ASTRAPÉ CONSULTING
innovation in electric system planning

SPP Energy Storage Study

Final Report

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PREPARED FOR

Southwest Power Pool (SPP)

PREPARED BY

Kevin Carden
Nick Wintermantel
Parth Patel
Cole Benson
Astrapé Consulting

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EXECUTIVE SUMMARY

METHODOLOGY

Astrapé Consulting was contracted by SPP to examine the capacity credit of energy storage resources on the SPP system using two methodologies: (1) Capacity Value and (2) Effective Load Carrying Capability (ELCC). Astrapé performed simulations to examine the effects of these resources on the SPP system using the Strategic Energy and Risk Valuation Model (SERVM).

To calculate the capacity credit of energy storage resources using the capacity value methodology, a "base" case of the system is first established. This involves calibrating SPP to an industry standard of reliability of 0.1 Loss of Load Expectation (LOLE). Once the "base" case has been established, the energy storage resources are added to the system which improves reliability. Then, conventional capacity with an equivalent forced outage rate (EFOR) of 5% or below is removed until the LOLE returns to 0.1. Figure 1 illustrates the capacity value methodology utilized. The ratio of the capacity of energy storage added to the capacity of conventional resources removed is deemed to be the capacity credit of the energy storage resource.

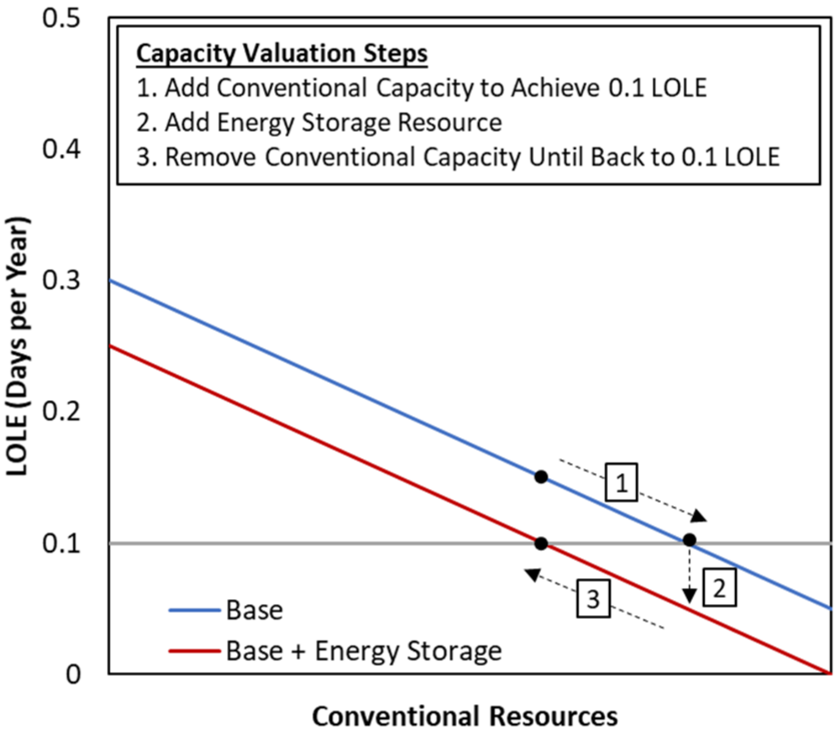

Figure 1: Capacity Value Methodology using SERVM

The ELCC of the storage resource is calculated in a similar way. The SPP system is calibrated to the industry standard of reliability of 0.1 LOLE and the base case is established. The energy storage resources are added to the system and reliability improves. After this step, the peak load of the system is artificially increased until the reliability returns to 0.1 LOLE. This increase is done in a way so that the load shape is scaled up keeping its original load shape. The ratio of the capacity of energy storage added to the system to the amount the peak load that was artificially increased gives the capacity credit of the energy storage resources.

Astrapé performed multiple sensitivities using both the capacity value and the ELCC methodology as described above to determine the capacity credit of the energy storage resources under different circumstances and assumptions including the penetration of the energy storage, the duration of the energy storage resources, the dispatch strategy, and the solar capacity on the SPP system. In addition to the stand-alone storage analysis, combined storage and solar projects were also evaluated.

RESULTS

STAND ALONE BATTERY RESULTS

The following figures summarize the capacity credit results. Full tables of results are available in the Appendix. Figure 2 compares the capacity value and the ELCC methodologies of varying energy storage penetration assuming 4-hour duration. As the figure demonstrates, using the capacity value methodology, the 4-hour batteries show 100% capacity credit up to 2,000 MW whereas the ELCC methodology shows a capacity credit of 99% up to 2,000 MW. The capacity value methodology provides a slightly higher capacity credit because the battery is being compared against a resource that has an EFOR whereas the ELCC methodology is comparing the battery to the peak load increase[1].

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[1] If the capacity value approach used comparison resources with perfect availability, the ELCC approach would provide slightly higher overall capacity credit since the battery is being compared to a load shape rather than a uniform block of capacity. This is why the capacity credits converge in Figure 1. At high penetrations of battery, the ELCC approach is comparing to load shapes that were scaled by significantly less than the magnitude of the battery capacity in some of the off-peak hours when battery energy is still needed.

