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Large-scale deployment of electric taxis in Beijing: A real-world analysis

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ABSTRACT

The national and municipal government of China enacted a series of regulations and policies to stimulate/promote the development of new energy vehicles, in order to mitigate the increasingly serious carbon emissions, environmental pollution, and energy shortage. As a large metropolitan and populated city subject to the notorious air pollution, Beijing has been making a remarkable progress in the large-scale demonstration of new energy vehicles in recent years, which could result in a significant impact on both transport and electricity sectors. As a result, there is an urgent necessity to study the characteristics of the large-scale new energy vehicles adoption for a deep understanding of operational status (e.g., energy consumption and battery charging patterns) and benefits, as well as charging facilities. Based on the operational data collected from realistic electric-taxi demonstration in Beijing, the driver behavior and charging characteristics are examined in this paper. The energy consumption and efficiency of two representative electric-taxi platforms are compared, and the influence of the driving schedules is discussed. The results show that the average driving distance per day of these electric taxes is 117.98 km, and 92% of drivers recharge their cars twice per day. Further study shows that the drivers make two trips per day, and the two peaks in the distribution of departure and arrival times coincide with the rush hour in the morning and evening. The taxi recharge duration is largely influenced by the charging power. Generally, the associated battery SOC (state of charge) swing is between 40% and 100%. By evaluating the energy consumption of 282 trips recorded in 2013 and 2014, we find that the two platforms have similar energy efficiency. The micro-trips method is utilized to probe the correlation of energy consumption and average speed.

1. Introduction

With the growing economy, the vehicle/mobility demand in China has experienced an explosive increase in the past decade, from 26.9 million in 2004 [1] to 154 million in 2014 [2]. It is estimated by the MIIT (Ministry of Industry and Information Technology) that car ownership of China will exceed 200 million in 2020 [3]. The drastic augment has brought enormous threats to energy security and environment protection. The great surge of oil consumption, more than 33% consumed by transport sector [4], has caused China to increasingly depend on imported oil that accounted for 58.2% of the total oil consumption in 2013 [5]. The daunting concentration of vehicles in metropolitan cities has incurred severe air pollution. Take the capital city Beijing as an example, the annual mean concentration of PM2.5 and PM10 in 2013 were 89.5 and 108 μg per cubic meter respectively [6], about nine times and five times greater than the WHO (World Health Organization) guideline of annual mean limits. This has rendered people highly vulnerable to cardiopulmonary diseases [7]. Beijing Municipal Environmental Protection Bureau states that vehicle tailpipe emissions contribute 31.1% of the total sources for the pollutant PM2.5 [8]. The transport sector has become the largest source of carbon emissions, approximately 23% of the global emissions from fuel combustion [9], and the carbon footprint of road transport in China are substantially increasing at an annual average rate of 11% [10].

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Facing the forgoing challenges, Chinese government decided to vigorously develop NEVs (new energy vehicles). Compared to conventional vehicle, NEVs have a higher energy efficiency, lower running cost, and less (even zero) tailpipe emissions, thus attracting significant interest and investment from government, industry and academia [11]. In China, EV (electric vehicle) research and development was firstly proposed in the eighth Five-Year Plan Period (1991–1995) through MOST (Ministry of Science & Technology's) "Research on the Key Technologies of EVs". After the development from the tenth to eleventh Five-Year Plan Period(2001–2010), the "Three Longitudes", referring to the three types of AFV (alternative fuel vehicle), and the "Three Transverses", referring to the three auto-related technologies, are formulated as the basic development regime for NEVs, as shown in Fig. 1 [12]. In 2009, the government initiated the "Ten Cities, Thousands Vehicles" program to subsidize the deployment of one thousand NEVs in each of at least ten participating cities in about three years [13]. In 2012, the State Council issued "Planning for the Development of the Energy-Saving and New Energy Automobile Industry", explicitly setting pure electric driving as the primary strategic direction of NEVs development and auto industry transition; in the next ten years, industrialization of PEV and PHEV (plug-in hybrid electric vehicle) will be promoted at high priority [14]. In the past two years, a series of financial incentive policies have been implemented to facilitate deployment of NEVs and construction of EV facilities [15]. NEVs production on 2014 has reached 83.9 thousands, with an annual growth by 379% [16].

