F. VARIABLE ENERGY RESOURCE INTEGRATION REPORT

This integration report assessed the incremental regulation costs to integrate more renewable resources—wind, solar, and BESS—into Black Hills Power's generation mix at several key sites. The report estimated the incremental regulation costs required to maintain reliability and frequency regulation, and assessed flexible capacity requirements. In addition, the report determined the accreditable capacity of VER for reliability planning.

Regulation costs through WAPA's OATT are: $1.04/MWh for wind at a 40% capacity factor; $1.12/MWh for solar at a 25% capacity factor.

The effective load carrying capacity (ELCC) ranges from 29% and declining to 4% as resource amounts increase. Wind is higher than solar, mainly because of the higher capacity factor. For BESS, ELCC values range from 80% for 20 MW to 49% for a 100 MW installation.

HITACHI ABB

REPORT

Black Hills Power Variable Energy Resource Integration Report

CCS-DA-20-00007680.00

PREPARED FOR

Black Hills Corporation

PREPARED BY

Hitachi ABB Power Grids Advisory Services

March 12, 2021

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1 Introduction

The Hitachi ABB Power Grids Energy Market Advisors team is part of the Energy Market Intelligence solution area that provides tools and analysis around market and transmission modelling, analysis, and price forecasting to support investment decisions, regulatory compliance, trading, energy operations, and renewable integration.

1.1 Scope of Study

Black Hills Corporation retained the Hitachi ABB Power Grids Energy Market Advisors team (PG) to complete an assessment of the incremental regulation costs of Black Hills Power (BHP) to integrate future levels of renewable resources onto its power system. In completing this assessment, PG examined forecast and actual load, wind generation and solar generation data to develop estimates of incremental regulation capacity that BHP will require to maintain reliability and frequency regulation. PG also completed production cost simulations using the Portfolio Optimization software to develop cost estimates of carrying the incremental regulation capacity amounts, and an additional assessment of flexible capacity requirements was also completed. These analyses were completed for a combination of wind, solar and battery energy storage resource expansions at several key sites on the BHP system. PG also completed an assessment to determine the accreditable capacity of Variable Energy Resources (VER) for reliability planning purposes.

1.2 Study Summary – Regulating Reserves

The assessment examined renewable and energy storage resource additions at several different locations to assess incremental impacts on BHP regulation requirements and costs. The assessment evaluated twelve different renewable and energy storage resource expansion options and five different potential geographic locations for those resources. These resource options and locations were specified by the BHP planning team, based on commercial interest it has seen in developing resources at those locations, and with a goal of capturing impacts of geographic diversity in wind and solar generation profiles within its service territories.

The basic approach taken to assess regulating reserve requirements for the BHP system was to evaluate compliance with the North American Reliability Council (NERC) Control Performance Standard 2 (CPS2) reliability requirements. While those requirements do not strictly apply to BHP, they were used in this assessment as a proxy for operational challenges that will arise from increased wind and solar integration and impacts of those challenges on BHP operations and resource expansion decisions. Under the CPS2 reliability requirements, BHP system Area Control Error (ACE) is monitored on a 10-minute interval, and any violations of frequency deviations are tabulated. Events where ACE deviates outside of high and low bands are tagged as a frequency violation and needed regulation capacity is calculated as incremental Regulation Up or Regulation Down capacity needed to ensure that the BHP ACE stays within upper and lower bands 98 percent of the time.

To determine the system cost of the additional Regulation Up and Regulation Down PG completed production cost simulations, modelling both the resource inclusion and associated incremental Regulation Up and Regulation Down capacity requirements. The difference in total system production costs between each portfolio’s simulation with and without the incremental regulation capacity was used to develop estimated cost per MWh for carrying the incremental Regulation Up and Down capacity.

Table 1 provides a summary of the renewable and energy storage resource options and projected regulation requirements resulting from the assessment. As shown, resource portfolios include wind additions of 50, 100 and 200 MW at Cheyenne, South Gillette and North Douglas, WY locations, and solar additions of 50, 100 and 200 MW at Cheyenne WY, Gillette WY and Hot Springs SD locations. The resource portfolios also include pairing of 100 MW solar with 40, 20 and 60 MW battery energy storage capacity at the Cheyenne, Gillette and Hot Springs locations, as well as stand-alone 20, 40 and 60 MW battery energy storage projects at those same three respective locations.

Table 1. Summary of Incremental Regulation Requirements and Costs

Portfolio	Type	Size (MW)	Location	98% CPS2: Incremental Regulation Up (MW)	98% CPS2: Incremental Regulation Down (MW)	Regulation Cost – BHP Generation ($/MWh)	Regulation Cost – WAPA Tariff ($/kW/Mo)
Existing System				55	50		
1	Wind	50	Cheyenne	24	0	$10.17	$0.303
2	Wind	100	S. Gillette	26	22	$6.56	$0.303
3	Wind	200	N. Douglas	50	40	$11.12	$0.303
4	Solar	50	Cheyenne	7	1	$5.38	$0.205
5	Solar	100	Gillette	10	1	$4.63	$0.205
6	Solar	200	Hot Springs	11	1	$1.57	$0.205
7	Solar + Storage	100 + 40	Cheyenne	0	1	$0.02	$0.205
8	Solar + Storage	100 + 20	Gillette	0	1	$0.03	$0.205
9	Solar + Storage	100 + 60	Hot Springs	0	1	$0.02	$0.205
10	Storage	20	Cheyenne	0	1	N/A	
11	Storage	40	Gillette	0	1	N/A	
12	Storage	60	Hot Springs	0	1	N/A	

As shown in Table 1, Regulation Up requirements for the BHP existing power system are 55 MW, and Regulation Down requirements are 50 MW. Incremental Regulation Up requirements range from zero to 50 MW, and incremental Regulation Down requirements range from 1 to 40 MW. Regulation costs projected from use of BHP's generation range from $1.57/MWh for a 200 MW solar addition at Hot Springs, SD, to $11.12/MWh for a 200 MW wind addition at North Douglas, WY. BHP also has an option to procure regulation from WAPA, through its Open Access Transmission Tariff (OATT) at a lower cost. WAPA's current tariff offers regulation service for a fixed cost of $0.303/kW/Month for wind resources, and $0.205/kW/Month for solar resources. At a 40% annual average wind capacity factor, the WAPA regulation cost is equivalent to $1.04/MWh for wind resources, and at a 25% annual average capacity factor for solar, it would be equivalent to $1.12/MWh for solar resources. For solar resource options that include battery storage, the battery capacity is sufficient to offset incremental Regulation Up capacity requirements associated with operation of the solar resources, so that on net, additional regulation capacity is not required. In those cases, the incremental regulation cost listed is associated with provision or procurement of Regulation Down.

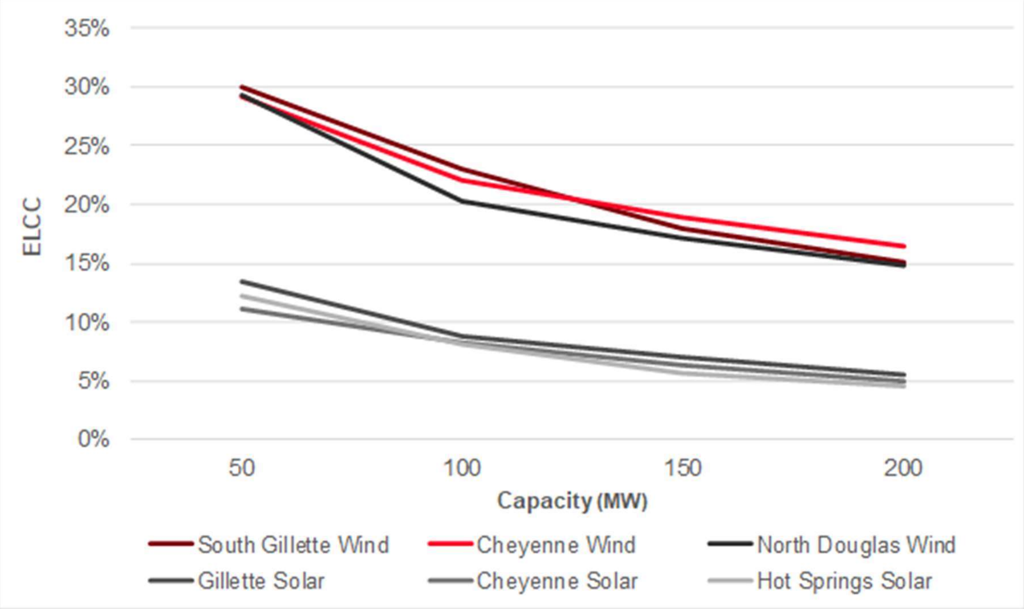
1.3 Study Summary – Flexible Capacity Requirement

In addition to assessing incremental regulation requirements and costs likely to be incurred due to changes in BHP operating costs, PG also completed an assessment of whether BHP is likely to require additional flexible capacity to integrate the Resource Portfolios. PG used a methodology originally developed by the California Independent System Operator (CAISO) to assess BHP's flexible capacity requirements. This assessment showed that BHP's existing flexible capacity is sufficient if the variable energy resources identified in the portfolios studied are added to their system with exception to three cases: 1.) Portfolio 3, which creates a Flexible Capacity need of 86 MW, 2.) Portfolio 5 which creates a 16 MW Flexible Capacity need, and 3.) Portfolio 6, which creates a 118 MW Flexible Capacity need. The cost of flexible capacity is typically tied to the carrying cost of flexible peaking capacity. Black & Veatch is currently completing a study of busbar costs for new generation on the BHP system, and those costs and the flexible capacity requirements identified above will be reflected in BHP's Integrated Resource Plan development for Resource Portfolios 3, 5 and 6.

1.4 Study Summary – Effective Load Carrying Capability

PG also completed an Effective Load Carrying Capability (ELCC) assessment of the wind, solar and battery storage resource portfolio options, to assess the level of reserve capacity that each option provides to BHP, for use in its resource planning studies and resource procurement activities. The ELCC analysis is used to determine the percentage of the nameplate capacity of each resource type and location that can be counted on for reserve margin planning purposes.

Figure 1. ELCC Capacity of Wind and Solar Resources



Variable Energy Resource Integration Study

As shown in Figure 1, the ELCC values for wind are comparable at all three locations for 50 MW resource additions. For 100 MW wind resource additions, ELCC values are highest at South Gillette, followed by Cheyenne and then North Douglas. Projected ELCC values at South Gillette begin at 30 percent with a 50 MW wind addition and decline with additional wind expansion. The ELCC values for wind at Cheyenne and Douglas begin in the 28 percent range and also decline with additional wind expansion. However, for the Cheyenne site, estimated ELCC values see a lesser decline than the other two sites, for wind additions of 150 and 200 MW.

For solar resources, ELCC values are highest at the Gillette location, followed by Hot Springs and then Cheyenne. Solar ELCC values are considerably lower than those for wind resources, ranging in the 11 to 13 percent range with 50 MW additions, and declining to around 5 percent with 200 MW solar additions. The primary driver for lower solar ELCC values is a lower capacity factor for solar resources, compared to wind.

PG also calculated the ELCC value of stand-alone battery storage at four capacity levels, 20 MW, 40 MW, 60 MW and 100 MW. We determined the battery charge level in every hour to calculate the amount of capacity that a stand-alone battery storage facility can provide. This capacity ranges between 0 MW and the maximum capacity of the storage facility. Table 2 lists the estimated ELCC values. As the size of the capacity increases from 20 MW to 60 MW, the effective capacity contribution is expected to decrease from 80% to 54%.

Table 2. ELCC of Battery Storage

Type	Capacity (MW)	Incremental Demand (MW)	ELCC (%)
Storage	20	16	80%
Storage	40	27	67%
Storage	60	33	54%
Storage	100	49	49%

2 Variable Energy Resource Projections

2.1 Introduction

Black Hills Corporation retained Hitachi ABB Power Grids (PG) to complete a VER Integration Study for Black Hills Power (BHP). BHP has been adding renewable resources to its system in recent years, given improvements in the economic and generation performance of wind and solar technologies. To support its Integrated Resource Planning, and in anticipation of adding greater amounts of wind and solar variable energy resources to its power system, BHP recognized the need to complete a study of operational and reliability requirements it is likely to face in response to greater levels of variable energy resources on its system.

