Economic and Reliability Benefits of Gas-Storage Hybrid Resources in Organized Energy Markets

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February 22, 2023

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Executive Summary

The effort to rapidly decarbonize the global energy system is challenging power system optimizations and the ability of system operators to economically balance supply and demand. Despite market and technology transformations advancing at a rapid scale and pace, market operators still face challenges accounting for increasing energy grid uncertainty in a reliable and efficient manner. As baseload resources like coal are phased out and replaced by intermittent renewable resources, innovative market-based approaches are being developed to ensure a secure and cost-effective transition. Energy markets across the world are implementing additional features to account for difficulties in forecasting renewable output and intermittent resources' fuel supply. New solutions include additional market products and pricing structures, virtual power plants, and integrating customer actions as demand response directly in the market optimization.

Despite these improvements, more technological and market advancements are needed as the deployment of carbon free and renewable energy resources must also accelerate even more significantly in order to meet clean energy goals. Even energy grids like Germany and California are only beginning to face the extent of challenges related to intermittent resources becoming a more significant portion of the energy mix. Aggressive low- or zero-carbon policies that must be met in the next decade are forcing a transition from conventional baseload technologies to faster flexible technologies that complement wind and solar resources. One new complementary technology is the gas-storage hybrid resource. Gas-storage hybrid ("gas hybrid") resources combine the benefits of both gas-fired power plants and energy storage systems and address key market issues introduced by increased uncertainty.

Significant amounts of renewable energy introduce uncertainty and market optimization issues on three major timescales: short-term, diurnal, and seasonal. Short-term market issues are due to unexpected variability in solar or wind output of a very short duration. So far, many grid operators have partially solved this issue through enhanced market optimizations and products as well as increased deployment of short-duration battery energy storage capacity. Diurnal and seasonal issues are even more challenging and costly to address. The diurnal mismatch between the timing of peak demand and when solar and wind generation are highest during the day is also known as the duck curve issue and is a well-known challenge for market operators. This issue frequently leads to maintaining baseload, must-run capacity to ensure peak load is met, which diminishes some of the benefits provided by renewable energy resources. The seasonal problem is even more significant especially in winter peaking systems where solar and wind may not be available for extended intervals, potentially consecutive days or longer during periods of cloudy and inclement weather.

Thus, one of the most significant challenges facing grid operators today is the need for flexible capacity on multiple timescales and also continuously available and able provide the responsiveness needed to address real-time uncertainty. Gas hybrid systems can offer several advantages in the electricity market given their near-perfect flexibility compared to many other resources. This flexibility allows the optimization software to rely on these resources for operating reserves and peak capacity without any minimum energy dispatched. The hybrid nature of these resources mitigates the must-run issues associated with most conventional resources and mitigates the duration concerns commonly associated with storage resources.

