General considerations for linked in of an electric technology buses in the transport systems – test results of an fully electric articulated bus (18 meters) from Bogotá to Pereira city, Colombia.

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ABSTRACT

The introduction to new technologies in the different land of transportation system represents a great opportunity for the academy, opening up space for applied research that evaluates from different angles, factors that are part of the processes and consequences that implicitly may come hand in hand with these. With this study a review of general aspects linked to operation of a fully electric articulated bus in the travel from Bogotá to Pereira, Colombia

This travel was started on early morning October 13, 2019, since the start point it has been monitoring the energy consumption for that make up the OPEX (Operational expenditures), in order to give a concept that is valid input information in the technical and economic evaluation process for change the buses in transport intercity systems, as a comparison is built with previous scientifically proven records for other diesel and hybrid articulated bus technologies.

Keywords: *BRT, OPEX, CAPEX, e-mobility, Articulated, Electric Vehicle (EV), SOC (State of charge)*

1 INTRODUCTION

Worldwide, the big cities, face a challenge in relation to air quality where traffic is a key element. Air pollution is the origin of a large number of deaths per year. The energy dedicated to transport exceeds 33% of all used energy and 40% of the emissions. In large urban centres, 66% of NO_x contamination, the most severe for people's health, is produced by road traffic. Buses on regular urban lines generate only 7.5% of this percentage¹, Public transport is therefore essential to achieve the objectives of air quality.

¹ Reina G., Paiano M., and Blanco J.: Vehicle parameter estimation using a model-based estimator. Mechanical Systems and Signal Processing. Vol. 87, Part B, 15 March 2017, Pages 227-241. <https://doi.org/10.1016/j.ymssp.2016.06.038>

Despite of this, the high initial investment (CAPEX) of e-buses compared to hybrid diesel-electric and diesel technology, in addition with the uncertainty of the variables in the operation stage, regarding the useful life and buses maintenance, it represents a difficult for the the implementation and massification of e-mobility.².

This investigation gathers information from the technical study of the operation variables of a fully electric articulated bus in the travel from Bogotá to Pereira, Colombia.

2 GENERAL OBJECTIVE:

Consolidate a review of the operating test results of an articulated fully electric bus on travel from Bogotá to Pereira city, Colombia.

3 SPECIFIC OBJECTIVES:

1. Present the general results of the operation test of an articulated fully electric bus from Bogotá to Pereira.
2. Performing a conceptual consolidation of the energy consumption cost hat make up the OPEX of an fully electric articulated bus compared to a hybrid bus and a traditional diesel combustion bus.

4 METHODOLOGY:

The process cites the concepts of experimental practical research that seeks to analyze the operation results of an articulated fully electric bus in travel from Bogotá to Pereira city, in Colombia.

It also includes elements of the field research carried out by the time and place of occurrence of the studied phenomenon. The research is framed in the experimental quantitative analysis.

The case of study and the applied research is proposed as the methodology "strategy aimed at understanding the dynamics present in unique contexts", which could lead to the study of operational experiences tests that are carried out in other transport systems and this way to review in context the general aspects of linking fully electrical technologies.

For this research, the quantitative analysis of the operation experience of a fully electric articulated bus in travel from Bogotá to Pereira city. The operation variables was analyzed as a field work looking for an approach as close as possible to the details of the experience:

- Route

² La electromovilidad en el transporte público en América Latina. Depósito legal: DC2019000315 ISBN: 978-980-422-143-9 (2019). Pages 10-11.

- Total km traveled
- Operation time
- Energy consumption
- Geographic characteristics

5 RESULTS STUDY

The route from Bogotá to Pereira city is part of an InterCitys roads Transportation System that walk the top of the line, that is a mountain route located in the Central Mountain range of the Andina Region, in the Salento municipality jurisdiction and connects Calarcá towns, in Quindío department, and Cajamarca, in Tolima department. Some route characteristics are detailed below in the Tables 1:

Table 1. Route characteristics

ROUTE	DISTANCE (km)	MAXIMUM SLOPE	MINIMUM SLOPE	MAXIMUM ALTITUDE (meters above sea level)	MINIMUM ALTITUDE (meters above sea level)
Bogotá to Pereira	312	19%	0%	3266	285

Source: made of authors

Some characteristics of the fully electric articulated bus are described below in the Table 2:

Table 2. fully electric bus Characteristics

DESCRIPCIÓN	VALOR
Brand	BYD
Long	18000 [mm]
Width	2530 [mm]
Height	3270 [mm]
Gross Weight (GVWR)	30000 [kg]
Seats / Passengers	33/ >160 PAS + Wheelchair area
Maximum speed regulation	60 [km/h]
Maximum climbing capacity on a slope	19 [%]
Height to the ground	280 [mm]
Autonomy	>350 [km] *
Suspension	Adjustable air suspension

Braking system	Brake Disc on 6 tires & ABS
Tires	295 / 80 R 22.5
Electric motors	AC permanent magnet motors
Maximum power	(180 [kW] x 2) y (492) [HP]
Maximum torque	3000 [Nm] / (1500 [Nm] x 2)
Battery Type	Iron phosphate battery
Energy capacity (nominal)	450 [Wh] / 550 [V]

* Relative reference value; it can vary depending on operating conditions
 Source: KF1 Operator manual fully electric bus

The OPEX in buses operation in transport systems, are made up of several cost centers, among those with a higher proportion, energy consumption, that is transversal for all bus technologies.

For the case study, information was recorded since the start point, and it was completed in destining station; for which a total of 17 data was obtained for each of the two independent variables (km traveled and kWh energy consumption).

