Electric vehicle development in China: A charging behavior and power sector supply balance analysis

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ABSTRACT

Possession of motor vehicles in China has been rising fast, along with continuous economic growth, social development and improvements in living standards, causing severe energy and environmental stress. To relieve the stress, China is promoting electric vehicles as good alternatives to conventional vehicles. By 2020, the accumulated production and sales of electric vehicles are expected to reach five million. Large-scale connection of electric vehicles to the power grid would inevitably bring challenges to the power sector. In this paper, an electric vehicle and multi-region load-dispatch grid-structure-based (EVMLG) mathematical model is presented, aiming to investigate the interaction between electric vehicles and the power sector. Impacts of charging behaviors are carefully considered. Through case studies, we conclude that (1) the development of electric vehicles will influence regional generation portfolio and operation pattern of the power sector, and increase the utilization of renewables, (2) guided charging can adapt to the power sector, and lead to better economic and environmental benefits, (3) electric vehicles are suitable to be deployed in resource-rich regions, and (4) the development potential of electric vehicles in China is huge from the viewpoint of power supply capacity.

1. Introduction

With sustained economic and social development and improvements in living standards, China has witnessed a rapid growth in possession of motor vehicles. By the end of March 2017, the national motor vehicle ownership has exceeded 200 million vehicles for the first time (MPS, 2017). Transport underpins development of society. However, the huge oil consumption, as well as the substantial emission of greenhouse gas and pollutants, poses enormous pressure on energy supply chain and ecosystem. In 2016, the degree of dependence on foreign petroleum in China has reached 65% (CNPC ETRI, 2017). Motor vehicles produced 30 million tonnes of carbon monoxide, 3.55 million tonnes of hydrocarbons, 5.35 million tonnes of nitrogen oxides, and 512,000 ton of particulate matter (MEP, 2017).

To reduce the negative impacts, China is moving toward a more sustainable transportation system. Electric vehicle (EV) is regarded as a good alternative to conventional vehicle. It uses electricity as 'fuel', instead of gasoline or diesel. Electricity can be generated from a wide

variety of primary energy resources, reducing petroleum dependence and enhancing energy security. Meanwhile, electric vehicle has higher efficiency (Linder, 2010) and zero-pipe emissions. To promote the development of electric vehicles, Chinese government has issued a series of policies and plans. *Energy saving and new energy automotive industry development plan (2012–2020)* announced that pure electric vehicles should be the development orientation, and the production capacity and accumulated production and sales should exceed two million and five million by 2020, respectively (The State Council, 2012). *Guiding opinions on accelerating the popularization and application of new energy vehicles* stated that charging facilities should be built to satisfy charging demand of electric vehicle users (The State Council, 2014). *The 13th Five-Year Plan (2016–2020)* reaffirmed the five million promotion target of electric vehicles, and emphasized the importance of technology breakthrough, infrastructure service network, as well as policy support system (The State Council, 2016). Under the joint efforts of the government, enterprises and research institutions, the technologies of electric vehicle are continuously improving, and the market is getting mature. Last few years see a rapid growth in electric vehicle population. And this trend is likely to continue at least in the short term.

As a new type of power load, electric vehicles can pose challenges on power sector (Li et al., 2012). Once electric vehicles are promoted in a certain region, total power demand would increase (Zhu and Lu, 2012). Moreover, the driving and charging behaviors of vehicles vary between different types (Luo et al., 2013) and drivers, different days and hours, which could cause strong fluctuation of power demand in both short and long terms. Thus, charging demand can increase peak load, as well as the risk of power system operation, if not properly controlled or guided. As for the power sector of China, there are some significant characteristics that should be noted. China has witnessed prominent mismatches of distribution between power resources and electricity demand in its vast territory. Resources are abundant in West and North China, whilst load centers are located in south-east coastal areas (Zhang et al., 2008). To connect regions and help balance supply and demand, the inter-regional transmission grid is expanding fast (Chen et al., 2014). In addition, the substantial deployment of renewable generation technologies in China has introduced intermittency and fluctuation to the power sector. The current utilization rate of renewables is relatively low, with severe curtailment of wind, solar, and hydropower. To realize coordinated development, the interaction of electric vehicles with the power sector of China should be specially investigated, considering charging demand of electric vehicles, spatial and temporal features of the power sector, as well as inter-regional power transmission issues.

