LATVIA UNIVERSITY OF AGRICULTURE
FACULTY OF ENGINEERING

Monograph

RESEARCH OF THE EXPLOITATIONAL AND INFRASTRUCTURAL PARAMETERS OF ELECTRIC VEHICLES

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ANNOTATION

The monograph includes research within the project “Usage of Electric Energy in Motor Vehicles of Physical Persons” in the period of three years. The monograph includes 4 chapters reflecting the research within the main project activities. Electric power vehicle analytical research has been performed stating the economic and ecological effect of these power vehicles, different electric power vehicle experimental investigations using electric bicycles and slow speed electric power vehicles have been carried out. Research has been performed also in the sphere of electric power vehicle infrastructure and alternative energy battery charging stations. The main statements of the performed research are indexed in *Scopus* data base.

ANOTĀCIJA

Monogrāfijā ietverti pētījumi, kurus projekta „Elektroenerģijas izmantošana fizisko personu spēkratos” pētnieki veikuši projekta laikā 3 gadu garumā. Monogrāfijā ietvertas 4 nodaļas, kurās atspoguļoti pētījumi galvenajās projekta aktivitātēs. Veikti gan elektrospēkratu analītiskie pētījumi, nosakot šo spēkratu ekonomisko un ekoloģisko efektu, dažādi elektrospēkratu eksperimentālie pētījumi, izmantojot elektrovelosipēdus un lēngaitas elektrospēkratus. Pētījumi veikti arī elektrospēkratu infrastruktūras un alternatīvās enerģijas akumulatoru uzlādes stacijas jomā. Veikto pētījumu galvenie atzinumi indeksēti *Scopus* datu bāzē.

CONTENTS

INTRODUCTION

The worlds' fossil energy resources decrease year by year. Scientists seek various ways to exploit other energy sources. The sector of transport is not an exception, as scientists seek to replace fossil fuel with other – renewable fuels. In vehicles, such renewable fuels as various biofuels, for instance, biodiesel fuel, bioethanol, and biogas may be used. By using such fuels, not only renewable energy sources are exploited, but also pollution to the environment is reduced.

One of the ways of using alternative energy in vehicles is the use of electric drive in automobile machines. Electric energy may be generated both from renewable sources such as wind, solar power, hydro power, biogas cogeneration, or sea wave power and from non-renewable resources, for instance, coal. One of the most essential advantages of electric vehicles is their quiet operation producing no emissions, which is very important to the urban environment.

In Latvia, too, the sector of electric vehicles starts developing, as electric bicycles as well as electric automobiles are introduced. Presently, the introduction of greater capacity electric vehicles is hindered by their high price and the limited availability of an adequate infrastructure, as well as insufficient information about the specifics of exploitation of electric vehicles under the climatic conditions of Latvia, which may differ from the specifics of exploitation in a warmer climatic zone.

To expand information on electric vehicles and their exploitation specifics in Latvia, a research on these issues has to be conducted. Such a research was conducted within the project "Usage of Electric Energy in Motor Vehicles of Physical Persons", which was carried out at the Faculty of Engineering of Latvia University of Agriculture. Within this project, research on various electric vehicles was conducted, a model of infrastructure and an electric vehicle charging point were developed, a battery charging station powered on solar and wind energy was designed, as well as an internal combustion automobile was converted into an electric vehicle. All the activities were focused on fostering the introduction of electric vehicles in Latvia.

The present monograph includes research papers of the researchers engaged in the mentioned project, which were produced within this project and published in international peer-reviewed publications in the period 2011-2013. The research performed will give a notion of the key exploitation specifics of electric vehicles in Latvia and their adequacy for various uses.

1. ELECTRIC TRANSPORT IN LATVIA

A study of electric vehicles in a historical aspect led to a conclusion that there were several stages in their evolution. In the early stage, before more than a century, electric vehicles competed with internal combustion vehicles, yet, in the beginning of the 20th century, mainly internal combustion vehicles spread and evolved. A wide use of electric vehicles was abandoned for almost a century. A wider use of electric vehicles was considered only in the beginning of the 21st century when auto manufacturers started designing their concepts of electric vehicle; there were developed hybrid technology automobiles in which a combustion engine and an electric engine were combined.

These evolutionary stages were more or less characteristic in Latvia. Electric transport in Latvia was exploited in closed territories, for instance, electric forklift trucks at warehouses. In the period when Latvia was part of the USSR, electric trucks with a carrying capacity starting with 1.5 t were designed in Moscow in 1948. These electric trucks were used for postal service in Moscow. At the Lviv Bus Plant, 10 electric trucks were produced, which were exploited in Leningrad for postal service in the period 1952-1958. The weight of these trucks was 2.64 t, the weight of its batteries was 1.1 t, the travel distance per charge reached 70 km, and the maximum speed was 30 km h^{-1}. In the 1980's, experiments on RAF, UAZ, and ErAZ brand automobiles of 25 various designs were carried out at an automobile plant in Moscow. Electric automobiles – ErAZ-3732 and VAZ-3702 – were designed. No information is available that some of these electric vehicles were exploited in Latvia.

At the RAF factory, a minibus, RAF-22038, with a three-phase asynchronic electric motor was designed. Heavy lead batteries were installed in the minibus, which made this minibus model very heavy, thus reducing also the minibus's carrying capacity, even though its weight increased. Among the models designed in the USSR, this minibus model might be regarded as one of the most progressive. The minibus had 7 seats, its weight was 3 t, the travel distance per charge reached 70 km, and the maximum speed was 70 km h^{-1}.

Based on the research in relation to the exploitation and purchase of electric vehicles, the following theses may be stated:

- electric bicycles, low-speed electric automobiles, and high-speed electric automobiles are exploited in Latvia. In Latvia, new electric bicycles and electric mopeds within a price range of LVL 200-1500 may be purchased. The lowest price group includes electric bicycles of comparatively low quality that are produced in China. Experiments showed that such vehicles are functional at least up to a kilometrage of 2000-3000 km, however, if purchased, consumers have to take into consideration a higher probability of their breakdown;

- not a single electric vehicle exploited in the experiments in any regime of operation met the guaranteed kilometrage and reached 70-80% of the parameters set. It is possible that the kilometrage guaranteed by the manufacturer was adequate for the exploitation of vehicles on better quality roads or for a smaller weight of riders;
- batteries of the new electric bicycles exploited in the experiments were functional for 2.5 years, yet, their electric capacity decreased on average by 15-20%, which affected their kilometrage per charge. The old batteries could be replaced with lead batteries of adequate capacity and voltage used for computer equipment, which were cheaper than those sold by dealers of electric bicycles;
- exploitation of electric vehicles, compared to an internal combustion engine vehicle, can be up to 2-3 times cheaper. Such materials used for maintenance as oil and some parts, for instance, oil and air filters, drive belts, etc. are not needed. Yet, it has to be taken into account that batteries, depending on their characteristics, will need to be replaced after the maximum number of charge/discharge cycles is reached, which requires large investments;
- the main environment for electric vehicles, based on scientific considerations, is an urban and suburban area where emissions and noises may be considerably reduced after introducing such vehicles. Nevertheless, a family having an electric automobile, for instance, to take its children to school or to go to work has to consider the need to have a second automobile for distant travels. With the present battery technologies, in Latvia, the use of electric automobiles may be problematic at distances more than 150 km;
- electric bicycles and electric mopeds are more suitable for people who have difficulty to keep pedalling a bicycle. It is useful to compare electric bicycles and electric mopeds with internal combustion mopeds and motorbikes in terms of technical, ecological, and economic aspects. A comparison with bicycles is not correct, as they have no motor and usually serve for other purposes – it is a vehicle useful for travelling and, at the same time, it maintains the rider in a good physical shape;

- if converting an internal combustion engine automobile into an electric one, it is important to determine such technical parameters as maximum speed and kilometrage per charge. In case a high maximum speed is not needed (70-80 km h^{-1}) and a travel distance per charge is not greater than 50-60 km, the cost of conversion of an automobile's units may be reduced up to twofold;
- to exploit Chinese electric bicycles normally in Latvia, several enhancements have to be made. For instance, the pedals of any electric bicycle ER-61 should be replaced with footrests or footboards to increase the rider's convenience, and, additionally, the rattling batteries and the baggage carrier have to be fastened. To make the seat convenient, it is possible to replace the bicycle-type seat with a seat of scooter. Similar improvements are advised to be done on other electric bicycles. Even though in Latvia, too, various pedal vehicles are manufactured, which are called electric bicycles, it would be correct to refer to an electric bicycle as a vehicle if its motor capacity is less than 200 W. Two-wheel vehicles of greater capacity are mopeds, and the Traffic Rules have to be applicable to such vehicles;
- electric bicycles whose speed is less than 30 km h^{-1} should be mainly used for travelling down streets rather than sidewalks, as such a speed of travelling may endanger pedestrians. When choosing an electric bicycle, especially for women, special attention has to be paid to its weight, as its weight and also mass centre may significantly differ from those of a traditional bicycle;
- dynamic characteristics of modern electric automobiles of medium capacity are similar to those of internal combustion automobiles, which enables electric automobiles to be conveniently used in urban traffic. Charging electric automobiles of large capacity, given the present electric infrastructure, is convenient to private house owners and enterprises having charging facilities, for instance, garages or squares with charging points. Charging electric vehicles at parking lots may be presently limited due to their limited electric capacity.

2. ANALYTIC RESEARCH OF ELECTRIC VEHICLES AND THEIR INFRASTRUCTURE

A wide infrastructure for electric vehicles is not presently available in Latvia. Of all charging points in Latvia, 70% are adapted to electric bicycles rather than electric automobiles. Yet, an argument that the lack of charging points is the key barrier for introducing electric vehicles is not correct. If electric vehicles were available in a sufficient number, it would be profitable to construct charging points and charge a fee for such services.

To promote the introduction of electric vehicles at the present situation in Latvia, it is advised to establish simple and safe, in terms of exploitation, charging points in which the cost of one charging spot should not exceed LVL 100. Given the present number of electric vehicles, it is not profitable to collect a fee for charging electric vehicles at charging points, as it may considerably increase the cost of constructing a charging point. Upon reaching a sufficient number of electric vehicles, a charging point may be equipped with an automatic vehicle identification system or, in the simplest case, charging points may be established as lockable compartments with identical locks in which an average subscription fee for the corresponding vehicle group is collected every month and an identification sticker is issued. The construction of expensive charging points is not presently efficient in Latvia, as their payback period may be infinite.

Electric vehicles are ecological in Latvia due to the high proportion of green electricity produced in the country. The high ecological level of electric vehicles is due to their lack of emissions and noises. The emissions produced by electric vehicles and those arising from the electricity generated from fossil fuel or other fuels are localised in their production site rather than in the area of exploitation of electric vehicles.

An algorithm for the choice of an electric motor or a battery developed within the mentioned project enables us to perform optimisation and make the right choice of units, which may considerably reduce the cost of converting an internal combustion vehicle into an electric one. The key advantage of converted vehicles is that their owners can determine the technical parameters that are most appropriate for themselves before their vehicles are converted, thereby reducing both the cost of such projects and the weight of their electric vehicles.

Nowadays, almost every automobile manufacturer offers electric vehicle prototypes, yet, their purchase is presently problematic in Latvia, as not all dealers in Latvia are ready to meet the requirements of these manufacturers owing to the small number of electric vehicles sold. Low-speed electric vehicles can be bought in Latvia, yet, their price, compared with similar internal combustion vehicles, is very high, which hampers their wide introduction.

An extensive research on battery charge parameters was conducted within the project. Most simple charging devices (for electric bicycles and electric mopeds) operate based on a similar algorithm – upon reaching a certain battery voltage, the electric current is gradually reduced and the charging process stops. An average charging time ranges within 6-8 hours.

ECONOMIC EFFECT OF ELECTRIC VEHICLES

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Abstract. Due to the decrease in fossil energy resources in the world and the increase in their consumption, new sources of energy are searched for. One of such kinds of energy is electricity. A methodology for assessing the economic effect of electric vehicles was developed. The methodology was approbated by computing economic effects for various types of electric vehicles. The electric vehicles were compared with analogous internal combustion engine vehicles. The expenses on charging a battery of electric vehicles are three times lower than the expenses on fuel for internal combustion engine vehicles. The expenses depend on the type of vehicles and exploitation conditions.

Keywords: electric vehicles, internal combustion engine vehicles, economic effect, cost, fuel consumption.

Introduction

More than 800 million automobiles are presently exploited in the world. On average, 55-75 million automobiles are produced in the world every year. Mostly fossil fuels are used in automobiles. The main kinds of liquid fuels produced from non-renewable resources and used in vehicles are diesel fuel and petrol. Liquefied petroleum gas (LPG) and compressed natural gas (CNG) are also used. Renewable energy sources, for instance, biofuel are used as well. In several countries in the world, for example, in Brazil, pure bioethanol or flex fuel E85 – a mixture of bioethanol and petrol in a ratio of 85:15 – is used. Biofuel and rapeseed oil are also used, but their use in vehicles that are not specially adapted for them is problematic, especially in winters when surrounding environment temperatures are below -5 °C.

One of the kinds of energy that is little used in vehicles is electricity. Electricity is extensively used in public transport in cities – trams and trolleybuses. Yet, due to the heavy weight and the relatively low energy capacity of batteries, electric vehicles with batteries are not popular. Such vehicles are mostly used in the USA. In most cases, vehicles are individually converted, replacing their internal combustion engine with an electric engine. Automobile manufacturers have designed several models of electric vehicles, however, so far they are not widely available in the market. The sale prices of such automobiles produced by the large auto manufacturers are high, which will limit purchases of such kind of vehicles and their fast spread.

Let us compute the economic effect for various electric vehicles compared with analogous internal combustion engine vehicles.

Materials and methods

Distribution of motor vehicles by type of fuel in Latvia

Automobiles using various types of fuels are exploited in Latvia. Of liquid types of fuels, petrol and diesel fuel are used. The largest consumer of diesel fuel is lorries. Cars use both petrol and diesel fuel. Automobiles running on liquefied natural gas are also used – mostly cars with Otto engines. Due to the closure of all compressed natural gas stations in Latvia in the spring of 2010, the use of such automobiles is limited, and such vehicles can be fuelled up only by means of individual low capacity gas equipment installed for private needs. Such equipment can fill an automobile up with compressed gas within 8-10 hours. The amount of gas filled up within this period is enough for driving as far as 250-300 km, however, 1-2 automobiles can be fuelled up at such a filling station simultaneously. The price of such equipment is high, therefore, they have not become popular. The distribution of motor vehicles by type of fuel as of 1 January 2011 is summarised in Table 1 [1-3].

Table 1

Distribution of motor vehicles by type of fuel in Latvia

Kind of vehicle	**Total**	**Petrol engine vehicles**	**Diesel engine vehicles**	**Liquefied and compressed gas engine vehicles**	**Electricity**
Cars	636664	402136	210075	24453	-
Lorries	71575	7063	62771	1741	-
Motorbikes and quadrocycles	18325	18320	-	-	5
Mopeds	19486	19486	-	-	-
Buses	5377	194	5143	40	-
Trolleybuses	346	-	-	-	346
Trams	315	-	-	-	315
Total	752088	447199	277989	26234	666
As percentage	**100 %**	**59.46 %**	**36.96 %**	**3.49 %**	**0.09 %**

None of the types of fuel is produced in Latvia. Since electricity is produced in Latvia, the exploitation of vehicles would not be related to using energy resources of other countries.

Consumption of various types of fuel in Latvia

The total number of automobiles and their distribution by the type of fuel is only one indicator showing the consumption of fossil energy resources in a region. Yet, it has to be taken into consideration that lorries and cars consume different amounts of fuel, besides, this difference could be even five times; therefore, it is of great importance to analyse the amount of fuel consumed. The amount of fuel consumed can be estimated by two methods: according to the data of the Central Statistical Bureau of Latvia or according to the average annual fuel consumption and kilometrage of automobiles. The data of the Central Statistical Bureau usually do not specify the fuel consumption for motor transport; therefore, the computation method that is based on several assumptions will be more precise.

In computing the amount of fuel consumed, it is assumed that a car consumes on average 8 l of petrol per 100 km, diesel fuel – 6 $\text{l}\cdot(100\ \text{km})^{-1}$, and liquefied gas – 10 $\text{l}\cdot(100\ \text{km})^{-1}$. It is assumed that the average annual kilometrage of a car is 20000 km.

For lorries and buses, the average consumption of fuel is 32 $\text{l}\cdot(100\ \text{km})^{-1}$ (buses with petrol engines – 40 $\text{l}\cdot(100\ \text{km})^{-1}$) and the average annual kilometrage is 100000 km (lorries with petrol engines – 20000 km).

For motorbikes and quadrocycles, the average consumption of fuel is 5 $\text{l}\cdot(100\ \text{km})^{-1}$ (2.5 $\text{l}\cdot(100\ \text{km})^{-1}$ for mopeds) and the average annual kilometrage is 10000 km (5000 km for mopeds). The computation includes only automobiles that have passed their technical checkup. The annual amount of fuel consumed for a particular type of motor vehicles is computed according to formula:

$$Q_g = \frac{L_g Q_{100km}}{100}, \tag{1}$$

where L_g – annual kilometrage of a vehicle, $\text{km}\cdot\text{year}^{-1}$;
Q_{100km} – consumption of fuel of a vehicle per 100 kilometres of travel, $\text{l}\cdot\text{km}^{-1}$.

The expenses on fuel are computed according to formula:

$$I_D = \frac{C_{D-1l} \times L \times Q_{100km}}{100}, \tag{2}$$

where $C_{D\text{-}1l}$ – expenses on purchasing 1 litre of fuel, LVL;
L – total kilometrage of vehicles during the period of exploitation, km.

The data of Table 1 were used for the computation. The computation result is presented in Table 2.

