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Potential of vehicle-to-grid ancillary services considering the uncertainties in plug-in electric vehicle availability and service/localization limitations in distribution grids

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HIGHLIGHTS

- The availability uncertainty of PEVs are modelled using Gaussian mixture model.
- Interdependency of stochastic variables are modelled using copula function.
- V2G bidding capacity is calculated using Free Pattern search optimization method.
- Localization limitation is considered for V2G service potential assessment.
- Competitive services for fleet of V2G-enabled PEVs are identified using fuzzy sets.

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ABSTRACT

The aim of the paper is to propose an approach for statistical assessment of the potential of plug-in electric vehicles (PEV) for vehicle-to-grid (V2G) ancillary services, where it focuses on PEVs doing daily home-work commuting. In this approach, the possible ancillary services (A/S) for each PEV fleet in terms of its available V2G power (AVP) and flexible intervals are identified. The flexible interval is calculated using a powerful stochastic global optimization technique so-called "Free Pattern Search" (FPS). A probabilistic method is also proposed to quantify the impacts of PEV's availability uncertainty using the Gaussian mixture model (GMM), and interdependency of stochastic variables on AVP of each fleet thanks to a multivariate modeling with Copula function. Each fleet is analyzed based on its aggregated PEV numbers at different level of distribution grid, in order to satisfy the ancillary services localization limitation. A case study using the proposed approach evaluates the real potential in Niort, a city in west of France. In fact, by using the proposed approach an aggregator can analyze the V2G potential of PEVs under its contract.

1. Introduction

Massive production perspective of plug-in electric vehicles (PEVs) causes serious challenges and grid congestion for the utility grids. The researches have shown that electricity distribution grid can be highly affected by arbitrary charging demand of electric vehicles [1–3]. However, vehicle-to-grid (V2G) technology and charging coordination during off-peak hours of local distribution grids have been proposed as solutions [4–7]. In addition, V2G enabled PEVs, which have the ability to inject power to the grid, have been presented as grid supporters [8] and potential ancillary service (A/S) providers, where eventually make the transportation electrification beneficial for the grids [9].

In the literature, the economic [10–13] and technical [14,15] feasibilities of PEV fleet as the energy storage and service providers are discussed. They are considered in different services markets such as, regulation, spinning reserve [16], peak power support [17] and power quality [18] and more from economic point of view. While, technical analyses are mainly limited to capacity estimation, optimal coordination, aggregator communication architectures and

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Nomenclature

PEV	plug-in electric vehicle
V2G	vehicle-to-grid
G2V	Grid-to-Vehicle
A/S	ancillary service
AVP	available V2G power
FPS	Free Pattern Search
GMM	Gaussian mixture model
HV	High Voltage
MV	Medium Voltage
LV	low voltage
TSO	transmission system operator
DSO	distribution system operator
SOC	state of charge
pdf	probability distribution function
FIS	fuzzy inference system
NEDC	New European Driving Cycle
DoD	Depth of Discharge
BC1	bidding capacity 1
BC2	bidding capacity 2
BC3	bidding capacity 3
MLE	Maximum Likelihood Estimation
MCS	Monte Carlo simulation
RF	reliability factor
BS	bidding start time
HJPS	Hooke and Jeeves Pattern Search
FS	Free Search
DLP	daily load profile
BM	balancing mechanism
PPSMV	Peak Power Shaving – Medium Voltage
PPSLV	Peak Power Shaving – Low Voltage
VRMV	Voltage Regulation – Medium Voltage
VRLV	Voltage Regulation – Low Voltage
LM	Losses Minimization
ETCM	Energy Transmission Cost Minimization
FR	Frequency Regulation
DUR	duration, input for Fuzzy system

battery degradation impacts [15,17,19,20]. The points related to aggregator volume requirements, grid/services localization limitations and PEVs availability uncertainty impacts on bidding capacities are not discussed or less explored. In addition, the aggregator volume in terms of the required number of vehicles for providing each ancillary service is not analyzed up to now.

In term of the energy management systems for plug-in electric vehicles and V2G technologies, different scheduling and management schemes are developed. An adaptive intelligent system using fuzzy logic controller and adaptive neuro-fuzzy inference system (ANFIS) is developed in [21]. In [22] an intelligent energy management using cloud computing network is proposed. These technics reduce operation of electric vehicle, grid and parking lot as well as the load demand prediction. A large scale fuzzy logic based intelligent control for V2G is also proposed in [23] which provides different services such as, peak power, balancing control, load levelling and voltage regulation. For specific services, different control strategies are developed. For instance, a preventive control strategy for controlling static voltage stability is proposed in [24,25] which maintains the static voltage stability of power system under the V2G concept and evaluates the V2G response capability with different charging strategies during a whole day.

The innovative aspects of this paper compared to the aforementioned papers is considering the uncertainty impact on the V2G capacity, and scalability of the flexible V2G power capacity for different level of distribution grid by considering localization limitation of different services. Hence the service assessment can be applicable up to the low voltage (LV) distribution grid services such as voltage regulation and load levelling at LV grid. Interdependency of stochastic variables such as arrival time, departure time and driving distance are also modelled and their impacts on the contracted power are analyzed.

The novelty of the paper is that it has provided a multi-level methodological approach in order to assess the V2G potential, suitable for regional distribution system operators. In this approach, the PEVs' availability uncertainty and localization/limitation are considered as the main factors affecting the potential of V2G for grid ancillary service participation. A probabilistic model is developed in order to estimate the availability uncertainty using only daily trips probability data. The interdependency of the stochastic variables are also modeled using a copula function. This modeling approach, takes into account the impact of uncertainty on the bidding capacities and improve the reliability of the contracted bidding. In addition, in order to be realistic, the distribution of electric vehicles in the distribution grid is estimated using real customers' distribution data to estimate the real potential of PEV fleet for different ancillary services.

A/S providers at the distribution grid level are faced with the localization limitation for each type of service. Such limitations make difficult to achieve the services' requirements for PEV aggregators, as the aggregated number of PEVs at the different level of the grid is not always sufficient. Moreover, the aggregators need to have sufficient information for offering a reliable bidding capacity, which depend upon the type of services for which they would be the candidate. However, the general requirements are the amount of energy in form of power and time interval. These are predefined by grid actors based on the grid characteristics in different countries.[1] The constraints related to PEVs aggregation such as, available aggregated power and PEVs availability uncertainty should be taken into account in order to be competitive in the markets. These constraints are the main concerns of this paper, where the effort is to propose an approach for potential assessment of a candidate PEV fleet under an aggregation contract, particularly at the level of distribution grid by considering; (1) Available V2G power of the fleet. (2) Availability uncertainty of the fleet and its impacts on the bidding capacities' reliability. (3) The flexibility of the available power interval under bidding capacity contracts. (4) Distribution grid services/localization limitations.

In this paper, at first the general approach for ancillary service assessment of V2G enabled PEVs at the distribution grid level is introduced. Afterwards, all necessary input data for the assessment are identified. The methodology is applied on Niort, a city in west of France, considering its mobility statistics and distribution grid topology. The methodologies for available V2G power modeling, availability uncertainty modeling, the flexibility of the bidding capacities' calculation and the service assessment system will be explained thoroughly in the next sections. A general research

[1] From August 2014, RTE, the French transmission system operator (TSO), announced that industrial consumers henceforth could be reserve service providers with a minimum power of 2 MW [26]. This is also estimated for the distributed energy storage systems at the distribution grid level with a minimum of 1–2 MW power [27].