Role of Energy Storage under Increasing Renewable Energy

UNIVERSITY of WASHINGTON

Final Report: EE 553

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Date: Mar 17, 2022

1. Introduction

As climate changes become a more serious problem worldwide, many countries and regions have dedicated themselves to reaching the zero-carbon electricity goal in the next few decades. To achieve this goal, they must consider producing carbon-free electricity. In other words, they need to increase the percentage of renewable energy sources in their energy profile. It is expected that wind, solar and hydroelectric will be the primary energy sources used to meet these targets. However, these energy sources have many operational challenges due to their different characteristics than conventional energy sources. The most critical challenge is that renewable energy sources will introduce high risks for system operators and increase the risk of the entire power system which leads to the threaten on the grid reliability. In conventional electricity markets, mechanisms such as reserves and capacity markets are used to help balance the system and maintain reliability. However, these mechanisms' abilities are questionable when more and more renewable energy sources are integrated. In terms of ancillary services, renewable energy sources bring significant additional needs for reserve.

Solar outputs change rapidly according to weather conditions and time of the day, while most of the time, it does not follow the demand pattern.Wind and hydroelectric power plants have similar issues. Hydroelectric and wind power plants have high energy production in wet (strong wind) years and low energy production in dry (weak wind) years. The changes can be even narrowed down to single days. The difficulty in forecasting makes system operators must install additional reservation capacity. So to solve the issues, energy storage and demand flexibility technologies are studied. This paper will be divided into several sections. Part 2 will describe the social and economic value of energy storage. In Part 3, solar energy storage and demand flexibility technologies will be discussed. Moreover, in Part 4, some technologies, methodologies, and policies are suggested for energy storage and demand flexibility with renewables. Lastly, in Part 5, a brief conclusion will be given with a flowchart to illustrate the development process of energy storage.

2. Value of Energy Storage

The value of energy storage can be categorized into three parts: energy value, capacity value, and ancillary services value. A high-level description of energy storage's value with renewable is that storage is the substitution of conventional fossil fuel plants. This means that it is expected to see a wide range of value. Storage should be deployed at different scales and be able to serve a significant amount of essential and different applications. A high-level summary of the services the storage should provide, listed in terms of scales, is shown in [1]. For energy value, it can create load shifts. Slide 13 in [3] shows that the storage can charge during the off-peak and discharge during peak hours to achieve a flatter net load shape.

The storage can smooth the load shape and the renewable energy output curves. Some large-scale energy storage will be valuable in reducing grid reinforcement and peak load shifting. Another value in terms of energy is reducing the curtailment of renewables. This value is increasing with more and more renewable energy integration. As described in the introduction section, most renewable generations, such as wind and solar, will have a particularly high production period. If, during those periods, the load is less than the supply, energy generated from wind and solar will be curtailed to balance the system. This is a waste of resources, and the waste increases with more and more renewable capacity installed. Energy storage will be a good solution for this issue. It can charge during the high production hours and discharge during the low production hours to reduce the curtailment. An example of peak demand reduction will illustrate the importance of value on absorbing renewable generation. When the system has no renewables, the Peak Demand Reduction Credit(PDRC) for storage is only about 2000 MW. However, this amount has increased fourfold when solar and wind penetration reaches 15%. By adding 6-hr and 8-hr grid-scale storage, the storage cost can be significantly decreased with increased renewable capacity installation since the other generation can be absorbed with long-duration storage, which matches the peak supply hours. The results from [7] demonstrate the positive feedback loop between peak storage and renewable generation capacity installed. It should be one of the most fundamental reasons energy storage is needed toward a 100% renewables profile.