According to Table 2, one can conclude that almost 2.2 thousand millions LVL are spent on fossil fuels a year. By introducing electric vehicles, these costs could be reduced, and fossil energy resources could be replaced with renewable energy sources owing to using, for instance, solar, wind, or hydro energies in generating electricity.

Table 2

Average amount of fuel consumed by various types of motor vehicles a year

Type of motor vehicles	**Petrol consumption, m^3**	**Petrol expenses, thsnd. LVL**	**Diesel fuel consumption, m^3**	**Diesel fuel expenses, thsnd. LVL**	**Liquefied gas consumption, m^3**	**Liquefied gas expenses, thsnd. LVL**	**Fuel expenses in total, thsnd. LVL**
Cars	521168.3	469051.4	204192.9	183773.6	39613.9	17826.2	670651.3
Lorries	34716.1	31244.5	1542660.1	1388394.1	8022.5	3610.1	1423248.7
Motorbikes, quadrocycles and mopeds	7116.5	6404.9	-	-	-	-	6404.9
Buses	3069.1	2762.2	130179.6	117161.7	506.2	227.8	120151.6
Total	-	509462.9	-	1689329.4	-	21664.2	2220456.4

Algorithm for computing the economic effect

An algorithm was developed to determine the economic effect. This algorithm can be used for any types of motor vehicles. The main types of vehicles with electric drive are cars, motorbikes and quadrocycles, as well as various low-speed four-wheel and two-wheel electric vehicles, for instance, low-speed tourist bicycles and mopeds.

Only the costs that can change depending on whether these vehicles have an internal combustion engine or electric drive were taken into account in the computation. The total expense on exploiting vehicles from the moment of their purchase is computed according to formula:

$$I = I_{ieg} + I_{TA} + I_{TR} + I_D + I_C , \tag{3}$$

where I_{ieg} – purchase cost of vehicles, LVL;
I_{TA} – maintenance cost of vehicles, LVL;
I_{TR} – repair cost of vehicles, LVL;
I_D – fuel cost of vehicles, LVL;
I_C – cost of vehicles participating in traffic that includes technical checkup cost, taxes, and other payments, LVL.

Instead of the fuel cost for electric vehicles, the cost of electricity used for charging an electric vehicle has to be included in the computation. Due to the specifics of exploiting electric vehicles, which is based on limited availability of the related infrastructure in Latvia, electric vehicles are mostly intended to be exploited in urban areas, for instance, to go to work. In this case, a daily distance of travel will not usually exceed 50-60 km. Therefore, it is preferable to use relative indicators, for instance, per 100 km of travel for an economic comparison of electric vehicles and internal combustion engine vehicles. The costs per 100 kilometres of driving are computed according to formula:

$$I_{100km} = \left(I_{ieg} + I_{TA} + I_{TR} + I_D + I_C\right)\frac{100}{L}, \tag{4}$$

where L – total travel distance of vehicles during their exploitation, km.

The purchase costs are computed according to formula:

$$I_{ieg} = I_{sp} + I_{reg}, \tag{5}$$

where I_{sp} – vehicle purchase cost, LVL;
I_{reg} – vehicle registration cost, LVL.

The maintenance costs are computed according to formula:

$$I_{TA} = I_{TA-RD} + I_{TA-J}, \tag{6}$$

where $I_{TA\text{-}RD}$ – cost of spare parts used in maintenance of vehicles, LVL;
$I_{TA\text{-}J}$ – labour cost for maintenance of vehicles, LVL.

The repair costs are computed according to formula:

$$I_{TR} = I_{TR-RD} + I_{TR-J}, \tag{7}$$

where I_{RD} – cost of spare parts used in repair of vehicles, LVL;
$I_{TR\text{-}J}$ – labour cost for repair of vehicles, LVL.

All types of vehicles do not incur the cost of taking part in traffic, for instance, electric bicycles and electric mopeds are not required to pass technical checkups. The owners of vehicles incurring such cost have to pay it once a year. Therefore, this cost is related to the duration of vehicle exploitation:

$$I_C = T \times C_C, \tag{8}$$

where T – total duration of vehicle exploitation, years;
C_C – costs of technical checkups, road tax, and other annual payments.

By integrating Formulas 2 and 5-8 in Formula 4, the cost per 100 km is obtained as follows:

$$I_{100km} = \frac{\left(I_{sp} + I_{re\acute{g}} + I_{TA-RD} + I_{TA-J} + I_{TR-RD} + I_{TR-J} + T \times C_C\right)100 + C_{D-1l} \times L \times Q_{100km}}{L} \quad (9)$$

Results and discussion

Economic effect for various types of vehicles

The economic effect will be computed for 9 compact class cars that might have a 1.2-1.4 l Otto engine or a 1.4-1.5 l diesel engine, for instance, Renault Clio:

- new standard automobile with an internal combustion Otto engine (*N-Otto*);
- new standard automobile with an internal combustion diesel engine (*N-Diz*);
- new standard automobile with an internal combustion compressed gas engine (*N-LPG*);
- 5 year old standard automobile with an internal combustion Otto engine (*5Y-Otto*);
- 5 year old standard automobile with an internal combustion diesel engine (*5Y-Diz*);
- 5 year old standard automobile with an internal combustion compressed gas engine (*5Y-LPG*);
- 5 year old standard automobile converted to an electric automobile individually (*5Y-ConvInd*);
- new serial electric automobile (*N-Electro*);
- 5 year old automobile converted to an electric automobile industrially (*5Y-Electro*).

The computation was done by applying Formula 9 and using Latvian statistical and other informative materials [4; 5]. An Excel table was used, in which not only the relative data (cost per 100 km of driving), but also the total costs were summarised and computed. The computation result is shown in Table 3.

Several assumptions were made for the computation in Table 3, the result of which will be analysed. If an automobile is converted by oneself, it is not purchased and its internal combustion engine is replaced with an electric engine. Instead of lithium-ion batteries, another type of batteries (cost less than 3000 LVL) are installed both on an automobile converted by oneself and on a 5 year old automobile converted to an electric automobile at a factory. Batteries are replaced after 100000 km of driving. It is assumed that batteries are rented from their producer for a new electric automobile. Such an activity will not be possible in Latvia in the nearest years, as it requires large government subsidies. In case of the automobile converted by oneself, its conversion registration cost, too, is included in the registration cost [6]. The labour cost for maintenance and repair is assumed to be 15 LVL·h^{-1}. Repairs do not include automobile body repairs. The cost of replacement of batteries for electric automobiles (except a new electric automobile) are included in the cost of repairs, but the cost of engine repair significantly decreases owing to the simple design of electric engine and a small number of its units. It is assumed that the cost of technical checkups for an electric automobile is the same as for an analogous Otto engine automobile. It is also assumed that the road tax for an electric automobile is paid only for its mass, but not for its engine capacity. An accumulated distance of travel over the lifetime of a vehicle for a new electric automobile is assumed to be 300000 km, but for a used automobile – 150000 km. The cost of electricity consumed per 100 km of travel for a new automobile is assumed to be 1.40 LVL and 1.50 LVL for used automobiles owing to the effectiveness of batteries.

Table 3

Main automobile costs per 100 km of driving

Type of motor vehicles	**Purchase cost, LVL**	**Purchase cost, LVL·(100 km)$^{-1}$**	**Registration cost LVL·(100 km)$^{-1}$**	**TA+TR cost LVL·(100 km)$^{-1}$**	**Technical checkup and taxes LVL·(100 km)$^{-1}$**	**Fuel (electricity) cost, LVL·(100 km)$^{-1}$**	**Daily distance of driving, km**	**Total cost, LVL·(100 km)$^{-1}$**
N-Otto	8300	2.77	0.01	0.42	0.18	6.84	82.2	10.22
N-Diz	9600	3.20	0.01	0.53	0.19	4.77	82.2	8.70
N-LPG	8800	2.93	0.01	0.43	0.19	3.60	82.2	7.16
5Y-Otto	3000	2.00	0.02	0.61	0.18	6.84	82.2	9.65
5Y-Diz	4500	3.00	0.02	0.72	0.19	4.77	82.2	8.70
5Y-LPG	3500	2.33	0.02	0.62	0.19	3.60	82.2	6.76
5Y-ConvInd	5000	3.33	0.11	3.13	0.32	1.50	27.4	8.39
N-Electro	20000	6.67	0.01	0.15	0.32	1.40	27.4	8.55
5Y-Electro	7000	4.67	0.02	3.15	0.32	1.50	27.4	9.66

To demonstratively show a comparison of costs, the relative costs, measured in LVL·(100 km)$^{-1}$, were computed (see Table 3). The relative costs are summarised and shown in Fig. 1.

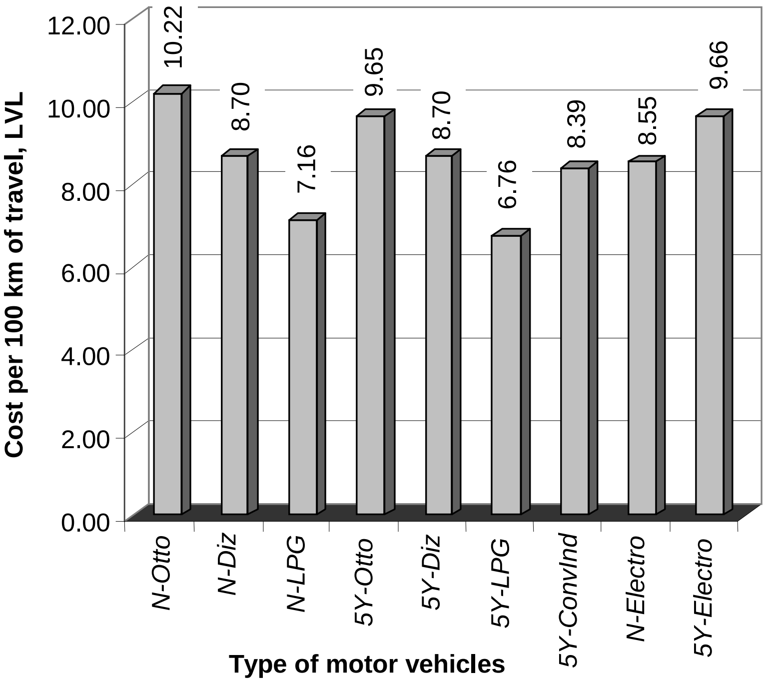

Fig. 1. **Total relative costs for various types of motor vehicles, LVL·(100 km)$^{-1}$**

Owing to the relatively low price of liquefied gas, the most efficient is an automobile of such type, besides, the lowest cost or 6.76 LVL is obtained for such used automobile. Among electric automobiles, the highest efficiency or the lowest cost is obtained for an automobile converted by oneself. In general, the cost of replacement of batteries increases the costs for all electric automobiles.

If lithium-ion batteries are replaced after 100000 km of driving for a new automobile, its efficiency is very low and reaches 20.50 LVL·(100 km)$^{-1}$, which is twice as much as for internal combustion engine automobiles. The cost of a used electric automobile is relatively high due to its shortage in the automobile market, and the prices of 5 year old automobiles usually range within 7000-8000 LVL [6].

The analysis shows that automobiles converted by oneself are the most prospective among the analysed electric motor vehicles. The owner of such an automobile can individually select the specific parameters for power, travel, and batteries that are directly related to the use of automobiles. For instance, if a daily travel by such an automobile is 30-40 km, one can choose cheaper and lower capacity batteries designed for a travel of only 50 km. In this case, no special infrastructure is required, as batteries can be charged at home.

Conclusions

1. By introducing electric motor vehicles in Latvia, fossil energy resources can be saved, and electricity can be domestically produced without consuming oil products.
2. The largest consumer of fossil fuels in Latvia is lorries, more than 1.4 thousand millions LVL are spent on fuel annually for the fleet of lorries, however, the introduction of electric motor vehicles in lorry transport is problematic due to the present technologies.
3. The algorithm for computing the economic effect includes all automobile exploitation costs per 100 km of travel. The algorithm was approbated by using the data on compact class automobiles and recognised as functional in comparing costs of various types of motor vehicles in an independent way.
4. Of automobiles using fossil fuels, the lowest cost or 6.76 $\text{LVL}\cdot(100\ \text{km})^{-1}$ was obtained for a 5 year old automobile running on compressed gas owing to its low purchase and fuel costs.
5. Among electric motor vehicles, the highest efficiency or 8.39 $\text{LVL}\cdot(100\ \text{km})^{-1}$ was obtained for a 5 year old automobile that is converted to electric power. Purchasing a used electric automobile is relatively expensive due to its high price exceeding 7000 LVL.
6. An economic effect of 8.55 LVL for a new electric automobile is possible only in case if its batteries are rented and there is no need to replace them during repair, however, such a service will not be available in Latvia over the next years due to a need for large government subsidies.
7. Electric automobiles in cities and urban areas can compete with fossil energy automobiles, especially in cases when they are designed to ensure certain parameters of exploitation.

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ECOLOGICAL EFFECT OF ELECTRIC VEHICLES

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Abstract. New solutions to the use of various alternative energies are searched for in the sector of transport owing to the fast increase in the consumption of energy resources. One of such alternative energies is electric energy used in electric vehicles. The use of electric vehicles is not only economically beneficial, but it also ensures fewer emissions as well as localises these emissions outside the exploitation site of these vehicles (outside cities). Electric vehicles produce less CO_2, CH, NO_x, and CO emissions, and in some conceptions the amount of emissions is even considered to be 0. The present paper analyses the potential effect of the increase in the proportion of electric vehicles on the ecology of Latvia.

Keywords: automobiles, electric vehicles, exhaust gases, toxic components, and calculation algorithm.

Introduction

The overall ecological situation in Latvia, compared with other European countries, is not very problematic. Yet, it is often related not to the introduction of the newest technologies protecting the environment, but to the poorly developed industry. One of the fields affecting the ecology is transport. Transport mainly consumes imported energy resources.

It is presently stipulated in Latvian legislation that conventional fuel is mixed with up to 5 % biofuel – petrol with bioethanol and diesel fuel with biodiesel fuel. Thus, the requirements of the EU directive regarding the use of 5 % biofuel in the transport sector are complied with.

When exploiting electric vehicles, it is possible to use domestic energy sources – electric energy produced in Latvia. Besides, 70 % of this energy in Latvia is generated from renewable energy sources, for instance, at hydropower plants. The remaining 30 % of electric energy is produced at thermal power plants [1]. Based on these principles, 100 % of the energy consumed by electric vehicles would be generated in Latvia, as well as this energy could be produced from renewable sources.

The main kinds of production of renewable electric energy in Latvia are as follows:

- hydropower (up to 71 % of the electric energy produced in the country in 2011);
- wind energy;
- electric energy generated from biogas.

The production of electric energy from biogas has developed fast over the recent years. If having a special contract with the JSC Latvenergo, it is possible to charge electric vehicles with electricity produced particularly from renewable sources, i.e., a producer of renewable energy is paid for it. Thus, consumers may be convinced that they receive electricity from renewable sources.

To reduce emissions from vehicles, electric drive has to be installed in vehicles in which the combustion engine may be replaced with an electric motor. Vehicles having no motor, but in which an electric motor is installed, for instance, bicycles have no positive effect on the ecology. From the viewpoint of environmental protection, a positive effect is obtained if a consumer, when purchasing a new vehicle, buys an electric bicycle or an electric moped instead of an internal combustion moped.

The research aim is to design an algorithm, based on the standards for vehicle emissions and the number of vehicles in Latvia, for identifying the type of vehicles, the exploitation of which as electric drive vehicles is useful from the ecological viewpoint.

1. Distribution of vehicles by type in Latvia

Various types of vehicles are exploited in Latvia. Electric drive is mainly used in vehicles with a gross weight of 3.5 t or less, yet an analysis will be performed for also the vehicle group with a gross weight from 3.5 to 12 t, as the exploitation of such vehicles with electric drive might become possible in the future due to the progress in technology. According to the CSDD (Road Traffic Safety Directorate) data [2] as of 1 January 2013, the distribution of vehicles by type is presented in Table 1.

According to Table 1, mainly electric drive cars are among vehicles with electric drive, yet there are also electric drive lorries, motorbikes, and mopeds. Electric bicycles with a motor capacity of more than 250 W have to be considered mopeds as well. Auto manufacturers have already designed hybrid lorries, for instance, Volvo FE Hybrid. As of 1 January 2013, 12 electric automobiles were registered in Latvia. Table 1 also summarises the average annual kilometrage for each type of vehicles.

According to Table 1, the number of vehicles significantly decreased in 2011, whereas the next year a slight increase was observed. The significant decrease in the number of vehicles may be explained by the fact that they were massively written off in 2010, as a vehicle use tax was introduced for all automobiles regardless of their use as well as the rules for writing off vehicles were simplified.

Table 1

Changes in the number of vehicles registered in Latvia that may be exploited as vehicles with electric drive

No	Type of vehicle	Number as of 1 January 2010	Number as of 1 January 2011	Number as of 1 January 2012	Number as of 1 January 2013	Kilometrage a year, km
1.	Lorries with a gross weight from 3.5 to 12 t	28407	11432	10549	9996	40000
2.	Lorries with a gross weight of 3.5 t or less	51681	37827	38955	42341	40000
3.	Cars with a diesel engine	227282	210075	221085	244410	20000
	Cars with a petrol engine	676984	426586	391229	378906	
4.	Busses with a gross weight of 3.5 t or less	2646	962	807	704	40000
5.	Motorbikes and tricycles	33590	17188	17385	17879	5000
6.	Mopeds	18373	19486	21238	23209	2000
7.	Quadrocycles	1477	1137	1142	1095	2000

Further analysis will be performed in relation to the number of vehicles in 2013, based on an assumption that by 2020 in Latvia, 10 % of vehicles will have electric drive, while the expected number of automobiles and their percentage distribution will not significantly change.

