RENEWABLE RESOURCE ADEQUACY STUDY

BLACK HILLS CORPORATION

July 30, 2024

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Executive Summary

Balancing Authorities (BA) routinely develop reliability metrics that are used by Load Serving Entities (LSE) within the BAs region for generation resource planning. These metrics include Planning Reserve Margins (PRM) and Effective Load Carrying Capability (ELCC). PRMs reflect the amount of reliable capacity a BA should carry over and above peak load to be reliable. ELCCs reflect the portion of a resource type's nameplate capacity that contributes toward reliability. A BA will perform Loss of Load Expectation (LOLE) studies to develop PRMs and ELCCs. LOLE analyses are supplemented with an evaluation of the impact that increased penetration of certain resource types has on reliability.

Black Hills Energy (BHE) commissioned 1898 & Co. to perform a LOLE study that identified PRMs and ELCCs under a requirement of a single load loss event in ten years (referred to as "1-in-10"). This study was performed for a combined Black Hills Power (BHP) and Cheyenne Power and Light (CLFP) system. The resources examined in the study were solar, wind, and energy storage resources (ESR). These resources were studied for several hypothetical portfolios that reflect various future levels of resource penetration within the BHE service territory. The remainder of this Executive Summary discusses the study approach and the study results.

STUDY APPROACH

This study involved modeling the combined BHP and CLFP systems in SERVM for a base year of 2030. The BHP/CLFP portfolio was then calibrated to a reliability metric of 1-in-10 LOLE by adding perfect generation to the portfolio. Solar, wind and ESR resources were then removed from the portfolio and perfect generation was added to re-calibrate the portfolio to a reliability metric of 1-in-10. The perfect generation needed to replace solar, wind, and ESR (which is the system ELCC) was used to calculate PRMs. Solar, wind, and ESR resources were then evaluated individually to determine technology specific ELCCs at various levels of resource penetration.

Six (6) resource scenarios were evaluated in addition to a Base Case to reflect medium and high levels of penetration for solar, wind and ESR. The table below shows the medium and high case capacity additions for solar, wind, and ESR.

Scenario Capacity Addition

Technology	Medium Case Additions (MW)	High Case Additions (MW)
Solar	355.5	711.0
Wind	355.5	711.0
ESR	341.0	682.0

STUDY RESULTS

The LOLE analysis performed by 1898 & Co. identified PRMs and ELCCs under a requirement of a single load loss event in ten years (0.1 LOLE). More specifically, we altered resource capacity to determine the amount of planning reserves necessary to achieve a 1-in-10 result for determining PRM. We also altered resource capacity to determine how much capacity a given resource (e.g., solar, wind, ESR) contributes to system reliability (i.e., the ELCC value).

PRM and resource specific ELCC results are highlighted below. Further process flow descriptions and results can be found in Section 3.

Planning Reserve Margin

Scenario	Planning Reserve Margin
Base Case	29.9%
Medium Solar Additions	30.9%
High Solar Additions	30.7%
Medium Wind Additions	30.5%
High Wind Additions	31.2%
Medium ESR Additions	30.5%
High ESR Additions	30.9%

The PRMs across the scenarios are fairly close together. This result suggests that for solar, wind, and ESR, as capacity increases and ELCCs decrease, this net impact on reliability is small. Or said differently, increasing solar, wind, and ESR in the portfolio does not significantly improve or diminish system reliability. The overall PRM levels of between 29.9 percent and 31.2 percent for the combined BHP/CLFP system are typical for smaller systems that include some large generating units or units with high outage rates. A larger, more diverse system will have lower PRMs.

Solar ELCCs were calculated under two different scenarios in addition to the Base Case representing three (3) levels of nameplate capacity. The solar ELCC results are shown in the table below.

Solar ELCC

Scenario	Solar Nameplate Capacity (MW)	ELCC
Base Case	80.0	35.8%
Medium Solar Additions	435.5	11.2%
High Solar Additions	791.0	7.0%

Wind ELCCs were calculated under two different scenarios in addition to the Base Case representing three (3) levels of nameplate capacity. The wind ELCC results are shown in the table below.

Wind ELCC

Scenario	Wind Nameplate Capacity (MW)	ELCC
Base Case	152.5	18.8%
Medium Solar Additions	508.0	12.7%
High Solar Additions	863.5	9.5%

ESR ELCCs were calculated under two different scenarios in addition to the Base Case representing three (3) levels of nameplate capacity. The ELCC values for ESR are unique in that they depend on the amount of other resources, which need to be available to charge ESR resources. Thus, it is important to note that the ELCC values calculated under the medium and high ESR cases were all calculated with the same levels of solar and wind. The ESR ELCC results are shown in the table below.

