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Day-ahead resource scheduling in smart grids considering Vehicle-to-Grid and network constraints

Tiago Sousa, Hugo Morais, João Soares, Zita Vale *

GECAD – Knowledge Engineering and Decision Support Research Center, Polytechnic of Porto (IPP), R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal

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ABSTRACT

Energy resource scheduling becomes increasingly important, as the use of distributed resources is intensified and massive gridable vehicle use is envisaged. The present paper proposes a methodology for day-ahead energy resource scheduling for smart grids considering the intensive use of distributed generation and of gridable vehicles, usually referred as Vehicle-to-Grid (V2G). This method considers that the energy resources are managed by a Virtual Power Player (VPP) which established contracts with V2G owners. It takes into account these contracts, the users' requirements subjected to the VPP, and several discharge price steps. Full AC power flow calculation included in the model allows taking into account network constraints.

The influence of the successive day requirements on the day-ahead optimal solution is discussed and considered in the proposed model.

A case study with a 33 bus distribution network and V2G is used to illustrate the good performance of the proposed method.

1. Introduction

Governments in Europe as well as in United States and Asia are promoting and implementing incentives to increase the electric mobility use. The transportation sector will change from fossil fuel propelled motor vehicles to Electric Vehicles (EVs) as the fossil fuel is being depleted and regulations on CO_2 emissions are getting stricter according to Euro 6 emissions standard [1,2]. EVs include Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs).

The electrification of the transportation sector brings more challenges and offers new opportunities to power system planning and operation. The possibility of using the energy stored in the gridable EVs batteries to supply power to the electric grid is commonly referred to as Vehicle-to-Grid (V2G). Continued improvements of EVs envisage their massive use, therefore meaning that large quantities of EVs must be considered by future power systems, in terms of the required supply to ensure their users' daily travels [3,4]. In future scenarios of intensive EVs penetration, the typical electric load diagram can be significantly different from the present one without EVs. On the other hand, power systems can use V2G as distributed energy sources when the vehicles are parked. This adds further complexity to planning and operation of power systems requiring new methods and more computational resources. Therefore, new scheduling methods are required to ensure low operation costs while guaranteeing the supply of load demand.

The smart grid concept appears as a suitable solution to guarantee the power system operation considering the intensive use of Distributed Energy Resources (DERs) and electricity markets. Essentially, the smart grid can be understood as a structure that has the main purpose to integrate different players, technologies and resources that act in this new power system context. In the smart grid context, it is possible to have several players with different responsibilities: Producers, Consumers, Independent System Operator (ISO), Market Operator (MO), Transmission System Operator (TSO), Distribution Network Operator (DNO) and aggregators such as Virtual Power Players (VPPs).

VPPs aggregate several energy resources, mainly in the distribution level. The aggregation of DERs can be seen as an important strategy to improve the management of these resources. This new paradigm implies a multi-level decentralized decision and control hierarchy. In the scope of this hierarchy, VPPs may assume the responsibility of one decision and control level, managing their aggregated resources as well as the electrical network in their geographic area. This decision and control model requires a close coordination among the several involved levels, namely between VPPs and the DNO or the TSO, depending on the level in which each VPP operates.

Apart from EVs, power systems will have to deal with other types of DERs at the distribution network level, such as Distributed Generation (DG), Storage Systems (SSs), and Demand Response

* Corresponding author. Tel.: +351 22 8340500; fax: +351 22 8321159
E-mail addresses: zitavale@sapo.pt, zav@isep.ipp.pt (Z. Vale).

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(DR). All the mentioned resources have to be considered in the energy scheduling problem, considering consequently their characteristics and requirements [5]. DER management can be performed by Virtual Power Players (VPPs) or by the distribution network operator [6–9]. However, DER should be strategically managed by their owners, according to their own goals, and not by distribution network operators which represent the network's interests. The intensive use of DERs in future smart grids, operating in a competitive and distributed decision environment, will require an agent capable of representing DER owners in the electricity markets [10,11]. VPPs can aggregate a set of DERs, in order to take the best possible advantage of the aggregated resources by strategically bidding in the market, either for buying or selling energy [12,13]. Therefore, the VPP needs adequate methodologies to efficiently support the DER scheduling so that the aggregated players can benefit from their aggregation [14].

This paper proposes a method to support VPP day-ahead resource scheduling in a smart grid context considering the intensive use of V2G and other distributed energy resources. The day-ahead optimal scheduling aims to obtain the best energy resource scheduling, meeting all the involved constraints, including the ones concerning EVs use. The main objective is to minimize the operation costs considering all the available resources for each operation period. Using the proposed method, VPPs are able to undertake a more effective management of their resources.