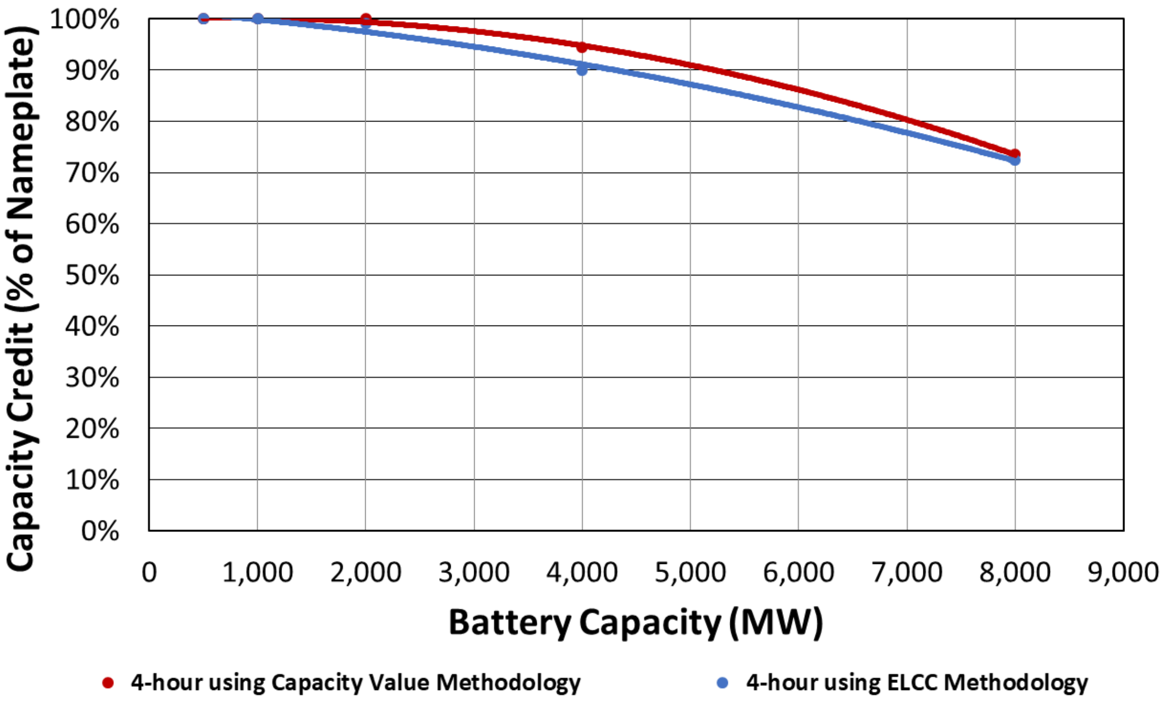

Figure 2: 4-Hour Capacity Credit using Capacity Value and ELCC Methodologies

The results shown in Figure 2 for 4-hour battery resources were calculated using a specific setting in SERVM that conserves the energy for peak periods called 'Preserve Reliability'. This ensures that the battery dispatches in the most reliable manner for the system. No battery energy is scheduled in advance; it is only dispatched when needed to prevent load shed.

Additional sensitivities were simulated that changed this setting to 'Economic Arbitrage' which schedules the batteries in a manner that optimizes economic arbitrage. SERVM still will schedule the dispatch of the batteries during high net load hours, but since the model does not have perfect foresight of generator performance, the schedule may be suboptimal from a reliability standpoint. For example, on a high net load day, the energy storage resource may have been scheduled to dispatch at the highest net load hours of the day. Then a generator may randomly fail toward the end of the high net load period creating a reliability event. Since the battery was dispatched during the high load hours, it is no longer available to prevent firm load shed. Whereas the 'Preserve Reliability' method would not have dispatched during the high net load hours if it wasn't needed to prevent firm load shed. This comparison is important as it illustrates the tradeoff of capacity credit for batteries when preserving reliability versus optimizing economics. As Figure 3 shows, the economic arbitrage operation strategy provides less capacity credit than the 'Preserve Reliability' operation strategy. The comparison in this case only quantifies the uncertainty impact of generator performance; additional uncertainties on load forecast or renewable output uncertainty would create additional divergence between an economic dispatch strategy and a 'Preserve Reliability' strategy. If generator performance was perfectly known, the 'Economic Arbitrage' and 'Preserve Reliability' strategies would produce identical results.

