Hybrid Power Plants –

Flexible Resources to Simplify Markets and Support Grid Operations

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Executive Summary

In this paper, we suggest that future deployment of energy resources on the electric power system will increasingly be in the form of "Hybrid Resources." In this context we define a Hybrid Resource as a combination of multiple technologies that are physically and electronically controlled by an owner/operator ("Hybrid Owner/Operator") behind the point of interconnection ("POI") and offered to the market or system operator ("Market/System Operator") as a *single resource* at that POI.

Our proposed Hybrid Resource concept is essentially an "intelligent agent" approach whereby the Hybrid Owner/Operator manages the characteristics of the components behind the POI and offers energy, ancillary services and resource adequacy capacity at the POI in the same way as a conventional thermal or hydro resource ("Conventional Resource"), but with more flexibility and fewer operating constraints (such as minimum load, start-up time, minimum down time, etc.) through coordinated use of generation, storage, power electronics and software technologies.

We further propose that the implementation of Hybrid Resource power plants can be done without significant changes to the existing markets and operating practices for today's power grids. While Hybrid Resources have many capabilities, the ability of the Hybrid Owner/Operator to manage the resource performance characteristics so as to deliver needed services to the Market/System Operator at the POI is perhaps the most important. To a large degree, it is possible for the Hybrid Resource to emulate any desired type of resource, including Conventional Resources that participate in the markets today.

We propose that, in any system or market, a Hybrid Resource that is willing and able to participate under existing participation models should be allowed to participate. In other words, at least for the near term, we propose to treat Hybrid Resources like Conventional Resources that can be easily accommodated by existing market rules and energy management systems. Moreover, as ISO/RTO provisions to comply with FERC Order 841 take effect in the next year or two, these new storage participation models can also be available to Hybrid Resources without requiring any additional special provisions.

This approach simply treats the Hybrid Resource comparably to a Conventional (generating or storage) Resource, and then expects the Hybrid Resource to perform comparably to a Conventional Resource. In other words, the Hybrid Owner/Operator is responsible for offering the Hybrid Resource's services to the Market/System Operator, and then delivering those services just like a Conventional Resource. The Hybrid Owner/Operator has full visibility to and control of the technologies on its side of the POI. The Market/System Operator is responsible for holding the Hybrid Resource accountable for meeting its commitments at the POI, but is not concerned with the individual component technologies behind the POI.

There are a number of advantages to accommodating Hybrid Resource power plants for both the Market/System Operator and the Hybrid Resource. The Market/System Operator will have access to a resource that is similar to – but in some ways better than – a Conventional Resource, without having to make complex changes to existing market designs and energy management software. At the same time, the Hybrid Resource will gain rapid access to full participation in the current markets and power systems, albeit with a slightly higher capital investment and the need for more sophisticated analytics, offers and operations, but knowing that its plant is highly flexible and can be modified with software enhancements to adapt to future opportunities, market designs and operating practices. Moreover, once our proposed approach is applied and validated in wholesale power markets, it will provide a straightforward path for resource developers to create new innovative hybrid arrangements to meet the evolving needs of the electric power system.

We are early in the exploration and innovation of what we can do with Hybrid Resources. Right now, however, Hybrid Resources can participate in the current market design as highly flexible resources that are treated comparably to Conventional Resources. We believe that Hybrid Resources will be very cost effective and extremely capable sources of capacity, energy and ancillary services. There are no significant obstacles for the use of Hybrid Resources in our current markets and power systems, and many advantages over today's separate use of the components, so we should proceed with using Hybrid Resources under existing participation models and rules that are essentially the same as those in place for Conventional Resources.

Background

The electricity power grid is an amazing and complex system with a long history. Based on the physical and electromechanical properties of Conventional Resources, system planners and operators have created reliable power grids that are among the most complex of machines. Operating practices and technologies have evolved over the many decades of experience, and over the last few decades, many regions added power markets for competitive procurement of the energy and capacity services for reliable and economic operation of the power grids.

Electricity from the power grid has broadly enabled other technical progress, including the advances with electronics and digital technologies. The advent of computers and software initially provided a way to manage information and data processing, but we've seen that these technologies also provide a means for creating new devices and physical machines. It is now common practice in other industries to use major components of systems that combine hardware with software-based controls to emulate the desired behaviors at the interface of the subsystem. Such subsystems often integrate energy storage and advanced software-based analytics to provide robust and sophisticated behaviors at the interface.