ESR ELCC

Scenario	ESR Nameplate Capacity (MW)	ELCC
Base Case	10	67.4%
Medium ESR Additions	351	8.5%
High ESR Additions	692	0.9%

CONCLUSIONS

PRMs for the various cases were fairly close, with the lowest PRM of 29.9 percent for the Base Case and the highest PRM of 31.2 percent for the High Wind Additions Case. This tight range in PRMs suggests that for solar, wind, and ESR, as capacity increases and ELCCs decrease, the net impact on reliability is small. Or said differently, increasing solar, wind, and ESR in the portfolio does not significantly improve or diminish system reliability. PRMs of 30 percent are indicative of a fairly small system with limited diversity and a system with fairly large units having high forced outage rates. Large systems with diversity typically see PRMs below 20 percent.

For technology specific ELCCs, values for a resource type will typically have an inverse relationship with the percentage that resource is of a portfolio. This can be seen in the table above showing ELCCs by technology type. For each resource type, as that resource's MWs increase, ELCCs decrease. Of the variable energy resources evaluated, wind is the large percentage of system load in the Base Case, with a nameplate of about 24 percent of peak system load. The Base Case wind ELCC is 18.8 percent. Thus, ELCC values are very much driven by the proportion a resource is of a portfolio.

The technology specific curves developed for the variable energy resources all show that ELCCs decline as resource capacity size increases. Solar ELCCs are slightly stronger than wind ELCCs at the same capacity levels when both are a smaller portion of the system portfolio. However, as both solar and wind capacity is increased, wind ELCCs decline at a slower rate that solar ELCCs indicating wind has more capacity value than solar when either are a significant portion of the BHP/CLFP portfolio.

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1.0 Introduction

Balancing Authorities (BA) routinely develop reliability metrics that are used by Load Serving Entities (LSE) within the BAs region for generation resource planning. These metrics include Planning Reserve Margins (PRM) and Effective Load Carrying Capability (ELCC). PRMs reflect the amount of reliable capacity a BA should carry over and above peak load to be reliable. ELCCs reflect the portion of a resource type's nameplate capacity that contributes toward reliability. A BA will perform Loss of Load Expectation (LOLE) studies to develop PRMs and ELCCs. LOLE analyses are supplemented with an evaluation of the impact that increased penetration of certain resource types has on reliability.

Black Hills Energy (BHE) commissioned 1898 & Co. to perform a LOLE study that identified PRMs and ELCCs under a requirement of a single load loss event in ten years (referred to as "1-in-10"). This study was performed for a combined Black Hills Power (BHP) and Cheyenne Power and Light (CLFP) system. The resources examined in the study were solar, wind, and energy storage resources (ESR). These resources were studied for several hypothetical portfolios that reflect various future levels of resource penetration within the BHE service territory.

2.0 Study Approach

The reliability analyses were performed using the Strategy Energy & Risk Valuation Model (SERVM) software package licensed through Astrapé Consulting. SERVM is a system-reliability planning and production cost model designed to analyze the capabilities of an electric system under varying demand, generation units outages, and generation production profiles. The study involved modeling the combined BHP and CLFP systems in SERVM for a base year of 2030. The BHP/CLFP portfolio was then calibrated to a reliability metric of 1-in-10 LOLE by adding perfect generation to the portfolio. Solar, wind and ESR resources were then removed from the portfolio and perfect generation was added to re-calibrate the portfolio to a reliability metric of 1-in-10. The perfect generation needed to replace solar, wind, and ESR (which is the system ELCC) was used to calculate PRMs. Solar, wind, and ESR resources were then evaluated individually to determine technology specific ELCCs at various levels of resource penetration. The specific processes utilized in these steps are discussed further in Section 3.1.

The remainder of this section discusses the inputs and assumptions used in the study as well as the scenarios used to reflect variable levels of resource penetration.

2.1 Inputs & Assumptions

Many of the inputs and assumptions used in this study were provided by BHE, including load, resource and contract operating characteristics, renewable energy profiles, and import/export capability, which was assumed to be zero. ESR technology was assumed to be 4-hour lithium ion batteries. Actual weather data for 20 years was used to vary hourly load and renewable resource generation profiles.

2.2 Scenarios

Six (6) resource scenarios were evaluated in addition to a Base Case to reflect medium and high levels of penetration for solar, wind and ESR. Table 2.1 shows the medium and high case capacity additions for solar, wind, and ESR.

