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Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques

Kang Miao Tan*, Vigna K. Ramachandaramurthy, Jia Ying Yong

Power Quality Research Group, Department of Electrical Power Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia

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A B S T R A C T

Energy crisis and environmental issues have encouraged the adoption of electric vehicle as an alternative transportation option to the conventional internal combustion engine vehicle. Recently, the development of smart grid concept in power grid has advanced the role of electric vehicles in the form of vehicle to grid technology. Vehicle to grid technology allows bidirectional energy exchange between electric vehicles and the power grid, which offers numerous services to the power grid, such as power grid regulation, spinning reserve, peak load shaving, load leveling and reactive power compensation. As the implementation of vehicle to grid technology is a complicated unit commitment problem with different conflicting objectives and constraints, optimization techniques are usually utilized. This paper reviews the framework, benefits and challenges of vehicle to grid technology. This paper also summarizes the main optimization techniques to achieve different vehicle to grid objectives while satisfying multiple constraints.

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* Corresponding author. Tel.: +60 12 9833753; fax: +60 38 9212116.
E-mail addresses: tankangmiao@gmail.com (K.M. Tan), vigna@uniten.edu.my (V.K. Ramachandaramurthy), yongjiaying89@gmail.com (J.Y. Yong).

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1. Introduction

The transportation sector has the largest share of total energy consumption growth in the world. Most of the energy consumption growth in transportation sector is due to the high economic and population growth [1]. The rapid increase of energy demand will result in excessive carbon dioxide emissions and energy crisis [2]. In many countries, mitigation plans have been undertaken to achieve a reduced emissions target and one of the promising solution is electrifying transportation.

Electric Vehicle (EV) is an alternative transportation option, which emits zero exhaust gases and generates minimal noises. EV uses electric motor and battery energy for propulsion, which has higher efficiency and lower operating cost compared to the conventional internal combustion engine vehicle. The continual development of lithium ion battery and fast charging technology will be the major facilitators for EV roll out in the near future [3,4]. However, the present EV industry encounters many technical limitations, such as high initial price, limited charging facilities, limited driving range and long battery recharge time [5]. Furthermore, the interconnection of EV on the power grid to receive charge has introduced negative impacts on the power grid operation.

Recently, the introduction of the smart grid concept has modernized the power system with additional communication features [6,7]. Vehicle to Grid (V2G) concept is one of the smart grid technologies, which involves the EV to improve the power system operation. V2G concept allows the energy exchange between EV and the power grid, which can provide numerous services to the power grid. Meanwhile, EV owners can also enjoy appealing revenues for their participations in the V2G services.

V2G technology can be categorized into unidirectional and bidirectional [8,9]. For unidirectional V2G, it utilizes the communication between the power grid operator and EV to throttle the charging rate of each EV. This action can prevent grid overloading, system instability and voltage drop issues [10,11]. From the perspective of the power grid, EV battery is an electric load but also can be considered as energy storage. Therefore, bidirectional V2G utilizes this idea to enable energy exchange between the EV battery and the power grid for EV charging or grid support. The bidirectional V2G provides greater flexibility for the power utility to control the EV battery energy to improve the reliability and sustainability of power system [12–14].

V2G technology is a complicated unit commitment problem associated with different conflicting objectives and constraints. Therefore, the realization of the V2G technology is achieved by using optimization techniques. There are various optimization techniques in the literature, but the main optimization techniques for V2G implementation are Genetic Algorithm and Particle Swarm Optimization. By satisfying certain constraints, these optimization techniques can achieve different objectives and services, such as peak load shaving, load leveling, voltage regulation and maximization of profit.

This paper reviews the concept, framework, advantages, challenges and optimization strategies of V2G. The key contributions of this paper are: (1) to deliberate about the overall V2G concept and framework, specifically on the unidirectional and bidirectional V2G, (2) to discuss comprehensively on the benefits, services and potential barriers of the V2G technology implementation, (3) to analyze various V2G optimization techniques with practical objective functions and constraints, and lastly (4) to provide new insights into the prospects of V2G technology. Section 1 gives an introduction on the V2G background. In Section 2, V2G framework and concept will be discussed. The comparison of unidirectional V2G and bidirectional V2G will be explained in Section 3. Section 4 presents the advantages and challenges of V2G technology. The optimization strategies for V2G are reviewed in Section 5. Section 6 concludes the paper.

2. Vehicle to grid concept and framework

EV technology has attracted the attentions of government and public due to the growing concerns on the environment and rising cost of fossil fuel. The integration of transportation sector and power grid will lead to many challenging issues to the power system. For instance, a large penetration of EVs will increase the power grid load during the EV charging process. Nevertheless, the projected penetrations of EVs have also opened up the possibility of the V2G implementation.

V2G refers to the control and management of EV loads by the power utility or aggregators via the communication between vehicles and power grid. There are three emerging concepts of grid-connected EV technologies, which are the Vehicle to Home (V2H), Vehicle to Vehicle (V2V) and Vehicle to Grid (V2G) [15]. V2H refers to the power exchange between the EV battery and home power network. In this case, EV battery can work as energy storage, which provides the backup energy to the home electric appliances and to the home renewable energy sources [16]. V2V is a local EV community that can charge or discharge EV battery energy among them. V2G utilizes the energy from the local EV community and trades them to the power grid through the control and management of local aggregator [17].

Generally, V2H, V2V and V2G involve elements such as power sources, power loads, power grid aggregator, power transmission system, communication system, electric vehicles, and vehicle to grid chargers. The framework of a typical V2G system is shown in Fig. 1.

3. Power flow from vehicle to grid

V2G refers to the interaction between electric vehicle and power grid with the assistance of the communication system. Power grid operator utilizes the communication facility to control and manage the power flow between the EV battery and the

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