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Virtual power plant auctions

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ABSTRACT

Since their advent in 2001, virtual power plant (VPP) auctions have been implemented widely. In this paper, we describe the simultaneous ascending-clock auction format that has been used for virtually all VPP auctions to date, elaborating on other design choices that most VPP auctions have had in common as well as discussing a few aspects that have varied significantly among VPP auctions. We then evaluate the various objectives of regulators in requiring VPP auctions, concluding that the auctions have been effective devices for facilitating new entry into electricity markets and for developing wholesale power markets.

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1. Introduction

Virtual power plant auctions are sales of electricity capacity which, rather than "physical" divestitures, are "virtual" divestitures by one or more dominant firms in a market. Instead of selling the physical power plant, the firm retains management and control of the plant, but offers contracts that are intended to replicate the output of the plant. Typically, these contracts are sold as divisible goods of varying durations, offered in periodic open and transparent auctions.

The motivation for and structure of a virtual power plant (VPP) auction is easiest seen by examining the Electricité de France (EDF) Generation Capacity Auctions, the world's first and longest-running series of VPP auctions. The EDF auctions began in 2001 as part of the regulatory *quid pro quo* for permitting EDF, the dominant electric utility in France, to proceed with the acquisition of a joint controlling stake in Energie Baden-Württemberg AG (EnBW), the fourth largest electric utility in Germany. The European Commission (EC) noted that EDF would be gaining joint control of one of the potential competitors particularly well placed to enter the French market, and the EC wished to require EDF to make available to other potential entrants a significant quantity of generating capacity in France. At the same time, given EDF's status as the largest nuclear producer in the world, the regulator recognized that physical divestment by EDF of its base-load nuclear plants would be undesirable in several respects. In particular, EDF had demonstrated a strong track record in the safety and security of its nuclear plants, and the public clearly benefited from economies of scale in EDF's management of nuclear plants. Consequently, the Undertaking agreed by the regulator and EDF in early 2001 provided for a virtual divestment by EDF of 6 GHz of French electricity capacity.

The VPP contracts offered in the EDF auctions are divided into two groups: base-load products and peak-load products. Each VPP product is an option contract for energy whose strike price approximates the variable cost of the respective energy. (For example, in the December 2009 auction, the strike prices of the base-load and peak-load VPP products were 10 €/MWh and 53 €/MWh, respectively.) As such, the base-load product is exercised essentially 24/7, whereas the peak-load product is exercised only a fraction of the time. Approximately 80% of the electricity capacity is offered as base-load products and approximately 20% is offered as peak-load products.[1] Within each of the two groups, a variety of durations would be offered: 3 months, 6 months, 12 months, 24

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[1] In the early EDF Generation Capacity Auctions, there were actually three product groups: base-load VPP products; peak-load VPP products; and Power Purchase Agreement (PPA) products. The intention was for a total of 4000 MW to be offered of base-load VPP, 1000 MW to be offered of peak-load VPP, and 1000 MW to be offered of PPA. The PPA product was essentially a firm base-load product from November to March. Experience showed that the market had only limited demand for the PPA product. The parties eventually agreed to reconfigure the auctions so as to replace the 1000 MW of PPA product with 400 MW of VPP product. Thus, in the recent EDF auctions, the total quantity offered has been 4400 MW of base-load VPP product and 1000 MW of peak-load VPP product.

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months and 36 months; all with the same starting date.[2] The principle followed for clearing is that all of the durations with a given starting date are treated equivalently for clearing: for example, 200 MW of a 3-month product offered in December, 200 MW of a 6-month product offered in December, and 200 MW of a 12-month product offered in December all count equivalently toward clearing. That is because each of these contracts has a start date of January 1st and, consequently, the sale of each of these contracts puts the same amount of electricity capacity in other parties' hands during the first quarter of the year. However, to the extent that the 3-month product is sold, an equivalent quantity will need to be auctioned again in March; to the extent that the 6-month product is sold, an equivalent quantity will not need to be auctioned until June; and to the extent that the 12-month product is sold, an equivalent quantity will not need to be auctioned until the following December.

The first EDF auction was conducted in September 2001; and, as of this writing, there have been 34 quarterly auctions successfully held. Meanwhile, the VPP auction has proven popular with regulators throughout Europe. The basic mechanism has been replicated for: Electrabel in Belgium; Nuon in the Netherlands; Elsam in Denmark; Endesa and Iberdrola, in combined auctions, in Spain; REN and EDP, in combined auctions, in Portugal; and E.ON and RWE, in separate voluntary auctions, in Germany. A similar structure was used in the Texas Capacity Auctions, in the US; and was planned in connection with the Exelon-PGE merger, in the US.[3] In addition, the so-called "gas release programme auction" — the natural gas counterpart of the VPP auction — has been utilized in Germany, Austria, France, Hungary and Denmark.

