

The Role of Renewable Energy Sources in the Capacity Markets of Island Electric Systems

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Introduction

Most of the world's electric markets enjoy some level of interconnection with neighboring markets. This interconnection allows access to other sources of, and customers for, electric power, as well as generating capacity that can increase the reliability of their own system. Island nations generally do not enjoy the advantages of interconnected markets, and instead provide energy, the kilowatt-hours used by electric customers, and capacity, the capability to generate energy, by themselves. The provision of reliable electric service is more difficult because of this isolation. Growing emphasis on sources of renewable energy, such as solar photovoltaic and wind energy may make the problem even more complicated. While these sources provide capacity, they also provide energy intermittently, that is, when the sun shines or the wind blows, respectively, and do not provide energy on demand.

Because the value of electric capacity is similar to an insurance policy, we can examine the effects of different capacity market compositions and analyze their effects on the provision of reliable electric service through Monte Carlo simulation. In this paper, we simulate the effects of intermittent resources, such as solar photovoltaic and wind energy, and the capacity and disposition of the fossil fueled generating fleet to examine the marginal effects of capacity on reliability. Through these simulations, we analyze the effects of additional fossil fueled capacity on the reliability of electric service. We also examine the effects of intermittent resources such as solar and wind energy on the reliability of electric service. These simulations can aid regulators and operators in determining the optimal amounts of fossil-fueled and renewable capacity to achieve desired levels of service reliability.

Mayer (2000) surveyed 37 island electric systems (including the members of Carilec) about the characteristics and reliability of their system. The information gathered included peak load, size of the largest generating unit, installed reserve margin, whether the utility has access to hydropower, and whether the utility conducts simulations to determine adequacy of generating capacity. He further asked whether the utility had sufficient installed capacity to meet its peak load if it lost its largest generating unit. Mayer found that larger utilities (over 100 MW) nearly always met this criterion, and that reserve margin tended to increase with the size of the largest generator, holding load equal, and fall with an increase in peak load, holding the size of the largest generating unit equal. Further, Mayer found that most utility systems did not employ simulation techniques in capacity planning, and thus were unable to calculate reliability measures such as loss of load probability for their system.

Probabilistic measures such as loss of load probability and energy not served allow a utility to assess the likelihood of system deficits. Loss of load probability (LOLP) is one commonly used measure. For example, if a system simulation shows that in 1000 simulations of a particular season, say the summer, 50 simulations resulted in some inability of the system to serve load, then the system would have a LOLP of 50/1000, or 5%. If the simulations are reasonable representations of what might happen in the

future, then the system is said to have a 5% chance of not being able to serve all load. However, LOLP treats all loss of load events as equally harmful to the welfare of the customers of the system, regardless of whether the system shortfall is 100 MW or 1MW. Presumably, the 100 MW deficit would be more of a hardship to the customers. Therefore, a reliability measure such as energy not served, the sum total of all energy not served by the system in a simulation year, would be a more useful measure of customer welfare. We have used this measure in our paper.

We have generalized this work to study the marginal effects of the capacity reserve margin and the concentration of electric generation on reliability. Further, electric systems around the world are assessing the feasibility of the integration of renewable energy sources into their generating portfolios. We study how these marginal effects change when wind and solar resources are integrated into the system.

Simulation Model of System Reliability

We have built a Monte Carlo simulator to test various configurations of a simplified electric generation and distribution system with an expected peak load of 100 MW and assess the reliability of that system. For the tests, 1000 iterations, or possibilities of electric load and generation availability, were simulated for each system configuration, and the reliability metric for each system configuration is recorded. System configurations tested varied by the type of renewable generation utilized (wind, solar, or none), the installed capacity reserve margin:

$$\frac{\text{Installed Capacity (MW)}}{\text{System Peak Load (100 MW)}} - 1$$

and the diversity of the generating portfolio. The most concentrated portfolio studied was where the island relied on a single generating unit for electricity. The least concentrated portfolio studied consisted of 20 identical generating units. For the purposes of this study, we have assumed that the volatility of the load is 10%. Additional assumptions were made about the reliability of the renewable capacity. The wind generation is assumed to have a capacity factor of 36%. That is, the energy produced by the listed capacity is 36% of what it would be if sufficient wind was available 24 hours per day. For the solar generation, we have assumed that the solar energy is available during daylight hours only, with an overall capacity factor of 21.7%. The capacity factors for the wind and solar generation are taken from the modeling assumptions used by the United States Department of Energy. The same basic load curve was used for as a basis for all of the simulations and is shown in Figure 1. The peak load of the curve is 100 MW, and the effective load factor is 50%. Therefore, in an expected model year, the system serves 438 GWh of energy.