Table 2.1 - Scenario Capacity Addition

Technology	Medium Case Additions (MW)	High Case Additions (MW)
Solar	355.5	711.0
Wind	355.5	711.0
ESR	341.0	682.0

The High Case solar and wind capacity levels were sized so that approximately two thirds of the system energy needs were coming from the resource being evaluated. This scenario represents a very high level of variable energy resource penetration. The Medium Case solar and wind capacity levels were sized so that approximately one third of the system energy needs were coming from the resource being evaluated. ESR Medium and High Case levels were set to approximate the Medium and High Case levels for solar and wind.

3.0 Study Results

The LOLE analysis performed by 1898 & Co. identified PRMs and ELCCs under a requirement of a single load loss event in ten years (0.1 LOLE). More specifically, we altered resource capacity to determine the amount of planning reserves necessary to achieve a 1-in-10 result for determining PRM. We also altered resource capacity to determine how much capacity a given resource (e.g., solar, wind, ESR) contributes to system reliability (i.e., the ELCC value). The study involved modeling the combined BHP and CLFP systems in SERVM for a base year of 2030. The BHP/CLFP portfolio was then calibrated to a reliability metric of 1-in-10 LOLE by adding perfect generation to the portfolio. Solar, wind and ESR resources were then removed from the portfolio and perfect generation was added to re-calibrate the portfolio to a reliability metric of 1-in-10. The perfect generation needed to replace solar, wind, and ESR (which is the system ELCC) was used to calculate PRMs. Solar, wind, and ESR resources were then evaluated individually to determine technology specific ELCCs at various levels of resource penetration.

The results below are organized by a description of the process flow 1898 & Co. followed to develop results, initial calibrations, system ELCC calculations, PRM calculations, and technology specific ELCC calculations.

3.1 Process Flow

To develop results, 1898 & Co. leveraged SERVM's Monte Carlo simulation engine. About 250 unit outage iterations were simulated for each weather year. These iterations were used to account for variations in random forced outages. Each iteration represented a single 8,760-hour simulation. The results from the 5,000 simulations per scenario created a probability distribution of the possible LOLE event outcomes. Validation of the 1,450 simulations was conducted to ensure that results converged around mean variables.

The process followed to perform the ELCC and PRM analyses is described by steps below. Some of these steps required the addition of "perfect capacity" to meet a 0.1 LOLE per year reliability metric. "Perfect capacity" was modeled as a combustion turbine with no outages.

Step 1: Calibrate portfolios to 1-in-10 LOLE (or 0.1 LOLE per year) by adding perfect capacity;

Step 2: Remove all intermittent, or variable energy resources (solar, wind, and ESR) and replace with perfect capacity to re-achieve 0.1 LOLE; the amount of replacement perfect capacity divided by the combined nameplate capacity for solar, wind, and ESR equals the System ELCC;

Step 3: With portfolio calibrated to 0.1 LOLE, remove capacity for solar, wind, and ESR individually and add perfect capacity to re-achieve 0.1 LOLE; the amount of capacity added back for a resource type divided by the nameplate capacity for the resource type equals the technology specific ELCC;

Step 4: Calibrate each technology-specific ELCC so that sum of the technology-specific ELCC capacity amounts equals the System ELCC capacity amount; and

Step 5: Calculate PRM by summing all reliability capacity in the portfolios, including solar, wind, and ESR adjusted by each's ELCC, and divide by peak load, then subtract 1 to arrive at PRM needed to maintain 0.1 LOLE.

3.2 Initial Calibrations

To calculate the ELCCs and PRM, 1898 & Co initially calibrated each portfolio to an annual LOLE at 0.1 by adding perfect capacity in each scenario. The amount of perfect capacity added for each scenario is shown in Table 3.1.

Table 3.1 - Initial Calibration Perfect Capacity Additions

Scenario	Perfect Capacity Addition (MW)
Base Case	12
Medium Solar Additions	(10)
High Solar Additions	(17)
Medium Wind Additions	(28)
High Wind Additions	(50)
Medium ESR Additions	(10)
High ESR Additions	10

As can be seen in Table 3.1, some scenarios require negative perfect capacity to achieve a LOLE of 0.1.

3.3 System ELCC

To develop PRMs, system ELCCs need to be developed. System ELCCs reflect the combined capacity contribution from variable energy resources, such as solar, wind, and ESR. System ELCCs for each of the scenarios were developed by removing all intermittent, or variable energy resources (solar, wind, and ESR) and replacing these resources with perfect capacity such that a reliability metric of 0.1 LOLE is re-achieved. Table 3.2 includes system ELCC percentages for the scenarios evaluated.

