Transportation System Based on Light Electric Vehicles

Grigore DANCIU, Virgil RACICOVSCHI, Mihaela CHEFNEUX, Liviu KREINDLER*

Abstract

The mobility needs of the modern society are in a continuous growth. On the other hands, people need comfort, and on the other hand clean, safe, and cheap transportation conditions. Following this idea, the authors produced a "bike-sharing" transportation system, based on light electric vehicles, such as bikes, mopeds, and scooters. The present paper presents this system and analyzes it from a practical point of view.

Keywords: transprtation system, light electric vehicle, in-wheel DLDC motor, digital controller, solar energy, bike-sharing

1. Introduction

Despite the limitations generated by pollution and rising price of fossil fuels, the modern society needs an increase of mobility, keeping in the same time clean, safe, cheap and comfortable transportation conditions.

As presented in table 1, the production of motor vehicles is growing, improving people's mobility, but generating also some drawbacks as: chemical and acoustical pollution, road congestion and accidents, and others.

Table 1. Production statistics of motor vehicles [1]

	2000	2003	2006	2010	2011
North America	17,697	16,244	15,882	12,176	13,468
South America	2,087	2,037	3,043	4,365	4,235
European Union	17,106	16,777	16,538	16,919	16,320
Japan	10,141	10,286	11,484	9,626	8,399
South Korea	3,115	3,178	3,840	4,272	4,657
China	2,072	4,444	7,189	18,265	18,419
Total	**58,347**	**60,664**	**70,105**	**77,857**	**80,108**

$x10^3$

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At this moment, 23 % of CO_2 emissions in EU are generated by the transport sector which is only one with growing emissions [2].

The EU response was very decided and 20-20-20 Directive is now into force and has by 2020 three main targets:

- 20 % reduction of greenhouse gases (mainly CO_2) compared with 1990 level,
- 20 % reduction of energy consumption by increasing the efficiency and
- 20 % use of renewable energy[3].

A main solution to these constraints is represented by the electric (EV) and hybrid electric vehicles (HEV) [4],[5],[6],[7].

Many implementation are already present in the world [8],[9], based on cars, vans, buses, trucks or light vehicles (bikes, mopeds, scooters).

In this context, the authors proposed not only a vehicle, but also a "bike-sharing" transportation system, based on light electric vehicles. The electric bikes are clean and environment friendly. The cruising speed is reduced (under 45 km/h, but usually it is about 25 km/h) and the vehicles are safe, assuring however a very good mobility at very low costs. At the same time, these individual electric vehicles allow for a perfect autonomy over a medium surface.

This experiment is based on the bike-sharing idea, which is already very popular in many countries, including Romania.

The difference is that the electric solution increases the comfort and autonomy by electric assistance, it is very simple and can be used by everyone, and it is very clean and cheap.

This transportation system is appropriate for applications, which fulfill conditions such:

a) The regular domestic transportation system does not cover that area.
b) The traffic volume and the moving direction do not motivate a special transportation system, like a shuttle or an air-train like in the case of an airport.
c) The moving area is quite large and it is difficult to walk.
d) A simple, cheap, and safe vehicle is needed.

Starting from a large university area, which is the campus of University "Politehnica", the system could be extended to many other places: from holyday resorts to tourist cities, parks and forests, large exhibition platforms, industrial areas, multi-location companies, etc.

