The Electricity Journal 30 (2017) 1–5

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/tej

How hydropower enhances the capacity value of renewables and energy efficiency

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ABSTRACT

One of the ways that hydropower contributes to reducing carbon is by enhancing the ability of new resources, including renewables, to meet peak loads. An analysis concludes that the hydropower system can triple the capacity value for Columbia Gorge wind from initially low values and increase the capacity value of Southern Idaho solar by a factor of 10. Energy efficiency has the highest overall capacity value relative to average energy.

1. Introduction

As utilities and policy leaders explore and invest in strategies to reduce carbon and other emissions, it is important to recognize that not all power systems require the same solutions. The Northwest is unique in many ways, but the dominant role of hydropower enables one of the cleanest power systems in the world. There are at least three characteristics of hydropower that contribute to reducing emissions.

First, of course, is the fact that hydropower is essentially free of emissions.[1] Second, hydropower is also a relatively low-cost resource for providing balancing reserves, which are used to follow minute-to-minute fluctuations in loads and in wind and solar generation. Balancing reserves have been increasing recently due to the rise in wind and solar penetration. A thermal plant can provide a similar service but not as easily or as cheaply as a hydropower plant. For this reason, Northwest power operators generally hold balancing reserves on the hydropower system rather than on thermal plants, thus reducing carbon emissions.

The third clean energy characteristic is the storage value of hydropower. Energy associated with any resource, including wind, solar, and energy efficiency, can be effectively saved by reducing generation at a hydropower facility, leaving water in a reservoir for generation at a later time. This feature is associated with two sources of value: first, it can improve the fundamental economics of any resource, including renewables and energy efficiency, by effectively moving energy to higher-priced hours, and secondly, by potentially reducing the amount of additional peak generating capacity needed to maintain adequacy. It is this last function – the additional capacity gained by integration with the hydropower system, referred to as hydropower capacity storage – which is analyzed in this article.

Like a traditional battery, a hydropower system can save energy and generate it later. Unlike the case of traditional batteries, however, there are many other constraints on the operation of the hydropower system. Because dams are operated for multiple purposes, they need to fulfill obligations for flood control, irrigation, fish migration and spawning, transportation, and recreation. Taken together, these obligations limit the storage potential under certain conditions during certain times, days, seasons, and years. The essential point is that the hydropower system has considerable storage potential[2] at some times and at other times it is limited or nonexistent. Because of these many complicated operating rules, the best way to assess the storage value of the hydropower system is to run models that simulate its operation over thousands of possible future conditions.

2. Capacity

The Northwest Power and Conservation Council has adopted a specific adequacy standard for the Pacific Northwest, which requires a probability of 5% or less of having to curtail load at any time during a future year because of insufficient generating resources. This metric,

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[1] There is a possibility that the reservoirs behind dams may, in some instances, release greenhouse gases, in particular methane. These releases are likely to be relatively small in the Northwest especially compared to coal and gas plants. https://www.nwcouncil.org/media/7490995/p3.pdf.

[2] The Columbia River hydroelectric system has a considerable amount of storage capability in terms of energy but not so much relative to the average volume of water that flows down the river. The entire useable storage of the U.S. portion of the Columbia River hydroelectric system would generate (very rough estimate) about 2000 average-megawatts of energy, which is a considerable amount of energy. However, U.S. storage reservoirs can only hold about 15% of the annual average volume of water that flows through the system.

http://dx.doi.org/10.1016/j.tej.2017.04.014

commonly referred to as the annual loss of load probability (LOLP), is evaluated for the power supply five years into the future based on a model of the Northwest power system and published assumptions. The model simulates the operation of the power system 6160 times, with each simulation drawing from different combinations of future unknown factors – temperatures, river flows, wind generation and forced outages. Any simulation in which the load exceeds generation at least one time over the course of the year is counted as an adequacy miss. The annual LOLP is calculated by dividing the number of adequacy misses by the total number of simulations. For example, a result with 308 misses produces an LOLP of 5% (308/6160), which would be the minimum adequacy required by the standard.

This definition for adequacy allows power planners to calculate the capacity value of adding different resources to the existing power system. More precisely, the addition of any new resource should reduce the amount of additional capacity needed to meet the adequacy standard. For example, using a simulation model, the addition of 1000 MW (nameplate) of a wind resource is shown to generate 300 average megawatts (aMW) of energy and to reduce the amount of capacity required to meet the adequacy standard by 100 MW. In this case the addition of 1000 MW (nameplate) of wind reduces the capacity requirements by 100 MW, which means that the wind's integrated capacity value is 10% of its nameplate capacity. The integrated capacity value for wind is higher than the expected capacity contribution from wind generators without the interaction with hydropower system.

