Applied Energy 150 (2015) 109–119

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Electrification of roads: Opportunities and challenges

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HIGHLIGHTS

- A historical overview of the technology development towards the electrification of road is presented.
- A review of the Inductive Power Transfer technology and the corresponding pilot efforts is given.
- The challenges over the infrastructural aspects of eRoads are discussed in details.
- The significance of environmental performance of eRoad infrastructure is emphasized.

ARTICLE INFO

Article history:
Received 13 December 2014
Received in revised form 11 March 2015
Accepted 14 March 2015
Available online 20 April 2015

Keywords:
Electrification
Inductive Power Transfer
Road infrastructure
Maintenance
Environment

ABSTRACT

The Electrical Vehicle (EV) has become a potential solution for enhancing the sustainability of our road transportation, in view of the environmental impacts traditional vehicles have regarding emissions and use of fossil fuel dependence. However, the widespread use of EVs is still restrained by the energy storage technologies, and the electrification of road transportation is still in its early stages. This paper focuses on the technical aspects related to the 'electrification of roads' (called 'eRoads') infrastructure that aims to diminish the limitations for using EVs. A historical overview of the technology development towards the electrification of road transportation is presented, along with an overview of prospective technologies for implementing an eRoad charging infrastructure. Of these, the Inductive Power Transfer (IPT) technology is examined in further details. The main objective of this paper is to explore the potential knowledge gaps that need to be filled for a successful integration of IPT technology within actual road infrastructure. As such, this paper can be used as an overview of the current state-of-the-art of eRoad infrastructure and also as guidance towards future research directions in this domain.

Contents

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http://dx.doi.org/10.1016/j.apenergy.2015.03.067
0306-2619/

1. Introduction

An Electric Vehicle (EV) is a road vehicle that moves with electric propulsion [1]. Given the reported high energy efficiency and zero tailpipe emission, the EV has been given focus as a potential solution for enhancing the sustainability in our road transportation sector. In recent years, no significant improvements have been found for the available energy storage technologies. Recharging opportunities away from home have thus become a critical concern in order to encourage widespread adoption for the use of EVs. Various charging solutions have been studied actively towards an electrified-road (eRoad) infrastructure network. However, a holistic point of view that includes all related technologies has not been given enough attention. For example, once a road integrates charging solutions for EVs, standard maintenance procedures and material recycling principles utilized today may be in need of severe modifications to ensure the sustainability of the integrated system. The background, motivation and scope of this study are given in the following subsections.

1.1. Background and motivation

Sustainable development as a principle can be found decades ago [2], described as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. A key concept is the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. The transportation sector contributes largely to global fossil fuel consumptions and GHG emissions, enhancing its sustainability has become a major issue. According to the statistics by the International Energy Agency (IEA) [3], the transport sector currently accounts for about 23% of total energy-related CO_2 emissions. And transport-related CO_2 emission is projected to increase by nearly 50% by 2030 and more than 80% by 2050 if in the absence of new polices. To move the sustainable development in the road transportation sector forward, short-term activities can promote improvement in fuel efficiency and vehicle emission controls while the long-term goal is to focus on the transfer from fossil-based energy source to other renewable resources. According to the IEA's statistics in [4], over 2.5 million BEV/HEV vehicles have been sold worldwide over the past decade; if all announced targets from the different countries are achieved by incorporating electrical vehicles, about 1.5 million BEVs/HEVs would be sold by 2015 and about 7 million by 2020.

Different electrical energy storage technologies have been found developed and widely used [5,6]. Currently, batteries and fuel cells are the main energy storage technologies that have been discussed for the move towards all-electric vehicles. Batteries are commonly used at the moment while fuel cells are noted for their potential to become part of the mainstream in the long term [7–10]. The characteristics of some main commercialized types of batteries are summarized in Table 1 [11–18], not considering other indirect factors such as the management issues [19] or the safety risks. It can be seen from Table 1 that, the lithium-ion type battery is viewed as more attractive than other types due to its good performance in specific energy, specific power and lifespan. Na-S also suggests good characteristics but it has limitations such as high operating cost and the need of an extra system to ensure its operating temperature [6]. According to the forecast by Roland Berger [20], the global automotive Lithium-ion battery market will grow from USD 1.5 billion to around USD 10 billion by 2015, and may exceed USD 50 billion by 2020. However, apart from the high initial cost, the technical performance of Lithium-ion batteries is still far from the level that would be needed for widespread acceptance of EVs. It was estimated in [7] that an advanced Li-ion battery in an EV could achieve 400–480 km range but would occupy a space of some 450–600 l. Moreover, it was concluded in [21] that the availability of natural lithium material can be a potential problem under future increased demand in Lithium-ion battery production, especially if this type of battery is widely used in the electrification of road transportation.

In view of the above, EVs have the potential to promote sustainability in the road transportation sector in the long term, but are currently constrained mainly by the energy source technology i.e. the battery. The idea behind the eRoad infrastructure is to focus not only on the battery but also on the infrastructures that allow for providing electrical power dynamically. In other words, EVs

Table 1
A summary of typical commercialized batteries' characteristic parameters.

Battery types	Specific energy (Wh/kg)	Specific power (W/kg)	Lifespan (full cycles)	Cost ($ kW h^{-1})
Li-ion[a]	100∼150 [11–13]	150∼200 [14], ∼400 [15]	>1500 [13], 800∼2500 [15]	900∼ 1300 [13], 700∼1200 [14], >600 [5]
NiMH[b]	70∼95 [12,13], 50∼70 [14]	200∼300 [12,15]	1000∼2500 [15]	200∼250[12], 250∼300 [15]
Lead-Acid[c]	30∼50 [13,16], 35∼40 [14]	∼180 [13], ∼200 [15]	1200–1800 [13], ∼1000 [15,14]	100∼150 [14], 300∼600 [16]
ZEBRA[d]	90∼120 [6,12,14]	150∼170 [6], ∼115 [12], ∼120 [15]	∼1300 [15]	230∼345 [12], 300∼600 [14,15]
Na-S[e]	150∼124 [12], ∼180 [17], ∼100 [18]	150∼230 [12], ∼160[17]	>800 [12], ∼2500 [16], 500∼2000 [17]	250–450 [12], 300∼350 [16], >100 [17]

[a] Lithium-ion battery.
[b] Nickel-Metal-Hydride battery.
[c] Lead-Acid battery.
[d] Sodium-Nickel-Chloride battery.
[e] Sodium-Sulfur battery.