In order to take the best advantage of the hourly available resources, accurate EVs information is required. This information must be detailed, including the geographical area where vehicles are parked during each considered period, as well as the minimum battery energy required by their users for their daily trips. This information enables to determine EVs minimum battery charge required for each period in order to guarantee the aimed range [15].

The proposed methodology aims to help dealing with the intermittence of renewable based production and V2G driving patterns. It considers several discharge price steps, depending on the battery level of the V2G and aiming to establish a fair remuneration scheme, which prevents unnecessary battery deterioration. The technical viability is ensured by an AC power flow algorithm included in the mathematical formulation, which considers all the relevant network constraints (namely the limits concerning line thermal characteristics and bus voltage magnitudes and angles). The problem is formulated as a Mixed-Integer Non-Linear Programming (MINLP), and it is implemented on Generic Algebraic Modeling System (GAMS) software [16].

The paper discusses the influence of successive day scenarios in the day-ahead scheduling. In fact, although the goal is to schedule the available energy resources for the next day, the scenarios that will become effective on the successive days will influence the optimal solution for the next day. Even though it is assumed that in principle the owners' are only committed to provide the manager with their requirements on a day-ahead basis, more information on the subsequent days may be available. For example, if a vehicle owner is able to provide the manager his requirements for the whole week, the manager will have this information at his disposal from the beginning of the week. The impact of considering data for the subsequent days is particularly important for the management of vehicle batteries and results in a significant objective function value reduction when the data for the subsequent day are considered. In fact, being the subsequent day requirements considered as an input of the scheduling problem allows better inter day battery management and prevents situations that can be impossible or very expensive to manage when only 1 day data is considered. This is modeled in the proposed methodology allowing obtaining more economic scheduling solutions.

The paper is organized as follows: after this introductory section, Section 2 presents the mathematical formulation of the envisaged problem. Section 3 presents the case study considering a scenario with 1000 V2G in the 33 bus distribution network with 66 DG plants and 32 loads. The main conclusions of this paper are provided in Section 4.

2. Energy resource scheduling

This section presents the proposed methodology to support Virtual Power Players (VPPs) efficient scheduling of the available resources, including Vehicle-to-Grid (V2G), in the smart grid context. As referred in Section 1, the VPP needs adequate tools to efficiently manage the available resources because, in the considered context, the resource scheduling is a large complex problem. Section 2.1 describes the concepts used to design the proposed method and presents its architecture. The mathematical formulation of the considered energy resource scheduling problem is presented in Section 2.2.

2.1. Proposed methodology conceptual design and implementation

The proposed method aims to obtain day-ahead scheduling for the available energy resources that are available in a smart grid managed by a VPP, considering an intensive use of V2G. The scheduling is undertaken on an hourly basis for the 24 periods of the next day. The goal of the resource scheduling is to satisfy load and V2G users' requirements, respecting all the involved constraints, at the minimum possible cost. V2G requirements are based on the contracts established between the VPP and their users. Some of these contracts consider that V2G users present day ahead detailed requests to the VPP. This requests concern the aimed trips for the next day, including details (e.g. trip range, V2G geographical location) according to contract clauses.

In order to satisfy the required load demand and requested V2G charges, the VPP can use the energy from several energy resources, namely Distributed Generation (DG) producers, external suppliers (including retailers, the electricity pool, and other VPPs) and can also discharge V2G batteries. It is considered that the VPP has contracts for managing the resources installed in the network, including generation and V2G charges and discharges. The costs of all the resources that are available in each period are determined according to the established contracts.

The energy resource scheduling model also includes the network simulation, through AC power flow calculation, which considers the relevant network constraints (line thermal limits and bus voltage magnitude and angle limits).

Although the goal is to schedule the available energy resources for the next day, the influence of successive day scenarios in the day-ahead scheduling should be considered. Experimental findings demonstrate that it is important to manage the available resources taking into account load and V2G requirements for the successive day. This effect is also described in [17] in which is stated that "unintended end effects in the optimization such as the tendency of the battery to deplete at the end of the time horizon can be partly avoided by a long time horizon".

This is especially important for scenarios involving intensive use of V2G, for which the successive day requirements can strongly influence the optimal solution for the next day. This is mainly justified by the fact that, according to the usual daily load, V2G, and price profiles, it is desirable that each day begins with a certain energy amount stored in EVs batteries. This amount and its geographical location, i.e. its distribution by the considered vehicles, depend on the V2G use that will occur in the successive day.

The diagram presented in Fig. 1 shows the scheduling target day, marked as light shadowed, and the days considered to take into account Successive Day Influence (SDI), dark shadowed. In