30-Minute Flex Reserve

on the

Public Service Company of Colorado System

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Introduction

In Public Service Company of Colorado's (the "Company") "2011 Wind Limits Study"[1] it detailed the creation and application of its 30-Minute Wind Reserve Guideline. The Company provided further details on the 30-Minute Wind Reserve Guidelines in a study report titled "An Investigation of Potential Electric Storage Options" dated December 8, 2014 and filed in Docket No. 14M-1160E (the "2014 Storage Study"). The guideline was adopted in order to help System Operators maintain enough standby resources that could be brought online within 30 minutes in response to large, sustained down ramps in wind generation.

On May 15, 2014 the Company filed with the Federal Energy Regulatory Commission ("FERC") for a new transmission tariff, Schedule 16: Flex Reserve Service. This new Schedule is a supplemental reserve category designed to address large reductions of online wind generation due to losses in wind speed. On December 5, 2014, FERC conditionally accepted the Company's filing with an effective date of January 1, 2015 subject to Hearing and Settlement Judge Procedures. On March 3, 2016, FERC issued a letter order accepting the settlement agreement between the settlement parties. As a result of the FERC's decision, the Flex Reserve Service included in the Company's transmission tariff has replaced the former 30-Minute Wind Reserve Guideline.

Flex Reserve is comprised of excess Contingency Reserve[2] as well as online and offline generation available within 30-minutes that is not already included in the Contingency Reserve calculation. This definition of Flex Reserve includes three of the four categories of flexible resources listed on page 15 of the 2014 Storage Study: (1) offline Flex Reserve capacity; (2) excess Contingency Reserve capacity; and (3) greater than 10-minute ramp capability from online/unloaded generation. The fourth category, curtailed wind generation, is not currently included as a Flex Reserve resource.[3] Of the three categories of flexible resources which the Company uses to meet its Flex Reserve requirement, only maximum potential offline Flex Reserve capacity is easily quantifiable without a detailed analysis of current system conditions which are constantly in flux.

Since the last Wind Reserve Guideline study was performed, the Company has added 850 MW of wind generation capacity.[4] This incremental wind generation has increased the size and frequency of large, loss-of-wind-generation events. This study report provides updates to the 30-minute Flex Reserve calculation for the existing wind generation portfolio and for incremental

[1] The 2011 Wind Limits Study was filed as Attachment 2.14-1 in Docket 11A-869E as part of the Company's 2011 Electric Resource Plan.

[2] Contingency Reserve (Operating Reserve) is generation capacity adequate to maintain scheduled frequency and avoid loss of firm load following transmission or generation contingencies. At least 50% of Contingency Reserve must be Spinning Reserve with the balance comprised of one or more of several types of resources including Supplemental Reserve (Non-Spinning Reserve).

[3] Wind curtailments do limit the potential for loss of wind generation but, as an inherently variable resource the volume of curtailed energy is not a dependably dispatchable resource for a future time (i.e., a 30-minute Flex Reserve product).

[4] The last Wind Reserve Guideline study anticipated the 400 MW wind generation contribution from the Limon 1 and Limon 2 wind farms. In addition to those facilities, the Company subsequently acquired generation from Limon 3 (200MW) and Golden West (250 MW) as a result of the 2013 All-Source Solicitation.

wind generation additions. It also examines whether existing offline Flex Reserve capacity[5] is sufficient to meet the wind generation down ramps that could occur with wind generation portfolios with incremental wind generation.

Flex Reserve Methodology

The previous 30-minute Wind Reserve Guideline calculation was a two-part formula. For wind generation levels up to 290 MW, the guideline generally required 1 MW of 30-minute Wind Reserve for each 1 MW of wind generation. For wind generation levels greater than 290 MW, when the largest wind ramps are possible, the guideline was based on a best-fit curve through a scatter plot of the largest 30-minute wind generation down ramps when plotted as a function of wind generation at the start of a ramp. This calculation resulted in a monotonically increasing Wind Reserve with increasing levels of wind generation. With increasing wind generation experience, this result did not match the Company's anecdotal experience in which it was observed that the largest wind generation down ramps occurred when total wind generation levels were closer to a 50% capacity factor rather than a 100% capacity factor.