Early researches focus on charging demand of electric vehicles. Charging demand mainly depends on the scale and charging behavior of electric vehicles. The scale is predicted by simply setting the penetration rate of electric vehicles (Richardson et al., 2010) or using Bass model (Kong and Bi 2014). The description of charging behavior often starts from classification of electric vehicles. Each type of electric vehicle has its corresponding vehicle parameters, charging methods, and user behavior (Han et al., 2014). The charging load can be obtained using Monte Carlo statistical modelling (Yang et al., 2013).

In recent years, many studies focus on the impacts of electric vehicles on the power sector. Yang et al. (2015) proposed a general evaluation method of assessing the impacts of large-scale electric vehicle on power grid economy. An evaluation indicator system was established and qualified, considering first-class and second-class indicators. The implications of uncontrolled charging behavior and controlled charging behavior were compared using this method. However, this method cannot be used for decision making of construction, retrofit, decommissioning of the power sector. Li et al. (2016) developed an integrated transportation-power system model that simulates power system operation on hourly basis, and regards China as a six-region system. It is capable of providing comprehensive evaluation of the value of electric vehicles in China from perspectives of energy portfolio, economic efficiency and environmental sustainability.

In consideration of substantial deployment of electric vehicles and renewables, operational constraints are contained in many studies to guarantee technical feasibility. Xiao et al. (2011) introduced a two-stage stochastic programming approach, with constraints carefully discussed in both stages. Belderbos and Delarue (2015) proposed a new modeling approach to power system planning, taking into account technical operational constraints. Koltsaklis et al. (2016) presented a model that could provide insights into the strategic and challenging decisions under real operating and design constraints. Few research focuses on the promotion limit of electric vehicles restricted by the power sector. Huang et al. (2013) studied the capability of a typical city-scale power grid in accommodating electric vehicles, based on the load characteristics of electric vehicles with different charging behaviors.

In this paper, a mathematical model, namely Electric Vehicle plus Multi-region Load-dispatch Grid-structure-based (EVMLG) model, is introduced. The model features a multi-region and multi-period structure, which divides China into seventeen regions and separates a year into ninety-six time-blocks. The model also covers seven optional types of power generation plants and nine types of electric vehicles, in order to better reflect the actual situation. Specially, the model combines electric vehicle with the power sector. With all these characteristics, this work contributes to answer three major questions: (1) what are the impacts of electric vehicle deployment on total costs and development pathway of the power sector, as well as environmental issues? (2) what are the different implications of unguided charging behavior and guided charging behavior? and (3) how many electric vehicles can the existing power sector accommodate?

The paper is organized as follows. Section 2 introduces the structure and main functions of the EVMLG model. Section 3 presents the key data used in this work and the scenario definitions. Section 4 analyzes the scenario results. The final conclusions are provided in Section 5.

2. Methodology

The EVMLG model is developed based on a power sector planning model LoMLoG (Guo et al., 2017). Key features of the LoMLoG model are firstly introduced in this section. The LoMLoG model contains various power generation types, fuel types, and power transmission lines. This model can well reflect the actual situation of the power sector, and it considers temporal and spatial features of the power sector in China, as well as the inter-regional transmission networks. We then discuss the charging behavior of electric vehicles, and calculate the charging demand. With the LoMLoG model and the EV charging module, we can investigate the interaction between electric vehicle promotion and the development of the power sector.

2.1. *Power sector planning model*

Existing models for power sector planning can be classified into two groups. In the first group, models consider China as a single entity. Examples include the Long-range Energy Alternatives Planning (LEAP) system developed by Cai et al. (2007) and the Integrated Policy Assessment Model developed by the Energy Research Institute of National Development and Reform Commission (NDRC) of China (Hu et al., 2009). Zhang et al. (2012) developed a long-term optimization model to plan the development pathway of the power sector of China. However, these models do not consider regional issues and inter-regional power transmission. In the second group, account is taken of regional differences. Gnansounou and Dong (2004) integrated the electricity markets in Shandong and Shanghai by inter-regional transmission. Wang and Nakata (2009) developed a national electricity model for China, focusing on the structure of the electricity supply and demand in coastal and inland regions. However, dividing China into two regions cannot satisfy the needs for research on electric vehicle penetration. Cheng et al. (2015) proposed a multi-