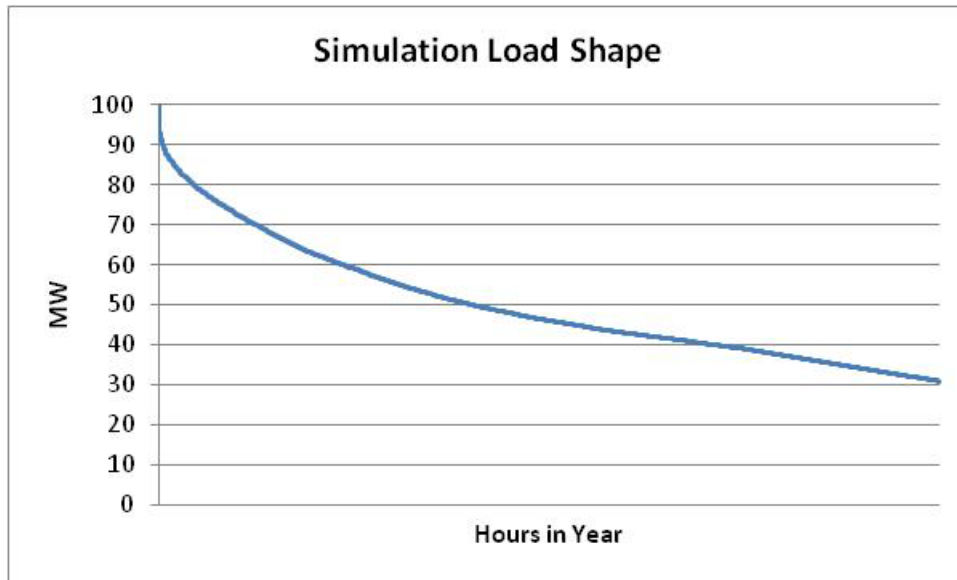


Figure 1: Base Load Shape Used in Simulation

The simulation begins by either increasing or decreasing the base load by 10% (the assumed volatility of the load) times a standard normal random variable. This means that 95% of the time, the load is less than 20% higher or lower than expected. Next, each configuration of the generating portfolio is dispatched against this load shape. Each individual generating unit in turn is checked for its availability during each hour, and any available units are dispatched to serve the electric load for that hour. The availability factors for the fossil fueled units were assumed to be 60%, 70%, and 80% for different model runs. The outages for individual oil fired generating units are assumed to be independent of one another. After all available units are exhausted; any remaining load is tabulated as energy not served (ENS), which is the reliability metric used in this study. The model output expresses this ENS as a percentage of the annual energy load. An ENS value of 10%, for example, would mean that 10% of the customer load in a given year was not served by the system.

Simulation Results

The results of the base case simulation are shown in Figure 2. For this simulation, the fossil fueled generating units were assumed to have an availability factor of 70%. That is, the units were available to generate electricity 70% of the time. The model makes no distinction between units that are unavailable due to planned outages or to unplanned ones. While the absolute level of ENS changed with different availability levels for the fossil units, the marginal effects remained largely unchanged. This figure shows the impact of changes in capacity margins and changes in the diversity of the generation fleet on the reliability of the electric system. Increasing reliability is shown here as a decrease in the percentage of ENS. The results from these simulations show that reliability can be increased in two ways. The system can either increase the amount of generating capacity above peak load, the reserve margin, or it can increase the diversity of the generating portfolio. Spreading the electric load over more generating units, then, can act as substitute for additional operating capacity. For example, an island system served by 10 identical generators with a total installed capacity equal to the peak load (no reserve margin)

leaves roughly 5% of the system load not served, on the average. Alternatively, the same system served by 4 identical generating units with installed capacity equal to 130% of peak load (a capacity reserve margin of 30%) leaves the same amount of system load not served, about 5%. This effect can be seen as the diagonal line running from 10 generators to 4 on the x-axis of Figure 2. Along this line, reliability is relatively constant, yet, the reserve margin is increasing while the concentration of the generating fleet is increasing. In this case, the effect from the increase in generating system diversity compensates for the decrease in capacity reserve margin to maintain system reliability. Therefore, systems should not rely merely on capacity reserve margin to ensure system reliability, as a system with greater diversity requires lower reserve margins to maintain reliability standards.