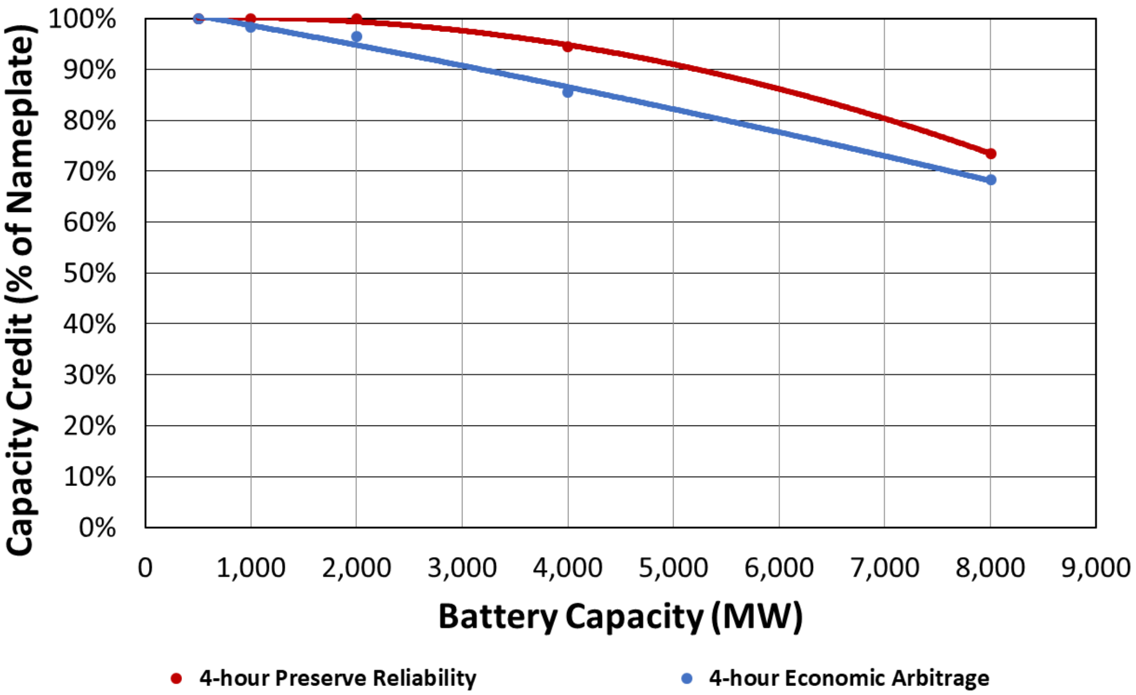

Figure 3: Preserve Reliability vs Economic Arbitrage

The next analysis performed considered different durations of energy storage. For this analysis, a range of battery capacities with 2-hour, 4-hour, 6-hour, and 8 -hour durations was simulated. The results are illustrated in Figure 4 below.

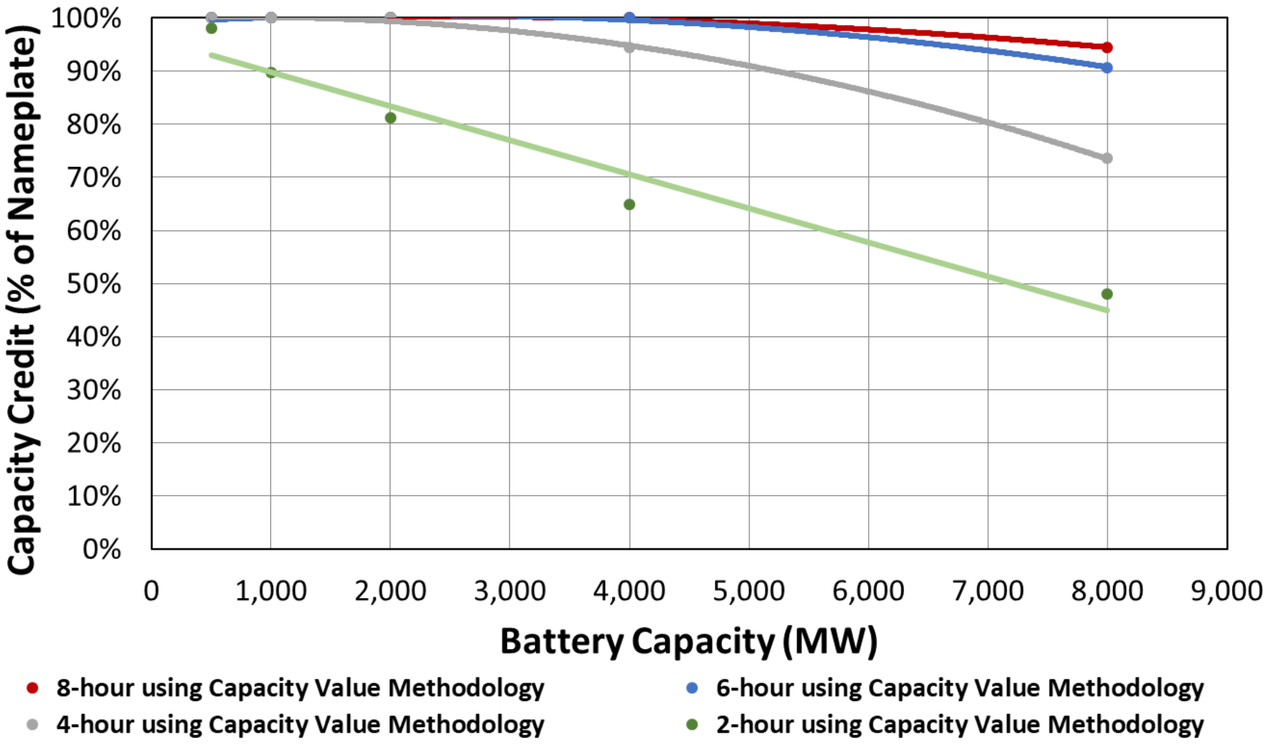

Figure 4: Varying Duration of Battery Systems

As Figure 4 illustrates, 8-hour and 6-hour systems have high capacity credits even at 8,000 MW of penetration whereas shorter duration resources have more significant declines in capacity credit. Intuitively, this makes sense because as the amount of energy storage is increased on a system, the net load shape flattens which means additional duration on these energy storage projects will be required. However, short duration battery resources can provide ancillary services all hours of the day since they would remain fully charged and only be dispatched for short periods for contingencies or balancing and then quickly fully re-charged. If emergency operating procedures assume some reserves would be preserved even during firm load shed, then some penetration of short duration batteries would demonstrate 100% capacity credit. Since this analysis assumed that no reserves would be preserved during firm load shed events, the capacity credit of 2-hour products drops below 100% almost immediately.

