Meeting the challenge of modernizing the grid to stabilize the integration of renewable energy
The electric grid must be, above all else, reliable. That’s why the integration of renewable generation is perceived to be—at the same time—a transformative opportunity and a formidable threat. We are on the brink of adopting renewable energy at a scale never seen before. To allow renewable power to meet its potential and continue its rapid development, we need long-term planning, investment at the right junctures, and smart grid management at scale.

Executive Summary

At its heart, renewable generation is a story of contrast. Renewable generation offers promises of reducing CO2 emissions to mitigate the effects of global climate change, reduced dependence upon fossil fuels, and tantalizing reductions in costs of energy. Not only are the costs associated with building solar and wind capacity falling, but the marginal cost of operating renewable generation is near zero once installed.

Renewable generation also poses difficult challenges that must be addressed through long-time planning and on-target investment. It is highly variable and difficult to forecast. It tends to peak at the moments when consumer demand is lowest and ebb at the moments when demand is greatest. Remote renewable generation sites often require power to travel across vast distances.

Ideally, when the sun is shining or the wind is blowing, utilities want to capitalize on all available renewable generation in real time. However, as the penetration of renewable generation grows, as one might expect, the challenges also grow. For example, utilities may have to curtail solar generation on a sunny day if demand is not sufficient to utilize the generation. Curtailment, in turn, diminishes return on investment and environmental benefits.

An ABB analysis revealed that for many geographies, curtailment can start when renewable capacity reaches about 25% of annual demand. When approximately half of the generation is renewable, curtailment might reach 5-10%. At this point, adding additional renewable generation capacity would result in increasingly smaller additions in the level of delivered renewable generation. On a grid that faces regional constraints, curtailment may begin even earlier.

These saturation effects can be mitigated with strategies, technologies and techniques. We cover some of the most important strategies in this paper. We also cover shifts in perceptions that we believe are inherent to realizing higher levels of centralized renewable generation.

Top among them is this: when most people picture renewable generation, the association is typically solar rooftop panels. That is one component, but while distributed energy resources (DERs) are generating a lot of attention and excitement, the reality is that rooftop (distributed) solar is expected to generate less than 10% of the total generation mix by 2050. As we explore in this paper, significant utility-scale renewable investment is not only happening—in fact, it must happen to reach renewable portfolio standards. And adequate transmission capacity will be essential to deliver this energy. As a result, investing in transmission is just as important—if not perhaps more important—as distribution and grid edge investments to enable the integration of renewable generation into the grid.

Finally, we predict that there will be a shift in the traditional thinking of dispatching generation to match load. Over time, we expect to see more aggressive shaping of consumer load to match renewable generation characteristics. Demand management may be done by industrial consumers (e.g., fully automated future factories) as well as smaller consumers.
The evolving power generation mix
Since the 1970s, fossil fuels have composed a steady 60-70% share of the global power generation mix. According to Bloomberg’s New Energy Outlook (NEO):

“We think this 50-year equilibrium is coming to an end as cheap renewable energy and batteries fundamentally remake electricity systems around the world.”

As coal-fire generation units retire, some of the slack has been taken up by natural gas, but renewable additions, especially solar and wind, are already dominating the US power sector build. According to the Bloomberg New Energy Finance, total US renewable capacity has nearly doubled since 2008.

The renewable buildout is predicted to accelerate. One fifth of the world's electricity is now produced by renewable energy, including hydro, reports IEA. This share is expected to grow to 64% globally by 2050 as seen below.

![Historical and projected world power generation mix](image)

What is driving this dramatic shift? In part, it is the push to decarbonize, but in large part, it is economic. Solar PV and wind already cost less than building new large-scale coal and gas plants, and the cost of an average PV plant is predicted by NEO to further drop by 71% by 2050. Wind energy is expected to drop 58% by 2050. And let’s not forget, batteries costs are also plummeting. Today’s prices are 80% lower than in 2010, opening the door to help stabilize the grid using battery capacity to store renewable energy generation until required.

Many people still associate renewable generation with rooftop solar, however, the significant investment is utility scale. Solar PV capacity added to the grid in the United States was two thirds utility scale last year and three quarters utility scale the year before. US wind generation—which is typically transmission connected—jumped 13% to 255TWh in 2017 alone.

