Distributed Generation, Storage, Demand Response, and Energy Efficiency as Alternatives to Grid Capacity Enhancement

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The need for investment in capital intensive electricity networks is on the rise in many countries. A major advantage of distributed resources is their potential for deferring investments in distribution network capacity. However, utilizing the full benefits of these resources requires addressing several technical, economic and regulatory challenges. A significant barrier pertains to the lack of an efficient market mechanism that enables this concept and also is consistent with business model of distribution companies under an unbundled power sector paradigm. This paper proposes a market-oriented approach termed as "contract for deferral scheme" (CDS). The scheme outlines how an economically efficient portfolio of distributed generation, storage, demand response and energy efficiency can be integrated as network resources to reduce the need for grid capacity and defer demand driven network investments.

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1. Introduction

A conventional power system is characterised by large scale generation sources that inject large amounts of power into the transmission grid, which in turn is transported to passive distribution networks, and then delivered to the end-users. A key feature of the low-carbon future power systems is that they will perform in an operating environment and paradigm in which distributed generation (DG), demand response, and storage facilities are important components of the system (Soares et al., 2012). These resources are connected to low (and medium) voltage networks thus making the distribution grid a crucial element of sustainable electricity sectors of the future. These changes are driven by climate and sustainability policies along with affordability and reliability of electricity supply. Thus, the future power systems will be based on coexistence of conventional and distributed generation sources, and tap into demand response and storage as network resources for efficient planning and operation.

The electricity distribution network operators (DNOs) are responsible for, expansion, reinforcement and maintaining the safety and reliability of the network to support power flows and ensure quality of supply. Integration of distributed resources[2] introduces new challenges and opportunities that require innovative technical, economic and regulatory solutions to overcome the barriers and utilise possibilities. This includes enabling distributed resources to compete with alternatives in providing network and non-network services to the DNOs. In the context of non-network solutions, there is an opportunity for replacing or deferring grid reinforcement by meeting demand locally through deployment of DGs, storage and reducing peak demand through demand response and energy efficiency[3]. In effect, due to potential benefits of distributed resources for the grid, especially at distribution level, they are natural alternatives to conventional network capacity enhancement (Sheikhi Fini et al., 2013).

From an economic viewpoint, a challenge is how to value these alternative energy resources. At present, there are no established methods to value the complex set of technical and financial opportunities (and challenges) arises from the integration of these resources. This stems from the lack of a market mechanism that supports this process. Moreover, adopting distributed resources to defer demand driven grid reinforcement requires extending the traditional business model of distribution utilities in a consistent manner with the unbundled sector. Thus, along with technical concerns, there is a need for innovative economic and regulatory solutions. For example, issues such as ownership model of resource facility, differentiating between costs of capacity and energy, dispatchable and non-dispatchable generation, possibility of trade in other

[2] Throughout this paper we use the term “distributed resources” to refer to distributed generation, storage facilities and demand response (and energy efficiency) that interact with distribution network.

[3] Energy efficiency, as a permanent reduction in energy demand, is emerging as a resource in capacity markets along with behavioural (temporarily) demand response.

markets, managing storage and demand response are important and need to be addressed. Moreover, the presence of uncertainties such as the sustainability of costs and possibility of demand reduction over time constitute some risk elements.

This paper proposes a three stage market-based approach termed as "contract for deferral scheme" (CDS) in order to employ an economically efficient portfolio of distributed generation, storage, demand response and energy efficiency to supply network capacity and to defer demand driven investments.

The next section discusses the need for innovative network solutions and explores the previous studies on the effect of distributed resources on network investment deferral. An extended business model of distribution companies including the contract for deferral scheme has been introduced in Section 3. Section 4 discusses the details of CDS market model in three steps: pre-auction stage, auction stage and post-auction stage. Finally, the study concludes with Section 5.

2. Demand Driven Network Investment

A feature of the traditional approach to upgrading the network is that as demand grows gradually, network reinforcement is carried out in large increments requiring lumpy investments. As a result, a portion of grid capacity remains idle for long periods in anticipation that demand will eventually increase. Therefore, in a network reinforcement cycle, the total capital employed, to deliver a given amount of output, can be higher than the theoretical optimum needed at any given time. At the same time, due to adverse effect of asset utilisation rise on energy loss; the network utilities face a trade-off between the rate of asset utilisations and reducing network energy losses (Ofgem, 2003). Figure 1 presents the demand growth path and a corresponding network capacity enhancement schedule. C_i denotes the initial capacity and C_r represents the added capacity as a result of reinforcement.

Underutilisation of assets, in demand driven network investments, is exacerbated when the mid- or long term development of demand are uncertain. As demand grows, the output of network, for a given level of capacity, also increases. However, demand for electricity can also decline, in which case the idle capacity and consequently the operating cost of network, per unit of output, raises (Jamasb and Marantes, 2011). The case of an upward deviation of demand from projections is less critical for asset utilisation, as it is normally possible to carry out investment such that the shortages in network capacity can be avoided.

An alternative to the traditional network enforcement is to meet part of the demand for energy services locally through DGs, storage and managing demand through demand response and energy efficiency measures. This is to use distributed resources whether on the supply side (DGs and storage) or on the demand side (demand response and energy efficiency) to avert the need for lumpy investment in costly redundant transformers (Hemdan and Kurrat, 2011). These resources can be procured to meet the extra demand projection plus a reserve margin for contingencies. The advantages of distributed resources are not limited to the deferment of network reinforcement but also include, peak shaving, spinning reserve, voltage and frequency regulation, and dealing with variability of supply side (Zafirakis et al., 2013).

From a regulatory perspective, integration of distributed resources as an alternative to conventional network reinforcement is in concert with the innovation incentives embedded in the regulatory frameworks of distribution companies. For example, in the UK, under the RIIO-ED1 regulatory model, innovative solutions are incentivised by rewarding the downward deviation from the expected capital expenditure in business plan of DNOs (Ofgem, 2012). These financial incentives play a pivotal role in directing the network companies towards implementing smart solutions.

