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Displacing natural gas with electric vehicles for grid stabilization

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ABSTRACT

High renewable and variable electricity penetration in power systems requires increased grid stabilization from balancing power plants, namely gas operated. In the future, however, stabilization might be provided by electric vehicles operating under the smart-grid framework. Departing from this, this paper discusses and quantifies to what extent electric vehicles are required to be possible to shut down gas power plants. The analysis is performed using the EnergyPLAN tool, for the case study of the Portuguese power system in 2050. The results suggest that even a small share of the fleet of electric vehicles providing load balancing could lead to important reductions in gas use and energy excess. The gas share in the electricity mix is reduced from 10.2% without electric vehicles providing for stabilization to zero with 30% of the fleet providing it; the energy excess is reduced from 1.5% to zero above 15% of electric vehicles stabilizing the grid. Therefore, to achieve a power system without fossil fuels, electric vehicles capable of supporting the grid should be developed and adopted, as should be promoted the market and regulatory conditions to allow this.

1. Introduction

A mostly carbon free power supply is envisaged for Europe by 2050. To accomplish it, renewable energy generation is being deployed at a fast pace: of the 24.5 GW of new gross power generation capacity installed in the European Union in 2016, almost 80% were wind (51%) and solar (27%) [1]. Until now, their share in the electricity mix is not very high – on average, 13% in the European Union [2] –, and so they do not yet imply great consequences in the way power systems are operated. However, with further deployment of these technologies, challenges arise [3].

Wind and solar are variable renewable energy sources (VRES), i.e., their output cannot be determined by the system operator, and there are limits to their forecast [4]; yet, electricity supply and demand must be permanently balanced, which is nowadays largely achieved by equalizing the generation to the demand through the adjustment of controllable generators (i.e., increasing or decreasing their output) acting as power reserve. Therefore, when the sun stops shinning or winds blow stronger, controllable generation must accommodate the sometimes abrupt fluctuations, especially if the operator wants to avoid curtailment, i.e., the use of less wind or solar power than is potentially available at a given time [5].

The rising share of VRES in power systems means that the net-load, i.e., the electricity demand minus the VRES generation, is gradually more volatile (both in frequency and amplitude), requiring increased grid stabilization. Base load power plants, e.g. coal and nuclear, will have to be run down to very low load regimens, to avoid major overcapacity when wind and sun power peaks; at the same time, power reserve should be available online to cope with the higher load following needs [6]. With increasing VRES share, the role of thermal power plants to balance the variability is increased, which means that in this scenario natural gas power plants will continue to be important to stabilize the grid, even if they gradually operate less hours in the year. Consequently, they inject less energy into the grid, becoming less profitable, and so expensive to maintain.

Besides conventional power reserve, a set of non-traditional options to provide grid stabilization, allowing greater VRES penetration, are available or projected for the future, such as demand side management (DSM), VRES control, resource diversity, stationary energy storage, or the smart grid. They all require significant changes in the way power systems operate [7].

One of those alternatives to provide stabilization is by means of battery electric vehicles, abbreviated as EVs in this paper, and the controllable energy storage that they represent. Electric mobility is taking off, expected to reach significant market share in the coming decades [8] – by 2050, EVs might represent around 70% of the total road transport [9]. The large combined battery capacity of EVs will

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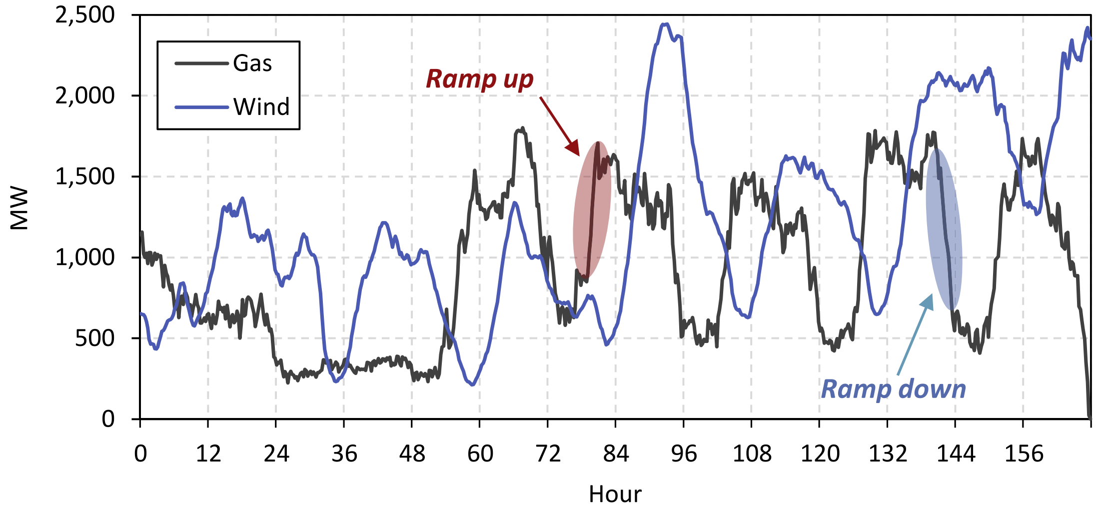

