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An electric vehicle dispatch module for demand-side energy participation

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HIGHLIGHTS

- Real-time measurement and assessment to calculate EV initial state-of-charge (SOC).
- Flexible EV charging allocation using measured available time duration (ATD).
- Owner participation using mobile phone apps and a new EV dispatch module.
- Online algorithm for real-time calculation of maximum and minimum adjustable limits.
- Business-trading models with data security, trending and commercial impacts of EV.

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ABSTRACT

The penetration of the electric vehicle (EV) has increased rapidly in recent years mainly as a consequence of advances in transport technology and power electronics and in response to global pressure to reduce carbon emissions and limit fossil fuel consumption. It is widely acknowledged that inappropriate provision and dispatch of EV charging can lead to negative impacts on power system infrastructure. This paper considers EV requirements and proposes a module which uses owner participation, through mobile phone apps and on-board diagnostics II (OBD-II), for scheduled vehicle charging. A multi-EV reference and single-EV real-time response (MRS2R) online algorithm is proposed to calculate the maximum and minimum adjustable limits of necessary capacity, which forms part of decision-making support in power system dispatch. The proposed EV dispatch module is evaluated in a case study and the influence of the mobile app, EV dispatch trending and commercial impact is explored.

1. Introduction

Power systems provide the infrastructure and energy conversion assets for electrical energy generation, transmission, distribution and consumption. In the absence of large-scale energy storage, supply and demand must be balanced instantaneously. With variations in generation output or loading, power and energy balance is normally achieved by automatic devices as well as power system dispatch and scheduling [1].

Power system loading can be both stochastic and periodic. However, statistical analysis can determine trends to calculate load forecasting and dispatch planning such that power output is controllable in near-real-time to follow demand patterns. A controllable power source is denoted by three output parameters: actual power, and maximum and minimum adjustable power. The actual power should be balanced with a load and the maximum and minimum limits provide an adjustable margin. In a unit-commitment or generation plan, these limits are also considered as constraints [2,3]. When there is a large change on the demand side and it is not possible to meet power balance by automatic generation control (AGC), system operators can issue dispatch orders based on these limits.

In response to global pressure to reduce carbon emissions and limit fossil fuel consumption, generation is increasingly derived from distributed and renewable sources – often with stochastic interconnection. Moreover, coupled with variable capacity availability, large-scale loading changes include projected connection of electric vehicles (EVs), which also pose particular challenges for energy system security and system dispatch [4]. Since renewable power output relies on primary energy density such as sufficient wind speed and adequate solar radiation, dispatch is capable of reducing power output when generation is abundant (although less able to augment output), which represents partial

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Nomenclature

AFAP	as-fast-as-possible
AGC	automatic generation control
ALAP	as-late-as-possible
ATD	available time duration
DSM	demand-side management
EOBD	European on-board diagnostics
EV	electric vehicle
GA	genetic algorithm
MiTM	man-in-the-middle
MRS2R	multi-EV reference and single-EV real-time response
OBD	on-board diagnostics
OS	operating system
PDF	probabilistic density function
PGP	pretty good privacy
PSO	particle swarm optimisation
SOC	state-of-charge
SQP	sequence quadratic programming
TLS	transport layer security
V2G	vehicle-to-grid
E_B	capacity of EV battery packs
$h_{EVi}(l)$	electricity tariff of the *i*th EV at time *l*
N_d	number of discrete time intervals
$P_{EV}(l)$	EV charging power at time *l*
$P_{EV}^{\max}(l)$, $P_{EV}^{\min}(l)$	maximum and minimum adjustable limits of EV charging power
$P_{EVi}^{\max}(l)$, $P_{EVi}^{\min}(l)$	maximum and minimum limits of the *i* th EV at time *l*
P_{EV0}	rated value of EV charging power
$\overline{P}_{EV}$	average EV charging power
$P_{EV}^{M}(l)$	EV charging cost at time *l*
$P_O(l)$	objective power at time *l*
$\mathrm{SOC}_i(l)$	real-time SOC of the *i* th EV at time *l*
$U\{\}$	discrete uniform distribution
z	objective function

or *semi-controllability*. At the electricity consumption end, the use of EVs is inherently intermittent and stochastic, broadly based on driver travel patterns [5]. If EV demand is also controllable, it will provide another solution in power system dispatch to mitigate the variation in energy supply and render *local capacity*. Therefore, it is of significant importance to analyse EV behaviour in terms of power system dispatch.

