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Battery electric multiple units to replace diesel commuter trains serving short and idle routes

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ABSTRACT

The need for efficient and sustainable intracity transportation system has now become indispensable. Electric trains are highly preferred for commuter rail service. However, full railway electrification is often applied to heavily-used routes on which the density of traffic is sufficient to justify the high fixed costs. Currently, lithium titanate batteries have proven success powering electric buses which consume more energy per passenger kilometer than trains. In this paper, the possibility to replace diesel commuter trains serving short and idle routes with battery powered trams and hence reduce fuel cost and emission level was studied, siting a diesel commuter train in Dar es Salaam, Tanzania. It was observed that such a replacement is indeed possible and gainful. Compared to the diesel commuter train in Tanzania which current operates at loss merely due to low fuel efficiency, the battery powered tram was found to reduce fuel cost and carbon dioxide emission by 86.67% and 64.96% respectively.

1. Introduction

Population and economy growth have resulted into the growth of mobility demand which in turn has increased concerns over environment, energy security and prices, and traffic congestion in cities. Currently, the need for efficient and sustainable intracity transportation system cannot be overemphasized. Having high passenger capacity and efficiency, low energy cost and emission levels; an electric train is currently one of the best solutions to urban mobility challenges [1–4].

Electric trains come with other advantages such as, low maintenance cost, quite operation, and increased passenger comfort. However, railway electrification is often applied to heavily-used routes where the density of traffic movement is sufficient to justify the high fixed costs [5,6]. This is the main reason why Diesel Commuter Trains (DCTs) are still operating on non-electrified railway networks. Compared to an electric traction motor, a diesel engine has low efficiency and high maintenance cost. The efficiency of a DCT is even much lower in a commuter rail service which is often characterized by a short journey with frequent stops.

To derive benefit from electric traction on lines of low traffic (which are usually not electrified), there have been several attempts to utilize battery powered trains. Despite the old battery technology, a Germany rail operator, Deutsche Bahn (DB) successfully operated battery driven trains class ETA 150 (later 515) for a period of about 40 years (from 1955 to 1995) utilizing lead acid batteries [4,3]. For reasons of increasing battery capacity, efficiency, cycle life, safety and robustness while lowering its cost, battery technology has greatly advanced. The technology has improved from lead acid battery to nickel-based battery and from nickel-based battery to Lithium-ion (Li-ion) battery. The Li-ion is currently a battery technology with the best performance [4,7,8].

Utilizing the Li-ion batteries, Japanese railway companies: JR East and JR West, have been developing catenary and battery hybrid trains since 2011. In March 2014, a two-car JR East catenary and battery hybrid tram (EV-E301 series) entered revenue-earning service on a 32.1 km route of which 21.4 km (Karasuyama line) is not electrified. Scheduled to be introduced in 2017, JR East will operate another two-car catenary and battery hybrid tram (EV-E801 series) on a 39.6 km route of which 26.6 km (Oga line) is not electrified. The EV-E801 series will replace the existing diesel multiple units (DMUs) operating on Oga line [9–14]. From October, 2016 a two-car catenary and battery hybrid tram (BEC819 series) entered revenue-earning service operated by a Japanese railway company, JR Kyushu on a 45.3 km route of which 10.8 km (Wakamatsu line) is not electrifie. This will be followed by six more two-car sets, entering service in 2017 [15]. In November 2015, Bombardier's battery train was reported to set a range record

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when it successfully completed a 41.6 km catenary-free test-run using lithium-ion batteries [16].

Recently, much effort has been made to promote application of batteries in electric vehicles, which demand light weight, small volume, long cycle life and abuse tolerant battery. Owing to its high power capability, long cycle life and chemical stability; lithium titanate (LTO) battery has emerged as a leading candidate for fast charging and power assist vehicular applications [17–19]. Battery buses have been on the forefront utilizing this improved Li-ion battery technology. A 78 kW h LTO battery pack used in Škoda HP Perun bus can be recharged quickly (within 5–8 min) to the full capacity and the bus is ready to run other 30 km [20]. Large capacity articulated electric bus TOSA, is using the titanate batteries' high charging capability to partly recharge the batteries at selected bus stops in a record time of 15 s, at the end of the bus line a 3–4 min ultrafast-charge is made to fully recharge the batteries [21,22].