In requiring VPP auctions, regulators may be attempting to further any or all of the following objectives:

- Facilitating entry into the electricity market by assuring the availability to new entrants of electricity supplies on the high-power grid;
- Promoting the development of and adding liquidity to the wholesale electricity market; and
- Reducing market power in the spot electricity market.

This paper proceeds as follows. Section 2 describes and explores the various design choices that virtually all VPP auctions have had in common, while Section 3 focuses on a few aspects of the auction design that have varied significantly among the VPP auctions to date. Section 4 considers whether VPP auctions have been an effective tool for promoting each of the pro-competitive objectives listed above, and Section 5 concludes.

2. Commonalities in the design choices for VPP auctions

Virtually all of the VPP auctions that have been adopted in practice have made the same general design choice: a simultaneous ascending-clock auction with a discrete round structure. In this section, we describe the simultaneous ascending-clock auction and we explore the reasons for the unanimous choice.[4]

2.1. Simultaneous ascending-clock auction with discrete rounds

In the ascending-clock auction with discrete rounds, the following basic procedure is typically used:

- The auctioneer pre-announces an available supply, S, in the auction, which may be subject to a reserve price or an increasing supply curve;
- The auctioneer announces to bidders an interval of prices, $[\underline{p}_t, \overline{p}_t]$, effective for round t;
- Each bidder i simultaneously and independently submits its demands $q_i(p)$ for prices $p \in [\underline{p}_t, \overline{p}_t]$, during round t, where $q_i(p)$ is constrained to be a downward-sloping demand curve;
- Following round t, the auctioneer calculates the aggregate demand $AD \equiv \sum_{i \in I} q_i(\overline{p}_t)$;
- If $AD > S$, then the aggregate demand AD is disclosed to the bidders and the auction progresses to round $t+1$, in which an interval of prices $[\underline{p}_{t+1}, \overline{p}_{t+1}]$, where $\overline{p}_{t+1} > \underline{p}_{t+1} = \overline{p}_t$, is effective; and
- If $AD \le S$, then the auction concludes at a clearing price of $p^* \in [\underline{p}_t, \overline{p}_t]$, where p^* is typically selected to be the smallest p such that $\sum_{i \in I} q_i(p) \le S$.

When the ascending-clock auction involves multiple products, they are typically auctioned simultaneously. Products may be in the same product group or in distinct product groups. When products are in the same product group, it is possible for bidders to "switch" from one product to another as prices ascend; while when products are in distinct product groups, they are auctioned independently (but simultaneously). For example, in many of the auctions, base-load products of different durations have been assigned to the same product group, while peak-load and base-load products have been assigned to different product groups. The rationale for this grouping has been that base-load products of different durations are generally viewed as substitutes, while base-load and peak-load products are generally viewed as complements. As such, a bidder may wish to shift its demand among the different base-load products as prices evolve, but probably will not need to shift its demand between base-load and peak-load products.

2.2. Dynamic vs. sealed-bid

By contrast, in the standard sealed-bid auction, bidders have a single opportunity to submit demand curves $q_i(p)$ that cover the entire possible range of prices.[5] They do not receive any feedback about the bids of other bidders until the auction has concluded. Based on the single round of sealed-bid submissions, the auctioneer determines the clearing price p^* to be the smallest p such that $\sum_{i \in I} q_i(p) \le S$ (or the largest p such that $\sum_{i \in I} q_i(p) \ge S$). Each bidder i wins the quantity $q_i(p^*)$ and pays either p^* per unit (uniform-price auction) or the amount of its winning bid (pay-as-bid auction), depending on the exact auction format.

[2] Subsequently, a 48-month product has been added to the base-load VPP product group. Moreover, the September auction has offered additional products: in addition to the usual array of products with start dates of 1 October (one month after the auction), there are 2-month, 12-month, 24-month, 36-month and 48-month (base-load only) products with start dates of 1 November (i.e. two months after the auction).

[3] However, the Exelon-PGE merger failed to receive the approval of New Jersey regulators, and merger efforts were ultimately abandoned.

[4] Additional details and discussions relating to dynamic clock auctions may be found in Ausubel and Cramton (2002, 2004), Ausubel et al. (2002), and Ausubel (2004). An exploration of the relationship between VPP prices and spot prices in the French market can be found in Armstrong et al. (2007).

[5] Often, in sealed-bid auctions, bidders are permitted to submit multiple bids, each for a given quantity of electricity and at a given price. The reader should observe that, when bids of a bidder are expressed in the latter form, they may be combined together to form an inverse demand curve, and the expression of an inverse demand curve is almost equivalent to the expression of a demand curve. Thus, the latter form is almost equivalent to the submission by bidders of demand curves.