It is not surprising to see this trend toward intelligent subsystems in the power sector, particularly because today's modern photovoltaic ("PV") solar energy and wind energy systems use power electronics and digital controls. Nor is it surprising to see the use of nascent energy storage technologies serving as the catalyst for the next phase of enhanced capabilities. Historically, we largely used renewable energy resources as variable energy sources and, separately, storage technologies as sources of ancillary services and capacity. In this paper, however, we suggest that Hybrid Resources that combine these technologies are likely to become the predominant approach for renewable resources in the near future, and perhaps for some conventional and distributed resources as well.

Hybrid Resource Power Plants

There are many different types and configurations of Hybrid Resources.

The most common types of Hybrid Resources being discussed today are solar PV + energy storage, wind generation + energy storage, and gas-fired generation + energy storage. Many other types of Hybrid Resources are possible, particularly for systems that differentiate between normal loads and resources that are allowed to generate "negative power" at the POI, such as for charging storage or other uses by the Hybrid Resource. This could be possible, for example, by using the Non-Generator Resource participation model in CAISO or flexible battery storage participation models in some other markets.[1] The Hybrid Resource concept can also be applied to microgrids and aggregated distributed energy resources, at least those that offer their services to the Market/System Operator at a defined POI.

It is critical to differentiate between a Hybrid Resource as described in this paper versus multiple devices at the same POI that are separately modeled and dispatched by the Market/System Operator. The latter is simply a group of separate resources whose use by the Market/System Operator is further complicated by the additional constraint of a shared interconnection limit at the POI. Using the components as resources that are separately dispatched misses the point and sacrifices the benefits of Hybrid Resources (as we describe in detail in this paper). For example, a PV resource cannot provide ancillary services without retaining headroom and a battery resource is an energy-limited, charging-dependent resource. As we show below, a Hybrid Resource can largely overcome both of these limitations.

Another approach, at least in theory, would be for the Market/System Operator to perform the modeling integration of the resource components at the POI and take responsibility for optimizing the use of the Hybrid Resource as a single resource. There is some initial attraction to this approach, as it seems comparable to current efforts for some conventional resources. For example, MISO's Enhanced Modeling of Combined Cycle Generators[2] effort will allow the participant to offer configuration transition costs; independent energy, no-load, and reserve offers for each configuration; minimum run time and down times for each configuration; and configuration transition and notification times, and then the system operator assumes the responsibility to commit the best configuration on an hourly basis subject to the configuration transition constraints offered by the participant.

This latter approach is similar to the "universal participation model" that was proposed by one of the authors[3] — essentially using a highly parameterized general market participation model rather than creating separate market participation models for different technologies. The resource owner/operator would use the parameters to describe the capabilities and constraints of their resource, and the Market/System Operator would be responsible for managing the constraints to optimally use the capabilities of the resource. While this approach could reduce barriers to participation by new resources (since they could participate by simply specifying the relevant parameters), it is likely to dramatically increase the constraints, software complexity and computational burden for the Market/System Operator. Even then, it is not clear that a truly general set of parameters could be designed and implemented in a practical way. This evolution of thought was obvious in a subsequent article[4] by the same author in which the preferable progression toward the Hybrid Resource concept is apparent.

[1] As noted earlier, all U.S. ISOs/RTOs will have operational participation models for storage resources in the near future in compliance with FERC Order 841.
[2] https://www.misoenergy.org/stakeholder-engagement/issue-tracking/enhanced-modeling-of-combined-cycle-generators/
[3] https://www.esig.energy/blog-the-universal-market-participation-model/
[4] https://www.esig.energy/why-storage-might-solve-really-big-problems-but-different-ones-than-you-think/

In contrast, a Hybrid Resource interacts as a *single* resource with the Hybrid Owner/Operator responsible for coordinating the activities of all the component devices that comprise the resource behind the POI. The Hybrid Resource enables the Market/System Operator to model the single resource in its operations and market algorithms, issue feasible dispatch/operating instructions and require the Hybrid Resource to comply with such instructions, all without the need for the Market/System Operator to have visibility or control of the component devices that are internal to the Hybrid Resource.[5] We argue that this approach provides a preferable allocation of performance risk between the Hybrid Owner/Operator and the Market/System Operator, because the Hybrid Owner/Operator controls the specification of performance characteristics and submission of feasible bids to the Market/System Operator, and controls real-time operation of all the Hybrid Resource components in order to follow market schedules and comply with dispatch instructions.