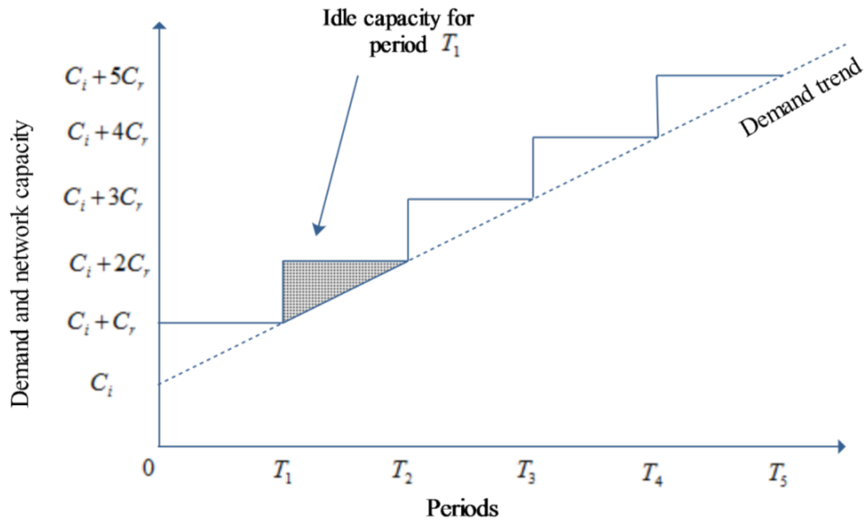

Figure 1: Demand growth and network capacity enhancement

Source: Authors

There is an extensive body of literatures that evaluates the effect of distributed resources on investment deferral of grid capacity, in particular with respect to integration of distributed generation. These studies explore different perspectives of this issue such as cost-benefit analysis, size, siting, type effect of generator and implication for regulatory model of network companies.

Pudaruth and Li (2007) investigate the costs and benefits of DG for investment deferral of distribution companies in terms of thermal capacity limits of lines and assets. Mendez et al. (2006) assess the medium and long term impact of DGs on investment deferral of radial distribution networks. The study demonstrates that after initial investment for connection of DGs, their net effect is to defer capacity enhancement driven by natural demand growth. They also show that the intensity of the effect depends on the type of distributed generation (e.g., wind power versus CHP).

The effect of siting on investment deferral of distributed resources has been discussed in several studies. Gil and Joos (2006) find that the benefits are maximised, if DGs are sited at the end of long feeder and near load pockets because of their effect on energy losses and congestion reduction. Zhang et al. (2010) show that effective site reallocation will increase the benefits of capacity deferral for the same amount of DGs connected. Moreover, Wang et al. (2009) demonstrate that significant benefits, in terms of investment deferral, can be harnessed if the DG contribution to system security is taken into account. They also show that the deferment varies significantly with location and size of the generator.

Although DGs are promising and reliable resources for investment deferral; this effect is not limited to these resources. In effect, storage facilities, demand response and energy efficiency are also potential resources that, along with DGs, can lead to grid investment deferral. Schroeder (2011) argue that demand side management and storage also constitute important tools in operation of distribution networks that could benefit system operation by avoiding capacity shortages. The study shows that, in the case of storage, for example, grid reinforcement can be avoided at some voltage level without harming system security because network capacity utilisation rate will remain well below the threshold. Also, the study noted that the effect of demand side management is stronger when more flexible demand, such as electric vehicles, is available.

These studies show there exists an opportunity for taking the advantage of the synergy between investment in distributed resources and the obligation of network companies with respect to network reinforcement. However, the effect of these resources on grid depends on many factors such as location, technological specification and timing of investments (Vogel, 2009). An effective regulatory framework, thus, is required to align these benefits between resource developer and network companies. In the absence of such mechanism, penetration of these resources can, sometimes, lead to adverse effect on the network. For example, DGs uptake can expose the grid to induced energy losses when installed capacity exceeds the demand (Harrison et al., 2007).

Distribution utilities can influence the siting of distributed energy resources such as DGs through connection and use-of-system charges (which could be based on their capacity and the sole-use network asset used) and reward when DG installation is in line with optimal operation of the network (Jamasb et al., 2005). The rewards can be grounded on generator exported power at system peak, proximity to the frequently congested zones and the network asset utilised. The implication of DNOs' preferences for size and location of DGs and the effect of regulatory model on optimal connection of DG within existing networks have been examined by Piccolo and Siano (2009).

3. An Extended Business Model

Integration of distributed resources to defer demand driven network investment requires both technical and economic changes to the current operational paradigm of distribution networks. From a technical perspective, network management needs to evolve from passive to active by using real time control and management of distributed resources and network equipment based on real time measurement of primary system parameters such as voltage and current (Zhang et al., 2009). From an economic perspective, the business model of distribution companies is required evolve and expand beyond the current only connection and use-of-system charges. The new economic and technical models will shift the operation of distribution companies from network operators (DNO) to distribution system operators (DSO). Figure 2 illustrates this paradigm shift.