Another value of storage is capacity value. This capacity value primarily refers to the value in reducing congestion and transmission network investment. This will be further described in the value of reserve later. The third aspect of the value of storage is the ancillary service value. This value refers to the value of frequency response, load shifting, and reserve. Frequency response is the best value for energy storage in current electricity markets. Right now, most frequency response services are done by thermal or combined gas turbine generators. Nevertheless, conventional fossil fuel generators are unsuitable for providing the frequency variation caused by renewable generation. The stochastic supply curve of renewable generation requires the frequency response to be quick and flexible. However, because of high minimum generation, limited ramp rate, and long preparation time for conventional generators, they will make the system into trouble. Most importantly, installing fossil fuel generators to balance renewable energy makes non-sense since it creates new pollution, which we do not want. So energy storage will take the responsibility. It is much more flexible. Different storage technologies satisfy all kinds of reliability services listed in [2] chapter 6.2.1.1. There is storage under 100 MW for regulation reserves and can respond to the request within a minute. The storage can also charge/discharge up to 3 hours for the non-spinning reserves. For the following reserves, there is storage up to 400MW that can hold for 3 hours.

The above clarified the value and services of storage. More importantly, some evaluation method should be developed to calculate the value of the storage that can emphasis its unique properties. For example, some storage, such as batteries, charging power, discharging power, and the energy rating is solid once the batteries are built. For this kind of storage, one can easily calculate the value as $/MW or $/MWh as conventional generators. However, there are also other types of storage, such as compressed air energy storage, whose charging and discharging power ratings are independent of each other, so It will be hard to calculate the value at the different periods and different storage stages. Also, other characteristics affect the calculation, such as self-discharging and battery lifetime. If the case of a highly integrated renewable energy system is considered, the calculation becomes more complex. For modern days, the most widely used method is called Levelized Cost of Storage(LCOS). LCOS is just an extension to the Levelized Cost of Energy(LCOE) expression. The expressions of LCOS and LCOE are identical. Like LCOE, LCOS calculated the break-even point to cover the storage's total cost. A specific equation can be found in [1] equation 1. As discussed in [1], LCOS has many drawbacks due to its simplicity, but this is still the first choice for the industry to compare and contrast the value of storage to other generation or reserve technologies.

One must notice that not all electricity markets worldwide are deregulated and have markets for reserves. Installing energy storage will be different in vertically integrated markets and deregulated markets. Fortunately, [4] concludes that the Energy Storage System(ESS) is beneficial for both markets. The saving increases when the output of renewable energy. Also, in both markets, ESS reduces the output from conventional energy. Furthermore, ESS reduces total investments in nuclear power and gas-fired peaking units. More importantly, as shown in [5]. ESS has positive effects on the revenue of current generations. [6] states that revenue is one of the incentives that many high-cost plants keep the capacity. However, with ESS, the high-cost plants can retire and build more renewable plants. As shown in the study of [5], gas plants will be forced to retire first when renewable storage is added. Also, the high-cost and high-pollution plants at peak hours will be retired since more storage will reduce the peak hour prices. However, [4] also concludes that the revenue from ESS is not able to cover its investments, and external support is needed.

3. Solar Storage Technologies and Demand Flexibility

The current technology for solar energy storage is for concentrated solar power plants(CSP). CSP allows the integration of Thermal Energy Storage(TES) units in the power plant. As listed in [8], some namable TES methods are two-tank indirect sensible heat storage, single-tank thermocline sensible heat storage, Latent heat storage, and Thermochemical heat storage. As concluded in [4], the storage cost is high and will result in a negative present value, as shown in [8]. However, as also shown in [8], the development of these storage technologies has already reached a level in which the cost is hard to decrease in configuration and system development. So reasonably, more and more storage is coming from user-side distributed PV systems. Studylike [9] has illustrated the benefits of integrating the demand-side storage into the grid. The user-side storage technologies are primary batteries. Lithium-ion batteries and Lead-acid batteries are the main types of storage used in residential and commercial loads. Like energy storage, user-side demand flexibility can provide additional ancillary service requirements created by renewable generation. However, since the demand-side storage is more distributed, some technologies such as residential demand response control and policies such as vulnerable consumer priority in administering system services described in [14] will make the demand flexibility more valuable.