For virtual power plants, dynamic auction formats offer at least four decisive advantages over sealed-bid auction formats. First, dynamic auctions offer the greatest transparency and, by contrast, sealed-bid auctions are comparatively opaque. Recall that VPP auctions are frequently invoked as competition remedies for facilitating entry into markets with dominant firms; consequently, it is important to the credibility and success of the programs for competitors, regulators and the public to be able to see that the auctions are conducted fairly and in accordance with the published rules. The transparency of dynamic auction formats is thus an important property favoring their adoption for VPP auctions. Second, an ascending-clock auction is a particularly simple and effective format for obtaining price discovery. Since another frequent objective of VPP auctions is to jumpstart the development of wholesale power markets, the promotion of price discovery (which, in turn, facilitates wholesale power transactions outside the auction) is another valuable feature of ascending-clock auctions. Third, in trying to explain why dynamic auctions are growing in popularity relative to sealed-bid auctions, the literature has observed that bidders will be reluctant to reveal their valuations truthfully in an auction where the seller may have the opportunity subsequently to use the information against the bidders. By contrast, a dynamic auction avoids this problem, as it does not require the high-value bidders to reveal their true valuations — the bidding stops as soon as the aggregate demand becomes equal to supply. Again, this issue is likely to be important in VPP auctions, as the seller is a dominant firm, and the bidders are potential entrants. Fourth, the ascending-clock auction format scales particularly well to a simultaneous auction of multiple products, which are frequently present in VPP auctions. By contrast, independent sealed-bid auctions perform particularly poorly when substitutes — for example, base-load products of different durations — or complements — for example, base-load and peak-load products — are auctioned together.

Given these advantages, it is not at all surprising that essentially all virtual power plant auctions to date have utilized some variation on a simultaneous ascending-clock auction.

2.3. Discrete rounds vs. continuous bidding

Although in theory one can imagine implementing an ascending-clock auction in continuous time, this is hardly ever done in practice in auctions of high-valued items. VPP auctions inevitably use discrete rounds for at least three important reasons. First, communication is rarely so reliable that bidders would be willing to be exposed to a continuous clock. A bidder would find it unsatisfactory if the price clock swept past the bidder's willingness to pay because of a brief communication glitch. Discrete rounds are robust to communication problems. Discrete rounds have a bidding window of significant duration, rarely less than ten mintues and often a half-hour or longer. This window gives bidders time to correct any communication problems, to resort to back-up systems, or to contact the auctioneer and have the round extended. Second, bids need to be legally-binding commitments in order for an auction process to work as intended. This implies that bidders need to be given sufficient time to reflect upon, carefully enter, check and submit their bids, if bidders are going to be held to their bids. Third, a discrete-round auction also improves price discovery by giving the bidders an opportunity to reflect between rounds. Bidders need time to incorporate information from prior rounds into a revised bidding strategy. This updating is precisely one of the sources of price discovery and its associated benefits.

It is only in sequential *descending* clock auctions (Dutch auctions) that a nearly continuous bidding process is used. This is seen in Dutch flower auctions, many fish auctions, and US tobacco auctions since 2003. All of these auctions are conducted on-site (avoiding communication difficulties) and they all involve descending clocks (reducing the role for price discovery within the auction).

2.4. Divisibility of the product

Given that electricity is nearly a perfectly-divisible good, it is natural for the auction process to treat it as highly divisible. Thus, many VPP auctions (e.g. France, Belgium and Denmark) have used minimum bidding units of 1 MW, in auctions where anywhere from 100 to more than 1000 MW of contracts are offered. The initial Spanish VPP auctions used bidding units of 2 MW — that was because the auctions were conducted jointly for Endesa and Iberdrola, and so the minimum bid was 1 MW attributable to each seller. Later, the bidding unit was raised to 10 MW (5 MW for each seller). In the E.ON VPP auction, the minimum positive bid was 5 MW, but above that, the bidding unit was 1 MW; the minimum was only to establish a minimum scale where it would be worth setting up contractual arrangements with a winner.

2.5. Activity rule

To promote price discovery, activity rules are generally imposed in ascending-clock auctions. In an ascending-clock auction for a single product, the prevalent activity rule takes the simple form of a monotonicity constraint: each bidder's quantity demanded is not permitted to increase as the price increases, consistent with downward-sloping demand curves. Without the monotonicity constraint, a bidder might hide as a "snake in the grass" — grossly understating demands at low prices and then jumping in with large demands near the end of the auction. Widespread use of a snake-in-the-grass strategy would undermine the very purpose of utilizing a dynamic auction.[6] A monotonicity constraint prevents this form of strategic behavior, thus encouraging better price discovery and facilitating rapid convergence to equilibrium.