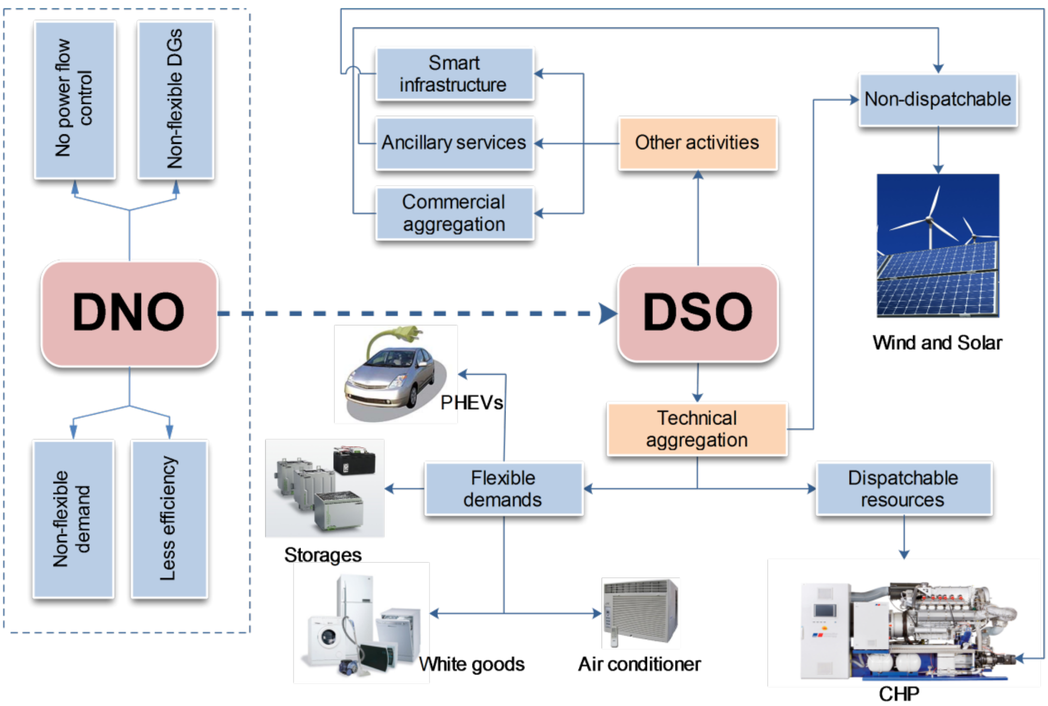

Figure 2: The transition from DNO to DSO model
Source: Authors

Currently, the revenue sources of distribution utilities have comprised of the regulated connection charges and use-of-system charges. Based on the type of consumer and regulatory framework model, new connection fees consist of shallow and deep cost charges (Jamasb et al., 2005). In an environment with high penetration of distributed resources the DSOs should be allowed to expand their revenue sources beyond provision of connections and energy transport charges only. This is because, over time, the presence of distributed energy resources close to the site of demand reduces the volume of energy transmitted in the grid and consequently, shrinks the revenue base of network companies (van Werven and Scheepers, 2005).

The extended business model of DSO includes interaction with different consumer categories, transmission system operator (TSO), distributed energy operators and retail suppliers. DSO can offer certain services to these players that construct extra sources of revenue and receive certain services from them that will constitute part of its costs. These services will include local balancing in the distribution network, premium reliability for some commercial or industrial customers and also offering system data to the DGs operators and retail energy suppliers as DSO is the only party that have such information (van Werven and Scheepers, 2005). These will bring new stream of revenue for the DSOs which are not currently possible under the DNO business model.

DSO will contribute to national load balancing and will be compensated for that by the TSO. This will be done through dispatchable DGs (and, where possible, storage and demand response resources) that are under the control of distribution system operators. Moreover, many commercial and industrial users need premium reliability as their production process is sensitive to the electricity input (Poudineh and Jamasb, 2013). DSOs will be reimbursed by those industries for providing highly reliable connections. Furthermore, with the use of information and communication technologies, valuable system data will be available that can be shared with DG operators and retail suppliers for efficient planning and operation in return for a payoff.

At the same time, the costs to DSO will include operation and maintenance, grid reinforcement (which can be either in a traditional approach or by procurement of distributed resources), acquisition of ancillary services from DGs and TSO, use of system charges and finally cost of energy losses. Figure 3, illustrates the existing and new services, flow of revenue, costs, and interaction of key players in an extended business model of DSO.

An important part of the extended business model is the possibility to integrate distributed resources as alternatives to grid capacity enhancement. This however, requires an economic model that is consistent with the regulatory framework of an unbundled sector. Moreover, the model must allow the DSOs to procure these resources cost efficiently and ensure compliance by resource providers. The rest of the paper introduces a new approach that enables the DSOs to utilise this possibility.

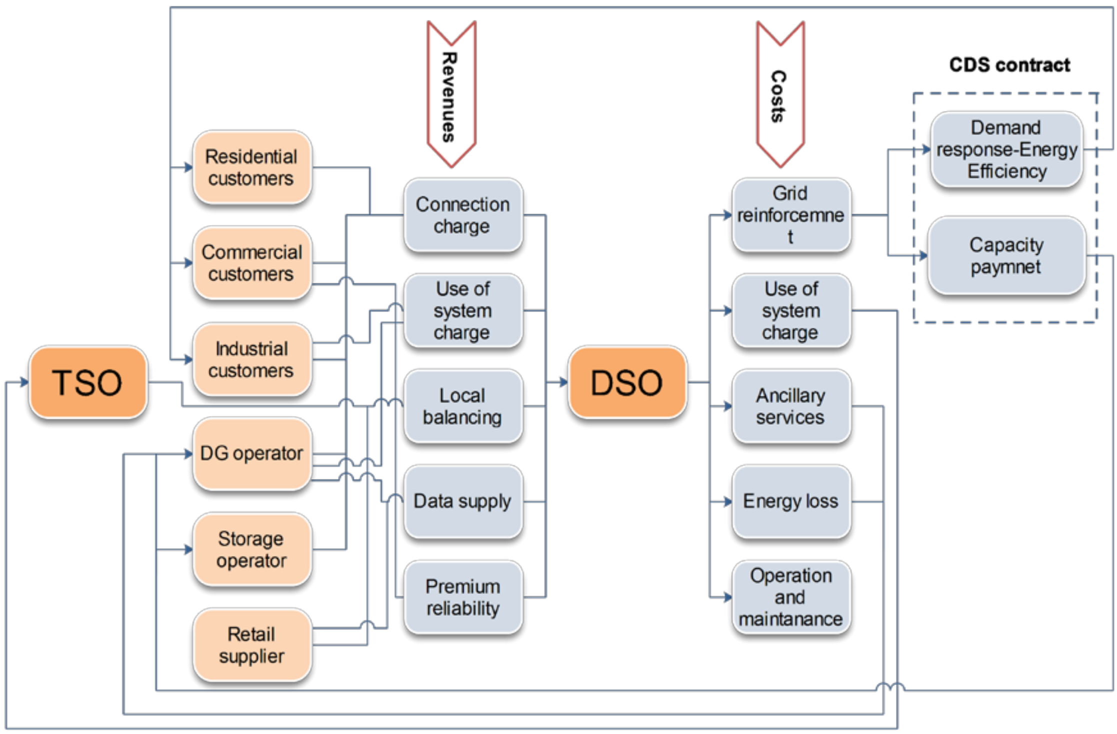

Figure 3: The extended business model for DSO

Source: Authors

3.1 Contract for deferral scheme (CDS)

A challenging task is to design of an economic model that delivers network service (network capacity) cost effectively using alternative resources (DGs, storage, demand response and energy efficiency). Provided the regulatory issue concerning the ownership of distributed resources by the network companies, under an unbundled power sector paradigm, our proposed model is based on a "contract for deferral scheme" (CDS). Under the CDS scheme, the DSOs can enter into contract with distributed generations, storage facilities operators, demand response and energy efficiency providers, which offer available capacity when needed. The market participants that enter a contract will be obliged to have available the required capacity at the time of network constraints (or upon being called). In return, the DSO offers them a capacity payment. The CDS contract acts as proxy for vertical integration and, at the same time, it is procured on a competitive basis.

