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Economic benefits of integrating Active Demand in distribution network planning: A Spanish case study

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ABSTRACT

The recent advances in smart metering and communication technologies in electricity distribution networks could bring new opportunities to distribution system operators (DSOs). In particular, new forms of Active Demand (AD) could be developed to help DSOs to alleviate network congestions and decrease peak capacity requirements, which could in turn reduce or postpone the need for network reinforcements. This paper explores the mechanisms that would allow DSOs to incorporate AD procedures into their network planning strategies. A Reference Network Model (RNM) is used to quantify the potential economic benefits that AD could bring to distribution grids. The analysis is supported by a case study of two rural and urban areas of Spain, based on realistic large-scale exemplary networks and real consumption data.

1. Introduction

Distribution system operators (DSOs) are responsible for the secure operation and management of the electricity distribution system and for ensuring network access to new users. They are also required to plan and develop their networks so as to accommodate a potential peak demand increase and the future connection of new loads and distributed generation (DG) units [1–3]. Following the traditional approach for planning and design of distribution networks, under the paradigm of passive behavior of loads and DG, large investments may be required to reinforce the network capacity in order to ensure a reliable supply of electricity even during periods of critical loading and congestion, which generally occur only a few hours a year [4].

The recently rising deployment of advanced metering infrastructure (AMI) and information and communication technologies (ICT) could modify this paradigm. More specifically, they could transform traditionally passive consumers into active players, facilitating the improvement of energy efficiency (EE) at the consumer's premises and the development of innovative forms of demand response (DR) at local level.

A more Active Demand (AD), entailing both EE and DR, is believed to offer a broad range of potential benefits on system operation, system expansion and market efficiency of electric power systems [5–10]. By promoting a more active role in system management and raising a greater awareness of the system conditions and costs among consumers, AD is to widely recognized by policy and regulatory institutions to potentially improve system adequacy and efficiency [6,8,11]. A more efficient utilization of existing generation and network capacity due to AD could result in a reduction of network congestion and generation costs in the short term. As a consequence, in the long term, AD could reduce the need for additional generation capacity and network reinforcements to satisfy the load growth and also integrate further renewable energy in the system [12].

The potential benefits of AD could therefore be realized across the value chain of electricity supply at different stages [6]. In particular, at distribution network level, AD brings opportunities as well as challenges [13]. If DSOs were allowed to use flexibility services provided by DR or other local sources to solve capacity constraints on the network, grid reinforcements could possibly be partially avoided or deferred, if that were the most efficient option [3,14–18]. This would also occur if the effects of specific AD programs on the loads were aligned with the local network conditions or if DSOs were incentivized to promote EE among consumers. Alternatively, critical states in the network could also arise due to certain DR actions that are not driven by network needs or that result in a higher simultaneity of loads or a new local peak, straining network conditions [19]. It is therefore becoming increasingly necessary that AD is integrated as a resource for distribution network optimization already in the planning stage in order to make the most efficient use of the grid capacity [15].

One of the key challenges of this new scenario is to understand how demand side flexibility could be effectively incorporated into DSO operational strategies and the implications it would have in

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network planning. Moreover, the quantification of the potential economic impact of these new mechanisms by which AD could be used as an alternative to the traditional network reinforcements is also a crucial aspect for regulators and DSO. A proper definition of the procedures to incorporate AD and the ex-ante estimation of the potential economic benefits would facilitate the evaluation of the cost-effectiveness for DSOs of investing on AD and the proper design of such mechanisms in the future.

Due to the relatively scarce experience on AD to support distribution network management, these issues largely remain to be solved. In fact, the ability of DSOs to resort to AD to support the operation and planning of their grids has been negligible up to now with the exception of a variety of pilot programs in various countries, e.g. in UK [20], the Netherlands [18], Sweden [21] and France [22]. Several studies have recently been conducted to investigate the regulatory conditions and the technical aspects required for the practical implementation of AD to support distribution network operation and planning. For instance, the authors of [23] review current practices in distribution network planning and look into the adaptation of traditionally passive methodologies to incorporate an active management of local resources, in [6] the regulatory aspects of the potentially active role of DSOs are explored and in [16] a market-oriented approach to defer network investments with the aid of Distributed Energy Resources (DER), including AD,[1] is proposed. Even so, the quantification of the potential economic benefits for distribution networks has not been sufficiently investigated in the literature. Numerous studies explore consumer responsiveness to AD initiatives but do not stress the economic value of that response for the distribution network or its implications in network planning. Only a few studies have been found that explore the potential of DER, in general, as operational resources to support distribution network management, being it, e.g. responsive demand to locational price signals, as in [24] and [25], demand response and energy storage, as in [14] and [3], peak load control, as in [18], or centralized management of electric vehicles, as in [26]. It is generally observed in these studies that either different instruments to implement AD are not distinguished, only simplified network topologies are used or, with the exception of [3] and [14], and investment decisions and costs are not explicitly addressed.