2. Transportation system structure

The system structure is presented in figure 1:

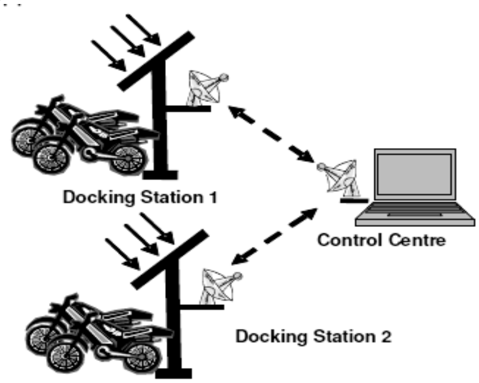

Figure 1: Transportation system structure

and contains the following components:

1. The Electric Vehicles represent the main component of the project. For evaluation purposes of this research, different types of electric vehicles were selected. The authors produced one scooter of original design, and purchased other vehicles: two electric bikes and one electric moped. In this way, it was possible to better evaluate the own design and to compare it properly with other international implementations, from many points of view as motor power and torque characteristics, electric drive organization (motor, controller, battery and auxiliaries), battery chemistry, driving facilities, auxiliary equipments (lamps, signals and gauges, actuators, etc), degree of standardization and others.

2. The Docking stations represent the facilities, where the vehicles are parked and recharged between two successive rental periods. The vehicles are automatically released/received to/from authorized users, charged and verified. For charging, the station uses a double source: photovoltaic panels and the power grid. When the produced power exceeds the necessary level, the panels could supply the grid. The station monitors the technical status of each vehicle: charging, availability and health. Each station is controlled by a microcontroller and has a wireless communication with the Control Center. It communicates with the users by a keyboard panel and a display.

3. The Control Centre uses a dedicated server and wireless communications with the docking stations. It manages the users, vehicles, trips and finally could send a bill.

3. Details of implementation

This section details the implementation of the elements presented above.

3.1. The scooter produced by the authors

Due to the financial and technological restrictions of the project, the vehicle body was adopted from a scooter acquired from the local market. The classical propulsion system (engine, transmission, tank, etc.) was replaced, keeping only the throttle and its cable. The authors produced an original electric drive with the structure presented in figure 2.

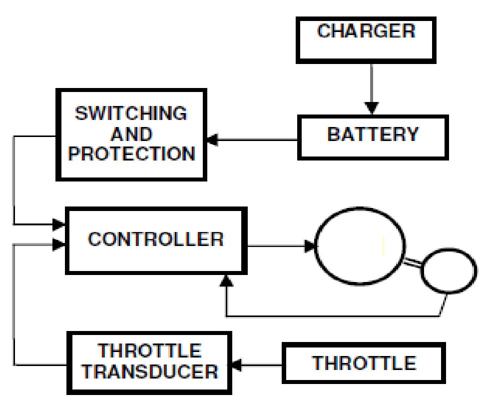

Figure 2. Electric propulsion system

The switching block disconnects the system, when the vehicle is parked, and protects it in case of over-current. It also monitors the charging status of the SLA (Sealed Lead Acid) battery.

The controller is connected to the in-wheel motor (machine and the incorporated Hall transducers). The controller command comes from the original throttle (mechanical), a cable, and a long life contact-less inductive transducer. The vehicle organization is presented in figure 3, including a standard charger 220VAC/ 60VDC for the batteries.

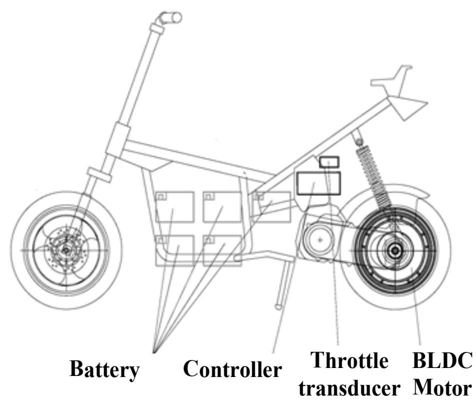

Figure 3. Vehicle organization

The final form of the scooter is presented in figure 4.