CDS is considerably different from both administrative and market based methods that have been introduced previously. CDS differs from the administrative approach proposed in Hof et al. (1996) which calculates a break-even price at which a distribution company is indifferent between undertaking conventional reinforcement and alternative approach. This is because their approach does not achieve economic efficiency as it ignores market mechanisms and opportunity cost of scare resources to the society and hence, it is not welfare maximising. Furthermore, their administrative approach has only been discussed in the context of DG whereas CDS is a market-based approach for integration of a portfolio of distributed resources which are treated equally.

CDS also differs from the market based approach proposed in Trebolle et al. (2010) termed as reliability options for distributed generation (RODG). Firstly, the CDS model takes into account the investment deferral effects from all types of distributed resources irrespective of being on the supply side (DG and storage) or demand side (demand response and energy efficiency) whereas the RODG model focuses on distributed generation only. Secondly, the auction structure proposed for RODG is based on a version of sealed bid auction which might not be suitable for acquisition of renewable resources (e.g., Gottstein and Schwartz, 2010). In contrast, the CDS contract is based on a model of descending clock auction (presented in the next section) used in some countries for capacity procurement and in particular for renewable resources acquisition (e.g., NYSERDA, 2004). Thirdly, the RODG model does not specify how this model fits into the wider business model of distribution utilities whereas CDS emerges out of an extended business model within the unbundled power sector paradigm.

The advantages of the CDS approach can potentially go beyond investment deferral by providing value added benefits to the power system. For example, following the market deregulation and liberalisation, the reserve capacities of large scale power generation is declining in many countries (Gordijn and Akkermans, 2007). This creates new business opportunities for small scale distributed resources that could supply some system reserve. Additionally, CDS motivates investment in storage technologies which currently their uptake is sensitive to a range of uncertainties such as future resource mix, technology development, market structures and the uncertainty of returns (Grunewald et al., 2011). Moreover, CDS give a boost to the integration of demand response and energy efficiency, which are currently perceived to be underutilised resources because the electricity markets and reliability requirements have been designed for, and evolved under, a generator supply paradigm (Capper et al., 2012).

In summary, CDS is a mechanism for procuring, on a non-discriminatory basis, a portfolio of capacity resources through a competitive forward auction process. The auctions can reveal the value of the product (capacity) and maximize the revenue obtained, if a sufficient number of non-colluding bidders participate (Newbery, 2003). The selected resource portfolio will act as a substitute for conventional demand driven network reinforcements.

4. CDS Procurement Procedure

Procurement of CDS contracts, by DSO, needs to be based on a well-designed and implemented auction. Overall, the process of CDS contracts acquisition can be described in terms of three stages: pre-auction stage, auction stage and post-auction stage. In the pre-auction stage (stage one), eligibility of potential suppliers needs to be verified with respect to certain requirements. Stage two, is the implementation of auction and process of price discovery. Stage three (post-auction), corresponds to the signing and implementation of CDS contract. Figure 4 schematically illustrates the process of CDS contract procurement.

4.1 Pre-auction stage

In this stage the DSO forecasts demand growth over the subsequent years and projects the required network capacity. That is to identify the constrained zones and the locations which can potentially experience distribution bottleneck, for delivery to the consumers. DSO often investigates the load duration curve of distribution facilities to find out possible over-load condition and also assesses the grid reliability to ensure that a component failure will not cause a long term interruption (Trebolle et al., 2010).

The major task at this stage, however, is to identify and evaluate resource suppliers. This means the DSO needs to initially decide which resources are eligible to submit offer. For example, the DSO needs to determine whether to allow only existing capacities or that both existing and new capacity providers can participate in the auction and also specifying type of resources.

The resources that are eligible to participate in the auction can be different based on the feasibility, regulation and institutional framework as well as technical condition of power system. In the UK, the upcoming capacity auction is technology neutral and includes both the existing and new resources except those that are operating under contract for difference (CfD), feed-in-tariff or renewable obligation, and interconnected capacity (DECC, 2013)[4].The eligible resources include traditional generation plants as well as demand response (behavioural demand reduction) and storage technologies.

Furthermore, energy efficiency (permanent demand reduction through adoption of more efficient processes and appliances) is being considered for inclusion in this list. ISO New England and PJM forward capacity markets[5] in the US, however, view energy efficiency as an eligible resource which can participate in the auction along with the

[4] This is to avoid overpayment because there are already under a form of capacity payment.
[5] ISO New England (ISO NE) market serves Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont. PJM is Pennsylvania-New Jersey-Maryland Interconnection.

other resources (Gottstein and Schwartz, 2010). Nevertheless, energy efficiency is treated differently in these markets. PJM allows energy efficiency to receive capacity payment, up to four years of their measured life, whereas ISO NE remunerate for its full measured life to encourage long-lived energy efficiency assets (Gottstein and Schwartz, 2010).

