Distributed Generation, Demand Response, and Storage As Alternatives to Grid Capacity Enhancement

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Abstract

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. This paper explores the main prerequisites in terms of operational and organisational paradigm as well as regulatory framework and incentives for distribution network utilities to innovate and overcome these challenges. We propose a market-oriented approach termed as "contract for deferral scheme" (CDS) in order to adopt an economically efficient portfolio of distributed generation, storage technologies and demand response as network resources that provide capacity and defer demand driven network investments. Moreover, we discuss potential incentive mechanisms to address the issue of commitment by resource providers for delivery upon the request of network operator.

Keywords: distributed generation, storage, demand response, grid reinforcement, investment deferral, network regulation, business model.

JEL Classifications: L43, L51, L52, L94

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1. Background

A traditional power system is characterised by conventional generation sources that inject large amounts of power into the transmission grid, which is in turn transported to passive distribution networks, and delivered to the end-users. Electricity distribution networks are a crucial element of power sector infrastructure and have a critical role to play in the smart and sustainable electricity sectors of the future. A key feature of the future networks is that they will perform in an operating environment and paradigm in which distributed generation (DG), demand response (DR), and storage facilities are important components of the system. This change is driven by climate and sustainability policies along with affordability and reliability of electricity supply. Future sustainable power systems will be based upon coexistence of conventional power plants and distributed generation, and tap into demand response and storage as network resources to defer and optimize network investments.

The electricity distribution network operators (DNOs) are responsible for 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 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 technologies and reducing peak demand through demand response. This implies a change in the operating paradigm from passive to active distribution networks which enables managing a portfolio of generators, users, and storage as network resources.

From an economic viewpoint it is important that innovative solutions are both effective and cost efficient. For instance, the cost of distributed resources as a means to satisfy local demand needs to be lower than traditional network reinforcement in order to be considered as an economical alternative. However, a challenge is to attribute a value to these energy resources. This is because there is no clear instruction available to value a complex set of technical and financial opportunities (and challenges) raised form integration of these resources. Moreover, adopting distributed resources in order to defer demand driven grid reinforcement requires extending the traditional business model of distribution companies. Thus, along with technical concerns, a great deal of complexity lies in the economic and regulatory sides of these innovative solutions. For example, the issue of ownership model of resource facility, differentiating between costs of capacity and energy, dispatchable and non-dispatchable generation, possibility

[2] Throughout this paper we use the term "distributed resources" to refer to distributed generation, demand response and storage facilities that interact with distribution network.

of trade in other markets, managing storage and demand response are important issues that 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 explores a new approach to integration of distributed resources as alternatives to distribution grid reinforcement and highlights some prerequisites of enabling innovative solutions in terms of operational philosophy and economic and regulatory issues. Also, we propose a three stage market-based approach termed "contract for deferral" scheme in order to employ a portfolio of generation, storage technologies and demand response to supply network capacity and defer demand driven investments.

The next section discusses the need for innovative network solutions from an efficiency perspective and explores some of the main other advantages of distributed generation. The need for a new operational model of distribution companies is explored in Section 3. Section 4 discusses the state-of-the-art of the literature on estimation of benefits of distributed generation in terms of investment deferral. Regulatory challenges and their possible solutions are presented in Section 5. Section 6 presents an extended business model for distribution network operators. Finally, Section 7 concludes the paper.

2. Innovative Approaches to an Old Issue

One of the main responsibilities of distribution utilities is to carry out necessary grid reinforcement in order to ensure continuity of supply as demand grows. In doing so, the network companies project the growth of electricity consumption and assess the scale and type of investment needed to meet future demand.

A feature of traditional network upgrade is that while demand grows gradually, network reinforcement is carried out in large increments requiring lumpy investments. As a result, part of grid capacity remains idle for long periods in anticipation that demand catches up. Therefore, in a network reinforcement cycle, the total capital employed, to deliver a given amount of output, is higher than the theoretical optimum needed at any given time. This, in turn, raises the issue of inefficient utilisation of resources and as a consequence leads to distorted connection charges. 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.

The issue of resource inefficiency, in demand driven network investments, is exacerbated when the mid or long term development of demand are uncertain. As demand grows the productive efficiency of network will improve because more capacity will be utilised. However, demand for electricity can also decline instead, in which case the idle capacity of the system increases the productive inefficiency (Jamasb and Marantes, 2011). Factors such as higher efficiency of appliances, demand-side management, higher building standards, higher prices and change in consumption profile of region due to movement of a large consumer (e.g., factories) can reduce the rate of increase or even reverse the demand growth. The case of upward deviation of demand from projections is less critical for system efficiency, as there is the possibility of investment according to the need such that shortages in network capacity can be avoided.

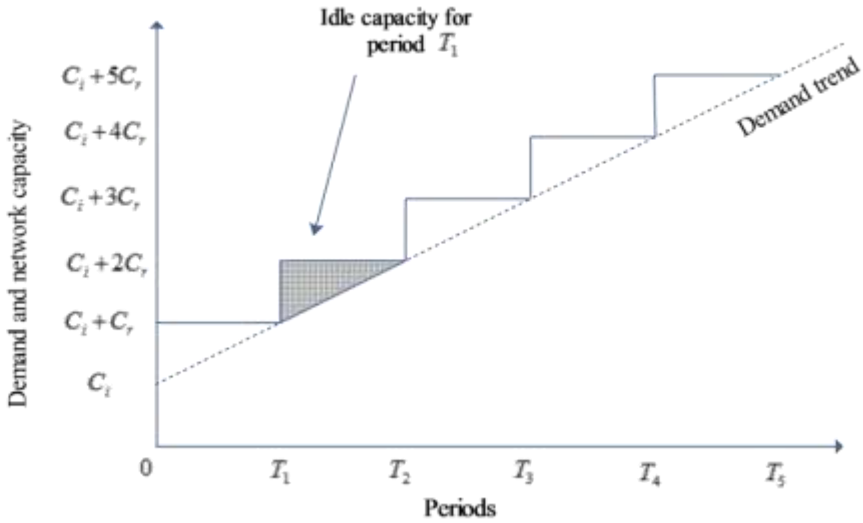

Figure 1: Demand growth and network capacity enhancement

Source: Authors

The electricity distribution networks are natural monopolies and their revenue is regulated in order to induce cost efficiency. However, while the conventional operation paradigm and incentive properties of the regulatory framework have mainly led to "operational cost efficiency" of the networks; there is less evidence of "investment efficiency" through implementing smart solutions. Considering the scale of investments associated with network reinforcement, even a partial solution that proportions capacity upgrade with demand growth can improve economic efficiency and social welfare.