In order to address this discrepancy, the Company changed the definition of "largest wind ramps" used to set the Flex Reserve levels. This was done by binning all wind generation down ramps into 100 MW bins based on the wind generation at the start of the 30-minute ramp and then selecting the largest wind ramp for each 100 MW bin.[6] 5-minute instantaneous wind generation data from November 1, 2014 through October 31, 2015 were used for this analysis.[7]

In Figure 1, a plot of these "largest wind ramps" from the current 2,566 MW wind generation portfolio is compared to the previous 30-minute Wind Reserve Guideline. As can be seen in Figure 1, the best fit trend line through the new definition of "largest wind ramps" for the current wind portfolio of 2,566 MW peaks at a wind generation level of 1,310 MW with a negative wind ramp/Flex Reserve requirement of 708 MW. Comparatively, the previous Wind Reserve Guideline would calculate 454 MW of reserves when instantaneous wind generation was at 2,566 MW.[8]

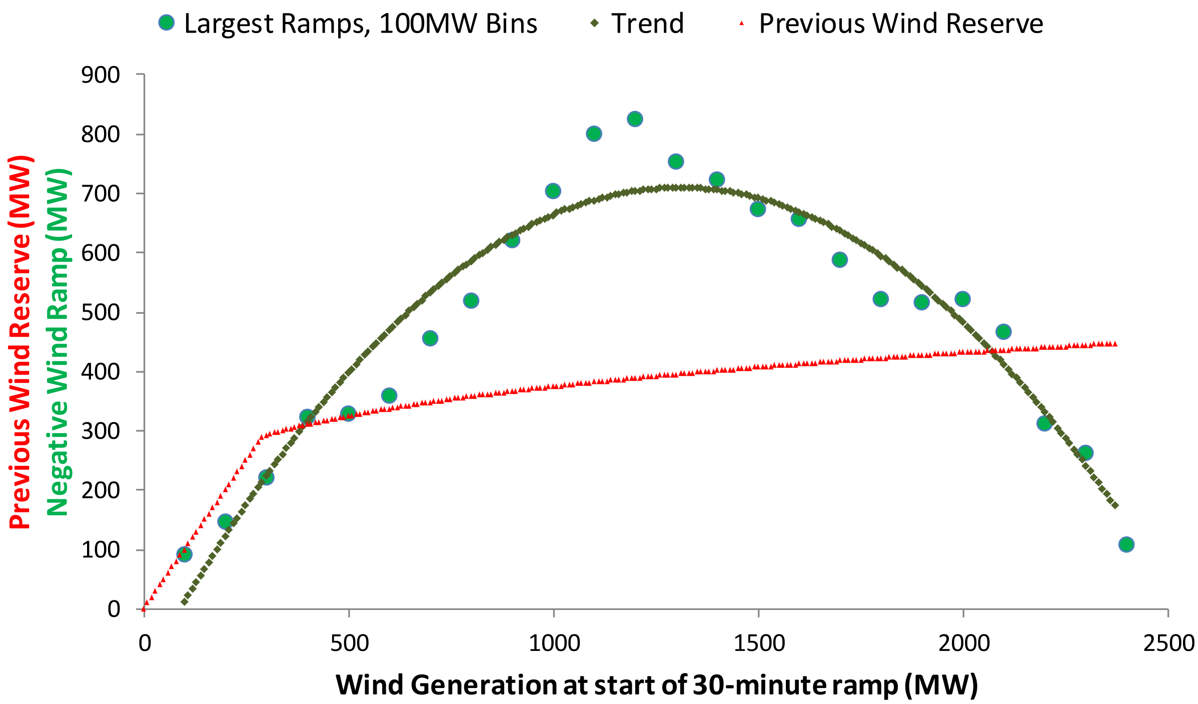
[5] Offline Flex Reserve capacity is the available capacity of those units which are offline, but can be online in less than 30 minutes, less the Rocky Mountain Reserve Group's Supplemental Reserve (Non-Spinning Reserve) requirement for the Company.