The objective of this paper is to explore the implications of AD in distribution network planning and present a quantitative analysis of the potential economic benefits AD could bring to distribution grid investments in the long term when different options for the implementation of AD are considered. The study is supported by a case study of Spain, which is built using realistic exemplary distribution networks, with real consumption data and the observed effectiveness of different types of AD pilot programs around the world.

Relevant contributions of this work with respect to the literature are: the application of a complex network planning tool that allows us to simulate investment scenarios in very detailed and realistic MV and LV networks for different mechanisms of AD implementation and the use of load and responsiveness data coming from real AD experiences. From this quantification of the potential benefits of AD for distribution networks, relevant key factors and contexts that hinder or strengthen the ability of network operators to optimize planning strategies counting on AD are identified.

The remainder of the paper is structured as follows. In Section 2, the implications of incorporating AD into network planning and the mechanisms by which this could be done in practice are analyzed. Section 3 presents the methodology proposed for the analysis of the economic impact of AD on network planning. In Section 4, the case study based on Spain is described. The results and discussion are shown in Section 5. Finally, the conclusions of this work are drawn in Section 6.

2. Active Demand in electricity distribution network planning

In this context of growing need for flexibility and increasing presence of smart technologies in distribution networks, the role of DSOs and the usual practices for grid operation and planning could evolve in future years to integrate AD into the network planning strategies. This section goes through the procedures by which AD could take place in distribution systems and their potential implications in network planning methodologies.

2.1. AD mechanisms for DSOs

AD refers to the inherent flexibility of consumers to adjust and manage their own electricity demand in reaction to external signals, in the form of prices, activation of a request to increase or decrease demand or feedback about individual consumption. In principle, AD could be implemented in the DSO perimeter by delivering activities, investments or incentives related to EE and DR.

EE involves a permanent reduction of energy consumption in the long term, e.g. by offering subsidies for equipment renewal or by raising awareness among consumers through the provision of some feedback about their own consumption. Alternatively, DR encompasses a wide range of strategies and mechanisms aimed at modifying the normal consumption patterns according to time and location-dependent conditions and costs of the system [6]. DR could be implemented through price signals or other type of interaction with consumers. For instance, cost-reflective network tariff structures could be designed, either centrally or by each DSO, so that a more efficient consumption pattern is incentivized in relation to network conditions, e.g. the form of an explicit charge for installed capacity, Time-of-Use (TOU) volumetric tariffs [5,27–29] or Critical Peak Pricing (CPP) [4,30,31]. Instead, network operators could be allowed to procure flexibility services from consumers (via retailers/aggregators) for temporary congestion management of distribution networks by means of direct and specific requests to raise or lower demand [6].

For instance, if certain grid constraints became visible in the long-term planning process, the DSO could be interested in acquiring flexibility by means of different forms of AD. This way, by alleviating capacity requirements while still satisfying operational constraints and without endangering reliability of supply, AD could result in lower reinforcement needs. In such a scenario, the DSO would need to look at the business case for both the investment solution and the service-based solution and decide on the most cost-efficient combination. Therefore, AD considerations should be effectively incorporated in the decision making process of network planning, which is a rather unusual practice in the long-established planning schemes.

2.2. How to integrate AD in distribution network planning scenarios

Network reinforcements and expansions are generally carried out in order to comply with reliability and security constraints for a few worst-case scenarios of expected future needs. For instance, these states may result from a combination of a simultaneous maximum (peak) demand in the absence of any generation and the minimum demand with the maximum generation of DG. AD could help to ease both of these planning scenarios, reducing the local peak load or shifting part of the demand from periods of higher

[1] Distributed Energy Resources (DER) include distributed generation, energy storage facilities and Active Demand in the context of distribution networks.