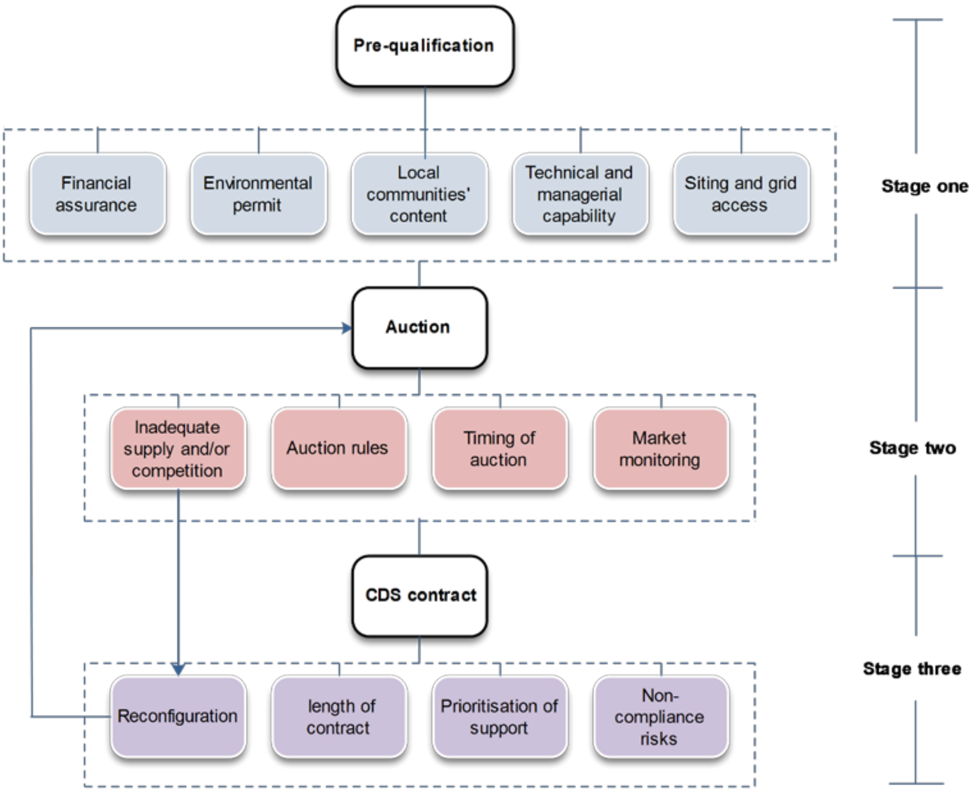

Figure 4: The procedure of CDS contract procurement

Source: Author

As the CDS contract aims to attract new investment in distributed resources, eligible bidders should be selected from both existing and new capacity providers, in a non-discriminatory and technology neutral manner. This will include, distributed generation, storage facilities, demand response and energy efficiency.

Depending on the nature of resources connected to the distribution network, the feasible options for CDS auction are: dispatchable distributed generations (e.g., CHPs), fairly electricity intensive and electricity dependent consumers (industrial and commercial consumers) which might be able to provide demand response and/or energy efficiency, and also storage facilities operators. Moreover, the DSO can set a minimum eligible volume of capacity to make the participation of small resources (e.g., residential consumers, small back-up generations, and small storages such as PHEVs' battery) possible only through an aggregator.

A DSO might allow intermittent resources such as wind and solar power to participate. However, these need to be treated differently due to their stochastic nature of outputs. For example, the DSO may need to exclude the intermittent resources from availability penalties and/or the poor performing as this is beyond the control of the resource provider. DSO can establish the value for winter and summer qualified capacity of intermittent resources such as wind based on the methods that have been developed for this purpose. One approach that has been studied for ISO NE forward capacity market is to identify the set of reliable hours that deliver the most reliable estimator of median generation during the system peak (IRWGM, 2006). PJM capacity market, however, adopts a different method by applying a 13 percent reduction factor on peak capacity of wind intermittent resources (Gottstein and Schwartz, 2010).

Therefore, CDS can take the advantages of all available resources whether on supply side or demand side including those with stochastic output. Particularly, participation of demand side resources (demand response and energy efficiency) along with supply resources (distributed generation and storage) can significantly improve efficiency of CDS acquisition. The evidence from ISO NE first capacity auction demonstrates that participation of demand side resources saved rate payers $24 million by making the market clearing price lower than it would have been otherwise (Jenkins et al., 2009)[6] . Additionally, demand side resources are carbon free and thus, in harmony with environmental policies. Furthermore, they improve system reliability by relieving the load at congested circuits and also reduce market power of supply side resources in determining market clearing price.

Following the initial identification of potential bidders, the DSO needs to verify the eligibility of resources providers with respect to conditions such as financial ability of new capacity providers, environmental compliance, siting and grid access etc. Below are the most relevant conditions which need to be verified before potential suppliers enter into the auction stage. The DSO

i) should ask for supply of financial assurance, by potential bidder, in case of a new resource which needs to be constructed.

ii) should demand potential bidders for submission of relevant environmental compliance documents as specified by the regulator for each type of generation technology.

[6] The ISO NE accounts DG as a demand side resource as well thus, in practice, the total saving from pure demand resources (demand response and energy efficiency) can be lower than this amount. Demand side resources (inclusive of DG in the case of ISO NE) made 2554 MW of 39142MW of offered capacity in the first auction (Jenkins et al., 2009).

iii) should investigate the siting of distributed resource and grid access condition especially for new resources. For example, position of resource with respect to frequently congested circuits and cost of grid connection.
iv) should ask for submission of relevant documents, in the case of new resources, that indicates local communities living at development proximity are content.
v) can ask for proof of technical expertise and managerial capability of resource provider.

Potential suppliers that are qualified in terms of type and capacity volume and also meet the aforementioned criterions will be invited to submit their bids. In order to help the auctioneer to choose the starting price, the DSO might include other requirements in this stage such as rendering an indicative bid (the approximate quantity of supply and price).

4.2 Auction stage

Several different auction designs can potentially be employed in this stage. These include: sealed bid, descending clock auction, hybrid, combinatorial and two-sided designs (Maurer and Barroso, 2011). Sealed bid auction can be in the form of uniform pricing, pay-as-bid or generalised Vickrey style in which the winner pays the social opportunity cost of the item won (Fabra et al., 2002). In the combinatorial auction, auctioneer sells multiple goods simultaneously where bidders are only allowed to place a bid on bundle of items and not the individual items. A two-sided auction allows both bid and ask so as to deal with multiple sellers and buyers at the same time and is proved to be effective in reducing market power when there are few seller and many elastic demands (Zou, 2009). Descending clock auction, on the other hand, is a dynamic simultaneous multi-round Dutch auction in which bidders submit quantity supplied at each price until no excess supply exists (Rego, 2013). Hybrid auction is the combination of different auction forms.

As the CDS contract acquisition is a form of single buyer model (i.e., DSO as the sole emptor deals with many potential suppliers), descending clock auction is the method of choice because of appropriate market characteristic. These characteristics, which are noted in NYSERDA (2004), make the descending clock auction a suitable approach for the CDS contract procurement. Firstly, it is an open auction with uniform pricing that discovers price with transparency and improves investment efficiency. Secondly, this auction only identifies the least cost suppliers as inefficient suppliers will withdraw from the auction when the clock ticks down (i.e., price starts to fall). Thirdly, this type of auction determines the winner in a simple manner and averts the need for complex comparisons of competitors' bids which, in turn, reduces the probability of subsequent disputes. Fourthly, under this auction both price and quantity of capacity committed are known at the end of the auction which allows the DSO to project more accurately future financial obligation as the result of CDS contacts acquisition.