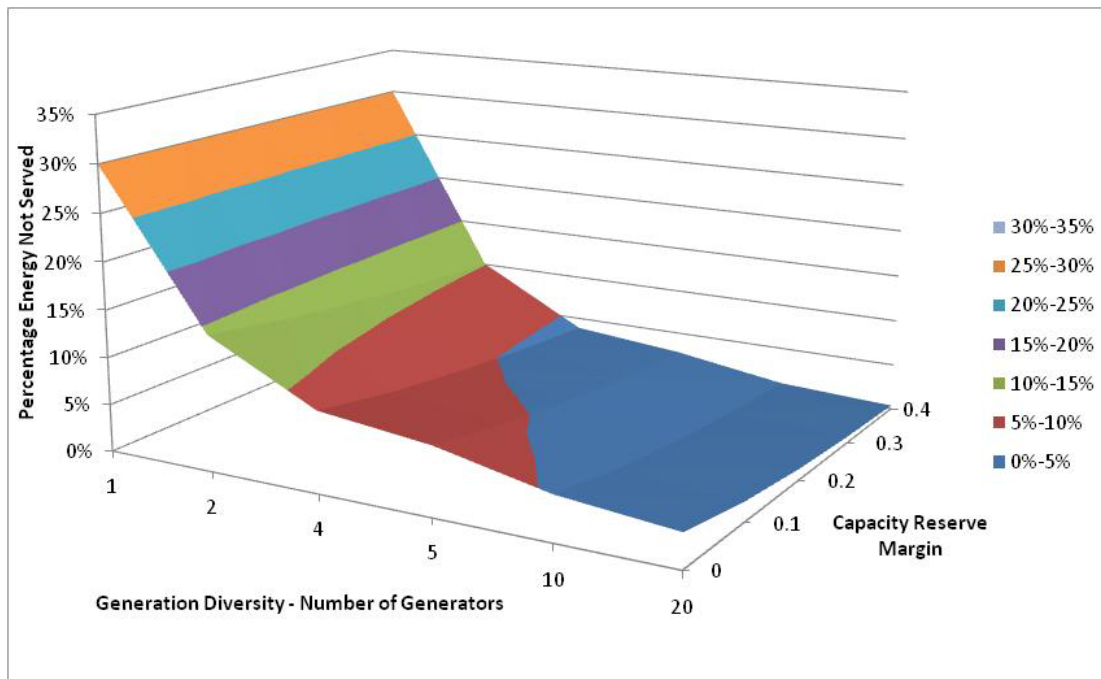


Figure 2: Reliability of Electric System with No Renewable Generation

Figure 2 also shows that the marginal value of the capacity depends on a number of factors. Initial capacity above the minimum required to serve load greatly increases reliability. However, successive capacity additions have declining marginal value, as the slope of the plane decreases at a decreasing rate. Similarly, adding a second generating unit increases reliability significantly, but successive efforts to diversify have declining marginal value.

Figure 3 shows the same system, but with 5 MW of solar capacity added to the portfolio. Note that the overall installed capacity of the system remains the same (capacity of 100%, 110%, 120%, 130%, or 140% of peak load), so that the renewable generation displaces some of the fossil fueled generation.