In situations with multiple goods that have relatively independent demands or are complements, a monotonicity constraint is often applied independently to each good. However, in situations where two or more products are close substitutes, applying monotonicity constraints independently to each good may be overly restrictive; it is natural for the bidder to want to switch to the product with the more attractive price. This would be excluded by the simplest application of independent monotonicity constraints.

A common approach is to organize different durations of the same type of contract into product groups. Since the goods within a group are denominated in comparable units (MW of power), the activity rule applied to all products within a group can simply be a monotonicity constraint on the sum of the demands for the respective products. This approach was utilized in the French and Belgian VPP auctions; it permits bidders to substitute among 3-month, 6-month, and 12-month contracts, etc., on a one-to-one basis. A variation on this approach has been utilized in the Spanish auctions: there, contracts of different durations are compared according to the total number of months, so that there, bidders can

[6] One motivation for a bidder to use a "snake-in-the-grass" strategy is to avoid conveying information to rivals in an environment where bidders exhibit interdependent values. If each bidder's estimate of value is based in part on rivals' information, one bidder demanding large quantities might induce her rivals to raise their value estimates and bid more aggressively. A second motivation for a bidder to use a snake-in-the-grass strategy arises from budget constraints. The bidder holds back on bidding for the good she wants most dearly, instead bidding for the goods her rivals want, in the hopes of exhausting the competitors' limited budgets. The bidder then shifts to bidding on her true interests late in the auction, now facing weakened competition for these goods.

substitute among 3-month, 6-month and 12-month contracts, on a 4-to-2-to-1 basis.

2.6. Information disclosure during the auction

In an ascending-clock auction, there are many possible policies for information disclosure during the auction. With respect to the level of aggregation or disaggregation of bidders' demands, one could disclose the aggregate demand for each product, disclose each individual bidder's demands anonymously, or disclose each individual bidder's demands identified by bidder. With respect to the information provided about demand in the price interval $[\underline{p}_t, \overline{p}_t]$, one could disclose demand at the end-of-round price $\overline{p}_t$ only, or one could disclose demand at all prices in the interval $[\underline{p}_t, \overline{p}_t]$.[7]

Reporting only the aggregate demand for each product at the end-of-round price, after each round, has been viewed as striking a comfortable balance between information useful for price discovery and information that facilitates collusion. In VPP auctions, the aggregate demand for a product contains most of the information needed for price discovery. If, instead, the auctioneer revealed the individual demands of each bidder, this detailed information could be used to coordinate reductions in demands at low prices. For example, the bidders might cooperatively reciprocate the quantity reductions of competitors, and attempt to punish those who do not reciprocate by shifting quantity toward products most desired by the non-reciprocating bidder. Consequently, in essentially all VPP auctions, the determination has been made to report only the aggregate demands for the products after each round.

2.7. Internet auction

Best practice for conducting auctions of high-valued items, today, is by internet-based software. Gathering the bidders together in a single location would both be unnecessarily disruptive to participants, whose offices are located across wide geographic regions, and be unnecessarily conducive to collusion. As such, essentially all VPP auctions have been conducted online on the Internet.

2.8. Frequency of the auction

Most VPP auctions have been conducted at frequent intervals. The EDF, Electrabel, Elsam and RWE auctions were all scheduled as quarterly auctions; while the Texas Capacity Auctions were conducted about five times per year. The Endesa–Iberdrola VPP auctions were also initially held quarterly, but they were later changed to be semi-annual auctions.

As devices for facilitating competition in the market of a dominant firm, frequent VPP auctions are helpful in offering entrants frequent opportunities to bid for assured supplies within the market. Entrants can buy electricity capacity when they need it, and they can adjust their purchases according to the penetration they achieve in the market. As devices for adding liquidity to the forward market, frequent releases of supply are also useful.

Sellers also often tend to value holding frequent auctions. By contrast, offering a significant fraction of a firm's capacity on a single date subjects the firm to a significant amount of market risk; sellers tend to prefer spreading out the sales over several auction dates so as to reduce the risk associated with market fluctuations. Moreover, there tends to be greater liquidity (and greater demand by bidders) for products of relatively short duration (3-month to 24-month contracts), as compared to longer-term contracts. There also tends to be limited appetite for purchases of products on a given date, which can easily be exhausted by offering a large supply of contracts on a one-off basis on a single date. Thus, sellers find frequent auctions much more palatable, which helps to explain why negotiated settlements with regulators often tend to include relatively frequent auctions.

However, it should be observed that the implementation of VPP auctions at frequent intervals sets apart the "virtual" divestiture from a "physical" divestiture, which would typically be the one-off sale of the entire useful life of a generating asset on a single date. This substantive difference between virtual and physical divestitures will be explored further in Section 4.