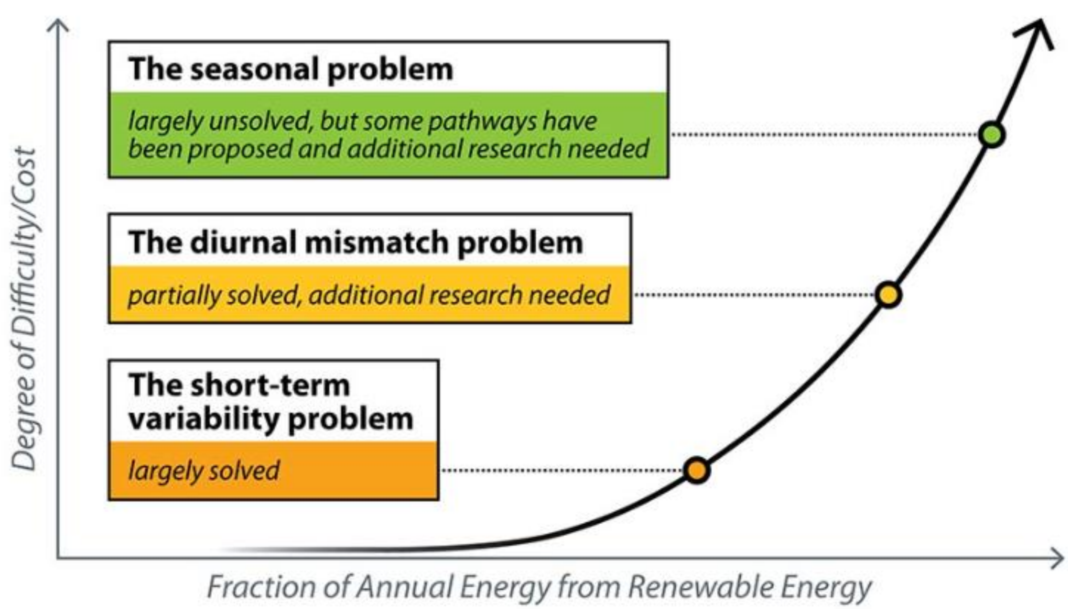
Application of the gas hybrid resources in California has shown they are typically relied on to provide flexibility reserves and other ancillary service capability to the grid. This is because they are able to provide operating reserves, primary frequency response, voltage support, and (if needed) blackstart services, all without any fuel consumption. When incorporating the potential for fuel consumption, gas hybrids can also provide instant peaking energy for local contingencies and high-speed regulation services, however, because local contingencies occur at relatively low frequency, the overall emissions associated with this use case of gas hybrids is typically very low. The integration of gas-hybrids into the California resource mix relatively decreased the average capacity factor of peaking plants, which was only possible because gas hybrids can deliver carbon free backup power indefinitely and provide grid stability and other ancillary services when renewable energy production is low. Ultimately, gas hybrids would be beneficial for any energy grid with increasing flexibility needs that are transitioning from primarily conventional resources to primarily renewable resources.

Renewable Integration Challenges

Reliable operation of the electricity system is crucial and depends on the ability to handle unexpected and uncontrollable factors, such as forced generation outages, transmission line failures, and fluctuations in electric demand, as well as intermittent renewable energy output. The system operator is also responsible for the economic optimization of the grid and ensuring a least-cost dispatch of available resources. The transition from conventional resources to renewable resources introduces both reliability and economic efficiency challenges.

Significant amounts of renewable energy introduce uncertainty and market optimization issues on three major timescales: short-term, diurnal, and seasonal. These are illustrated in a graphic from the National Renewable Energy Laboratory in Figure 1.

Figure 1: The Balance Challenges of Economically Matching Supply and Demand



Source: NREL May 19, 2021, Perspective on Decarbonization Challenges Featured Story

Short-Term

One of the main challenges grid operators face today with high levels of intermittent resources is the ability to manage short term uncertainty efficiently. In the context of intermittent resources such as wind or solar generation, the market optimization must account for the lack of predictability and consistency of their energy output. There are two main factors that contribute to uncertainty of intermittent resources – variability and forecasting inaccuracy. Intermittent resources, such as wind and solar, can be subject to sudden changes in availability due to fluctuations in weather patterns, which can cause significant variations in their energy output. This variability can create difficulties in accurately scheduling the amount of energy that will be generated from these sources, leading to uncertainty about their reliability as energy sources. Forecast inaccuracy further exacerbates the unpredictability of intermittent resources.

The main drivers of unpredictability are due to wind, solar, and power consumption fluctuations over the course of the day. Events such as sudden cloud cover and consequently less solar energy require sophisticated forecasting and subsequent rapid energy deployment. The more significant the unforeseen change, the faster the technology must react to provide flexibility to smooth the fluctuation.

To mitigate the effects of uncertainty in the context of intermittent resources and forecast inaccuracy, electric market policy design, optimization approaches, resource characteristics, and system operator actions need to provide the ability to respond quickly to changes in energy supply and demand. This may also involve the use of ancillary services and new market-based uncertainty products, such as flexible reserve products. It is also necessary to leverage the capabilities of energy storage systems, virtual power plants, and other resources that can help to balance the system and ensure reliable and efficient use of the portfolio of resources.