Descending clock auction has previously been used successfully in various public and private procurement contexts[7]. In the power market, this approach is used for procurement of renewable portfolio standard by New York State Energy Research and Development Authority (NYSERDA, 2004). Moreover, ISO New England's Capacity Market uses a descending clock auction in which, energy efficiency, demand response, and distributed generation compete for capacity contract on an equivalent basis (Gottstein and Schwartz, 2010).

The DSO will execute a descending clock auction in multiple rounds with the following procedure. In the first round the auctioneer (DSO in this case) begins with a "starting price" (P_{start}) which is a fairly high price. The DSO can use information obtained during pre-auction stage such as indicative bid and breakeven price to choose the starting price. The resource suppliers, have some time (often between a quarter to few hours) to bid for the quantity of capacity they are willing to supply at this price. Then, the DSO adds up all the committed quantities and compares these with required network capacity to estimate the excess capacity.

In the second round the DSO reduces the price and allows resource providers to bid again for capacity they are willing to supply at the new price. The new quantity will be lower, or the same as before (but not larger), because of the lower price compared with the previous round. If the excess capacity reaches zero, the auction terminates and the winners will be the suppliers that placed a bid in the last successful auction round will win. However, if the excess capacity is still not zero, the DSO will continue the auction over subsequent series until excess capacity is eliminated[8]. The winning suppliers receive the last price cleared by auctioneer. Figure 5 illustrates the procedure of a descending clock auction.

The descending clock auction is an effective process for price discovery compared with the sealed bid auctions. Moreover, the dynamic nature of the auction allows the bidders to continuously adjust their bids based on the information revealed during the auction so that they can reduce the so called "wining curse". Although the descending clock auction appears to be more complicated than the sealed bid auctions however, the past experience shows that it is not difficult to implement and also, the practitioners are more in favour of this model (Maurer and Barroso, 2011). However, the main weakness of the descending clock auction is that it increases the possibility of collusion among the

[7] Descending clock auction has been used in US, Spain, Columbia, and the reverse form of it (ascending clock auction in which auctioneer sells) has been adopted in France, Spain, US and Canada (Maurer and Barroso, 2011).

[8] If in round n the committed capacity fall short of demand then auctioneer announce the price in round $n-1$ as the market clearing price and allocate demand among successful bidders pro rata.

bidders under the condition of weak competition. The case of insufficient competition is addressed in Section 4.2.3.

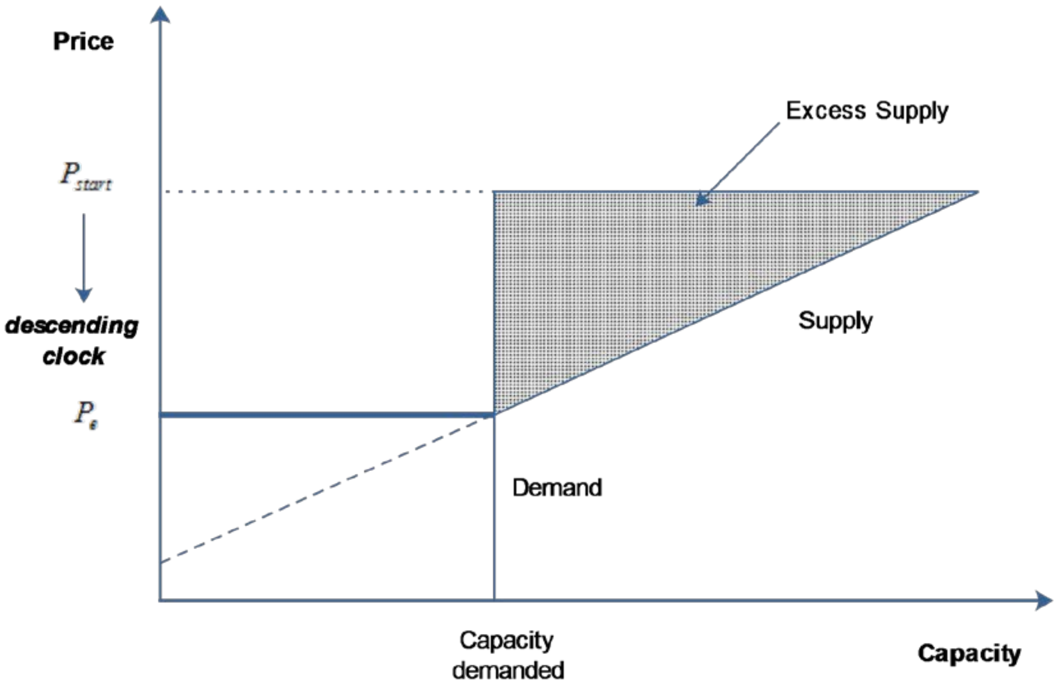

Figure 5: The descending clock auction

Source: Authors

4.2.1 Auction rules

In order to conduct the CDS auctions in an effective and efficient manner, a number of rules need to be in place. These rules need to be transparent and known to all participants as they embrace the conditions to run the auction. The main auction rules, in the context of CDS procurement, are outlined in the following.

i) The rule concerning the information to be released at the end of each round (e.g., whether or not participants can see the bids submitted by other bidders).

ii) Withdrawal and re-entering in a multi-round auction (e.g., whether the winners must participate in all rounds of auction).

iii) The incremental quantity of price decline in each round (e.g. this can be specified as a constant or as an interval).

iv) Whether a bid can be modified after it is submitted.

v) The format of bid submission such as bidding on an electronic platform provided by the auctioneer or in a different form.

vi) The "bidding window" of the auction (i.e. specifying when the bidding round starts and ends).

vii) The minimum volume of capacity that supplier can bid in each round. This is to prevent inefficient bids and to allow aggregators to take part on behalf of many small scale storages and demand response providers.

viii) Indication of minimum price at which the bidder would be willing to commit supplying capacity in the round that bidder has withdrew.

ix) Rules concerning disqualification of bidders and allowing the auctioneer to remove a bid from the current or future submission.

4.2.2 Auction lead time

The time of the auction depends on several factors such as the prediction of demand growth in distribution network and the presence of new resources in the auction and their associated technology. The DSO will determine the lead time that new projects need to be completed and hence, fulfil their obligation for supplying capacity. However, if the bidders are existing resources only, the lead time will be shorter (e.g., the following year). Therefore, taking into consideration the different lead times for existing and new projects, the auction needs to be held well in advance of demand growth to allow sufficient time for the construction of new capacity if required.