Table 3.2 - System ELCC

Scenario	System ELCC
Base Case	26.4%
Medium Solar Additions	15.4%
High Solar Additions	10.3%
Medium Wind Additions	18.1%
High Wind Additions	14.1%
Medium ESR Additions	15.4%
High ESR Additions	7.8%

The system ELCCs above reflect the perfect capacity needed to replace the combined solar, wind, and ESR resources divided by those resources' nameplate capacity. The system ELCCs decrease as renewables capacity increases for each technology scenario. This is a typical trend for ELCCs. The increased wind scenarios experienced the smallest reduction in ELCC going from Base Case to the Mid Wind Case, and from the Mid Wind Case to the High Wind Additions Case. This is due, in part, to the strong performance of wind in the region. ESR, on the other hand, experienced the largest drop in ELCC value going from the Base Case to the Medium ESR Additions and High ESR Additions Cases. This poor ESR performance is driven by ESR capacity being unable to contribute capacity on its own when solar and wind are left unchanged.

3.4 PRM

PRMs reflect the amount of reliable capacity a system should carry over and above peak load to be reliable. For this analysis, PRMs were calculated based on a reliability metric of 0.1 LOLE per year. PRM is defined in the below equation:

$$PRM = \left(\frac{Base\ Capacity}{Peak\ Load}\right) - 1$$

Base Capacity is the net generating capacity that contributes to reliability. So, for solar, wind, and ESR, base capacity is nameplate capacity times the ELCC for the resources combined as shown in Table 3.2 above. The BHP/CLFP system PRMs for each scenario based on a reliability metric of 0.1 LOLE annually are shown in

Table 3.3 - Planning Reserve Margin

Scenario	Planning Reserve Margin
Base Case	29.9%
Medium Solar Additions	30.9%
High Solar Additions	30.7%
Medium Wind Additions	30.5%
High Wind Additions	31.2%
Medium ESR Additions	30.5%
High ESR Additions	30.9%

As seen in

Table 3.3 above, the PRMs across the scenarios are fairly close together. This result suggests that for solar, wind, and ESR, as capacity increases and ELCCs decrease, this net impact on reliability is small. Or said differently, increasing solar, wind, and ESR in the portfolio does not significantly improve or diminish system reliability. The overall PRM levels of between 29.9 percent and 31.2 percent for the combined BHP/CLFP system are typical for smaller systems that include some large generating units or units with high outage rates. A larger, more diverse system will have lower PRMs.

3.5 Technology-Specific ELCCs

Individual technology specific ELCC values were calculated to better understand how increasing renewable penetration impacts ELCCs for Solar, Wind and ESR. All technology specific ELCCs were calculated based on a 0.1 LOLE annually. The technology specific ELCCs under the different renewable penetration scenarios are discussed below.

3.5.1 Solar ELCCs

Solar ELCCs were calculated under two different scenarios in addition to the Base Case representing three (3) levels of nameplate capacity. The solar ELCC results are shown in Table 3.4 below.

Table 3.4 - Solar ELCC

Scenario	Solar Nameplate Capacity (MW)	ELCC
Base Case	80.0	35.8%
Medium Solar Additions	435.5	11.2%
High Solar Additions	791.0	7.0%

As shown in Table 3.4 above, solar ELCCs decrease as more solar is added. This is an expected result, especially when significant amounts of solar have been added, like the amounts added in this analysis. By interpolation between the solar MW and corresponding ELCCs, a curve can be developed showing solar ELCCs at various increments of solar additions. Table 3.5 below shows interpolated solar ELCCs at 50 MW increments from 80 MW to 680 MW.

Table 3.5 - Solar ELCC with 50MW Capacity Increments

Nameplate Capacity (MW)	ELCC
80	35.8%
130	29.0%
180	24.7%
230	21.5%
280	19.0%
330	16.9%
380	15.0%
430	13.4%

480	12.0%
530	10.7%
580	9.5%
630	8.5%
680	7.5%

3.5.2 Wind ELCCs

Wind ELCCs were calculated under two different scenarios in addition to the Base Case representing three (3) levels of nameplate capacity. The wind ELCC results are shown in Table 3.4 below.

Table 3.6 - Wind ELCC

Scenario	Wind Nameplate Capacity (MW)	ELCC
Base Case	152.5	18.8%
Medium Solar Additions	508.0	12.7%
High Solar Additions	863.5	9.5%

As shown in Table 3.4 above, wind ELCCs decrease as more wind is added. This is an expected result, especially when significant amounts of wind have been added, like the amounts added in this analysis. By interpolation between the wind MW and corresponding ELCCs, a curve can be developed showing solar ELCCs at various increments of wind capacity. Table 3.57 below shows interpolated wind ELCCs at 50 MW increments from 153 MW to 752 MW.