Diurnal

Another well-known challenge for market operators as it relates to intermittent resources is the mismatch between the timing of when solar and wind generation are highest during the day and the peak demand. We believe the gas hybrid is particularly well-suited to address diurnal challenges. The diurnal issue is also commonly referred to as the duck curve issue and is more challenging and costly to address than the short-term challenges. Organized markets not only have to ensure sufficient and reliable resources are available to meet peak demand, but also that they have the ability to meet net peak demand, which occurs at different times of the day. Net peak demand refers to gross demand minus wind and solar output. Net peak demand tends to peak just as the solar and wind generation are dropping off. Thus, the market optimization also has to ensure non-intermittent resources are positioned and able to ramp up quickly to meet net peak demand as the solar and wind generation drastically drops during the evening hours.

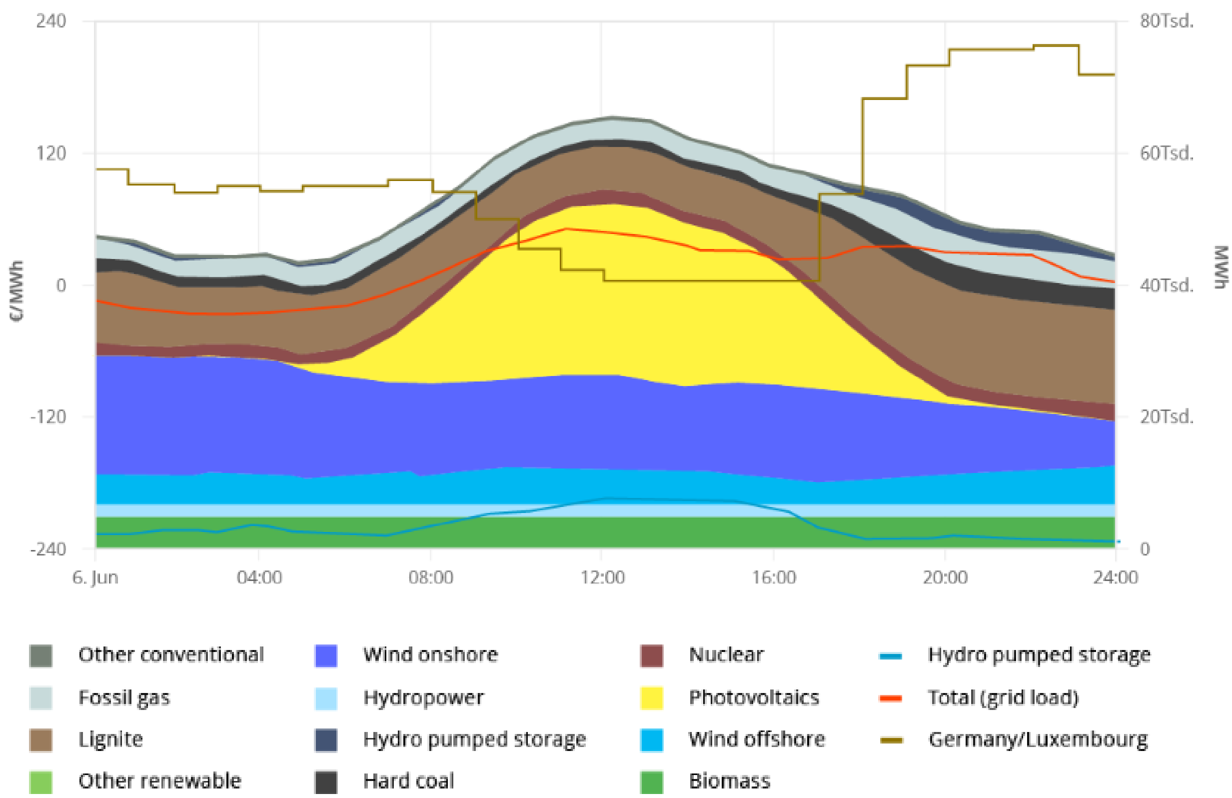
This challenge was identified as a key issue in Germany during the summer of 2022. A Fluence case study described the challenges of a sunny day in Germany on Whit Monday.[1] Solar and wind resources were abundant and peak load was 47.8 GW. Despite the significant amount of renewable energy online, convention powerplants continued to run across the day, including 6.2 GW of lignite, 1.8 GW of coal, 2.2 GW of nuclear, and notably 2.5 GW of gas plants, despite the scarcity and high cost of gas. Total