A sensitivity was performed which assumed that reserves equivalent to 1% of load would be preserved even during firm load shed events. Since battery storage would most efficiently serve this requirement, their capacity credit increases commensurately in the sensitivity shown in Figure 5.

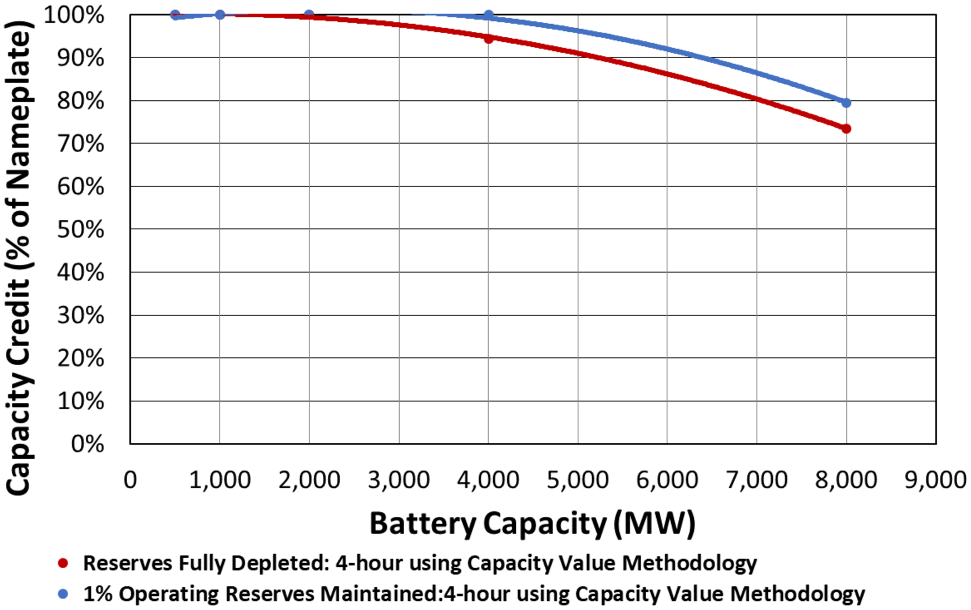

Figure 5: 4-hour Battery Assuming 1% Operating Reserves Are Always Maintained

An additional sensitivity on the stand alone 4-hour storage was simulated which changed the amount of existing solar on the SPP system. In general, as solar penetration increases, the peak net load shifts to later in the day and develops a shorter peak making the duration of peak load shorter. Because of this, it is expected that batteries will provide more capacity credit as solar penetration increases. While Figure 6 shows this effect, the amount of solar in this sensitivity changed from approximately 1% to approximately 8% as a percentage of peak load[2]. It is expected that if higher penetrations were analyzed, then this effect will become more pronounced. Figure 7 shows the net load curve for the 500 MW and 4,282 MW case for July. While the peak shifts slightly to later in the day, it does not shift it far enough to begin creating the needle peak that would provide storage substantially more value.