The first Hybrid Resources to see widespread deployment will use PV solar with batteries ("PV + Battery Hybrid Resource"), and for reasons that we describe below, we see a rapidly growing trend toward connecting the PV panels and batteries on the "DC side" of the inverters that convert the direct current (DC) of PV and batteries to the alternating current (AC) of the power grid. For simplicity, we will use this example in this paper, and we will discuss the operation of this Hybrid Resource based on using the PV as the primary energy source and augmented by the batteries for offers and extended operating periods, although it is quite possible that other energy sources will also be "hybridized" and the storage component will sometimes be used in additional ways.

The Hybrid Resource will remain under the control of the Hybrid Owner/Operator.

The Hybrid Owner/Operator will internally determine the amount of energy that the Hybrid Resource can provide with a high degree of confidence, and will offer this volume (as energy and/or ancillary services) for each hour in the day ahead and real time markets. For a PV + Battery Hybrid Resource or similar wind Hybrid Resources, the Hybrid Resource's offer will be based on renewable energy forecasts and internal algorithms for using the tightly-coupled battery storage to address renewable variability, including sophisticated use of probabilistic forecasts. The Hybrid Resource will also take advantage of design optimizations (including the oversizing of the PV capacity in the plant, as we discuss below in the PV + Battery Hybrid Resource example) and will manage all system attributes and characteristics behind the POI.

For renewables, the approach used with a Hybrid Resource is completely different than dispatchable renewables or flexible solar resources.

The Hybrid Resource concept challenges a number of assumptions that have historically been used to integrate and dispatch renewable resources. Most Market/System Operators currently integrate variable renewable generators in the five-minute energy dispatch using a very short-term forecast, and allow the renewable resource to deviate from that dispatch setpoint without an imbalance penalty except during constrained periods that require the Market/System Operator to curtail the renewable resource. Rather than being dispatched by using a very short term forecast as its power capability for the next dispatch period or being treated as a "generate as much as possible when wind or sun is available unless I tell you to curtail" resource, the Hybrid Resource would be expected to internalize the

[5] While the Market/System Operator should have no need for control of component devices behind the POI under normal operations, it may be desirable to telemeter some information for the benefit of emergency operations and goodwill with the Market/System Operator. For example, the Market/System Operator's real time desk may benefit from seeing the aggregated capacity that is currently in battery storage (i.e., state of charge) and available for critical emergency situations.

constraints, forecasts, variability and costs of its own resources behind the POI to align with the needs of the power system and would be subject to the same imbalance penalties as a conventional generator.

The Hybrid Resource approach is also different from the "Flexible Solar Plant" concept that self-curtails the PV to retain headroom for other services.[6] The addition of storage in a Hybrid Resource makes it unnecessary to maintain PV headroom. An interesting analogy is that a Hybrid Resource is like a hydropower plant, but with forecasting and operating decisions on much faster timescales. For hydro, the energy source is the water flow, the hydrology forecasting is seasonal/annual in nature, the storage is the water that is saved in the reservoir, and the services to the grid are provided by controlling the rate of discharge (how much water do I convert to electricity and use now). For a PV + Battery Hybrid Resource, the energy source is the sunlight that is converted to electricity by the PV panels, the solar forecasting is hours/daily in nature, and the services to the grid are provided by controlling the rate of battery charging (how much electricity do I store in the battery versus provide to the grid right now) or battery discharging. For both the hydropower and PV + Battery Hybrid Resource cases, the operating paradigm is to minimize "spillage" that would prevent putting the clean energy to productive use.[7]

When renewables are used in a Hybrid Resource, special treatment as a variable energy resource is no longer needed or desired.[8] Benefits of renewable energy (e.g., low marginal cost of energy) and flexibility are rewarded through competitive market products without the need for technology-specific rules or uplift payments. Of course, market enhancements that improve the economics of competitive market products in technology-neutral, performance-based ways could obtain even more value from Hybrid Resources and other flexible resources, but special treatment or uplift payments are not needed.

