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A new smart charging method for EVs for frequency control of smart grid

Saber Falahati [a], Seyed Abbas Taher [a,*], Mohammad Shahidehpour [b]

[a] Department of Electrical Engineering, University of Kashan, Kashan, Iran
[b] Department of Electrical and Computer Engineering, Illinois Institute of Technology, United States

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ABSTRACT

Nowadays, due to the shortage of fossil fuels on the one hand and their high prices on the other hand, using electric vehicles (EVs) has been increased. Charging of EVs has imposed new loads on power systems. These new and major loads have faced the frequency control and stability of power systems with new challenges. One way to deal with this new challenge is smart charging of EVs. In this method, grid condition is a key parameter that affects the charging of EV. In other words, in smart charging method, charging is performed with respect to power system parameters such as frequency. In this paper, a smart charging method based on fuzzy controller is proposed, in which charging process is performed with respect to the frequency deviation of grid and state of charge (SOC) of EV battery. To evaluate the performance of the proposed controller in control of grid frequency, IEEE 39-bus system in the presence of renewable energy sources is considered as test system. In order to the frequency analysis, this system is converted into a three-area system and, for each area, several EV categories with different numbers of EVs, battery capacity, start time of charging, and initial SOC are supposed. Moreover performance of proposed method is compared with an optimized PI controller in terms of frequency control. To investigate performance of proposed method in charging of EVs, a two area system is assumed and charging of EVs is verified by applying step loads to both areas. Simulations are carried out in MATLAB/SIMULINK environment. Results of the simulations reveal the good performance of the proposed controller in terms of frequency control of grid and charging of EVs.

Introduction

In recent years, electric vehicles (EVs) have gained renewed interest in the global research and industrial sectors. The major factor causing the promotion of EVs is the pollution- and emission-free transportation it could offer, which is a much needed global necessity for sustainable future [1]. According to [2], the number of EVs in the United States in 2020, 2030, and 2050 will reach 35%, 51%, and 62%, respectively. International Energy Agency (IEA) has predicted the sales of passenger light-duty EV/plug-in hybrid EV will boost from 2020 on and might reach more than 100 million of EV/plug-in hybrid EV sold per year worldwide by 2050 (Fig. 1) [3]. High electric energy demand of plug-in EVs (PEVs) on the one hand and their increasing number on the other will impose a significant load on grids. This load, if not controlled, may cause frequency deviation and even power system instability.

Global challenges of climate change, energy security, and environmental pollution have made renewable energy increasingly significant in the energy system. The national policies in many countries have set ambitious targets for the promotion of renewable energy. In the European Union (EU), goals are set for 35% of electricity generation from renewable sources in 2020 [1]. Since the output power of almost all of these resources depends on environmental conditions, their output powers are variable during the day. So it is need to more reserve energy for frequency control of grid. Energy storage technologies can be used for this purpose. In Fig. 2 some of electric storage technologies have been shown. Compressed air storage (CAES) is one the large-scale storage technologies in terms of power and energy capacity. However it has limitations in geographical suitability of the installation site for large underground caverns. The flow batteries like vanadium redox and zinc-bromide are characterized by longer storage duration time compared to typical electro-chemical batteries. However, this technology is still under development stages and has some disadvantages which include higher capital and running cost. The lead acid batteries are the most matured technology among the electro-chemical batteries. Compared to these batteries, the lithium-ion batteries have higher storage efficiency close to 100% and a high storage capacity which are increasing further with the introduction of its new models [1]. However use of these storage

* Corresponding author at: Department of Electrical Engineering, University of Kashan, Kashan 87317-51167, Iran. Tel./fax: +98 3615559930.
E-mail address: sataher@Kashanu.ac.ir (S.A. Taher).

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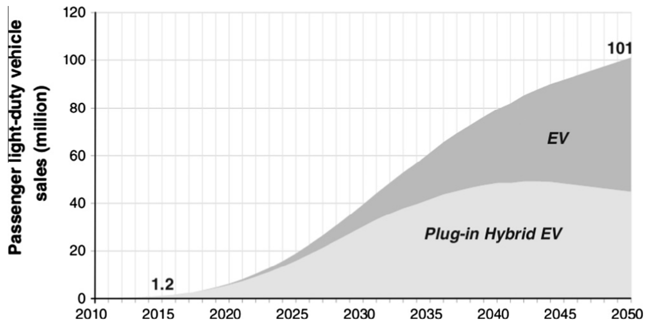

Fig. 1. Passenger light-duty vehicle sales [3].

