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A future auction mechanism for distributed generation

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30 November 2016

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A future auction mechanism for distributed generation

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Auction designs in current electricity markets will need to be adjusted to cope with massively increased small-scale distributed generation and demand response, as these are integrated into the electricity system. We present a VCG mechanism that addresses the two most important challenges facing future power systems, namely uncertainty of costs and complexity of bidding strategies. The mechanism is built up around heterogeneous goods, useful for different levels of response time of electricity or different Quality of Service agreements, package bidding and a proxy agent. The proxy agent will ensure optimal bids from non-professional suppliers. Our mechanism has the expected desirable properties by design.

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1. Introduction

The electricity network of the future will likely be subject to increasing 'new' energy sources, more significant small-scale (renewables) suppliers and increased consumer participation (McArthur *et al*., 2012). At the moment we can envisage that these will be some combination of customer owned PV panels, small-scale distributed electrical energy storage (EES) facilities and responsive demand – smart electricity consuming devices - capable of being turned up and down by artificial intelligence in near real time. Additional small-scale distributed supply and demand might come from electric vehicles (EV) and heat and cooling systems (heat pumps) with smart energy storage capability. The growth and exact grid location of PV, EES, smart demand, EVs and controllable

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heating and cooling and their degree of allowed controllability is highly uncertain, because it involves several variables including consumer acceptance, technological developments and their interaction with progress in large-scale energy technologies.

Operating such a system efficiently presents a major governance challenge for the existing system operator. Appropriate innovation in market design might play a key role in accommodating and incentivising a more or less distributed future for electrical energy. However, it is by no means certain whether markets can be redesigned appropriately and whether many of the latent advantages of such a small-scale system may simply be too difficult to properly incentivise given the fact that market arrangements often require high transaction costs and business models often seek to be shield the customer from economic exposure to the technical complexity behind given technologies.

What is clear already is that technological changes mean that the current market design needs to evolve. Hence in the Great Britain we have seen the electricity system operator (National Grid) create a new market for a super-fast frequency response product (enhanced frequency response or EFR) in April 2016 (National Grid, 2016), creating a market for services that can only be supplied by new types of EES. And in the State of New York, the Reforming the Energy Vision (REV) process has proposed a new distribution service platform approach which would create new markets for electricity service products that could be supplied by distributed energy resources (DERs) of the type outlined above (State of New York Department of Public Service, 2014). All this suggests that the significant shift that we have already seen in many markets towards greater shares of distributed and intermittent renewables is changing the market design today.

One vision of the electrical future emphasises the potential for a system characterised by small-scale distributed energy resources to work as an autonomous power system (McArthur *et al*., 2012), where the physical power flows are managed by a large amount of distributed artificial intelligence. We have discussed in another paper how this could be reconciled with a significantly increased resolution of electricity product prices (Greve *et al*., 2016). What we examine here is the appropriate mechanism design that should be used to resolve such prices.

One of the most important challenges of the future is a more sophisticated bidding environment, where small-scale consumers/producers will be market players through smart technology. Currently, electricity consumers can only ask for instant supply of electricity at one price and consumers face very unsophisticated contracts with prices not varying by location, time of day or power quality. The true price can vary during the day, and is expected to vary more in the future, but consumers are not given the flexibility and opportunity to subscribe different levels of response time of electricity at a given price.

This is unfortunate because it does not signal the value of precisely the sort of consumer located and owned distributed energy resources that might be of real value to the system and leaves only sophisticated larger-scale players the opportunity to be paid to respond to such incentives. Such sophisticated larger players are often incumbent companies with legacy investments – network companies, large suppliers, large generators and global equipment manufacturers - and limited incentives and opportunity to adopt innovative technologies and the optimal small scale.

This situation has already created significant problems for the adoption of new technologies, by miss-signalling the value of new technologies when unsophisticated price signals are the only ones that are readily available. Thus the widespread use of net metering to incentivise adoption of PV, overvalues local generation most of the time and may yet stifle the incentives to invest in customer owned EES, indicating the problem that a price simplification, which seems to encourage one desirable technology, may just as easily discourage another (see Eid et al., 2014).