2.2 Study Approach

It is important to understand the impact that higher levels of wind and solar penetration will have on BHP operations, and to identify operational and resource planning steps that can be taken to assure that grid stability is not compromised. BHP has successfully integrated several wind projects onto its current system, but with additional wind and solar resources expected to come on-line in coming years, additional steps may be required to manage increased variability in generation and net load levels. PG completed this study of variable energy resource integration requirements by implementing a series of integrated analytic steps, and results from this analysis will be further implemented into BHP's current Integrated Resource Planning process and study results.

In completing this assessment, PG examined forecast and actual load, and thermal, wind and solar generation data to develop estimates of incremental regulation capacity that BHP will require to maintain reliability and frequency regulation. A key goal of the analysis was to quantify the variability in wind and solar generation facilities and to estimate the quantity and value of 10-minute operating reserves necessary to maintain reliable system operation. The assessment examined the impact of wind and solar resource additions separately to estimate incremental regulating reserve capacity required with each resource type and location. PG also completed production cost simulations using the Portfolio Optimization software to develop cost estimates of carrying the incremental regulation capacity amounts. These analyses were completed for a combination of wind, solar and battery energy storage resource expansions at several key sites on the BHP system. PG also completed an assessment to determine the accreditable capacity of VERs for reliability planning purposes.

The basis analytic steps implemented by PG in completing this study include the following:

1. Data Development – PG worked with the BHP team to gather available system load data at the hourly and sub-hourly level, and to develop generation profiles for the renewable resource portfolio options, again at an hourly and sub-hourly level. The BHP team also provided historical and forecast generation data at an hourly and sub-hourly level. For areas where data gaps existed, particularly for sub-hourly level data, the PG team supplemented available data by utilizing publicly available data from the National Renewable Energy Lab (NREL).

2. Estimate Incremental Regulation Capacity Requirements – To estimate incremental regulation capacity, PG utilized available BHP and NREL data to develop a consolidated set of actual and forecast load, thermal generation, and renewable generation on a 10-minute interval basis. The historical data were adjusted to reflect planned resource additions and load growth on the BHP system for the year 2025. The actual and forecast load and generation data were used to estimate ACE for the BHP system, both with and without each of the Portfolio renewable resource and battery energy storage resource additions. ACE values on a 10-minute basis were compared to base level regulation requirements, where base level requirements were developed using NERC's recommended L_{10} formula. ACE values were then re-calculated independently for each of the 12 renewable resource portfolios, and CPS2 violations were tagged. Incremental Regulation Up and Regulation Down capacity levels were identified as the minimum amount of regulation capacity needed to ensure there are no CPS2 violations at least 98 percent of the time.

3. Estimate Cost Impact of Carrying Incremental Regulation Reserves – For each of the renewable resource portfolio options, PG completed Portfolio Optimization simulations, modeling both the resource inclusion and associated incremental Regulation Up and Regulation Down capacity requirements. The difference in total system production costs between each portfolio's simulation with and without the incremental regulation capacity was used to estimate the cost, per MWh, for carrying the incremental Regulation Up and Down capacity. The values calculated are per net energy production for each respective renewable project in the portfolio. PG also examined maximum 3-hour ramping requirements associated with the wind and solar additions and used those data to estimate the current and incremental need for flexible capacity on the BHP system, associated with each of the renewable resource portfolios. This assessment also included an evaluation of BHP's current flexible capacity resources, to determine if any of the renewable resource portfolios is likely to require procurement of incremental flexible capacity.

4. Estimate Effective Load Carrying Capability – For each of the renewable resource portfolio options, PG developed estimates of the Effective Load Carrying Capability (ELCC) of the resource, based on analysis of changes in loss-of-load probability associated with including that resource in BHP's supply portfolio, compared to inclusion of a "perfect" capacity resource as a substitute.

2.3 Variable Energy Resource Integration Considerations

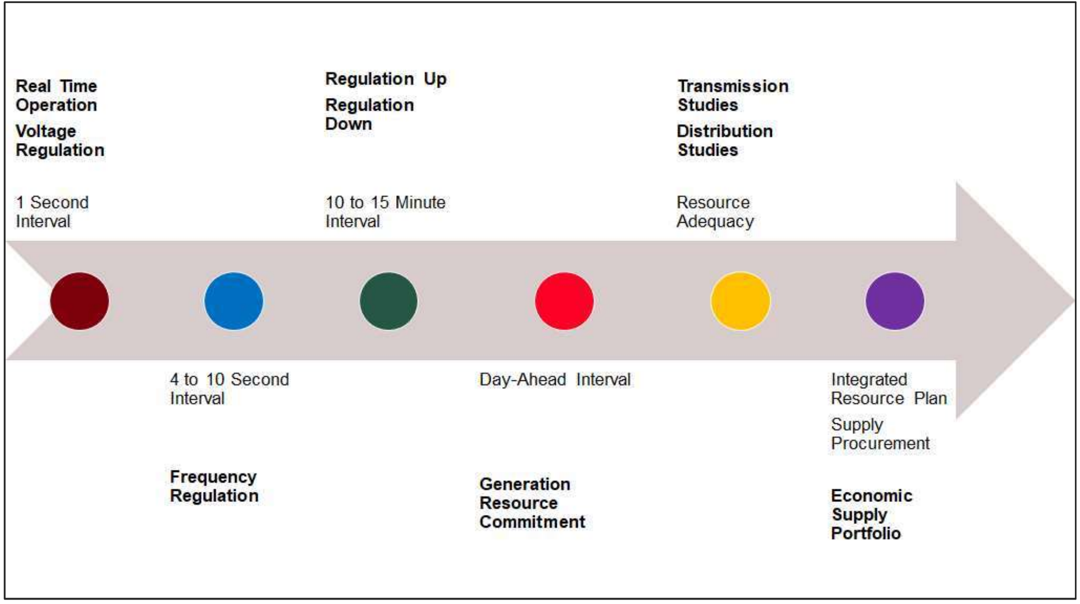
Renewable generation resources, such as wind and solar, are variable and uncertain in nature because generation output depends on ever-changing wind speeds and solar irradiance that cannot always be accurately predicted. To manage the uncertainty associated with these types of resources, system operators can hold additional reserves so the power system can economically respond to unexpected events and generation fluctuations. High penetration levels of wind and solar resources leads to an increase in reserves necessary to reliably operate the power system. The fundamental need when integrating variable energy resources on a system is to have sufficiently flexible capacity or load to allow for adjustments for unpredicted increases or decreases in variable energy generation levels, without creating reliability problems or unacceptable levels of imbalance energy. There are a number of factors that improve the ability to integrate variable energy resources:

- Geographic diversity in siting variable energy resources reduces overall variability in generation for those resources, due to weather diversity and reduced adverse impacts on wind and solar generation from localized weather events
- Improved load and variable energy resource generation forecasting reduces unplanned swings in generation and net load, and reduces the overall integration requirement and cost
- Scheduling generation resources on a sub-hourly basis also reduces overall resource variability and deviation from forecast, and reduces overall regulation requirements in operating a power system
- Availability of flexible generation and/or energy storage on the power system to rapidly increase or decrease generation to offset unplanned decreases or increases in variable energy resource output.

2.4 System Operations and Planning Timeline

Reliable operation of a power system requires different actions and resource adjustments within different timeframes, ranging from real-time operations with conditions varying instantaneously, to unit scheduling, commitment and dispatch decisions that occur over hours or days, to long-term planning and resource procurement activities that span months and years. Figure 2 provides an illustration of the operations and planning timeline and required actions.

Figure 2. Operations and Planning Timeline



Wind and solar resource generation levels can vary instantaneously, sometimes by relatively large magnitudes. Voltage and frequency regulation are maintained in short-time steps varying from seconds to minutes, by altering dispatch of regulating reserves, typically with generation resources on Automatic Generation Control (AGC). As higher penetrations of variable energy resources are grid-connected, variability in generation and net load can increase significantly, requiring greater levels of regulating reserves. In assessing variable energy resource integration requirements and costs, PG has focused on understanding operational integration requirements for Regulation Up and Down capacity, in the 10-minute interval. This aspect focuses on changes in operational requirements for BHP, and measurement of fuel and variable operating costs needed to meet those requirements.

As illustrated in Figure 2, longer-term operational and planning/resource procurement actions focus on commitment, dispatch and scheduling of generating units on a day-ahead or longer basis, and development of resource plans and supply procurement processes to assemble generation portfolios that maintain reliable system operation and economic power supply. In these areas, PG has focused on Resource Adequacy and planning requirements associated with having sufficient flexible generation resources on the system, and incremental capital costs required to procure those resources and have sufficient flexible capacity available to meet the short-term operational requirements.

2.5 Reserve Requirements

NERC establishes a set of reliability and operational measures that must be met by Balancing Authorities (BA) to maintain reliable system operations. The NERC compliance requirements are designed to minimize system disturbances and to avoid inadvertent power interchanges between balancing areas and load-serving entities. For BHP, the NERC requirements are administered through the Western Energy Coordinating Council (WECC). WECC develops and implements Regional Reliability Standards and WECC Regional Criteria for the Western Interconnection.

The reliable operation of the interconnected power system requires that adequate generating capacity be available at all times to maintain scheduled frequency and avoid loss of firm load following transmission or generation contingencies. This generating capacity is necessary to:

- Meet supply requirements for load variations
- Replace generating capacity and energy lost due to forced outages of generation or transmission equipment
- Meet on-demand obligations
- Replace energy lost due to curtailment of interruptible imports
- Balance fluctuations in renewable resource generation

Based on NERC guidance, WECC has established operating reserve requirements for Balancing Authorities in the Western Interconnection, with operating reserves comprised of the following:

1. Regulating Reserves

    - Regulation Up – Rapid response load or capacity held in reserve that can be quickly dispatched to increase net power injections on the system

    - Regulation Down – Rapid response load or capacity that can be quickly reduced to decrease net power injections on the system

2. Contingency Reserves

    - Spinning Reserves – Generation reserve capacity from resources currently spinning, that can be dispatched to increase or decrease net power injections within a 10-minute period

    - Non-Spinning Reserves – Generation resources not currently spinning, but which can be dispatched to increase net power injections within a 10-minute period

Regulating reserves are controlled by AGC which enables generating units to increase or decrease power output marginally in response to smaller scale system energy imbalances. Contingency reserves are used to correct for larger scale system imbalances caused usually by a loss of a generating unit or transmission line.

2.6 Projected Renewable Resource Additions

BHP currently has one planned solar resource addition anticipated to achieve commercial operation between now and 2025. The 80 MW Fall River solar project is expected to come on-line in 2023. In addition, the BHP team identified additional likely sites and wind, solar and storage capacity additions to be included in assessing variable energy resource integration costs and requirements. Table 3 below lists the renewable and energy storage capacities and locations examined in this assessment. The sites were selected both to recognize areas where project development activity is likely, and to capture benefits of geographical diversification in assessing generation variability for wind and solar resources. As shown, several of the resource portfolios examined include battery energy storage resources, which represent a mitigating technology for managing variable energy production from wind and solar resources.

Table 3. Variable Energy Resource Portfolios

Portfolio	Type	Size (MW)	Location
1	Wind	50	Cheyenne
2	Wind	100	South Gillette
3	Wind	200	North Douglas
4	Solar	50	Cheyenne
5	Solar	100	Gillette
6	Solar	200	Hot Springs
7	Solar + Storage	100 + 40	Cheyenne
8	Solar + Storage	100 + 20	Gillette
9	Solar + Storage	100 + 60	Hot Springs
10	Storage	20	Cheyenne
11	Storage	40	Gillette
12	Storage	60	Hot Springs

As shown in Table 2, the study examines wind, solar and battery energy storage resources at different capacity levels, located in Cheyenne, WY, South Gillette, WY, North Douglass, WY and Hot Springs, SD. The resource portfolios listed in Table 2 were each examined independently in the analyses described below. PG did not examine the resource expansion portfolios in combination, under the scope of this study.