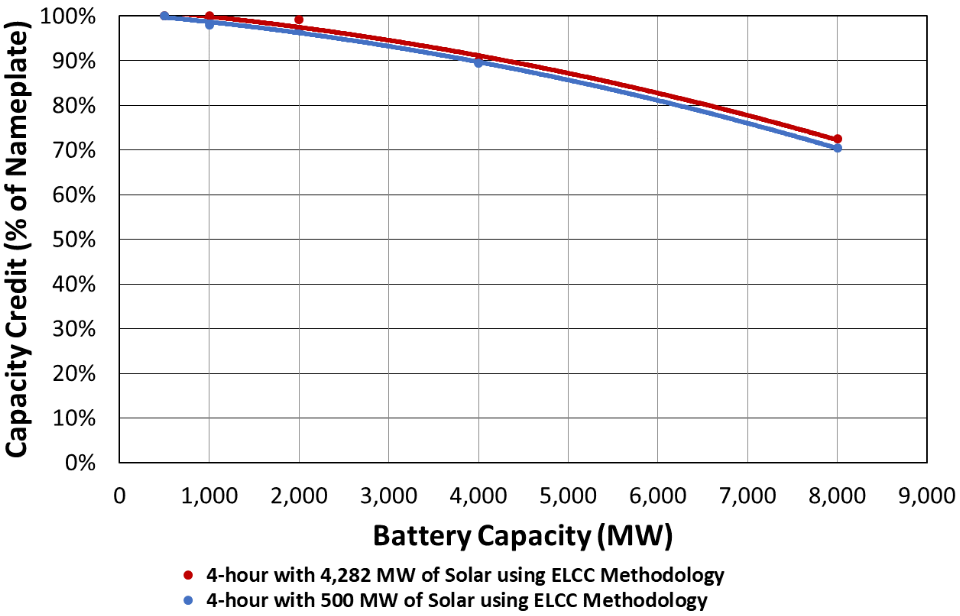

Figure 6: Different Amounts of Existing Solar

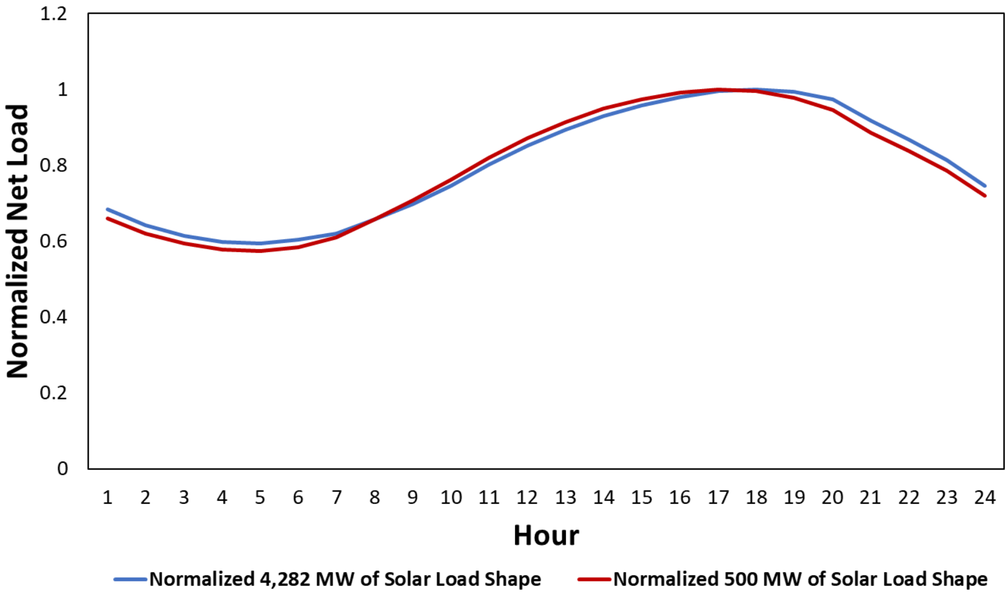

Figure 7: July Net Load Shape for Varying Amounts of Solar

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[2] These solar penetrations are 0.7% and 2.8% respectively if based on energy rather than capacity.

COMBINED SOLAR BATTERY PROJECTS

Finally, scenarios of coupled battery and solar installations were analyzed. In these scenarios, the batteries can only be charged from on-site solar generation. It was assumed these projects were DC coupled meaning the battery charged from the solar on the DC side of the inverter. If solar generation was not available to fully charge the battery prior to a critical load period, then the battery would provide less capacity credit than a scenario where batteries could charge from excess generation on the grid. In these coupled solar and battery scenarios, it is challenging to isolate the capacity credit being supplied by the battery and that supplied by the on-site solar. As shown in Figure 8, the capacity credit of the combined projects is less than 100% even for the first block of capacity. This is because while batteries are likely providing 100% capacity credit, the solar output during peak periods is less than nameplate capacity bringing down the average capacity credit for the combined facility. The figure shows analysis for projects with 1.0 solar to battery and 1.5 solar to battery projects. The y-axis is the capacity credit as a % of the total nameplate capacity of the facility (battery and solar MW). The x-axis represents only battery capacity. While the batteries provide additional capacity credit in the 1.5 scenario, the solar makes up a larger percentage of the project and lowers the overall capacity credit of the total project. At the highest penetration level, the solar capacity provides substantially less value so the two scenarios merge.

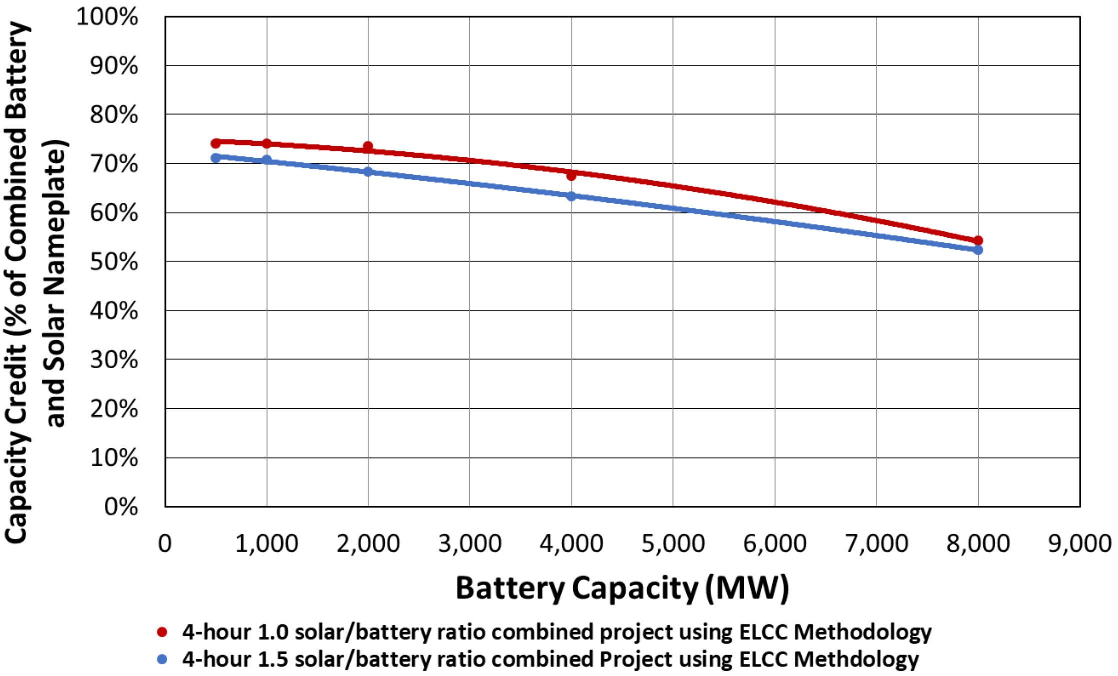

Figure 8: Combined Solar/Battery Capacity Credit as a Function of Solar/Battery Ratio