3. Differences in the design choices for VPP auctions

While essentially all virtual power plant auctions to date have followed a common basic structure, described in Section 2, there have also been significant differences in the design choices made. This section considers some of the differences.

3.1. Fixed supplies of one or more duration versus supply flexibility

The VPP auctions to date have taken three divergent approaches to the durations of VPP contracts. In some (as exemplified by the French VPP auctions), several different durations with the same starting date are offered in each auction, with the clearing condition based only on the total quantity sold and no preconditions on the quantities sold of any particular duration. In others (as exemplified by the Danish VPP auctions), a limited set of durations is offered in each auction and only a fixed predetermined quantity of each is sold. And in others, only a single duration is offered in the auction.

In the case of the French auctions (as well as the auctions in Belgium and Spain), it was recognized that different bidders might prefer buying different durations. The view taken was that the regulators' interest was only in the aggregate flow quantity of VPP contracts in the hands of parties other than the dominant firm at any moment in time, and not in the duration that these contracts would take. Meanwhile, neither EDF nor the regulators had a reliable method for predicting the demands for the various durations — other than through the auction itself — and the relative demands for the various durations might change from auction to auction, depending on which bidders choose to participate and their respective needs. By way of contrast, there existed good methodology for developing the "term structure" of relative valuations for the contracts of various durations that would make the seller indifferent between selling one duration or another.

Observe that if both the quantities and the relative prices of the various durations were allowed to be determined endogenously, then the entire system would be underdetermined. For example, suppose that it was decided that 500 MW of base-load power would be sold as 3-month or 12-month contracts, and that no quantity relationship or price relationship would be imposed on sales of the two contracts. Then observe that one possible outcome would be prices p_3 and p_{12} such that 500 MW of the 3-month contract and 0 MW of the 12-month contract were demanded by bidders. A second possible outcome would be prices p'_3 and p'_{12} such that 250 MW of the 3-month contract and 250 MW of the 12-month contract were demanded. And a third possible outcome would be prices p''_3 and p''_{12} such that 0 MW of the 3-month contract and 500 MW of the 12-month contract were demanded. Then, under ordinary demand conditions for substitutes, we would expect that $p_3 < p'_3 < p''_3$ and $p''_{12} < p'_{12} < p_{12}$. That is, the auction

[7] One could also elect not to disclose any demand information after each round, other than the fact that aggregate demand exceeds supply and so the auction remains open. But this would run opposite to the motivation for using an open dynamic auction, and so this policy of nondisclosure is seldom taken.

Table 1
Quantity sold and final prices in June 2009 EDF VPP auction.

Duration of base-load product	3-Month	6-Month	12-Month	24-Month	36-Month	48-Month	Aggregate total
Quantity sold	95 MW	40 MW	70 MW	125 MW	50 MW	100 MW	480 MW
Final price per month	€19,500	€25,556	€28,811	€31,605	€33,217	€34,706	

outcome would not be pinned down at all unless the quantities to be sold of the different durations were pre-specified or if the price relationship was pre-specified.

Since the composition of different durations was intended to be market driven and since the term structure of prices was reasonably well understood, the decision was made that the prices of the various product durations within a group would be linked together and would increase in lockstep. (However, the prices associated with different product groups — base-load versus peak-load — move independently of one another.) Before the start of the auction, and under the supervision of a trustee, the seller determines an "indifference table" expressing the price differentials (i.e. a yield curve) amongst the various products within a group that would make the seller indifferent between selling one product or another. With two product groups containing six and five products, respectively, there are effectively just two degrees of freedom (and two price "clocks"), although eleven prices in total. The clearing condition is then that the aggregate demand for each product group is to be no greater than the total supply offered. The auction itself then determines endogenously the distribution of sales across the various durations.

Table 1 illustrates the success of this approach by providing the results, with regard to both quantities and prices of the base-load products, in the June 2009 EDF auction. The last row of Table 1 shows the indifference table that was used in the auction. Prices prior to the final round were additive transformations of this curve: for example, the end-of-round prices of Round 1 were (€17,300 €23,356 €26,611 €29,405 €31,017 €32,506), respectively, for the six different durations. In general, there may be some minor concerns that the seller might attempt to manipulate the indifference table to its advantage: for example, if the seller believed that bidders favoring 24-month or 36-month contracts were more effective competitors than bidders favoring shorter-term contracts, then the seller might price the longer contracts disadvantageously. However, apart from the obvious difficulties for the seller in obtaining sufficient information to use such a strategy, making such manipulation implausible, observe that the results displayed in Table 1 are strongly suggestive of a fair indifference table. Aggregate demand for each of the six durations was no lower than 8% and no greater than 26% of the total demand, aggregated over all durations.