Fig. 1. Aggregated wind and gas power generation output for the whole Portuguese power system over a period of one week in 2015 [13].

allow them to assist on the integration of VRES into existing power grids [10]: since vehicles are parked most of the time, they are expected to be a new player by storing VRES energy, such as in times of generation surplus [6], or by stabilizing the grid, through the provision of ancillary services [11].

This article departs from this context to explore from the perspective of energy and power balances the extent to which EVs may substitute thermal power plants in stabilizing the grid. For that, a scenario of the Portuguese power system in 2050 with several levels of EVs providing for stabilization was modelled and simulated. The feasibility of the scenario is assessed from the standpoint of the model operation, and the implications are analysed. Presently, the reliability of the Portuguese system is mostly assured by combined cycle gas (CCGTs[1]) and large hydro power plants [12], and thus it represents a good testbed for what is proposed. The intention and contribution of this work is to quantify how electric vehicles can displace gas power generation for load balancing national-scale power systems with high penetration of renewables.

The article proceeds as follows: Section 2 presents the framework of grid stabilization by electric vehicles, followed by a literature review; Section 3 presents the methodology adopted for this study; in Section 4 the results are presented and discussed; and Section 5 finalizes with the conclusions.

2. Background

2.1. Framework of load balancing by electric vehicles

Changes in power plants output are called ramps. The traditional generators possessing the required quick ramping capabilities to balance large systems are large hydro and gas units.[2] To exemplify, Fig. 1 shows the aggregated wind and natural gas power generation output for the whole Portuguese power system over a period of one week, where the complementarity between the output of wind and natural gas is evident. Examples of ramping are signalled.

The aggregated load and generation are balanced in real time by a set of ancillary services that differ according to the time frame of application, such as load following (inter and intra-hour) and regulation (minute timescale), by which generation is matched to load in real-time by increasing or decreasing the former [14]; these services are continuously required to stabilize the grid [15]. The increase of VRES leads to the need of thermal generation for the role of balancing the variability in net load. However, the capacity factor of these thermal power plants is reduced, because they are less needed for bulk power, and so VRES impact directly on their profitability [16].

There are prospects about using EV batteries to provide grid ancillary services, reducing or replacing the need of thermal generation. This is possible since their response time is very short and the development and deployment of the smart grid, with a proper communication structure, will allow their control and dispatch [17]. The concept of using EVs as a grid resource, acting as load and storage/generation, is called vehicle-to-grid (V2G) [18]. From the grid standpoint, an individual EV has a negligible storage capacity, and it is an unpredictable power resource given that it might be unplugged from the grid and driven at any time [17]; thus, they have to be grouped together and managed by aggregators. Under this approach, EVs might become active players in the reliability of the power grid [19], and in its economics [20]. This is today an active topic of research (see Section 2.2).

The V2G system operates in two possible modes: (1) unidirectional, in which the power flow direction is just from the grid to the vehicle; (2) bidirectional, where the flow is both ways, i.e., the batteries are able to discharge to the grid. Both modes allow the provision of ancillary services, by request of the transmission system operator (TSO). In unidirectional mode, the EV load may be regulated up or down. It emulates spinning reserve, i.e., additional generation of fast response, by decreasing the EVs charging rate. The time difference between the time the vehicles are plugged and the charging duration provides flexibility that can be exploited for these purposes [21]. In bidirectional mode, spinning reserve can be additionally provided by injecting power from the batteries into the grid, actively contributing for peak load shaving [19]. Fig. 2 represents the dispatch of ancillary services in both modes. For additional insights on uni- and bidirectional V2G operation, see Ref. [14].

Unidirectional V2G has less ability to provide ancillary services than bidirectional V2G, but its realization is much cheaper and simpler, given that it could be done by adding a simple controller to the EV chargers to manage their charge rate [22]. In contrast,

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[1] ‘T’ stands for turbine.

[2] By means of CCGTs and open cycle gas turbines.