What is needed is a market design that allows small-scale suppliers, such as households with PV, EES and EVs connected at their homes to participate in electricity product markets. The problem is that well designed electricity product markets are not well suited to the participation of small-scale suppliers because they require such suppliers to formulate sophisticated bidding strategies in the auction markets by which these products are generally bought and sold. These small-scale suppliers are not professional bidders and may need guidance on how to bid in an auction. One solution is to add the mechanism of a proxy agent. This agent will submit bids on behalf of a bidder. The mechanism will use the agent as a tool to ensure that small-scale suppliers submit optimal bids subject to both their own capability and outside conditions, such as location, weather and demand.

Besides the challenges, another significant problem of today's market designs going forward is that they are not based on social welfare. This is an issue since the reliability of the networks and the delivery of electricity are referred to as being a public good (Kiesling and Giberson, 1997; Newbery, 2006; Joskow and Tirole, 2007).

We present a Vickrey-Clark-Groves (VCG) mechanism. The VCG is based on social welfare. It allows for heterogeneous goods and package bidding. It meets the expected challenges of the future by offering different levels of response times. Further, it is built up around a proxy agent to ensure optimal bids from small non-professional bidders. Package bidding allows suppliers to benefit from cost synergies across the supply of multiple electricity products (such as energy, reserve and fast frequency response). With the expected increase in competition, package bidding should reduce consumer prices over the longer run.

An important assumption of our design is that we assume that by the year 2050 there will be significantly increased computer power. This allows many more players to submit supplies and demands in order to resolve prices in finer detail for multiple products, on very short time frames in a large number of locations. Such a feature makes the presented design more useful. A simpler version has already been suggested by leading auction researchers, but may not be implementable with the current technology (e.g. Cramton, 2012).[2] With unlimited computer power, such a design may be feasible. It can work at the distribution level.[3]

It is important to say that we are talking about spot prices of electricity products here. Individual customers/producers may choose to limit their financial exposure by signing hedging (and bundling) contracts with suppliers, aggregators and network companies, which purchase their services at fixed prices, however some party will still hold the underlying real-time price risk associated with buying and selling certain electricity products. Many customers who might not own smart energy equipment can have unsophisticated contracts of the type they have today, but there would be the potential for much greater and more targeted incentives to be faced by those who do own such equipment. Indeed, such deep exposure to underlying risks for these customers/producers is essential to not overpaying for distributed energy resources and avoiding the inequity of PV, EV or storage owners being underpaid (overcharged) for the electricity products they produce (consume). Behavioural economics suggests that risk-averse individuals can be straightforwardly exposed to real time prices via fixed price contracts that offer variable discounts (see Pollitt and Shaorshadze, 2013).

2. The VCG mechanism

Our VCG mechanism works along with the flexible zoning structure presented by Greve *at al.* (2016). The zoning structure will support the mechanism to reach its desired properties in case of grid congestion or stability problems.

In the presence of sophisticated consumer participation and to respond to the unpredictable nature of renewable generation, consumers can buy and suppliers can offer different levels of quality in terms of response time – i.e. different Quality of Service

[2] The reason why the VCG may not be feasible today is because the technology has to compute an individual price per supplier every, for example, 30 minutes. As seen today when implementing package bidding, we may have a computational problem (Krishna, 2009).
[3] The family of the VCG mechanism is used today. For example, Google uses the Generalised Second Price (GSP) auction (Edelman et al. 2007; Varian and Harris, 2014) and Facebook uses a VCG auction (Varian and Harris, 2014).

agreements. In particular, consumers might pay different prices for high quality (instant supply on demand), medium quality (supply within specified short horizon limits) or limited quality (supply when available) offers. In the presence of sophisticated consumer-level control, these might be offered on a per-appliance basis (so that users might demand that their lights respond instantly, but their washing machine within 8 hours, say). Hence, in principle, each household/individual will have the opportunity to subscribe to different types of electricity for different electrical devices. Also, Quality of Service demands could be used to match requirements to the constraints that can be met by suppliers, for example from small-scale suppliers which could be unsure about their delivery capability. We use a VCG mechanism because of its desirable properties. The VCG has proved controversial in practise (Rothkopf, 2007), but, for example, Google is using a variant of it to sell advertisements (Edelman, 2007; McLaughlin and Friedman, 2016).