The June 2009 EDF auction also included 556 MW of "advance sales" of products to be offered in the September auction: ten products of various durations with starting dates of 1 October or 1 November 2009 (not shown in Table 1). These were similarly offered with a yield curve of indifference prices; and a positive quantity of each of these ten products was sold.

In some other series of VPP auctions, multiple durations are offered to bidders, but only in fixed supplies. Table 2 illustrates the approach that has been taken in the Danish VPP Auctions. Contracts of 3-month, 12-month and 36-month durations are offered according to a planned schedule, in fixed supplies of 100 MW or 200 MW in a given auction.

Meanwhile, in some other VPP auctions (e.g. the Netherlands, RWE Germany and Portugal auctions), only a single product duration was generally offered to bidders.

The approach of supply flexibility appears the most desirable, for three reasons. First, in terms of the objectives of facilitating the obtaining of supply by new entrants and of increasing the liquidity of wholesale markets, the extra flexibility is highly desirable. New entrants are better able to obtain quantities of electricity capacity over time that match their needs; while new liquidity will gravitate to durations that are in the greatest need of liquidity in the wholesale market. Second, value is maximized among sellers and bidders by offering flexibility in duration: if there are greater gains from trade at a particular duration, the auction will shift sales toward that duration. Third, the probability of a product failing to sell (due to receiving bids less than the supply) is minimized, improving the likelihood that the regulatory objectives of the VPP auction program are met.

By the same token, the approach of offering multiple durations, each in fixed quantities, appears to be superior to offering only a single duration. Given the heterogeneity of bidders, it is unlikely that a "one size fits all" contract would meet entrants' needs or maximize gains among sellers and bidders. Additional durations and additional flexibility will generally be beneficial.

3.2. Structure of bid submissions

The VPP auctions to date have also taken three divergent approaches to the exact structure of bid submissions. In many (for example, the French, Belgian, Spanish and E.ON German VPP auctions), bidders are permitted in round t to submit essentially arbitrary non-increasing step functions of quantities associated with the interval of prices, $[\underline{p}_t, \overline{p}_t]$. In some auctions, bidders are permitted in round t to submit step functions of quantities with a single reduction in the interval $[\underline{p}_t, \overline{p}_t]$ ("exit bids"). And in a few auctions (for example, the Dutch and Danish VPP auctions), bidders are permitted to submit quantities at only the single price $\overline{p}_t$, and the resulting "overshoot" is resolved by having bidders re-bid in a final sealed-bid round.

The approach of having bidders re-bid in a final sealed-bid round generally achieves poor results relative to the objectives of efficiency or revenue maximization. The reasoning is as follows: suppose a situation where the true clearing price is $½(\underline{p}_t + \overline{p}_t)$, the midpoint of the interval of prices effective in round t. Then the auction will attract insufficient demand in round t at the price $\overline{p}_t$, and the bids of round t will be re-bid in a final sealed-bid round. Bidders, learning the "bad news" that there was insufficient demand at $\overline{p}_t$, will (regardless of their preexisting assessments of value) tend to bid close to the minimum allowable amount of $\underline{p}_t$ in the re-bidding. Thus, the contracts will tend to be allocated randomly among the remaining bidders rather than allocated efficiently to the bidders with the highest valuations, and the revenue per contract will tend to be approximately $\underline{p}_t$ — unambiguously less than $½(\underline{p}_t + \overline{p}_t)$.

By the same token, allowing bidders to submit essentially arbitrary non-increasing step functions of quantities associated with the current interval of prices will tend to produce the true clearing price, with bids dispersed according to the bidders' underlying valuations rather than clustered at the minimum possible price. Thus, the design used in France, Belgium, Spain and for E.ON in Germany tends to produce more efficient and higher revenue outcomes. Meanwhile, the approach of allowing bidders to submit step functions of quantities with a single reduction is a part-way measure that also improves upon the approach of re-bidding

Table 2
Quantities offered in Danish VPP auctions, May 2008–Nov 2009.

Duration of product offered	3-Month	12-Month	36-Month
Quantity offered in Aug 2008 auction	200 MW		100 MW
Quantity offered in Nov 2008 auction	100 MW	200 MW	
Quantity offered in Feb 2009 auction	100 MW		
Quantity offered in May 2009 auction	100 MW		
Quantity offered in Aug 2009 auction	100 MW		100 MW
Quantity offered in Nov 2009 auction	100 MW	200 MW	

in the final round but sacrifices some of the efficiency and revenues achievable using arbitrary step functions.