The Hybrid Resource looks like a highly flexible Conventional Resource, not like a standalone renewable resource or a standalone energy storage system.

In our proposed Hybrid Resource concept, the Hybrid Resource closely resembles a Conventional Resource with a low forced outage rate and superior operating flexibility. The Market/System Operator no longer forecasts or treats the renewable component of the Hybrid Resource as a variable energy resource. In fact, the variability of the renewable component becomes much less relevant because the Hybrid Owner/Operator accounts for the renewable forecasts and variability in its offers.

Similarly, the Market/System Operator no longer treats the energy storage component as a standalone energy storage resource. In some cases, and for various reasons, the Hybrid Resource may not want to charge from the grid at all. For example, the battery storage portion of a PV + Battery Hybrid Resource must currently charge from the PV to qualify for the federal investment tax credit, and the preferred market participation model may make it impossible or undesirable to charge from the grid. Particularly during times when the energy component of the Hybrid Resource is usually generating energy, grid charging may not be needed or used.

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[6] See https://www.esig.energy/event/webinar-investigating-the-economic-value-of-flexible-solar-power-plant-operation/ or https://www.ethree.com/projects/investigating-the-economic-value-of-flexible-solar-plants/

[7] In addition, if the hybrid is also used to consume charging energy from the grid at certain times (e.g., to absorb excess grid supply), it can transition between charging and discharging mode instantaneously, whereas a conventional hydro storage plant requires a transition period between the two operating modes.

[8] This is a significant (and controversial) issue, as the Hybrid Resource approach places much more responsibility and risk on the owner/operator. To be clear, we are not arguing that current treatment of variable energy resources should be changed, but only that owner/operators that wish to use variable energy resources within a Hybrid Resource should be allowed to do so.

The Hybrid Resource typically makes day-ahead offers that are co-optimized by the Market/System Operator, with additional real-time energy often available (as with co-optimization of offers from Conventional Resources today), with the Hybrid Resource determining the maximum volume of energy and ancillary services that it can confidently provide for any given period based on its forecasts and operating strategy. The day-ahead and real-time offers of the Hybrid Resource are treated consistently with the treatment of Conventional Resources (i.e., the same performance incentives, penalties for failure to perform, and forced outage practices apply). In other words, there is comparable treatment between Hybrid Resources and Conventional Resources for failure to perform due to insufficient fuel availability (e.g., extreme forecasting tail event errors for fuel supply — whether the fuel is sun, wind or gas) and forced outage events.

Benefits of Hybrid Resource Power Plants

While they behave like Conventional Resources and often include renewable and storage resources, Hybrid Resources have advantages over both.

- Compared to Conventional Resources, Hybrid Resources will:
  - Avoid operating constraints and "non-convex" market characteristics, with no startup time, no min-run time, no min-down time, and fast, accurate, controllable, continuous ramping down to Pmin=0 MW; and
  - Offer one-part offers (rather than three-part offers of Conventional Resources with startup costs and no-load costs) without advance commitment requirements, uplift payments or other constraints.[9]
- Compared to standalone renewable and storage resources, Hybrid Resources will:
  - Gain rapid access to participation by using whatever existing flexible, conventional market participation model the Market/System Operator prefers the Hybrid Resource to use;
  - "Drop in" and be treated like a Conventional Resource with full co-optimization of energy and ancillary services offers using the existing day ahead and real time constructs;
  - Allow the renewable component of the Hybrid Resource to generate fully without the need to be curtailed to retain headroom, while maintaining the ability to provide ancillary services;
  - Allow the storage component of the Hybrid Resource to be charged from the renewable component of the Hybrid Resource (or charged from the grid, when optimal to do so); and
  - Comply with incentives/penalties for performance at the POI that are identical to those currently used for Conventional Resources.

[9] Briefly, for our purposes here, "convex" refers to nondecreasing incremental energy offers, which provide significant economic and computational advantages for optimal market solutions, and three-part offers include startup cost and no-load cost in addition to the energy offer. Utilities historically used three-part offers to make commitment and dispatch decisions, and U.S. ISO/RTO markets adopted the three-part offer approach even though other commodity markets (and the UK energy market) use one-part offers. For a wonderfully clear and entertaining explanation of economic convexity and offers, see **https://www.iso-ne.com/static-assets/documents/2015/06/price_information_technical_session11.pdf**.

