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Energy management systems aggregators: A literature survey

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ABSTRACT

In the Smart Grid context, the involvement of end-users is a key element for the implementation of demand response, as a way to enhance the energy efficiency of the electricity infrastructure also enabling to cope with the intermittency of renewable energy sources. Although the participation of end-users may result in higher complexity of system management, it may have a positive impact on mitigating the volatility of electricity prices. End-users may also be a key component in the provision of ancillary services using demand side resources to offer the system operator additional means to enhance system flexibility, robust planning, constraint management and operation scheduling, contributing to the balance between load and supply under a load follows supply paradigm.

Demand response is seen as an effective and reliable strategy for the successful integration of renewable energy sources, in a perspective of integrated energy resource management, handling the demand curve using load flexibility whenever the system requires it. This embodies the possibility of changing/controlling the load profile by optimally time deferring the use of some equipment.

This paper focuses on the role of energy management systems aggregators, both concerning actual practice in industry as well as research, which can be seen as relevant players contributing to that endeavour. A review of recent literature and projects is made, putting in perspective the role of energy management systems aggregators in the Smart Grid context, in association with demand response programs and technologies, involving the participation of end-users in the provision of ancillary services. The aim is recognizing trends, opportunities, challenges and potential barriers regarding the creation of energy management systems aggregators to improve overall system performance, characterizing the services provided by aggregators and identifying potential research gaps.

1. Introduction

The efforts to reduce greenhouse gases (GHG) emissions related to electricity generation, oil crisis and economic concerns have been leading to a fast increase in the deployment of generation based on renewable energy sources (RES), in particular photovoltaic and wind power [1]. RES are being deployed not only as bulk generation but also as distributed local generation facilities or even private consumption infrastructures. However, the associated generation patterns normally do not follow the typical demand profile and can be neither predicted with great accuracy nor reliably dispatched. In fact, RES generally exhibit significant temporal variability due to environmental conditions, which are inherently inconstant and outside the control of generators and System Operator (SO), often requiring the dispatch of reserve resources. The Distribution System Operator (DSO) is responsible for distributing low voltage power and delivery to the end-user's costumer premises, while the Transmission System Operator (TSO) is responsible for high-voltage infrastructures between generation plants and DSO's transformer stations. Since the operation duties of DSO and TSO responsibilities and roles can vary between countries, in this paper we refer generically to an SO entity. The SO has the responsibility to ensure the security and reliability of the power system, in real-time, and coordinate the load and supply of electricity, avoiding oscillations in frequency and interruptions of supply. The SO function may be owned by the TSO depending on the organization of the energy sector of each country.

Electricity supply must dynamically provide ancillary services (AS), i.e. the balancing services that are delivered by power system entities to the SO for ensuring reliable system operations, to assist matching demand and ensuring technical quality parameters, such as frequency stability and voltage control [2]. According to Eurelectric "it is not easy to define what AS actually are, and how they should be procured; anyone attempting to create rules for an AS market might soon see his structure rapidly becoming unmanageably complex" [3].

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The penetration of RES represents a major challenge and new tools (technologies, management strategies, control and optimization algorithms) are essential to guarantee the system reliability and technical quality patterns. Presently, the adjustment is mainly done using “fast-reacting” generation technology systems (as peak plants) to safeguard the system against unexpected events such as production deficit, speedy generation variations and load variations [4]. Therefore, additional methods to compensate unpredictable imbalances should be envisaged, such as reduction of load during peak hours or periods of generation reduction, by interrupting, shifting or re-parameterizing end-use loads, possibly also using storage in the batteries of electric vehicles (EV) that can later be used in Vehicle-to-Grid (V2G) mode. A better integration of intermittent sources needs to take into account these issues, namely concerning the possibilities of managing demand in a perspective of integrated energy resource management to deal with supply volatility.

The price of electricity usually encompasses the costs to build, finance, maintain, and operate the power plants and the whole network infrastructure. Wholesale electricity prices may change in short time frames. However, in general, end-users are subject to rates based on seasonal cost of electricity, without being affected by market conditions. Changes in electricity prices generally reflect variations in electricity demand, availability of different generation sources, fuel costs, and power plants. In a deregulated context, the SO should deal with the variability of electricity costs and the demand requests, in order to manage the whole system securely and safely [5].

The availability to modify the generation injection (generation flexibility) and/or load consumption profile (load flexibility) in response to signals (a price signal or of other type) is an instrument to provide AS [6]. Generation flexibility can be provided by generators having large up and down ramping rates and short minimum up and down time. The interconnection with more flexible systems is another conventional solution for the provision of AS, using the availability of neighborhood countries, although this involves that transmission lines capacity is kept for the reserve market, which will bound the capacity in the day ahead spot market and thereby probably originate higher electricity prices. However, relying solely on generators to provide flexibility is expensive because it often involves producing energy with more agile but less efficient generation units or operating thermo-electric power plants below their maximum efficiency loading.