[1] Germany Case Study: Electricity System Flexibility is Crucial to Unlocking the Clean Energy Transition, July 8, 2022

generation was far in excess of German grid needs and between 11am and 4pm wholesale market prices were below 1€/MWh and over 10.8 GW of power was exported.

Figure 2 shows the resource mix and impact on pricing on June 6, 2022. It demonstrates that while pumped hydroelectric plants were able to absorb a significant amount of the excess energy to use later in the day, conventional generation was dispatched and operating at significantly and inefficiently higher output than needed to serve load alone, likely due its must-run status and inherent physical capabilities.

Figure 2: Power Generation and Consumption



Source: SMARD| Data

In a 2021 report, the German regulator stated the conventional must-run capacity for Germany was between 16.7 GW and 19 GW. [2] They noted this was driven by the need to provide ancillary services such as frequency regulation or voltage support and the inability for conventional power plants to respond flexibly in real-time. This example illustrates that while the market optimization was able maintain reliability, at a macro level it was an inefficient solution due to the inflexibility of the available resource mix.

Seasonal

Seasonal challenges associated with high renewable resource systems are due to the fact that solar and wind generation profiles tend to be lower during certain months or seasons of the year compared to

[2] Bericht uber die Mindesterzeuguang 2021

others. These challenges are more prevalent in winter peaking systems when peak demand occurs during the months that renewable generation is at its lowest. The solutions to these challenges often take place in more of the forward planning process rather than in market solutions. For example, ensuring sufficient reliable capacity that is available during low solar and wind seasons is procured ahead of time and obligated to be made available to the market. This issue is likely to become more significant as increasing amounts of solar and wind displace conventional resources with a less variable fuel source.

Flexible Resources in Market Optimization

The renewable transformation can have a significant impact on the cost-effectiveness and competitiveness of renewable energy and can also affect the functioning of electricity markets. The market optimization is limited by the resource mix. As identified above, there are significant challenges to renewable integration, and these have a direct impact on the ability of the market optimization to reliably ensure a least-cost dispatch.

Short-term issues are best resolved by flexible market products and operating reserves that are met by low emitting, flexible resources. These may be of a short- or longer-duration but must be able to respond quickly to unexpected events. In day-ahead electricity markets, electricity generation and consumption are planned ahead of time that take into account forecasted demand. However, the actual electricity demand can differ from the forecast, leading to imbalances between day-ahead scheduled supply and real-time demand. The difference between day-ahead and real-time outcomes may cause a need for a type of flexible reserve product to cover this uncertainty. Energy prices are determined by supply and demand balances, and uncertainty can cause fluctuations in resulting energy prices. For example, when there is a sudden decrease in supply of energy due to unexpected cloud cover reducing solar resource production, there will be a need to increase production from other, more expensive resources, which can result in increased production costs and prices. These increased production costs can have a significant impact on end use customer's retail rates and the economics of long-term financing and cost recovery for generation units, including thermal, storage, and renewable resources. To mitigate the effects of uncertainty in the economics of electricity markets, it is important to develop flexible and adaptable energy systems that can respond quickly to changes in energy supply and enable a more efficient and cost-effective use of the entire portfolio.