Hybrid Resources benefit the Market/System Operator by enabling it to:

- Utilize existing "conventional" market participation models, rather than develop new "custom-fit" hybrid participation models;
- Treat the Hybrid Resource as a Conventional Resource, rather than attempt to force-fit it into an existing renewable resource or energy storage participation model;
- Delegate battery storage state-of-charge management to the Hybrid Owner/Operator, with the Hybrid Owner/Operator managing this through their offers;
- Receive offers of energy and ancillary services from Hybrid Resources in both the day ahead and real time markets;
- Co-optimize energy and ancillary services offers from Hybrid Resources as it would for Conventional Resources;
- Provide ancillary services and grid services such as primary frequency response (and fast frequency response, and even future synthetic inertia, if needed) without having to curtail renewable production to maintain headroom; and
- Take advantage of fully convex, one-part offers without advance commitment requirements, startup costs, minimum generation levels or other constraints.

Hybrid Resources constructively motivate Hybrid Owner/Operators to design, offer and operate their resources in appropriate ways that benefit the system by:

- Optimizing their power plant design to maximize the services that are useful to and valued by the system while minimizing their risk of delivering such services;
- Using the best available forecasts of the renewable resource (and investing in improving those forecasts, including probabilistic forecasts that better reflect risk and certainty around the forecasts) because this allows them to offer larger volumes of the services while managing their risks;
- Building battery state-of-charge assumptions and battery degradation costs into offers using their access to all components and information, and analyzing how their algorithms for complying with dispatch instructions, renewable resource variability and forecast errors will relate to their specific state-of-charge and degradation characteristics; and
- Forecasting and offering their services to ensure that they are most available during the most critical hours of system need, as this should align with periods of highest value.

Detailed Example – PV + Battery Hybrid Resources vs. Standalone PV Resources

Below we provide a specific example of how the Hybrid Resource concept would apply to the design and offers of a transmission-connected PV + Battery Hybrid Resource without charging from the grid.[10] In the near term, this is a useful and practical example because it represents the majority of Hybrid Resources that are currently being proposed and developed. It is also a simpler concept that focuses on the critical attributes of the Hybrid Resource power plant without enhancements or complications.[11]

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[10] If desired, a PV + Battery Hybrid Resource could switch to use a battery participation model at night for grid charging to take advantage of very low night prices and be fully charged for early morning grid services, but this is the exception rather than the rule for Hybrid Resource operating mode, and there may be reasons why the Hybrid Resource would not wish to be used in this way. Alternatively, in cases where the System Operator must slow the morning PV ramp, the battery may want to be partially discharged to capture ramp-limited or curtailed energy.

[11] This is not to say that extensions and generalizations of the Hybrid Resource construct are not important and likely to happen quickly. Depending on the market, specific participation models for Hybrid Resources may already be available for use. Also,

The design of a PV + Battery Hybrid Resource is different from the design of a standalone PV resource.

- The optimized design for a standalone PV resource will often have a 1.3 DC/AC ratio with some clipping during peak solar intensity periods. This ratio means that the PV arrays can produce 30% additional direct current energy beyond the POI interconnection limit during the sunniest times. While some of this extra energy will be discarded ("clipped") during these peak periods, the extra energy serves to provide the most cost-effective overall annual energy production given the solar variability and internal electrical losses.
- For a PV + Battery Hybrid Resource, the extra energy from the PV panels can be stored in the battery rather than being curtailed or discarded. Thus, optimized hybrid designs have a much higher DC/AC ratio (e.g., perhaps 1.8 DC/AC ratio or even higher), with the extra energy available for charging the battery and providing other services.
- As shown in Figure *1*, the higher ratio increases the plant's PV energy production due to the broadening of the shoulders of the solar power curve and by making more PV power available at all solar conditions (i.e., the PV output is increased and spends more time in the "clipped" range, at or above the interconnection limit at the POI).
- Knowing that the plant will operate as a PV + Battery Hybrid Resource may influence other technology choices, such as preferring bifacial PV panels that further broaden energy production on the shoulder periods and during cloudy/hazy conditions, or changing the layout and orientation of PV panels, as the high DC/AC ratio may already provide ample midday energy.
- The higher DC/AC ratio and other design choices, coupled with the flexible capabilities of the battery, can work as a system to make the Hybrid Resource's output more certain and controllable (e.g., the PV output spends more time in the "clipped" range where there is ample PV output to deliver to the grid and the variability is absorbed by the battery charge rate). Plant design can be optimized to improve forecasting skill and reduce risk in a cost-effective manner.
- As we will see below, these reductions in the variability and uncertainty at the POI (and also the ability of the market participant to use probabilistic forecasting information in their offers and in the operation of the hybrid plant) provide benefits to the system in terms of the energy and ancillary services that the PV + Battery Hybrid Resource can offer.