The VCG mechanism is based on social welfare and as presented in this paper, it has the desired properties in mechanism design – incentive-compatible (truth-telling about cost), allocative efficiency (the electricity ends up in the hands of those who value it the most), individual rationality (participation is voluntary) and weak budget balance (there will always be a surplus in the overall social system) (Krishna, 2009). The VCG surpluses that this gives rise to must not themselves incentivise untruthful bidding (we demonstrate how the VCG surpluses are calculated below). In the electricity system this is quite straightforward, as they could be used to reduce the other charges in the system for all users, such as contribution payments to transmission and distribution system fixed costs. This would ensure that the use of the surplus had no influence on the behaviour of individual bidders in any given power market auction.

3. Package Bidding

A central idea in a multi-product auction is that there is a potential for package bidding.[4] This is very important in the future electricity system market design. This is because a given distributed energy resource or set of DERs (Distributed Energy Resources) could deliver multiple electricity products. This suggests that the product environment could become more complex in the future. For instance, a storage facility can deliver power in near real-time (for frequency response), in two minutes and in one hour[5]. While a given PV facility might have a certain minimum expected output in any given time window (even if there is cloud cover), but more output when the cloud passes in an hour's time. This means that package bids for a vector of quantities of different electricity products

[4] Others have proposed package bidding in the electricity context: for example, DotEcon (2015).
[5] We explore package bidding in the context electrical energy storage in Greve and Pollitt (2016).

would be possible. This is desirable given that the DER costs are often fixed, suggesting that a bulk supply discount for a package of products is desirable, whereas a single product offer to supply would be less competitive given that its acceptance would not guarantee that the rest of the fixed cost, which might otherwise be allocated to other products, would be covered.

4. Proxy Agents in Electricity

An important concept in auction theory is that of the proxy bidding system (proxy agent). The proxy agent (or relevant software) takes the expressed preferences and converts them into a sensible bidding strategy. The proxy agent is successfully used in practice. One of the best-known applications is the auction design run by eBay (Ockenfels and Roth, 2002). Here bidders in the eBay auction submit a maximum willingness to pay and the eBay proxy agent bids in increments on behalf of each bidder, such that the bidder with highest willingness to pay wins but pays only the price step (one increment) just above the price of next highest bidder.[6]

The point is that the proxy agent in the future electricity market is potentially a very sophisticated piece of artificial intelligence. The proxy agent is an agent helping bidders to formulate complex bidding strategies. For instance, a proxy agent could calculate likely output from a solar PV panel at a particular location and bid the estimated quantities into the market in any given time frame, it could also know the cost of the panel and bid on the basis of attempting to recover these costs. Even more interestingly, PV panels could be sold with proxy agents associated with them. These could also provide estimates of past and future returns, based on forward projections of resolved prices at the grid location of the customer. This would massively reduce the apparent uncertainty and risk, which high-resolution prices would seem to induce. The customer might merely be required to report to the proxy agent when the panel was due to be taken out for maintenance: real time operating status could be monitored remotely via automated meter infrastructure (i.e. a smart two-way meter).[7]

The benefit of proxy agents would seem clear. They remove the need for owners of DERs to be sophisticated bidders and they significantly reduce the costs of market participation. The proxy agent will be part of the allocation process as a neutral and trustworthy feature of the market, without a conflicting relationship with any other

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[6] Reversed in our case since the objective is to drive the costs downward.