2. An algorithm for assessing the ecological effect of electric vehicles

Based on the present electric energy accumulation technologies, it is difficult to imagine that an electric automobile might be the only vehicle in the family. There are various infrastructural solutions – fast charging when a battery is charged up to 80 % of its capacity within 30 minutes as well as battery change stations where a robot changes the battery within a few minutes. Yet, in order that these expensive infrastructure systems can function at full capacity, such systems have to be available in all countries where electric automobiles are exploited. It means that if such systems are introduced in Europe, it is possible to travel across the entire Europe and fast charge the automobile or change its battery when necessary. Unfortunately, such an infrastructure presently is not available, and the introduction of such a global system is not expected over the nearest future. Therefore, one has to conclude that the exploitation of an electric automobile is useful mainly in towns and cities where the average daily kilometrage does not exceed 120-150 km. In the case if the kilometrage is greater, it is advised to use an internal combustion engine automobile.

Over the nearest future, no mass transition to electric automobiles may take place in Latvia owing to several factors:

- users of vehicles are not ready to limit themselves to small kilometrage or impose self-control by choosing the right mode of vehicle driving in order to achieve greater kilometrage;
- relatively little information is available on electric vehicles, no reliable information on the lifespan of electric vehicle batteries as well as their exploitation specifics;
- users of vehicles are not morally prepared for exploiting electric vehicles without a network of charging stations. Efficient charging of electric vehicles, if no charging infrastructure exists, is not possible only at private homes. Separate charging stations have to be established for electric automobiles at public overnight parking lots, which requires additional electric capacity, and the owners of the parking lots might not be ready for it;
- supply of electric vehicles is still limited in Latvia, especially in the case if the supply of some brand is associated with additional requirements, for instance, battery rent;
- prices of electric vehicles, compared with analogical internal combustion engine vehicles, are very high, which deters potential buyers. The potential buyers are doubtful about how economical an electric vehicle is, as a primary investment in an internal combustion engine vehicle is smaller, whereas the exploitation opportunities of such a vehicle are greater.

Based on the previous analysis, one can conclude that, at best, we can hope that the share of electric vehicles might reach 10 %, assuming that it will take place by 2020.

The main gains if introducing electric transport:

- if electricity is produced in Latvia, for instance, at hydro power plants, domestic energy sources are exploited to power electric vehicles, besides, these sources are renewable;
- even in the case if electricity is produced from non-renewable sources, for instance, coal, electric vehicles ensure that pollution is localised at the site of electricity generation (at a thermal power plant);
- electric vehicles produce no gas emissions;
- structure and maintenance of electric drive vehicles are simpler, the motor has fewer wear parts;
- electric vehicles are not noisy, electric vehicles may be exploited in zones where noise is not recommended;

- electric vehicles need no fuel that causes a bad smell as well as the amount of such materials as oil is less consumed compared with internal combustion engine vehicles;
- net efficiency of the motor of electric vehicles is higher, power and torque curves are more effective and appropriate for vehicle driving;
- owing to the limited kilometrage, the driver of an electric vehicle sometimes has to choose a steadier mode of driving, thus saving resources.

When calculating the ecological effect, it has to be taken into consideration that two types of engines – Otto engines and diesel engines – are mainly used in the analysed vehicle groups.

There are different emission standards for each of these vehicle groups, and it has to be taken into account in calculations. The general algorithm for calculating the emission amounts for the entire car fleet of Latvia has already been analysed in other research papers published by the authors of the present paper [3].

To identify the vehicle group, the introduction of electric drive in which is the most beneficial, calculations are performed for each vehicle group according to Table 1. The calculations are focused on the forecast for 2020. Owing to the fact that automobiles with an average age of 10-12 years had been exploited in Latvia over the recent 10 years, it is assumed that a similar trend will continue in the period of analysis. For this reason, the emission standard being effective for the period 2008-2010 is used for comparisons of internal combustion engine automobiles. The emission standard Euro 5 was in force in this period. Yet, the factor of depreciation for automobiles the kilometrage of which exceeds 80000 km has to be taken into account. The values of the emission standard Euro 5 and the factor of depreciation [4-6] are summarised in Table 2.

Annual amounts of emission components for internal combustion engine vehicles are calculated by the following formula:

$$\sum I_G = \frac{A_v l_g M_{km}}{10^6}, \text{ t}\cdot\text{year}^{-1}, \tag{1}$$

where A_v – number of internal combustion engine automobiles in the corresponding vehicle group;

l_g – annual kilometrage of automobiles in the corresponding vehicle group, km;

M_{km} – amount of the n-th component of automobile exhaust gases in accordance with the standard Euro 5, $\text{g}\cdot\text{km}^{-1}$.

Table 2

Emission standards (g·km^{-1}) and their corrections used for calculations

No	Vehicle characteristics		Components of exhaust gases					
	Type of vehicle	**Fuel**	**CO**	**CH+NO$_x$**	**Weight of all hydrocarbons THC**	**Weight of hydro-carbons, except methane, NMHC**	**NO$_x$**	**Solid particles PM**
1.	Lorries with a gross weight of 3.5-12 t	D	1.5	-	0.46	-	2.0	0.02
2.	Lorries with a gross weight of 3.5 t or less	D	0.74	0.35	-	-	0.28	0.005
3.	Cars	P	1.0	-	0.10	0.068	0.060	0.005*
		D	0.50	0.230	-	-	0.18	0.005
4.	Motorbikes and tricycles	P	0.114	-	0.017	-	0.009	-
5.	Mopeds	P	0.1	-	0.063	-	0.017	-
6.	Quadrocycles	P	0.19	-	0.073	-	0.017	-
7.	Depreciation rate	P	1.3	-	1.3	1.3	1.3	-
		D	1.3	-	1.1	1.1	1.1	1.0

* *Direct injection engines*

According to the formula (1), the amount of emissions may be calculated only for vehicles, the test of which can be performed on a roller power test bench in accordance with the standard Euro 5 [4]. Tests of lorries with a gross weight of 3.5 t or more are performed on a stationary engine test bench, and, in accordance with the standard, the unit of measure is g·(kWh)$^{-1}$. The amount of a component of gas emissions for these vehicles may be calculated by the following formula:

$$\sum I_G' = \frac{A_k l_g M_{kWh-km}}{10^6}, \text{ t·year}^{-1}, \qquad (2)$$

where A_k – number of internal combustion engine automobiles in the corresponding vehicle group;

l_g – annual kilometrage of automobiles in the corresponding vehicle group, km;

$M_{kWh\text{-}km}$ – amount of the n-th component of automobile exhaust gases in accordance with the standard Euro 5 for automobiles tested on an engine test bench, converted into g·km^{-1}.

To calculate the amount of exhaust gases emitted per 1 km for automobiles to which the emission standard, g·(kWh)$^{-1}$, is applied, the following formula is used:

$$M_{kWh-km} = \frac{N_{e.avg} t_k}{s} m_{kWh}, \text{ g·km}^{-1}, \tag{3}$$

where $N_{e.avg}$ – average vehicle engine power in the calculated road section, kW;

t_k – vehicle movement period in the measured road section, h;

s – length of the road section, km;

m_{kWh} – amount of the n-th component of automobile exhaust gases in accordance with the standard Euro 5, g·(kWh)$^{-1}$.

By inserting Formula 3 in Formula 2 and given the fact that velocity may be expressed by the formula $v = s \cdot t^{-1}$, the following formula is obtained:

$$\sum I_G' = \frac{A_k l_g N_{e.vid} m_{kWh}}{10^6 v}, \text{ t·year}^{-1}. \tag{4}$$

Results and discussion

The calculations are focused only on the toxic components of exhaust gases. The analysis of CO_2 emissions, which directly relate to fuel consumption, requires a separate and profound examination.

Formulas 1 and 4 are used for the calculations. The calculations are based on the emission standards and depreciation rates from Table 2, and it is assumed that that electric vehicles will account for 10 % of the total number of vehicles in Latvia, their average annual kilometrage is assumed according to Table 1, the average capacity of lorries with a gross weight of 3.5 t or more while moving is 70 kW, and the average speed is 50 km·h^{-1}. The calculation results on emissions are summarised in Table 3.

Data on the exhaust gas components CO and NO_x are summarised in Fig. 1. These components are set as standards for all the analysed vehicles.

As Fig. 1 shows, the greatest part of CO pollution in Latvia arises from cars. The annual CO emissions produced by cars with a petrol or diesel engine amount to 1289.73 t, which is almost two times more than from lorries. Due to the wide use of diesel engine lorries in the automobile sector, the total annual NO_x emissions from these automobiles are 14.3 % greater than those from cars.

The total emissions produced by such vehicle categories as busses, motorbikes, mopeds, and quadrocycles in Latvia are minimal due to the small number of such vehicles.

Table 3

Calculation results for the toxic components of exhaust gases for 10 % of Latvian automobile fleet

No	Type of vehicle	CO	CH+NO$_x$	THC	NMHC	NO$_x$	PM
1.	Lorries with a gross weight of 3.5-12 t	109.16	-	28.32	-	123.15	1.12
2.	Lorries with a gross weight of 3.5 t or less	162.93	59.28	-	-	52.16	0.85
3.	Cars, petrol	972.00	-	97.20	66.10	58.32	3.74
4.	Cars, diesel	317.73	112.43	-	-	96.79	2.44
5.	Busses with a gross weight of 3.5 t or less	2.08	0.99	-	-	0.79	0.01
6.	Motorbikes and tricycles	1.02	-	0.15	-	0.08	-
7.	Mopeds	0.46	-	0.29	-	0.08	-
8.	Quadrocycles	0.04	-	0.02	-	0.004	-

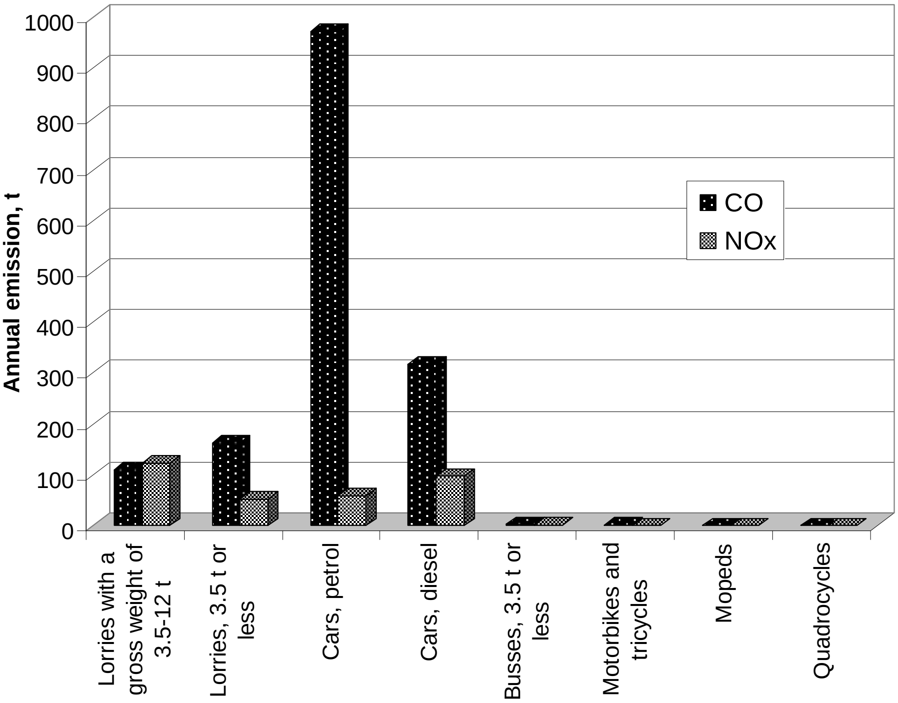

Fig. 1. **Annual CO and NO$_x$ emissions from 10 % of the vehicle fleet of Latvia**

The emission standards for other exhaust gas components (CH, NO$_x$ and PM) are not set mainly for motorbikes, mopeds, and quadrocycles, therefore, they are not presented graphically (Fig. 2).

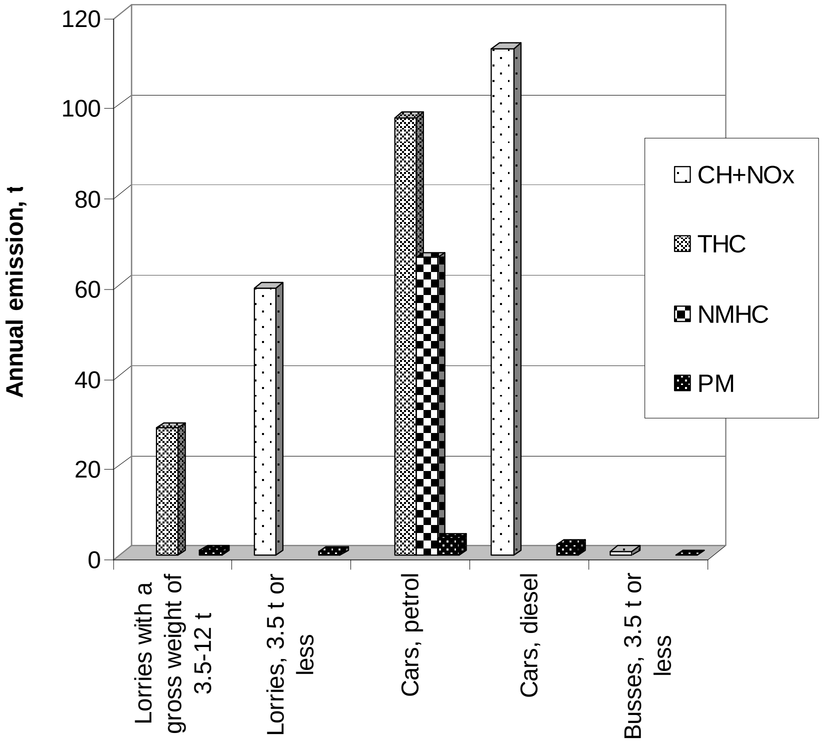

Fig. 2. **Annual CH, NO_x and PM emissions from 10 % of the vehicle fleet of Latvia**

The annual CH emissions from lorries are 3.2 times greater than those from cars. The emissions of solid particles from cars are 3.1 times greater than those from lorries.

According to the calculation results, the largest pollution in the emission balance of Latvia arises from cars. As regards all the components of emissions from cars, they exceed emissions from other vehicles by even several times. Only NO_x emissions from lorries are slightly greater. Based on these calculations, one can conclude that from the viewpoint of environmental protection in Latvia, it is particularly beneficial to use electric drive cars. If 10 % of the conventional cars were replaced with electric drive cars in Latvia, it would be possible to decrease CO emissions by 1289.73 t, CH+NO_x emissions by 112.43 t, total hydrocarbon emissions by 97.20 t, NO_x emissions by 115.11 t, and PM emissions by 6.18 tons a year. It has to be noted that another positive aspect is that a low noise level is specific to electric vehicles, which reduces the overall noise level; it is especially important in cities.

The use of electric drive in motorbikes, mopeds, and quadrocycles is beneficial; yet, their effect on total emissions is insignificant, especially if compared with the emissions produced by lorries and cars.

Conclusions

1. At the beginning of 2013 in Latvia, the number of registered cars is almost 12 times greater than that of the lorries with a gross weight of less than 12 t.
2. The calculation method of automobile exhaust gas components was approbated and recognised as useful both for assessing the effect of certain vehicle groups and for comparative analyses of toxic emissions from various vehicles depending on their kilometrage.
3. The total CO emissions from cars – 1289.73 t per year – are 4.74 times greater than those from lorries.
4. Regardless of the wide use of diesel engine lorries and their large engine capacities, NO_x emissions from these automobiles are only 13 % greater than those from cars.
5. If 10 % of conventional cars were replaced with electric drive cars in Latvia, the following ecological effects in relation to emission reductions would be achieved: 1289.73 t of CO, 112.43 t of $CH+NO_x$, 97.20 t of C_nH_m, 155.11 t of NO_x, and 6.18 t of PM a year.
6. The use of electric drive in motorbikes, mopeds, and quadrocycles can reduce noise in cities, yet, their ecological effects are small in Latvia due to the small number and the small annual kilometrage of such vehicles.
7. The calculation algorithm approbated in the present research may be employed for calculations of CO_2 emissions and other exhaust gas components.

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RESEARCH IN ELECTRO AND INTERNAL COMBUSTION ENGINE MOTOR VEHICLE ENERGY COSTS

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Abstract. At the beginning of automobile development electromobiles successfully competed with internal combustion engine motor vehicles. But with the development of internal combustion engine constructions automobiles were widely used outside cities and electromobile mileage without charging turned out not to be competitive. The beginning of the 21st century can be considered as rebirth of wider application of electromobiles when hybrid automobiles were started to be used and also modern electromobiles and other electric vehicles were constructed. One of the most essential advantages of electric vehicles is low application costs. The most important part of the application costs is fuel costs for internal combustion engine vehicles or charging costs of electric vehicles. The article presents the methods of determination of electric bicycle, slow pace purchasing electromobile, slow pace electromobile and electromobile charging parameters and the analysis of the costs as well as a comparison with analogical internal combustion motor vehicles.

Keywords: electromobile, electric bicycle, slow pace electromobile, costs, charging.

Introduction

A new stage of electric transport development has started with the beginning of the 21st century. The first modern electric automobiles were hybrid automobiles the pioneer of which production being the Japanese auto producer *Toyota*. Also other producers started to develop electromobiles. Several modern technology constructions without internal combustion engines only with electro motors and accumulator batteries were elaborated. Charging of these automobiles is planned from domestic electric nets.

The cheapest charging of electric transport is in home conditions. For promotion of the development of electric transport in several charging places in Latvia charging is free. Nevertheless, such charging is oriented to either a short charging period, for instance, 0.5 h, or for electric transport for charging of which a large amount of electric energy is not necessary, for instance, electric bicycles.

Calculating the consumption of electric energy for electric vehicles per one kilometer mileage the trends can be different from the internal combustion motor vehicles. For instance, in cities electric transport can consume less energy for one kilometer mileage than in traffic outside cities.

