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Distributed generation, storage, demand response and energy efficiency as alternatives to grid capacity enhancement

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HIGHLIGHTS

- The paper explores a practical framework for smart electricity distribution grids.
- The aim is to defer large capital investments in the network by utilizing and incentivising distributed generation, demand response, energy efficiency and storage as network resources.
- The paper discusses a possible new market model that enables integration of distributed resources as alternative to grid capacity enhancement.

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ABSTRACT

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.

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[1] 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

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[1] 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.

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response and energy efficiency[2]. 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 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 (Hoff et al., 1996). 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). Fig. 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

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

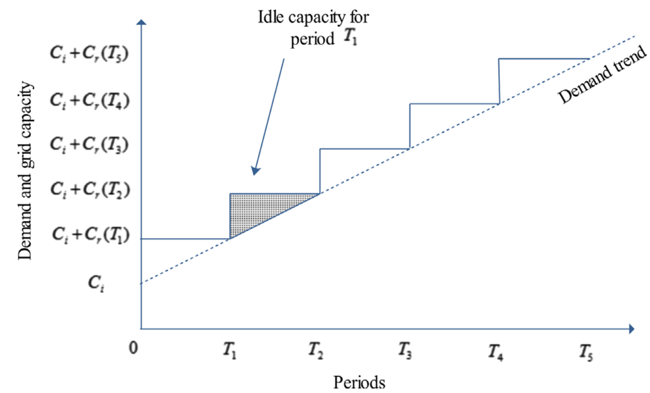

Fig. 1. Demand growth and network capacity enhancement.
Source: Adapted by authors from Hoff et al. (1996).

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.

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 and type effects of generator and also 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.