2.7 Study Data Development

The study was completed utilizing detailed generation and load data from several sources. Assessing CPS2 performance and regulating capacity needs requires both actual and forecast power system data, on a 10-minute interval basis and assessing ELCC contributions from wind and solar resources requires detailed generation data on an hourly basis. PG utilized data provided by BHP to the greatest extent possible in completing the analysis and supplemented those data in areas where additional data were needed in order to complete the assessment.

2.7.1 Black Hills Power Data

BHP provided detailed system operations data for the historical year 2019, on both an actual and forecast basis, in addition to forecast data for wind and solar resources expected to achieve commercial operation over the next several years. BHP data utilized in the assessment include:

- Historical and forecast hourly system load data
- Historical hourly and sub-hourly generation and net interchange data
- Historical sub-hourly generation data for existing wind resources
- Forecast hourly data for wind and solar resource additions

Projected capacity factor for wind and solar resources at those three locations are listed in Table 4.

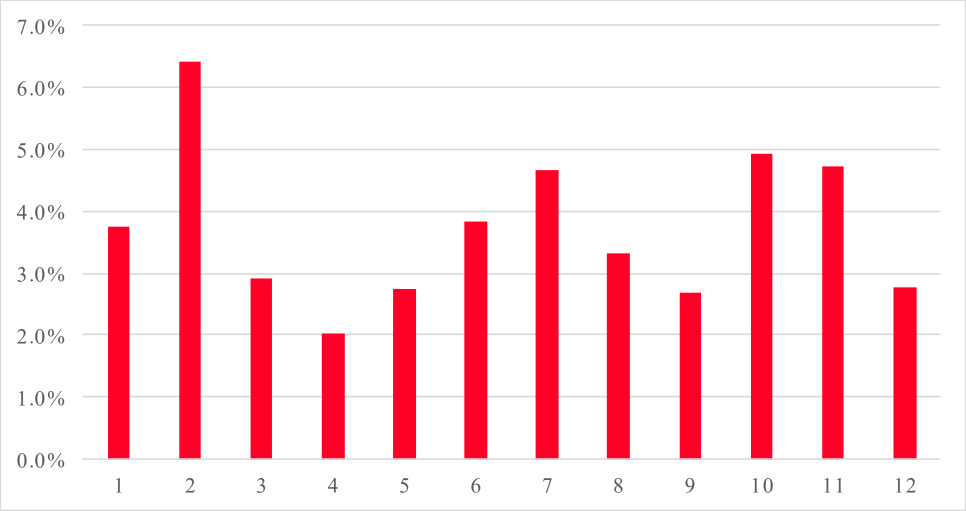
Table 4. Wind and Solar Project Capacity Factor (%)

Site	Wind Capacity Factor (%)	Solar Capacity Factor (%)
Cheyenne, WY	45	26
Gillette, WY	40	24
Douglas, WY	43	NA
Hot Springs, SD	NA	28

PG utilized the BHP 2019 Actual Data, adjusted for load growth and resource additions to 2025. As sub-hourly load forecast data and generation forecast data were not available from BHP, PG developed a sub-hourly load forecast by applying percent differences between hourly actual and forecast data, with the same percentage value for each hour applied to 10-minute intervals within that hour. PG assumed no sub-hourly forecast error for thermal resources.

Figure 3 illustrates monthly average load forecast error, based on the BHP 2019 hourly load data. PG used wind, solar & load forecasting error to calculate the number of regulating reserves required in 2025 to maintain projected reliability requirements.

Figure 3. Monthly Average Hour-Ahead Load Forecast Error (%)



2.7.2 NREL Wind Data

Because 10-minute actual and forecast data were not available for the wind resources, PG researched NREL data availability and obtained data from NREL's Techno-Economic Wind Toolkit dataset for wind resources. The WIND Toolkit includes meteorological conditions and turbine power data for more than 126,000 sites in the continental United States for the years from 2007 to 2013. The data available includes both actual and forecast data for each site. For actual data, wind generation is available at a 5-minute interval. For forecast data, projected wind generation for each site is available on an hourly basis, including 1-hour, 4-hour, 6-hour and 24-

hour day-ahead forecasts. The forecast data were developed by 3Tier, under contract with NREL.

PG selected three sites in the closest possible proximity to Cheyenne, North Douglas and South Gillette. Table 5 lists the location of selected sites, along with the capacity underlying each data series in the NREL data. PG utilized the NREL data and made adjustments to reflect projected sizes of each wind resource as listed earlier in Table 3. PG also converted the NREL 5-minute interval actual wind generation data to a 10-minute interval for completing the CPS2 reliability analysis.

Table 5. NREL Wind Site Data

Site	Site ID	Longitude	Latitude	Capacity (MW)
Cheyenne, WY	63094	-105.108673	41.150742	10
Gillette, WY	103689	-105.943146	44.393757	16
Douglas, WY	96825	-108.575897	43.561279	14

The NREL data set includes data for the years 2007 through 2013. Assessment of the data showed considerable variability between different years. To address that variability, PG used the seven years of NREL data to calculate a set of synthetic annual data for each site. The synthetic shapes were derived by calculating median level actual wind generation for each 10-minute interval in a year, and by calculating median level actual and forecast hourly generation for each hour interval in a year.

While the NREL data included 5-minute resolution actual generation levels, for both the NREL data and for the Black Hills wind data, sub-hourly forecast data were not available. Using available hourly-level forecast data, PG constructed 10-minute interval forecast data for both generation and load, by applying the percentage difference between forecast and actual from the available hourly datasets. This approach introduces some auto-correlation into the analysis of 10-minute data. PG inspected the hourly and sub-hourly data used, and believes it is reasonably representative and suitable for the variable resource integration analysis.

2.7.3 NREL Solar Data

Because 10-minute actual and forecast data were also not available for the solar resources, PG further researched NREL data availability and obtained data from NREL's Solar Power Data for Integration Studies dataset for solar resources. The Solar Power Data for Integration Studies consist of 1 year (2006) of 5-minute solar power and hourly day-ahead forecasts for approximately 6,000 simulated PV plants. Solar power plant locations were determined based on the capacity expansion plan for high-penetration renewables in Phase 2 of the Western Wind and Solar Integration Study and the Eastern Renewable Generation Integration Study. NREL generated the 5-minute data set using the Sub-Hour Irradiance Algorithm. The day-ahead solar forecast data for locations in the western United States were generated by 3TIER based on numerical weather predication simulations for Phase 1 of the Western Wind and Solar Integration Study.

PG selected three sites in the closest possible proximity to Cheyenne and Gillette, WY, and Hot Springs, SD. Table 6 lists the location of selected sites, along with the capacity underlying each data series and projected capacity factor implicit in the NREL data. PG utilized the NREL data with adjustments to reflect projected sizes of each solar resource as listed earlier in Table 3. PG also converted the NREL 5-minute interval actual wind generation data to a 10-minute interval for completing the CPS2 reliability analysis.

Table 6. NREL Solar Site Data

Site	Site ID	Longitude	Latitude	Capacity (MW)
Cheyenne, WY	63094	-104.85	41.15	9
Gillette, WY	103689	-105.55	44.35	6
Hot Springs, SD	96825	-102.95	43.45	14

While the NREL data included 5-minute resolution actual generation levels, for both the NREL data and for the Black Hills solar data, sub-hourly forecast data were not available. Following the same approach that had been developed for the wind data, PG again used available hourly-level forecast data to construct 10-minute interval forecast data for solar generation by applying the percentage difference between forecast and actual from the available hourly datasets.

3 Variable Energy Resource Integration Requirements and Costs

3.1 Overview

A number of studies have been completed examining wind and solar resource integration needs and costs, including large-scale studies of the Western U.S. completed under NREL direction and funding. A common methodology used in renewable integration studies across the industry is to focus on changes in regulation capacity needed to offset generation uncertainty created due to the intermittent nature of generation from wind and solar resources. It is well-recognized that the extent to which renewable resource variability becomes an issue will depend on numerous system-specific factors including power system size and the proportion of generation that is variable, the potential output of the resources, and the ability to forecast that output.

This study focused on the operating reserves required to integrate wind and solar in dispatch operations. Specifically, this study considered the operating reserves that can respond to changes in system ACE in a 10-minute timeframe to ensure reliable system operation. The system ACE is measured as the difference in the scheduled generation and load versus the actual generation and load for each 10-minute clock interval. Under-forecasting the load can be offset by under-forecasting of the wind or solar. Conversely, over-forecasting of the load will be exacerbated by under-forecasting of the wind or solar and cause a higher frequency bias, unless AGC or the system operator can take corrective action.

To assess 10-minute regulating reserves, PG developed an approach that approximates NERC CPS2 for maintaining balancing area reliability. The NERC CPS2 criterion is a statistical measure of the ACE measured in 10-minute clock intervals. The CPS2 reliability criterion stipulates that the system ACE must be within a tolerable deviation range (defined as the L_{10}) for 90 percent of the 10-minute clock intervals for each month. PG developed an Excel model ("Variable-Resource Integration model") to calculate the difference between the predicted and actual output of the wind and solar energy on the BHP system in 2025.

The increase in 10-minute regulating reserves required to keep the number of future CPS2 errors within either a 5 percentile band or a 2 percentile band was used as the basis to estimate incremental Regulation Up and Regulation Down requirements associated with different variable energy resource expansion options, and to assess variable energy resource integration costs[1].

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[1] Note that the 5 percentile and 2 percentile bands are more conservative than the NERC standard requiring ACE to be within required limits at least 90 percent of the time. There are two factors supporting the use of higher, more conservative performance levels. First, examination of individual years of NREL wind data reveals considerable variation in actual and forecast wind generation levels, so under varying meteorological conditions, regulation needs will vary upward. Second, the approach utilized by PG in this study mirrors an approach utilized by Black & Veatch in completing a similar study of the Black Hills Colorado system in 2015, which will facilitate consistency in resource planning approach and decisions across the Black Hills Corporation organization.

The impact of variation in load was also reflected in the CPS2 model. Actual 5-minute and hourly load data and forecasts provided by BHP were used to develop ACE estimates, along with the wind and solar data.

3.2 Black Hills Power Baseline Regulation Requirements

As indicated above, PG completed an assessment of CPS2 performance for BHP, both based on its current power system, with load and supply resources expected to be in place in 2025, and with additional wind, solar and storage resource additions. For this analysis, ACE was calculated as:

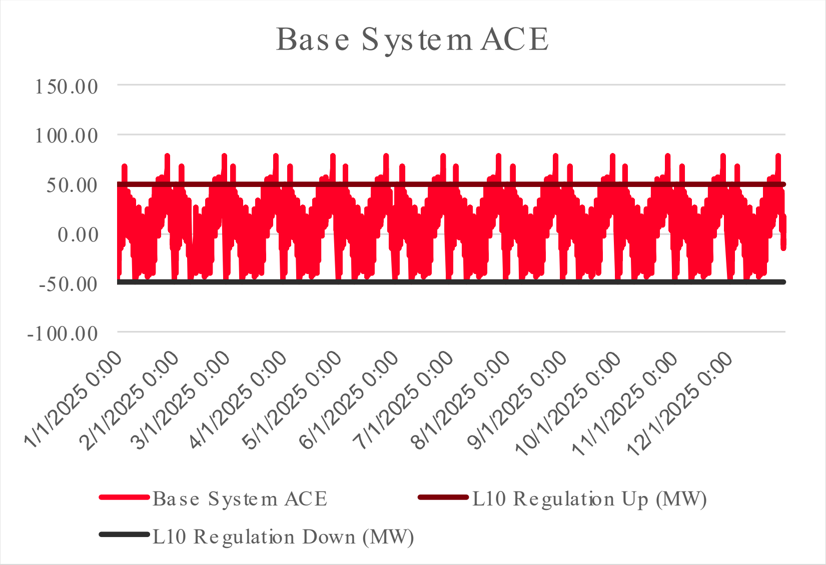
$$\begin{aligned} ACE_{\mathrm{MW}} = {} & (Actual\ Load - Forecast\ Load) \\ & + (Actual\ Thermal\ Generation - Forecast\ Thermal\ Generation) \\ & + (Actual\ Wind\ Generation - Forecast\ Wind\ Generation) \\ & + (Actual\ Solar\ Generation - Forecast\ Solar\ Generation) \end{aligned}$$

ACE values were first calculated for each 10-minute interval for the year 2025, based on BHP's existing system, including load growth and resource additions planned through 2025.