Besides, sometimes the mileage of the same transport vehicles is very different from the traffic regime, especially from the speed of traffic. The covered mileage with one complete charging can differ even two times.

The longest mileage with one complete charging of electric vehicles can be achieved at the speed 50 – 70 % of the maximal. It is positive that for this reason using electric vehicles we should remember the fact that we need to get to the charging place. Due to this more considerate movement regime will be chosen that will ensure saving of the surrounding environment even more.

From the ecological point of view surely it is essential from what energy source the electric energy is obtained. There are calculations that in Latvia up to 70 % of electric energy is "green", obtained from renewable resources but other electric energy is obtained in thermoelectrostations working in the process of cogeneration [1]. Due to this, charging electric transport in Latvia, this transport is one of the most ecological in the EU. For this reason introduction of electric transport in Latvia is very essential from the point of view of environment protection.

Materials and methods

1. Analysis of electroenergy tariffs

Depending upon the country where the electromobile is applied the charging costs can be different; it depends on the electroenergy tariffs in the definite country. Besides, the electroenergy tariffs even in the EU countries can differ to a greater extent than the prices of internal combustion motor fuel. In Latvia the basic electroenergy tariff is 0.1074 $\mathrm{LVL \cdot kWh^{-1}}$ or 0.1528 $\mathrm{EUR \cdot kWh^{-1}}$. This tariff occupies the 12th place among the European Union countries and is higher than in the neighbouring countries. In Estonia it is 0.1141 $\mathrm{EUR \cdot kWh^{-1}}$ and in Lithuania – 0.1309 $\mathrm{EUR \cdot kWh^{-1}}$.

If electric transport is intensively applied, especially in case if it is high power, at least with 2 – 3 kW motor, it can be envisaged that the tariff will be exhausted already after 3 – 4 months as for charging of electric transport 5 – 20 kWh of electroenergy will be used per day. These costs depend on the intensity of electric vehicle application. Due to this, using electromobiles in Latvia it would be better to transfer to T3 tariff that envisages subscription cost for this tariff 41.66 EUR per year and the costs for the amount of the protection apparatus current is 1.68 $\mathrm{LVL \cdot A^{-1}}$ per year. The T3 tariff provides for 0.0993 $\mathrm{EUR \cdot kWh^{-1}}$ electroenergy start tariff on week days from 23.00 to 7.00, but the basic tariff 0.1193 $\mathrm{EUR \cdot kWh^{-1}}$, but during day time from 7.00 to 23.00 the tariff correspondingly is 0.1220 $\mathrm{EUR \cdot kWh^{-1}}$, but the basic tariff 0.1572 $\mathrm{EUR \cdot kWh^{-1}}$ [2]. More precise calculation and the possible efficiency of choosing the tariff for different groups of motor vehicles will be analysed below.

Considering that in Germany the costs of 1 kWh do not exceed 0.25 EUR·kWh^{-1}, but in Norway and Denmark approach 0.30 EUR·kWh^{-1}, the electromobile application costs increase in these countries.

The above analysed electroenergy costs are given charging at home. But, charging at charging places the electroenergy costs can be higher depending on what the owner of the charging place has determined. In Latvia on 16.02.2012 there are 9 charging places operating among which at six charging is free [3]. Free charging is meant for development of electrotransport application, but with the increase of the number of electric vehicles and with this also the increase of the demand for charging services it can be envisaged that it will be necessary to pay for charging.

The possibilities to charge electric vehicles at different charging places depending on the price of electric energy are summarized in Figure 1.

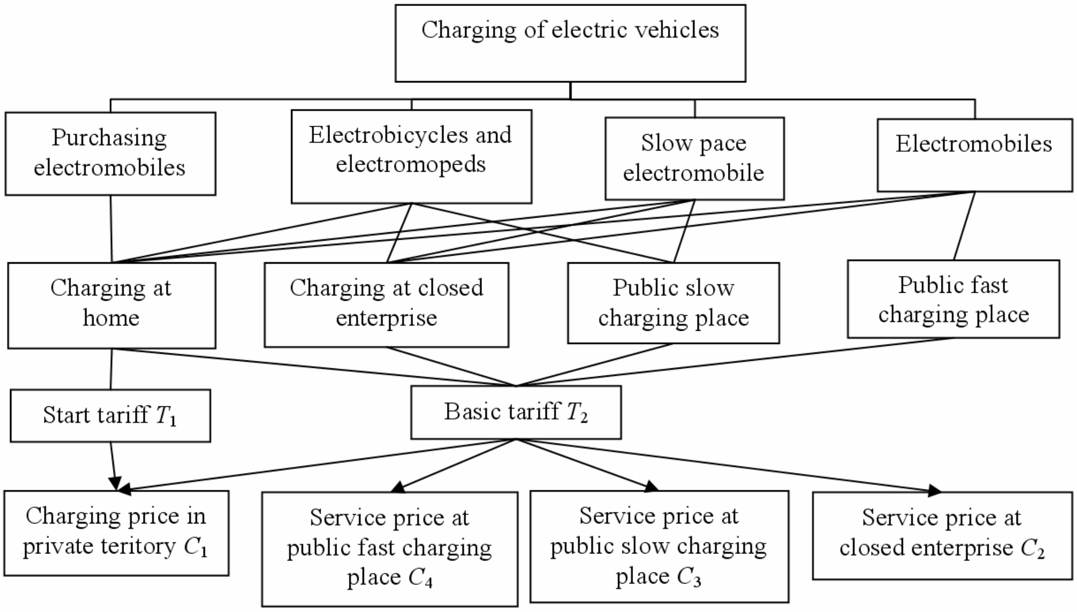

Fig. 1. **Formation of charging price**

Depending on the status of the charging place the charging price is formed. In any case the charging price will be higher that the electroenergy tariff, even at a private house. Usually in such cases it is assumed that the price C_1 (See Fig. 1) approaches the electroenergy tariff, nevertheless, in this price the costs of building of the charging place are included, especially in cases if the automobile is stored in open storing conditions and this charging place is to be built especially for an electromobile. In this case building of a simple charging place, including the electricity cable and charging box, does not exceed 40 – 60 EUR, including the work if installation is done by the owners themselves.

The price $C_2 \geq C_1$ as in private territories charging vehicles that do not belong to the enterprise will usually be of higher price than for the local users.

In public charging places this price can be even higher and the correlation $C_3 \geq C_2$ will be valid. In relation to the high costs of building of fast charging places the depreciation costs of these places should be included in the service price. Due to this, based on the above analysis the correlation will be valid:

$$C_1 \leq C_2 \leq C_3 \leq C_4 = T_x E + I_A + I_O + I_N + \frac{I_{LP}}{t}, \qquad (1)$$

where T_x – corresponding existing tariff – start or basic, LVL;
I_A – service costs, LVL;
I_O – servicing operator or system costs (system of settlements costs), LVL;
I_N – costs for taxes, LVL;
I_{LP} – charging place building costs, LVL;
t – charging places exploitation time or number of charging cycles till replacement of the charging place equipment;
E – amount of electric energy consumed for charging of electric vehicles, kWh.

Special cases are possible when the price can differ from the above analysis as it is determined also by the geographical position of the charging place, its exclusiveness, operator’s salary (presence of automatic or manual registration system).

2. Methods of calculation of electric vehicle charging costs and internal combustion motor vehicle fuel costs

The costs necessary for charging of electric vehicles depend on the charging place. In Latvia charging is for payment only in three charging places, besides, mainly bicycles are charged. According to provisional research 0.05 $\mathrm{LVL \cdot h^{-1}}$ are charged for charging of a bicycle.

The direct charging costs can be calculated according to the correlation:

$$I_u = T_N \times E + \frac{I_{LP}}{t}, \qquad (2)$$

where T_N – charging tariff at the corresponding charging place.

If electric energy is not recorded in the charging place but payment is done for hours of charging, the following correlation is valid:

$$I'_u = C_h t_L \,, \tag{3}$$

where C_h – charging price, LVL·h;
t_L – time consumed for charging, h.

In case if the charging current does not exceed 16 A. It is not necessary to build a special charging place in home conditions; then using the existing garage power point $I_{LP} = 0$.

Let us analyse the costs of electric energy or fuel per coverage of a definite distance. Electric vehicles consume W·km^{-1} electric energy, but for internal combustion motor vehicles the fuel consumption is l·km^{-1}. The internal combustion motor vehicle fuel costs can be calculated according to the correlation:

$$I_d = C_d \times Q \,, \tag{4}$$

where C_d – price of the corresponding fuel, LVL;
Q – consumed amount of fuel, l.

Relating the obtained correlations 2 – 3 to the covered mileage a correlation for energy (electric or fuel) costs per km is obtained. As most often in practice values per 100 km mileage are used, calculations for electromobile 100 km mileage costs, if registration of electric energy is applied, are performed according to the correlations:

$$I_{lE} = \frac{I_u \times 100}{l} = \frac{100 T_N \times E}{l} + \frac{100 I_{LP}}{t \times l} \,, \tag{5}$$

where l – mileage with the corresponding amount of energy, km.

Calculations for electromobile 100 km mileage costs, if the payment is per hours, is performed according to the correlations:

$$I'_{lE} = \frac{I'_u \times 100}{l} = \frac{100 C_h t_L}{l} \tag{6}$$

Using internal combustion motor vehicles the following correlation is obtained:

$$I_{lA} = \frac{I_d \times 100}{l} = \frac{100 C_d \times Q}{l} \tag{7}$$

If it is necessary to determine the energy costs per 1 km, in the correlations 5 – 7 the coefficient 100 is not used.

Results and discussion

In order to state the energy consumption for charging of electric vehicles experimental investigations with different motor vehicles have been performed.

In the experiments the electric vehicles are operated in the city or mixed movement regime until charging the battery by 90 – 95 %, determining the mileage with the GPS data logger. The experiments have been performed with five different electric bicycles. For driving the electric bicycles 180 W, 250 W and 500 W motors have been used. The average running speed 20 – 25 km·h^{-1} has been maintained depending upon the riding conditions. After the test the batteries are charged with the charging equipment provided for every electric vehicle. The charging equipment used in the tests switches off automatically ensuring the optimal battery charging time.

The driving and charging tests are performed similarly with the slow pace electric automobile *Melex 963 DS* and electromobile *Fiat Fiorino Elettrico HC-S* offered for the experiments by the stock company *Latvenergo*.

The experiments determining the consumption of internal combustion engine fuel are performed with electric moped *YY50QT* and internal combustion engine automobile *Renault Clio* with 1.2 l Otto motor. The moped is operated similarly as the electric bicycles maintaining the possible higher speed 50±5 km·h^{-1}. For the automobile *Renault Clio* the fuel consumption tests are performed on the roller stand *Mustang-1750* doing the *IM-240* driving cycle. The automobile *Renault Clio* has been chosen for the tests due to the reason that its internal combustion engine will be replaced by electric motor and in further research comparative energy consumption data will be necessary.

As there is not an automobile *Fiat Fiorino* with internal combustion engine at disposal of the research group, the data on fuel consumption of this automobile are taken from the technical data on the amount of fuel consumed in the European driving mixed cycle [4].

During charging for registration of the consumed electric energy the electric energy meters *ES-T9162* are used. The experiments are repeated five times. The parameters for electric vehicles stated in the experiments:

- electric vehicle mileage, km;
- electric energy consumed during charging, kWh;
- maximal charging capacity, W;
- charging time, h.

The parameters for internal combustion vehicles stated in the experiments:

- volume of consumed fuel, ml;
- mileage;
- output parameters – fuel consumption, l·100 km^{-1}.

The average values for different vehicle groups obtained in the experiments are summarised in Table 1. The table summarises the data from the experiments with electric vehicles as well as simultaneously performed experiments with internal combustion engine vehicles.

Table 1

Experimental data of charging

No.	Electric vehicle kind, brand	Mileage with full charging, km	Electric energy for charging, kWh	Consumed electric energy, Wh·km^{-1}	Consumed energy, Wh·100 km^{-1} or l·100 km^{-1}	Costs, EUR·km^{-1}	Costs, EUR·100km^{-1}	Maximal charging power, W	Charging time, h
1.	ER61	42.05	0.99	23.45	2344.94	0.0036	0.36	115.3	7.5
2.	Le Velec	18.86	0.38	20.28	2028.10	0.0031	0.31	90.5	7.5
3.	Easy Bike	15.50	0.36	23.23	2322.58	0.0035	0.35	85.0	8.0
4.	EMR750	24.78	0.53	21.47	2146.89	0.0033	0.33	63.8	7.4
5.	Giant	27.32	0.61	22.25	2225.48	0.0034	0.34	96.4	7.0
6.	MELEX 963DS	33.93	7.59	223.56	22356.48	0.0342	3.42	1855.8	7.8
7.	Fiat Fiorino Elettrico HC-S	96.18	20.55	213.68	21368.38	0.0327	3.27	2908.6	9.0
8.	Internal combustion moped YY50QT	–	–	–	2.57	0.0365	3.65	–	–
9.	Renault Clio 1.2 l	–	–	–	6.41	0.0910	9.10	–	–
10.	Fiat Fiorino Combi 1.4 l	–	–	–	6.90	0.0981	9.81	–	–

For transparency of the data graphical comparison of electric vehicle mileage, km and consumption of electric energy, Wh·km^{-1} has been presented in Fig. 2. According to the data in Fig. 2 the largest mileage is for the electric bicycle *ER61* – 42.05 km. Still, this mileage is not corresponding to the given in the technical specification and differs by 30 %. The mileage of other electric bicycles is in the range from 18 to 27 km and in total it corresponds to the bicycle specification data.

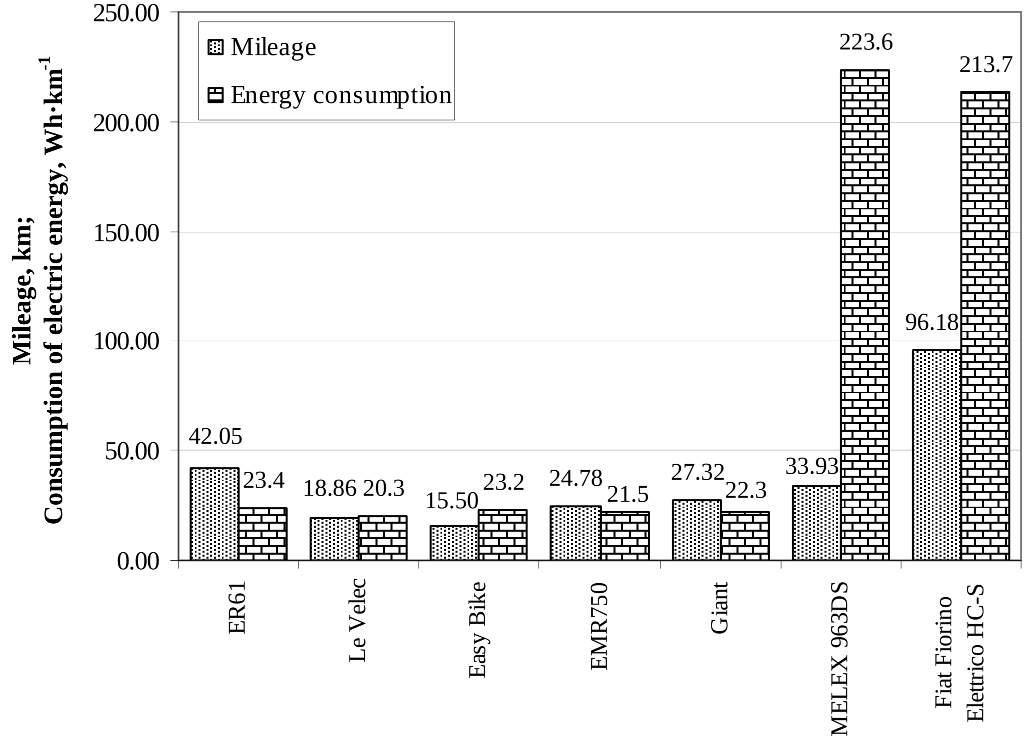

Fig. 2. **Mileage of electric vehicles and consumption of electric energy**

The electric energy consumption data differ essentially. The lowest electric energy consumption – 20.3 W·km^{-1} is for the electric bicycle *Le Velec*. This is the only electric bicycle for which the electric motor is activated afterwards when it is treadled. Due to this the movement cannot be started and the inertial mass cannot be overcome only by means of electric motor and the consumption of energy in the acceleration regime is minimal. This electric bicycle conception ensures the cheapest motorised movement possibility.

The largest energy consumption, 23.4 W·km^{-1}, is for the most powerful of the experimental electric bicycles (500 W motor) *ER61*.

The largest energy consumption, 223.6 W·km^{-1}, is for the automobile *Melex 963DS*. It could be explained by accumulator batteries the remaining resource of which could be about 40 % that does not ensure the average exploitation mileage – 50 km. For increasing the mileage it is necessary to operate the electric vehicle in the speed that does not exceed in the average 70 – 80 % of the maxim al movement speed.

According to the amount of energy consumed during charging and the mileage the energy costs are calculated for 100 km mileage (See Fig. 3). The lowest costs are for electric bicycles and they are in the range from 0.31 to 0.36 EUR per 100 km. The highest costs of electric vehicles are for electromobiles, but they in the experimental regimes do not exceed 3.50 EUR per 100 km. It is interesting that the internal combustion moped energy costs 3.65 EUR per 100 km are higher that the costs for the electromobiles *Melex* and *Fiat Fiorino*.