[7] The academic literature has already begun to see proxy agents as potentially useful. Bourazeri and Pitt (2014) describe a potential self-organising socio-technical system. Here, the proxy agent might be particularly useful for these systems where both the demand and supply side can express preferences in real time and the scope for transformation between qualities has been increased.

market player. Furthermore, bidders, including small-scale suppliers, can still go through a third party aggregator to ensure more competitive bids via lower transaction costs. The aggregator we have in mind is sometimes better thought of as a Virtual Power Plant (DONG Energy, 2013, p.11). The most competitive solution with the lowest transaction costs could well be to give such small-scale suppliers the opportunity to participate at low cost in the way we describe below. This does involve aggregation, but of a type where the aggregator is not itself a potentially unsophisticated third party. The proxy agent will be part of the allocation process and part of the market design. It could be subject to mathematical regulation that would limit their ability to exploit market power or engage in anti-competitive behaviour. However, contracting with a conventional aggregator will remain an outside option to all bidders. A third party aggregator will submit a joint bid from a number of bidders and can implement its own auction revenue allocation rule, reflecting the contract terms that it offers those who sign up to its aggregation services.

5. Examples of the future market design using VCG and package bidding

The VCG mechanism we propose is illustrated by the following examples.[8,] Let's imagine a situation, for the purposes of description, where there are three qualities of electricity and two locations to be delivered to, in a time specific auction (say, a given 5 minute time window). The qualities of electricity are Gold and Silver.[9] Gold is electricity that has to be delivered in 1 second (i.e. real time), Silver electricity has to be delivered within 2 minutes. There are two zones (1 and 2) in the electricity system where the prices are potentially different, due to distribution system capacity constraints. Where necessary supply and demand may be reallocated between zones if this is physically possible and lowers system cost (and potentially raises social welfare). This is an electricity system where small-scale supply is prevalent and location and power quality matter and need to be resolved in a set of auctions. The system operator has to ensure supply and demand are equal for all power qualities and in each location. The system operator is assumed to maximise social welfare and act as a social planner.

Consider a social planner (i.e. the system operator) that has the responsibility to ensure the reliability of the network and the delivery of the electricity. A number of suppliers submit bids. Example 1 illustrates our design where two different suppliers win the

[8] Throughout, the following assumptions are made: (1) the suppliers and the social planner do not have any overall limit on their costs of procurement, (2) the goods for sale have strong complementarities. That is, the total cost of a mix between Gold and Silver is lower than a cost containing only Gold or only Silver, (3) Gold is more expensive than Silver, (4) we have unlimited computer power, and (5) the proxy agent is trustworthy and has no conflict of interest with any other participant in the auction.

[9] Besides Gold and Silver, other varieties could be added the auction, for example Bronze (which might be electricity which has to be delivered in one hour) etc.

auction and where no proxy agent is used. Example 2 replicates Example 1, but now a proxy agent is used. Example 3 illustrates our design where a package bid will win the auction, but at the same time we combine our auction with a flexible zoning structure.

Example 1

Figure 1 shows a number of suppliers in two zones – Zone 1 and 2. Demands 1 and 2 (D1 and D2) and Suppliers 1 and 2 (S1 and S2) submit offers and bids to supply Zone 1 and Demands 3 and 4 (D3 and D4) and Suppliers 3 and 4 (S3 and S4) in Zone 2.[10] Demand and Supply can be stand-alone bids, or aggregations of smaller units being offered and bid in by sophisticated aggregators or by proxy agents.

Figure 1

Initial zoning

Suppose that demand in a given period is 2 MWh Gold (hereafter, denoted 2G) in Zone 1 and 2 MWh Silver (hereafter 2S) in Zone 2. Table 1 shows the offers and bids from Demand and Supply in Zone 1. For example, D1 has submitted a Willingness to Pay (WTP) of £120 to ensure 2G and D2 an individual bid of £110. S2 has submitted an offer to supply 2G in Zone 1 of £111 and a package bid of 2G in Zone 1 and 2S in Zone 2 of £200.

