Will you be there for me the whole time? On the importance of obligation periods in design of capacity markets

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ABSTRACT

This paper discusses the importance of length of capacity products traded in wholesale capacity markets when there is seasonal variation in both the electricity load and the electricity generation. We first discuss how investments and bidding behavior are affected by the length of the capacity product traded in the market. Then, we explain the potential welfare consequences of procuring subannual capacity product in addition to annual capacity product.

1. Introduction

Even though capacity markets have been around for two decades, the necessity as well as the design of these markets are subjects of ongoing debates. Many design questions, such as how to determine the amount of capacity to be procured, how to prevent market power, or how to provide incentives for performance dominate both the academic literature and the policy-making discussions.\textsuperscript{1} However, a thorough analysis of one crucial design aspect — the length of the capacity product procured ("obligation period") — has been overlooked. Yet, the capacity obligation period, because it defines the length of time for which a seller commits to maintaining its capacity available, plays a crucial role for market participants.

A longer capacity obligation period implies reduced price volatility and less price risk, and as a result it can help generators secure more favourable borrowing terms in financial markets. On the other hand, because the electricity demand varies significantly over time, a shorter capacity product means better alignment between the needed and the procured amounts of capacity. Shorter commitment duration is also favorable to generators characterized by seasonal generation capabilities because capacity products with long durations, e.g. annual capacity products, limit what those generators can offer. The same is true for units scheduled to come online or retire in the middle of a year.

Consequently, long obligation periods might encourage the creation of more capacity than needed for reliability purposes.

Currently, there is a wide variation in the types of capacity products traded around the world. For example, in the United States, PJM procures only an annual capacity product, while NYISO procures winter and summer capacity products, with incremental monthly auctions. In the United Kingdom, existing plants and technologies such as storage and demand side response could receive contracts for a year, while new plants could have contracts for up to 15 years.

Despite the potential stark welfare implications of the chosen obligation periods, to the best of our knowledge, no comprehensive analysis on the efficiency implications of the length of the procured capacity product has been done. The question of the optimal length of procurement has been studied in economics, but mostly in the context of infrastructure procurement tenders (Engel et al., 1997; Greve and Pollitt, 2017), often with the focus on optimal project financing (Greve and Pollitt, 2017) or contract-specific investments (Joskow, 1987). However, the lessons learned through those studies cannot be easily applied to today's capacity markets because of the various idiosyncrasies of the current capacity market such as the changing physical ability on the supply side, among others. We know of only two papers that analyzed different contract durations for capacity procurement. The study by Just (2011) investigates markets for reserve capacity in

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\textsuperscript{1} See for instance (Cramton and Stoft, 2005) and (Brown, 2018).
Germany, but the author looks only at the seasonality of load and disregards the seasonality of supply. And Stauffer (2006) focuses solely on the role of financing costs for capacity market design.

As the share of renewable resources such as renewables grow, and newer technologies enter the market, understanding how generation and load seasonality affect the optimal capacity market design, and identifying conditions under which one market design dominates others, is crucial to ensuring the functionality and efficiency of capacity markets. Capacity market revenue is substantial and for some resources it constitutes a major source of revenue. Therefore, changes in the design of capacity markets can strongly affect the generators’ entry and exit behavior.

In this paper, we start to fill this gap by discussing how variations in the availability of various resources (generation seasonality) and the fluctuations in the electricity usage (load seasonality) relate to efficient capacity market design.

Our goal is to understand how the length of the capacity commitment affects the efficiency of a capacity market. In particular, we are interested in the welfare effects of shortening the obligation period given the increasing share of renewable resources which tend to have seasonal generation. Once we understand these effects and their directions, the optimal length of the obligation period can be debated: Should the cleared capacity be committed for a full year, for a period of couple of months, or for a day? Should the capacity be procured separately for night- and day-time?

Our paper adds to the current literature in at least two ways. First, we believe we are the first to point to the importance of the obligation duration for the efficiency of capacity market design. While there have been studies that looked at seasonal variation in outputs (e.g. Bothwell and Hobbs, 2017; Keane et al., 2011), a comprehensive discussion of implications of that seasonality for costs of procuring capacity and its interactions with load seasonality has been lacking. We identify the relevant seasonality factors and provide a high-level discussion of their relationship to efficiency of capacity markets. We also discuss how policymakers should take these factors into account when designing the capacity markets.