For each 10-minute interval, the calculated ACE values were compared to projected NERC L_{10} values. L_{10} is a guideline metric calculated by NERC, which expresses balancing capacity targets as a function of peak demand. If the ACE value exceeded the projected L_{10} value, by a positive quantity, then that period was flagged as a Regulation Up violation, and if the ACE value was less than the negative of the projected L_{10} value, then that period was flagged as a Regulation Down violation. Based on BHP's projected 2025 load, the NERC L_{10} values are 49 MW, which were interpreted as Regulation Up and down requirements for BHP's 2025 power system, absent any additional supply resource additions.

Comparing the estimated ACE values to L_{10}-based Regulation Up and Regulation Down requirements, PG estimated that at a 95th percentile CPS2 compliance level, the BHP 2025 power system will have both Regulation Up and Regulation Down requirements of 49 MW based on its forecast load, current thermal resources, and current and projected renewable resources. At a 98th percentile CPS2 compliance level, the BHP 2025 power system would have a slightly higher 55 MW Regulation Up requirement, and 50 MW Regulation Down requirement. As BHP is not an independent balancing authority subject directly to NERC compliance, these values can be interpreted as guideline and baseline metrics for BHP to consider in its resource planning and supply procurement activities.

Figure 4. BHP Base System ACE and Regulation Requirements



As shown in Figure 4, there are a small number of hours where ACE values exceed the Regulation Up requirement, which is permissible under the CPS2 metric. Those exceedances occur less than two percent of the 10-minute intervals shown. Under the base system, Regulation Down requirements do not exceed the lower level L_{10} band.

3.3 Black Hills Power Incremental Regulation Requirements

For each of the renewable resource portfolio additions, PG developed estimates of incremental regulation requirements at both a 95 percent and 98 percent CPS2 performance level. Table 7 summarizes estimated incremental regulation requirements for each resource portfolio examined. As shown, incremental Regulation Up quantities vary from zero MW to 50 MW. Because wind generation forecast error is much more volatile than solar, the incremental regulation requirements are higher for wind resources.

Table 7. Estimated BHP Regulation Requirements

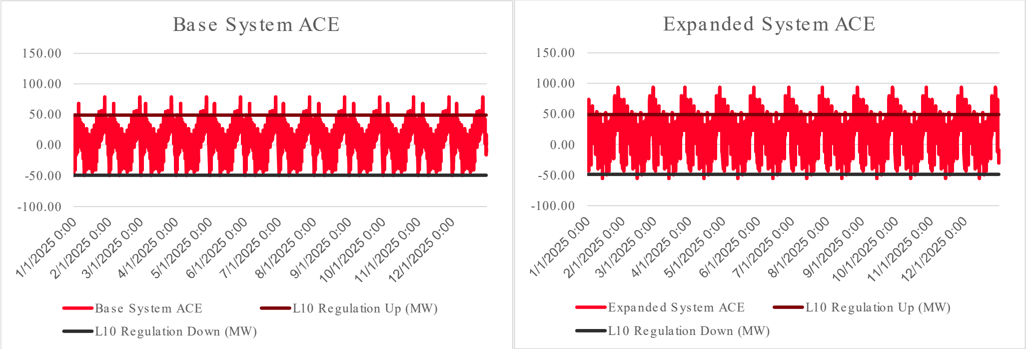
Portfolio	Type	Size (MW)	Location	95% CPS2: Incremental Regulation Up (MW)	95% CPS2: Incremental Regulation Down (MW)	98% CPS2: Incremental Regulation Up (MW)	98% CPS2: Incremental Regulation Down (MW)
Existing System				55	49	49	55
1	Wind	50	Cheyenne	8	0	24	0
2	Wind	100	S. Gillette	7	6	26	22
3	Wind	200	N. Douglas	25	32	50	40
4	Solar	50	Cheyenne	0	0	7	1
5	Solar	100	Gillette	0	0	10	1
6	Solar	200	Hot Springs	1	0	11	1
7	Solar + Storage	100 + 40	Cheyenne	0	0	0	1
8	Solar + Storage	100 + 20	Gillette	0	0	0	1
9	Solar + Storage	100 + 60	Hot Springs	0	0	0	1
10	Storage	20	Cheyenne	0	0	0	1
11	Storage	40	Gillette	0	0	0	1
12	Storage	60	Hot Springs	0	0	0	1

3.3.1 Resource Portfolio 1: 50 MW Wind Addition at Cheyenne, WY

Resource Portfolio 1 includes a 50 MW wind resource addition at Cheyenne, WY, with a wind regime similar to existing BHP wind generators. Figure 5 provides a comparison of system ACE values under the base and expanded system. As shown, adding a 50 MW wind resource at Cheyenne results in higher positive ACE values, approaching 100 MW in some hours, and exceeding the L_{10} Regulation Up requirement with greater frequency.

For the Cheyenne wind resource addition, PG estimates that BHP would require 8 MW of additional Regulation Up capacity to achieve 95 percent CPS2 compliance, and 24 MW of additional Regulation Up capacity to achieve 98 percent CPS2 compliance. The magnitude and frequency of Regulation Down exceedances are minor for this resource portfolio, and do not require any additional Regulation Down capacity.

Figure 5. BHP Base System and Expanded Ace – Cheyenne 50 MW Wind Addition

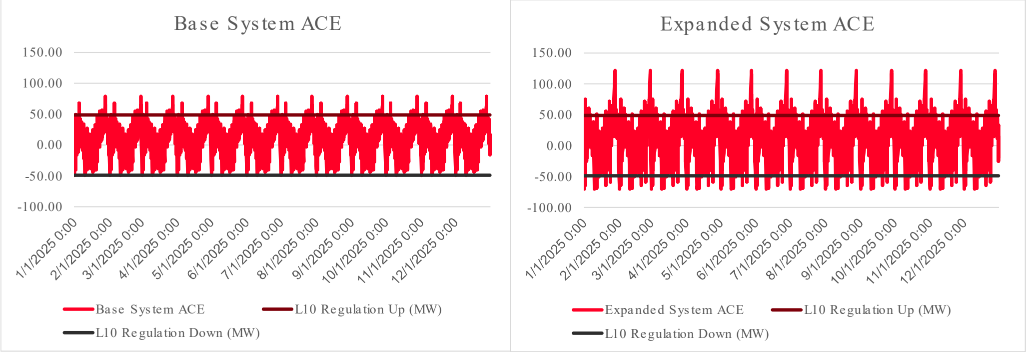


3.3.2 Resource Portfolio 2: 100 MW Wind Addition at South Gillette, WY

Resource Portfolio 2 doubles the assumed wind addition at South Gillette, WY, to 100 MW. Figure 6 provides a comparison of system ACE values under the base and expanded system for this wind resource addition. As shown, with the 100 MW wind addition, the frequency of ACE exceeding the Regulation Up L_{10} level increases, and some upward ACE values approach 125 MW, which is 75 MW higher than the L_{10} Regulation Up band.

For the South Gillette 100 MW wind resource addition, PG estimates that BHP would require 7 MW of additional Regulation Up capacity to achieve 95 percent CPS2 compliance, and 26 MW of additional Regulation Up capacity to achieve 98 percent CPS2 compliance. There is also a greater frequency of Regulation Down exceedances. The 100 MW wind addition at Gillette is estimated to require 6 MW of incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 22 MW of Regulation Down capacity to meet the 98 percent standard.

Figure 6. BHP Base System and Expanded Ace – South Gillette 100 MW Wind Addition

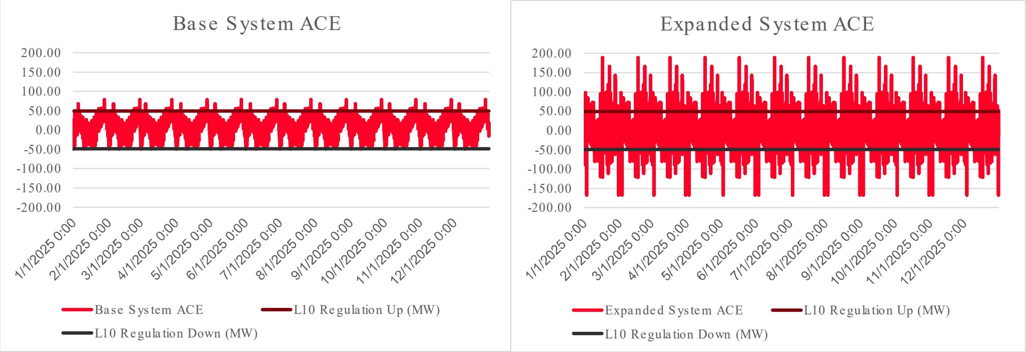


3.3.3 Resource Portfolio 3: 200 MW Wind Addition at North Douglas, WY

Resource Portfolio 3 again doubles the assumed wind addition, to 200 MW, in this case at North Douglas, WY. Figure 7 provides a comparison of system ACE values under the base and expanded system for this wind resource addition. As shown, with the 200 MW wind addition, the frequency of ACE exceeding the Regulation Up L_{10} level further increases, with a wider range of upward ACE exceedance levels, and some upward ACE values approaching the full 200 MW.

For the North Douglas 200 MW wind resource addition, PG estimates that BHP would require 25 MW of additional Regulation Up capacity to achieve 95 percent CPS2 compliance, and 50 MW of additional Regulation Up capacity to achieve 98 percent CPS2 compliance. The Regulation Down exceedances are more frequent and of greater magnitude with a 200 MW wind addition. PG estimates that 32 MW of incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 40 MW of Regulation Down capacity to meet the 98 percent standard.

Figure 7. BHP Base System and Expanded Ace – North Douglas 200 MW Wind Addition

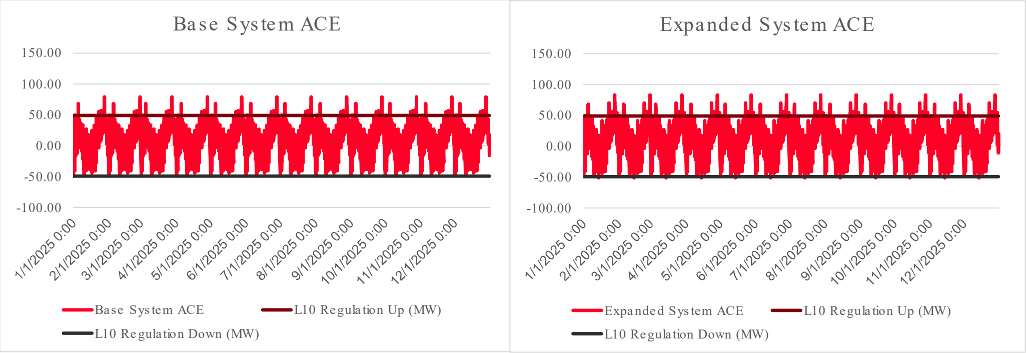


3.3.4 Resource Portfolio 4: 50 MW Solar Addition at Cheyenne, WY

Resource Portfolio 4 assumes a 50 MW solar resource addition at Cheyenne, WY. Figure 8 provides a comparison of system ACE values under the base and expanded system for this solar resource addition. As shown, with the 50 MW solar addition, there is an increase in the frequency of ACE exceeding the Regulation Up L_{10} level, but the frequency and magnitude of those exceedances are relatively low. There are only minor instances of ACE levels exceeding the L_{10} Regulation Down band. In general, the forecast error for solar resources is substantially lower than for wind, so the frequency and magnitude of ACE exceedances is lower.