[6] This new methodology of binning wind ramps based on wind generation output is a technique borrowed from the National Center for Atmospheric Research's ("NCAR") power conversion process used in Xcel Energy's Wind Forecasting System. NCAR uses multiple weather models to predict the hub-height wind speeds at Xcel Energy's various wind farms, then converts those wind speeds into wind generation forecasts. The power conversion from wind speeds to wind generation is based on empirical power curves developed through extensive data mining in which the expected wind turbine generation output is based on observed wind generation data binned by wind speeds of one tenth (0.1) of a meter per second.

[7] Estimates of wind curtailment levels were added back to the generation meter data so that these curtailments did not appear in the data sets as sudden losses in wind generation caused by decreasing wind speeds.

[8] The 30-minute Wind Reserve formula was monotonically increasing, so Wind Reserve was always higher for increasing levels of wind generation. The current wind portfolio has 2,566 MW of wind generation capacity, so the 30-minute Wind Reserve formula was highest at 2,566 MW of generation, that is, at a 100% capacity factor.

Figure 1: Largest Ramps vs. Previous Wind Reserve

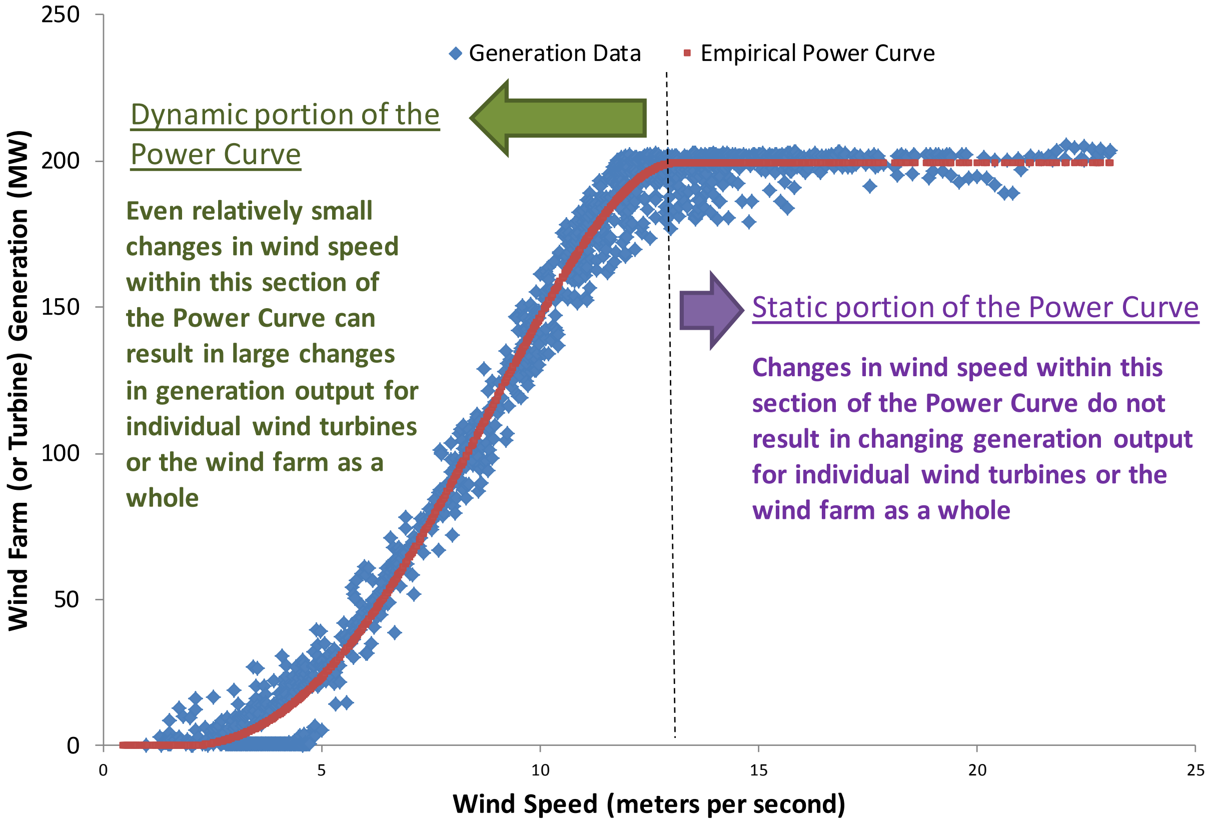


Why do the largest ramps occur near 50% capacity factor?