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although we will focus on transmission-connected hybrid resources, the concepts can be extended to distribution-connected Hybrid Resources and aggregated distributed energy resources.

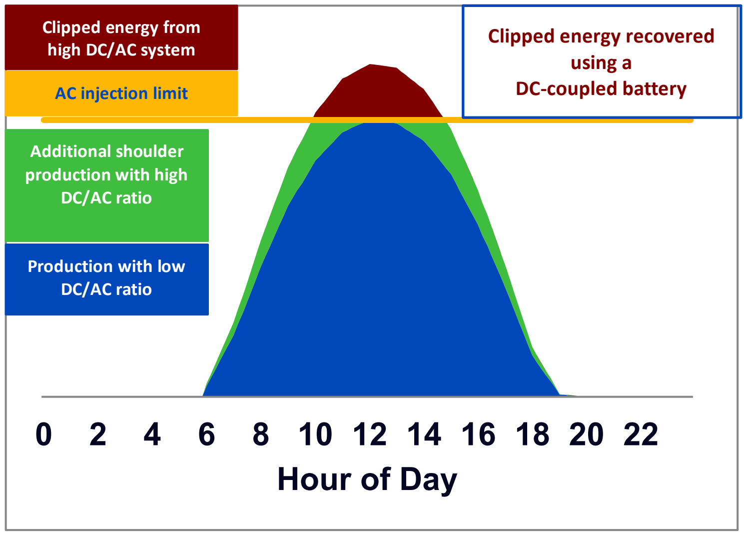

Figure 1. Comparison of PV and PV + Battery Hybrid Resource optimized plant design

Offers of energy and ancillary services for a PV + Battery Hybrid Resource are different from offers for a standalone PV resource.

For a standalone PV resource, offers of firm energy and ancillary services would require maintaining PV headroom to provide responses that require increasing the power level and to account for normal variability of the solar irradiance within the hour. PV + Battery Hybrid Resource offers are completely different, based on 1) a high-probability solar forecast of energy for the offer period, and 2) the capacity and performance of the battery. The operating strategy is to generate power from the PV resource at all times, and to use the battery's rate of charge to create headroom and other services offered at the POI.

The PV + Battery Hybrid Resource can improve on standalone PV power plant forecasting accuracy in a number of important ways. For example, total output at the POI is more predictable due to the higher DC/AC ratio and the coordinated use of the battery, and the relative sizing of the battery power (MW) and battery duration (MWh) can be a design parameter that is optimized for the characteristics of the site, the market and the services that are likely to be of most value. The multi-hour capacity of the battery can be used to smooth shorter-term variability and PV forecast errors, particularly for partly cloudy situations that cause dramatic minute-to-minute variability while having more predictable total energy across an hour or two. For example, the Hybrid Resource can offer energy, regulation and spinning reserve at a high-probability solar forecast confidence level, then the battery can be used to further improve on the confidence level and to charge with the excess energy that is cleared but not deployed for regulation and spinning reserve.

For both offers and performance, PV + Battery Hybrid Resources can mitigate the energy-limited nature of separate PV and battery resources.

When allowed to control the operation of the PV and battery technologies behind the POI and make integrated offers as a single resource, PV + Battery Hybrid Resources are internalizing energy management considerations into their offers. During many daytime hours, offers are largely based on the solar energy forecast rather than the battery size or duration (i.e., the battery removes variability and short-term uncertainty, not as the primary source of net energy to satisfy the energy and ancillary service offers). The Hybrid Owner/Operator can implicitly control the state-of-charge through the types of services that are offered for various periods. For example, when it is best to increase the battery's state-of-charge during that period, offers of more spin or regulation-up will tend to do so, as the PV + Battery Hybrid Resource will usually be charging the battery to create the headroom for the spin or regulation-up service, and when deployed for the service will simply slow the battery rate of charge.