4. Suggestions

It is clear that with the great value, variety of services, and well-developed technologies, energy storage should play a significant role in the power system. Especially with reducing curtailment and maintaining reliability, energy storage should not be optional but required in renewable integrated power grids. Nevertheless, as also described above, there are many limitations. So energy storage should be encouraged, and other supplementary mechanisms should be developed. Three strategies can be addressed to encourage building more energy storage:

1. Price-sensitive user-side renewable generation and storage
2. New methods of evaluation and accreditation storage capacity value
3. The spot market for energy storage

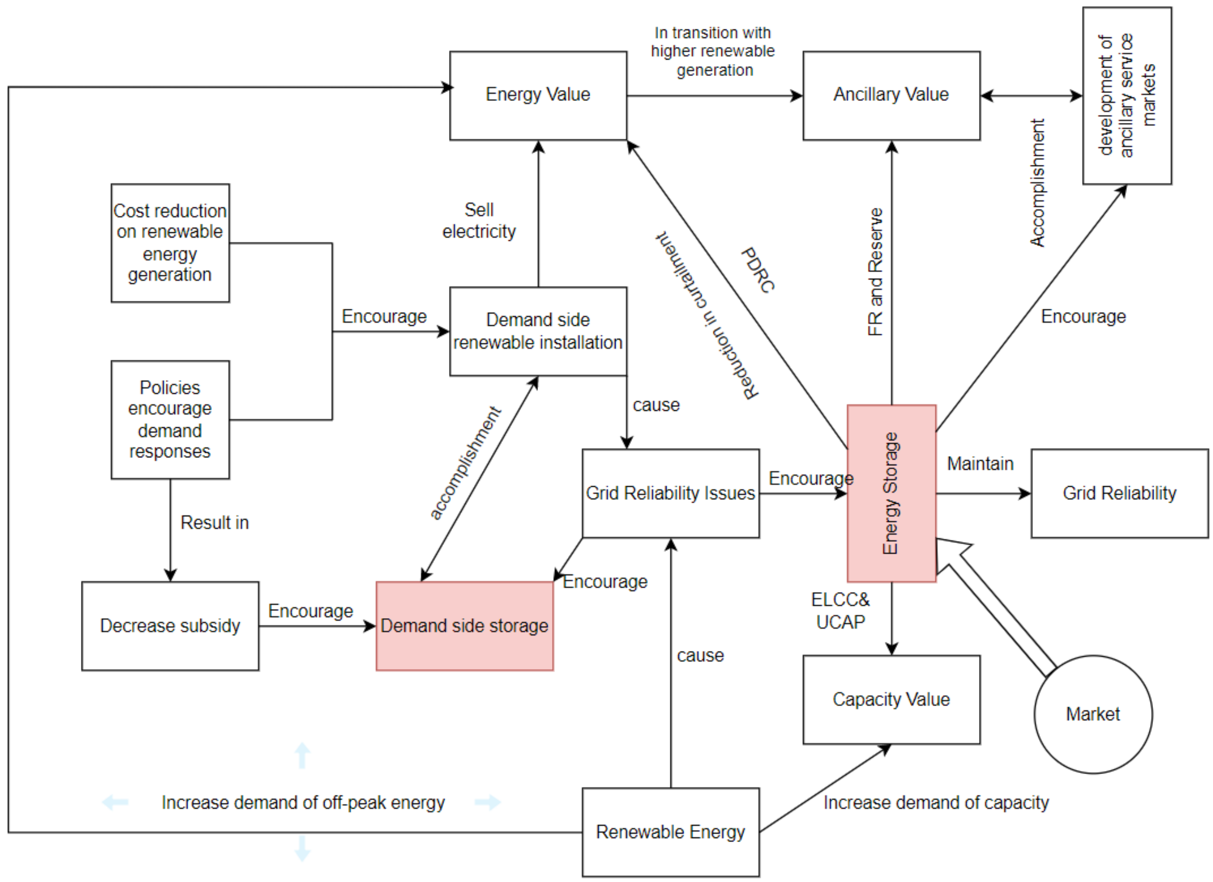
The first strategy is intuitive. There used to be many policies that encouraged users to install renewable energy generation, such as rooftop PV panels and small size wind turbines. With the technology development, the cost of installation is decreasing. With the subsidy from policies, many users start to allocate together and sell electricity to the grid to profit. This action should be encouraged since selling electricity can be viewed as a decrease in loads. However, with more and more generations installed, the user side starts to threaten the system's reliability. So now, many regions have decreased the subsidy to discourage users from installing more capacity. With zero marginal cost of renewable energy, It is reasonable to assume that selling electricity to grids will no longer be very profitable in the future, so one can imagine that the users will try to use as much as they generate. This willingness will create opportunities for user-side energy storage. A vivid example is the owner of an electric car with solar panels. Suppose the owner leaves home in the morning, returns home in the evening, and used to charge at dinner time, he/she will encounter peak hour tariffs. However, the owner's solar power peaks at midday when the electricity price is low. Suppose the owner chooses to sell electricity to the grid simultaneously as generating electricity at noon. In that case, he/she will get far less than if he/she saves the electricity generated at noon to charge his/her car when the electricity is at peak rates. The government should address policies to encourage users to install storage. For example, users will get a higher subsidy if they are willing to install storage while installing new PV capacities. Also, the market should give price incentives for users to perform load shifting. For example, a variable electricity rate should be used instead of a flat rate, so users will have the incentive to avoid using electricity during peak hours and save energy generated during off-peak hours. These two proposals are already implemented in some areas, such as California, which has a high percentage of solar power. From the report [10], there are very positive effects. So these policies are worth promoting. The second strategy is recommended mainly for storage capacity value.