Second, we develop a framework for studying how the factors we identified interact with each other and how to model the welfare effects of the obligation period. We thus enhance the approach to modeling capacity.

The rest of the paper is organized as follows. Section 2 explains the factors that affect the optimal design of seasonal capacity markets. Section 3 analyzes different combinations of load and generation seasonality to learn about the implications of shortening obligation period under different circumstances. Section 4 summarizes the policy implications.

2. Seasonality-related factors to consider in designing capacity markets

As this paper argues, the optimal design of capacity markets, in particular the optimal length of the obligation period, depends on the interactions between several factors. Before discussing how the optimal design varies under different circumstances, it is helpful to review these factors individually to develop the intuition. Below, we discuss each of these factors and study how they relate to designing the obligation period.

2.1. Load seasonality

Electricity usage fluctuates in a relatively predictable manner over time. The fluctuations are partly determined by weather patterns: in the summer, there is additional electricity demand driven by air conditioning, and in the winter the additional demand occurs because of electric furnaces, heat pumps, space heaters, electric blankets, and the need for additional lighting. And, the peak load in these seasons generally occurs in the hottest days and the coldest days. Fall and spring periods, on the other hand, are usually characterized by relatively low loads.

For example, in PJM, the summer load peaks above 150,000 MW, the winter load peaks around 135,000 MW, while the peaks in the spring and fall range between 110,000 MW - 120,000 MW. For example, in PJM, the summer load peaks above 150,000 MW, the winter load peaks around 135,000 MW, while the peaks in the spring and fall range between 110,000 MW - 120,000 MW.5

In addition to fluctuating between the seasons of year, the load exhibits systematic variation between night and daytime, with day usage being sometimes twice as high as the usage in the early morning hours.6

Those above described load patterns are illustrated in Fig. 1.

This systematic variation in load implies that the amount of capacity sufficient to maintain reliability of the system also varies cyclically. However, if the obligation period is defined as one year (annual capacity product), then the amount of capacity that needs to be procured has to be based on the highest demand throughout the year, which in most of the U.S. systems is the summer daytime peak. Clearly, this implies overprocurement of capacity for the rest of the year. Shortening the obligation period allows tailoring the capacity procurement to the actual needs for capacity. For example, based on Fig. 1, it might be rational to consider a winter-only and a summer-only product, with obligations only in their respective seasons, in addition to an annual capacity procurement. Of course, any potential cost savings depends on properties of the supply, in particular the offer bids submitted for the shorter product.

Economic models that disregard the seasonal load fluctuations will overlook the problem of capacity overprocurement in some seasons, and, thus, might draw incorrect inferences about the efficiency of various capacity market designs. Importantly, both the load variation throughout the year (seasons of year cycle) and throughout the day (day-night cycle) matter for the efficiency of design. We will refer to both of those types of fluctuations as “load seasonality” to emphasize that they have similar implications for market design.

2.2. Generation seasonality

The generation performance of some resources, like nuclear power plants, is relatively constant throughout the year. Therefore, those resources are referred to as “annual resources.” Many generators, on the other hand, have a recurring time pattern to their generation. For instance, as a result of wind patterns, wind resources are least able to deliver energy in mid- to late summer, while they have high generation potential in winter and spring months. Their generation capability is also usually higher at night than during the day (Coughlin and Eto, 2010). Solar photovoltaics are twice as productive in the summer as they are in the winter. However, the power and efficiency of combustion turbines sharply increase with decreasing temperatures, leading to the highest generation capability for combustion turbines during the coldest months in the winter.7


For instance, in PJM on the 9th of July 2018, the load at 3am was 69,677 MW and 133,482 MW at 5 pm (Eastern Prevailing Time).


As EPA explains, “At elevated inlet air temperatures [the power decreases
generation capability varies considerably across regions, but in general their magnitudes can be very high.⁸

We will refer to the predictable fluctuations in generation capability as “generation seasonality,” notwithstanding whether the fluctuations are driven by the differences in performance throughout the seasons of the year cycle or the day-night cycle. To quantify that variation in generation capability, we will use the fraction of nameplate capacity that is the potential achievable performance in a given time period, and refer to it as “effective capacity.”⁹

With an effective capacity of 1, the generator needs a 1 MW facility to deliver 1 MWh of electricity within one hour. With an effective capacity of 0.5, the facility needs 2 MW of nameplate capacity to deliver the same output.