Table 3.7 - Wind ELCC with 50MW Capacity Additions

Nameplate Capacity (MW)	ELCC
153	18.8%
202	17.36%
252	16.18%
302	15.23%
352	14.41%
402	13.71%
452	13.09%
502	12.53%
552	12.03%
602	11.57%
652	11.15%

702	10.76%
752	10.39%

3.5.3 ESR ELCCs

ESR ELCCs were calculated under two different scenarios in addition to the Base Case representing three (3) levels of nameplate capacity. The ELCC values for ESR are unique in that they depend on the amount of other resources, which need to be available to charge ESR resources. Thus, it is important to note that the ELCC values calculated under the medium and high ESR cases were all calculated with the same levels of solar and wind. The ESR ELCC results are shown in Table 3.4 below.

Table 3.8 - ESR ELCC

Scenario	ESR Nameplate Capacity (MW)	ELCC
Base Case	10	67.4%
Medium ESR Additions	351	8.5%
High ESR Additions	692	0.9%

As shown in Table 3.48 above, ESR ELCCs decrease as more ESR is added. The amount of ESR capacity added in both the medium and high ESR cases are so much that other resources, including solar and wind, cannot easily charge the large amounts of ESR. Thus, ESR ELCCs decrease dramatically for the volumes evaluated. By interpolation between the ESR MW and corresponding ELCCs, a curve can be developed showing ESR ELCCs at various increments of ESR capacity. Table 3.5 below shows interpolated ESR ELCCs at 50 MW increments from 153 MW to 752 MW.

Table 3.9 - ESR ELCC with 50MW Capacity Additions

Nameplate Capacity (MW)	ELCC
10	67.4%
60	38.5%
110	28.8%
160	22.8%
210	18.5%
260	15.1%
310	12.3%
360	9.9%
410	7.8%
460	5.9%

510	4.3%
560	2.8%
610	1.4%

4.0 Analysis Summary & Conclusions

The study was performed to develop PRMs and ELCCs under a requirement of a single load loss event in ten years (referred to as "1-in-10") for a combined Black Hills Power (BHP) and Cheyenne Power and Light (CLFP) system. The resources examined in the study were solar, wind, and energy storage resources (ESR). These resources were studied under a Base Case and under cases with two higher levels of capacity for each resource type.

System ELCCs, which are needed to calculate PRMs and which reflect capacity contribution from solar, wind, and ESR combined divided by nameplate capacity for solar, wind, and ESR combined ranged from 26.4 percent in the Base Case to only 7.8 percent in the high storage additions case. Evaluating ELCCs for ESRs should be done with the context that ESR relies on other technologies, such as solar and wind, for providing capacity value. In the Medium and High ESR Additions cases, both solar and wind resource capacity was held to Base Case levels. Thus, as ESR capacity increased, the charging energy was not available to allow ESRs to provide significant reliability capacity value.

PRMs for the various case were fairly close, with the lowest PRM of 29.9 percent for the Base Case and the highest PRM of 31.2 percent for the High Wind Additions Case. This tight range in PRMs suggests that for solar, wind, and ESR, as capacity increases and ELCCs decrease, this net impact on reliability is small. Or said differently, increasing solar, wind, and ESR in the portfolio does not significantly improve or diminish system reliability. PRMs of 30 percent are indicative of a fairly small system with limited diversity and fairly large units with high forced outage rates. Large systems with diversity typically see PRMs below 20 percent.

For technology specific ELCCs, values for a resource type will typically have an inverse relationship with the percentage that resource is of a portfolio. As an example, the Base Case ESR capacity is only 10 MW, or about 2 percent of peak system load and has an ELCC of 67.4 percent. Of the variable energy resources evaluated, wind is the large percentage of system load in the Base Case, with a nameplate of about 24 percent of peak system load. The Base Case wind ELCC is 18.8 percent. Thus, ELCC values are very much driven by the proportion a resource is of a portfolio.

The technology specific curves developed for the variable energy resources all show that ELCCs decline as resource capacity size increases. Solar ELCCs are slightly stronger than wind ELCCs at the same capacity levels when both are a smaller portion of the system portfolio. However, as both solar and wind capacity is increased, wind ELCCs decline at a slower rate that solar ELCCs indicating wind has more capacity value than solar when either are a significant portion of the BHP/CLFP portfolio.

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