[10] We have deleted other bidders for simplicity, but assume there would be sufficient competition to deliver competitive prices in each zone.

Table 1

Submitted bids and offers in Zone 1

Bidders	**2G**	**-**	**2G+2S**
D1	£120	-	-
D2	£110	-	-
S1	£100	-	-
S2	£111	-	£200

Table 2 shows the submitted WTPs and bids in Zone 2.

Table 2

Submitted bids and offers in Zone 2

Bidders	**-**	**2S**	**2G+2S**
D3	-	£80	-
D4	-	£75	-
S3	-	£60	-
S4	-	£76	£188

The social planner looks at the bids and chooses the allocation that maximises social welfare. Table 3 shows all the submitted offers and bids.

Table 3

Submitted bids and offers in Zone 1 and 2

Bidders	**2G**	**2S**	**2G+2S**
D1	£120	-	-
D2	£110	-	
S1	£100	-	-
S2	£111	-	£200
D3	-	£80	-
D4	-	£75	
S3	-	£60	-
S4	-	£76	£188

Table 3 shows that social welfare is maximised if D1 and S1 are the winners of 2G to receive and supply Zone 1, and D3 and S3 of 2S to receive and supply Zone 2. Using the VCG payment rule, the payments are: D1 pays £110, S1 receives £111, D3 pays £75 and S3 receives £76. There is a negative VCG surplus of £2 (£110-£111+£75-£76).[11] Yoon (2008) points out how negative payments can be avoided in a VCG mechanism. He presents a participatory VCG mechanism, which charges a participation fee for the right to participate. The fee ensures that the system budget-balances on average. Hence, we can avoid the risk associated with having to collect negative surpluses ex post.

Example 2

Suppose S3 actually has a cost of £86 for 2S and not £60 as submitted in Example 1 (i.e. S3 has bid too low by mistake). Suppose we add a proxy agent to guide the bidders. Compared to Example 1, suppose the proxy agent submits a bid on behalf of S3 of £86 instead of £60. This might be because S3 is a positively charged distributed storage unit and the round-trip cost of supplying 2G given wear and tear and energy charge costs calculated by the proxy agent is actually £86. Otherwise all the other bids and offers remain the same. Table 4 and 5 show the submitted bids in Zone 1 and 2.

Table 4

Submitted bids and offers in Zone 1

Bidders	**2G**	**-**	**2G+2S**
D1	£120	-	-
D2	£110	-	-
S1	£100	-	-
S2	£111	-	£200

Table 5

Submitted bids and offers in Zone 2

Bidders	**-**	**2S**	**2G+2S**
D3	-	£80	-
D4	-	£75	-
S3	-	£86	-
S4	-	£76	£188

[11] It is well known in the literature that every efficient, individually rational and dominant strategy double auction runs a deficit (Loertscher, 2015).

The social planner looks at the bids and offers and chooses the allocation that maximises social welfare. Table 6 shows all the submitted bids and offers.

Table 6

Submitted bids and offers in Zone 1 and 2

Bidders	**2G**	**2S**	**2G+2S**
D1	£120	-	-
D2	£110	-	-
S1	£100	-	-
S2	£111	-	£200
D3	-	£80	-
D4	-	£75	-
S3	-	£86	-
S4	-	£76	£188

Table 6 shows that social welfare is maximised if we have the same winners in Zone 1 as in Example 1, but now S4 is the winner in Zone 2 and receives £86. The negative VCG surplus is now £12 (£110-£111+£75-£86). S3 has lost in the auction but its actual payoff has increased from -£10 (£76-£86) to zero.

<u>Example 3</u>

Take Example 2 and suppose the initial zone structure is given as in Figure 1 and the Demand is the same as before: 2G in Zone 1 and 2S in Zone 2. Suppose now that S3 has submitted a package bid of £170 instead of £188; the rest is as before and it can technically supply both zones. Table 7 and 8 show the submitted bids in Zone 1 and 2.