Offers during low solar hours (e.g., sunrise/sunset and night hours) are based on the PV + Battery Hybrid Resource's perception of its future opportunity cost for its stored energy and its ability to replenish energy (e.g., from "clipped" PV production over the future time periods, as discussed above), and these perceptions of future opportunity cost will also reflect the PV + Battery Hybrid Resource's projections of forward prices and influence its internal optimization strategy for charging the battery.

Under existing market participation models for Conventional Resources, when the PV + Battery Hybrid Resource perceives that it may have limited energy available and its perception of the future opportunity cost must be considered, there are multiple approaches that could be used in the market:

- The PV + Battery Hybrid Resource could offer energy only into the future hours where it wants to clear (i.e., saving itself for future hours of most need, and clearly telling the Market/System Operator when it expects those hours to occur via its offers). In this case, the PV + Battery Hybrid Resource is taking the risk for when it wishes to be cleared.
- Alternatively, the PV + Battery Hybrid Resource could include opportunity cost in its offer for all hours (i.e., the System Operator is responsible for ensuring that prices properly reflect the need, and to clear and dispatch the PV + Battery Hybrid Resource in a way that reflects energy limitations from the resource).

Ancillary services, particularly those that are energy-neutral by design, can continue to be separately co-optimized during all hours (taking energy constraints into account for services that deplete stored energy, particularly during non-daylight hours). Ideally, future ancillary services that more directly reflect the future system needs for balancing, flexibility and other grid services will be created. This could further simplify the offers, clearing and volumes of the valuable services from PV + Battery Hybrid Resources.

Comments on Interconnection, Capacity Accreditation and Market Power

A Hybrid Resource is a highly flexible resource that is being planned, designed and operated with the most sophisticated of analytical capabilities. This is a huge advantage to the power system because the Hybrid Resource will respond logically, flexibly and quickly to price signals, congestion, contingencies and control signals. Some assumptions in our current interconnection and capacity accreditation processes may need to be revisited if they assume a more static and less responsive resource, as it would be wrong to penalize resources for being flexible, logical and responsive.

Ironically, some seem to view this level of flexibility and logical behavior as a concern, largely because they are used to resources that don't have it. Some also suggest that this intelligence and flexibility would be used for nefarious purposes, even when such actions would be illogical and counterproductive for the Hybrid Owner/Operator. There is always the possibility that market flaws that were not otherwise apparent with conventional resources will become a concern with more flexible resources, or will be identified by the analytics used to optimize their offers and operations. This should not be an argument against logical and intelligent market participants or flexible resources, but it does suggest that Market/System Operators and market monitors, as always, need to remain vigilant and identify gaps or flaws in market designs. However, any suggestion that an intelligent and logical market participant is somehow a special concern is perplexing, particularly when other markets would love to have more logical market participants (and the assumption of a logical participant is core to the underlying theory of market design itself).

For interconnection studies and dispatch assumptions, the Hybrid Owner/Operator would be responsible to ensure that the Hybrid Resource never exceeds its interconnection limit at the POI, and it will logically respond immediately to local price signals, so there is no justification for assuming otherwise. For Hybrid Resources like the PV + Battery Hybrid Resource in our example, the same inverter is used at all times, therefore the electrical properties are also unchanged regardless of how the Hybrid Resource is operating, configured or even modified behind the inverters. It will be common to add storage to existing PV and wind plants in the near future to create Hybrid Resources, so given these reasonable and logical assumptions, PV or wind that subsequently adds storage should not be required to go through a new interconnection process provided that the Hybrid Resource will be operated to stay within the interconnection limit that was specified in the original interconnection agreement; such changes should typically be treated as a non-material modification of the interconnection agreement.