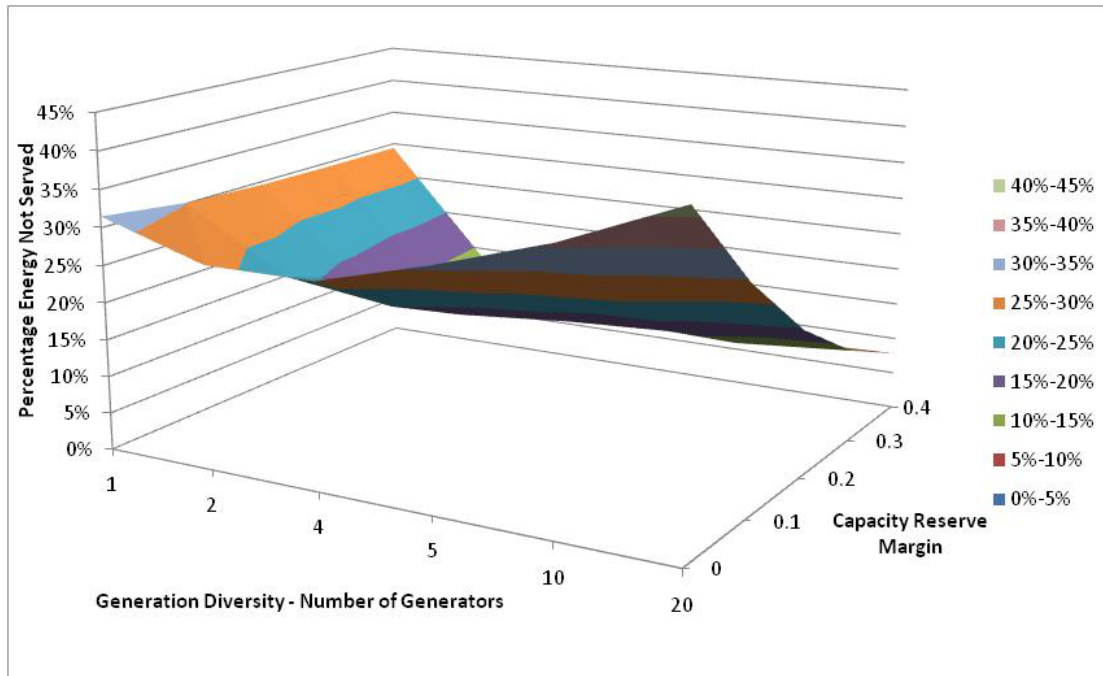


Figure 3: Reliability of Electric System with Solar Generation

The effect of the solar resource on a system that has little excess capacity is to decrease reliability significantly, even with diversity in the generating fleet. This is due to the intermittent nature of the solar resource, and the fact that the solar capacity produces energy only about 22% of the time, despite the fact that this production occurs during the daylight hours when electric loads are higher. As additional fossil capacity is added to the system, shown as an increase in the reserve margin, system reliability increases rapidly. However, the marginal effect of diversifying the system has changed. In the base system, greater diversity always increased reliability, but in this case, reliability can increase or decrease.

Figure 4 shows the same system with 5 MW of wind capacity added to the portfolio. As with the solar case, this wind generation displaces a portion of the fossil fueled generation.

