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Performance investigation and analysis of market-oriented low-speed electric vehicles in China

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ABSTRACT

Electric vehicles are thought to be an effective solution to the fossil fuel energy resource crisis and environmental pollution, but a wide gap remains between current market conditions and the anticipated products. Despite this, low-speed electric vehicles have already achieved commercial success in the low-end performance electric vehicle market in China. This paper examines the ride characteristics, dynamic performance, battery performance, and power efficiency of a low-speed electric vehicle. Accurate vehicle characteristics under road ride loads were achieved through dynamometer tests that mimic practical road conditions. The overload performance is tested under drive power demands that approach 4.3 times the rated value. The effects of different batteries on the cost performance of low-speed electric vehicles are also analysed. Although the lithium-ion polymer battery is currently more expensive than the lead-acid battery, the increased efficiency of this battery provides a more economical full-cycle lifetime driving distance for practical applications. Despite the excellent overload capability, the low power efficiency of the DC drive motor and its control system limit the general power efficiency of the low-speed electric vehicle and determine its economical speed. Thus, low-cost, efficient drive systems are required to improve the cost performance of low-speed electric vehicles. Some optimisation methods for improving low-speed electric vehicle performance are suggested. By analysing the factors that influence power efficiency and cost performance, this article provides a baseline for improving low-speed electric vehicle performance and advancing the application of this market-oriented electric vehicle.

1. Introduction

With the crises of insufficient fossil fuel energy resources and their subsequent environmental pollution, renewable energy is viewed as a significant alternative energy source around the world. Three major technological efforts are involved in sustainable energy development strategies: efficiency improvements in energy production, energy savings on the user side, and source diversification of renewable energy (Lund, 2007). In accordance with these latter two aspects, electric vehicles (EVs) and other alternative fuel vehicles (AFVs) such as fuel cell, hybrid electric, liquid petroleum gas, and compressed natural gas vehicles are considered valid solutions to these energy and environmental issues. In addition to providing energy diversification, EVs have proven their ability to achieve greater energy efficiency, zero local exhaust emissions, low noise, and vibration-free operation (Chan, 2002; Chau et al., 1999). Because the development of EVs can potentially impact on various areas such as energy, transportation and environmental issues, the development of these vehicles has become an important governmental strategic policy around the world (ARRA; Liu and Kokko, 2013; Ahman, 2006; Lieven et al., 2011; Leaver and Gillingham, 2010; Lu et al., 2013). These policies support EVs in various aspects, including marketing, regulation, and physical environment (Sierzchula et al., 2012). Nevertheless, due to the high vehicle and battery costs, poor reliability, and short driving range compared to traditional internal combustion engine (ICE) vehicles, the practical market application of EVs is further away than anticipated (US EIA, 2013; Lieven et al., 2011; Kimble and Wang, 2013) and is further hampering their development. However, there is a great desire for industrial and technical development strategies for EV production

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Acronyms: AC, alternating current; AFV, alternative fuel vehicle; BMS, battery management system; DC, direct current; EV, electric vehicle; ICE, internal combustion engine; LAB, lead-acid battery; LSEV, low-speed electric vehicle.

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that are substantially accepted by the market and common users. In a remarkable story, Tesla has thus far successfully introduced its electric racing cars into the high-end performance automotive market. This manufacturer has clearly demonstrated that a specific niche market can accept that an EV that has added value, even though the vehicle is much more expensive than an ICE vehicle. Tesla's model provides a promising outlook for the future of the EV industry (Hardman et al., 2013).

Meanwhile, less high-tech versions of EVs are appearing in China as low-speed electric vehicles (LSEVs) that have a top speed between 40 and 70 km/h, corresponding well to the Chinese urban area speed limit of 60 km/h. These EVs commonly consist of an accelerator, brakes, a steering wheel and a lead-acid battery (LAB) pack. Most LSEVs do not possess sophisticated battery management or motor control systems. The maximum driving range of a common LSEV is greater than 50 km. A 220 V AC household outlet can easily charge the LAB pack. Although LSEVs are neither supported by the central government nor legally allowed to drive on public highways in China, these vehicles have achieved an absolute predominance in sales quantities compared to mass-market EVs such as the Nissan Leaf, Mitsubishi i-MiEV, Peugeot iOn, and Smart Electric that offer comparable quality and performance with corresponding ICE vehicles. In 2011, the 77209 LSEVs sold in Shandong Province alone dwarf the total sales of conventional EVs in all of China (5579) (Kimble and Wang, 2013). LSEVs have also begun to enter overseas markets (Wang and Kimble, 2012).