The cyclicality of generation capability of individual resources can translate into the cyclicality of the whole generation fleet. In other words, the capacity supply might exhibit strong fluctuations even when the fleet of generators, and, therefore, the resource mix, is kept constant. Should this be the case, the equilibrium capacity prices would vary between seasons for subannual capacity products. And indeed, in NYISO, where capacity is procured separately for May to October and November to April periods, there are striking differences between seasons for subannual capacity products. And indeed, in NYISO, where capacity is procured separately for May to October and November to April periods, there are striking differences between summer and winter auction results. Fig. 2 shows the capacity bids (the supply curves) in NYISO for summer and winter auctions in 2015, 2016, and 2017. The summer bids are almost twice as high as the winter ones. Given that NYISO’s generation mix includes a substantial share of resources with higher winter generation capabilities (wind and combustion generators) (Power Trends, 2018), the bidding behavior corroborates our above discussion. As Table 1 shows, the distinct supply curves, combined with NYISO’s higher summer demand for capacity, led to drastically higher summer clearing capacity prices.

When bidding into a market, resources are often allowed to offer only their lowest effective capacity value for the obligation period. For example, in PJM, where only an annual capacity product is traded, combustion turbines get assigned their summer capacity factor even though their effective capacity in the winter is much higher. A report (Newell et al., 2018) estimated that in the November 2017 to April 2018 period, the combustion turbines capacity in PJM was 9,500 MW higher than in the rest of the year. Clearly, PJM’s rule of assigning minimum effective capacity as the bid, combined with long obligation periods, does not allow for taking full advantage of the existing resources for ensuring reliability. Consequently, it might encourage new entry even when the existing capacity is sufficient to cover the load needs.

Similarly, economic modeling that assumes resources have constant effective capacity throughout the year will misrepresent the minimum costs for ensuring reliability.

2.3. Aggregation of seasonal resources

Even with capacity markets that procure exclusively annual capacity commitments, a purely seasonal capacity resource might still have the possibility of market participation. Most capacity markets have provisions allowing seasonal resources to aggregate their generating capabilities with capabilities of resources from “opposite” seasons and to submit a joint offer. With such an aggregation, the joint effective capacity is relatively constant throughout the year.

(footnote continued)

due to the decreased air flow mass rate (the density of air declines as temperature increases), and the efficiency decreases because the compressor requires more power to compress air of higher temperature⁸ (U.S. Environmental Protection Agency Combined Heat and Power Partnership, 2015). For an illustration of the relationship between ambient temperatures and the performance of turbines, see Figure 3-5 in (U.S. Environmental Protection Agency Combined Heat and Power Partnership, 2013).⁹

For more detail on wind seasonality in individual regions see U.S. Energy Information Administration, https://www.eia.gov/todayinenergy/detail.php?id=20112

For resources with marginal costs close to zero, effective capacity can be approximated by a relatively well-known measure of a resource’s operation — capacity factor (the ratio of actual output over a period of time, to the potential output if the resource could operate at full nameplate capacity continuously).¹⁰

Winter peak demand in NYISO corresponds to around 25,000 MW, whereas the summer peak is slightly above 30,000 MW.

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Fig. 1. PJM’s load patterns across the year (left) and across the day (right). Each point represents the highest load level that occurred in years 2012-2017 on a given day (left) or hour (right). Hourly load is represented for September 7th. Source: Own calculations based on PJM metered hourly data.

Fig. 2. Bids into NYISO winter and summer strip auctions. Source: NYISO.

(footnote continued)
As there are many possibilities for designing the aggregation process, the implementation differs significantly across regions. At the same time, the details of aggregation rules determine the extent to which aggregation enables the participation of seasonal generators, and thus increase efficiency of the market.

Perfect aggregation rules would fully incorporate the seasonal character of a resource by allowing it to bid different amounts of capacity in different subperiods of the obligation period, according to its seasonal effective capacity. A good aggregation rule would also create no barriers to matching between the resources. For instance, by imposing how the capacity payments are to be split between the matched resources, the rule might prevent some beneficial matches from being formed. For the effectiveness of aggregation, absence of transaction costs for match searching is also necessary.