Diurnal issues are best resolved by the market optimization having access to long-duration flexible resources with the ability to stop and start multiple times a day. High output of solar and wind at mid-day frequently requires conventional resources to be operated at a fixed level across the day so that they are able to ramp up to meet the peak net load. In California, the issue of must-run capacity during high renewable periods is referred to as the "Pmin burden" which is the minimum energy production level from resources online; the market cannot dispatch resources below the minimum production level unless turning them offline. Once a resource is offline, then the market no longer has access to that resource for future grid needs until other constrains (such as minimum amount of time required to be offline and time needed to start up and synchronize to the grid) are met.[3] Dispatching a unit that is

[3] In the CAISO, the "Pmin" terminology is defined as the applicable California Independent System Operator (CAISO) certified minimum operating level of the Facility and in the context of the "Pmin burden" concept refers to

already online to cover the uncertainty in a system requires the resource to have available flexibility in one or both directions. Because many conventional resources lack this ability and there may not be sufficient flexible resources available on the system to meet future forecasted ramping and variability needs, the market operator often must commit less flexible resources that result in periods of significant quantities of minimum operating levels or Pmin burden to be reflected in market optimization outcomes.

Seasonal issues are also a significant challenge for grid operators because most low carbon or zero-carbon resources are not consistently available throughout all seasons. Seasonal issues are best resolved through forward procurement and planning processes that can help ensure sufficient capacity is available during low wind and solar months to meet winter peaking load levels while also ensuring that capacity is flexible enough to help with the diurnal issues that arise during higher renewable output seasons. This typically involves the market operator or forward planning and procurement entity to ensure there is sufficient capacity available to the market that has sufficient duration to generate in absence of renewable generation while also flexible enough to help address the diurnal issues without contributing to "Pmin burden". Procuring resources that can address both seasonal and diurnal issues while contributing to meeting decarbonization and clean energy goals results in a more efficient and reliable resource mix. Beyond forward planning considerations, the challenges associated with seasonal energy production variability can also be addressed through investments in more drastic solutions including even longer-duration storage technologies and capacity able to shift energy production across seasons, as well as leveraging gas hybrids to provide low carbon emission peaking capacity during increasing extreme weather and climate impacts as a transitional solution before more advanced storage capabilities are developed and deployed.

Benefits of Gas Hybrids

Gas hybrid resources are able to efficiently mitigate short-term, diurnal, and seasonal market issues. A gas hybrid combines a natural gas resource with a battery energy storage resource. Thus, a gas hybrid combines the immediate responsiveness and flexibility capabilities of a storage plant, with the long-duration attributes of a gas plant. This allows the resource to solve renewable integration short term issues very similar to a battery. Without using any fuel, a gas hybrid can provide operating reserves, primary frequency response, and voltage support. Its ramping capability and ability to quickly respond to grid changes is identical to a storage resource. However, unlike storage, it is also able to then consume fuel to act as a longer duration resource. This makes it a uniquely situated resource to address diurnal issues and seasonal issues. If the gas hybrid is required to remain online for an extended period of time, the gas resource can begin its normal start sequence while the battery handles the flexibility required until the gas resource has started up and is operating normally. This combination allows the market to request exactly what is needed from the plant and have it provided nearly instantaneously, with the ability to sustain its output level regardless of which part of the overall resource is providing the power.

Another benefit the gas hybrid gains from the battery is the ability to operate at any point within the range of the overall resource without a time constraint. Unlike the traditional standalone gas peaking resource that requires a minimum operating threshold to be safely dispatched, the gas hybrid can move

the minimum operating level or minimum energy output level of a resource that is committed and dispatched by the market.

along the full range of its output capability due to the shared responsibilities of the two parts of the overall resource. This removal of minimum on and off times of the gas component makes gas hybrids a perfect complement to renewable resources as it only needs to dispatched when it is actually needed. This is accomplished due to the improvements made to the stabilization of the resource, and the battery's interplay with the gas resource to determine the output of the overall resource.

Lastly, where a battery is limited in the duration it can behave as a generator, the gas hybrid resource is backed by a true conventional generator. So long as the fuel supply remains uninterrupted the gas hybrid can continue to provide power for as long as required. This also ensures that the resource can always provide power and even if the state of charge of the battery were to be fully depleted, the gas resource could perform just like any other gas resource would be expected to. Gas hybrid resources provide the market with a reliable firm source of energy that can be available year-round and help meet winter load levels, at an overall lower emission rate than traditional thermal resources, when renewable generation is less prevalent. Additionally, the gas hybrid resources help facilitate a timely and reliable transition away from a primarily conventional resource mix to a primarily renewable resource mix.