An alternative solution to the traditional network enforcement is to meet part of the demand for energy services locally through DGs, storage technologies and managing demand through effective demand response programs. Although the effect of investment deferral is not coming only from DGs, they are among the most promising and reliable resources for this purpose. Demand response and storage facilities, when adopted along with DGs, can give a boost to grid investment deferral.

Distributed generation sources are connected to the low voltage distribution network so they avert the need for costly redundant transformers. Hemdan and Kurrat (2011) show that efficient integration of DGs can, by correctly siting them in the network, provide a solution to the increasing demand for load. Depending on the location and network condition, some grid reinforcement with shallow costs may be involved in initial connection of distributed generation. However, beyond that, one effect of DG can be that it defers deep investments for grid capacity expansion. Moreover, as DGs can be installed frequently and in small increments they can alleviate the inefficiency from the underutilised capacity when grid is reinforced (Hoff et al., 1996).

The benefits of DGs are not limited to deferral of investments in distribution networks. The main driver of DGs is environmental policies aiming at a sustainable electricity supply. Furthermore, there are potential technical advantages in the uptake of DGs including reduction of network energy losses, quality of supply and reliability improvement (Zangiabadi et al., 2010; Jamasb et al., 2005). Table 1 presents the main advantages of distributed generation and the services they provide. As shown, peak power reduction and ancillary services are tied in with all benefits of DGs. The case in favour of the integration of DG becomes stronger when taking the entire network and system benefits into account, although deferral of investments and resource efficiency improvement are sufficient standalone economic justifications.

DG Services	DG Benefits
Peak power reduction (*) Ancillary service provision (Δ) Emergency power supply (∇)	Energy cost saving * Δ ∇
	Investment deferral of generation capacity* Δ
	Investment deferral of network reinforcement* Δ
	Reduce right of way need for grid infrastructure * Δ
	System reliability benefits * Δ ∇
	Reduce network energy loss and congestion * Δ ∇
	Power quality benefits * Δ ∇
	Increase power system resiliency * Δ ∇
	Environmental advantages * Δ ∇

Table 1: Services and associated benefits offered by distributed generation

Source: Adapted from DOE (2007)

3. Distribution Network Management: From Network Operator to System Operator

Distribution grids have traditionally operated as passive networks which receive power from high voltage transmission grid and then transfer it to the end user without having much control over the power flows. As the grid only relies on the reserve element of capacity to avoid outages and other rare events, the grid capacity available to new generation connection is often about half of installed capacity. Therefore, network capacity for DGs integration is limited under the current planning and operation of distribution companies.

However, under an active management paradigm, the connection capacity is aligned with the improvement of technical characteristics and efficiency of the network. This allows the system operator to create additional capacity to host more new generation resources without voltage and thermal constraints violations (Zhang et al., 2009). Under this condition, DGs also serve as network equipment or an integral part of DNOs and not only as conventional power plants that are connected to the grid.

Moreover, public opposition concerning new grid infrastructure is increasingly an issue for network companies (Tobiasson et al., 2013). Local community opposition, protests, and legal challenges, can significantly impede grid expansion plans and raise the project cost to the network operators and rate payers. Investment in technologies that allow effective utilisation of installed grid capacity will be more likely to gain public support compared to traditional network expansions. Therefore, active management of network to increase utilisation of existing network capacity can offer significant benefits for distribution utilities in this respect.

Active management of networks requires real time control and management of DGs and distribution network equipment based on real time measurement of primary system parameters such as voltage and current (Zhang et al., 2009). This is to ensure that these parameters remain within their operating constraints. Integration of DGs might result in bidirectional power flow, something which the current distribution grids are not designed for. The main issues confronting the grid as a result of distributed generation connection include: islanding, voltage regulation, harmonics, reverse power flow effects, over-voltage condition, metering, and system losses (Dondi et al., 2002). Investments in remote DG control can overcome some of these issues. At the same time, ancillary services can be provided as by-product of these technologies. Thus, the need for active network management will increase as more DGs are connected to the low voltage network. Also, the scale of DGs can open new possibilities for managing and planning the network.

Penetration of DGs in low voltage network requires a shift in operational philosophy of distribution network operators. The DNO does not have the ability to influence the demand and generation, as required, when the reliability of system is endangered. In fact the system possesses finite flexibilities to meet the regulatory requirements concerning quality of supply and to prevent major network failure. Moreover, DNOs can only carry out network expansion in response to peak demand growth and there is little room for innovative solutions under their current operating paradigm. Thus, a paradigm shift in the role from DNO to distribution system operator (DSO) can pave the way towards implementing smart solutions (Poudineh and Jamasb, 2012a).

The distribution system operator (DSO) will control a portfolio of generation, demand response and storage technologies and effectively use them for efficient operation of the distribution network. A DSO will be able to manage a network with more flexibility and has more control over the power flow and voltage profile. The flexibility of power flow and control in the network along with access to the demand and generation response will enable the DSO to contribute to balancing of the power system. Figure 2 illustrates a schematic view of the new opportunities arising as a result of evolution of DNO to DSO. As shown in the figure, DSO can manage dispatchable, non-dispatchable, storage facilities and flexible demands resources to promote efficient operation of distribution network. Moreover, some resources such as flexible demand can contribute towards the resource adequacy as well as reliability of whole system when there is a smart infrastructure in place that enables an effective demand response.