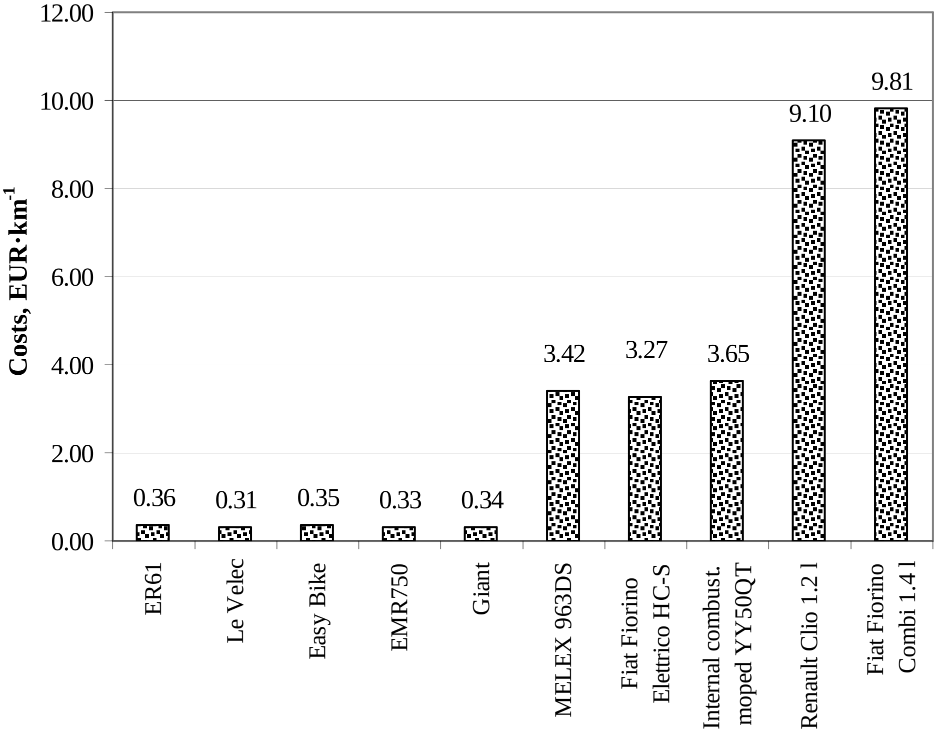

Fig. 3. **Motor vehicle energy costs**

The energy costs of the internal combustion motor automobile *Fiat Fiorino Combi* are exactly three times higher than the costs of the analogous prototype *Fiat Fiorino Ellectrico* – 9.81 EUR per 100 km.

This research has been performed based on the fuel and energy prices in Latvia in February, 2012. In other countries these costs and their relation can be different due to other energo resource prices.

Conclusions

1. The electric vehicle electric energy costs depend on the kind of the charging place and the price for electric energy at it. The cheapest charging is at home conditions.
2. From the point of view of energy costs the cheapest are electric bicycles without exceeding 0.36 EUR per 100 km.
3. Using bicycles with electric motor activisation at definite speed of pedalling the lowest energy costs can be obtained for 100 km mileage –

0.31 EUR, that can be explained by overcoming of inertia resistance starting movement using the power of muscles and relieving the electric motor.

4. The costs of the internal combustion motor automobile *Fiat Fiorino Combi* are three times higher than of the analogous internal combustion motor automobile *Fiat Fiorino Ellectrico* – 9.81 EUR per 100 km.
5. The energy costs depend on the tariffs in the country and fuel prices and they can essentially differ from the research results in Latvia.

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AUTOMOBILE TECHNICAL SOLUTIONS AND SELECTION OF PARAMETERS FOR REBUILDING INTO ELECTROMOBILE

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Abstract. Developing an electromobile or rebuilding it from an automobile with an internal combustion motor selection of its unit technical parameters is very important. The article analyses the possibilities for rebuilding electromobiles, a calculation algorithm has been developed for selection of electromotor parameters. The main technical solutions are analysed based on the internal combustion automobile Renault Clio 1.2. For the automobile 30 kW alternate current electromotor and Lithium ion batteries have been selected. The planned technical characteristics: mileage with one charging at least 100 km, battery energy capacity 25 kWh, maximal speed 120 $km \cdot h^{-1}$.

Keywords: rebuilding of automobiles, rebuilding parameters, electromotor capacity, speed, mileage.

Introduction

With the decreasing oil resources the issue on development of new industrially produced electromobiles as well as on rebuilding of internal combustion engine automobiles into electomobiles becomes more topical. Development of such individually built electomobiles has got wide application in the USA and starts to become popular also in the European countries and unavoidably also in Latvia. Although in Latvia at present there is no registration of official rebuilding of internal combustion engine automobiles into electomobiles there are a lot of enthusiasts in this field.

In order to rebuild internal combustion engine automobiles into electomobiles sevaral aspects should be considered. One of them is the needs of the clients related to the expected technical parameters. The main of these parameters are:

- maximal elctromobile speed;
- motor technical parameters – power, torque, rotation frequency;
- mileage with one charging depending on the battery capacity;
- automobile mass and carrying capacity, correct axle load.

Also the constructive aspects are important that are related to legalisation of the rebuilt electromobile for road traffic. For the rebuilt construction the basic units have to be chosen that have the CE compliance certificate. The choice of only such units can ensure successful registration of rebuilt electromobiles in Latvia.

Further in the analysed calculation algorithm we will use dependencies on all kinds of resistances working on the automobile and the power curves given by the electromobile producers.

Calculation of electromobile parameters

In order to state the power for electromobile wheel drive the power balance for an automobile with mechanical transmission will be used [1]:

$$N_k = N_f + N_\alpha + N_w + N_j, \tag{1}$$

where N_f – power for overcoming of rolling resistance, kW;
N_α – power for overcoming upgrade resistance, kW;
N_w – power for overcoming air resistance, kW;
N_j – power for overcoming inertia resistance, kW.

The motor power is higher than the power for the wheels as there are losses in transmission. The motor power and the power for the wheels are related by correlation [1]:

$$N_k = N_e \eta_T, \tag{2}$$

where η_T – transmission efficiency coefficient.

Considering the efficiency coefficient the motor power is calculated according to the correlation [1]:

$$N_e = \frac{N_f + N_\alpha + N_w + N_j}{\eta_T}. \tag{3}$$

Splitting the necessary power for overcoming every kind of resistance the power for overcoming all kinds of resistance is obtained:

$$N_i = \left(fG_a \cos\alpha v + G_a \sin\alpha v + kFv^3 + m_a\left(1.04 + 0.0025 i_k{}^2 i_0{}^2\right) jv\right), \tag{4}$$

where f – automobile rolling resistance coefficient;
G_a – automobile weight, N;
α – road upgrade angle, in degrees;
v – automobile speed, km·h^{-1};
k – air resistance coefficient;
F – automobile forehead area, m^2;
m_a – automobile mass, kg;
i_k – gear box gear number;
i_0 – gear box gear number;
j – automobile acceleration, m·s^{-1}.

Automobile movement speed can be calculated according to correlation [2; 3]:

$$v_{teor} = 0.10472\frac{n_e r_k}{i_T}, \tag{5}$$

where n_e – electromotor revolution frequency, min^{-1};
r_k – wheel kinematic radius, m;
i_T – transmission gear number.

Transmission gear number is calculated according to correlation:

$$i_T = i_k \cdot i_0, \tag{6}$$

The automobile moving speed changes depending on the chosen gear. For electromobiles due to the efficient torque and power characteristic curves not always all gears are necessary, though choosing the parameters it is useful to analyse movement in all gears.

Inserting the correlation 5 in the expression 4 we get

$$N_i = 0.10472\frac{n_e r_k}{i_T}\left(fG_a\cos\alpha + G_a\sin\alpha + 0.011kF\left(\frac{n_e r_k}{i_T}\right)^2 + m_a\left(1.04 + 0.0025 i_k{}^2 i_0{}^2\right)j\right) \tag{7}$$

When the automobile has reached the maximal speed it moves evenly without acceleration, due to this the part of the correlation 7 that characterises the power necessary for overcoming the inertia resistance will be equal to 0 and:

$$N_i = 0.10472\frac{n_e r_k}{i_T}\left(fG_a\cos\alpha + G_a\sin\alpha + 0.011kF\left(\frac{n_e r_k}{i_T}\right)^2\right) \tag{8}$$

Most of automobile rotating components, such as power steering pump, air condition compressor and heater fan are powered by internal combustion engine, in the direct or indirect way.

Direct drive uses mechanical link, for instance, belt to connect power steering pump or air condition compressor pulley to engine crankshaft pulley.

Indirect drive is realized by using alternator, which creates electrical power, and electrical motor for powering mechanical components, for instance, windscreen wipers or heater fan. In case of the electrical vehicle, all such components will not be powered directly from electrical motor. Necessary amount of energy will be drawn from electrical batteries. It means that batteries will be loaded additionally.

Energy, used to supply additional components of electrical vehicle can be calculated as follows:

$$N_{Ag} = N_{St} + N_{Br} + N_{Kl} + N_{Apg} + N_i\,, \tag{9}$$

where N_{St} – power necessary for the driving steering booster, kW;
N_{Br} – power consumed for driving the electric brake vacuum pump, kW;
N_{Kl} – power necessary for the system ensuring the climate in the salon, kW;
N_{Apg} – power necessary for the lighting system, kW;
N_i – power necessary for other electrically driven systems, kW.

In order to determine the electromobile maximal speed with the corresponding resistance parameters it is advisable to choose at least 2 movement conditions.

In the first case the planned easiest operation conditions can be considered at which the maximal speed will be achieved, for instance, for the case when the road resistance coefficient $\psi = 0.015$ [2; 4] that characterises asphalt concrete road cover in good condition.

In the second case hard movement conditions can be considered when the road resistance coefficient is $\psi = 0.1$ [2; 4] that corresponds to movement on naturally trodden road. In that case maximal movement speeds will be obtained for both conditions and it will be possible to choose the corresponding gearbox gears.

Other gears can be dismounted from the gearbox to decrease the influence of the gearbox mass and rotating mass.

Calculating the possible electromobile mileage the electromotor efficiency coefficient is very essential.

With the electromotor operating depending on the rotation frequency in the mechanical rotation energy it can transform different amounts of energy that are characterized by the efficiency coefficient.

In literature several algorithms can be found how to calculate the electromotor efficiency coefficients, but in practice it is easier to use definite motor characteristic curves that can be obtained in the electromotor specifications.

This way it is possible to determine what automobile characterizing indices can be obtained with electromotors of different capacity.

Simplified scheme of calculation algorithm is shown in Fig. 1.

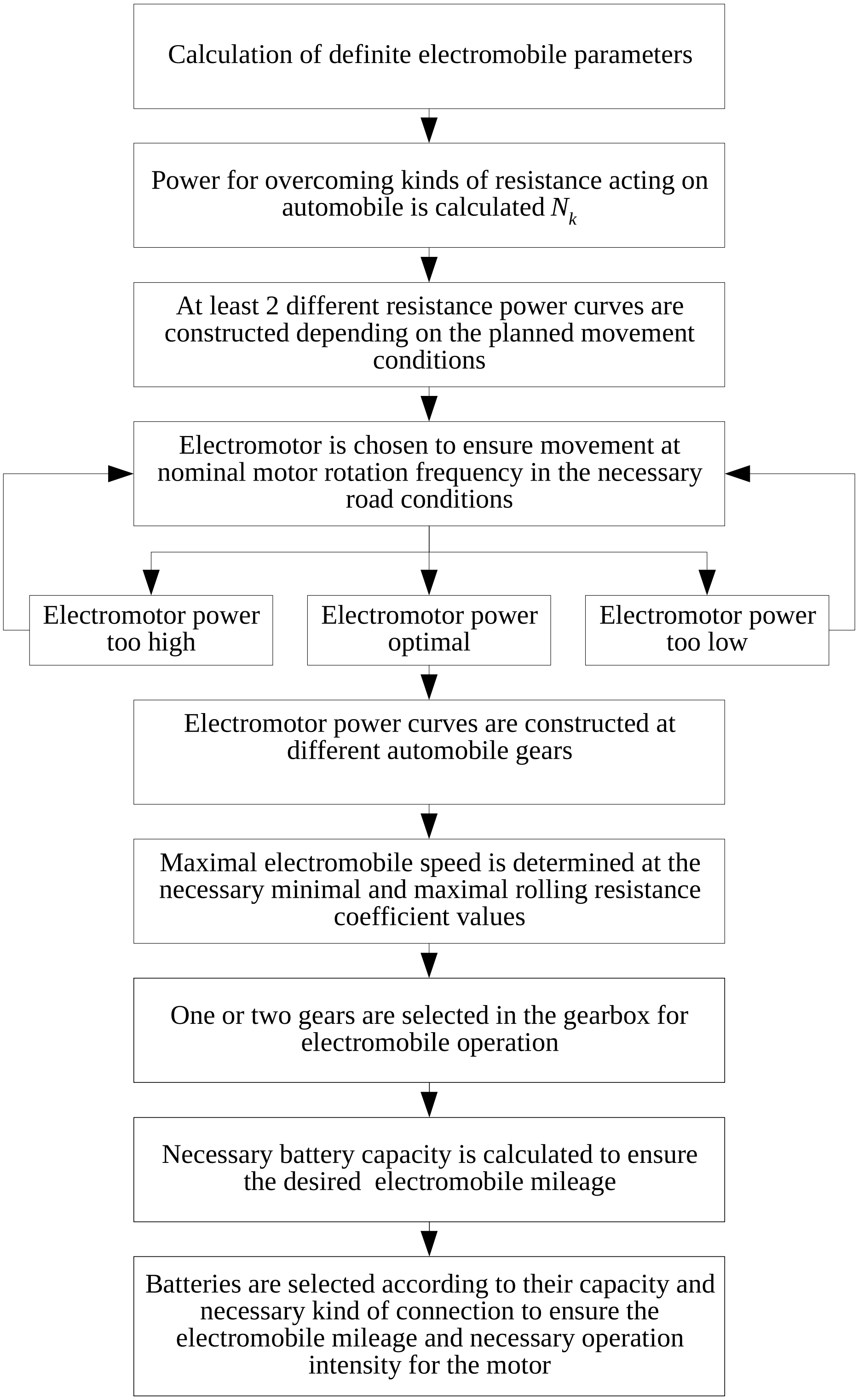

Fig. 1. **Simplified scheme of calculation algorithm**

An automobile with the average driving speed v_{vid} can cover a definite distance s in corresponding movement time. In this case the movement time or the time for discharging of the batteries can be determined according to correlation:

$$t_{iz} = \frac{s}{v_{vid}}, \tag{10}$$

where s – desired mileage of electromobile, km;
v_{vid} – average movement speed of electromobile, km·h^{-1}.

The average movement speed can be calculated according to correlation:

$$v_{vid} = k_v v_{pieļ}, \tag{11}$$

where k_v – driving speed correlation coefficient that evaluates the movement regime;
$v_{pieļ}$ – permissible average movement speed mentioned in road traffic regulations.

In cities in the Republic of Latvia $v_{pieļ}$ = 50 km·h^{-1}, but in traffic outside cities $v_{pieļ}$ = 90 km·h^{-1}. The driving speed correlation coefficient shows by what the average driving speed is lower than the permissible. This coefficient can be assumed for city traffic k_v = 0.5 – 0.7, but in traffic outside cities k_v = 0.7 – 0.9.

The current consumed by the electromotor and other electric units in a definite moment of movement is calculated according to correlation:

$$I = \frac{N_{el} + N_{Ag}}{1000U}, \tag{12}$$

where N_{el} – electromotor average momentary power, kW;
U – voltage fed to electromotor, V.

The battery theoretical capacity, Ah, considering the electromotor efficiency coefficient is calculated according to correlation:

$$C_{ak} = \frac{t_{iz} \cdot I}{3.6 \cdot 10^3} \tag{13}$$

Results and discussion

In order to analyse more deeply the calculation algorithm should be verified. It is done using the technical data and parameters of the automobile Renault Clio. The technical data necessary for Renault Clio calculations:

- m_a = 1425 kg;
- k = 0.23;

- body-size width $B = 1.377$ m, body-size height $H = 1.417$ m, forehead area $F = 1.58$ m^2;
- tyres 165/70R14, $r_k = 0.283$ m;
- gear numbers $i_I = 3.364$; $i_{II} = 1.864$; $i_{III} = 1.321$; $i_{IV} = 1.029$; $i_V = 0.821$; $i_0 = 4.067$.

The power graph of the electromotor used in the calculations (AC induction motor M2-AC25/4-A/L) [5] is shown in Fig. 2. The nominal power of electromotor M2-AC25/4-A/L is 25 kW at 5500 min^{-1}. Doing calculations the transmission efficiency coefficient η_T should be considered, a part of the electromotor power is used for operation of transmission units. Due to this the power driven to the wheels N_k will be lower.

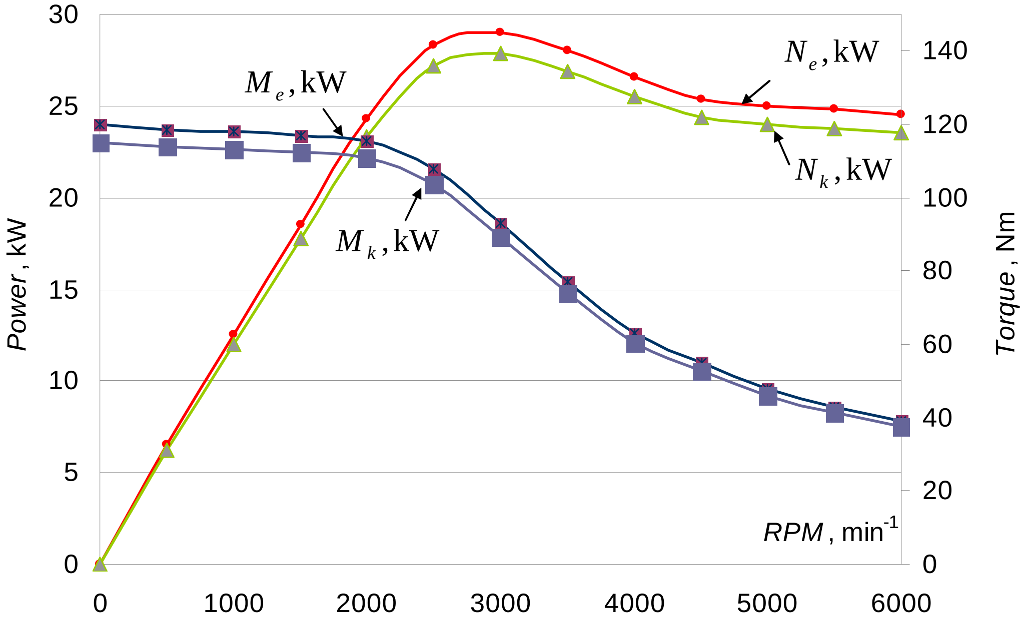

Fig. 2. **Primarily selected electromotor characteristic curves:**
AC induction motor M2-AC25/4-A/L

For calculations two rolling resistance coefficients are assumed $f_1 = 0.015$ and $f_2 = 0.1$. Calculations are done also for the third case when the automobile will move along a good quality asphalt concrete cover with f_1 and ascend with 5° upgrade angle. In calculations for ensuring uniform movement of the automobile correlation 8 is used. Calculating the power driven to the wheels according to correlation 2 the transmission efficiency coefficient is considered that is assumed to be $\eta_T = 0.96$. As a result of the calculation s the graph in Fig. 3 has been developed.