For the Cheyenne 50 MW solar resource addition, PG estimates no incremental Regulation Up capacity would be required to achieve 95 percent CPS2 compliance, and 7 MW of additional Regulation Up capacity would be required to achieve 98 percent CPS2 compliance. The Regulation Down exceedances are minor, with no incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 1 MW to meet the 98 percent standard.

Figure 8. BHP Base System and Expanded Ace – Cheyenne 50 MW Solar Addition

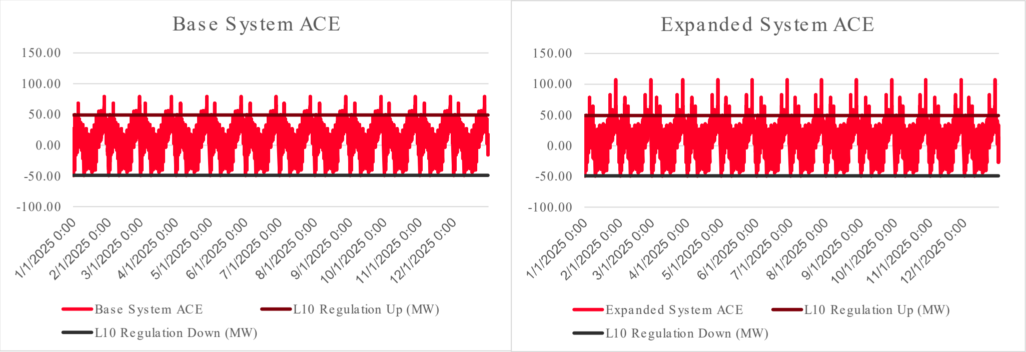


3.3.5 Resource Portfolio 5: 100 MW Solar Addition at South Gillette, WY

Resource Portfolio 5 assumes a 100 MW solar resource addition at South Gillette, WY. Figure 9 provides a comparison of system ACE values under the base and expanded system for this solar resource addition. As shown, with the 100 MW solar addition, there is an increase in the frequency of ACE exceeding the Regulation Up L_{10} level, with some upward ACE values approaching 100 MW, which is 60 MW above the L_{10} Regulation Up band. There are only minor instances of ACE levels exceeding the L_{10} Regulation Down band.

For the South Gillette 100 MW solar resource addition, PG again estimates no incremental Regulation Up capacity would be required to achieve 95 percent CPS2 compliance, and 10 MW of additional Regulation Up capacity would be required to achieve 98 percent CPS2 compliance. The Regulation Down exceedances continue to be minor, with no incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 1 MW to meet the 98 percent standard.

Figure 9. BHP Base System and Expanded Ace – South Gillette 100 MW Solar Addition

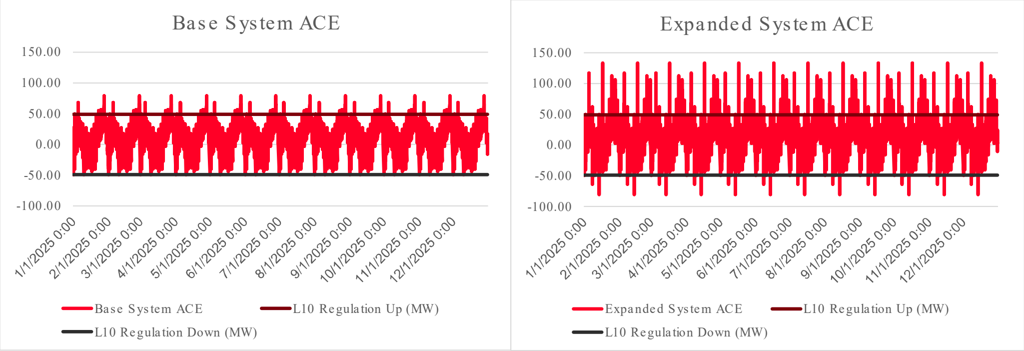


3.3.6 Resource Portfolio 6: 200 MW Solar Addition at Hot Springs, SD

Resource Portfolio 6 assumes a 200 MW solar resource addition at Hot Springs, SD. Figure 10 provides a comparison of system ACE values under the base and expanded system for this solar resource addition. As shown, with the 200 MW solar addition, there is a further increase in the frequency of ACE exceeding the Regulation Up L_{10} level, with some upward ACE values approaching 140 MW, which is 90 MW above the L_{10} Regulation Up band. There are only minor instances of ACE levels exceeding the L_{10} Regulation Down band.

For the Hot Springs 200 MW solar resource addition, PG again estimates that BHP would require 1 MW of additional Regulation Up capacity to achieve 95 percent CPS2 compliance, and 11 MW of additional Regulation Up capacity would be required to achieve 98 percent CPS2 compliance. This can be seen in Figure 10, where there the magnitude of ACE Regulation Up exceedances are greater, with upward ACE values approaching 130 MW, the relative frequency of such exceedances is still relatively moderate. The Regulation Down exceedances continue to be minor, with no incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 1 MW to meet the 98 percent standard.

Figure 10. BHP Base System and Expanded Ace – Hot Springs 200 MW Solar Addition



3.3.7 Resource Portfolio 7: 100 MW Solar Addition Plus 40 MW Battery Energy Storage at Cheyenne

Resource Portfolio 7 assumes a 100 MW solar resource addition combined with a 40 MW Battery Energy Storage (BESS)[2] resource at Cheyenne, WY.

Figure 11 provides a comparison of system ACE values under the base and expanded system for this solar resource addition. As shown, with the 100 MW solar addition, there is an increase in the frequency of ACE exceeding the Regulation Up L_{10} level, with some upward ACE values approaching 90 MW, which is 40 MW above the L_{10} Regulation Up band. There are only minor instances of ACE levels exceeding the L_{10} Regulation Down band.

For the 100 MW solar resource addition, PG again estimates no incremental Regulation Up capacity would be required to achieve 95 percent CPS2 compliance, and 8 MW of additional Regulation Up capacity would be required to achieve 98 percent CPS2 compliance. The 40 MW battery addition is sufficient to cover that incremental 8 MW of regulation capacity, so on net, PG estimates no incremental Regulation Up requirement for the combined solar/storage project. The Regulation Down exceedances are minor, with no incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 1 MW to meet the 98 percent standard. That Regulation

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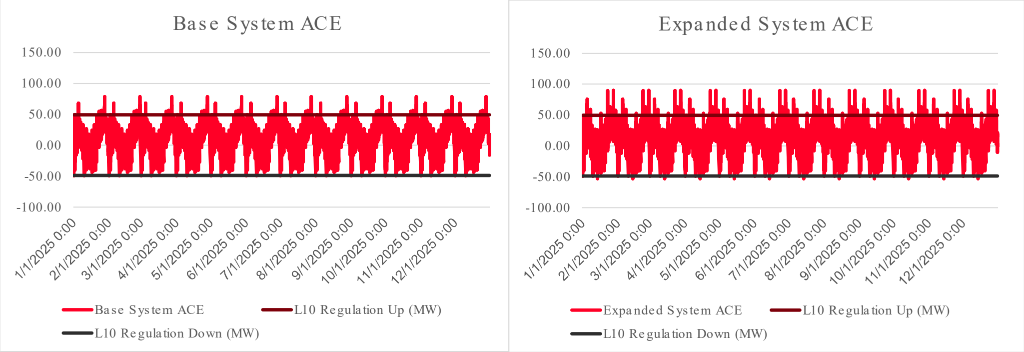
[2] Energy storage resources in the solar plus BESS portfolios are assumed to exclusively charge from the solar resource that they are paired with in order to be eligible for the investment tax credit.

Down capacity can also be met with the battery, so on net, no incremental regulation capacity is needed.

Figure 11. BHP Base System and Expanded Ace – Cheyenne, WY 100 MW Solar Plus 40 MW Battery Energy Storage Addition



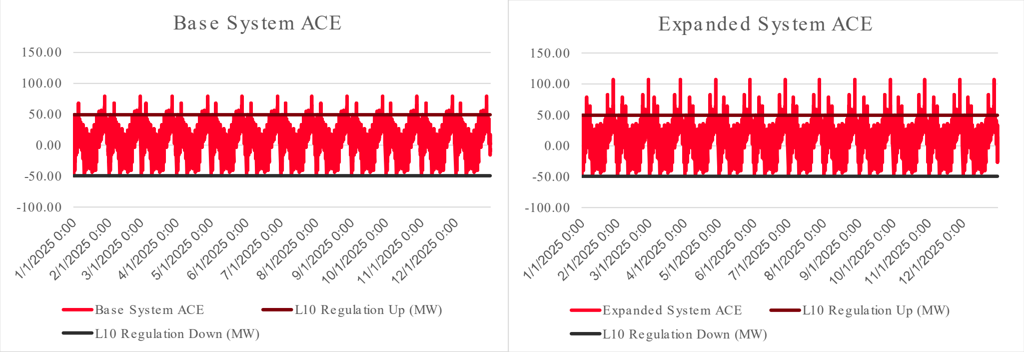
3.3.8 Resource Portfolio 8: 100 MW Solar Addition Plus 20 MW Battery Energy Storage at South Gillette

Resource Portfolio 8 assumes a 100 MW solar resource addition combined with a 20 MW Battery Energy Storage (BESS) resource at Gillette, WY. This portfolio essentially adds a 20 MW battery to Resource Portfolio 5 discussed above.

Figure 12 provides a comparison of system ACE values under the base and expanded system for this solar and battery resource addition. As shown, with the 100 MW solar addition, there is an increase in the frequency of ACE exceeding the Regulation Up L_{10} level, with some upward ACE values just over 100 MW, which is 50 MW above the L_{10} Regulation Up band. There are only minor instances of ACE levels exceeding the L_{10} Regulation Down band.

For the 100 MW solar resource addition, PG again estimates no incremental Regulation Up capacity would be required to achieve 95 percent CPS2 compliance, and 10 MW of additional Regulation Up capacity would be required to achieve 98 percent CPS2 compliance. The 20 MW battery addition is sufficient to cover that incremental 10 MW of regulation capacity, so on net, PG estimates no incremental Regulation Up requirement for the combined solar/storage project. The Regulation Down exceedances are minor, with no incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 1 MW to meet the 98 percent standard. That Regulation Down capacity can also be met with the battery, so on net, no incremental regulation capacity is needed.

Figure 12. BHP Base System and Expanded Ace – South Gillette, WY 100 MW Solar Plus 20 MW Battery Energy Storage Addition

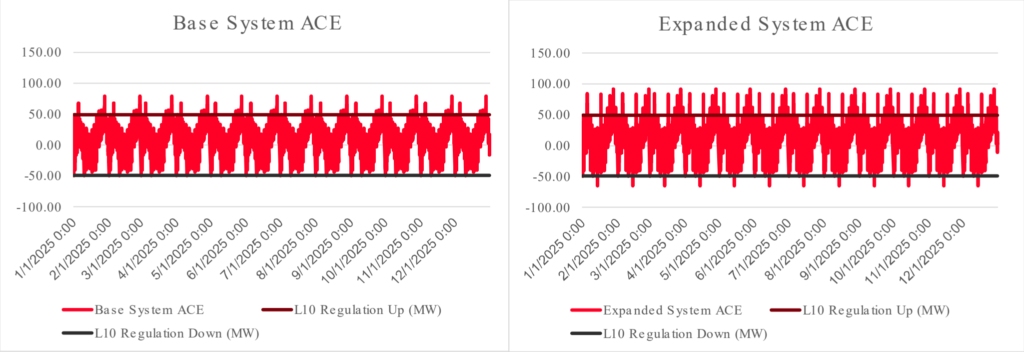


3.3.9 Resource Portfolio 9: 100 MW Solar Addition Plus 60 MW Battery Energy Storage at Hot Springs, SD

Resource Portfolio 9 assumes a 100 MW solar resource addition plus a 60 MW Battery Energy Storage (BESS) resource at Hot Springs, SD. Figure 13 provides a comparison of system ACE values under the base and expanded system for this solar and battery resource addition. As shown, with the 100 MW solar addition, there is an increase in the frequency of ACE exceeding the Regulation Up L_{10} level, with some upward ACE values just over 90 MW, which is 40 MW above the L_{10} Regulation Up band. There are a small number of instances of ACE levels exceeding the L_{10} Regulation Down band.