Measuring the grid reliability contribution, in this paper it is referred to as the capacity value of energy storage, is critical and complex. The capacity value of a resource determines how much money the resource owner gets paid. As described in section one, many operators use LCOS to determine the value, which is over-simplified. Currently, many operators also use Effective Load Carrying Capacity(ELCC) to precisely measure the capacity value. This term is similar to the PDRC described for storage potential in peak demand reduction. However, one problem with ELCC, as shown in [11], is that the average value of ELCC will decrease rapidly as more energy storage is installed. So in the future, with high energy storage capacity, new capacity value calculation methods are needed. A better methodology developed in recent years may be the unforced capacity(UCAP) method. This method is suggested to apply to generators and also energy storage. The underline idea is letting energy storage participate in the capacity market so that the participants can manage risks.

Lastly, the third recommendation is to expand the spot market for energy storage. Currently, most energy storage uses long-term forward or future contracts in capacity markets. With increased uncertainty from more renewable generations, the price risks also increased. Nevertheless, it also means that day-ahead and real-time markets are economically profitable for energy storage. As explained in [1] and [13], arbitrage becomes one of the energy storage services. Even though the revenue gain is less than capacity markets right now, its economic potential is enormous in the future.

5. Conclusion

In conclusion, I summarized a flow chart for the development of energy storage. With more renewable energy, The demand for capacity and off-peak supply-load balancing will increase. Moreover, the increase in the energy value will end up with the increase in ancillary services such as reserves and frequency response. These requirements can all be done by energy storage units, and the effects will be more efficient with the demand side storage integrated.



Energy Value
In transition with higher renewable generation
Ancillary Value
development of ancillary service markets
Accomplishment
Cost reduction on renewable energy generation
Sell electricity
Encourage
Demand side renewable installation
Policies encourage demand responses
PDRC
Reduction in curtailment
FR and Reserve
Encourage
cause
Grid Reliability Issues
Encourage
Energy Storage
Maintain
Grid Reliability
accomplishment
Result in
Decrease subsidy
Encourage
Demand side storage
Encourage
ELCC& UCAP
cause
Capacity Value
Market
Increase demand of off-peak energy
Renewable Energy
Increase demand of capacity

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