For capacity accreditation, a Hybrid Resource will be highly motivated to provide its energy during the periods of greatest system need (i.e. the periods with the highest price for the services) and to store its energy production during periods of excess grid supply. This behavior is, in many ways, superior to the usual assumption that generators provide flat blocks of power that will hopefully align with critical periods of system need. So, for example, whether based on the system's future notifications or indicative price forecasts, or on the Hybrid Resource's own forecasts of future need, the Hybrid Resource will optimize its available capabilities and opportunity costs to maximize the benefit that it can provide to the system for critical periods of possible shortage events. For example, some system operators such as CAISO now experience a "peak shift" — the high volume of solar energy on the system reduces the normal late afternoon peak, after which air conditioning demand continues to rise as solar production declines creating a new "net peak" just after sunset. Hybrid Resources are well-suited to provide continuous energy output to serve the new net peak as a clean alternative to gas generation, so their capacity accreditation should reflect this value. While this may challenge simplified methods of capacity accreditation, it is extremely likely that a Hybrid Resource with a renewable energy source (such as PV) and flexible storage (such as several hours of batteries) will provide very high capacity value to the system.[12]

In a future with growing contributions from highly flexible resources and variable energy resources, it is quite likely that the concept of capacity value should be revisited. Some experts are encouraging a move from traditional "effective load carrying capability" methods toward more dynamic "expected unserved energy" methods with additional consideration of scenario analysis and probabilistic methods.[13] Increasingly, we should look for ways to close the gaps between the models, data and software that we use for planning, assessment, markets and operations, and take advantage of the latest computing capabilities to use more realistic simulations for assessing the capacity contributions of all resources.

Fundamentally, the purpose of "capacity" is to ensure the availability of sufficient resources for maintaining a balanced (and therefore reliable) system at all times. While peak load hours and longer-duration capacity will continue to be part of the need, it is likely that shorter and more dynamic products and responses will be of growing value as well. A critical role of Market/System Operators will be to ensure that prices reflect the value being provided toward maintaining a balanced and reliable

[12] Hybrid Resources should also be more adaptable to longer-term changes in the needs of the system, and able to reduce stranded asset risk, because many services can be augmented or created in software. This is a very valuable (and increasingly necessary) feature of resources, and this robustness to change should support high long-term capacity value.

[13] See, for example, http://www.milligangridsolutions.com/Milligan-Comments-FERC%20from%20ferc%20web.pdf

system, and to create products and services that more directly align with these system needs. For example, if future system needs are more effectively satisfied by specific services on faster timeframes (five-minute, one-minute, four-second, or sub-second/autonomous), it may be inefficient or even counterproductive to use coarser services. Given clear indications of what services are most needed, preferably through market products that directly align with those services and with prices to show when they are needed, Hybrid Resources and other flexible resources will quickly adapt to fill the need.

Finally, it should become clear that combining limited energy and flexibility capabilities to be able to provide the maximum benefit during the system's critical periods, and to logically and consistently reflect the opportunity cost of doing so, is a benefit to the system. Market products that attempt to retain ramping capability or do look-ahead commitment and dispatch are doing the same thing, and if intelligent resources can contribute similar benefits through additional forecasting and analytics, so much the better. There will be large and growing populations of Hybrid Resources on the system, and this population of market participants should behave independently and logically based on the diversity of their location, situation, risk tolerance, capabilities and opportunity costs. Operating within the boundaries of market constructs that are fair and consistent for all market participants, this will provide more efficient market outcomes.

Conclusion – Creating the Platform for Innovation

We are early in the exploration and innovation of what we can do with Hybrid Resources, both for renewables and perhaps for conventional energy sources combined with physical storage or storage services. While we use a concrete example of the PV + Battery Hybrid Resource in this paper, we believe that other technologies will realize analogous opportunities for internal optimization and innovation on the Hybrid Owner/Operator's side of the POI, with similar benefits provided to the Market/System Operator as a result of this innovation.

Down the road, the characteristics that Hybrid Resources will offer to the Market/System Operator should allow consideration of simpler markets and changes to operating practices. As we have noted, there are numerous benefits to the internalization of non-convexities, prevalence of one-part offers, elimination of uplift payments, and ancillary services that directly correspond to the higher-level grid service needs for balancing, flexibility and reliability.

Today, however, Hybrid Resources can immediately participate in current market designs as highly flexible resources that are treated comparably to Conventional Resources. We believe that currently proposed Hybrid Resources (including PV + battery and wind + battery hybrids) will be very cost effective and extremely capable sources of capacity, energy and ancillary services. Other than some fairly straightforward updating of capacity accreditation rules and clarification of interconnection requirements, there are no significant obstacles for the use of Hybrid Resources in our current markets and power systems, and many advantages over today's separate use of the components, so we should proceed with using Hybrid Resources under existing participation models and rules that are essentially the same as those in place for Conventional Resources.