It should be noted that these capacity values are not universal and do not necessarily apply to any other power system or even the same system with a different resource mix. The capacity value is uniquely determined based on how a resource interacts with loads and other resources in the Northwest power system.[3]

A simple method for approximating capacity values can be illustrated graphically. Fig. 1 is based on a hypothetical model run to determine the capacity required to achieve a 5% LOLP. Suppose a future year's power supply is simulated stochastically 200 times and for each simulation the largest curtailment hour is graphed, sorted from highest (left) to lowest (right).[4] The largest curtailment hour has a shortage of 1500 MW and the smallest has a shortage of less than 100 MW. In total, there are 18 misses (out of 200) which represents a 9% loss of load probability. In order to achieve a 5% LOLP, the number of misses would have to be reduced to 10 (10/200 = 0.05). One way to achieve that target would be to add 500 MW of capacity to the system, thus eliminating misses 11 through 18 which are all 500 MW or less. Another way to state this conclusion is that this system requires 500 MW of capacity to achieve adequacy.

A more general approach replaces the number of misses on the horizontal axis with loss of load probability (LOLP) and the bar chart with a line as pictured in Fig. 2. Similar to Fig. 1, the figure shows that an increase of 500 MW of capacity is required to reduce the loss of load probability to 5%. Now suppose a new resource is added and the loss of load curve changes from A to B. With the new resource only 300 MW are required to achieve the adequacy standard, which means it has added 200 MW of effective capacity to the system. This provides a practical method for estimating the integrated capacity value of adding any resource to an existing power system. It is defined as *integrated* capacity because the resource is integrated into the power system, allowing the hydropower system to utilize whatever storage it has to avoid a loss of load.

[3] For more about the Northwest power system and how others calculate capacity values see Keane et al. (2010), NERC (2011), Milligan and Porter (2005), Rogers and Porter (2010), and the Seventh Power Plan.

[4] Each simulation is done with different combinations of temperature (demand), river flow, wind speeds, and forced outage conditions in the year being analyzed.

3. Hydropower system capacity storage

In order to measure the added capacity value provided by the hydropower system's storage, it is necessary to estimate the standalone capacity value of a new resource and compare that to the integrated capacity value. The *standalone* capacity is estimated by assuming that hydropower operations are not changed by the addition of the new resource. It can be estimated for non-dispatchable resources (wind, solar, and energy efficiency) by determining resource output during each of the loss of load events in Fig. 1 and reducing the loss of load accordingly. This is illustrated in Fig. 3.

This figure starts on the left with a ranking of peak hour curtailments similar to Fig. 1. The loss of load record changes when the wind resource happens to generate in the exact same hour as a loss of load event. Suppose a wind resource would have generated power during the 2nd, 5th, 8th, and 12th events represented by the shaded areas in the bars. Re-sorting the loss of load events from high to low produces a lower curve C, which is used to calculate the standalone capacity value of the additional resource without the benefit of the hydropower system.

The basic theory is summarized in Fig. 4. The base case (A) shows that 500 MW of capacity are required to achieve a loss of load probability of 5%. Adding a particular resource to the power system (B) reduces that need to 300 MW which means that the resource provides 200 MW of integrated capacity. Without the benefit of hydropower storage (C), the resource only adds 80 MW of standalone capacity (500–420). In summary, the resource adds 200 MW of capacity, of which 120 MW can be attributed to the effects of the storage of the hydropower system.

4. Results

The method described above was used to estimate both the integrated and standalone capacity values of several resources. Model simulations were performed for the Northwest power system and the results are reported in Table 1. The wind resource was located in the Columbia Gorge on the border of Washington and Oregon and the solar resource was a photovoltaic solar farm in Southern Idaho. Energy efficiency and a single-cycle natural gas plant are also included. Consistent with the theory, the integrated capacity is equal to the sum of standalone capacity and hydropower capacity storage.

There are several important results in this table, starting with the fact that the average energy produced from wind and solar resources is well below their nameplate capacities. This is because wind does not always blow and the sun doesn't always shine (in other words, their generation is limited by fuel supply). The annual energy production is about 30% of nameplate for wind and about 26% for solar.

For each resource the integrated capacity is greater than the standalone capacity and for some resources, much greater. Integrated capacity is 40% higher than the standalone capacity for energy efficiency (1184 MW compared to 713 MW), three times higher for wind (286 MW compared to 90 MW) and 10 times higher for solar (1157 MW compared to 109 MW). The interactions between these resources and the hydropower storage system adds significant capacity.

There is also a need to standardize the results so that different-sized resources can be compared. One way to do that is to calculate the ratio of integrated capacity to nameplate capacity for each resource. These ratios are presented in Table 2 for each resource except energy efficiency because it does not typically have a nameplate capacity.

As expected, investments in wind and solar provide capacity values, but in widely different proportions. Solar provides 0.39 MW of integrated capacity for each MW of nameplate capacity while wind only provides 0.10 MW of integrated capacity. In other words, each megawatt of solar adds four times as much net capacity to the system as a megawatt of wind. Because the standalone capacity is very similar for the two renewable resources, the difference in their integrated capa-