Improvement over Conventional Technology

Standalone storage and peaking resources cannot provide these benefits separately and the issues with individual dispatch of these resources can be resolved by joint dispatch through hybridization.

Market Solutions using Battery Energy Storage

Use-Limited resources, more specifically Battery Energy Storage systems, are another option available to markets to resolve market issues related to renewable penetration. Battery systems, unlike most generator resource types, have the ability to charge, drawing energy from a system. This allows for greater flexibility when it comes to covering uncertainty or firming the grid due to the ability to act as a load on the system as well as a generator. Most of these battery systems also react at a relatively instantaneous speed, but have limited duration they can discharge to provide energy back to the grid. Their best use is typically short term energy shifting to help store excess renewable resources during the day for later use during the net peak load and to provide fast ramping capability for unexpected events. They are less helpful for long duration events, including extended reliability needs and events that happen over a day or longer, and are especially poor at addressing seasonal concerns when solar and wind are unavailable to charge the battery.

Market Solution using Conventional Peaking Gas Plants

A typical peaking resource is designed for usual fast start capabilities with a "Pmin" or minimum amount of energy that must be dispatched so the resource can provide reserves or energy. While a peaking resource respond relatively fast, it still requires time to be started up if it is not already committed and online. This results in a time window where the resource is incapable of responding to system needs and more costly resources may be used until they are available. As increased intermittent generation is integrated into the market, the less capable peaking resources become at resolving some of the uncertainty events. For example, if a cloud system were to pass over a large enough solar farm the market might see a sizable drop in power output from that field very quickly. Depending on the weather that day the cloud system might move on just as quickly, which would result in the recovery of power generated by the solar field just as fast. In this instance you could have a situation where the market sees a drop of power over 10 minutes just to see the resurgence of that power in the next 10 minutes. In this instance a peaking resource would require a notice to start, which requires time, and then a normal start sequence. In the California ISO market, for example, a start notice is issued with roughly 15 minutes of notice, 10 of which would cover the start. Meaning the peaking resource would be online ready to resolve the issue roughly halfway through the resurgence of the missing power.

This outcome also introduces another limitation of a peaking resource. Once the peaking resource is online the unit requires a length of time to stabilize so that it becomes sustainable and efficient and is required to be operated above a certain threshold power wise. Both of these introduce constraints in the market optimization if an event like the solar field issue described above were to occur. Assuming the event occurred without notice and the peaking resource was started, the plant would be online at load with about 5 minutes left where it is needed. However, the resource has a minimum online time (ex. 30 minutes) as well as a minimum power threshold. Meaning this resource needs to remain online and at least at a set threshold of power regardless of the market's current need for the resource. These resource operating and engineering constraints results in a surplus of uneconomic energy production, potential recommitments of more flexible resources to accommodate the surplus, and unnecessary emission generation. Overall, these impacts can reduce the efficiency of market outcomes that can lead to higher production costs and resulting end use customer rate impacts, as well as environmental consequences that are often externalities that have not been incorporated into electricity production costs, but that can have a significant burden on society as a whole.

Conclusion

In conclusion, it is well known that the transition from conventional to renewable energy resources has brought both reliability and economic efficiency challenges to electricity systems. High levels of intermittent renewable resources, such as wind or solar generation, have caused difficulties in managing short-term uncertainty and diurnal challenges, which refer to the mismatch between the timing of when solar and wind generation are highest during the day and the peak demand. Moreover, seasonal challenges have arisen due to the lower levels of solar and wind generation during certain months or seasons of the year. Gas hybrid resources have proved to be particularly well-suited to address these challenges by providing flexible, low-emitting, and quick-response solutions to unexpected events, mitigating the impact of uncertainty in the economics of electricity markets, and enabling a more efficient and cost-effective use of the entire resource portfolio. By incorporating gas hybrid resources, the electricity system can continue to achieve reliable and efficient operations, ensuring a least-cost dispatch of available resources, while assisting society in transitioning to a more sustainable energy future.