The capacity credit for these combined configurations was quantified for both a low solar penetration (500 MW) base case and a higher solar penetration base case (4,282 MW). As expected, the high solar base case initially confers more capacity credit to storage. However, starting at a higher solar penetration means that the additional solar being added with the combined projects provides less capacity credit. These effects essentially offset for the particular penetrations analyzed and the capacity credit of the combined projects is very similar for the low and high background solar scenarios as shown in Figure 9.

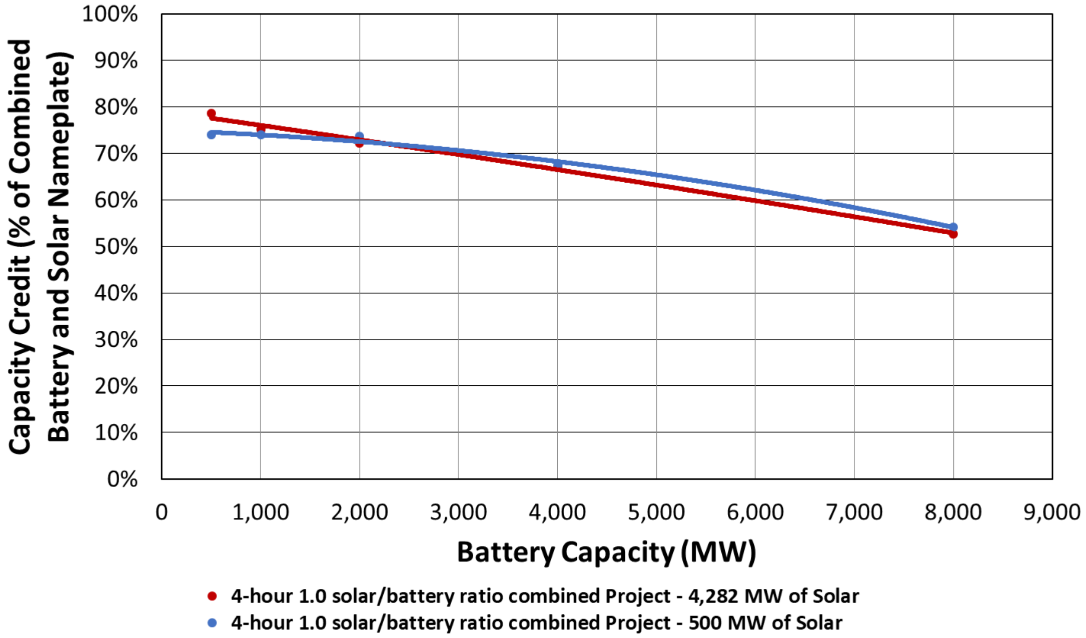

Figure 9: Combined Solar/Battery Capacity Credit as a Function of Background Solar[3]

To isolate the reduction in battery capacity credit due to the charging restriction, separate cases were simulated where the incremental solar and battery were not linked. A coupled battery and solar project that was restricted, forced the battery to only be charged by the solar resource it was paired with whereas the no restriction case allowed the battery to be charged from the grid. These cases were only performed for the 500 MW background solar scenario. Figure 9 highlights the gap in capacity credit between charging restricted configurations and unrestricted configurations which is only significant at the higher battery penetration levels as there are more days when the battery is required. With a higher ratio of solar to battery, the gap between charging restricted and unrestricted is smaller.

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[3] Note that the 4,282 MW solar case is using the Capacity Value Methodology while the 500 MW solar case is using the ELCC Method.