A short lead time can become a problem for capacity market design as it deters new entry even with high prices. A short lead time might also incentivise resource providers to withhold strategically in order to raise the price. The decision to run the UK capacity market with a four-year lead time between auctioning time and delivery period is to mitigate the impact of withholding and make the market sufficiently contestable by attracting new investment (see DECC, 2012).

In the context of CDS auctions, the lead time should be based on the gestation period of energy-based distributed resources such as CHP plants or storage facilities which are often shorter compared with conventional power plants (e.g., coal or nuclear plants). Also, DSO can differentiate between existing and new resources to prevent a long lead time come at the cost of undervaluing the investment of existing resources. Moreover, specifying different delivery periods will facilitate the participation of demand response as they will not be constrained by the lead time of constructing projects.

4.2.3 Inadequate supply and weak competition

In CDS contracts, the issue of inadequate supply can occur if at the starting price, in the descending clock auction, the total capacity offered (by existing distributed generation, storage facilities, demand response and energy efficiency) is less than the network capacity demanded. Insufficient competition, on the other hand, occurs when the number of bidders is limited (this can be accompanied with inadequate supply as well, though not necessarily).

The issue of inadequate supply due to insufficient existing resources can be alleviated by changing the auction parameters such as price and lead time. One approach to modify descending clock auction is to differentiate between existing and new resources based on the price. For instance, allowing existing resources to have market clearing price but the new resources to collect the penultimate round price in the first year of delivery and market clearing price thereafter (i.e., if the market clears after n round; this corresponds to the price in round $n-1$ and since the auction is descending in price we always have $P_{n-1} > P_n$). This approach provides incentive for new resources to participate and thus, attracts more new developers into competition and can potentially reduce probability of inadequate supply. The discriminatory price descending clock auction can be accompanied with a suitable lead time to incentivise investors.

The second approach to address the issue of inadequate supply is to include the amount of inadequate supply in the subsequent reconfiguration auction to correct for the inadequacy. This auction will cover both inadequate supply and change in the position of potential suppliers due to unpredicted circumstances. The reconfiguration auction has been explained in Section 4.3.

As mentioned previously, the descending clock auction is vulnerable to weak competition. That is the bidders can misuse the available information during the auction to coordinate their actions and raise the market clearing price. One approach to address the issue of weak competition is to carry out a hybrid auction in which the first phase starts with a descending clock auction followed by a sealed bid auction. The advantage of this approach is that it attracts more of small bidders and hence, strengthens competition. This form of hybrid auction has been used in Brazil to auction hydro power resources and has proved to be effective, to some extent, in handling market power and weak competition (Maurer and Barroso, 2011). However, a weakness of hybrid auction is that it can increase complexity of auction process and raises transaction cost. Therefore, it can be difficult to implement a hybrid auction.

Another approach, to address the market power, would be to use a single round sealed bid auction. Herrera-Dappe (2013) demonstrate that a sequence of two uniform price auctions gives lower expected revenue than a single uniform price auction when the market is not sufficiently competitive.

Despite these possible remedies, under insufficient competition, the DSO might seek permission from regulator not to run an auction. In this case the DSO can adopt alternative approaches to procure capacity which have been suggested to developing countries in these circumstances. Some of these alternatives are: negotiations between the DSO and potential suppliers, using an administratively set price such as feed-in tariff on a first-come-first served basis until the demand is met, or using a "beauty contest form of allocation" in the sense that DSO defines the criteria and conditions for contract with some room for discretion and subjective evaluation (Maurer and Barroso, 2011).

4.2.4 *Market monitoring*

A competitive process can result in an undesirable outcome, if it is not appropriately designed, implemented and monitored. There are a number of potential obstacles such as liquidity, market power, collusion, gaming etc., from which the CDS auction is not necessarily immune. These highlight the need for oversight. Therefore, regulator needs to appoint a third party, as the auction monitor, to superintend the CDS acquisition process.

The task of the auction monitor is to oversee the procurement process and report any evidence of breach of rule or non-conformity to the regulatory body. This includes all the stages from pre-auction to post-auction phase. The market monitor identifies the structural deficiency of CDS market design and the way these deficiencies can be misused by market participants. Moreover, the market monitor provides regulator with an assessment of market outcome to ensure they are consistent with a competitive process and policy objectives. Furthermore, the regulatory body can consult with the auction monitor in case that the conduct of the auction is disputed by a bidder.

The auction monitor can also help with designing the auction procedure for the specific contract procurement. However, the tasks of auction design and auction auditing should ideally be delegated to two independent entities, as in the case of PJM capacity market, to reduce possibility of conflict of interest and increase transparency.

4.3 Post-auction stage: Awarding CDS contract

Following the acceptance of offers and clearing price, DSO will enter into CDS contracts with successful bidders. According to the CDS contract, the capacity supplier will be paid based on the price in the agreement and the resource operator is obliged to deliver capacity or to reduce demand when called by the DSO. As CDS is a contract, many of the relevant issues in the context of contracts theory (i.e., principal-agent relationship such as information asymmetry, moral hazard etc.), are also applicable to CDS. Moreover, in practice writing a complete contract (taking all contingencies into consideration) for CDS is both unfeasible and costly. However, the following important issues need to be elucidated in a CDS contract.

4.3.1 Length of CDS contract

An important feature of the CDS contracts is the duration of agreement between DSO and capacity provider. Short agreements have the advantage that they are more easily tradable in a secondary market and also there is no long term financial obligation for DSO. However, long term agreement gives more financial security to capacity providers and avoids boom and bust in capacity market. In practice, a uniform contract length for all resources is not feasible, given the different cost structures, technology and asset age of capacity resources. Thus, in order to encourage investments and reduce the risk to investments, the DSO needs to differentiate between the existing resources and new capacities. It may be preferable to give more time to new capacities because a longer term agreement will enhance the certainty of return to investment and reduce the cost of capital.

A possible risk of differentiating between the existing and new capacities is that the projects that are under construction at the time of the auction will be treated as existing resources. This creates incentive for investors to withhold new investments until an auction is announced. In order to mitigate this effect, the definition of existing and new resources should be based on the capability to deliver at the time of the auction so as to treat only those resources that are operational as existing resources.