For Flex Reserve purposes, the metric of interest is how much wind generation can be lost ***in the next 30 minutes*** due to declining wind speed. A wind turbine or wind farm power curve is helpful to illustrate that similar changes in wind speed can have very different effects on generation output. Figure 2 depicts the generation output (y-axis) at a 200 MW wind farm as a function of wind speed (x-axis). A wind turbine power curve has the same shape as this wind farm power curve;[9] the only difference is the scale of the y-axis.

[9] The generation output for a wind farm is the sum of all the individual turbines at that wind farm.

Figure 2: Empirical Power Curve for 200 MW PSCo wind farm



As can be seen in Figure 2, a five meter-per-second (mps) loss of wind speed from 20 mps to 15 mps would result in no expected change in wind farm generation output. A similar 5 mps loss of wind speed from 15 mps to 10 mps would result in a loss of ~50 MW, from 200 MW to 150 MW of wind farm generation. A loss of 5 mps of wind speed from 10 mps to 5 mps would result in a loss of ~130 MW, from 150 MW to 20 MW of wind farm generation. So the change in total wind farm generation output can vary widely depending on where the 5 mps loss of wind speed occurs on the power curve.

Similarly, when wind generation for the Company's total wind portfolio approaches a 100% capacity factor almost all of the individual wind turbine generators are somewhere in the static portion of the power curve where small changes in wind speed result in virtually no change in generation output. When wind generation for the total wind portfolio approaches 50% capacity factor, a much larger percentage of individual wind turbine generators are somewhere in the dynamic portion of the power curve where small changes in wind speed can result in significant changes in generation output. That is, the largest wind generation down ramps occur when many individual turbines are in the dynamic portion of their power curves and simultaneously experience a loss of wind speed.

20-Minute vs. 30-Minute Offline Flex Reserve Capacity

The change in Flex Reserve was discussed earlier and as shown in Figure 1 results in a larger reserve requirement compared to the prior Wind Reserve Guideline which more accurately reflects the size of the largest 30-minute wind generation down ramps that Flex Reserve is intended to address. The Company has also changed the definition of offline Flex Reserve capacity from those used in the 2011 Wind Limits Study and the 2014 Storage Study.

In the 2011 Wind Limits Study, the Company only counted offline Flex Reserve capacity which could be online within 20 minutes. The logic was that the System Operator might take up to 10 minutes of the 30-minute wind generation down ramp to recognize the ramp event, which would only leave 20 minutes to dispatch the offline Flex Reserve capacity. In the current study, offline Flex Reserve capacity includes all offline resources that can be online within 30 minutes. This change of including all offline generation capacity available within 30 minutes rather than just 20 minutes results in a higher offline Flex Reserve capacity because large frame combustion turbines (e.g., Blue Spruce 1&2, and Fort St. Vrain 5&6) typically take ~22 minutes to come online.