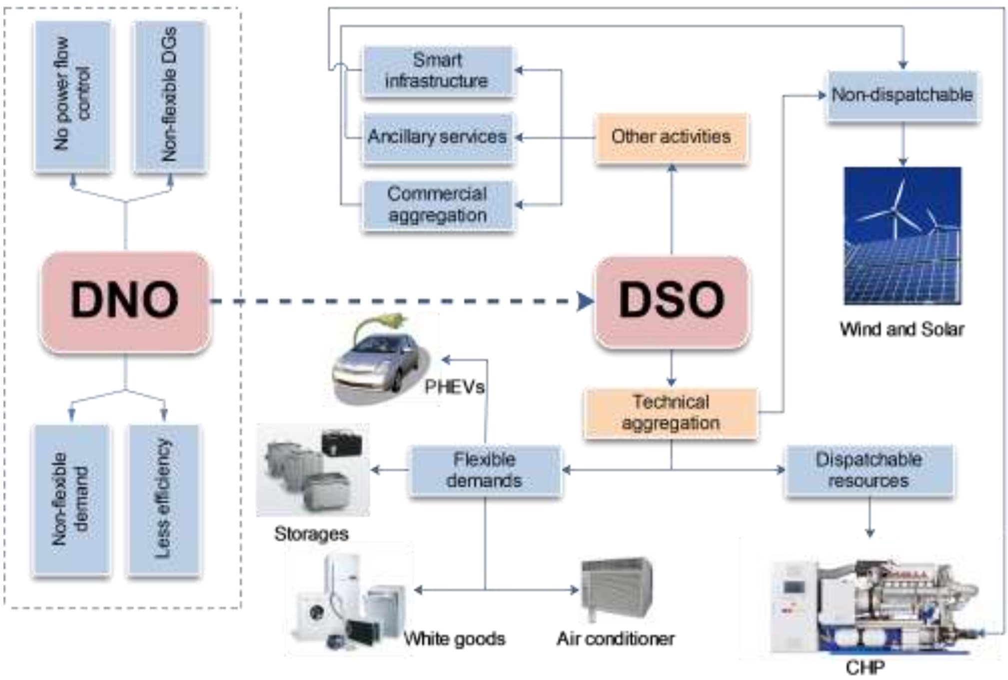

Figure 2: A future distribution system operator (DSO) model
Source: Authors

Non-regulated activities

An increasing volume of embedded generation along with the evolution of distribution system operator will introduce new business opportunities such as creating a market for ancillary service at distribution level, commercial and technical aggregations of non-dispatchable resources etc. Ancillary services are those interconnected operations that are necessary to support flow of power from generator to the end consumers. Some of the most important ancillary services are: frequency response, primary and secondary reserve through generation or demand, fast start load reduction, warming and hot standby, reactive power and black start (Waghorn, 2003).

Under the current operating paradigm, DNOs do not purchase any ancillary services from distributed generations connected to their network. This is because, firstly, these services are procured by transmission system operator (TSO), on behalf of the all customers, and then the cost of these is passed to the consumers through uplift in transmission payment (Raineri et al., 2006). Secondly, due to traditional engineering requirement and security standards, up to now, the incentives were concentrated on network assets and distribution companies were required to provide these services through the installed network capacity rather than embedded generation. Thirdly, there is currently no market in place, at the level of distribution network operators, which enable trading ancillary services.

The active network management provides an opportunity for a DSO-managed market based solution for ancillary services rather than viewing it as an integral part of transmission system operator. This market will bring about technical as well as financial benefits. From a technical view point, distribution networks need to meet power security and supply requirement based on a set of specified standards. From an economic perspective, these services need to be procured at the lowest possible cost. Therefore, such a market model will help achieving technical objectives in a cost effective way.

The operation of companies in this market will be outside their current regulated activities and will not affect the regulated part of their business. This might create incentive for the companies to engage in this market. However, the objective of local balancing should not come at the detriment of national balancing system. Thus, the balancing operations of DSO need to be in full coordination with transmission system operator. Moreover, if network companies at different geographic regions are able to define their needed product based on their own requirement, there will also be a possibility for a single ancillary service market across different regions (Waghorn, 2003).

4. Distributed Resources and Investment Deferral: Value Assessment

The plethora of studies has attempted to assess the value of distributed resources with respect to their impact on distribution network investment deferral. These studies mainly revolve around distributed generation as it is considered a promising energy-based alternative for distribution network capacity enhancement. The proposed methods in the literature are based on two different perspectives of this issue. The first approach attempts to attribute a cost to the distributed generation for a given level of network investments whereas the second approach tries to investigate the impact of (a given) distributed generation on network investment deferral. Figure 3 summarises the approaches adopted in the literature.

Hof et al. (1996) in an early study address the issue of valuing DGs as alternative to grid reinforcement. They simplified the assessment by assuming that the value of DG originates from two sources: the effect on operating costs and the effect on capacity investment of distribution companies. The study calculates a break-even price for investment deferral taking into account economic and technical constraints. The break-even price is per unit of capacity value of DG that makes a distribution company indifferent between undertaking conventional investments and procuring this service from DG. Other studies in this category include Miri-Larimi and Haghifam (2012) that attempted to obtain a minimum energy price for DGs while taking into account a number of benefits.

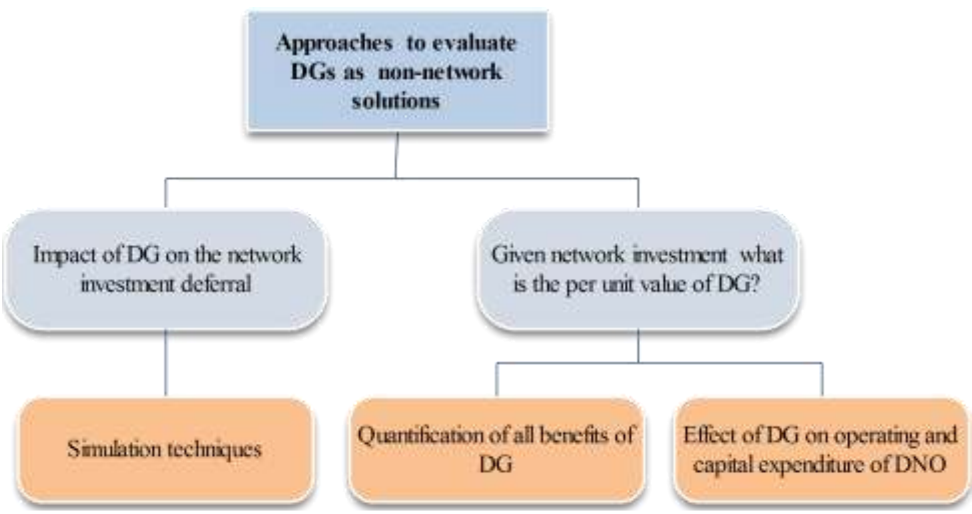

Figure 3: Approaches to evaluate DG as a non-network solution

Source: Authors

The second category is based on evaluating the effect of DGs penetration on deferring network investments. Mendez et al. (2006) propose an approach, based on Monte Carlo simulation, to 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, the net effect of DG is that it can defer capacity enhancement driven by natural demand growth. Also, they show that the intensity of the effect depends on the type of distributed generation. For example, wind turbines have less effect on investment deferral compared with combined heat and power (CHP) due to the intermittent nature of the production of the former. Moreover, their approach shows that a dispersed siting of DG resources will improve the effect.