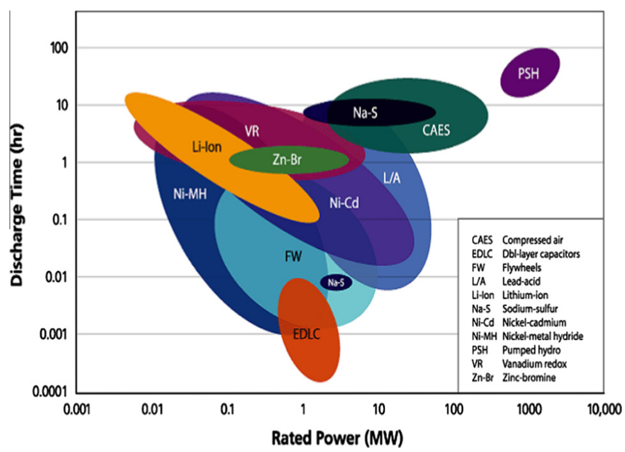

Fig. 2. Comparison of electricity storage technologies based on rated power and storage duration [1].

technologies needs to investment and it can be an obstacle for employing of these technologies.

Demand side management (DSM) which has been used by many researchers [4–6] can be used to deal with this problem. Using of EVs as grid support is one of the DSM methods. In this method, EVs are connected to the grid by bidirectional converters; when load of the grid is low, battery is being charged; but, at high loading of the grid, it is discharged in the grid. This concept is known as V2G (Vehicle to Grid) and was used in [7] for the first time. V2G concept has been employed in several papers for the frequency control of grids [8–13]. In [8], V2G concept was used for the grid frequency control along with proposing a scheduled charging method. Ref. [9] has proposed a new coordinated V2G control and conventional frequency controller for robust LFC in the smart grid. In [10], decentralized V2G control was proposed for frequency regulation. But in this paper unlike Ref. [8–10] EVs have been controlled by smart charging instead of V2G concept. Use of plug-in hybrid electric vehicles (PHEVs) along with controllable loads for frequency control was investigated in [11]. Also, in [12], a number of EVs and heat pump water heaters were employed as controllable loads for load frequency control. Unlike references [11,12] which EVs have been used in secondary frequency control in this paper they have been employed in primary frequency control loop. Fuzzy control of photovoltaic systems along with using V2G for frequency control was proponed in [13]. It has used from frequency deviation of grid to control EVs charging but in this paper in addition to frequency deviation of grid, SOC of batteries have been used for control of EVs charging.

Although employing V2G concept poses several benefits for the grid, using this concept needs a variety of considerations as follows [14]:

- The grid is initially developed for a ‘‘top-down” power flow; so, converse power flow may cause problems to it.
- V2G concept may meet voltage control with some problems, because EVs providing V2G could potentially push the grid voltage up before the transformer shifts to the next discrete step and takes the voltage down again.
- Synchronization between vehicle and network is an important issue that should be considered for energy injection into grid.
- Implementation of V2G concept needs the infrastructures such as bidirectional converters.

So, currently, smart charging can be used, instead of V2G concept. In this method, unidirectional converters are employed and, with respect to the grid condition, charging is carried out. Smart charging has been used in several works [15–18]. In [15], a method for smart charging in IEEE 13-bus system was investigated. In this study focus was most on voltage and current of grid. In [16], the effects of smart charging of EVs on the lifetime of transformers were studied. In [17], two methods of centralized and decentralized smart charging were considered to minimize system-wide generation costs while respecting grid constraints. Ref. [18] developed a decentralized smart charge controller for EVs. It proposed a method of smart charging of EVs based on grid voltage, battery state of health and user's trip requirements. In Refs. [15–18] there is no verifying on frequency control of grid but in this paper a method for smart charging of EVs to reduce frequency deviation of grid has been proposed. The proposed method is based on fuzzy controller and it has been employed in primary frequency control loop. In this method in addition to frequency deviation of grid, SOC of EV battery is considered for control of EVs.

The rest of this paper is organized as follows. In the second section, the studied system and its modeling are presented. In the third section, the proposed controller for smart charging is described. Moreover, a brief discussion about the fundamentals of fuzzy controllers is given in this section. Simulations are carried out and the results are analyzed in the fourth section. Finally, in the fifth section, conclusions are expressed.

Modeling of system

Frequency control loops of a power system can be represented as in Fig. 3 [19]. In this figure, primary and secondary frequency control loops are performed on the generation side only, while tertiary and emergency frequency control loops can be used on both generation and demand sides. In Fig. 4, the relationship between frequency deviation and control loops is shown. Values of Δf_1, Δf_2, Δf_3, and Δf_4 in different grids are various [19]. Primary control is governor control, which is sufficient until frequency deviation is lower than $\Delta f_2/2$. If the value of the frequency deviation exceeds this certain limit, then primary control will not be sufficient anymore and secondary frequency control or supplementary control should be employed. Secondary control is called load frequency control (LFC). In this study, in order for the frequency control of grid, EVs smart charging based on fuzzy controller along with governor and secondary frequency control loops is used.

The studied IEEE 39 bus system is shown in Fig. 5. In this grid, photovoltaic systems and EV charging stations are employed in addition to conventional energy resources and so it is called modified IEEE 39-bus system. In order for the frequency analysis, the above system is considered to be a three-area system, as in Fig. 6 [13,19]. In this figure, $K_i(s)$ is controller of area i and PI controller