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Numerical simulation model for the preliminary design of hybrid electric city bus power train with polymer electrolyte fuel cell

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ABSTRACT

A hybrid power train, consisting of a Polymer Electrolyte Fuel Cell (PEFC) system and batteries, which feeds an electric motor for city bus propulsion, can be dimensioned ad hoc respect to the performed route, avoiding his oversizing in the greater energy rationalization optic.

In this article a calculation tool is developed and implemented in Matlab® and Simulink® environments in such a way that it can be used both for verifying the electric motor proper operation in the route and for dimensioning the hybrid system (PEFC system and batteries), after that city bus characteristics and route have been defined.

It considers the electric energy recoverable by city bus both downhill and in the deceleration phase (regenerative braking), can simulate various traffic conditions and can be used to obtain a good estimate of both the hydrogen amount on city bus board and the batteries state of charge along the route.

Introduction

The transport system requires 30–35% of the industrialized countries primary energy needs and a large part of this request is related to road transport [1].

In the optic of greater energy rationalization and of air quality improvement, the road transport system is the sector, where research and development activities are more concentrated, with the objectives of reducing its energy consumption end its emissions of pollutants and of greenhouse gases, as carbon dioxide.

In urban areas a policy of improving people mobility as city buses would not only reduce its pollutants and greenhouse gases emissions, but would encourage its increased use by citizens at the expense of private transport. In a short time this phenomenon would produce a substantial reduction in the number of private vehicles circulating on the road with a consequent reduction of the road network congestion and a

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Nomenclatures

Symbols

P	power, kW
η	efficiency, -
MTT	vehicle mass excluding the PEFC system, hydrogen cylinders and batteries masses, kg
l	length, mm
w	width, mm
h	height, mm
n	number, -
fa	friction factor, -
d	diameter, mm
m	mass, kg
c	coefficient, -
I	inertia moment, kg m^2
C	capacity, Ah
V	voltage, V
T	temperature, °C
e	specific energy, Wh kg^{-1}
M	torque, N m
i	electric current, A
N	revolutions per minute, rpm
t	time, h
x	distance, km
Δt	interval of time, h
SOC	state of charge percentage, %
f	frequency, Hz
R	electric resistance, Ω
L	auto inductance, H
Lm	mutual inductance, H
s	slip, -
φ	magnetic flux, Wb
ω	Angular velocity, rad/s
F	Combined rotor and load viscous friction coefficient, J s
H	Combined rotor and load inertia constant, J s^2

Subscripts

seats	seats
bearings	bearings
conv	conventional
wheels	wheels
brakes	brakes
axles	axles
r	resistance
t	transmission
tot	total
TAM	Three phases Asynchronous electric Motor
m	mechanical
gb	mechanical gearbox
bridge	bridge
net	net
system	system
PEFC	Polymer Electrolyte Fuel Cell
aux	auxiliaries
auxiliary	auxiliary
H_2	hydrogen
cylinder	hydrogen cylinder
oc	open circuit
rated	rated
op	operative
DC	continuous electric current
max	maximum
hyp	hypothesized
st	stop
i	i-th
cs	change of slope
charge	charge
discharge	discharge
rot	rotor
stat	stator
rms	rms current value
AC	alternating current
poles	TAM magnetic poles
start	in the starting phase
1	chosen value
Gross	Gross value excluding the electric power consumed by auxiliary system
Heat	heating
bidir	Bidirectional
DC–DC conv	DC–DC converter
Inverter	inverter
serv	daily service
charge–discharge line	Batteries charge–discharge line
act	active
react	reactive
app	apparent
sim	simulated
com	commercial
stroke	bus stroke
pt	Power train
batt	batteries
AB	At A and B nodes
Q	q axis quantity
D	d axis quantity
e	electromagnetic

Superscripts

*	tentative value
′	operative condition of TAM as electric generator
″	referred to relative reference system

further reduction in fuel consumption and in polluting and greenhouse gases emissions.

Today the traditional power trains for city buses are based on internal combustion engines (ICE) coupled to a transmission system, but already the main vehicles manufacturers are developing new solutions which make use of electric power trains through prototypes designed for short-term applications and in some cases already placed on the market. Three different solutions are now available:

- Batteries Electric Vehicles (BEV), where the batteries store the electric energy supplied by the electric network during