The existing aggregation rules, though, often hinder effective matching, and therefore the participation, of seasonal resources. For instance, in PJM, the winter increase in the generation ability of combustion turbines remains unrecognized as the market rules allow turbines to offer only their summer effective capacity levels. A report by Brattle Group (Newell et al., 2018) found that as a consequence of that, almost 10 GW of capacity could not match and aggregate. Additionally, PJM imposes an equal split of capacity payments between two matched resources. However, with such a split of revenues, a more expensive resource may not see its capacity cost recovered even after clearing an auction, thus preventing a match from taking place.

While well-designed aggregation rules enable participation of seasonal resources, thus increasing the cost-efficiency of the market they do not fully alleviate problems associated with seasonality. In particular, they can’t remedy the problem of capacity overprocurement that exists when load is changing seasonally but the obligation period is relatively long.

The existence and design of aggregation rules need to be considered when modeling the capacity procurement in the context of seasonality, otherwise the estimates of cost of reliability will be biased.

### 2.4. Dynamic bidding behavior, cost structures, and mothballing

The cost effectiveness of a given obligation period duration hinges on many other factors in addition to the aggregation rules and the seasonality patterns themselves. Two factors are of particular importance: the cost of providing capacity and the possibility of mothballing. Those factors can change the welfare implications of various market designs by affecting the saving potential from changes in obligation period and by changing the bidding behavior by firms.

The cost of providing capacity is often associated with just the fixed costs of construction. However, generators also incur costs of keeping the generator ready to run, like non-fuel Operation and Maintenance Costs, Selling, General and Administrative Expenses, property taxes, insurance and similar. Those costs are sometimes referred to as “costs of going forward” and can be very significant. Consequently, even if the energy market revenues are sufficient to cover the variable costs of generation, they might not be sufficient to cover the costs of going forward and thereby allow the generator sustained operation.

As capacity markets are meant to enable the recovery of such non-generation costs, competitive bids represent the amount of capacity revenue that a generator needs to stay in the market, adjusted by the costs of committing the capacity. The costs of capacity commitment encompass the risk of non-performance penalties caused by outages, as well as opportunity costs of committing capacity. For simplicity, we assume that the costs of committing capacity are zero.

Importantly, in determining its bid in a given period, a generator looks at all of the expected profits over all future periods in which it expects to operate, not just the single period in question. As a result, the minimum capacity payment a generator is willing to accept ensures that it does not incur losses over its lifetime. In other words, a generator might be willing to accept a loss in a single period if it expects to have high revenues in other periods that will compensate for the loss. This dynamic nature of bidding behavior becomes especially important with subannual obligation periods (“seasonal capacity markets”), in which case the expected clearing prices vary between the seasons.

Another predictor of bidding behavior associated with a particular seasonal design is the availability of mothballing and the fraction of going forward costs that are avoided by mothballing. Mothballing refers to deactivation and preservation of equipment or a production facility for possible future use or sale. On electricity markets, there have been prominent examples of that behavior. For instance, in ERCOT in 2017, over 2.5 GW of capacity was mothalled, and one of the generators, a 470 MW coal-fired plant, Gibbons Creek, is scheduled to operate only between June 1 to September 30 each year (SARA, 2017). Mothballing can have significant effects on generator behavior as well as efficiency. For example, with many short obligation periods, annual resources risk clearing some but not all of the capacity auctions in a given year. If the annual resource cannot avoid any of its going forward costs by mothballing for part of the year, then its failure to clear the market in some of the seasons would be socially inefficient. Not only it would save no costs, but also because some other, possibly newly constructed, resource would be cleared total social costs can increase.

Additionally, if that annual resource expects not to clear in some season, it could increase its bids in other seasons to ensure it can recover its cost of going forward, driving up the capacity prices in the seasons whenever the unit is on the margin. In such a case, it is conceivable that introducing seasonality into capacity markets would decrease market efficiency and increase total payments to generators.

However, if capacity costs can be avoided through mothballing, the annual resources that fail to clear in a particular season could mothball during those times to prevent losses. In the extreme case, when mothballing can reduce the going forward costs directly proportionally to the share of time spent mothballing, an annual resource would be extremely flexible in its ability to participate in the market. It could choose to participate in only some seasons, and therefore, from the perspective of the system, could be thought of as a flexible combination of seasonal resources.