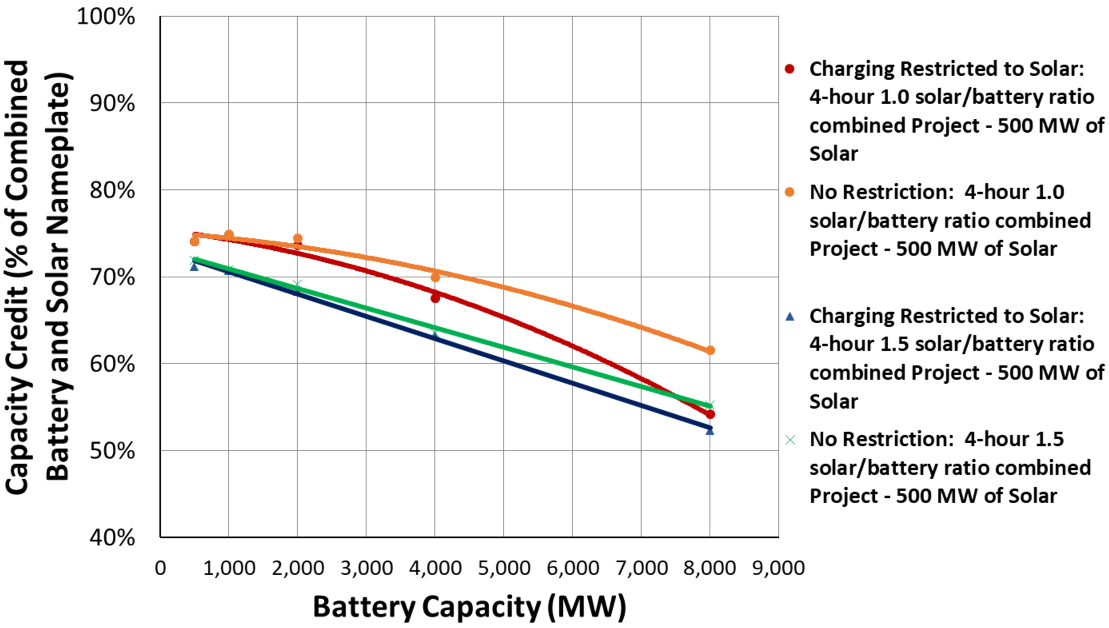

Figure 9: Charging Restriction Capacity Credit

CONCLUSIONS/SUMMARY

In general, the results show that 2,000 MW of 4-hour storage will receive 100% capacity credit and that the average capacity credit of a 4,000 MW storage portfolio is still approximately 90%[4]. The 'Preserve Reliability' scenario provides slightly more capacity credit than the 'Economic Arbitrage' dispatch strategy. The 2-hour storage is significantly limited with even the first 500 MW providing less than 100% capacity credit. If some operating reserves were assumed to be preserved during a firm load shed event, some short duration storage could provide full capacity credit. The 6 and 8-hour storage provided substantially more capacity credit than the 4-hour storage as expected.

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[4] All capacity credits quoted are the average of the battery portfolio being analyzed. The incremental capacity credits could be inferred from the average values.

APPENDIX

RESULTS OF STAND-ALONE STORAGE

ELCC vs Capacity Value Methodology

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	Base (4,282 MW)	4	Grid	Preserve Reliability	ELCC	100.0%
1000	Base (4,282 MW)	4	Grid	Preserve Reliability	ELCC	100.0%
2000	Base (4,282 MW)	4	Grid	Preserve Reliability	ELCC	99.22%
4000	Base (4,282 MW)	4	Grid	Preserve Reliability	ELCC	90.02%
8000	Base (4,282 MW)	4	Grid	Preserve Reliability	ELCC	72.44%
500	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100.0%
1000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100.0%
2000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100.0%
4000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	94.4%
8000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	73.5%

Preserve Reliability vs Economic Arbitrage

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100%
1000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100%
2000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100%
4000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	94.4%
8000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	73.5%
500	Base (4,282 MW)	4	Grid	Economic Arbitrage	Capacity Value	100%
1000	Base (4,282 MW)	4	Grid	Economic Arbitrage	Capacity Value	98.4%
2000	Base (4,282 MW)	4	Grid	Economic Arbitrage	Capacity Value	96.4%
4000	Base (4,282 MW)	4	Grid	Economic Arbitrage	Capacity Value	85.6%
8000	Base (4,282 MW)	4	Grid	Economic Arbitrage	Capacity Value	68.3%

Capacity Credit of Varying Durations

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration (Hrs)	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	Base (4,282 MW)	2	Grid	Preserve Reliability	Capacity Value	98.11%
1000	Base (4,282 MW)	2	Grid	Preserve Reliability	Capacity Value	89.77%
2000	Base (4,282 MW)	2	Grid	Preserve Reliability	Capacity Value	81.13%
4000	Base (4,282 MW)	2	Grid	Preserve Reliability	Capacity Value	64.94%
8000	Base (4,282 MW)	2	Grid	Preserve Reliability	Capacity Value	48.13%
500	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100.0%
1000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100.0%
2000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	100.0%
4000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	94.4%
8000	Base (4,282 MW)	4	Grid	Preserve Reliability	Capacity Value	73.5%
500	Base (4,282 MW)	6	Grid	Preserve Reliability	Capacity Value	100.00%
1000	Base (4,282 MW)	6	Grid	Preserve Reliability	Capacity Value	100.00%
2000	Base (4,282 MW)	6	Grid	Preserve Reliability	Capacity Value	100.00%
4000	Base (4,282 MW)	6	Grid	Preserve Reliability	Capacity Value	100.00%
8000	Base (4,282 MW)	6	Grid	Preserve Reliability	Capacity Value	90.71%
500	Base (4,282 MW)	8	Grid	Preserve Reliability	Capacity Value	100.00%
1000	Base (4,282 MW)	8	Grid	Preserve Reliability	Capacity Value	100.00%
2000	Base (4,282 MW)	8	Grid	Preserve Reliability	Capacity Value	100.00%
4000	Base (4,282 MW)	8	Grid	Preserve Reliability	Capacity Value	100.00%
8000	Base (4,282 MW)	8	Grid	Preserve Reliability	Capacity Value	94.43%

Capacity Credit 4-Hour Resources with 500 MW of Solar

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration (Hrs)	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	500	4	Grid	Preserve Reliability	ELCC	100.00%
1000	500	4	Grid	Preserve Reliability	ELCC	98.01%
2000	500	4	Grid	Preserve Reliability	ELCC	96.79%
4000	500	4	Grid	Preserve Reliability	ELCC	89.54%
8000	500	4	Grid	Preserve Reliability	ELCC	70.40%