Gil and Joos (2006) attempt to quantify the value of network capacity upgrade deferral of DGs. The study found 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. They also suggest that assessment of DG value in terms of capacity ($/kVA) and/or energy ($/KWh) is a function of the utilities upgrading strategies and under circumstances that DG is not owned by utility, it is important to quantify the value with respect to both.

Pudaruth and Li (2007) have attempted to quantify the costs and benefits of DG for investment deferral of distribution companies. Their approach is based on the principle that the time horizon of future reinforcement of an asset in the network can be evaluated from the asset loading level and the projected load growth rate. Their method aims to translate the investment horizon into monetary terms reflecting future network development cost. The study quantifies the network costs or benefits introduced by DGs in terms of thermal capacity limits of lines and assets.

Piccolo and Siano (2009) analyse the implication of DNOs' preferences for the size and location of DGs uses a multiyear multi-period optimal power flow method. They also, examine the implication of regulatory model on optimal connection of DG within existing networks. Wang et al. (2009) adopt the UK Engineering P2/6 approach and demonstrate that significant benefits, in terms of investment deferral, can be harnessed if the DG contribution to system security is taken into account. Moreover, they show that the deferment varies significantly with the location and size of the generator. Another related work is Zhang et al. (2010) that attempt to measure the effect of micro-generation on deferral of investments in transmission lines and show effective site reallocation will increase the benefits of capacity deferral for the same amount of DGs connected.

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. He shows that, in the case of storage, for example, grid reinforcement can be avoided at some voltage level without harming system security because the network capacity utilisation rate will remain well below the threshold. Also, he noted that the effect of demand side management will be stronger when more flexible demands such as electric vehicles are available. Similar to the case of distributed generation, the advantages of storage and demand response are not limited only to the deferment of network reinforcement but they also include, peak shaving, spinning reserve, voltage and frequency regulation, and dealing with variability of supply side (Zafirakis et al., 2013).

5. Regulatory Aspects

Under the current power sector operating paradigm, adoption of storage technologies, demand side participation and penetration of DGs are policy driven rather than being market oriented. Hence, the rate of penetration of these resources are influenced by regulation and incentives provided by the energy regulators. These incentives usually address the principal stake holders that are DNOs and resource provider (e.g., DG developers). In order to unlock the system benefits of distributed resources, the technical and institutional framework that form the behaviour of the power sector need to be realigned. A significant part of this change involves levelling the playing field for distributed generation and allowing DNOs to take on a new and more active role. Some of the most important challenges as a result of distributed resources uptake are presented here.

5.1 Ownership model of DGs

In order to fully realise the system benefits of DGs concerning investment deferral and technical requirements, DNOs need to exert some degree of control over the location and operational status of DGs. Under the current regulatory framework, the power sector is unbundled and DNOs are prevented from owning generation resources (Niesten, 2010). Although, this is important in terms of economic advantages and efficiency for the wholesale electricity market, it hampers coordination between network and generation planning when DG is planned and connected. Moreover, the European directives 2005/89/EC and 2003/54/EC state that DNOs should consider DG connection as a solution for network expansion (Piccolo and Siano, 2009; Wang et al. 2009). However, the directives give no instruction as how this can be achieved under the unbundled sector model.

There is some scope for regulatory innovations that can alleviate this problem to some extent. These solutions are a function of rate of DG uptake in a particular region and can broadly be categorised into low penetration and high penetration scenarios. For example, where penetration of DGs is very low in a particular region and virtually there is no chance of competition, regulator can authorise some limited "conditional ownership" of DGs by DNO given that the following conditions are satisfied:

- DNO can demonstrate that DG is strategically located within the grid in order to avoid demand driven network investments.
- DNO can show that it is more appealing economically than conventional network reinforcement.
- DNO commits to transfer the ownership of DG to the third party upon request of regulator based on some pre-specified agreements with regulator.

The reasons behind the third condition is that if the situation of the region changes over time in the sense that more independent DGs are installed, then there is no justification for DNO ownership of DGs as the model of high penetration scenario can be implemented. Moreover, the regulator may be concerned about non-discriminatory access to the network by new DG developers. Therefore, the exit strategy is to ensure that there is no discrimination and it converges to the high penetration scenario where feasible, and also to reduce the possibility of gaming the regulator. Despite these possible challenges, this method is straightforward for DNO as it averts the need for economic evaluation of per unit of capacity cost of DG because it is feasible where the total cost of integration is lower than that of network reinforcement.

In the high penetration scenario, the regulator can, where feasible, directly or indirectly incentivise connection of DGs by the DNO, as an alternative to grid reinforcement. At the same time, it allows the DG developers to bid in competitive auctions for capacity contracts. From the regulatory perspective, this approach is preferable over the previous method, because it is independent of network operator's situation and the DNO does not need to meet a specific condition. Also, it does not violate the operating condition of an unbundled power sector paradigm. Furthermore, the presence of a well-designed market with sufficient number of players will more likely produce efficient outcomes. However, in smaller parts of the network a DNO-owned model may be preferable.

5.2 Incentives and alignment of benefits

The current incentives for integration of DGs by DNOs are not directly relevant in terms of the impact that DG would have on network infrastructure and on generation supply. For example, siting a DG close to demand centres or an area served by frequently congested lines will be beneficial for DNO as it reduces network energy losses and has a real impact on demand driven investments. Therefore, the effect of DG on grid depends on many factors such as location, technological specification and timing of investments (Vogel, 2009). Lack of a mechanism that aligns these benefits between DG developer and DNO might reverse the expected advantages of DGs integration.

An example, in this respect, is the network energy losses. Networks are incentivised to reduce losses and are rewarded or penalised for outperforming or underperforming the loss targets. Although, DG can reduce energy losses, it is generally bounded by time and location and under the condition that capacity exceeds the demand it even can increase overall energy losses because the relationship between capacity and loss is U-shaped (Harrison et al., 2007). Therefore, given this relationship, DNOs might be exposed to DG induced losses with consequences for their revenue. On the other hand, generators are not incentivised for their positive or negative impact on the network losses. Hence, there is an inherent conflict between the interest of developers that might wish to increase DG penetration and the DNO which might avoid DG induced losses.

The solution for these issues might lie in devising an efficient connection charges for DGs. A mechanism that not only includes the real cost of connection but also rewards when DG installation is in line with the optimal operation of the network (Jamasb et al., 2005). The distribution use of system charge (UoS) can play an important role in this respect. In fact connection charges, for DGs, could be based on their capacity and the sole-use network asset used. On the other hand, rewards can be grounded on generator exported power at system peak, proximity to the frequently congested zones and the network asset utilised. This is to ensure that the reward will reflect the estimated investment deferral driven by demand growth. Taking into account these cost drivers for devising the charges and rewards will help to guarantee that they are aligned with the costs imposed by DGs on the network.