3.3. Reserve prices

The VPP auctions conducted to date have varied in their reserve-price policies. The French VPP auctions have not utilized any reserve price for the base-load and peak-load products, but this was accompanied by a confidence that aggregate demand in the auction would far outstrip the supply.[8] Indeed, in the typical EDF auction, there has been approximately a four-to-one ratio between the aggregate demand in Round One and the supply. Most of the other VPP auctions have utilized some form of announced or secret reserve price, but this was accompanied by the recognition that demand in many of the other markets was much weaker and that the seller needed the protection of a reserve price in the event of insufficient demand.

An announced reserve price can be implemented very simply in an ascending-clock auction, by starting the price clock at the reserve price. A secret reserve price is typically implemented under the supervision of a trustee or monitor, who assures that the reserve price has been fixed before the bidding starts. A given product does not clear until aggregate demand is less than or equal to the supply *and* the reserve price is reached. If the aggregate demand is less than or equal to the supply but the auction remains open, bidders can infer that the reserve price is the level at which the auction ultimately closes; but otherwise the "secret reserve" price stays undisclosed.

Observe that a reserve price is a useful instrument for addressing limited competition within the auction. It does this in two ways. First, it reduces the incentive for collusion by limiting the maximum gain from collusion. Bidders must pay at least the reserve price no matter how effective their collusion. Second, an appropriately chosen reserve price guarantees that the seller receives a significant fraction of value, even when competition is weak.

A generalization of a reserve price is for the auction to utilize an increasing supply curve. In a clock auction, a supply adjustment is most easily accomplished by specifying an explicit upward-sloping supply curve. This has the effect of expanding the quantity offered for sale when there is ample competition, but reducing the quantity offered (and implicitly introducing a reserve-like mechanism) when there is insufficient competition within the auction.

3.4. Information disclosure after the auction

The VPP auctions conducted to date have varied substantially in their post-auction information-disclosure policies. In many (for example, the French, Belgian and Spanish VPP auctions), the same information that becomes available to winning bidders during the auction is also made available to the general public shortly after the auction. The disclosed information includes the prices and aggregate demands for each product after every round, including the final round. In some other VPP auctions, the only information that is announced publicly is the final price and quantity.

A policy of widespread disclosure is preferable for several reasons. First, it facilitates participation by new entrants, by putting them on a level playing field with past participants. Second, it helps to assure a high level of transparency in the auction process. Finally, the disclosure enhances the secondary market.

4. VPP auctions as tools for promoting competition and liberalization

The most common motivation for virtual power plant auctions has been to promote competition in and the liberalization of electricity markets with one or more dominant firms. In this section, we explore and evaluate the possible pro-competitive effects of VPP auctions. Commentators have suggested at least three mechanisms by which VPP auctions may promote competition and liberalization:

- They may facilitate entry into the electricity market by assuring the availability to new entrants of electricity supplies on the high-power grid;
- They may promote the development of and add liquidity to the wholesale electricity market; and
- They may reduce market power in the spot electricity market.

The first two mechanisms have been foremost in the minds of regulators and are probably the most important. For example, in the merger procedure leading up to the EDF auctions, the European Commission (2001) wrote: "Access to generation capacity in France would only realistically be possible if EDF granted such access since EDF is the main generator in France." (paragraph 34). In assessing the competitive situation in 2001, the EC concluded: "Newcomers have only marginal chances to purchase electricity in the framework of trading in France" (1.3.2.2); "Newcomers face difficulties when entering the French market via imports" (1.3.2.3); and "The overwhelming position in electricity generation in France allows EDF to outbid competitors trying to enter the French market" (1.3.2.4).

In requiring VPP auctions as a *quid pro quo* for allowing EDF to take a joint controlling interest in EnBW, the EC believed that the new auctions would facilitate new entry and competition: "The access to generation capacity will enable foreign suppliers to become active on the market for supply to eligible customers to a significant extent." (paragraph 107). "Furthermore, German suppliers will also be able to gain a foothold in France and thus become sufficiently strong in France in order to cope with EDF's potential for retaliation resulting from its presence in Germany." (paragraph 108). "Finally, the access to generation capacity in France will put foreign suppliers in a better position regarding Pan-European supply contract since they will be able to supply customers with eligible production sites in France through a VPP contract with EDF." (paragraph 109).

The various VPP auctions appear to have been generally successful, operating primarily through the first two mechanisms. One important data point is the development of the wholesale electricity market in France. In 2001, any wholesale electricity market was close to nonexistent in France — to the point that, for the setting of reference prices in the early EDF auctions, the price data was taken from the German wholesale market (the French data being too thin and lacking in meaning). However, after eight years of VPP auctions, the French market is now generally considered to be the third most active electricity wholesale market in Europe.

[8] A reserve price was introduced in the French auctions of 2003–2005 for the Power Purchase Agreement (PPA) product, after it became clear that the demand for the PPA product was much lower than for the base-load and peak-load VPP products. When the PPA product was discontinued in 2006, the reserve price was also discontinued.