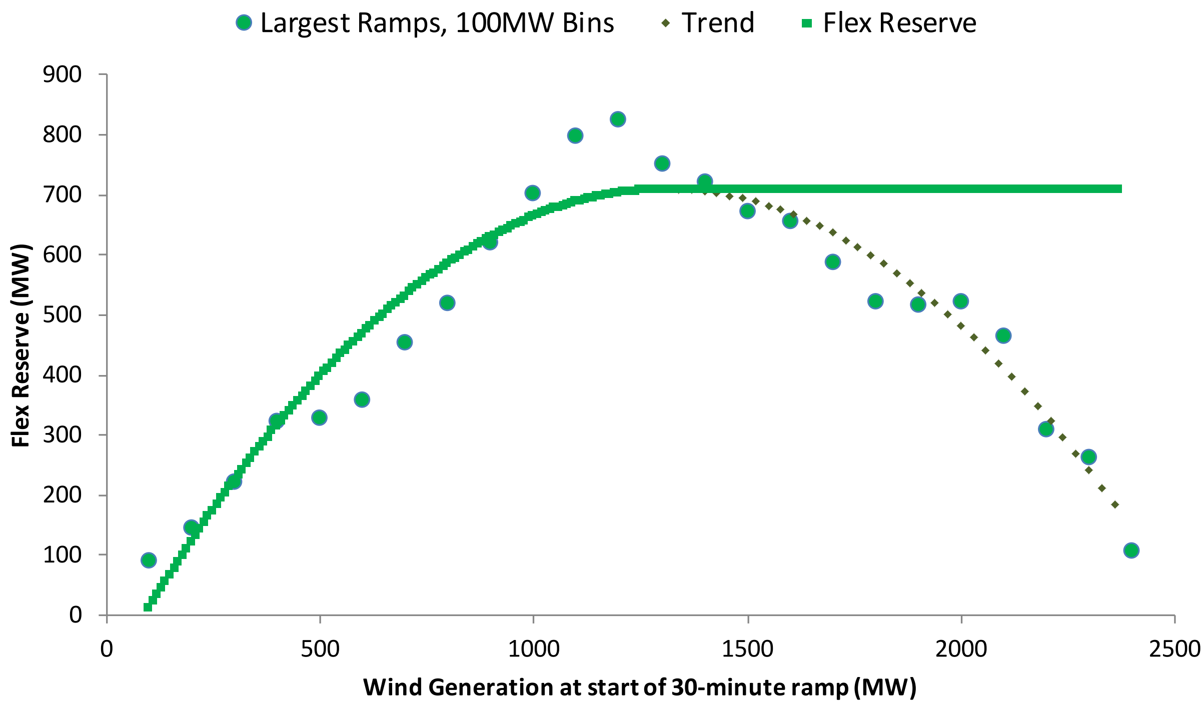
The largest 30-minute wind generation down ramps represent the steepest 30-minute loss of wind generation that is almost always embedded within a longer and larger wind generation down ramp. The System Operator typically has plenty of warning that a wind generation down ramp is in progress before the start of the steepest 30-minute portion of that ramp, so it appeared overly conservative to only credit offline capacity which can be available within 20 minutes. The Company believes this change from 20 minutes to 30 minutes is a more accurate metric of system flexibility.

Flex Reserve Requirement

Flex Reserve is intended to cover large 30-minute wind down ramps. The Company has had great success reducing average day-ahead forecast error, but less success at accurately predicting the onset of very large wind generation down ramps. Further, data show that very large wind ramps occur during all seasons and at any time of the day.

The data also show that the size of the largest wind generation down ramps decreases after instantaneous wind generation exceeds an ~50% capacity factor; however, reducing the Flex Reserve at higher levels of wind generation to match this reduction in ramp amplitude poses an operational risk. The concern is that a reduction in wind generation output, say from 2,000 MW to 1,500 MW, would be accompanied by an increase in the Flex Reserve obligation from 447 MW to 681 MW. In other words, at the same time that wind generation has decreased by 500 MW and must be replaced by non-Variable Energy Resource (non-VER) generation (which of itself decreases the available Flex Reserve resources), the Flex Reserve requirement would be increasing by 234 MW. To mitigate this coincident depletion of Flex Reserve capacity and increase in Flex Reserve requirement, the final Flex Reserve calculation is based on the best-fit parabolic curve up to the vertex and then this maximum Flex Reserve value is applied to all higher levels of instantaneous wind generation (see Figure 3).

Figure 3: 30-minute Flex Reserve



Flex Reserve Requirements for Incremental Wind

In order to evaluate Flex Reserve requirements for portfolios with incremental wind generation, the Company studied two scenarios: 1) a portfolio with 2,974 MW of total wind generation and 2) a portfolio with 3,174 MW of total wind generation. The portfolio with 2,974 MW was created by adding an incremental 600 MW of Energy Resource Zone 2 ("ERZ 2")[10] wind generation and removing currently-existing wind generation totaling 192 MW that is subject to purchase power agreements scheduled to expire within the next three years. The 3,174 MW portfolio added an additional 200 MW of ERZ 2 wind to the 2,974 MW portfolio. A single ERZ 2 wind generation profile was developed for both the incremental 600 MW and 800 MW scenarios.[11]