Addressing potential constraints
This changing power mix introduces several conditions that challenge grid stability. None of these challenges are new to the industry; however, each is more pronounced as the penetration of renewable generation grows. The result may be the need to curtail renewable generation.

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This potential saturation effect is due to a number of constraints:

**Distance** – The most productive renewable generation sites are often located far from large loads. One of the best US resources for wind, for example, is in North Dakota, far from load centers. And with more and larger wind parks set to be built offshore, major investments are needed to feed the power into the grid. HVDC (high voltage direct current) transmission lines and cables, as one example, can be an effective solution for providing grid access for remotely located renewable generation, including undersea.

**Congestion** – The converging trends of retiring fossil generation and more remotely located renewable generation can result in more power traveling over longer distances, increasing congestion, and pushing existing lines toward their dynamic stability limits.

Renewable additions may also be concentrated in a specific area or new locations may be different from retiring generation, creating different flow patterns which could create bottlenecks on some paths.

Access to the transmission grid is a key component for siting utility scale renewable generation. As well, during the times when line capacity is unavailable, renewable generators may be forced to curtail production. Congestion, if not properly managed, could risk grid stability. Congestion could also potentially impede delivery of solar or wind, lowering revenues and impacting the cost of delivered renewable energy.
Balancing supply and demand – Load behavior is relatively stable and the technology to predict load has matured, however, renewable output is difficult to predict because of weather variability. This, in turn, contributes to the difficulties balancing supply and demand on the grid as renewable penetration increases.

In 2013, the California Independent System Operator published the California Duck Curve, pictured below, highlighting supply/demand timing imbalances that increases with growing deployment of PV power.

The Duck Curve—which resembles the silhouette of a duck—displays a 24-hour period in springtime California. It demonstrates the timing imbalance between demand and the supply of available solar energy over the course of a day. As you can see in the 2012 (actual) line, the load which had tapered starting at midnight, begins a slow increase toward the morning, increases toward midday, tapers down, and then reaches its peak in the evening. As solar production increases over years, the curve illustrates a deepening valley representing an over-generation of solar energy in the afternoon. At this point, either the solar or the baseline generation may need to be curtailed to manage over-generation. Both options have a downside.

- Curtailment of solar generation would diminish return on investment and environmental benefits.
- Curtailment of baseload generation would increase the challenge to ramp up to meet peak demand in the evening, which coincides, unfortunately, with the time in the day when solar production becomes unavailable.

“How renewables compel you to capitalize on the generation capacity when it is available because the marginal cost of renewable generation is near zero,” said Gary Rackliffe, Vice President of smart grid North America for ABB.

The duck curve in California also illustrates broader system-level concerns. One concern is that the existing centralized generation resources will be challenged to accommodate the ramp rate and range required to fully meet the California peak demand. Imports from neighboring operational areas may be needed to meet these peak demands, requiring adequate transmission capacity to access available generation. The evening ramp may also increase operation and maintenance costs of the conventional generation, and would likely exacerbate fuel consumption and emissions.

**Strategies to facilitate higher levels of renewable generation deployment**

How do we as an industry mitigate the renewable saturation effects that could lead to curtailment? Important strategies include investing in transmission, storage, and active management of grid edge resources.

**Investing in transmission**

DERs are generation and storage resources (e.g., solar, batteries) connected to the grid at the distribution level “downstream” from the utility substation. While DER deployments still account for only a small fraction of installed generation capacity, it’s hard to go a day without coming across an article about their potential. There’s no question that DERs will play a critical role in our renewable future. However, the hype shouldn’t overshadow the importance of the role of transmission in the modern grid.

“For all the excitement about DERs, it is critical to shift the perception that distribution and grid edge investments are more important than transmission investments,” said Rackliffe. “I don’t think we will get to 50% penetration of renewable generation with only behind-the-meter roof-top solar. I don’t see a scenario where the transmission grid goes away, and in fact, the transmission grid becomes more important. Utility-scale generation is needed to meet renewable portfolio standards and that means centralized grid resources based on wind, hydro and solar PV.”
As a prominent example, the US has vast untapped sources of wind. Most of the potential, however, is not near a load center. “Without transmission, you can’t develop the wind,” said Rackliffe.