Figure 4. Vehicle implementation (*in front*)

3.1.1. Vehicle model

In order to support the design phase, the authors developed and validated a single-dimension mathematical model of the vehicle dynamics, as presented in [10], based on [11] and [12]. The model uses the torque characteristic of the drive at rated and peak conditions, and the usual resistances of the bike (rolling, drag, slope, and inertia), with and without wind. It does not consider a speed controller. Using this model, the authors developed a Matlab-Simulink simulation tool, which can predict and verify the vehicle dynamics in defined conditions like: maximum velocity on horizontal road with/without wind, imposed velocity on a given slope, maximum slope, etc. For short intervals, the peak power and torque are used to calculate the vehicle dynamics.

Figure 5 exemplifies a simulation of vehicle acceleration at peak torque and nominal load.

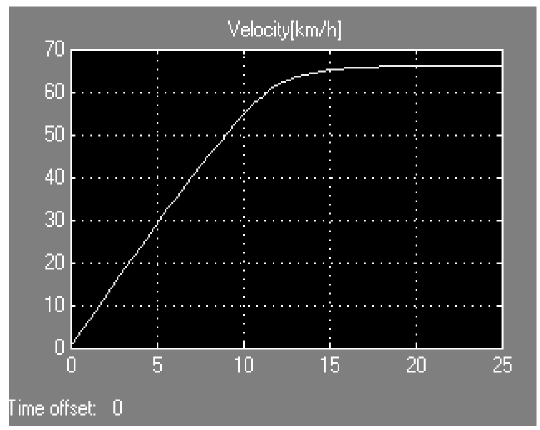

Figure 5. Simulation of vehicle acceleration at peak torque

Due to high motor power, the maximum velocity is exceeded. In real conditions, an electronic limitation to 45 km/h would be necessary. Otherwise, the vehicle enters other legal class and the driver needs a driving license. However, the high power is useful in some traffic conditions, e.g., to climb a hill.

Using the parameters of the scooter body and the actual values of the drive system (motor, controller, batteries) it was possible to estimate the vehicle performances as in table 2.

Table 2. Estimated scooter parameters

Parameter	Value	Parameter	Value
Mass	175 kg	Load	100 kg
Rated speed		Range	60 km
Rated power	3.5 kW	Rated torque	54 Nm
Rated voltage	60 V	Charging time	5-7 h
Climbing ability	15 %	Maximum torque	115 Nm

3.1.2. Electric motor

The electric motor, developed by Icpe Bucharest, is included in the 13" rim of the rear wheel, as in figure 6.

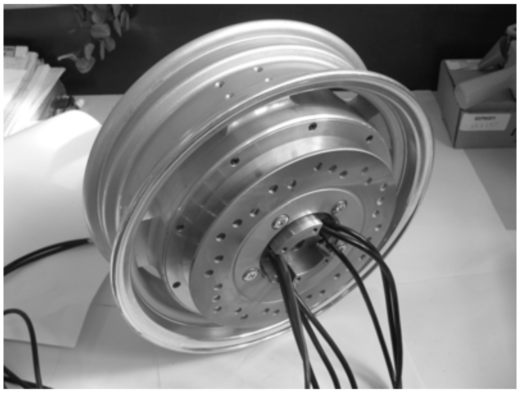

Figure 6. In-wheel "Brushless DC Motor

It is a permanent magnet brushless DC motor (PM-BLDC) with outer rotor and neodymium (NdFeB) permanent magnets. The motor has the Hall and temperature sensors included. It was designed to produce high torque and no gear is normally necessary. However, for a higher dynamic, a planetary gear could be considered. The gear solution involves financial and technological difficulties, which exceed the level of this project and has been denied. Specifications of the motor are given in table 3.

Table 3.In-wheel motor

Parameter	Value	Parameter	Value
Rated torque	54 Nm	Maximum continuous torque	59 Nm
Rated power	3.5 kW	Rated speed	600 rpm
Peak torque (estimate)	115 Nm	Peak power (estimate)	7.4 kW
Rated line EMF	30 Vrms	Rated phase current	33 Arms
Rim diameter	13"	Connection	Y
Mass	15 kg	Maximum speed	800 rpm

3.1.3. Electric drive and battery

The controller is developed by Technosoft International SRL. The controller implemented a new cost-effective technique to apply the vector control method, which usually requires a high-resolution position transducer, to a low-cost BLDC configuration, which uses only 3 very cheap digital Hall sensors.