Also, within the regulatory framework, the instructions should be transparent, consistent and unidirectional in order to boost innovations. For example, in the UK, under the RIIO-ED1 regulation model, innovative solutions are incentivised by way of rewarding the downward deviation from the expected capital expenditure in business plan of DNOs (Ofgem, 2012). While this seems desirable, the regulatory framework does not provide clear indication of how to address the issue of network reinforcement using non-network solutions. This potentially increases the barriers for DNOs to implement smart solutions and might force them to forego operational benefits of DGs and choose conventional network reinforcement.

5.3 Demand response and storage facilities

Demand response and storage technologies are also potential resources that can act as alternative to the conventional network reinforcement. In order to fully utilise these resources and improve efficiency of grid operation, the challenges concerning participation of demand response and storage technologies need to be addressed effectively. For example, the rules governing electricity markets and reliability requirements have been designed for, and evolved under, a generator supply paradigm (Capper et al., 2012).

Therefore, there might be regulatory limitations on the amount of demand response that can participate in network balancing as it is often categorised as a non-energy resource. However, demand response is usually an underutilised resource that is very effective in the sense that it is speedier than many generation types. This feature of demand response is particularly helpful when peak demand and network constraints coincide. Hence, an extended product definition is helpful in order to allow demand response to provide bulk power system and certain types of ancillary services. Moreover, the definition of bulk power system also can be extended to adopt demand response along with other new resources such as storage technologies.

The current regulations of most electricity markets require a resource, which provides balancing services, to be able of providing both ramping up and down services something which is not compatible with all types of loads. Thus, separation of balancing up and down services will enable those loads with unidirectional balancing capability to participate as well. Moreover, investment deferral decision with respect to demand response requires polices and tools consistent with the nature of the service as demand response has statistical properties. This includes broadening the regulatory view of capital expenditure because, investment in demand response, through it can substitute network capacity upgrade, is not a form of investment in primary network assets.

Additionally, Grunewald et al. (2011) shows that the penetration of storage facilities are sensitive to a wide range of uncertainties such as future plant mix, technology development, market structures and the stochastic uncertainty of returns. In order to facilitate the uptake of these resources, policies and regulation need to reduce the risk for investors. This, in part can be achieved through a supportive regulatory framework that provides certainty in future trading arrangement, especially in the balancing market. Moreover, there might be many small scale storages in which case an aggregator needs to act on behalf of them. Furthermore, as demand response and storage technologies are able to offer capacity for only a short period of time, regulation needs to be tailored so that more of these resources can be accommodated.

6. An Extended Business Model

The revenue sources of distribution companies are the regulated connection charges and use of system charges (UoS). Based on the type of consumer and regulatory framework model, new connection fees can be divided into shallow and deep cost charges (Jamasb et al., 2005). Deep costs also include the incurred expenses as a result of reinforcement needed to maintain connection. Under the shallow connection charge, the consumer will pay the costs in order to become connected to the nearest grid point.

Implementing smart solutions for grid issues in an environment with high penetration of DGs requires flexible regulation as the power network operation lacks competition. The current incentive regulation schemes only promote cost efficiency for delivering a given quantity and quality of output and does not provide much flexibility for innovative solutions (e.g., the same energy service but with a different type of output). Over time, this might result in shrinking the revenue base of DNOs as the presence of DGs close to the site of demand reduces the volume of energy transmitted in the grid (van Werven and Scheepers, 2005). Therefore, there is a need for diversification and extension of the DNO's business model beyond provision of connections and energy transport charges only. This extended business model will form an important part of the evolution of DNO to DSO.

In order to realise the full potential of a DSO business model, it is helpful to identify the key actors and the services they receive from or offer to networks. The key players that interact with DSOs include residential consumers, commercial users, industrial customers, DG operators, storage facilities operators, retail suppliers and transmission system operator (TSO). DSO can offer certain services to each of these players that construct its main sources of revenue and receive certain services from them that will constitute part of its costs. The interaction among these players will lead to socio-economically beneficial activities and outcomes for all actors through new business framework. For example, due to deregulation and market liberalisation, the capacities of large scale power generation reserves are declining in many countries (Gordijn and Akkermans, 2007). This creates new business opportunities for DGs that could be realised through adopting many small scale dispatchable distributed generations which supply part of system reserve.

The new organizing paradigm of distribution companies as DSO will bring new opportunities in terms of offering new services. 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 services will offer new sources of revenue for DSOs which were not possible under a conventional DNO business model. At the same time, the costs to DSO will include operation and maintenance, grid reinforcement which can be either in a traditional way or in the form of demand response and capacity payment (DG and storage), procurement of ancillary services from DGs and TSO, and finally cost of energy losses. Figure 4, illustrates the existing and new services, flow of revenue, costs, and interaction of key players in an extended business model of DSO.