Various European utilities today view participation in VPP auctions as an important element of their pan-European strategies. For example, Iberdrola (itself required to sell in the Spanish VPP auctions) recently trumpeted the fact that it had successfully acquired 1500 MW of capacity in 2008 in VPP auctions in Germany, France and Portugal (Iberdrola, 2009). While European utilities have been consolidating, their operations outside their principal markets have been expanding, partly due to the access to capacity afforded by VPP auctions.

The third mechanism has been emphasized, for example, by Christian Schultz (2005). Physical or virtual divestitures by dominant firms have the potential to reduce market power in the spot market by creating less concentrated market shares in generating capacity. Schultz argues that VPP auctions, as typically implemented, diminish spot market power much less than is possible, since the contracts are relatively short-lived (as compared to physical divestiture) and the auctions are generally frequent. Schultz would therefore prefer unstaggered VPP contracts of long duration (or physical divestitures).

Our assessment is that VPP auctions as currently practiced are not oriented toward making major reductions of concentration levels in spot markets. VPP contracts are intended to be relatively long-term contracts, and they are intended to be bought by competitors of the dominant firm(s). This means that the demand for VPP contracts is relatively limited. Consequently, VPP auctions as currently practiced must involve a relatively small fraction of electricity capacity in the given market. For example, in France in 2001, EDF accounted for greater than 80% of the overall electricity market, while the VPP auctions have never sold more than 10% of total generating capacity. In Spain, Endesa and Iberdrola together accounted for greater than 60% of the overall electricity market, while the VPP obligations were less than 6% for Endesa and less than 5% for Iberdrola (Federico et al., 2008).

Thus, the current magnitudes of electricity assigned to the VPP auctions are insufficient to have a major impact on concentration levels in spot markets. Moreover, there may be no practical way to increase the capacities subject to VPP auctions; even at current levels of sales, many of the VPP auctions (outside France) have bumped against the reserve prices.

While VPP auctions are effective devices to enable entrants to gain footholds in markets with dominant firms and for developing wholesale markets, they are thus ill-suited for making major changes in spot market concentrations. By contrast, forward markets are effective devices for reducing market power in the spot electricity market (Ausubel and Cramton, in this issue). More than anything, what distinguishes the forward auctions useful for correcting the spot market from VPP auctions is that the buyers of contracts in such forward markets are principally the load (hedging the spot market), while the buyers of VPP contracts are ideally competitors (enabling new entry). Note also that, while a VPP auction obligation is normally placed on a dominant firm, the forward trading by suppliers in the envisioned forward market should extend to all generators.

In the longer term, one could easily imagine the current VPP auctions enlarging and evolving in the direction of larger auctions that take on the dual role of facilitating entry by new suppliers and yielding forward sales from suppliers to load. But, for this to occur, the regulatory structure will need to evolve in a direction where suppliers and load are both given incentives or obligations to engage in forward trading.

5. Conclusion

We have reviewed the structure of virtual power plant auctions that began in 2001 and have subsequently spread widely in use. We have seen the aspects of the auction design that are common to essentially all VPP auctions, and we have seen the aspects that differ among the various auctions. We have also seen that VPP auctions are effective devices for facilitating new entry into electricity markets and for developing wholesale markets, while they have not been oriented toward making substantial reductions of concentrations in spot markets.

One important reason for evaluating the various mechanisms by which VPP auctions can promote competition is that it provides insights into the appropriate duration of VPP contracts and the appropriate frequency of auctions. If the primary objective was to equalize market shares in the spot market, then VPPs might be designed to replicate physical divestitures as closely as possible: contracts would be extremely long term, and they would be sold in one-off auctions. However, such timing would be antithetical to the principal objectives of facilitating new entry and of developing wholesale markets. Entry would be facilitated only at the time of the one-off auction; and later arrivals might find themselves lacking any mechanism for obtaining capacity. Meanwhile, liquidity would not be added for those contracts (such as 3-month and 12-month contracts) that can most plausibly become actively-traded products in wholesale electricity markets. As such, one can expect that most VPP contracts offered will continue to be in 3-month to 36-month durations, and that most VPP auctions will continue to occur quarterly.

Given their success, VPP auctions will deservedly continue to receive widespread use in electricity markets with dominant firms. In the longer term, they could desirably evolve in the direction of more comprehensive forward trading among suppliers and load. Such evolution will require changes in the regulatory structure such that both suppliers and load are given incentives or obligations to engage in forward trading — without this, an expansion of the supply offered in today's auctions would simply cause a collapse in prices and for reserve prices to become binding. But with such regulatory evolution, today's VPP auctions could provide a road map toward forward auctions where facilitating entry, developing wholesale markets, and reducing spot market power are all accomplished.

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