This lesson was illustrated in West Texas where there was a significant overbuild of renewables before the completion of transmission lines between 2007 and 2011. The figure below illustrates the discrepancy. Wind generation capacity in West Texas increased by around 6,400 MW between 2007 and 2011, without significant transmission capacity addition. Therefore, transmission capacity was insufficient to deliver all the electricity to load centers.

ABB then conducted a study of line capacity, the reactive compensation that would allow for optimal power flow, and economic objectives. These studies allowed ERCOT to create a transmission system connecting the wind energy generated at remote wind farm locations with some of the most populated areas in Texas.

Storage
It is a basic operational requirement for utilities to maintain voltage and frequency on the grid. However, as you increase penetration of variable resources like renewable generation, meeting this requirement becomes more complicated.

Energy storage is gaining ground as an acceptable approach to increase flexibility to maintain voltage stability and active power balance on the grid. According to NEO’s global prediction: “We see $548 billion being invested in battery capacity by 2050, two thirds of that at the grid level and one third installed behind-the-meter by households and businesses. The arrival of cheap battery storage will mean that it becomes increasingly possible to finesse the delivery of electricity from wind and solar, so that these technologies can help meet demand even when the wind isn’t blowing and the sun isn’t shining.”

The California duck curve, for example, could potentially be addressed by adding additional storage that can capture surplus solar PV generation during the day and then discharge the energy during peak demand during the evening, thus eliminating the solar curtailment problem and reducing the ramping generation requirements to meet the evening peak demand. Sizing storage capacity to capture renewable overgeneration,
address seasonal variations, and maintain high storage utilization are key success factors.

Grid operators also use resources called spinning reserves to keep excess generation online in the event that it needs to be quickly dispatched to adjust to a disturbance on the grid. The downside is that spinning reserves require capacity, and if they are idly spinning, they consume energy without benefit. The variability of renewable generation may increase spinning reserve requirements, but storage represents a way to offset these requirements without limiting available generation capacity.

There are two primary uses of storage to mitigate the integration of renewables:

1. As discussed, one is deployed when you are trying to avoid curtailment and capture excess generation so it can be used to offset peak demand later.
2. The other use of storage is called capacity firming. In this case, variable, intermittent power output from a renewable power generation plant, such as wind or solar, can be maintained at a committed level for a period of time. The island of Kauai provides an illustration of capacity firming benefits.

### Case study

**Battery energy storage solution enables solar integration for the island of Kauai**

**Situation**
Hawaii’s target of 100% renewable energy generation by 2045 is one of the most ambitious renewable portfolio standards in the United States. Maintaining stability on an island grid with intermittent sources of power requires technology to help compensate for fluctuations in power output.

**Site information**
The Kauai Island Utility Cooperative (KIUC), the Island’s only electric service provider, meets the average load of 75MW using a combination of generation sources. On its sunniest days, 90% of Kauai’s daytime energy needs are currently met by renewable sources. To meet its clean energy targets and provide more cost-effective and locally generated power, KIUC installed a 12 MW solar farm. KIUC turned to energy storage to ensure that the grid can maintain system stability while running the PV power plant as efficiently as possible.

**Solution**
KIUC contracted ABB, in partnership with SAFT, to install a 6 MW/4.63MWh Battery Energy Storage System (BESS). The system can provide 12MW of power for a short period of time utilizing the overload capability of the Power Conversion system. The unit provides spinning reserve designed to respond to sudden changes in frequency within permissible tolerance irrespective of the change in solar farm output. The application requires a very fast response from the BESS without losing synchronization to the grid so that the variable, intermittent power output from the solar power generation plant can be maintained at a committed level.

**Bringing stability to the grid**
By providing grid services such as capacity firming and frequency regulation, the BESS can quickly respond to changes in generation levels, optimizing the efficiency of the solar PV plant, and allowing for a smooth power output onto the grid.
The future: shaping demand to match renewable characteristics

Today’s grid is primarily managed by evaluating the load and then matching the dispatching generation to meet peak demand. “I believe the low-hanging fruit in terms of grid operations with renewables is in thinking about how can we better manage loads to match the characteristics of renewable generation,” said Rackliffe. “For example, how can we increase load in the middle of the afternoon?