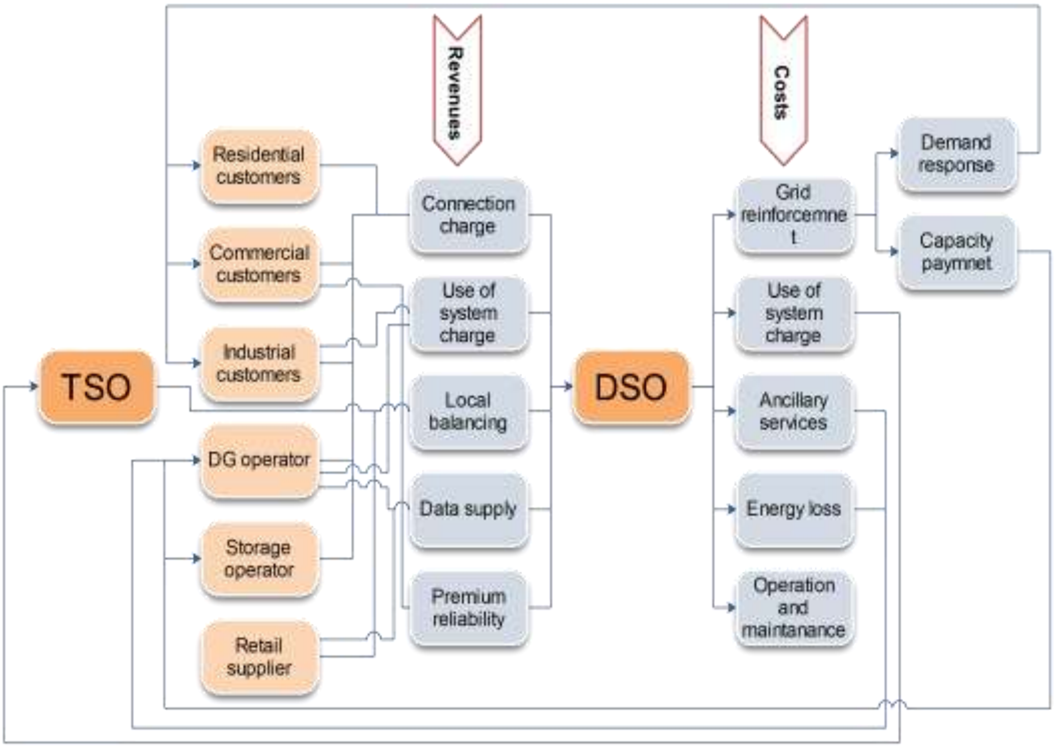

Figure 4: The extended business model for DSO

Source: Authors

The new environment will, as a result of high penetration of DGs and evolution of distribution companies to DSOs, extend the business model beyond the traditional connection and UoS charges which, in turn, will improve the process of revenue generation. DSO will also contribute to the national load balancing and will be compensated for that by TSO. This will be done through dispatchable DGs (and possibly 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, 2012b). 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/or retail suppliers for the purpose of efficient planning and operation in return for a payoff.

On the cost side, along with traditional operating and maintenance expenditures and cost of energy loss, DSO will purchase ancillary services from DGs as well as TSO. Also, the DSO will utilise storage facilities, demand response and DGs as alternatives to grid capacity enhancement and pays for the capacity provided by these resources.

6.1 Contract for deferral scheme (CDS) auctions

Perhaps the most challenging task is designing of an economic model that delivers the network service (network capacity) cost effectively using alternative resources (DGs, storage and demand response). Provided the regulatory issue concerning the ownership of distributed generation and an unbundled power sector, our proposed model is based on a contract for deferral scheme (CDS). Under this approach, DSOs will be able to enter into contract with distributed generations, demand response providers and storage facilities operators that offer available capacity when needed. The market participants, who enter a contract, will be obliged to have available the required capacity at the time of network constraints (or when they are called) and in return, the DSO offers them a capacity payment.

In fact, CDS is a mechanism to select a portfolio of capacity supply from DGs, storage facilities, and demand response 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. CDS auctions can be implemented in three stages as outlined in the following subsections.

6.1.1 Evaluation phase

In this stage the DSO forecast demand growth over the subsequent years and projects the required network capacity. Also, DSO determines which resources are eligible to submit offer at the price they are willing to provide capacity. For example, DSO needs to determine whether to allow only existing capacities or both existing and new capacity providers can participate in the auction and also specifying type of resources. In terms of type, the feasible options usually 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 storage facilities operators. DSO might allow intermittent resources such as wind and solar power to participate. However, these need to be treated differently due to their intermittent nature. For example, a DSO could exclude resources that already receive feed-in tariff[3]. Moreover, DSO can specify the minimum volume of storage facility that is allowed to participate in the auction.

[3] This is because, firstly, the output is stochastic. Secondly even though aggregation is possible, however, they will be overpaid as feed- in tariff is a form of capacity payment.

The DSO will then stack all the offers to construct a merit order curve and based on the capacity needed (C^*), for the duration of contract, clears the price (P^*) (Figure 5). The DSO accepts the offers which are below the market clearing price. The conditions of feasibility of such an auction are: a) the clearing price should be at maximum equal to break-even price that makes DSO indifferent between conventional reinforcement and smart solution, and b) the price needs to be desirable for resource developers as well, otherwise they might decide to withdraw from the auction (this can happen if the price is set administratively and resource developer are asked to bid only for volume of capacity).

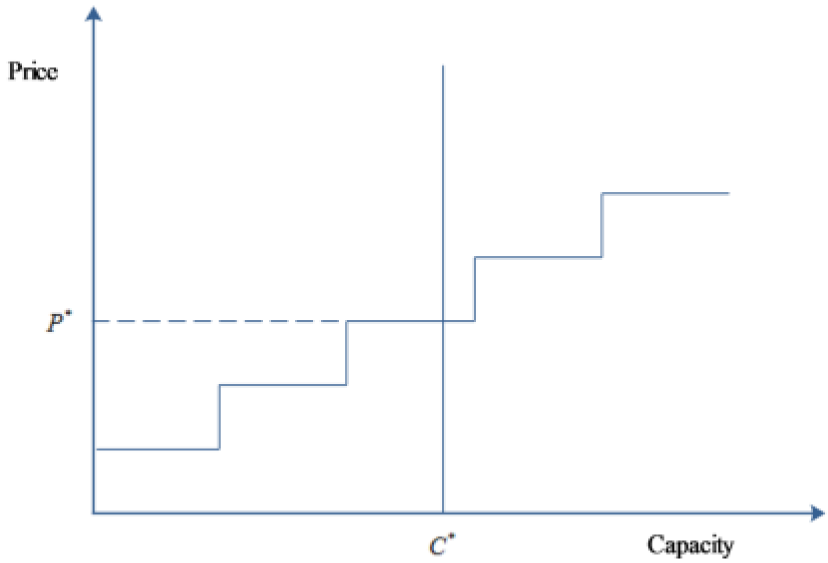

Figure 5: Market clearing price for capacity

6.1.2 Planning phase

Following the acceptance of offers and clearing price, the DSO can determine the lead time that the new projects needs to be completed and hence, fulfil their obligation for capacity supply. However, if it is an existing resource then the lead time will be shorter (e.g., the following year). Therefore, taking into consideration the different lead time 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. Moreover, specifying different delivery periods will facilitate the participation of demand response as they can avoid the lead time of constructing projects.

6.1.3 Implementation phase

In this stage, accepted offers needs to deliver capacity they have committed to. This stage can be of any time interval based on the agreement between DSO and capacity provider. However, it is likely preferable to give more time length to the new capacities because longer term agreement will enhance certainty of investment return and reduce the cost of capital. For example, allocating one or two years commitment period to the existing resources and then offering five years to the new capacity providers can be a reasonable approach.