As one of the tier-one pilot cities to carry out the "Ten Cities, Thousands Vehicles" demonstration program, Beijing definitely takes the national leadership in the deployment of NEVs and charging facilities under the promotion of municipal funding and policy support. From 2009 to early 2014, there were 8975 NEVs deployed in private and public service fields in Beijing, as shown in Fig. 2 [17]. It can be seen that the promotion scale in the public field is larger than that in the private field, because public transportation such as buses and taxis are the major transportation modes in medium-large cities in China, and public service fleets are easier to monitor and maintain than private vehicles, due to constraints on technology, manufacturing capability, and supporting infrastructure at early stage of NEV demonstration [12]. Considering the working time (usually early in the morning) characteristic of low-speed congested operation, high-efficiency electric taxis exhibit a great potential to decrease energy consumption and pollutants,

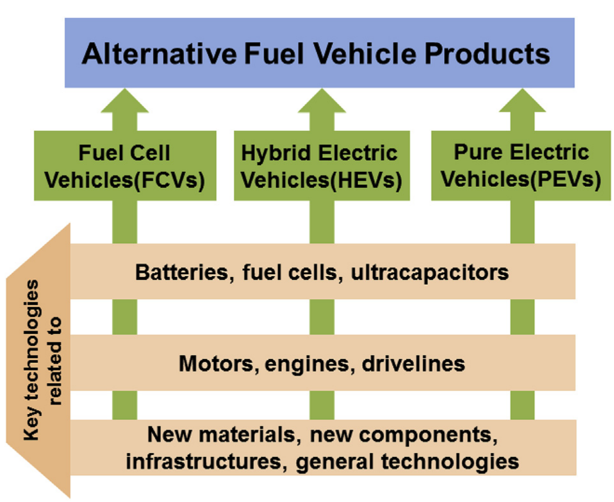

Fig. 1. "Three Longitudes, Three Transverses" development regime.

which grants the electrification of this type of vehicle a top priority. In 2011, 50 electric taxis were firstly adopted in the suburban city Yanqing, starting the large-scale demonstration and deployment in Beijing. In June 2014, the municipal government enacted "Plan for Demonstration and Adoption of EVs in Beijing (2014–2017)", stating that all the taxis in ten suburban cities will be replaced with EVs gradually, and new deployment of taxis in urban area must be EVs [18]. By the end of 2014, there were 2550 electric taxis operating in Beijing [19]. The projected demonstration scale will exceed 5000 in 2017 [20]. The EV sharing demonstration program was implemented in May 2013, powered by "EV Beijing Partnership Plan". Now the EV sharing service points locate in universities, downtown areas, and big communities, offering more than 600 rental EVs as well as the public charging facilities [17]. By the end of 2014, the cumulative amount of NEV demonstration in Beijing has reached 13 thousand [21]. Meanwhile, the construction of charging facilities is developing rapidly owing to the considerable support of local government and State Grid. At present in Beijing, there are 5 large-scale EV charging & battery swapping stations and 98 charging point colonies, including 1195 private charging points and 366 public charging points [17].

There is an increasing possibility that in the near future, EVs will achieve large-scale market penetration, especially in the pilot metropolises. In Beijing, the NEV market penetration target by 2017 is 170,000 [18]. The International Energy Agency states that the EV deployment target for 9 pilot countries is 20 million by 2020 [22]. A significant impact on existing transport system and electric grid naturally results. In 2013, China proposed the IEGT ("Integration of large-scale EVs, Grid and Transportation in the metropolitan scenario") program at the 18th APEC Auto Dialogue. This proposal gained approval of some other economies, finalized as an APEC project. The research is being carried out under the support of MIIT and Energy Foundation China. This article is the research accomplishment at the first stage of the project.

The IEGT project aims to model interactions among the large-scale electrified vehicles, grid, and transport system, discuss the systematic optimization for EVs and charging infrastructure, as well as optimize the integration of large-scale EVs into current grid and transport system. Accurate prediction of EV charging load on the electricity grid is essential for utility grid operators to ensure an adequate generation capacity available at the correct time, and distribution of charging infrastructure can accommodate considerable EV charging [23]. Studies from Lawrence Berkeley National Laboratory summarized the previous research findings related to PEV charging load profiles prediction, by means of a three-step methodology [23]: 1). Estimating the time when vehicles are plugged in; 2). Estimating the amount of energy required to charge the vehicle battery; and 3). Estimating charging rates while a vehicle is plugged in. To estimate EV charging time precisely, it is necessary to acquire sufficiently reliable data characterizing driver behavior. To estimate the amount of energy required to charge the vehicle battery, the energy efficiency, which means how much energy is consumed after the vehicle driving through a distance, as well as the battery capacity, must be analyzed based on the recorded data. Ref. [24] demonstrates how driving patterns databases from Italy and data mining can be used to appropriately design recharge infrastructure. Micaael Metz et al. simulated the charging loads under the restrictions of the individual mobility for the scenario 2030, using real driving profiles from German [25]. Hewu Wang et al. investigated passenger-car driving patterns, including distribution of daily driving distance, number of trips, parking time, etc., based upon the onboard GPS (global positioning system) records and the questionnaire surveys in Beijing, to explore the potential for the adoption of NEVs [26]. However, due to lack of large-scale NEVs demonstration operating data in real world, these