In Fig. 3 it can be seen that moving along a horizontal good quality road with gear 4 or 5 it is possible to develop the maximal speed ~130 km·h^{-1}.

In the first gear the maximal movement speed is 46 km·h^{-1}, in the second gear – 84 km·h^{-1}, but in the third gear – 119 km·h^{-1}. Depending on what the desired maximal speed is, it is possible to select the most appropriate gear. In order to ensure the necessary maximal speed for the Latvian conditions, it is possible to choose the gears 3, 4 or 5 depending on whether the automobile is planned to be used in the city or in traffic outside cities. Choosing a lower gear we will get better dynamic characteristics at low and average movement speeds, but lose at the maximal speed (120 km·h^{-1}). Selecting the highest gear we will get higher possible maximal speed as well as improved dynamic characteristics of the automobile at the maximal speed.

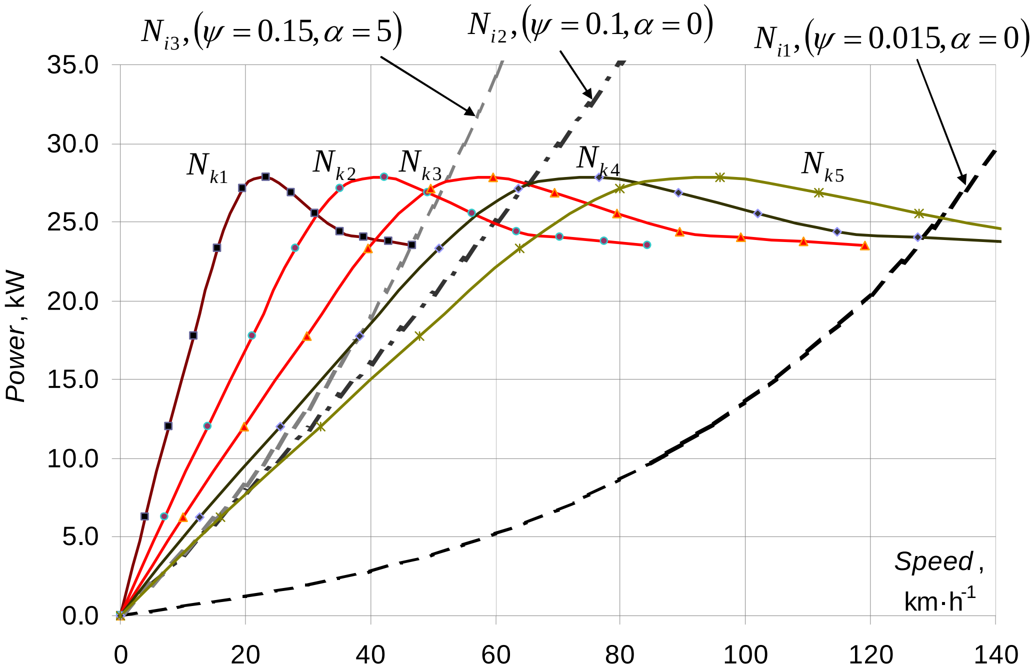

Fig. 3. **Automobile power balance**

Nevertheless, considering that in the Latvian condiotions there are also many hilly areas as well as lower quality road coverage it should be forseen that for driving along these roads the most part of the power developed by the motor will be consumed. It can be seen in Fig. 3 that with the gear 5 it is not possible to drive along low quality roads with high road resistance coefficient (ψ = 0.1), in turn, with the gears 3 and 4 it is possible to drive but the maximal speed possible to be developed will be ~66 km·h^{-1}. Selecting the gear 3 in this situation we will get better automobile dynamic characteristics.

Considering that the automobile will have to ascend up to 5°, also the gear 4 is not exactly appropriate. In this gear the automobile dynamic characteristics are very limited as well as the maximal mov ement speed does not exceed ~36 km·h^{-1} at higher road resistances.

Due to the above considerations, for the automobile to show good dynamic characteristics on low quality roads and upgrades as well as to develop the necessary maximal speed and dynamics at high speed, it is useful to select a gearbox with two gears. In this definite case it is efficient to select the gears 2 and 4. The gear 2 will ensure the automobile movement possibilities on upgrades that exceed 5°, but the gear 4 will ensure a possibility to drive with higher speed at the same time maintaining good dynamic characteristics at average and high speed.

Besides the above mentioned, it must be considered that the power developed by the electromotor and with it also the dynamic characteristics depend on the battery discharging level. At larger electromobile mileage and more empty batteries the dynamics of the automobile will worsen.

In case if the car owner need electromobile only for usage in city conditions, it is possible to choose an electromotor with lower power, for instance, 10 – 15 kW. In this case the electromobile maximal movement speed will not exceed 80 $km \cdot h^{-1}$, but a smaller number of batteries will be possible to choose this way decreasing the electromobile mass and rebuilding costs.

Conclusions

1. The elaborated electromobile motor selection algorithm has been verified with calculations and approved as able to operate.
2. The input parameters necessary for calculations c an be found in the technical data of definite automobiles and electromotor power curves at the producers or dealers of these components.
3. The electromotor selection algorithm can be corrected and specified after actual rebuilding of the definite electromobile and experimental investigation.
4. For the chosen prototype Renault Clio it is optimal to choose the gears 2 and 4 driving it with the speed up to 100 $km \cdot h^{-1}$. In case if the automobile is planned for operation also at higher speeds the gears 3 and 4 can be selected.
5. To simplify the construction the gearbox can be disassembled and the non-used gear couples can be dismounted. This way it is possible to reduce the influence of the revolving masses in the process of acceleration and increase the transmission efficiency coefficient.
6. In the planned construction it is possible not to use the standard clutch and flywheel so decreasing the revolving masses.
7. In separate operation cases also usage of the investigated prototype only with one gear, for instance, the gear 3, is possible. In this case the total gearbox mass and the inertial masses decrease.

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ELECTRIC VEHICLES FROM CAR MANUFACTURERS AND COMPARISON OF THEIR TECHNICAL CHARACTERISTICS

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Abstract. Nowadays, the electric vehicles are used more and more often. The spread of such vehicles is clearly facilitated by the rise of fossil fuel prices and environmental pollution resulting from the use of these fuels. In recent years all major automakers are seriously resorted to this issue by including in their model range also electric vehicles. Different solutions are applied in the design of electric vehicles that generally affect the overall characteristics of the vehicles. The aim of the present study is to analyze the technical characteristics of electric vehicles available already in the market and the performance of these vehicles depending on the technical parameters. The published technical information from electric vehicle manufacturer was used as source information in this study.

Keywords: electric vehicles, performance, technical characteristics.

Introduction

During the development of motor vehicle market there have been several attempts to put into production and sale the personal vehicles, which energy source is an electric battery. Starting from 2009 almost every car producer has presented conceptual models of their own electric vehicles in the world's largest motor shows. In 2010, some carmakers began to offer in the market commercially available electric vehicles.

Now it is possible to buy many newly designed electric vehicles from the car manufacturers, for example, "Mitsubishi i-MiEV", "Nissan LEAF" and "Tesla Roadster" (Figure 1).

There are also many companies in the world which rebuild new and second hand internal combustion engine cars to the electric cars.

Several of the newly designed electric vehicles available in the market from the largest car manufacturers are covered in this study. More detailed three of them are studied – *Mitsubishi, Nissan* and *Tesla Motors.* The following data were summarized using different available information sources:

- car body parameters;
- technical data;
- electrical battery structure and arrangement.

Fig. 1. **Electric cars** “***Mitsubishi i-MiEV*”, “*Nissan LEAF*” and “*Tesla Roadster*”**

Materials and methods

The automaker *Mitsubishi Motors Corporation* presented a conceptual model of the electric car “i-MiEV” in Yokohama exhibition in October, 2006 [1]. The name is an abbreviation of “Mitsubishi Innovative Electric Vehicle”. The electric car is designed on the base of the micro car Mitsubishi “I”. The *Mitsubishi Motors Corporation* in collaboration with the French carmaker *PSA*, which produces and distributes *Peugeot* and *Citroen* brand cars, distributes this electric car in the European market also with the titles *Peugeot Ion* and *Citroen C-Zero*. The *Mitsubishi i-MiEV* is produced in Japan and the product distribution has been launched in several countries in America, Asia and Europe as well.

The *Nissan Motor Company* is one of the first car makers, which started production of electric vehicles on a large scale. In this initial phase one model of electric vehicles is available – *Nissan LEAF*. The first delivery of the electric vehicle *Nissan LEAF* to the customer was to the U.S., California, San Francisco in December 11, 2010. Starting from December 13, the car is available in limited numbers, also in Southern California, Arizona, Oregon, and Tennessee States [2]. Since 1992 the automaker Nissan does research and develops the lithium-ion battery technology. From 2007, by establishing a joint venture with *NEC* – “Automotive Energy Supply Corporation” (AESC), it has developed a new type flat layered lithium-ion battery with a manganese-containing positive electrode [3]. The layered structure provides a better temperature mode and a simple composition. The battery is shown in the Figure 2.

Fig. 2. **Battery and its element**

The “Tesla Motors” is a relatively new American company, but its name is already quite well known in the world with regard to its electric street sports car *Tesla Roadster*. The company “Tesla Motors” was founded by *Silicon Valley* engineers in 2003 [4]. With this model the company “Tesla Motors” has shown that electric cars can be economical, ecological, attractive and fast. The method of analogous comparison is used in this study by which conclusions are made on the design similarity of electric vehicles and technical specifications, which include characteristics of separate components.

Results and discussion

The body is a separate technical unit of the car, which includes all interior and exterior equipment of the vehicle. The body usually is fastened to the vehicle frame. There are also bodies without a frame, monocoque, which fulfil also the function of the frame. The above mentioned electric cars have monocoque bodies, to which all aggregates and assemblies are fixed.

The compared electric vehicles have similar bodies according to the mass, but other technical parameters are different, because the body of each model has its own design solutions, which provide different technical functions. For example, built-in solar panels are integrated in the rear wing of electric cars *Nissan LEAF*, which provide 12 V car battery charging [5].

The study of electric car bodies and chassis shows that independent suspension and disc brakes are mostly used in electric cars, but their size depends on the number of the carried passengers. But the wheel size and clearance are approximately the same size because these electric vehicles are expected to operate on paved roads. The specifications of the bodies and chassis design are summarized in the Table 1. For the vehicle to start motion, it is necessary to ensure conditions when the traction force acting to the drive wheels exceeds all resistance forces of the motion. The traction force on the drive wheels is expressed as the engine torque, taking into account the main gear and gearbox ratios, as well as power transmission losses and the wheel radius. In order to analyze all the factors that affect the performance of electric cars, it is necessary to have additional technical information, which is not published by the manufacturers. Therefore, Table 2 summarizes only the main technical parameters that provide an insight into the dynamic and operational characteristics of electric vehicles. One of the most important operating parameters of electric vehicles is the maximum speed and cruising range per charge. According to Table 2, these indicators for the car *Tesla Roadster* are significantly higher, but for the *Mitsubishi i-MiEV* and *Nissan LEAF* at a similar level.

Table 1

Specifications of bodies and chassis design [6 – 10]

Parameter	**Electric vehicle**		
	Mitsubishi i-MiEV	***Nissan LEAF***	***Tesla Roadster***
Length, mm	3474	4445	3947
Width, mm	1475	1770	1852
Height, mm	1608	1550	1127
Wheelbase, mm	2550	2700	2352
Front track, mm	1310	1540	1466
Rear track, mm	1270	1535	1499
Ground clearance, mm	150	160	N/A
Minimum turning radius, m	4.5	5.2	N/A
Kerb (dry) weight, kg	1100	1520	1235
Gross vehicle weight, kg	1608	1795	N/A
Seating capacity, persons	4	5	2
Drivetrain layout	RWD	FWD	RWD
Front suspension	Independent	Independent	Independent
Rear suspension	3 link	Torsion spring	Independent
Front brakes	Disc	Disc	Disc
Rear brakes	Drums	Disc	Disc
Tyres	145/65/R15 175/55/R15	205/55/R16	175/55/R16 225/45/R17

Table 2

Dynamic and operational characteristics [6 – 10]

Parameter	**Electric vehicle**		
	Mitsubishi i-MiEV	***Nissan LEAF***	***Tesla Roadster***
Maximum speed, kmh^{-1}	130	145	201
Power plant max output , kW/rpm	49/2500 – 8000	80/ 2730 – 9800	182/5000– 6000
Power plant max torque, Nm/rpm	180/0 – 2000	280/0 – 2730	374/0 – 5400
Power plant max frequency, rpm	N/A	10390	14000
Electric range, km	150	175	400
Traction battery / V	Lithium / 330	Lithium	Lithium / 375
Full charging time, h	6	7	3.5

The main component defining the dynamic characteristics of electric vehicles is the electric motor. According to the data in Table 2, the electric motor of *Tesla Roadster* is about 100 kW more powerful, and it has a higher torque and a higher maximum speed, thus ensuring the highest dynamic performance between the selected cars.

The charging options for the selected electric vehicles are different. If for the cars *Mitsubishi i-MiEV* and *Nissan LEAF* a full charge can take a similar mode, then Tesla Roadster is intended only for fast charging, which takes up a half shorter period.

The characteristics, which are related to the battery parameters, weight and location, are very important for every electric vehicle. They directly affect the capacity of the vehicle and its dynamic performance. All three electric vehicles have batteries containing lithium-ion cell elements in a metal casing.

Totally 22 battery modules are located in *Mitsubishi i-MiEV*, each containing four elements. The battery module compartment layout is shown in Figure 3.

Fig. 3. ***Mitsubishi i-MiEV* battery compartment**

The battery compartment is positioned in the lower part of the body. Such a battery arrangement provides a low center of gravity and it does not reduce the car interior and trunk volume. The battery compartment location in the car is shown in Figure 4 [1].

Fig. 4. **Battery compartment location in *Mitsubishi i-MiEV***: 1 – motor; 2 – lithium-ion battery compartment; 3 – inverter; 4 – charger

The main parameters of *Mitsubishi i-MiEV*, *Nissan LEAF* and *Tesla Roadster* batteries are summarized in Table 4.

Table 4

Comparison of main parameters of battery compartments [6 – 10]

Parameter	**Electric vehicle**		
	Mitsubishi i-MiEV	***Nissan LEAF***	***Tesla Roadster***
Type of the battery	Lithium-ion	Laminated-type lithium-ion	Lithium-ion
Cell weight, kg	1.8	N/A	N/A
Battery weight, kg	158	N/A	N/A
Battery compartment weight, kg	230	N/A	450
Number of cells	88	N/A	N/A
Number of modules	N/A	48	11
Number of cells in module	N/A	4	69
Cell capacity, kWh	0.187	N/A	N/A
Cell voltage, V	3.75	N/A	N/A
Cell min voltage, V	2.75	N/A	N/A
Cell max voltage, V	4.1	N/A	N/A
Total capacity, kWh	16	24	N/A
Total voltage, V	330	360	360
Max power, kW	N/A	90	90
Slow charging characteristics	6 h, AC 230 V, 15A	7 h pie 230 V / 16A (25 ºC)	N/A
Fast charging characteristics	30 min, DC, 330 V, 150 A (up to 80 %)	30 min, DC, 480 V / 125 A (25 ºC)	3.5 h / 240 V / 70 A

Totally 48 battery modules are located in *Nissan LEAF*, each containing four elements.

The battery compartment is positioned in the lower part of the body. The cross-section of the body is shown in Figure 5. Such a battery arrangement provides a low center of gravity and does not reduce the car interior and trunk volume.

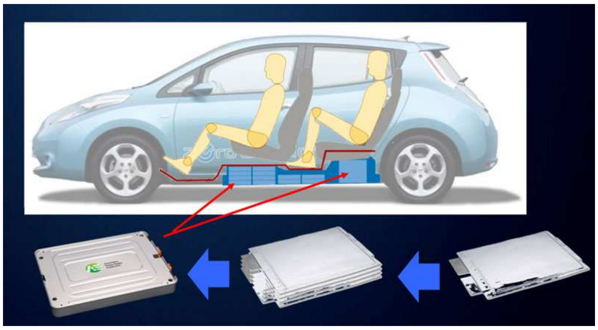

Fig. 5. **Battery compartment layout**

The battery module compartment layout in *Tesla Roadster* is shown in Figure 6.