In practice, there are two possible approaches to running CDS auctions. The first is based on a pay-as-bid or discriminatory price auction and the second is based on a single price mechanism. There are some advantages and disadvantages of adopting any of these approaches. For example, while the first case seems to be cost efficient, the participants have incentive to game the DSO by bidding for a higher price as they try to mimic the most expensive bid. The second case, on the other hand, suffers from allocative inefficiency problem because except for the most expensive bid, the rest of bidders will receive a price well above their marginal cost. At the same time, this approach provides more stability for revenue of resource developers and is more appealing in terms of investment, innovation and resource adequacy. There is a body of literature discussing the merits and weaknesses of these two models of auction running in electricity markets (see, e.g., Bower and Bunn, 2001; Liu et al., 2012; Damianov and Becker, 2010; von der Fehr and Harbord, 2002; Fabra et al., 2006).

In order to encourage investment and reduce risk of investment, DSO needs to differentiate between existing resources and new capacities. A better approach would be to pay the same price in the first year of commitment period to all the capacity providers that win in the auction. However, thereafter, only new capacities are able to adopt market clearing price for the whole period. This approach encourages investment in new resources and at the same time reduces allocative inefficiency under the condition that every bidder receives market clearing price.

The CDS auction based on the aforementioned procedure has several advantages. Firstly, it protects developers of DGs and storage facilities from market risks, decreases the financing cost and improves commercial bankability of investments. Secondly, it improves competition, encourages investments and hence; speeds up deployment of DGs, storage facilities and participation in demand response. Thirdly, the 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, in countries with “energy only electricity market”, CDS auctions help to alleviate the “missing money” and gradual reduction of reserve margin problems which arise from capping price spikes in the wholesale electricity market.

6.2 Prioritisation of support

Generation scheduling and control is an important component of day to day operation of a power system which needs a high degree of coordination among various players in the hierarchy of power system control. This becomes even more important with the presence of DGs as they operate in a widely varying power system control environment ranging from highly autonomous to strongly interconnected systems with hierarchic multi-level control.

Under the CDS contracts, DG operator, DSO and TSO are the entities that will have control over operational status of DGs. 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 distributed generation and the initial purpose of developing DG. For example, if DG is installed at first place to satisfy the developers' own demand, a feasible arrangement would be to give the owner of DG priority because it is usually needed as a backup power supply. The DSO then would be the second entity that has priority to call generation for local balancing as there is no other alternative, and finally TSO is the third. Where the DG output is not required locally or nationally, the produced energy can be sold into the wider electricity market.

6.3 Incentives to fulfil commitment

According to the CDS contract the capacity supplier will be paid based on the price specified in the agreement and the resource operator is obliged to deliver capacity or to reduce demand when called by DSO. A challenging issue from the perspective of DSO is the commitment of the capacity provider to deliver when needed. Any uncertainty in this will undermine the effectiveness of smart solution as alternative to grid capacity enhancement. Therefore, a penalty mechanism needs to be designed in order to reduce the possibility of this event occurring and also improve efficiency of CDS auction. This mechanism needs to take into consideration several aspects of this issue, 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 the total volume of capacity payment etc.

Drawing on the experience from the established capacity markets, there are two possible approaches to incentivise resource operators to deliver at the time of need. One approach would be to pin the terms of CDS contract to some reference capacity market in such a way that when the reference price is above the contract price, the resource operator will need to pay the difference. This incentivises 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 many countries such a national level capacity market might not be available to provide a reference price.

The second approach would be that the resource owner receives capacity payment for their availability period according to CDS contract and to be penalised based on an administratively set price if they fail to deliver when they are called or when they fail a spot check by DSO. This method is more straightforward and easier to be implemented. However, total annual penalties should be capped in order to avoid unquantifiable risk to the investors. For example, the cost of 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, DSO should offer the option to resource provider to default on its commitment and pay penalty when called under condition that unpredicted faults developed.

7. Conclusions

The power sector is evolving with anticipated penetration of distributed generation and storage technologies. 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 to implement innovative solutions for traditional issues such as demand driven network reinforcement, through locally satisfying of demand, using a portfolio of resources including distributed generation, storage technologies and demand response. This paper analysed the new possibilities and challenges that are arsing as a result of adopting distributed resources as alternative solution to the demand driven investment and proposed some regulatory innovations to reduce those challenges.

The necessity for evolution of distribution companies from DNO to DSO was discussed and the methodologies that are adopted in the literature to measure the value of DG are reviewed. The key regulatory challenges which DNOs are facing and their possible remedies are identified. Specifically, we proposed a three stage market-oriented approach termed “contract for deferral scheme” (CDS) to overcome some of those regulatory issues and value the services offered by capacity providers. Moreover, the issue of capacity provider commitment to deliver upon the request of DSO was explored and potential solutions, based on the experience of established capacity markets, are introduced.

The CDS contracts have several potential advantages. For example, they protect the developers of DGs and storage facilities from market risks, decrease the financing cost and improve commercial bankability of investments. Moreover, such contracts improve competition, encourage investments and hence speed up deployment of DGs, storage facilities and participation in demand response. Furthermore, they 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. Finally, in countries with "energy-only" electricity markets, CDS auctions can help to alleviate the problems of "missing money" and gradual reduction of reserve margin due to lack of incentives for investment in capacity.

References

Bower, J. and Bunn, D. (2001), "Experimental Analysis of the Efficiency of Uniform-Price versus Discriminatory Auctions in the England and Wales Electricity Market" *Journal of Economic Dynamics & Control* 25: 561-592.

Cappers, P., Mills, A., Goldman, C., Wiser, R., and Eto, J.H. (2012), "An Assessment of the Role Mass Market Demand Response Could Play in Contributing to the Management of Variable Generation Integration Issues" *Energy Policy* 48:420–429.

Damianov, D.S. and Becker, J.G. (2010), "Auctions with Variable Supply: Uniform Price Versus Discriminatory" *European Economic Review* 54: 571–593.

Dondi, P., Bayoumi, D., Haederli, C., Julian, D., and Suter, M. (2002), "Network Integration of Distributed Power Generation" *Journal of Power Sources* 106: 1-9.

DOE (2007), "The Potential Benefits of Distributed Generation and Rate-Related Issues that May Impede Their Expansion" A study pursuant to section 1817 of the Energy Policy Act of 2005, U.S. Department of Energy, available online at: www.ferc.gov/legal/fed-sta/exp-study.pdf

Fabra, N., von der Fehr, N.-H., and Harbord, D. (2006), "Designing Electricity Auctions" *RAND Journal of Economics* 37(1): 23–46.

Gil, H.A. and Joos, G. (2006), "On the Quantification of the Network Capacity Deferral Value of Distributed Generation," *IEEE Transaction on Power System* 21(4): 1592–1599.