The electricity consumption in households has been steadily growing due to the widespread utilization of new types of loads and the requirement of higher levels of comfort and energy services, representing a significant untapped savings potential due to waste and load flexibility [7]. The distribution of electricity consumption in households has been characterized, and it has been shown that some loads display flexibility in their usage; consequently, if appropriately managed those loads can serve as a demand side resource able to offer responsive energy behavior [8]. As an example, washing and drying appliances can be rescheduled to periods of lower energy consumption (and lower prices) thus flattening the demand curve, or periods of higher energy generation from RES thus better matching consumption with RES generation. Thermal loads (cold appliances, water heating and air conditioning systems) can be interrupted during shorts periods of time without major reductions in service quality, to avoid the most unbalanced situations between generation and consumption, thus compensating the effects of the variability of RES availability.

In a Smart Grid (SG) context, a modernized power system extensively using Information and Communication Technologies (ICT), intelligent devices and autonomous controllers, with advanced data management, two-way communication means are incorporated across the entire system, from generation to consumption at the end-users' premises. The gradual implementation of the SG is expected to improve overall efficiency, reliability and sustainability [9], enabling the end-user becoming a prosumer (i.e., simultaneously producer and consumer) and dynamic, i.e. time-differentiated, electricity tariffs being the price structure seen by customers [10].

DR programs use price signals and incentive/reward/penalty schemes to influence changes in the end-uses of electricity. In general, programs are designed to induce lower electricity consumption at times of high market prices or when grid reliability is endangered [11], as a way to manage power usage preferences to benefit not only end-users but also the whole system. To make DR programs operational households need to have energy management systems (EMS) based on fully interactive ICT, also making the most of the evolution of the Internet of Things[1] (IoT). EMS are aimed at helping end-users optimizing energy usage, i.e. achieving energy savings and satisfying constraints on the quality of the energy services provided (namely concerning comfort requirements). However, in a scenario of a low price signal from the grid, all EMS devices would attempt to achieve benefits for the end-user engaging in similar actions (e.g., by shedding the same type of loads), eventually taking no notice of the instability that could impair in the operation of the system, since the true impact of residential consumption arise when it is summed up over a large number of households. In this setting, DR can become a new source of revenue for entities that “aggregate” load flexibility and DR schemes. Energy Management Systems Aggregators (EMSA) offer the opportunity to exploit the flexibility potential of small end-users and promoting their access to the retail electricity market by selling load flexibility and benefiting from rewards or lower energy bills.

A few recent studies have addressed the combination of demand and supply sides to implement DR programs for the provision of AS using load flexibility [8]. These services have been usually arranged by generators prepared to adjust their output quickly in response to unexpected imbalances between load and supply. The provision of these services by aggregating end-users load flexibility using DR programs is becoming an attractive alternative to the ones that involve the supply side [8].

The aim of this paper is to offer an overview about the role of EMSA in the SG context, in association with DR programs and technologies, involving the participation of end-users to provide AS. The aim is recognizing recent trends, opportunities, challenges and potential barriers regarding the creation of EMSA to achieve improved system efficiency, characterizing the AS provided and identifying potential research gaps.

The paper is structured as follows. Section 2 reviews AS, presenting their categories as well as the main AS that can be provided by an EMSA followed by an analysis of the EU policy regulation to this topic. Section 3 offers a comprehensive literature review of research on concepts, architectures and models for aggregators using Distributed Energy Resources (DER), loads and energy storage systems (static batteries and EVs) to provide AS. In Section 4 the main conclusions are presented.

2. A review of Ancillary Services

Historically, electric utilities were vertically integrated, owning and operating the whole electricity industry chain from generation to transmission, distribution and supply. Therefore, AS were required and provided within the same company. With deregulation and liberalization, those activities have been separated, in general becoming independent legal entities with independent ownerships. This creates additional difficulty in the definition and procurement of AS. The creation of rules for AS markets may lead to complex structures

[1] The Internet of Things (IoT) is the interconnection of uniquely identifiable embedded computing devices within the existing Internet infrastructure. Typically, IoT is expected to offer advanced connectivity of devices, systems, and services that goes beyond machine-to-machine communications (M2M) and covers a variety of protocols, domains, and applications [146]. The interconnection of these embedded devices (including smart objects), is expected to usher in automation in nearly all fields, while also enabling advanced applications like a Smart Grid.