By shaping demand to take advantage of renewable generation when it is available, we can eliminate—or at least reduce—the peak requirements.”

As one example, if a time-of-use rate for an evening-peak utility is lower in the afternoon and higher in the evening, customers may be incentivized to use timers that would could run their pool pumps and pre-air-condition their homes in the afternoons when there is a surplus of solar. Using rates introduces potential social equity issues which would need to be managed, but it is also, we believe, a powerful example of the opportunity to actively shape demand.

Taking a step back, it is important to remember that power systems are designed to meet peak demand. However, peak demand may be significantly higher than the average load. In New York, as an extreme example, the state’s bulk power system is designed to meet retail peak demand that is about 75% higher than the average load, reports The New York Battery and Energy Storage Technology Consortium (NY-BEST). They draw an analogy to building a 16-lane highway for traffic that occurs on three holidays a year.

“Demands on the system at peak times have grown at rates above that of the system’s base loads,” NY-BEST reports. “As a result, the electricity system’s utilization factor has declined and the entire system—every single generator, pole, wire, substation and transformer—is sized to meet peak demand levels that may only occur a few days or even hours a year.”

The result is an oversizing of generation, transmission and distribution assets and significant underutilization of assets. The New York Public Service Commission estimates that eliminating the top 100 hours of peak demand in its system would save $1.2-1.7 billion dollars a year.

Because of these challenges and opportunities, we predict that there will be a shift in the balancing authority for grid operations. Since solar PV and wind generation resources can be curtailed, but are not considered to be dispatchable resources, shaping the load to match available renewable generation resources will prove more critical as levels of renewable generation grow. The overarching goal is to make the dispatch of centralized generation more efficient by eliminating, or dramatically reducing, the peak requirement.

Electric vehicles – More active management of load or demand at the grid edge will, in turn, improve the overall electric power efficiency for both generation and delivery. This will prove critical not only as we see increasing penetration of renewable generation but as adoption of electric vehicles (EV) grows. EVs are expected to grow from around 1.8% of global passenger vehicle sales today, to 55% of new sales by 2040, reports Bloomberg’s NEO. This will add around 2,000TWh of new electricity demand globally by 2040 and 3,414TWh by 2050, when EVs are predicted to be 9% of demand.

“Electrification of transportation is poised to be the biggest addition to the grid that utilities have seen in some time,” said Rackliffe. “How do we charge these vehicles without contributing to additional system peak demand?”
MEETING THE CHALLENGE OF MODERNIZING THE GRID

EV adoption may be a perfect case use of how to apply time-of-use rate structures to change load to match renewable generation. More than 25 US utilities have already introduced or are trialing EV-specific time-of-use rate structures, typically incorporating a significant gap between peak and off-peak prices.

“In California, for example, charging EVs in the afternoon is a win-win-win, said Rackliffe. “You get internal combustion engines off the road. You charge when there is excess generation so there is no increase in peak demand. You enable better utilization of renewable generation reducing the need to curtail.”

Over the years, the growth of PV is likely to push demand towards midday in many markets, when low-cost renewables are available. By 2050, NEO predicts that about half of the EV fleet is able to be plugged in at all times when not on the road, charging from the grid via a time-of-use tariff when this low-cost renewable power is available. Electricity demand will thus shift to the middle of the day to align with the solar maximum and support the further build-out of PV capacity. V2G options will also likely benefit from future standards and products to leverage the growing fleet of batteries on wheels.

Conclusion

While the opportunities offered by renewable generation are significant, the challenges can also seem formidable. Solutions are available to address these challenges and to enable the growing renewable generation investments needed to meet renewable portfolio standards and greenhouse gas reduction pathways.

Key takeaways include:

1. Utilities must modernize their grids now to address the saturation effects that can lead to curtailment of renewable generation.
2. We need to shift the perception that distribution and grid edge investments are more important than transmission investments.
3. A modern grid will need transmission capacity along with storage to accommodate higher levels of renewable generation.
4. Finally, a modern grid will also need active shaping of customer load to align demand with renewable generation characteristics.
Endnotes


