Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 27 (2017) 117–124

Transportation Research Procedia

www.elsevier.com/locate/procedia

20th EURO Working Group on Transportation Meeting, EWGT 2017, 4-6 September 2017, Budapest, Hungary

Design and evaluation of electric solutions for public transport

Valentina Conti[a], Silvia Orchi[a],Maria Pia Valentini[a]*

Marialisa Nigro[b]*, Raffaella Calò[b],

[a] *Laboratory of Systems & Technologies for Sustainable Mobility & Electric Storage, ENEA, Via Anguillarese, 301 S.P. 116, Rome 00123, Italy*
[b]*Department of Engineering, Roma Tre University, Via Vito Volterra 62, Rome 00146, Italy*

Abstract

This study deals with the design and the evaluation of technological solutions for the electrification of public transport in urban areas. A Decision Support System (DSS) developed by ENEA[†] within the Research program on Electric System (RSE) has been adopted in order to verify the technical feasibility of several electric architectures of single bus lines and compare the investment and management costs, as well as the external costs due to vehicle emissions and noises, of the feasible solutions with respect to the conventional alternatives (Compressed Natural Gas, CNG, and diesel).
The DSS has been applied to several bus lines located in the south-west area of the city of Rome, Italy, and covering different types of service: peripheral lines, main lines connecting suburbs with the city center and secondary lines going to the main metro stations. Input data for the DSS derived both by simulation and by open database available from the public transport operator in Rome (ATAC). Results show that a suitable electric architecture can be found for each of these lines with lower or comparable total costs with respect to the traditional alternatives. Finally, a sensitivity analysis has been performed considering several scenarios in terms of discount rate of recharge stations and batteries, battery's duration, price of conventional fuels.

Peer-review under responsibility of the scientific committee of the 20th EURO Working Group on Transportation Meeting.

Keywords: Battery Electric Buses; e-buses; opportunity (on-route) charging; decision support system

* Corresponding authors *E-mail address: marialisa.nigro@uniroma3.it; mariapia.valentini@enea.it*
† Italian National Agency for New Technologies, Energy and Economic Sustainable Development

2352-1465 © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 20th EURO Working Group on Transportation Meeting.
10.1016/j.trpro.2017.12.033

1. Introduction

Road vehicular emissions in our cities are reaching critical levels. An increase in the use of alternative fuels (biodiesel, gas, or electricity) and latest-generation bus engines represent a possible strategy in the public transport sector to obtain significant emissions savings.

Battery Electric Buses (BEBs) are emerging types of "clean" buses and even more cities in the world are choosing this technology to deal with poor air quality and noise (Seredynski and Viti, 2016). Since starting operations in 2012, Nottingham City Council's fleet of 45 electric buses have reduced CO2 emissions by more than 1,000 tons at a third of the running cost. In Milton Keynes Arriva successfully operates UK's first all-electric route, which includes the first UK application of inductive charging. It is generating huge savings in both fuel costs and carbon emissions compared with diesel vehicles (Haigh, 2016).

The energy storage capability is one of the most important features when dealing with BEBs and two categories of BEBs can be defined as a function of the battery characteristics: 1) first category BEBs, adopting medium capacity batteries (typically 20-60 kWh, CIVITAS Tech. Rep. 2016), charged at end stations of routes for approximately 4 to 6 minutes. This charging system is usually known as opportunity (on-route) charging; 2) second category BEBs adopt large battery packs—typically 200-350 kWh (CIVITAS Tech. Rep. 2016)—that are charged at night in bus depots.

Several new BEBs system deployments with on-route charging started to emerge. In the United States (San Gabriel region, California) Proterra/Eaton BEV system with 88 kWh battery is charged on-route via 500-kW fast charge with an average charge duration of 5 minutes (Prohaska *et al.*, 2016). In the TOSA system deployed in Switzerland (ABB/HESS), a BEB with battery capacity of 38 kWh is charged in route terminals for 4 to 5 minutes with 200 kW (Patey *et al.*, 2016). Additionally, 600kW boost are performed at bus stops every 1 to 1.5 kilometers for 15 seconds. In Luxembourg (ABB/Volvo), a plug-in hybrid BEB is charged at terminus stations for 6 minutes with a 150 kW boost. In Charleroi and Namur (Belgium), the public transport operator TEC Group has ordered 12 opportunity charging stations and 90 electric hybrid buses (ABB/Volvo): delivery and installation will get under way in autumn 2017.

In general, charging infrastructure results in strong dependency between infrastructure planning and bus operations (Rogge *et al.*, 2015). The White Paper on "Best practices regarding electric vehicles" reports that only with proper planning, transportation electrification can result in "*more efficient and less costly operation of the grid, provide ancillary services, lower electricity prices for ratepayers, and facilitate greater integration of renewable energy resources*". Therefore, existing research deals on BEB system design from the perspective of locations of battery charging stations (Fusco *et al.*, 2012, Pternea *et al.*, 2015). Simultaneously, energy efficiency aspects are also addressed from the perspective of engine energy management strategies (Peng *et al.*, 2017), battery management (Cai *et al.*, 2016) and regenerative breaking technologies (Li *et al.*, 2016).

This study deals with the design and the evaluation of technological solutions for the electrification of public transport in urban areas. A Decision Support System (DSS) developed by the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) within the Research program on Electric System has been adopted in order to verify the technical feasibility of several proposed architectures based on the most recent BEB's technologies. Then, the DSS compares the investment and management costs, as well as the external costs due to vehicle emissions and noises, of the feasible architectures respect to the standard fuel alternatives (Compressed Natural Gas - CNG, and diesel).

The paper contains four sections including this introduction: Section 2 deals with a description of the DSS in terms of electrical architectures considered, technical feasibility checks implemented and internal and external costs evaluation. Section 3 presents the application of the DSS on a set of five bus lines in Rome (Italy). Moreover, a sensitivity analysis has been conducted modifying the discount rate of recharge stations and batteries, battery's duration and price of conventional fuels. Conclusions follow in Section 4.

2. The Decision Support System

The electrification of the urban public transport with BEBs requires an accurate verification of the technical and economic feasibility. For this purpose, in the latest year (2015-2016) of the Research Programme on the National