It is very interesting that, attributable to the low rolling resistance, rail transport consumes less energy per passenger kilometer than road transport for the same traffic [1,23]. Thus, as LTO batteries have proven success powering electric buses; it is therefore expected that, they will prove even more success powering trains. To study the possibility of Battery Electric Multiple Units (BEMUs) replacing DCTs serving short and idle routes, and analyze reduction in fuel cost and carbon dioxide (CO_2) emission, this paper sites a DCT serving a 12 km route in Dar es Salaam, Tanzania. An electric multiple unit (EMU) to be used in the study is chosen and modelled as a BEMU, its movement is then simulated in MATLAB from which energy consumption of the BEMU is computed. The fuel cost and CO_2 emission of the DCT and BEMU are then compared.

The rest of the content in this paper have been structured as follows: The subject of research is described in Section 2. Mathematical formulation is presented in Section 3. Simulation details and results are presented and discussed in Section 4, and finally a conclusion is drawn in Section 5.

2. The subject of research

After the rehabilitation of the old locomotives and coaches which were used for up-country journeys, the government of Tanzania introduced commuter train system in October 2012, as one of the two initiatives to ease travelling within the congested commercial city of Dar es Salam; the other being bus rapid transit system. The commuter trains are diesel powered and operated by Tanzania Railways Limited (TRL) and Tanzania-Zambia Railway Authority (TAZARA), in the morning and evening rush hours throughout the week excluding Sundays and public holidays [24–26].

A commuter train serving a route of 12 km from Ubungo-Maziwa to city center (Central-station) with a total of eight stations as shown in Fig. 1 (for convenient purposes, in this paper the stations are named as S1, S2, . . . , S8 starting from Central-Station) is operated by TRL. The train makes three trips in the morning and evening rush hours, and the ease of commuting it brings is enormous [24]. However, high operating cost which is merely attributed to the low fuel efficiency of the train in a short journey with frequent stops and, frequent required maintenance jeopardizes the reliability and continuity of the service. The low fuel

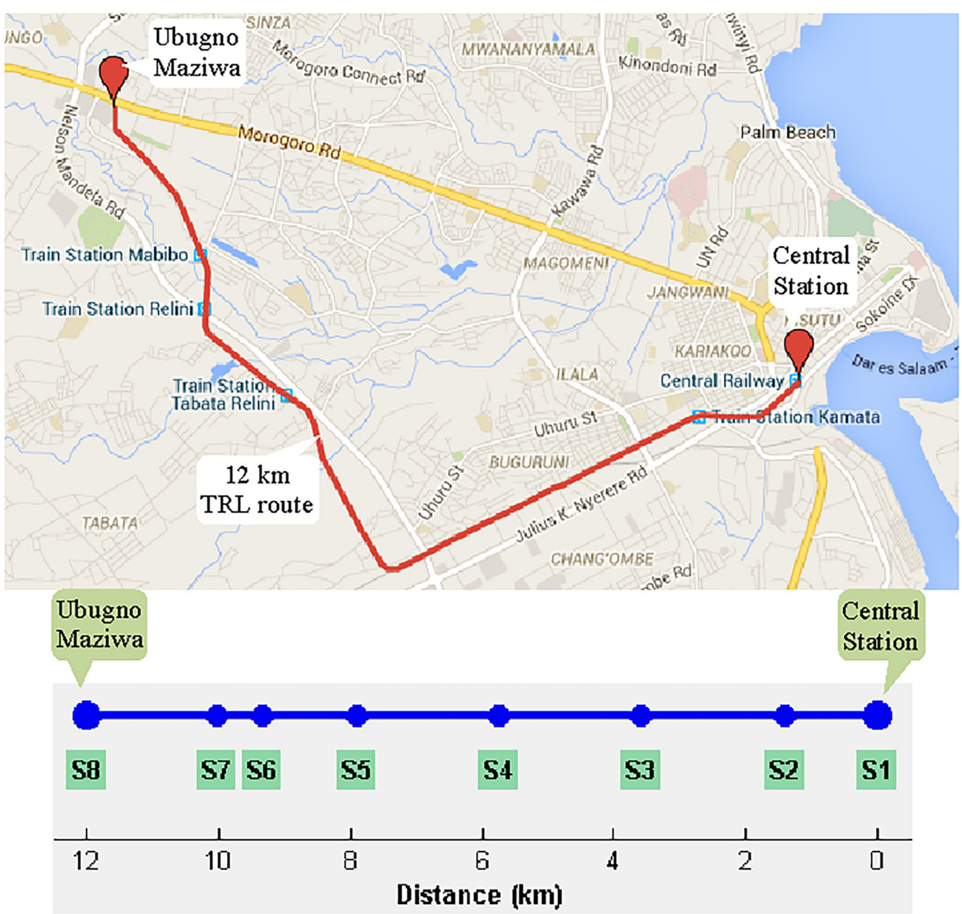

Fig. 1. TRL commuter train route from Central station to Ubungo Maziwa.