The idea is to estimate the intermediate position of the rotor, based on the Hall signal of a sensor and the previous value of the speed, considered constant between two consecutive Hall transitions. A 16-bit timer was used to precisely capture each Hall transition.

The controller clock frequency was pre-scaled with a factor of 128. The proposed method was implemented as an extension of the standard Technosoft MotionChip^{TM} firmware structure, with a fixed-point, 150 MHz, 16-bit DSP chip.

The controller is set to match the electric scooter motor, operating at Un = 60 $_{CC}$V, In = 150 A peak, and a nominal speed of 600 rpm.

A three-phase inverter, DSP controlled, with specific short-circuit, over and under voltage, motor and drive over temperature and I^2t protections was implemented.

A torque control loop using d-q vector control structure was implemented at a 100 μs sampling period. Optionally, a speed control loop could be closed at 1 ms sampling rate.

The proposed speed and position estimation method provides an alternate method of controlling in sinusoidal mode a brushless motor equipped with Hall sensors only.

This approach minimizes the current ripple and improves system efficiency, reducing overall losses and EMC noises.

The method is robust and works even for very low speeds, and is a very cost-effective alternative to solutions requiring absolute or incremental position sensors.

Concerning the battery, due to dramatic financial limitations, a sealed lead-acid (SLA) solution was considered as a first step. To cover the motor necessities, a 60 V_{CC} rated voltage was adopted. It corresponds to 5 unites of 12 V-VRLA batteries of type12-24, produced by BSB.

The rated capacity is 24 Ah, corresponding to a range of at least 60 km. The gross mass of batteries is 40 kg. The next step to improve the vehicle performance, if the budget permits, is to change the batteries to a lithium chemistry.

3.2. Purchased vehicles

In order to produce a fleet of vehicles and also evaluate and compare the different solutions, other electric vehicles were purchased: two electric bikes (“Eco Bike”) and an electric moped (“E-scooter”).

These vehicles are presented in figure 7 and figure 8, and the specifications are summarized in table 4.

Figure 7. Electric bike "Eko Bike"

Figure 8. "E-scooter"

Table 4 Purchased vehicles specifications

Parameter	**Eco Bike**	**E-scooter**
Motor	Brushless 36 V/250 W	Brushless 36 V/250 W
Battery	Lithium 36 V/10 Ah	SLA 36 V/10 Ah
Charging time	4-6 h	6-8h
Range	>60 km	35 km
Battery life	>500 cycles	–
Load	100 kg	75-100 kg
Frame	Aluminium	Steel
Mass	25 kg	38 kg+11.5 kg
Command	Intelligent pedal assist	Throttle
Wheels	26”	18”

All vehicles are attached a docking frame in order to can be parked and locked in the locking place.

3.3. Docking station

The docking station is the designed place to park, to dock and to charge the electric vehicles. It is microprocessor controlled for all functions, and is presented in figure 9.

Figure 9. Docking Station

The station is composed of:

1. Four docking places. Each docking place has a guiding frame for a specified bike, an electromagnetic lock to hold the parked bike, two LEDs, L-RED and L-GREEN to communicate with the user and a power shoket. The docking frame of the bike enters into the guiding frame of the station, is locked and assures the safe parking of the bike. The lock has associated an inductive transducer to "see" the presence of the bike in the docking place.

The shoket has two wires for 220 VAC to supply the bike charger, two wires to "see" the presence of the plug in shoket, and three wires to "see" the status of charge of the battery.

These last signals come from the on-vehicle charger, actually from the LEDs of the charger (GND, LED Green-charged, and LED Red-uncharged). This strategy allows using the charger monitoring system, which is specific to the battery chemistry and permits to connect every bike in every shoket, regardless of the type of bike.