For the 100 MW solar resource addition, PG again estimates no incremental Regulation Up capacity would be required to achieve 95 percent CPS2 compliance, and 9 MW of additional Regulation Up capacity would be required to achieve 98 percent CPS2 compliance. The 60 MW battery addition is sufficient to cover that incremental 10 MW of regulation capacity, so on net, PG estimates no incremental Regulation Up requirement for the combined solar/storage project. The Regulation Down exceedances are minor, with no incremental Regulation Down capacity to meet the 95 percent CPS2 standard, and 1 MW to meet the 98 percent standard. That Regulation Down capacity can also be met with the battery, so on net, no incremental regulation capacity is needed.

Figure 13. BHP Base System and Expanded Ace – Hot Springs, SD 100 MW Solar Plus 60 MW Battery Energy Storage Addition



3.3.10 Resource Portfolios 10, 11 and 12: 20 MW, 40 MW and 60 MW Battery Storage Additions at Cheyenne, Gillette and Hot Springs

Resource Portfolios 10, 11, and 12 assume stand-alone Battery Energy Storage installations at Cheyenne, WY, Gillette, WY and Hot Springs, SD, respectively. PG assumed that a stand-alone battery installation would not create any incremental forecast error that would contribute to ACE, and as such, there is zero incremental Regulation Up or Regulation Down requirements due to installation of stand-alone battery storage facilities.

3.4 Black Hills Power Incremental Regulation Cost

For each of the renewable resource portfolio additions listed above in Table 7, PG utilized the Portfolio Optimization (PO) model to simulate the BHP power system, including each resource addition. PG also modelled incremental Regulation Up and Regulation Down capacity requirements for each of the resource portfolios as outlined in Table 7.

For each PO simulation, the difference in total system production costs between each portfolio's simulation with and without the incremental regulation capacity was used to develop estimated cost per MWh for meeting the incremental Regulation Up and Down requirements. PG also evaluated the need for additional flexible capacity, and associated cost in cases where incremental capacity is needed.

3.4.1 BHP Thermal Station Ancillary Services Capabilities

To model the regulation requirements, PG specified two ancillary services variables:

- AS1 was defined as Regulation Up and AS2 was defined as Regulation Down. These variables were modeled to reflect incremental Regulation Up and Regulation Down requirements for each portfolio.

- In the PO model, the A/S Contribution Type was set to On-line Only for all Thermal units used to provide AS1 and AS2.

PG completed an assessment of the existing BHP generation portfolio and specified nine thermal generating units as having capability to provide Regulation Up and Regulation Down capacity.

Incremental battery storage resources included in Portfolios 7 through 12 would also have capability to provide regulation capacity. For existing thermal resources, ancillary services capabilities reflected in the PO simulations are listed in Table 8.

Table 8. Thermal Station Ancillary Services Capabilities

Station	Can provide Regulation up or down (Y/N)	Capacity Minimum (MW)	Capacity Maximum (MW)	Notes
1_CT BF1	Yes	2	20	1-hour minimum run time.
1_CT BF2	Yes	2	20	1-hour minimum run time.
1_CT BF3	Yes	2	20	1-hour minimum run time. Black Start Unit.
1_CT BF4	Yes	2	20	1-hour minimum run time. Black Start Unit.
1_CT Lange	Yes	20	38	1-hour minimum run time (2 hours when temperature is below 20 degrees).
1_LMCC CPGS BHP	Yes	1x1 - 20 2x1 - 50	1x1 - 48 2x1 - 95	2-hour minimum run time.
1_Neil Simpson2	Yes	60	80	
1_Wygen III	Yes	70	103	

3.4.2 BHP Incremental Regulation Cost

Estimated costs for BHP to carry additional Regulation Up and Regulation Down capacity are listed below in Table 9. These cost estimates reflect changes in BHP operating cost as the system unit commitment and dispatch is altered to reflect an increased Regulation Up and Down capacity operating reserve requirement. The costs in Table 9 do not reflect any capital related cost needed to procure additional flexible regulation capacity. As shown, PG estimated incremental regulation costs assuming Regulation Up and Down quantities needed to meet the 98 percentile CPS2 standard. For resource portfolios that include only battery storage projects, PG has not estimated an incremental regulation requirement or cost, as storage only resources are unlikely to cause incremental ACE deviations.

Estimated regulation costs for wind additions vary by location and project size, ranging from $6.56/MWh for a 100 MW wind resource at South Gillette, to $10.17/MWh for a 50 MW wind resource at Cheyenne, and $11.12/MWh for a 200 MW wind resource at North Douglas.

For solar resource additions, incremental regulation costs range from $1.57/MWh for a 200 MW solar resource at Hot Springs, WY, to $4.63/MWh for a 100 MW solar resource at Gillette, to $5.38/MWh for a 50 MW solar resource at Cheyenne. For resource portfolios including solar with battery storage, PG concluded that incremental Regulation Up requirements could be met by the installed battery capacity and stored energy, in which case the incremental cost shown is to cover Regulation Down requirements only.[3]

BHP also has an option to procure regulation from WAPA, through its Open Access Transmission Tariff (OATT) at a lower cost. WAPA's current tariff offers regulation service for a fixed cost of $0.303/kW/Month for wind resources, and $0.205/kW/Month for solar resources. At a 40% annual average wind capacity factor, the WAPA regulation cost is equivalent to $1.04/MWh for wind resources, and at a 25% annual average capacity factor for solar, it would be equivalent to $1.12/MWh for solar resources.

Table 9. Incremental BHP Regulating Reserve Cost

Portfolio	Type	Size (MW)	Location	98% CPS2: Incremental Regulation Up (MW)	98% CPS2: Incremental Regulation Down (MW)	Regulation Cost – BHP Generation ($/MWh)	Regulation Cost – WAPA Tariff ($/kW/Mo)
Existing System				55	50		
1	Wind	50	Cheyenne	24	0	$10.17	$0.303
2	Wind	100	S. Gillette	26	22	$6.56	$0.303
3	Wind	200	N. Douglas	50	40	$11.12	$0.303
4	Solar	50	Cheyenne	7	1	$5.38	$0.205
5	Solar	100	Gillette	10	1	$4.63	$0.205
6	Solar	200	Hot Springs	11	1	$1.57	$0.205
7	Solar + Storage	100 + 40	Cheyenne	0	1	$0.02	$0.205
8	Solar + Storage	100 + 20	Gillette	0	1	$0.03	$0.205
9	Solar + Storage	100 + 60	Hot Springs	0	1	$0.02	$0.205
10	Storage	20	Cheyenne	0	1	N/A	
11	Storage	40	Gillette	0	1	N/A	
12	Storage	60	Hot Springs	0	1	N/A	

3.4.3 The Dynamics of Providing Regulation Capacity on the BHP System

In completing the PO simulations, PG examined unit operations for the BHP generation portfolio to better understand the dynamics of meeting incremental regulation requirements. Figure 14 provides an illustration of thermal resource contributions to a 50 MW Regulation Up requirement on the BHP system. As shown, Regulation Up Ancillary Services are provided primarily by Neil Simpson 2 Steam, Wygen III and LMCC1 CPGS generators. The Ben French CTs and the Lange CT operate and provide Regulation Up capacity during more limited time periods when more economical units are offline for planned maintenance or forced outage.

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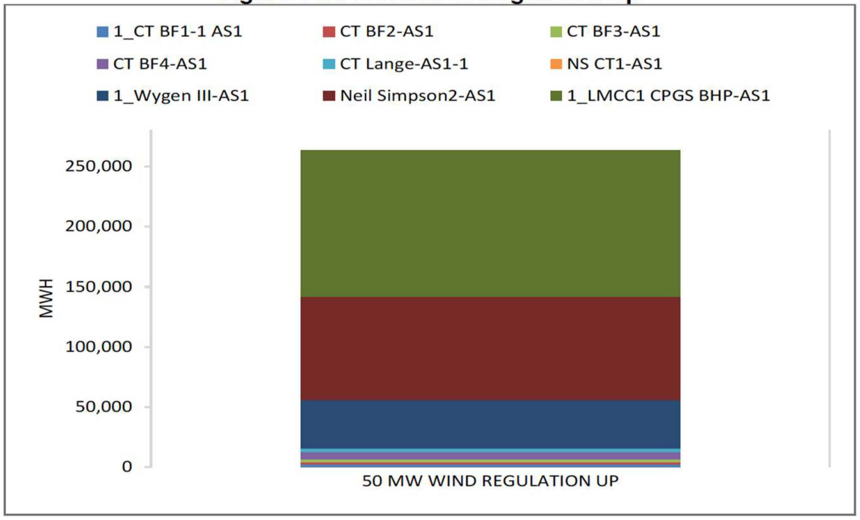
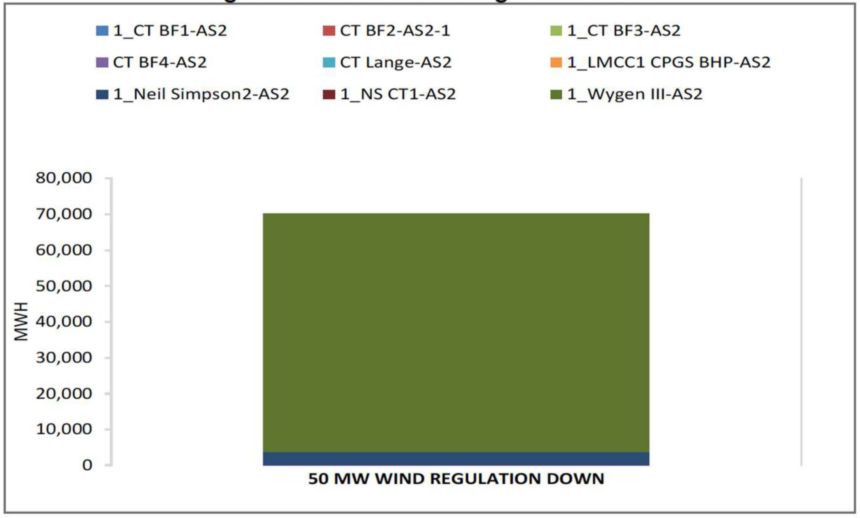
[3] If the battery storage facility is not operated to meet the incremental regulation requirement, then total regulation/integration costs for those three portfolios would be higher, estimated at $2.56/MWh for Resource Portfolio 7, $3.41/MWh for Resource Portfolio 8, and $2.80/MWh for Resource Portfolio 9.

Figure 14. Provision of Regulation Up



Regulation Down ancillary services are provided primarily by the Wygen III unit. Figure 15 provides an illustration of thermal resources providing 50 MW of Regulation Down services on the BHP system. As shown, a large share of such services are provided by Wygen III, with a small portion of additional Regulation Down services provided by Neil Simpson II.