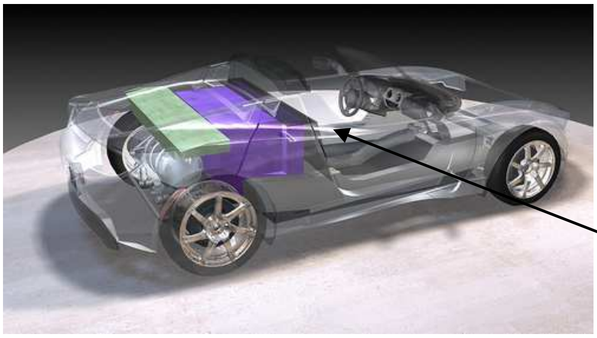

Fig. 6. ***Tesla Roadster* battery compartment layout**

The battery compartment is positioned in the back part of the body. Such an arrangement of the battery compartment does not reduce the interior volume and provides extra load on the car drive wheels.

Conclusions

1. The largest carmakers of the world are paying increasing attention to the development and production of electric vehicles by introducing the latest technology and various other improvements in order to improve the operating parameters of electric cars closer to the performance of vehicles working with internal combustion engines.
2. One of the most important factors for successful operation of electric vehicles is the design of the body shape in order to improve aerodynamics, as well as the body use for solar energy conversion into electrical energy.
3. The electric motor has an important role for improvement of the dynamic properties of electric cars. The study shows that using higher power electric motors, both dynamic and operational performance is better.
4. The location of the batteries in the electric car is also important, because it affects the interior and luggage space size as well as the location of the car center of gravity.
5. The battery capacity determines the distance that the car can make between charging. The battery charging time is important. Therefore, continuous studies are carried out on battery weight reduction and capacity increase.

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ELECTRIC VEHICLE CHARGING CHARACTERISTICS

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Abstract. During the recent years interest about electric vehicle use on public roads is increasing. One of the most important and unsolved topics is about infrastructure creation for electric vehicle charging. It is not clear how much and what kind of connections to electricity network will be needed. In this study there is a practical research about Fiat Fiorino Elettrico HC-S automobile – about its needed connections and ability to charge batteries from household electricity connection 230 V, 16 A and AC 50 Hz. The experiment results show that there is a need to carefully reconsider the options for untroubled electric vehicle battery charging from household electricity connections, without disturbing the whole electricity connection operation. It was established that for the researched automobile in 7 hour charging cycle with voltage 230 V AC, the current from electricity network was 12 – 13 A, which is a remarkable part of the connection maximal value. At the beginning of the charging, during the first 60 seconds, the current from the electricity network was increasing gradually before reaching its nominal value 12 A, avoiding from the protection equipment interference.

Keywords: charging, batteries, electric vehicle.

Introduction

The world's population and standard of living is only growing, so there is an increase in energy demand. Fossil fuel prices are high, but alternative fuel implementation is slow and fragmented. Electric vehicles seem to be the next direction or trend, and are slowly gaining interest also in Latvian society. Most popular electric vehicles are bicycles, cars, scooters, senior and golf carts. Electric vehicles have 2 major disadvantages – the driving range and charging time. The range depends on the vehicle, terrain, weather, performance of the driver, weight and battery capacity. The electric vehicle charging time depends on many factors – the battery type, capacity, charger power, charging program, temperature etc. The charging time can range from 30 minutes to 20 hours or more depending on these factors. Development of compact and efficient electronic power converters allows some electric vehicles to be fitted with on-board chargers, to be connected directly to the electricity network, greatly improving the flexibility for the vehicle. Some chargers are also designed to maintain batteries in full working condition during storage. Electric vehicles need to be tested, so it is important to develop methods for gathering the characteristic data of charging.

Using modern equipment and data loggers, it is possible to measure the charging characteristics continued and without assistance.

Every electric accumulator battery can be described with: voltage (V), capacity (Ah) (describes indirectly how much energy is stored), current (A) (depends on the capacity and load regime), electrolyte density ($g \cdot cm^{-3}$) (ratio of the weight of a solution to the weight of an equal volume of water at a specified temperature), internal resistance (Ω) (all resistance sum from the active mass, electrolyte, connectors, temperature and charge rate) and temperature (ºC).

Most chargers in use today use the so-called I-U characteristic, where the constant current I is used for the main charge and the constant voltage U for the final charge (see Fig. 1).

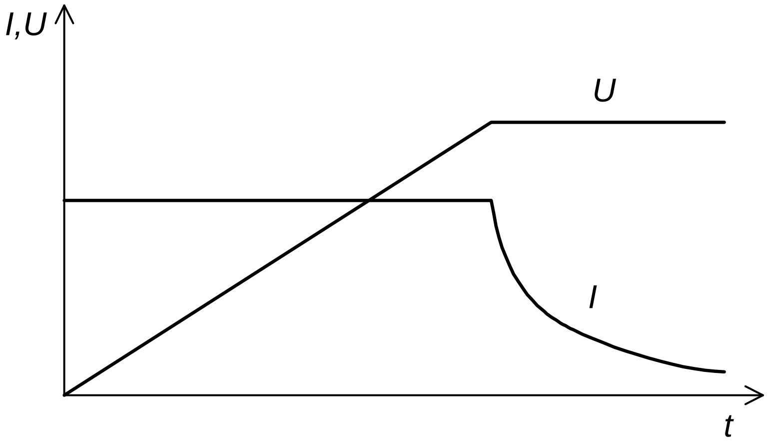

Fig. 1. **Accumulator I-U charging characteristics**

The charging mode can be described with:

- charging time, h;
- charging voltage, V;
- charging current, A.

The charging mode consists of:

- main charging phase, where the bulk of energy is recharged into the battery;
- final charging phase, where the battery is conditioned and balanced.

IEC61851-1 is an international standard for a set of electrical connectors and charging modes for electric vehicles and it has introduced 4 different charging modes [1]:

- Charging mode 1 – slow charging from a household socket. The electric vehicle is connected to a single-phase or three-phase AC network with a standardized socket. This charging mode is not permitted in few countries due to that the required earthing is not present in all domestic installations;

- Charging mode 2 – slow charging from a household socket with a cable protection device. The electric vehicle is connected to a single-phase or three-phase AC network, with a charging control function, with an in-line module in the charging cable. The use of this charging mode requires both, an overcurrent protective device and a residual-current circuit breaker on the network side. Use of a surge arrester is recommended;
- Charging mode 3 – slow or fast charging using a specific socket with monitoring and protection controller. The electric vehicle is connected to a single-phase or three-phase AC network, with a charging control function, via an electric vehicle on-board charging device and a control module in the charging installation. The use of this charging mode requires both, an overcurrent protective device and a residual-current circuit breaker (RCCB) on the network side. Use of a surge arrester is recommended;
- Charging mode 4 – fast charging with external charger. The electric vehicle is connected to a single-phase or three-phase AC network with a rectifier. The use of this charging mode requires an AC/DC-sensitive RCCB on the network side, as well as overcurrent protective devices for AC and DC. Use of surge arresters is recommended.

Materials and methods

The experiments were carried out on Fiat Fiorino Elettrico HC-S automobile (see Fig. 2).

Specifications: 2 passenger vehicle, full mass 1700 kg, engine power: 30 kWh (nominal) 60 kW (peak), maximum gradient: 24 %, batteries: lithium 31.1 kW, motor: asynchronous three-phase, braking: regenerative, charger input: 230 VAC/16 A/3 kW, maximum speed 100 $km \cdot h^{-1}$, maximum distance 100 km [2].

For electrical characteristics measurement and data storage a Pico Technologies PicoLog ADC-24 data logger was used. Specifications: 24-bit resolution, accurate to within 0.1 %, up to 8 true differential inputs, up to 16 single-ended inputs, fast conversion time, digital output for control, galvanic isolation from the PC to eliminate noise pickup, dimensions 135×184×36 mm, power supply 100 mA (max.) from USB port, weight approx. 505 g.

Fig. 2. **Experiment object during charging**

The inertial rolling stand operates with the automobile driving wheels proportionally to the driving speed, imitating driving conditions and in this case it was used for discharging of the electric vehicle. Our tested vehicle was equipped with a battery safety feature that does not let the batteries to go bellow certain voltage, thus making sure that the batteries do not lose their capabilities during exploitation time by switching off power supply from the batteries. It can happen on a road, so it is safer to use a dynamometer for this purpose. The Mustang MD-1750 chassis dynamometer consists of mechanical, electro-mechanical, and electronic modules, that simulate actual road loads to get data not only for performance, but also for emission and driving cycle tests. Specifications: maximum power – 1283 kW, maximum absorbed power – 294 kW, maximum speed – 100.56 $m \cdot s^{-1}$, Pentium-based PC controls, MD-7000 control platform. The vehicle must be fixed on the chassis dynamometer with straps from front and back, to keep the automobile straight and in place.

REV digital energy measuring tool (190 – 276 V, 20 mA – 16 A, 5 – 3680 W, ±0.01 kWh) was used for measurement of the consumed energy. The electricity characteristics were measured with 10 second intervals during the charging measurements. PicoLog ADC-24 data logger was used for gathering the experiment results. The data logger was equipped with a current converter A1 and current transformer T1 (see Fig. 3.). The actual power, current and voltage values were controlled by REV digital energy measuring tool P1, which also was registrating the total consumed electric energy.

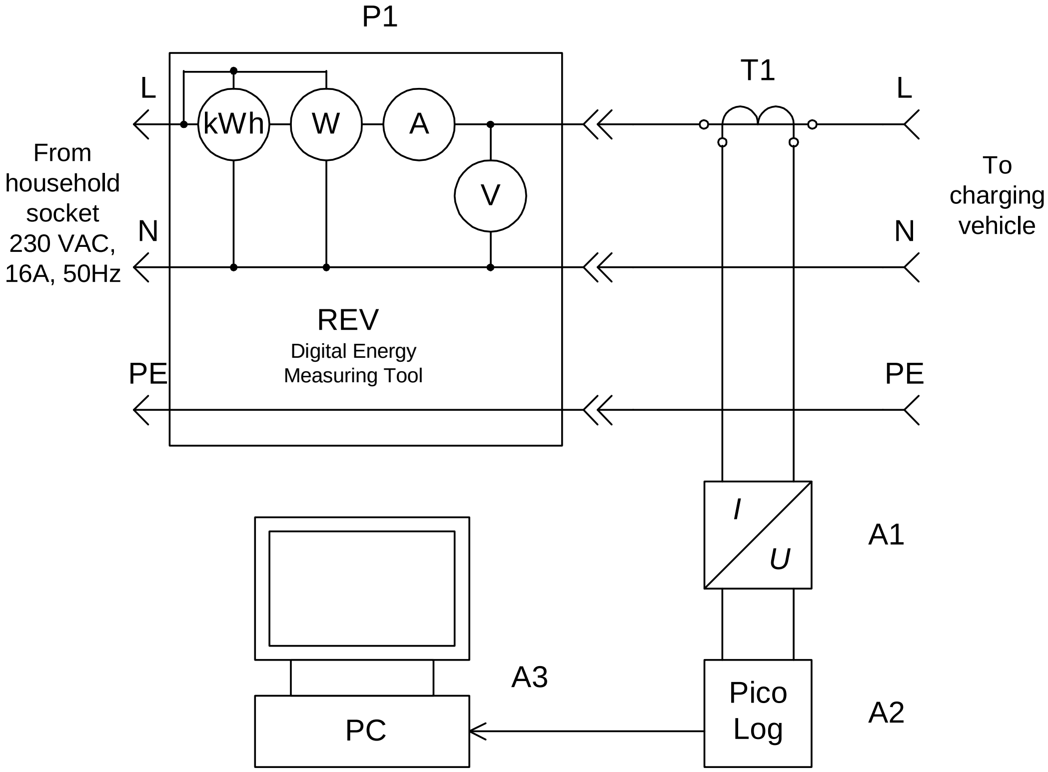

Fig. 3. **Electric measurement diagram**

Results and discussion

Charging current increase is very important at the beginning of the charge, there should not be any high peaks that can cause overloading of the power source.

The experiments were carried out 5 times, in which the total consumed electric energy curves were similar, the charging time differed because the automobile batteries could not be discharged absolutely similarly. The consumed electricity current value and change in the time was very similar. When the batteries were fully charged, the electricity network current value decreased to 1.86 A. Then it increased to 6.29 A, then decreased to 1.86 A, after that increased to 4.47 A and again shortly decreased to 1.86 A. The final increase was to 3.12 A, which followed by decrease to 1.86 A and switched off (Fig. 4).

The average total consumed electricity energy during the charging cycle was 20.02 kWh, averaging 98 km driven distance. Maximal charging power 2923 W was registered by the energy measuring tool REV. After the charging cycle ended, the current decreased to 0.13 A. The electricity network voltage was average 230 V during charge.

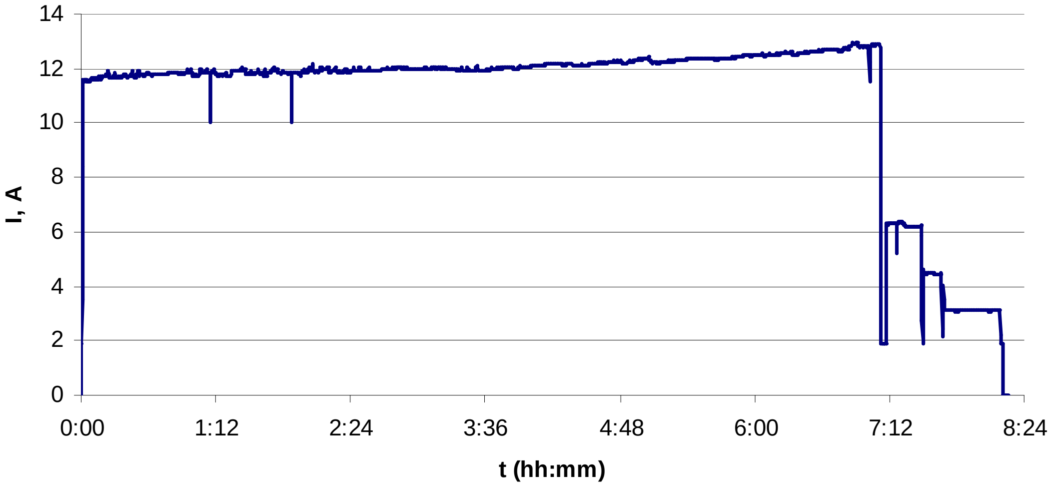

Fig. 4. **Full charging cycle current characteristics**

The experiment results confirmed that the Fiorino charging type corresponds to mode 2 and can be used in household typical sockets with ground wire. The standard household one phase electricity connection is 230 V and 16 A inlet fuse. This kind of electricity connection can provide electric vehicle charging on condition, that the household consumed electricity does not exceed 4 A. That means, other household electricity consumer loads need to be reduced to guarantee stable connection operation. The remaining theoretical usable power reaches $4 \cdot 230 = 920$ W. That means, no electric kettles, washing machines, irons or water boilers can be used during charging, the remaining power could be used for lighting and computer use, or there is a need that more efficient home appliances are introduced.

Precisely planning the electrical power consumption, the vehicle charging can be coordinated with home appliance use. The simplest solution is to charge the electric vehicle during the night, when home appliances are not in use. A more advanced and expensive solution is to increase the power of electricity connection. There is also a solution to introduce a smart electrical load distribution system, determining the priorities for electricity consumers and vehicle charging. The worst impact on effective connection use is given by short time big loads, for example, electric kettles, ovens and water flow heaters.

During the study of the charging results, we established that at the beginning of charging, the current value is steady increasing before reaching its nominal value in 60 second time. This technical solution provides a stable connection to the electricity network. The experiment results are given in Table 1.

Table 1

Charging current increase at the beginning of charging

Time, s	0	10	20	30	40	50	60
Charging current, A	0	1.867	1.904	3.509	8.425	11.249	11.586

The Fiorino automobile charging current gradual increase is a very important factor for the occasion when there is a need to use alternative energy sources, where for current transformation an electronic inverter is used, which has protection for a short period overload. This can be related also to portable autonomic internal combustion engine generators used for battery charging in urgent situations.

Conclusions

1. From the study results it is clear that the Fiat Elettrico Fiorino HC-S automobile battery full charge needs 7 hours, with electricity connection that can provide 12 – 13 A, 230 V, 50 Hz alternating current, that means that a regular household connection is used near to its maximal current.
2. Charging electrical automobile at home means reducing other household electricity consumer total power used simultaneously.
3. In case of automobile charging, it is worth exploring new technical solutions for creation a smart charging system, dividing the electricity consumer connection priorities in a household.
4. With growing of the electric vehicle popularity, there will be increased electricity network load expected, that can lead to the necessity for household connection power upgrade.

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3. EXPERIMENTAL RESEARCH OF ELECTRIC VEHICLES

The exploitational characteristics and parameters of electric vehicles under the climatic conditions in Latvia may considerably differ from similar parameters in warm climatic zones. In Latvia, the air temperature can fall up to -25ºC and even -30ºC. Electric vehicles might not be adapted to such low temperatures and their cabin heating system as well as battery protection system may also be unsuited, which can prevent them from being exploited. Road conditions may also significantly differ from those under which electric vehicles were tested. The following essential exploitational parameters may differ: kilometrage per charge, especially in the winter period, as well as acceleration parameters. For this reason, the experimental research of key exploitational parameters of electric vehicles was carried out. The experiments were performed on general roads in Jelgava district, taking into account the motion regimes characteristic of particular electric vehicles.

In electric vehicles, batteries of various types are used, ranging from lead-acid batteries, which are well-known for more than a century, to the latest generation lithium iron batteries. Each generation of batteries can differently react on low temperatures as well as on poor road conditions, for instance, gravel roads.

So far a research of similar nature and scope has not been conducted in Latvia. Informing the public about how various groups of electric vehicles and particular vehicle models are adapted to local exploitation conditions can reduce the doubts of potential owners regarding purchasing electric vehicles and expose the key advantages of these vehicles.

Within the project “Usage of Electric Energy in Motor Vehicles of Physical Persons”, the electric vehicles subject to experiments may be classified into several categories:

- electric bicycles and electric mopeds;
- low-speed electric vehicles for shopping;
- low-speed electric automobiles;
- high-speed electric automobiles.