2. The solar supply system has two photovoltaic panels type STP190S-24Ad+ produced by Suntech, with dimensions 1580×808 mm and a maximum power of 190 W each. The panels are parallel connected and supply two SLA batteries of 100Ah controlled by a STECA PR1010 24 V-10 A solar charger, as in figure 10.

Figure 10. The pannel of controller and batteries

3. The station controller is implemented by a Stellaris DK-LM3S9B96 development

board produced by Texas Instruments, associated with an I/O interface board to control the electromagnetic locks and to format the battery status signals, as presented in figure 11.

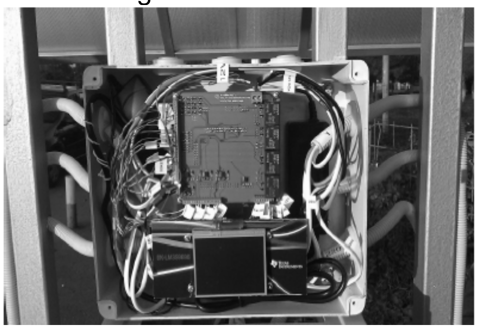

Figure 11. Station controller Stellaris and interface

The Stellaris has a touch sensitive display which allows communicating with the users.

A wireless access point is also present in the controller box. It connects the Station controller with another IEEE 802.11 wireless router placed in the Control Center building and assures the wireless communication system.

Each user has pre-allocated a username and a password. The table with the users is uploaded into Stellaris by the Control Centre.

A user identifies him and then he can take a charged bike, or leave an already rented bike.

The two LEDs on each docking place communicate with the user based on an established code of signals, resulted by combining the two LEDs of the docking place, L-RED and L-GREEN. Stellaris transmits to Control Centre every event from the Docking Station: a user took a certain bike, or it left a certain bike, he accessed the station without any operation, a certain bike is "dead", or a certain docking place is "dead", etc.

The station has a double supply system: photovoltaic panels (solar) and the power grid. The primary source is solar and the grid will be used only if it is necessary.

3.4. Control Centre

The Control Centre communicates with the docking stations, users and technical staff. It has (at least) the following functions:

- a) User management, which enrolls the users, deletes the users and edits the users' attributes.
- b) Station management, which communicates with the docking stations to transmit the list of users and to receive the status of each station and docking place, and to list each event (user interrogation, vehicle release/docking, etc).
- c) Vehicle management, which monitors and records the status of each vehicle. If something is damaged, the maintenance staff will be informed.
- d) Billing which keeps the evidence of trips.

4. Acknowledgment

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6. Biography

Grigore DANCIU was born in Bucharest (Romania), on June, 22, of 1954. He graduated the University "Politehnica" of Bucharest (Romania), Faculty of Electric Engineering, in 1979. He received the PhD degree in electric engineering from the University "Politehnica" of Bucharest, (Romania), in 1988.
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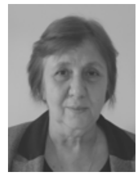

Mihaela CHEFNEUX was born in Bucureşti (Romania), on May 24, 1954. She graduated University "Politehnica" of Bucharest (Romania), Faculty of Electric Engineering. She is senior research engineer in the field of electric engineering at Icpe, has more than 30 years experience in research and national and international projects management. Personal area of expertise is in the field of electric vehicles application.
She is secretary of the Romanian Association for Electric Vehicles and author or co-author of scientific papers and books in the field of electric vehicles.

Liviu KREINDLER graduated from Polytechnic Institute of Bucharest in 1979, and received a Ph.D. degree in Electric Engineering from the same university in 1986. He is a full professor at the same university since 1998, and also director at Technosoft since 1994. He is involved in research and development activities in the field of digital motor and motion control, mainly using DSP controllers. His main research areas cover digital motion control, electric drives, with special emphasis on advanced control algorithms, sensorless control and DSP real-time control implementation.