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11 The implementation in PJM is referred to as “resource matching”, ISO- New England as “composite offers”.


13 Notice that, as energy storage technologies are still under development, electricity produced in different time periods is a distinct product. This allows for clearing prices to fluctuate predictably over time.
Consequently, mothballing also impacts the general bidding strategy. If a generator expects to make a high level of profits in the future and mothballing is not a viable option, it will be willing to operate in the near future even at a loss. Therefore, it could even submit a zero bid into the capacity market. On the other hand, with cost-effective mothballing, the generator would never operate at a loss, but instead shut down and re-open once the economic conditions are favorable again. Thus, it would never bid below its one period going-forward costs, adjusted downwards by costs of mothballing.

The existing literature tends to overlook the going forward costs, as well as the potential to mothball. Often it is assumed that after the initial investment costs, generators incur no further fixed costs, leading to the bids being just a reflection of market power (Brown, 2018) or a reflection of the opportunity cost of committing capacity to a given market (Creti and Fabra, 2007). While such abstraction can be used for studying issues like the equilibrium capacity amount, it does not allow for investigating how the bids of the generators, and the efficiency of equilibrium outcomes, would be impacted by seasonality. Further, disregarding dynamic effects rules out examination of other important determinants of efficiency such as entry and exit behavior or potential to mothball.

3. When short capacity obligation can be beneficial

There are two main potential sources of cost savings associated with shorter obligation periods. First, resources that are available only seasonally are able to participate in capacity markets without having to match with a resource from the other seasons. If those are cheaper resources that are unable to participate in annual auctions (for example, due to lack of a match for aggregation), then the introduction of seasonality can reduce costs. Second, the seasonal market allows different amounts of capacity to be procured in different seasons in alignment with seasonal variation in load. As a result, less capacity can be procured in some seasons, thus possibly reducing costs. The bigger the load fluctuations, the larger the cost-saving potential. Consequently, the welfare implications of the obligation period length are largely driven by interactions between supply and load seasonality.

On the other hand, shorter obligation periods might increase costs of financing for generators as revenue risk increases (see Greve and Pollitt, 2017) and (Stauffer, 2006)). Additionally, having shorter commitment periods implies an increased number of auctions run and higher complexity of the market, making it more costly for generators to develop an appropriate bidding strategy. Increasing the number of auctions can also increase administrative costs.

This section examines different configurations of generation and load seasonality to learn the total welfare effects of short obligation periods. We compare the cost outcomes of a uniform price auction with annual capacity product to costs when subannual products are introduced. We allow for co-existence of capacity products with varying obligation periods. For instance, if the load is constant for all the months but two in summer, the market could procure annual capacity corresponding to the non-summer load levels and summer-only capacity reflecting the summer jump in load.

For simplification, we make three important assumptions. First, we assume that the various auctions pertaining to a one year cycle are co-optimized.\footnote{Co-optimization of auctions (as done in many regions for energy and ancillary services markets) by choosing the combinations of bids that minimize the total costs leads to outcomes that are weakly more cost-effective than outcomes when auctions are not co-optimized.} Second, given that the electricity demand is relatively inelastic, we assume that the load profile is exogenous. As a result, we can infer the welfare consequences of a particular design by looking at only the cost of meeting that demand. In other words, when the demand is inelastic, economic efficiency requires minimizing the costs incurred to meet the demand.\footnote{These costs include up-front investment costs (I), fixed operation & maintenance costs (FOMC) associated with the capacity built, and the variable costs of energy generation (MC).} Third, to be able to focus on the potential cost impacts of seasonal capacity markets without introducing any confounding factors related to different characteristics of seasonal resources, we assume that the (constant) marginal cost of generation is the same for all resources.

3.1. Case 1: seasonal load, annual generation

Assume first a case in which there is seasonal variation in load, but all resources are annual. In this case, the procurement of an annual capacity product is cost-minimizing despite the seasonal fluctuations of load if resources cannot mothball. Even if a subannual capacity product is procured based on differing loads during the year, no costs can be saved because all resources still have to pay their full year-round costs and the amount of resources corresponds to the highest load (plus any reserve requirement) of the year. For example, in a two-season market, if a resource clears the summer auction but not the winter auction as a result of lower winter load, it will still incur its annual costs, leading to no cost savings from a societal perspective.