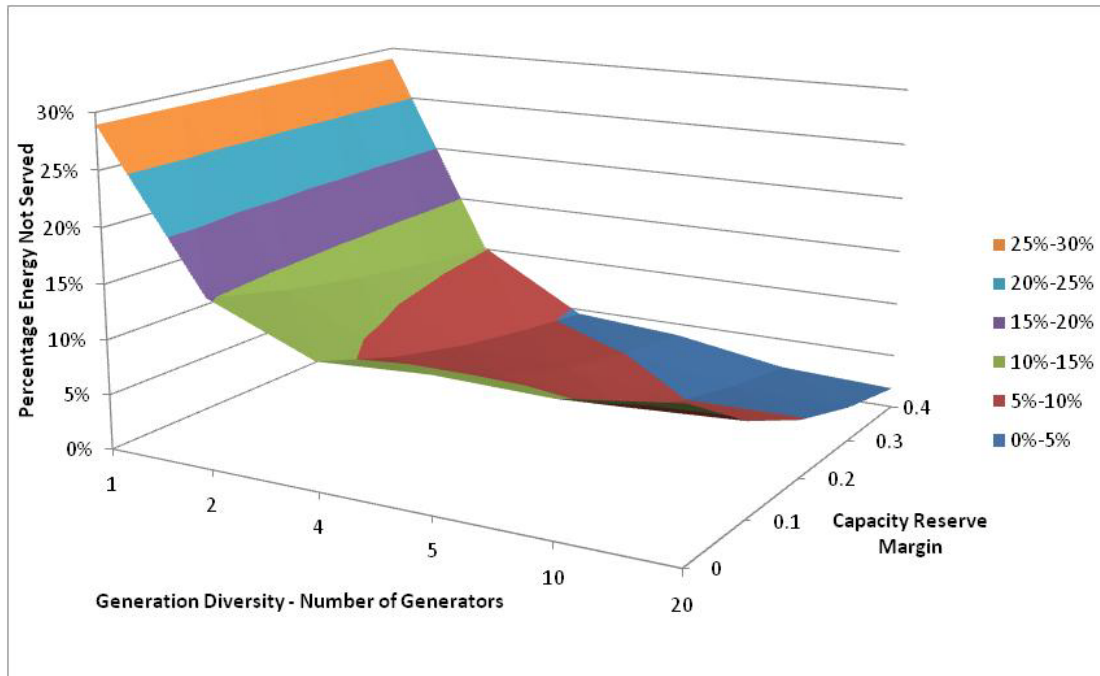


Figure 4: Reliability of Electric System with Wind Generation

The effects of the wind generation are similar to the effects of the solar generation, just not as pronounced. The availability of the wind generation is higher than solar, but the energy generated can come at any time, and thus is equally likely to be available at night as during the day. Similar to the solar case, the problems with system reliability are most pronounced when the system has little excess capacity. As the amount of capacity increases, the increase in system reliability looks more like Figure 2, the base system. Further, this marginal value depends on many factors such as the type of renewable generation deployed, the degree of diversification in the generating base, and the capacity reserve margin maintained. Therefore, it is critical for any utility seeking to provide a particular level of reliability examine all factors to determine the least cost method of provision.

All else equal, then, the intermittent nature of renewable solar and wind energy makes it an imperfect substitute for dispatchable generation with regard to reliability. However, investment in renewable energy sources may be accompanied by opportunities to improve the distribution grid. For example, upgrades to the distribution grid may be necessary to facilitate the integration of the new resource, and these upgrades may convey the ancillary benefit of increased reliability in the form of reduced distribution losses or general failure of the distribution grid. This paper is concerned only with the failure of the generation system. Note that this analysis is one dimensional, focusing only on a reliability metric and neglecting other possible benefits of renewable generation. Because the price of electricity tends to be higher on island systems than electricity prices in the United States or Mexico, renewable resources may be better able to provide electric service at a reasonable price. Wind energy is competitive on the margin in only a few regions in the United States, yet may be more cost competitive in the Caribbean, depending on fuel prices and other operating expenses. Investments in renewable energy may also yield renewable energy certificates, or reduce the amount of carbon emissions if global energy policies to

promote renewable energy and reduce carbon emissions are implemented. Wind and solar generation do not require fuel, so they also allow the utility a hedge against volatile oil prices, as well as provide electricity generated from a local fuel source to increase the energy security of the island system.

Conclusions

The provision of reliable electric service is more difficult because of the isolation of island electric systems. These systems cannot rely on generating capacity outside its own borders and must supply all capacity within its system. Increasing system reliability, then, comes at additional cost. However, the utility has flexibility in determining the expenditures that are most cost effective. The utility can increase reliability by simply installing additional generating capacity. That is, by increasing its reserve margin. Alternatively, the utility may increase reliability by diversifying its generation fleet. This diversification may come at a cost beyond the installed cost of new generation if economies of scale are present, that is, if operating expenses per megawatt are decreasing as the size of the generating unit increases. If, however, the diversity is realized by locating multiple units within the same generating station, then these economies of scale might still be realized. If the utility is considering additional generating capacity to increase reliability, then the value of diversifying the system should be studied when making the determination regarding the proper size of the generating unit. The value of diversification may allow the installation of a smaller unit to achieve the desired level of reliability.

Growing emphasis on sources of renewable energy, such as solar photovoltaic and wind energy may make the problem even more complicated, due to the intermittent nature of these resources. It is clear from these simulations that an island contemplating the addition of renewable capacity should first have adequate dispatchable capacity to serve load. This way, any benefits of adding renewable energy resources are less likely to be outweighed by the costs of system reliability. However, simulation modeling is well-suited to help the utility and regulators determine the least cost solution to meet the policy goals of a reliable, reasonably priced service that incorporates any renewable energy requirements.

References

Mayer, Peter C. (2000). "Reliability economies of scale for tropical island electric power." *Energy Economics*, 2: 319-330.