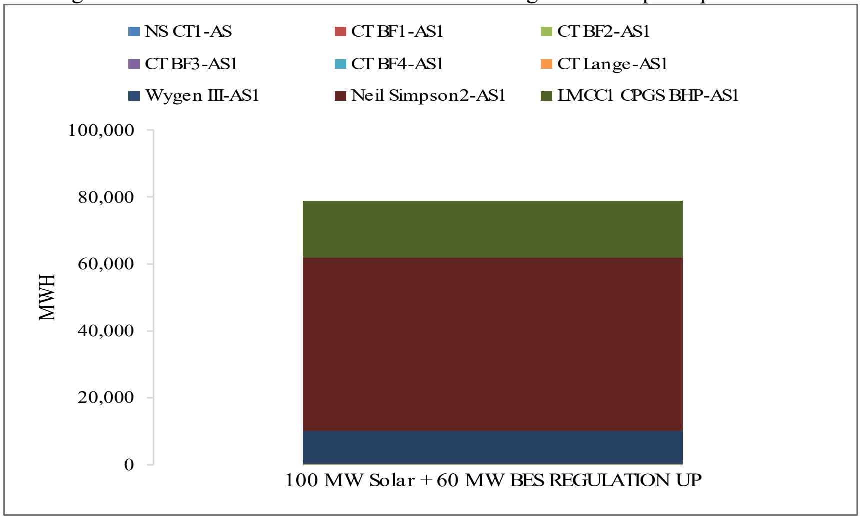
Figure 15. Provision of Regulation Down



Changes in operating costs and the cost of providing regulating reserves are sensitive to the magnitude of additional Regulation Up capacity that BHP will be required to carry with each of the Resource Portfolios. For example, for Resource Portfolios requiring incremental Regulation Up Capacity in the 8 to 10 MW range, such as for the solar resource expansions, the balance of

Regulation Up capacity can be supplied by Neil Simpson 2, at a relatively low cost. Figure 16 provides an illustration of thermal resource contribution to provide 9 MW of Regulation Up capacity. With that level of incremental regulation requirement, most of the Regulation Up provision occurs from Neil Simpson 2, and the incremental system cost is less than $3/MWh.

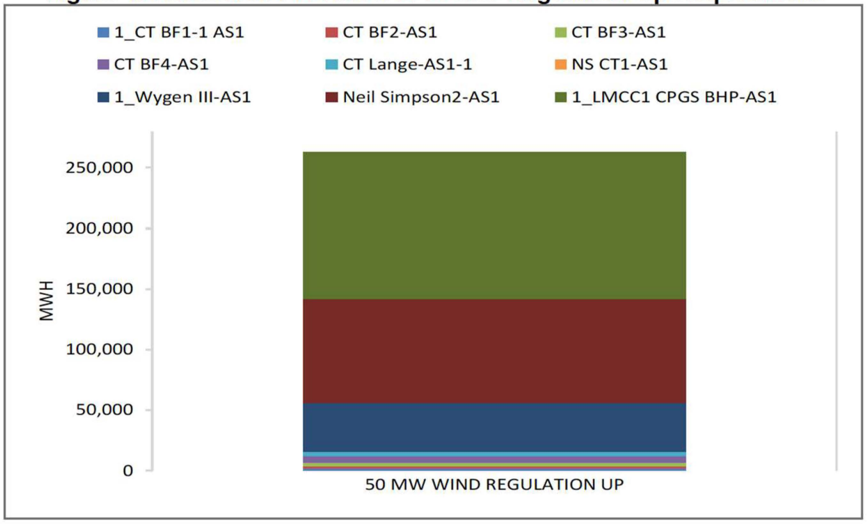
Figure 16. Resource Provision of 9 MW Regulation Up Requirement



In contrast, with a 30 MW incremental Regulation Up requirement, over 50 percent of regulation capacity on the BHP system is provided by the natural gas-fueled LMCC1 CPGS. The incremental operating cost and change in BHP system costs is considerably higher with that level of regulation requirement, with incremental regulation costs exceeding $10/MWh.

Figure 17 provides an illustration of thermal unit regulation capacity contribution under those conditions.

Figure 17. Resource Provision of 30 MW Regulation Up Requirement



3.4.4 Flexible Capacity Requirements

In addition to assessing incremental Regulation Up and Regulation Down costs and quantities likely to be incurred due to changes in BHP operating costs, PG also completed an assessment of whether BHP is likely to require additional flexible capacity to integrate the Resource Portfolios. PG completed this assessment by applying a methodology originally developed by the California Independent System Operator (CAISO) to assess flexible capacity requirements[4].

Under that approach, the need for Flexible Capacity Need is determined by examining the capacity of the most severe single contingency and the monthly maximum contiguous 3-hour ramp on the BHP system. At 103 MW, Wygen III represents the single largest contingency on the BHP system. PG created an hourly 2025 Net Load forecast for the existing system by subtracting BHP's existing VER generation forecast from the BHP Full load forecast. PG then calculated the maximum three-hour Net Load contiguous ramp for each month of 2025. Results of those calculation are illustrated below in Figure 18.

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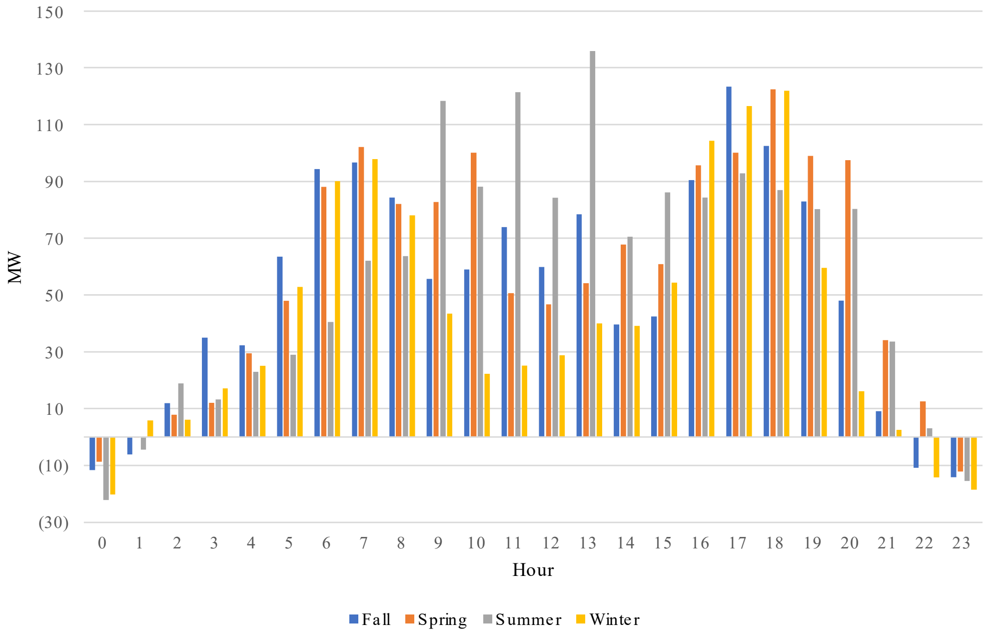
[4] See, http://www.caiso.com/Documents/Final2020FlexibleCapacityNeedsAssessment.pdf

Figure 18. Maximum Net 3-Hour Ramp – Existing BHP System



Using the net 3-hour ramp calculations, incremental Flexible Capacity requirements were estimated by subtracting Black Hills Power's existing Flexible Capacity (excluding the largest contingency, Wygen III – 293 MW from the Maximum Flexible Capacity Need.

Table 8 illustrates results of this assessment. As shown, three of the Resource Portfolios require procurement of additional Flexible Capacity, including Portfolio 3, which creates a Flexible Capacity need of 86 MW, Portfolio 5 which creates a 16 MW Flexible Capacity need, and Portfolio 6, which creates a 118 MW Flexible Capacity need. The cost of flexible capacity is typically tied to the carrying cost of flexible peaking capacity. Black & Veatch is currently completing a study of busbar costs for new generation on the BHP system, and those costs and the flexible capacity requirements identified above will be reflected in BHP's Integrated Resource Plan development for Resource Portfolios 3, 5 and 6.

Table 10. BHP Flexible Capacity Need

Portfolio	Type	Size (MW)	Location	Max Three-Hour Ramp (MW)	Incremental Three-Hour Max Ramp (MW)	Max Flexible Capacity Need (MW)	Resource Need (MW)
Existing System				55	136		239
1	Wind	50	Cheyenne	162	26	265	0
2	Wind	100	S. Gillette	172	36	275	0
3	Wind	200	N. Douglas	276	140	379	86
4	Solar	50	Cheyenne	166	30	269	0
5	Solar	100	Gillette	206	70	309	16
6	Solar	200	Hot Springs	308	172	411	118
7	Solar + Storage	100 + 40	Cheyenne	187	51	272	0
8	Solar + Storage	100 + 20	Gillette	187	51	289	0
9	Solar + Storage	100 + 60	Hot Springs	197	61	252	0
10	Storage	20	Cheyenne	N/A	N/A	N/A	N/A
11	Storage	40	Gillette	N/A	N/A	N/A	N/A
12	Storage	60	Hot Springs	N/A	N/A	N/A	N/A

4 ELCC Calculation for Black Hills Power's Renewable Resources

4.1 Overview

VERs such as wind and solar have fluctuating availability throughout the year and present variable capacity contribution towards system peak demand. The power system planners implement the Loss of Load Expectancy (LOLE) method or the rather novel Effective Load Carrying Capability (ELCC) method in order to determine the accreditable capacity provided by those resources to safeguard the grid's reliability.

LOLE method targets a reliability level of 0.1 days/year during which the capacity of resources are not sufficient to supply the demand. Certain generators have forced outage rates and resulting total generator availability levels cause insufficient generation when it is compared with hourly demand. LOLE is calculated based on the Loss of Load Probability (LOLP) that occurs primarily during the peak hours. However, evaluating a capacity contribution of resource during the peak hours results in an underestimation of the value provided by renewable resources. In order to understand the additional reliability contribution of variable energy resources to energy demand throughout the year, PG examined the impact on expected unserved energy value as well. The LOLE approach traditionally has been implemented to attain the planning reserve margin. Traditionally, a 0.1 day/year LOLE threshold for a power system has been targeted. When power systems consisted primarily of controllable thermal generation, the LOLE standard was measured and achieved by setting a reserve margin level and ensuring that load serving entities had sufficient capacity resources to meet the reserve margin during the peak hour. As the amount of variable energy resources increased on regional power systems, the industry began to examine metrics in addition to reserve margin to ensure the LOLE threshold is met, and for ways to recognize that variable energy resources contribute to system reliability beyond the expected generation level provided in just the peak hour. The ELCC method has been recognized as a sound analytic technique to better assess the reliability contribution of variable energy resources. The ELCC approach measures a new variable generator's contribution to overall resource adequacy by calculating the additional load that can be supplied at a certain reliability level. ELCC illustrates the new resource's load carrying capability for all hours in a year.

In order to determine the accreditable capacity for VERs, ELCC was calculated for BHP based on the LOLE metric. The LOLE metric is used to measure the effective capacity contribution of an individual variable energy resource addition by calculating the incremental impact on the same system. The Initial system's LOLE level represents the target reliability level to achieve after the variable resource addition. These calculations were completed for each of the Resource Portfolios with varied solar and wind resource additions, as well as paired solar and energy storage combinations as listed above in Table 3.

4.2 Methodology

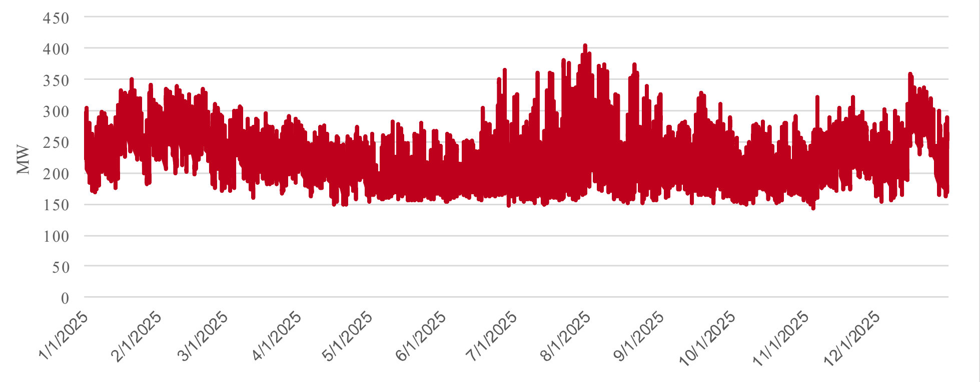
LOLE was used as the metric to calculate the ELCC value for each Resource Portfolio. ELCC values represent the percentage of accreditable capacity that a given resource can reliably provide compared to its nameplate capacity.