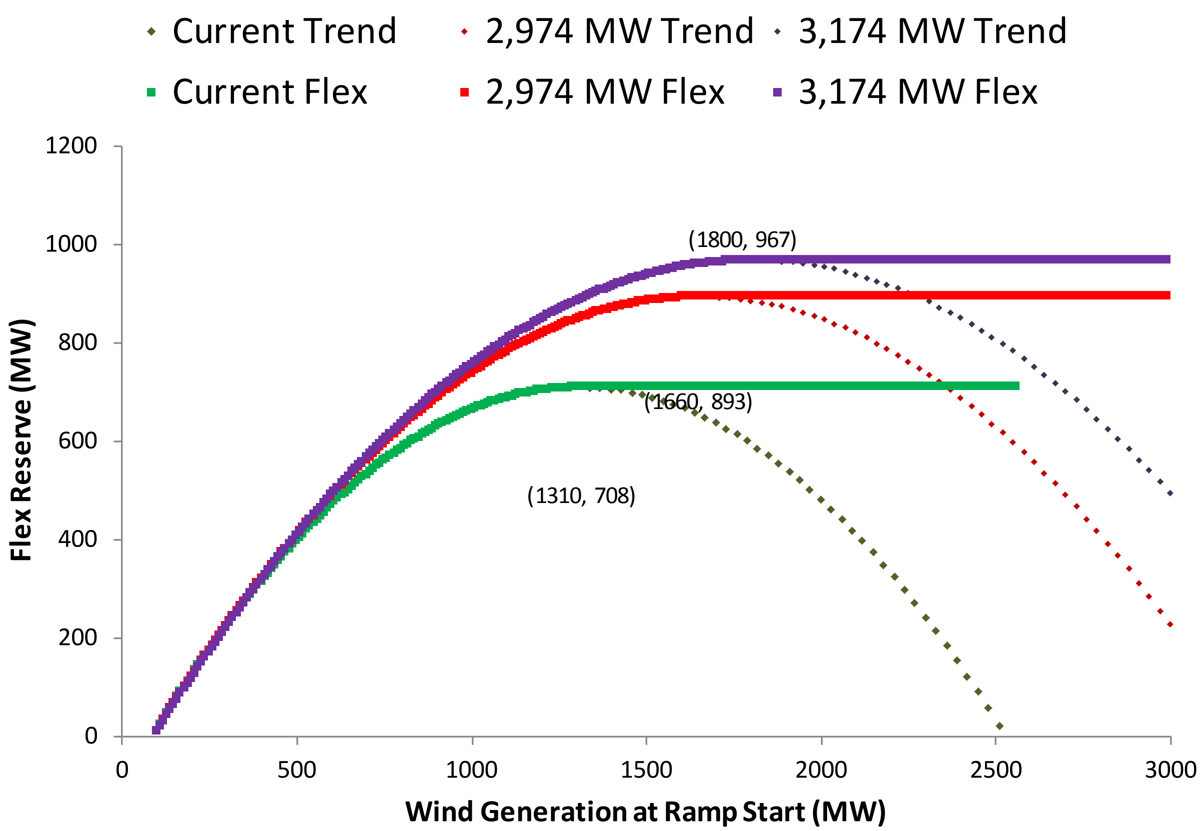
As can be seen in Figure 4, the 2,974 MW and 3,174 MW portfolios increase the size of the potential 30-minute loss of wind generation events which, in turn, increase the 30-minute Flex Reserve requirements. The coordinates shown on the Figure indicate the vertex of each curve with the first value representing the volume of wind generation at the start of the ramp and the second value representing the volume of Flex Reserve required for that volume of wind

[10] ERZ 2 is a geographical area east and southeast of the Denver metro area. It encompasses all or parts of the following counties: Adams, Arapahoe, Cheyenne, El Paso, Elbert, Kiowa, Kit Carson, Lincoln, Washington, and Yuma.

[11] In order to represent geographic diversity, 5-minute wind speed data for five ERZ 2 wind farms (Cedar Point, Limon 1, Limon 2, Limon 3 and Golden West) was gathered for the study period. Two separate wind farm empirical power curves (Limon 3 and Golden West) were used to convert the wind speeds to generation volumes. These ten wind generation profiles were combined into a single generation profile that is representative of the geographic diversity that currently exists within ERZ 2. This single generation profile was then scaled to represent either 600 MW or 800 MW of new ERZ 2 wind capacity.

generation. For example, for the 3,174 MW wind scenario 967 MW of Flex Reserve would be required given the apex in the curve fit that occurs at 1,800 MW of Wind Generation at Ramp Start.

