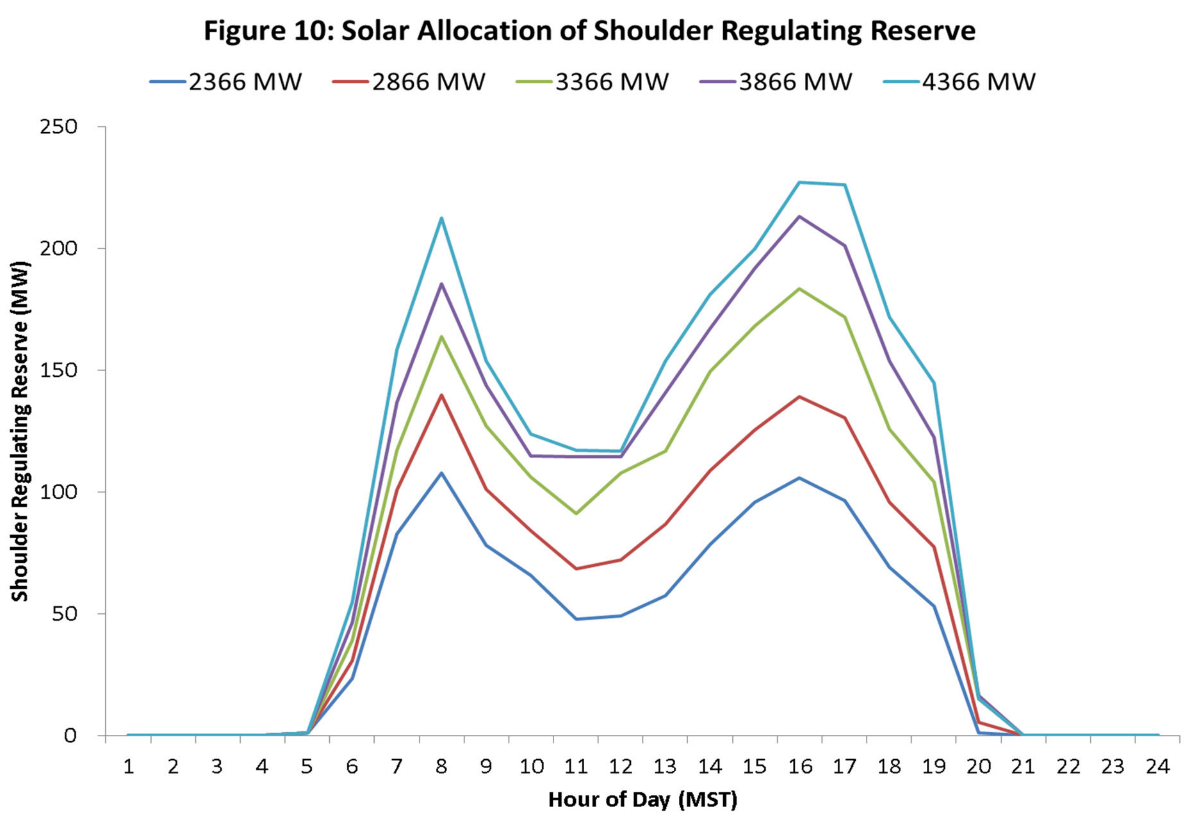
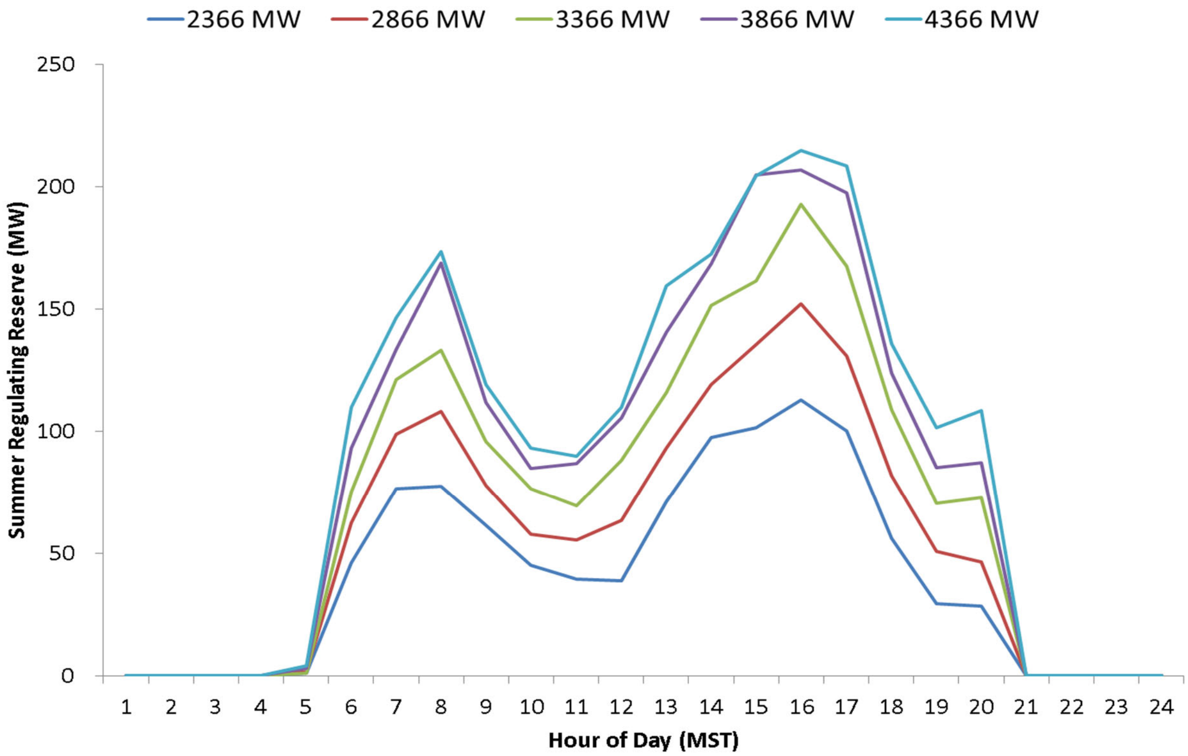


Figure 10: Solar Allocation of Shoulder Regulating Reserve
2366 MW
2866 MW
3366 MW
3866 MW
4366 MW
Shoulder Regulating Reserve (MW)
0
50
100
150
200
250
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour of Day (MST)

Figure 11: Solar Allocation of Summer Regulating Reserve



The Base Portfolio for solar generation represents the volume of solar generation already committed to by the Company and others within the BAA and includes over 2.3 GW of solar generation. Note that an increase of 2 GW of solar generation increases the maximum hourly Regulating Reserve volume by 82 MW in the Winter season, 119 MW in the Shoulder season, and 102 MW in the Summer season.

<u>Next Steps</u>

This study has determined the incremental volumes of reserve necessary to reliably integrate up to 1.5 GW of new wind generation and up to 2 GW of new solar generation within the BAA beyond levels already committed to by the Company and others. These incremental reserve requirements will be used as an input to production cost models used during Phase 2 of the Company's Electric Resource Planning Process. In Phase 2, the Company will evaluate various portfolios of generators to determine a preferred portfolio which meets the 80% carbon reduction by 2030 mandate while maintaining sufficient reserves to address the uncertainty of the portfolio of renewable generation and while keeping costs low for our customers.