The LOLE calculation was performed hourly for the 2025 planning year. First, the reliability adequacy level of the BHP baseline system was calculated. This target reliability level is measured in hours of loss of load per year. Second, a variable energy resource (e.g. 50 MW wind) was added to the baseline system. Each incremental resource improves the baseline's LOLE value by providing a higher level of reliability. Then, PG calculated the additional load (e.g. 20 MW) that can be added to the system while achieving the same reliability level as the base system. Finally, this additional demand was divided by the nameplate capacity of the variable energy resource addition to calculate the ELCC of that resource. The ELCC value represents the quantity of 'perfect capacity' (with 100 percent availability) that could be replaced or avoided with wind, solar, storage, etc. while providing equivalent system reliability.

For example, if a 50 MW wind resource is added to the BHP system and it allows the system demand to be increased by 20 MW while achieving the same reliability level as the base system, the ELCC of that wind farm is equal to 20/50= 40%. As expected, adding larger amounts of renewable resources result in lower ELCC value provided by those resources. This approach is different than assessing the firm capacity of a renewable resource by just looking at its capacity contribution during the peak hour or a group of peak hours. The ELCC approach considers the value of the resource throughout the year and allows for a certain loss of load threshold.

PG received hourly data from BHP staff for its current and projected system demand and variable energy resource generation. BHP staff also provided thermal and renewable resource characteristics (e.g. unit capacity, generating unit forced outage rates). PG developed a spreadsheet-based tool to calculate the reliability of the BHP system by incorporating generator data, hourly system demand, and hourly capacity of named renewable resources and future renewable portfolios for the year 2025. The tool compares the hourly net load of the BHP system with 5,000 iterations of generation levels developed with Monte Carlo simulation. Collectively, those simulations reflect the forced outage rate of each generator. Those hours where the hourly net load exceeds a simulated generator availability level, are counted as loss of load hours.

Figure 19. 8760 Hourly Load Profile for BHP



4.3 ELCC Results

PG calculated the hourly LOLE for the BHP base system for the year 2025. The BHP Base system's LOLE is 2.18 hours per year, which is less than the widely accepted 0.1 days/year (1 day in 10 years) reliability standard. BHP's base system for 2025 included ownership of 419 MW of thermal generation[5] and 159.5 MW of wind and solar resources.

Once a new variable energy portfolio is added to the system, the LOLE improves. The tool was then used to calculate the additional demand that the system can carry while still maintaining the 2.18 hours/year LOLE level attained by the base system. For example, with the addition of 100 MW wind at North Douglas, the LOLE changes to 0.77 hours/year, which represents an improvement due to new resource availability. The systemwide demand can be increased by 20.3 MW for every hour while the level of reliability reaches to 2.18 hours/year resulting in an ELCC value of 20.3% for the 100 MW wind located at North Douglas.

BHP requested that PG complete ELCC assessments for the solar, wind and solar plus energy storage portfolios shown in Table 3. In order to illustrate the impact of incremental capacity at the same location, PG calculated the ELCC for 50 MW, 100 MW, and 200 MW levels at each of the locations identified for the solar and wind portfolios.

Table 11 summarizes the ELCC value for all incremental portfolios including the solar plus energy storage portfolios. Energy storage resources in the hybrid portfolios are assumed to exclusively charge from the solar resource that they are paired with in order to be eligible for the investment tax credit. Thus, their charging and discharging schedule is optimized around the availability of solar.

Table 11. ELCC values for the BHP Portfolios

Portfolio	Type	Size (MW)	Location	Incremental Demand (MW)	ELCC (%)
1	Wind	50	Cheyenne	15	29%
2	Wind	100	S. Gillette	23	23%
3	Wind	200	N. Douglas	30	15%
4	Solar	50	Cheyenne	6	11%
5	Solar	100	Gillette	9	9%
6	Solar	200	Hot Springs	9	4%
7	Solar + Storage	100 + 40	Cheyenne	15	15%
8	Solar + Storage	100 + 20	Gillette	14	14%
9	Solar + Storage	100 + 60	Hot Springs	18	18%

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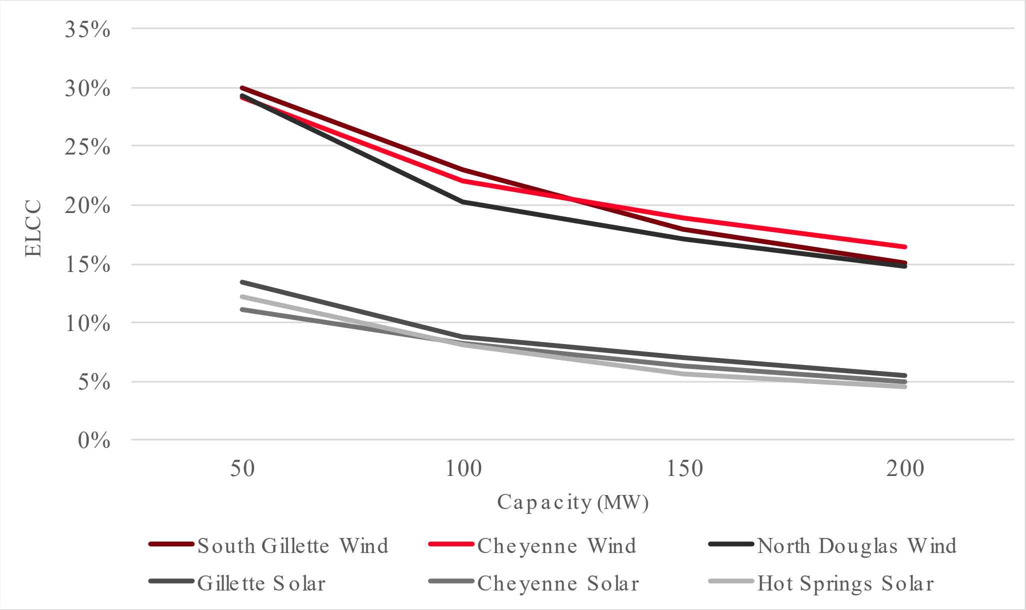
[5] MDU's and COG's ownership of Wygen III is excluded from BHP's thermal generation total.

Pairing energy storage with solar resources resulted in an increase in the accreditable capacity for the solar plus BESS portfolios. Adding 20 MW, 40 MW, and 60 MW of energy storage increased the capacity value of the solar portfolios by 5 MW, 6 MW, and 9 MW, respectively. The energy storage charges from the solar resource during day-light hours reducing the availability of solar output during those hours but because of low and no solar irradiance periods the overall availability of the solar plus BESS resource is extended increasing the accreditable capacity of the resource

Figure 20 illustrates the calculated ELCC values for solar and wind resources. As the capacity of the resources increase, the accreditable capacity is reduced. The solar resources located at Gillette, Cheyenne, and Hot Springs have lower ELCC values than the wind resources at South Gillette, Cheyenne, and North Douglas. ELCC values for solar resources ranges from 4% to 13% while ELCC values for wind resources ranges from 15% to 30%. Future solar resources on average have a 26% capacity factor, which is much lower than the capacity factor for wind resources at 43%. This is the major reason for lower solar ELCC values. Low solar irradiance during the late afternoon periods also played a role in lower ELCC values for solar portfolios. Cheyenne Wind and Gillette Solar resulted in slightly higher ELCC values in their respective resource categories.

Figure 20. ELCC for Wind and Solar Portfolios



PG also calculated the ELCC value of stand-alone battery storage at four capacity levels, 20 MW, 40 MW, 60 MW and 100 MW. We determined the battery charge level in every hour to calculate the amount of capacity that a stand-alone battery storage facility can provide. This capacity ranges between 0 MW and the maximum capacity of the storage facility. Table 12 lists the estimated ELCC values. As the size of the capacity increases from 20 MW to 60 MW, the effective capacity contribution is expected to decrease from 80% to 54%.

Table 12. ELCC of Battery Storage

Type	Capacity (MW)	Incremental Demand (MW)	ELCC (%)
Storage	20	16	80%
Storage	40	27	67%
Storage	60	33	54%
Storage	100	49	49%

5 Conclusion

In this study, PG examined Variable Energy Resource availability on the BHP system, considering both existing and planned new resources. PG estimated incremental amounts of Regulation Up and Regulation Down capacity that would be needed to reliably balance the BHP system considering twelve different potential portfolios of renewable energy and/or battery storage additions. PG also estimated likely changes in BHP operating costs for each of the resource portfolios, based on production cost modeling and changes in BHP system costs due to incremental regulation requirements. PG further estimated the potential need for BHP to procure additional flexible capacity resources for a subset of the resource portfolios, in cases where BHP's current generation portfolio is unable to meet flexible capacity needs driven by large ramps in VER generation output. Finally, PG estimated Effective Load Carrying Capability for wind and solar resource additions varying between 50 and 200 MW, at four different site locations including Cheyenne, WY, Douglas, WY, Gillette, WY and Hot Springs, SD. Table 13 below summarizes quantitative results from each of those sets of analyses.

Table 13. VER Integration Summary Results

Portfolio	Type	Size (MW)	Location	98% CPS2: Incremental Regulation Up (MW)	98% CPS2: Incremental Regulation Down (MW)	Regulation Generation Cost ($/MWh)	Regulation WAPA Tariff ($/kW/Mo)	Flexible Resource Need (MW)	ELCC (%)
Existing System				55	55			239	
1	Wind	50	Cheyenne	24	0	$10.17	$0.303	0	29%
2	Wind	100	S. Gillette	26	22	$6.56	$0.303	0	23%
3	Wind	200	N. Douglas	50	40	$11.12	$0.303	86	15%
4	Solar	50	Cheyenne	7	1	$5.38	$0.205	0	11%
5	Solar	100	Gillette	10	1	$4.63	$0.205	16	9%
6	Solar	200	Hot Springs	11	1	$1.57	$0.205	118	4%
7	Solar + Storage	100 + 40	Cheyenne	0	1	$0.02	$0.205	0	15%
8	Solar + Storage	100 + 20	Gillette	0	1	$0.03	$0.205	0	14%
9	Solar + Storage	100 + 60	Hot Springs	0	1	$0.02	$0.205	0	18%
10	Storage	20	Cheyenne	0	1	N/A		N/A	80%
11	Storage	40	Gillette	0	1	N/A		N/A	67%
12	Storage	60	Hot Springs	0	1	N/A		N/A	54%

As shown in Table 13, Regulation Up requirements for wind resources vary from 24 to 50 MW depending on the size and location of a wind resource. Regulation Down requirements for wind resource vary from zero to 40 MW, and regulation costs vary from $6.56/MWh to $11.12/MWh when provided by BHP generation. Regulation Up and Regulation Down requirements for solar resource additions are much lower, ranging from 7 to 11 MW for Regulation Up, and 1 MW for

Regulation Down. For solar resources, regulation costs vary from $1.57/MWh to $5.38/MWh when provided by BHP generation. Pairing battery storage technology with solar resources lowers the regulation cost and requirements significantly, as the battery facility is able to cover incremental Regulation Up requirements, and Regulation Down requirements remain at 1 MW.

Regulation costs are lower when procured through WAPA's OATT, in which case regulation costs are $0.303/kW/Month for wind resources and $0.205/kW/Month for solar resources. At a 40% annual average wind capacity factor, the WAPA regulation cost is equivalent to $1.04/MWh for wind resources, and at a 25% annual average capacity factor for solar, it would be equivalent to $1.12/MWh for solar resources.

Three of the Resource Portfolios outlined in Table 13 have flexible capacity requirements, with estimated capacity needs of 86 MW for Resource Portfolio 3, 16 MW for Resource Portfolio 5, and 118 MW for Resource Portfolio 6. Costs associated with procuring that additional flexible capacity will be reflected in BHP's IRP, based on a Busbar cost study that is currently being completed by Black & Veatch.

ELCC values for the renewable technologies in each Resource Portfolio vary from 29 percent down to 4 percent, with ELCC declining as the size of a project addition increases. ELCC values for wind resources are considerably higher than for solar resources, due primarily to a higher capacity factor. For battery resources, ELCC values are estimated at 80 percent for a 20 MW installation, declining to 67 percent for a 40 MW installation, 54% for a 60 MW installation, and 49% for a 100 MW installation.