Figure 4: 30-minute Flex Reserve Requirement



Offline Flex Reserve capacity as a measure of portfolio flexibility

As discussed earlier, for the purposes of this study, maximum potential offline Flex Reserve capacity is the only component of Flex Reserve that is easily quantifiable. The Company believes that maximum offline Flex Reserve capacity is the best available—though not perfect—measure of system flexibility necessary to meet the Flex Reserve requirement. Figure 5 lists the maximum dependable capacity for all the existing generation resources in the Company's portfolio which, if offline and available, are capable of providing 30-minute Flex Reserve. Assuming all these generators are both offline and available, there is 1,501 MW of available Flex Reserve capacity after accounting for the Company's 211 MW Supplemental (Non-Spinning) Reserve requirement which is met with this same pool of resources.

The Company is not suggesting that all of the generating resources listed in Figure 5 are always, or even usually, both offline and available. For example, one or more of these resources may be unavailable due to planned or unplanned maintenance outages, some units may not be staffed during overnight hours and therefore may not be immediately available, several plants may be unavailable at times due to the lack of firm gas supply, and many of these resources are often online providing economic energy to meet load. When offline Flex Reserve capacity is solely insufficient to meet the Flex Reserve requirement, System Operators are responsible for ensuring that sufficient additional flexible resources are available from the other two categories of Flex Reserve: 1) excess Contingency Reserve capacity, and 2) greater than 10-minute ramp capability from online/unloaded generation.

Figure 5: 30-Minute, Flex Reserve Capable Generation Resources (when offline and available)[12]

Generator(s)	Flex Reserve (MW)
Cabin Creek	320
Ft. Lupton	89
Fort St. Vrain 5 or 6	145
Blue Spruce 1 or 2	130
Valmont 6	43
Alamosa	26
Fruita	14
Spindle Hill 1 or 2	158
Manchief	267
Arapahoe 5,6,7	39
Plains End	215
Fountain Valley 1-6	236
Brush 3	30
Total Generation	1,712
RMRG Reserve Req.	211
Max. Offline Flex Reserve	1,501

Figure 6 shows the Flex Reserve required for the current wind generation portfolio and for the 2,974 MW and 3,174 MW wind portfolios. The maximum, excess offline Flex Reserve capacity is calculated by subtracting the Flex Reserve requirements for each scenario from the 1,501 MW of maximum offline Flex Reserve. Figure 6 demonstrates the Company currently has sufficient offline Flex Reserves to accommodate a wind portfolio with the 3,174 MW of wind assumed in this study.

[12] Blue Spruce and Spindle Hill are listed as "1 or 2" and Fort St. Vrain is listed as "5 or 6" to indicate that, as currently configured, these facilities only have a single unit at any one time that qualifies as a 30-minute Flex Reserve even though these facilities have two identical generators. The installation of load cummutated inverters ("LCIs") at any of these sites would allow both units to start simultaneously and double the amount of offline Flex Reserve capability shown in the Figure for those facilities.

Figure 6: Excess Offline Flex Reserve Capacity

Wind Portfolio	Flex Reserve Requirement (MW)	Excess Flex Reserve (MW)
2,566 MW	708	793
2,974 MW	893	608
3,174 MW	967	534

Conclusions

The Company has recently altered the methodology through which it maintains sufficient flexible generation resources to reliably accommodate its wind generation portfolio. The new methodology quantifies in real time: 1) offline Flex Reserve capcity, 2) excess Contingency Reserve capacity, and 3) greater than 10 minute ramp capacity from online/unloaded generation. These available resources are compared to a 30-minute Flex Reserve requirement that has been created based on a historical examination of large wind down ramps on the Company's system.

In the current study, the Company has also examined the change in 30-minute Flex Reserve requirements that would be expected with wind portfolios of 2,974 MW and 3,174 MW of total wind. The Company believes its current portfolio of maximum potential offline Flex Reserve capacity is sufficient to reliably integrate these levels of incremental wind generation. Should incremental Flex Reserve capacity be needed, the Company has multiple low-cost opportunities at its existing generators to obtain those resources.