This result, however, changes if there is mothballing. If generators can avoid some costs by mothballing during different periods of the year, having subannual capacity products might be more cost efficient than using annual products only. The larger the cost-saving potential of mothballing, the smaller the changes in financing terms as revenue risk increases, and, the larger the magnitude of fluctuations in the load, the more probable that short obligation period is socially preferred.

3.2. Case 2: annual load, seasonal generation

Now, assume a case with no seasonal variation in load, but seasonality in generation. In this setting, whether a short obligation period is more efficient than an annual one depends on the aggregation rules.

With a perfect aggregation rule that assigns different effective capacity to resources in different seasons and costlessly matches resources, an annual capacity product would be efficient. But if there is less than perfect aggregation, then a shorter obligation period could improve efficiency. For example, in PJM, where some seasonal resources are assigned their annual minimum effective capacity when they bid, shortening the obligation period would allow seasonal resources to be assigned different capacity factors during the various periods. This, in turn, would reduce the amount of nameplate capacity that needs to be procured during those seasons, and, hence, could reduce costs. Here, the smaller the changes in financing terms as revenue risk increases and the more pronounced fluctuations in the load, the more probable that a shorter obligation period is preferred.

3.3. Case 3: seasonal load, seasonal generation

Finally, assume the more realistic scenario in which both the load and the generation capacity varies by season. In this setting, allowing subannual capacity products in the periods of spikes in load (e.g. summer capacity) in addition to annual procurement tends to increase efficiency.

This result is an extension of (Joskow and Tirole, 2007), which shows that, when there are generators with different marginal costs of energy generation and fluctuating demand, having one capacity market might fail to restore the efficiency.

The intuition for the welfare enhancing effect of subannual capacity products can be explained as follows: With load seasonality, the marginal value of a given capacity level differs throughout the year. With long obligation periods, the signals about the differing value of capacity
are muted. If there are generators that are particularly well-suited to provide capacity in the time of load spikes, but they do not receive the signal from the market to enter, strong inefficiency is created.

Therefore, whether the addition of subannual products strictly increases welfare depends largely on how well seasonal generation matches the seasonal load. For instance, if the load peaks in summer but seasonal generation is related to winter, the additional shorter obligation period cannot improve market efficiency.

3.4. Optimal obligation period

We argued that additional “shorter” obligation periods can be more efficient than annual-only products. The question then becomes, what is the optimal length and number of subannual capacity products? In the example above, for simplicity, we discussed summer and annual capacity products. In theory, though, there can be a separate capacity procurement for every day, or even every hour, of the year. Alternatively, there could be separate annual capacity products associated with daytime and nighttime. On the other hand, it is conceivable to introduce capacity procurement for one specific season (e.g. summer) but in a form of multi-year contracts to decrease the revenue uncertainty for generators.

The optimal capacity product portfolio will trade off the financing costs and complexity costs on the one side, and the costs of capacity overprocurement and costs of excluding seasonal generators on the other side. It will also need to consider the match between the seasonality in load and generation. We leave the derivation of the optimal capacity products based on the factors described above for future work.

4. Conclusion

With increasing penetration of renewable resources, which usually have seasonal variation in their generation capability, the questions of whether seasonal capacity markets are needed, and, if so how these markets should be designed are becoming important policy questions. As the discussion above shows, these questions have no trivial solutions. Whether or not seasonal capacity markets can improve efficiency depends on the interaction between the variations of generation availability and the variations of load, as well as a number of other factors such as aggregation rules and the ability to avoid costs by mothballing. The optimal choice of length of capacity product is also expected to vary strongly between the regions.

However, the complexity of the questions should not deter the discussion on, and a move toward, shorter commitments in capacity markets. As our discussion shows, given the seasonality of both load and generation, shorter obligation periods will likely improve the efficiency of capacity markets.

References


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16 Currently, the issue is hotly debated in context of the review by the U.S. Federal Energy Regulatory Commission of PJM’s lack of seasonal capacity products. See dockets EL17-32-000 and EL17-36-000.