In the table 3 there is testing data summary:

Table 3. Test data summary

SOURCE	DATA
ORIGIN	Bogotá - Portal Suba
DESTINATION	Pereira - Cuba Station
DISTANCE TRAVELED	312 km
START SOC	100%
ARRIVAL SOC	56%
OCCUPANCY	8 people on board

Source: made of authors

The energy consumption as a result of the relation between the total of kWh as a result of the relation between SOC and the total battery capacity 450 kW:

$$\text{Total consumption kWh} = 450 - (\text{SOC} \times 450)$$

kWh: Kilowatt hour

SOC: State of Charge

In table 4 there are data details of the energy consumption during the route, also the energy efficiency as a result of the relation between the total of kWh and the km traveled. As a reference taken the calculation shows a cost of 0,16 USD (\$608 COP) per one kWh (exogenous variable taken from the commercial information of the supplier energy service company in Bogotá), the total cost of energy consumption is calculated, and finally the relationship between the total cost and the kilometers traveled, allows obtaining the cost per unit of km.

$$\text{CTO. CE/km} = \frac{\sum \text{kWh}}{\sum \text{km}} \times 0,16 \text{ USD}$$

CTO. CE: Energy consumption cost

kWh: Kilowatt hour

km: Kilometers traveled

Table 4. Efficiencies and costs of energy consumption

KM TRAVEL	SOC (%)	ENERGY CONSUMPTION (kWh)	RELATIVE ENERGY COST (0,16 USD/ kWh)
0	100	0	USD 0,000
27,3	93,3	30,15	USD 0,177
40	97,1	13,05	USD 0,052
89,9	100	0	USD 0,000
102,1	100	0	USD 0,000
117	97	13,5	USD 0,018
131,4	95,4	20,7	USD 0,025
145,2	94,3	25,65	USD 0,028
161	89,4	47,7	USD 0,047
172,6	85,2	66,6	USD 0,062
191	78,4	97,2	USD 0,081
209,3	70,2	134,1	USD 0,103
233	49,5	227,25	USD 0,156
254,4	30,4	313,2	USD 0,197
270	51	220,5	USD 0,131
294	44	252	USD 0,137
312	56	198	USD 0,102

Source: made of authors

In the image 1 there is data details of the SOC and km traveled in some different points during the route, and the red line in the graphic represents the altitude above sea level and geography during the route:

Image 1. Altitude and data details of the SOC and km

Source: made of authors

The fully electric articulated bus used in the test, has a property that allows to regenerate energy changing the motor roll, this component is no longer consumer, all times that the driver not accelerates or brake, the bus will search the inertia, and the kinetics energy released by the movement will be converted of an electric energy through a converter integrated on the bus. In the Graph 1 you can see the relation between Energy consumption (kWh) and the bus SOC (%), with the distance traveled (km).

Graph 1. Energy consumption and SOC vs km

Source: made of authors

6 DISCUSSION / PARTIAL OR FINAL RESULTS

In the table 6 you can see the data summary with the analysis of variables:

Table 6. Analysis of variables

	RELATION kWh / km	CONSUMPTION kWh	RELATIVE ENERGY COST (0,16 USD/ kWh)	RELATIVE ENERGY COST (0,16 USD/ kWh) / km
Maximum	1,23	383,76	61,4016	0,1968
Minimum	0,11	34,32	5,4912	0,0176
Average	0,63	196,56	31,4496	0,1008
Standard deviation	0,39	121,68	19,4688	0,0624

Source: made of authors

According with the last table, a combination of variables was made to calculate the average energy consumption costs that make up the OPEX for one unit of the operation control variable (km), and a direct comparison was made with the consumption data of hybrid technologies and traditional diesel combustion. For the comparison exercise, the results presented by the National Laboratory of the U.S. were taken as reference. Department of Energy Office of Energy Efficiency & Renewable Energy, in Technical Report NREL / TP-540-39742 of April 2006, King County Metro Transit Hybrid Articulated Buses: Interim Evaluation Result, study by K. Chandler and K. Walkowicz³, on this document the data was presented in cost USD / mile (0,78 USD / km for Diesel bus, and 0,61 USD / km for Hybrid bus), and for this exercise the equivalence is 1 mile = 1.60934 km.

In the table 7 you can see the comparison of operating costs between traditional technologies and fully electric bus:

Table 7. Comparison of operating costs between traditional technologies and electric bus

TECHNOLOGY	USD / km ENERGY COST
Fully electric articulated bus	0,1008 USD
Hybrid Articulated Bus	0,4846 USD
Difference	-0,3838 USD
Percentage difference	-79,19%
Diesel articulated bus	0,3790 USD
Diference	-0,2782 USD
Percentage difference	-73,39%

Source: made of authors

³ K. Chandler., K. y Walkowicz (2006). King County Metro Transit Hybrid Articulated Buses: Interim Evaluation Result. *Technical Report NREL/TP-540-39742*, 1 – 42.

The study results carried, allowed to conclude that in articulated buses (18 m) fully electric traction technology there is a difference of 79,19% in energy consumption compared to traditional Diesel technology, and 73,39% in energy consumption in respect to hybrid technology, these are positively impacts on the OPEX; this generates new input information to feed the economic evaluation models in the fleet renewal processes of transport systems.

RECOMMENDATIONS

- It is necessary to carry out a comparative analysis between traditional and fully electrical technologies for other bus typologies different than the articulated (18 m), in other transport systems.
- It is necessary to develop tests of vehicles for fully electrical technologies in transport systems such as special transport systems, inter-city transport systems, distribution logistics systems, internal logistics systems in industrial processes, in order to evaluate the performance conditions and impact on the operation cost.

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