4.3.2 Prioritisation of support

Under the CDS contracts, resource operator, DSO and TSO are the entities that will have control over the operational status of distributed resource. In order to improve coordination among these players and avoid conflict of interest, prioritisation of support needs to be clearly determined. The form of allocating priority can be based on the type of resource and the initial purpose of developing the resource. For example, if the resource is a DG which was originally installed to satisfy the developers' own demand, a feasible arrangement would be to give the owners of DG resources priority because it is usually needed as backup power supply. The DSO would then be the second entity that has priority to call the generation for local balancing as no other alternative is available, and finally the TSO is the third entity. Where the resource output is not required locally or nationally, the energy produced can be sold into the wider electricity market.

4.3.3 Non-compliance risks

There are several sources of non-compliance risks such as the failure of successful bidder to sign the CDS contract, failure to complete the project (for new resources), risks related to the delays and failure of supplier to deliver the committed capacity, risk of underbidding and finally regulatory and administrative risks. As in other contracts, the CDS needs to address these issues at an appropriate stage. For example, the risk of delay and underbidding can be reduced by applying stringent compliance rules. Frequent monitoring of project development can reduce the risk of failure with respect to construction of new resources. Moreover, strict qualification checks at pre-auction stage reduce regulatory and administrative risks such as those related to the project siting, grid connection and environmental obligations.

A challenging issue from the perspective of the DSO is the commitment of the capacity provider to deliver when needed. Uncertainty in this will undermine the effectiveness of smart solution as alternative to grid capacity enhancement. Therefore, the DSO needs to ensure that a credible, effective enforcement and compliance mechanism is in place that guarantees a timely delivery and applies a penalty in the event of non-compliance. Drawing on the experience from the established capacity markets, there is a spectrum of approaches to reduce probability of non-compliance. The market-based methods rest at one end and the administrative approaches are located at the other end of the spectrum. The hybrid methods lay somewhere in between.

One market based approach is to pin the terms of CDS contracts to some reference electricity market such that when the reference price is above the contract price, the resource operator is required to pay the difference. This incentivises the resource owners to deliver at the time of network constraint and peak demand, because even if they do not operate they still need to pay the difference. The price spikes usually coincide with time of peak demand and network constraints. However, if they do not coincide this method can be problematic. Moreover, in some countries such a market might not be available to provide a reference price.

The administrative approach would be that the resource owners receive a capacity payment for their availability period, as specified in CDS contract, and to be penalised based on an administratively set price if they fail to deliver when they are called or fail a spot check by DSO. This method is more straightforward and easier to be implemented. However, the total annual penalties should be capped to avoid unquantifiable risk to the investors. For example, the penalty could be proportional to the volume of capacity (e.g., a percentage of the annual payment for that resource during the capacity commitment period). Moreover, the DSO should offer the option to resource provider to default on its commitment, when called, and pay the penalty if unexpected faults developed.

The compliance monitoring approach that the DSO can adopt is context bounded. However, regardless of the approach chosen; it needs to take into consideration several aspects, such as the possibility of strategic behaviour and gaming the DSO, allowing for maintenance planning of energy-based resources, and linking the size of penalties to total volume of capacity payment etc. Moreover, in many capacity markets the penalty price is not uniform across different resources. For example, the PJM and ISO NE capacity markets differentiate between supply side resources and demand side resources for non-compliance and associated penalties (Gottstein and Schwartz, 2010). This differentiation can also be helpful in the context of CDS contract given different nature of energy based and non-energy based resources.

4.3.4 Reconfiguration auction

Due to the possibility of unpredictable circumstances and change in economic factors, there might be discrepancies between the contractual obligation of bidders and the actual cost of their contract fulfilment. Thus, when there is evidence of such condition, a reconfiguration auction should be held in an appropriate time, ex-post, in order to allow suppliers to correct for these differences. For example, the ISO New England's capacity market runs monthly and yearly reconfiguration auction to allow deficient supplier to procure replacement capacity (Gottstein and Schwartz, 2010). The lack of such a mechanism increases probability of unavailability of resource in the time of need.

Other situations that require reconfiguration auction include the state of inadequate or excess supply of capacity. As mentioned in Section 4.2.3., the inadequate supply dominates when there is insufficient supply from the existing capacities at the first round of the descending clock auction. The excess supply can prevail when there is a decrease in load forecast[9] following the auction and capacity acquisition. Under these conditions, the reconfiguration auction can help the DSO to buy or to sell CDS contracts and match supply with demand more accurately. The reconfiguration auction, for a specific target, can be held close to the year of delivery. The price in the reconfiguration option can be higher or lower than the initial CDS auctions.

5. Conclusions

The power sector is evolving with anticipation of increase in penetration of distributed generation, storage technologies and demand side participation. Distribution networks which were originally designed as passive and one way transporters of electrical energy are entering a new era in which operational philosophy will change to the bi-directional power flows and the use of information and communication technologies. These will bring new opportunities for implementing innovative solutions for traditional issues such as demand driven network reinforcement, through locally satisfying of demand, using distributed resources.

[9] The error in forecast is natural when looking far into the future i.e. the CDS auction has been held few years in advance of delivery period.

This paper proposed a new market-based model termed “contract for deferral scheme” (CDS) to integrate an economically efficient portfolio of distributed resources including distributed generations, storage technologies, demand response and energy efficiency, as an alternative for demand driven network investment. The concept of CDS is consistent with an unbundled power sector paradigm, and lies within the wider context of an extended business model of distribution utilities. The details of the CDS procurement was discussed in three stages: pre-auction, auction and post-auction. Pre-auction stage explored the conditions for resource eligibility; the auction stage discussed the process of price discovery and market rules and finally post-auction stage addressed issues such as the length of contracts and compliance monitoring.

The CDS contracts present several potential advantages. Firstly, they protect the developers of distributed resources from market risks, decrease the financing cost and improve commercial bankability of investments. Secondly, they improve competition, encourage investments and hence; speed up the deployment of DGs, storage facilities and demand side participation. Thirdly, CDS auctions help with creating an integrated market for substitution of a resource portfolio as a virtual network capacity, at distribution level, and simplifying the process of valuing alternative solutions to grid reinforcements. Fourthly, CDS helps, to some extent, alleviating the gradual reduction of reserve margin which is currently a major issue in the post-liberalisation power sector.

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