Grunewald, P., Cockerill, T., Contestabile, M., Pearson, P. (2011), "The Role of Large Scale Storage in a GB Low Carbon Energy Future: Issues and Policy Challenges" *Energy Policy* 39: 4807–4815.

Gordijn, J. and Akkermans, H. (2007), "Business Models for Distributed Generation in a Liberalized Market Environment" *Electric Power Systems Research* 77: 1178–1188.

Harrison, G.P., Piccolo, A., Siano, P., and Wallace, A.R. (2007), "Exploring the Trade-offs Between Incentives for Distributed Generation Developers and DNOs" *IEEE, Transaction on Power Systems* 22(2): 821–828.

Hemdan, N.G.A. and Kurrat, M. (2011), "Efficient Integration of Distributed Generation for Meeting the Increased Load Demand" *Electrical Power and Energy Systems* 33(9): 1572–1583.

Hoff, T.E., Wenger, H.J., and Farmer, B.K. (1996), "Distributed Generation: An Alternative to Electricity Investments in System Capacity" *Energy Policy* 24(2): 137–47.

Jamasb, T., Neuhoff, K., Newbery, D., and Pollitt, M. (2005), Long-Term Framework for Electricity Distribution Charges, Report for the Office of Gas and Electricity Markets (Ofgem), March, London.

Jamasb, T. and Marantes, C. (2011), Electricity Distribution Network: Investment, Regulation, and Uncertainty, in Jamasb, T. and Pollitt, M.G., Eds., the Future of Electricity Demand: Customers, Citizens, and Loads. Cambridge University Press: Cambridge.

Liu, Z., Yan, J., Shi, Y., Zhu, K., and Pu, G. (2012), "Multi-agent Based Experimental Analysis on Bidding Mechanism in Electricity Auction Markets "*Electrical Power and Energy Systems* 43: 696–702

Miri-Larimi, S.M. and Haghifam, M.R. (2012), "Determination of Minimum Guaranteed Purchasing Price From Renewable Sources at Distribution Network Buses With Consideration Investment Dynamics" CIRED Workshop, Lisbon, 29-30 May.

Mendez, V.H., Rivier, J., de la Fuente, J.I., Gomez, T. Arceluz, J., Marin, J., and Madurga, A. (2006), "Impact of Distributed Generation on Distribution Investment Deferral" *Electrical Power and Energy Systems* 28: 244–252.

Newbery, D.M. (2003) "Network Capacity Auctions: Promise and Problems" *Utilities Policy* 11: 27–32.

Niesten, E. (2010), "Network Investments and the Integration of Distributed Generation: Regulatory Recommendations for the Dutch Electricity Industry" *Energy Policy* 38: 4355–4362.

Ofgem (2012), “Strategy Consultation for the RIIO-ED1 Electricity Distribution Price Control Overview”, Office of Gas and Electricity Markets (Ofgem), September 2012, London. Available online: http://www.ofgem.gov.uk/Networks/ElecDist/PriceCntrls/riio-ed1/Pages/index.aspx.

Piccolo, A. and Siano, P. (2009),”Evaluating the Impact of Network Investment Deferral on Distributed Generation Expansion”, *IEEE Transactions on Power System*, 24(3): 1559–1567.

Poudineh, R. and Jamasb, T. (2012a), “Smart Grids and Energy Trilemma of Affordability, Reliability and Sustainability: The Inevitable Paradigm Shift in Power Sector”, US Association for Energy Economics, USAEE Working Paper 2111643, July.

Poudineh, R. and Jamasb, T. (2012b), “Interdependency Effects of Disturbed Network Electricity Supply Interruption: An Implication for Policy”, Unpublished mimeo, Department of Economics and Finance, Durham University Business School.

Pudaruth, G.R. and Li, F. (2007), “Costs and Benefits Assessment Considering Deferral of Assets Expansion in Distribution Systems,” in Proc. 42nd International Universities Power Engineering Conference, September 4–6, 872–878.

Raineri, R., Rios, S., and Schiele, D. (2006), “Technical and Economic Aspects of Ancillary Services Markets in the Electric Power Industry: An International Comparison” *Energy Policy* 34: 1540–1555.

Tobiasson, W., Beestermöller, C., Jamasb, T., and Meier, H. (2013), “Conceptualising Public Engagement in Electricity Network Development: An Economic Approach” Unpublished Mimeo, Durham University Business School.

Schroeder, A. (2011), “Modeling Storage and Demand Management in Power Distribution Grids” *Applied Energy* 88: 4700–4712.

van Werven, M.J.N. and Scheepers, M.J.J. (2005), “The Changing Role of Distribution System Operators in Liberalised and Decentralizing Electricity Markets”, Future Power Systems International Conference, November 18, Amsterdam, Netherlands.

von der Fehr, N.-H., and Harbord, D. (2002), “Modeling Electricity Auctions” *Electricity Journal* 15(7): 72–81.

Vogel, P. (2009), “Efficient Investment Signals for Distributed Generation” *Energy Policy* 37: 3665-3672.

Wang, D.T.C., Ochoa, L.F., and Harrison, G.P. (2009), ”Distributed Generation and Security of Supply: Assessing the Investment Deferral”, In 2009 IEEE Bucharest Power Tech Conference, June 28th - July 2nd, Bucharest, Romania.

Waghorn, P. (2003), “Local Ancillary Services and Their Value to the Distribution Network” Report number K/EL/00285/REP-URN03/774, submitted to the department of trade and industry. Ems Consulting Limited, UK. www.bis.gov.uk/files/file15127.pdf

Zangiabadi, M., Feuillet, R., Lesani, H., Hadj-Said, N., and Kvaloy, J.T. (2010), "Assessing the Performance and Benefits of Customer Distributed Generation Developers under Uncertainties" *Energy* 36: 1703-1712.

Zafirakis,D., J. Chalvatzis, K. Baiocchi, G., and Daskalakis, G. (2013), “Modeling of Financial Incentives for Investments in Energy Storage Systems that Promote the Large-Scale Integration of Wind Energy” *Applied Energy* 105: 138–154

Zhang, J., Cheng, H., and Wang, C. (2009), “Technical and Economic Impacts of Active Management on Distribution Network”, *Electrical Power and Energy Systems* 31:130–138.

Zhang, Y., Gu, C., and Li, F. (2010), ”Evaluation of Investment Deferral Resulting from Micro Generation for EHV Distribution Networks” *In*: *IEEE Power and Energy Society General Meeting 2010.* New York: IEEE.