Capacity Credit 4-Hour Resources with 1% Operating Reserves Maintained

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration (Hrs)	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	4,282	4	Grid	Preserve Reliability	Capacity Value	100.00%
1000	4,282	4	Grid	Preserve Reliability	Capacity Value	100.00%
2000	4,282	4	Grid	Preserve Reliability	Capacity Value	100.00%
4000	4,282	4	Grid	Preserve Reliability	Capacity Value	100.00%
8000	4,282	4	Grid	Preserve Reliability	Capacity Value	79.40%

RESULTS OF COMBINED BATTERY/SOLAR PROJECTS

Capacity Credit of Combined Solar/Battery with 1.0 Ratio

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration (Hrs)	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	4,782	4	Solar	Preserve Reliability	Capacity Value	78.58%
1000	5,282	4	Solar	Preserve Reliability	Capacity Value	75.13%
2000	6,282	4	Solar	Preserve Reliability	Capacity Value	72.19%
4000	8,282	4	Solar	Preserve Reliability	Capacity Value	67.18%
8000	12,282	4	Solar	Preserve Reliability	Capacity Value	52.75%

Capacity Credit of Combined Solar/Battery with 1.0 Ratio (500 MW of starting solar)

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration (Hrs)	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	1,000	4	Solar	Preserve Reliability	ELCC	74.00%
1000	1,500	4	Solar	Preserve Reliability	ELCC	74.00%
2000	2,500	4	Solar	Preserve Reliability	ELCC	73.61%
4000	4,500	4	Solar	Preserve Reliability	ELCC	67.52%
8000	8,500	4	Solar	Preserve Reliability	ELCC	54.21%

Capacity Credit of Combined Solar/Battery with 1.5 Ratio

Battery Capacity (MW)	Solar Capacity (MW)	Storage Duration (Hrs)	Charging Source	Dispatch Strategy	Method Used	Capacity Credit
500	1,250	4	Grid	Preserve Reliability	ELCC	71.14%
1000	2,000	4	Grid	Preserve Reliability	ELCC	70.74%
2000	3,500	4	Grid	Preserve Reliability	ELCC	68.31%
4000	6,500	4	Grid	Preserve Reliability	ELCC	63.29%
8000	12,500	4	Grid	Preserve Reliability	ELCC	52.32%

DATA INPUTS AND ASSUMPTIONS

The simulations were performed using a SERVM Database provided by SPP that was already populated with generators and load for the 2019 Study Year. Before the capacity credit simulations were performed, Astrapé made changes to the SPP database to convert the study to an economic study versus simply must running the generation fleet to serve load. This allows all thermal generators, hydro, storage resources and demand response resources to be dispatched economically to load. Thermal generators are given heat rate curves, minimum generation levels, ramp rates, minimum up and down times, and start up times. These resources were also provided a fuel and variable O&M cost. Hydro resources are modeled with monthly energies and dispatched to shave the peak. Storage resources are modeled with maximum charge and discharge capacities, storage duration, and round-trip efficiency.

Load Shapes

Multiple load shapes representing weather years from 2012 to 2017 were included for each zone for this study and were all given equal probability. These load shapes were scaled to a similar base year and then further scaled so that the average winter peak, average summer peak, and average total energy matched the 2019 SPP forecasted data.

Solar Shapes

The solar shapes used in the study were based on solar shapes created by SPP. Each of solar shape in the database was tied to a weather year. The 4,282 MW of solar were modeled by 60 units across the different SPP zones with an average capacity factor of 22%.

In the scenarios modeling the combined battery and solar projects, the solar profiles in SERVM were adjusted by applying a multiplier of 1.2 to the output from 11:00 A.M. to 3:00 P.M. which represents the clipping assumed on the solar profiles. This was done to properly model the additional benefit gained by the solar/battery combo being DC-DC coupled which allows the battery to charge from the solar before it is clipped.

Economic Load Forecast Error

For each weather year simulated, the following economic load forecast error multipliers and probabilities were applied. This introduces additional variability above the weather on loads[5] .

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[5] While the weather shapes and economic forecast error introduce a reasonable amount of load variance, because the system is targeted to 0.1 on the outset, the economic load forecast assumptions do not significantly drive the analysis.

Load Uncertainty (%)	**Probability (%)**
-4	7.26
-2	24.10
0	37.27
-2	24.10
4	7.26

Iterations

Each case was simulated using 6 different weather years and 5 different load forecast errors with varying amounts of generator outage iterations on a case by case basis to achieve convergence.

Operating Reserves

Consistent with SPP's LOLE Study, the operating reserves of the system were allowed to deplete to 0 MW rather than always maintain some level of operating reserves during firm load shed events.

If there was an assumption that some level of operating reserves would always be maintained during firm load shed events in the modeling, for example 200 MW, then any storage device no matter the duration up to that first 200 MW limit would be able to provide 100% capacity credit. This presents a niche opportunity for batteries because a storage device can sit fully charged at 0 output and never operate but still meet operating reserve requirements and provide capacity credit. This was not assumed for this Study.

Battery Dispatch

SERVM allows batteries to be dispatched for economic arbitrage in a way that always preserves reliability. In the economic arbitrage operation, the battery is optimizing economic benefit which may allow the battery to not always be fully charged during high net load peak hours. The preserve reliability option optimizes around reliability and the battery will be fully charged for peak periods. In addition, the battery is the resource that is called last in the dispatch stack making its energy limited characteristics more reliable.