The main contribution of this paper is based on a proposed online algorithm to calculate maximum and minimum adjustable power limits for EV dispatch decision-making support, from which an EV module for power system dispatch is developed. The power limits are derived from optimised EV demand profile, available time duration (ATD) and real-time state-of-charge (SOC) [6]. EV owners are able to participate in the dispatch procedure by flexible setting of the ATD using mobile-phone apps. The real-time SOC can be obtained through on-board diagnostics (OBD), which is further considered in the following section. This level of cooperation is broadly considered as demand-side participation. The technical merits of the paper contributions are considered timely and relevant to manufacturers – to improve the viability and acceptability of EVs, to owners – through participation inclusion, and to energy system operators – by offering a reliable calculation of accurate dispatch margin.

Since EVs are emerging as participant components for demand response, their connection and power system integration – as units for energy consumption or storage – require careful technical and societal negotiation. The work presented in this paper is therefore of particular relevance in demand-side management since it considers realistic and participatory connection of EVs, potentially in the context of emergent micro-grids, with respect to owner behaviour. This paper also presents the impact of vehicle integration on energy sources, especially the timely availability of local capacity to meet charging demand. In addition to rigorous development of a robust energy dispatch module framework, the paper considers practical issues, such as available time for charging, which influence and shape vehicle usage and which ultimately define how available energy is used to support driver needs.

The paper is organised as follows: Section 2 introduces related published work in EV characteristics, requirements for system dispatch, OBD, and ATD; Section 3 describes the EV module in a power system dispatch context; thereafter, Section 4 proposes a multi-EV reference and single-EV real-time response (MRS2R) (online) algorithm to calculate maximum and minimum adjustable limits of capacity; in Section 5, two objectives – the *minimum payment* and *flat line*, are established to test the feasibility of the proposed module in a case study; finally, the influence of the mobile app, EV dispatch trending and commercial impact is explored in Section 6.

2. Related work

This section presents a review of published literature and technologies relevant to EV behaviour in electrical energy system dispatch. Specific topics for EV integration are considered, which includes: ATD; requirements for system dispatch; and OBD. EVs are broadly being considered in energy planning; however their role in providing ancillary services (beyond operating in a discharge mode in a vehicle-to-grid capacity) is an emergent research topic. The particular issues for EV integration, in the work reported in this paper, concern the impact on energy dispatch and available capacity (for charging, primarily) and the role of EVs in terms of demand-side participation. Therefore, the following review considers these issues in detail in terms of a *parametric* context of EVs as aggregate units of substantial load (or capacity) in applied energy studies.

2.1. EV characteristics

EV *behaviour* can be parameterised in terms of *time*, *location* and *magnitude*. In previous studies, these issues are mathematically expressed in probability density functions (PDF), which characterise:

- The *time* parameter, which describes the probability of charging at a certain time interval and is expressed as a decision variable with respect to different kinds of optimisation objectives. It includes start time, end time, charging duration, and discharging duration. The charging [7] and discharging [8] duration are usually continuous from the start to end time. Such behaviour is considered as AFAP (as-fast-as-possible) charging or delayed ALAP (as-late-as-possible) charging [9]. If the ATD is introduced [10–12], the required duration will be much smaller than the setting duration (ATD), which leads to provision of non-continuous charging and discharging, and thus offers greater flexibility in EV charging management. This issue will be further considered in Section 2.2.
- The *magnitude*, which describes the level of charging power at a certain time interval and is related to the other decision variables while limited by uncertainties (in [13]), where the PDF