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Dynamic frequency response from electric vehicles considering travelling behavior in the Great Britain power system

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HIGHLIGHTS

- A dynamic EV frequency control strategy considering travelling behaviors of the EV user is proposed.
- A Forced-Charge Boundary (FCB) and a Forced-Charge Area (FCA) are used to guarantee the travelling demand of the EV user.
- The frequency response capacity of the EV clusters is evaluated by the dynamic Virtual Energy Storage System (VESS).
- The frequency deviations and power plant output variations are reduced by the frequency response from EVs.

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ABSTRACT

In order to pursue the low-carbon development around the world, a large scale of renewable generation will be connected to the power systems. Take the Great Britain (GB) as an example, the GB power system has a large wind energy integration potential. The intermittency of wind generation will have great impact on the system frequency stability. Electric vehicles (EVs) have a crucial role in decarbonizing the transport sector. To increase the utilization of wind energy, EVs are suggested to provide frequency response service to the power system due to their quick power reaction characteristic. This paper proposes a general dynamic EV frequency control strategy considering the travelling behavior of the EV users. A droop control method is used to regulate the EV charging/discharging power according to the frequency signal. A Forced-Charge Boundary (FCB) and a Forced-Charge Area (FCA) are proposed to guarantee sufficient energy in the EV battery for user's travel at the plug-out time. A dynamic Virtual Energy Storage System (VESS) is developed to evaluate the frequency response capacity of the EV clusters. In the case study, the model of the GB power system is used to investigate the frequency control effect of the control strategy. The simulation results show that the proposed strategy provides effective EV frequency response to the power system and thus is able to facilitate the integration of wind energy.

1. Introduction

The uncertainties brought by the variability of renewable energy introduce inevitable concerns over the operation of the power system. In particular, the imbalance between the total power generation and the power load increases the difficulty in frequency regulation [1,2]. In the UK, it is estimated that there may be up to 30 GW of wind generation within a total generation capacity by 2020, which imposes a significant demand for frequency regulation services [3,4]. The National Grid has the obligation to control the system frequency within the limit (49.5–50.5 Hz) as set in the 'Electricity Supply Regulations'. The frequency response requirement and the contracted responses in the GB power system are shown in Fig. 1 [5]. As depicted in Fig. 1, there is a shortage of frequency response volume in most time of the month.

Demand side management has been proved to be an effective way for frequency response, which has gained increasing interests by researchers in recent years [6–8]. With large penetrations of EVs enhanced with Vehicle-to-Grid (V2G) capabilities, V2G tends to be an alternative solution to system frequency regulation [9,10]. The V2G technology gives EVs the ability to allow bidirectional power flows in order to suppress the frequency deviation [11]. The UK Government has supported the EV trials with the anticipation that EVs will play a major role in the future transport sector [12,13]. According to the UK Department for Business Innovation and Skills,

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Nomenclature

t_{start}	plug-in time of EV	FCB	Forced-Charge Boundary
t_{end}	plug-out time of EV	FCA	Forced-Charge Area
Δf	frequency deviation	β	shift of dynamic boundary
Δf_{db}	threshold value of dead-band	α	variable coefficient
SoC	state of charge	P	charging/discharging power
SoC_{start}	SOC at t_{start}	P_0	normal charging power
SoC_{end}	SOC at t_{end}	$P_{\max}$	maximal charging power
SoC_{target}	user expected SOC at t_{end}	$P_{\min}$	minimal charging power
$SoC_{\max}$	the upper limit of SOC	E_r	rated capacity of EV battery
$SoC_{\min}$	the lower limit of SOC	k	utilization degree of EV

the number of EVs will be greatly increased which has been estimated at 550,000 in 2020 [14].

