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Review

Flexibility products and markets: Literature review

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ABSTRACT

This paper reviews flexibility products and flexibility markets, currently being discussed or designed to help in the operation of power systems under their evolving environment. This evolution is characterized by the increase of renewable generation and distributed energy resources (including distributed generation, self-consumption, demand response and electric vehicles). The paper is an attempt to review and classify flexibility products considering its main attributes such as scope, purpose, location or provider, and to summarize some of the main approaches to flexibility markets designs and implementations. Main current literature gaps and most promising research lines for future work are also identified.

Contents

1. Introduction

Power systems are undergoing deep transformations towards decarbonized, clean and more efficient energy generation and consumption mechanisms. This changing environment is partially characterized by the following topics:

- Increasing investments in Renewable Generation (RG, mainly wind and solar), located both at the transmission and distribution grids, are changing the net demand (demand minus nondispatchable generation) hourly patterns as well as the consumption patterns.
- RG uncertainty requires stable generation support, increasing reserves and ramping needs from conventional generation, still more adapted to meet these flexibility needs.
- Low variable costs of RG are reducing electricity prices in valley hours, discouraging conventional generation from keeping

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running, reducing their total operation hours, and making costs recovering harder. However, conventional units are still essential for meeting the demand and providing reserves for the security of supply.

- Current markets are often price-cap energy markets where RG is not fully integrated due to feed-in tariffs. Additional remuneration mechanisms are then needed to incentivize flexible generation, causing market distortions.
- Increasing Distributed Generation (DG) is posing new challenges to the grids operation. At the transmission grid, balancing and frequency regulation are the main issues, and new flexibility markets to guarantee ramping availability are being implemented. At the distribution grid, reverse power flows, new congestion and voltages issues are appearing, and research seeks to provide new flexibility services to Distributed System Operators (DSOs) to optimize the distribution grid operation and defer investments. DSO tasks are then evolving from long-term planning to include also short-term grid operation, and coordination of Transmission System Operators (TSOs) and DSOs becomes essential for efficient resources usage at both systems.
- Energy Storage Systems (ESS) are expected to gain importance to integrate RG, smoothing prices variability and providing additional reserves and flexibility services.
- Electric Vehicles (EV) are expected to develop, thanks to technological improvements and pollution regulation policies (such as conventional vehicles limitation inside city centers). EVs will increase electricity load, but Vehicle-to-Grid (V2G) mechanisms can help to smooth load profiles and even provide reserve and flexibility services.
- Consumers, more concerned with climate issues and aware of their potential capabilities, are expected to assume much more active roles, investing in Distributed Energy Resources (DER), including DG for domestic generation, Demand Respond (DR) mechanisms to consume in a more clean, efficient and economical way, ESS to integrate DG and contribute to DR, and EV. They are also expected to partially participate in wholesale markets by grouping under aggregators' agents to overcome market barriers. Concepts like peer-to-peer energy trading are emerging to empower consumers and boost the large-scale adoption of demand-side management technologies.
- Communications and metering improvements, as well as new paradigms such as Smart Grids and Smart Cities, are laying the technological foundations to support the power sector evolution. For example, as an essential part of Smart Cities appear the microgrids as clusters of microgeneration, storage and flexible loads, that act as single controllable entities, able to operate in both grid-connected or island-mode, the later especially fitted for emergencies.

Flexibility needs comes from the increasing RG which is giving place to a net load with larger variability and uncertainty, and larger ramping needs [1,2]. To date, traditional flexible units (thermal and hydro power plants) connected at the transmission network, have been supplying the net demand and the flexibility needed by means, among others, of intraday and reserves markets [3,4]. But as some TSOs argue [1,5–7], the increasing variability and uncertainty are making more difficult to balance generation and load, and flexible units often lack sufficient ramping capability, forcing the use of real time (RT) automatic reserves (such as spinning or frequency containment reserve [8]), and promoting the design of new flexibility markets. In fact, if enough power and ramping capacity is available in the system, even if the net load could be ramping rapidly, as long as perfectly forecasted, energy only market prices would appropriately reward generators for their flexibility [9], meaning that uncertainty and no variability is the main cause of flexibility needs.

In addition, DG and EV can make the distribution grid operation more complex, with reverse power flows, congestions, voltages drops and losses (regardless the added complexity of allocating grid costs under this consumption patterns changes). However, smart metering and the potential of DR (both as elastic or load shifting responses) could also provide flexibility services to the distribution grid, and from the distribution to the transmission grid, with new flexibility usages (distribution grid management, portfolio optimization, etc.).

Flexibility is a general non-standard concept or product [10], to be procured by different market agents (TSOs, DSOs, Balance Responsible Parties or BRP, see Section 2) and expected to be supplied from different types of agents (supply and consumer side agents), located at the transmission or at distribution grids (with different operation problems), which needs to be integrated into the existing markets designed for more traditional power systems [11]. The literature, while large, tend to focus on particular problems without providing general approaches to flexibility products or markets, being still a matter of research. Indeed, a classification of the different flexibility approaches is needed since they may differ significantly in purposes and implementations.

This paper reviews flexibility products, and classifies and organizes most relevant issues related with flexibility products and flexibility markets. Section 2 introduces the flexibility concept and the main stakeholders involved. Section 3 describes and classifies flexibility products depending on their location and purpose attending at the literature reviewed. Section 4 focus on flexibility metrics, Section 5 on market implementations, Section 6 on TSO–DSO coordination aspects, and Section 7 concludes.

2. Flexibility and stakeholders

Flexibility is usually defined as the possibility of modifying generation and/or consumption patterns in reaction to an external signal (price or activation signals) to contribute to the power system stability in a cost-effective manner [12–14]. Flexibility is usually characterized by the following attributes [15,11,13,16,17]:

- Amount of power modulation
- Duration
- Rate of change
- Response time
- Location (transmission or distribution grids node)

Other additional attributes are also mentioned frequently [17,11,15]:

- Delivering time
- Time availability (for example limited for EVs to the plugged-in periods)
- Predictably
- Controllability
- Purpose, such as market players portfolio optimization, or balancing and constraints management in the transmission or distribution grids (congestion relief, voltages drops, loss minimization, component life extension and grid reinforcement deferrals) [15,18].

While the above attributes are very general so as to deal with most kind of energy or power products, the literature refers mainly to three distinct flexibility products:

Ramping capacity (power), demanded by TSOs to face the increasing uncertainty of the net demand [6,7,1]. Ref. [1] emphasizes the difference with traditional reserves, arguing that these new flexibility products are traded in markets closer to RT, com-