As a maturely developed battery, the LAB is widely used in almost all of LSEVs because of the advantages of no maintenance and low cost (Husain, 2003; Chan and Chau, 2001). However, the disadvantages of LABs are also obvious, including a low specific energy of approximately 35 Wh/kg and a limited lifetime of between three and five years (Gerssen-Gondelach and Faaij, 2012). Serious environmental issues are also a particular concern with LAB manufacturing, and the limited profit margins of LABs have resulted in the closure of many plants in recent years (Chen et al., 2009). The potential rise in lead prices and the production of pollution are further increasing the costs of using LABs.

Considered the most promising technology in the next decade, lithium-ion batteries are the most popular power source used in EVs; they provide an energy density of up to 125 Wh/kg, but their safety characteristics still need to be improved and their cost is very high (Ulrich, 2005). The lithium-ion battery pack or module typically used in an EV is composed of various numbers of cells that are connected both in series and in parallel. They are commonly required to be monitored and controlled by a battery management system (BMS) for safety and reliability considerations (Wang et al., 2012; Zhu et al., 2013). Using a BMS further increases the excessive cost of the entire battery system. Nevertheless, the quickly developing lithium-ion battery is already been used in electric bicycles and tricycles that are made in China. With further production improvements, the cost of lithium-ion batteries has the potential to decline (Hensley et al., 2012), which may enable the replacement of LABs in LSEVs in the near future (Tezcan et al., 2006).

However, existing literature does not report on the performance of typical LSEVs or the newly emerging force of AFVs through either theoretical analyses or practical tests. Thorough investigations of the dynamic performance of EVs using road and dynamometer tests are also very rare, and these tests could allow the energy efficiency and cost performance of these vehicles to be optimised.

This report investigates the dynamic performance and power efficiency of an LSEV by using road and dynamometer tests in the full power range. The power efficiencies along the power transfer process are calculated and analysed, and the cost performance characteristics of the LSEV with different batteries are studied and summarised. The results of this investigation can be used to optimise the cost performance of market-oriented LSEVs.

2. Theory

In order to study the performance and power efficiency of an LSEV, the general dynamic characteristics and power transfer process of the vehicle must first be modelled. The drive force F applied to the wheels of an LSEV must overcome the force of air drag F_{ar}, the wheel rolling resistance F_{wr}, and slope resistance of the road F_{sr} in order to produce an accelerating or decelerating force on the vehicle F_{ad}, which is described in Equation (1) (Husain, 2003).

$$F = F_{\mathrm{ar}} + F_{\mathrm{wr}} + F_{\mathrm{sr}} + F_{\mathrm{ad}} \tag{1}$$

The air drag resistance F_{ar} can be calculated by

$$F_{\mathrm{ar}} \approx 0.5 \cdot \rho \cdot C_d \cdot A_f \cdot v^2 \tag{2}$$

where ρ is the air density, C_d is the coefficient of air drag, A_f is the effective frontal area of the vehicle, and v is the velocity of the vehicle with zero air movement velocity (Ulrich, 2005).

The wheel rolling resistance F_{wr} can be approximated by

$$F_{\mathrm{wr}} \approx m \cdot g \cdot C_0 \tag{3}$$

where m is the total mass of the vehicle, g is the gravitational constant, and C_0 is the rolling resistance coefficient.

The slope resistance of the driving road F_{sr} can be defined by

$$F_{\mathrm{sr}} = m \cdot g \cdot \sin\theta \tag{4}$$

where θ is the angle between the slope and the horizontal plane. Therefore, the overall force can be represented by

$$F \approx 0.5\rho C_d A_f v^2 + m \cdot \frac{dv}{dt} + mg(C_0 + \sin\theta) \tag{5}$$

where t represents time.

Correspondingly, the required drive power P can be derived from Equation (5) with the simple relationship $P = F \cdot v$ as

$$P \approx 0.5\rho C_d A_f \cdot v^3 + mv \cdot \frac{dv}{dt} + mg(C_0 + \sin\theta)v \tag{6}$$

Under bench testing with a dynamometer, F_{ar} and F_{sr} are both equal to zero. If the tested vehicle remains at a stable speed, Equation (6) can be replaced by Equation (7)

$$P \approx (mgC_0 + F_L) \cdot v \tag{7}$$

where F_L is the load force applied to the wheel by the dynamometer. Equation (7) shows that, under the dynamometer test, the dynamic power is proportional to the sum of the wheel rolling resistance and the load force produced by the dynamometer.

The required drive power P is supplied by the battery of the LSEV, with the general power transfer efficiency η operating under the following relationship:

$$P = P_E \cdot \eta = U_{\mathrm{oc}} \cdot I \cdot \eta \tag{8}$$

where P_E is the produced general electric power by the battery and equal to the product of the open circuit terminal voltage U_{oc} free of electric load and the discharging current I of the battery.

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