According to the existing literature, the main features of EVs are listed as follows:

(1) EVs are commonly used for about 4% time of the day, and remain idle (parked home or office) with the rest of the time (96%) [15]. Although the available time of a particular EV is highly unpredictable, it is possible to reckon with the total availability of the EV loads [16].
(2) The charging and discharging of EVs are chemical and electromagnetic processes, without mechanical processes. Consequently, the EVs are characterized with quick response which makes them especially suitable for providing dynamic frequency response to the power system [17].
(3) The travelling behavior of the EV users has a significant impact on the available response power from the EV loads. The EVs are only available for frequency regulation during the parking period. Moreover, the battery SOC at the departure time should be high enough for the travelling [18].

The challenges brought by the intermittent renewable energy have triggered the interests from power utilities in the large-scale energy storage systems. In the past research, energy storage systems (ESS) have been widely used for frequency regulation [19–21]. The ESS discharge energy when the system frequency is below the nominal value and absorb energy when the frequency is above the nominal value. However, there is a contradiction between the objective to minimize the ESS cost and the objective to maximize the ESS capacity for frequency response. The ESS cost is too high to allow a monetary profit for large scales of installation by now. EVs can act as a virtual ESS for providing dynamic frequency response and spinning reserve [22]. When the system frequency goes downward, EV load can be reduced to prevent the further frequency drop. On the contrary, when the system frequency goes upward, EVs can absorb the power to prevent the further frequency increase.

A number of studies have already been carried out to evaluate different frequency control strategies for EVs. There are two main EV frequency control strategies: centralized control strategy and decentralized control strategy. The centralized control based strategies need the support of a high-performance communication system. Matthias presented a method for tracking a secondary frequency control signal by groups of EVs [23]. Han realized an optimal charging control for each EV based on a dynamic programming algorithm [24]. Decentralized control strategies have also been noticed. Yang developed an optimal frequency regulation method for EVs based on the distributed acquisition using only a general-purpose communication platform, and obtained a better regulation result than the general decentralized control [25]. In comparison, the decentralized control strategies can even realize EV frequency control without the support from the communication infrastructure. However, in some cases only the system operation was considered in the first place and the EV user's travelling behavior was often neglected.

In this paper, a general dynamic EV frequency control strategy considering the travelling behavior of the EV users is developed. The control strategy takes both the frequency response for the power system and travelling behavior of EV users into consideration. In order to evaluate the response capability from EVs, an EV based Virtual Energy Storage System (VESS) is proposed. The power and energy indexes of the VESS are dynamically calculated which reflect the frequency response capacity from EV clusters. The methods proposed in this paper are applicable to the power systems with EVs integration. The GB power system has a large wind energy and EV integration potential. Consequently, the model

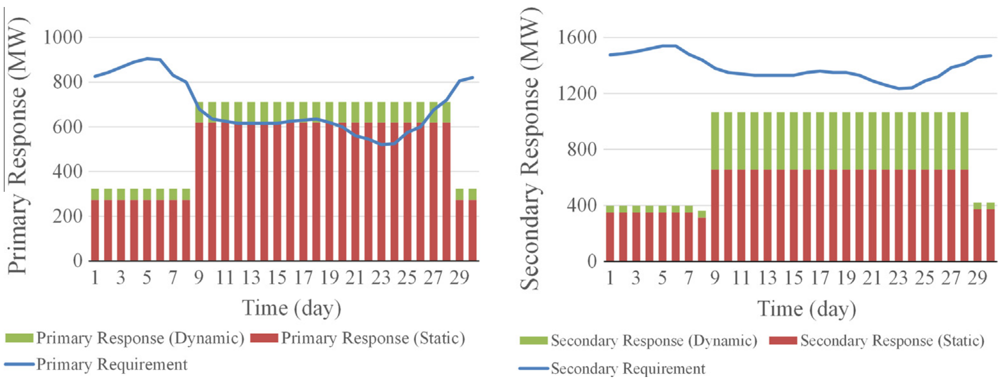

Fig. 1. Frequency response requirement and contracted responses.