Table 7

Submitted bids and offers in Zone 1

Bidders	**2G**	**-**	**2G+2S**
D1	£120	-	-
D2	£110	-	-
S1	£100	-	-
S2	£111	-	£200

Table 8

Submitted bids and offers in Zone 2

Bidders	-	2S	2G+2S
D3	-	£80	-
D4	-	£75	
S3	-	£86	-
S4	-	£76	£170

Once again, the social planner looks at the bids and offers and chooses the allocation that maximises social welfare.

Table 9

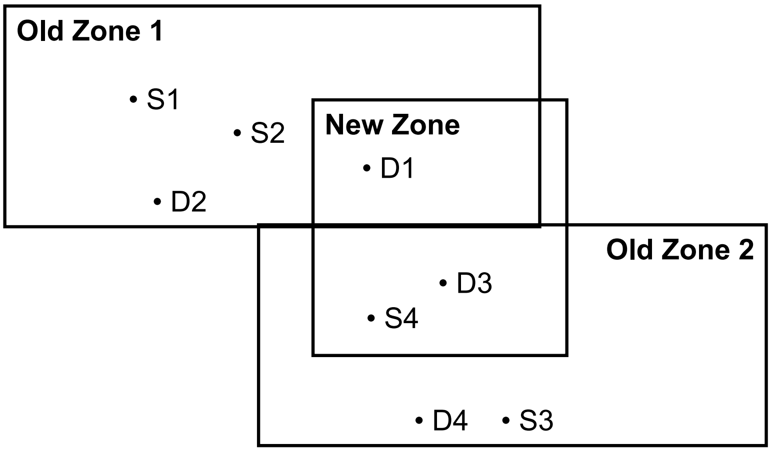
Submitted bids and offers in Zone 1 and 2

Bidders	2G	2S	2G+2S
D1	£120	-	-
D2	£110	-	-
S1	£100	-	-
S2	£111	-	£200
D3	-	£80	-
D4	-	£75	-
S3	-	£86	-
S4	-	£76	£170

Table 9 shows that social welfare is maximised if D1, D3 and S4 win. S4 can supply both zones. Applying the flexible zoning structure, the network (through the mechanism) will self-optimise and self-configure to deliver the suggested configuration. We have a "New Zone" (Figure 2).

Figure 2

"New Zone"



Following the VCG mechanism, D1 pays £110, D3 pays £75 and S4 receives £186 (because the next best offers are from S1 and S3). There is now a negative VCG surplus of £1 (£110+£75-£186).

6. Conclusion

We have presented a VCG mechanism that makes the electricity network ready for our vision of the future. The VCG is based on social welfare, which is missing in the designs used today. Specifically, the VCG yields efficiency and can be applied to the electricity market, where potential surpluses (negative or positive) are reallocated to elsewhere in the system. It can contribute positively to a social optimum.

We are in an environment of small-scale suppliers, but there may be areas with less competition, because of congestion, where suppliers enjoy a potentially higher uniform-price, for example, the preferred design in today's electricity markets. In our design, each supplier will have individual prices. Also, unlimited (relative to today) computer power gives us the opportunity to work with package bidding, because it eliminates today's computational problems.

We suggest that future auctions should have a number of key features. They should use a VCG mechanism, they should allow package bidding for multiple products and they should make use of proxy agents to encourage mass participation of individually small players. The novelty of our approach is to imagine that this might be much more feasible in the future than it is today.

Our examples illustrate the mechanism in action. We imagine prices that vary in time, location and power quality with a trading period. Our illustration shows the price resolution with two products and two zones. It is built up around heterogeneous goods allowing for different electricity subscriptions (Gold and Silver), package bidding and a proxy agent. The proxy agent will ensure optimal bidding strategies from non-professional bidders. Real electricity markets will require a wider range of products to be defined, the careful specification of the units of quantity and the definition of the time periods and number of zones for which price resolution is possible. Hence we suggest the use of package bidding. However, the basic principles of good auction design, which we illustrate, still apply.

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