Thus, almost all categories of electric vehicles, which are and will be exploited in Latvia in future, are encompassed. The experiments were carried out to determine the following key exploitational parameters for each category of electric vehicles:

- average kilometrage per charge at various motion regimes and at various air temperatures;

- average cost per 100 km of travel;
- battery charge curves;
- effect of using solar batteries placed on the roof of an electric vehicle in Latvia;
- power of electric vehicles established on a roller power test bench;
- exploitational parameters of electric vehicles at various loads and at various performance regimes;
- research of the effect of the regenerative system of electric vehicles;
- research of kilometrages of electric vehicles with partially charged batteries.

Some of the experimental results are discussed in this chapter.

DYNAMICS OF SLOW-MOVING ELECTRIC VEHICLES

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Abstract. Slow-moving electric vehicles that are available in the Latvian market were ascertained. A methodology for determining the parameters of dynamics for slow-moving electric vehicles was developed. The maximum speed, acceleration time and distance were determined for various electric vehicles. An electric moped had the best acceleration characteristics among the vehicles chosen. By using the graphs of acceleration intensity, an optimum speed for the electric vehicles tested was determined to achieve their maximum distance of driving.

Keywords: electric energy, electric motor vehicles, electromobiles, acceleration time, acceleration, distance of driving.

Introduction

Deposits of fossil energy are gradually running out in the world. The extensive use of fossil energy in motor vehicles pollutes the environment with such toxic substances as CO, C_nH_m, and NO_x as well as promotes global warming due to CO_2 emissions. Therefore, possibilities to use other sources of energy, which are environmentally friendly, in automobiles are searched for. One of such sources of energy is electricity that can be used for cars and slow-moving motor vehicles.

The first electric vehicles have been known since the year 1830. Yet, their exploitation was limited. A more extensive use of electric vehicles was observed only in the beginning of the 20th century when electric taxis appeared in New York. Even in those times, electric vehicles had a few advantages compared to internal combustion engine vehicles, for instance, they did not have to be started up by spinning the engine by means of a crank, as electric starters were not available then; they were not noisy, no gases were emitted, and no fuel smell was felt. With developing the internal combustion engine designs, their use in motor vehicles sharply increased, whereas electric motor vehicles were used quite rarely. In those times, the main problem in exploiting electric vehicles was the same as today – no light, cheap, and relatively capacious battery is available that could ensure a large distance of driving, especially in non-urban traffic [1].

Every vehicle is suited for specific conditions of exploitation. Electric vehicles, irrespective of their disadvantages, can occupy a market niche and find their own use. This use can be related to the specifics of this type of vehicles – pollution localisation at the site of electric energy generation and noiseless operation.

One of the types of electric vehicles is slow-moving electric motor vehicles [2].

Slow-moving vehicles include electric bicycles and electric mopeds as well as electromobiles for shopping, golf, and tourism and other types of electromobiles, the driving speed of which does not exceed 50 km·h^{-1}.

Since such vehicles can be used in urban traffic where their dynamics can play an essential role in traffic safety, an experimental study on the dynamics of slow-moving electric motor vehicles will be conducted.

Materials and methods

1. *Slow-moving electric motor vehicles and their types*

Slow-moving vehicles can be classified into two groups:

- vehicles that can take part in road traffic – electric bicycles, mopeds, single-seat electric shopping cars, and certified tourist automobiles;
- vehicles that are not certified for road traffic – golf electric cars, hearses, electric trucks for closed territories.

The engine power of four-wheel slow-moving electric motor vehicles is within a range of 1-5 kW, and their distance of driving is 40-75 km. These vehicles are usually equipped with lead deep discharge batteries. In Latvia, 10 slow-moving electric motor vehicles produced by the Melex company are presently used for tourist transportation in Sigulda and Jūrmala.

Electric bicycles are two-wheel vehicles the engine power of which is usually within a range of 0.18-0.35 kW, maximum speed of driving is 20 to 30 km·h^{-1}, and distance of driving per battery charge is 25 to 40 km. Lead deep discharge batteries are most frequently used for electric bicycles, but lithium-ion batteries can be also used. The engine of electric bicycles can be activated in two ways: by means of a traditional accelerator handle or at the moment of engine start-up when the driver spins pedals at certain spin rate. Electric bicycles can be quite popular, as their price is within EUR 300-700. One of the main advantages of electric bicycles is the possibility to get home by spinning pedals in a traditional way after the battery is fully discharged.

Electric mopeds are usually more powerful than electric bicycles and no pedals are available. The power of mopeds is within 1-2.5 kW, their speed of driving is up to 40 km·h^{-1}, and their distance of driving is up to 60 km. Due to a larger engine power, mopeds require more capacious batteries that ensure sufficient dynamic characteristics [2].

2. *Methodology for determining the parameters of dynamics*

Slow-moving electric motor vehicles are not intended for fast driving, yet the ability of electric motor vehicles to adapt to urban traffic can be analyzed by determining their parameters of dynamics as well as the optimum speed of driving to achieve the maximum distance of driving per battery charge can be determined according to their acceleration curves.

Before the tests are started, the air pressure required by the manufacturers was provided in the tyres of electric motor vehicles. All the electric motor vehicles were tested with fully charged batteries. The measurements of the electric motor vehicles were done on a 200 m long section of road in the suburbs of Rīga, Sigulda, and Jelgava. The road surface was asphalt in a good condition, the rolling resistance coefficient was 0.018-0.020, and the slope of the road did not exceed 1 %. The air temperature during the experiments was 15 ºC and the wind speed was 2-3 $m \cdot s^{-1}$.

A scientific radar Stalker ATS placed on a tripod was used for the measurements. The radar measures the speed, while the other parameters – distance and acceleration – are computed. The main parameters of the radar are as follows:

- accuracy ±0.1 $km \cdot h^{-1}$;
- speed range 1-480 $km \cdot h^{-1}$;
- time of capturing a vehicle 0.01 s;
- weight 1.45 kg;
- operation distance up to 2500 m [3].

To conduct the research, 5 various electric motor vehicles were chosen – an electromobile Melex 963DS, an electric moped eGo Helio M37, an electric bicycle ER61, an electric shopping car Hawaii, and an electric shopping car City-Liner. The technical characteristics of the vehicles used in the experiments [4-7] are presented in Table 1.

Table 1 presents also the specific power of the electric motor vehicles. This indicator can characterise dynamic qualities of vehicles if the vehicle power is not too large and the adherence of wheels can ensure full use of its maximum power. The power of slow-moving electric motor vehicles is not large, therefore, it is expected that no slipping of wheels will be observed on asphalt with an adherence coefficient $\varphi = 0.7$ for all the vehicles mentioned in Table 1.

Larger specific power indicates larger potential acceleration dynamics. According to this parameter, the largest potential acceleration dynamics will be observed for the electric moped eGO Helio M37, while the smallest one – for the electric bicycle ER61. The correctness of these assumptions will be verified by conducting an experimental study.

Table 1

Technical characteristics of the electric motor vehicles used in the experiments

Technical characteristics	Model of electric motor vehicles				
	Melex 963DS	**eGO Helio M 37**	**ER 61**	**Hawaii TM4401DX**	**City-Liner**
Driving distance at full charge, km	65	40	65	40	35
Largest driving speed, $km \cdot h^{-1}$	25	37	32	6	6-8
Batteries	8 units, 12 V	2 units, 12V, 34 Ah	4 units, 12 V, 12 Ah	2 units, 12V, 40 Ah	2 units, 12 V, 40 Ah
Voltage of electric engine, V	48	24	48	24	24
Power of electric engine, kW	3.9	1.75	0.35	1.00	1.00
Carrying capacity, kg	450	114	115	159	150
Gross weight, kg	1135	173	150	255	245
Specific power, $kW \cdot t^{-1}$	3.44	10.12	2.33	3.92	4.08
Specific power in experiment, $kW \cdot t^{-1}$	5.30	12.50	2.80	5.12	5.37

Technology of the experiments

Any measurement is done by experiment operators. One operator accelerates the electric motor vehicles, while the second one operates the scientific radar. The electric motor vehicles are placed in the front of the radar at a distance of 1-2 m. The height of the radar is adjusted, so that it operates at the best angle of reception.

After the start signal is given by the radar operator, the mode of filming is activated on the radar and the electric motor vehicle starts moving. The data were registered in a computer connected to the radar. Any acceleration of the electric motor vehicle is done at maximum intensity, pushing the accelerator handle to the utmost position.

The acceleration is performed until stable maximum speed is achieved, keeping this speed for at least for 2-3 seconds. After the maximum speed is achieved, the radar operator stops filming and saves the data. The operator of the electric motor vehicles turns the vehicles around to drive them in an opposite direction and places them at the start position in front of the radar. In the same way, three measurements are repeated.

Results and discussion

3. *Results of the experiments*

One of the significant indicators in vehicle dynamics is acceleration until certain speed is reached. For cars, this is the speed of 100 km·h^{-1}, and modern street automobiles can usually reach such speed within 6-15 s. The slow-moving electric motor vehicles, which were studied, have various maximum speeds of driving that vary within 6-37 km·h^{-1}. Due to this reason, the acceleration dynamics were compared for speeds up to 5 km·h^{-1} and 15 km·h^{-1}.

Based on the research methodology, the measurements were done for the electric bicycle ER61, the electric moped eGO Helio M37, the slow-moving electromobile Melex 963DS, and the electric shopping cars Hawaii TM4401DX and City Liner. After completing the experiment, the data were processed and the average data were obtained from three measurements. Based on the measurement data, calculation was done and the result is presented in Fig. 1.

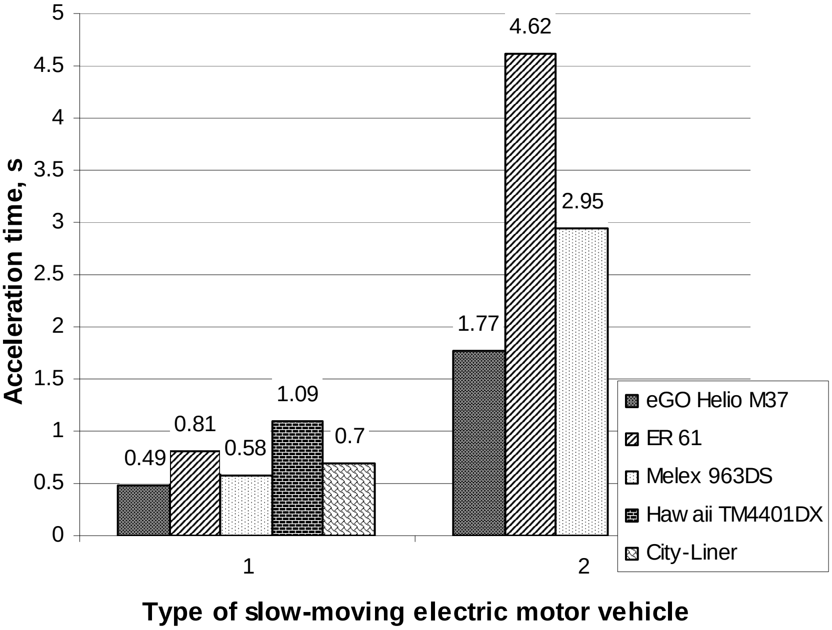

Fig. 1. **Acceleration time for slow-moving electric motor vehicles:** 1 – up to 5 km·h^{-1}; 2 – up to 15 km·h^{-1}

The best acceleration dynamics both at a speed up to 5 km·h^{-1} and 15 km·h^{-1} was observed for the electric moped eGO Helio M37, respectively 0.49 s and 1.77 s. Since the maximum speed of the electric shopping cars does not exceed 8 km·h^{-1}, the cars are not shown in the right side of the graph.

Among the vehicles studied, the poorest result in reaching a speed of 15 km·h^{-1} was gained by the electric bicycle ER61. It can be explained by its relatively weak engine – only 0.35 kW. In accordance with EU legislation, the engine power of electric bicycles is limited and should not exceed 0.25 kW. The electric bicycle ER61 can also be used as a moped by operating the accelerator handle. It is possible that the engine power mentioned in normative documents may not be increased due to this reason.

The engine power of the electric motor vehicles is smaller compared to analogous internal combustion vehicles. The only exception is the electric moped, the engine power of which is approximately the same as for an internal combustion moped. Irrespective of the relatively small engine power, the electric motor vehicles showed sufficiently good dynamic characteristics owing to their excellent engine power and torque curves.

To compare the acceleration parameters more precisely, a graph $v = f(t)$, which is shown in Fig. 2, was constructed.

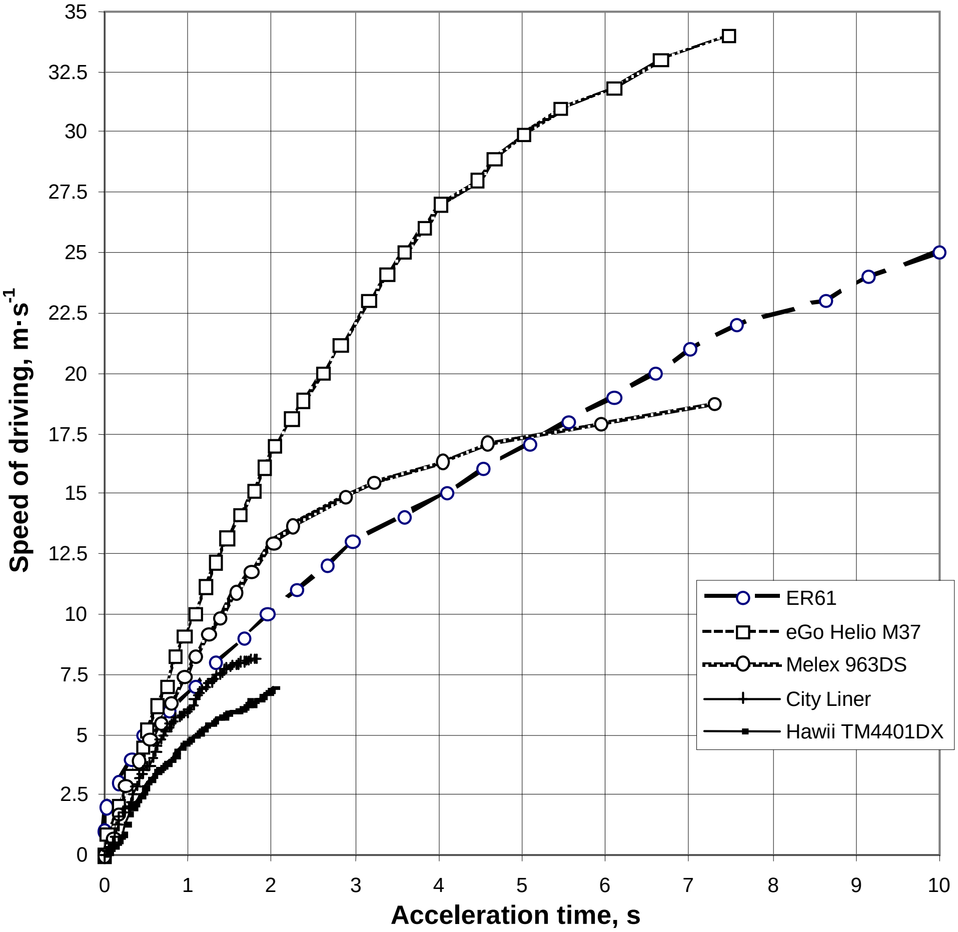

Fig. 2. **Acceleration dynamics for slow-moving electric motor vehicles**

In case if the vehicle power is not sufficient to achieve good dynamic characteristics, the speed curve is steep. At larger speeds of driving when the engine power reaches its maximum, the acceleration curve becomes flatter. As regards the electric motor vehicles studied, the curve bending point is reached at (0.7-0.8) $v_{\max}$.

According to provisional studies, if this speed of driving is exceeded, the engine of the electromobile is overloaded and consumes more electric energy accumulated in the battery. Therefore, the distance of driving of vehicles per battery charge decreases. Among all the electric motor vehicles, the most explicit bending point is observed for the electromobile Melex 963DS, which is reached at approximately 15 $km \cdot h^{-1}$ or after 3 second acceleration. Further acceleration, until the maximum speed is reached, takes place very slowly.

A fact has to be noted that sometimes producers indicate larger speeds of driving for their electric motor vehicles than it is in reality. The maximum speed of driving (6 $km \cdot h^{-1}$), which is shown in the technical characteristics, is reached only by the electric shopping cars.

As in the acceleration analysis of a speed of up to 15 $km \cdot h^{-1}$, the fastest acceleration at the full range of speed was also observed for the electric moped eGO Helio M37. It reaches the maximum speed of driving in 7.49 seconds. Such acceleration is quite convenient for urban traffic and for merging into the flow of traffic. Given the relatively small speed of driving and the large size of it, the electromobile Melex 963DS is not well suited for urban traffic. It, according to the producer recommendations, can be better used for entertainment trips in streets without heavy traffic and outside urban areas when the nature can be enjoyed owing to the lack of engine noise.

The dynamics of the electric shopping cars is the lowest among the vehicles studied. Yet, taking into account the specifics of using these vehicles – on sidewalks, in shops, and on pedestrian crossings – the maximum acceleration is achieved in less than two seconds, which is absolutely sufficient. These vehicles can compete with pedestrians and are even faster than an average pedestrian, taking into consideration their distance of driving of up to 40 km and their maximum speed of driving that exceeds the average speed of walking of pedestrians.

The acceleration distance (see Fig. 3) was analysed only for the electric motor vehicles that run faster than 10 $km \cdot h^{-1}$. The acceleration distance for the electromobile Melex 963DS is 28.8 m, but the electric moped needs a distance of 47.39 metres to achieve its maximum speed. The largest acceleration distance or 59.28 m was observed for the electric bicycle, which can be explained by its small engine power.

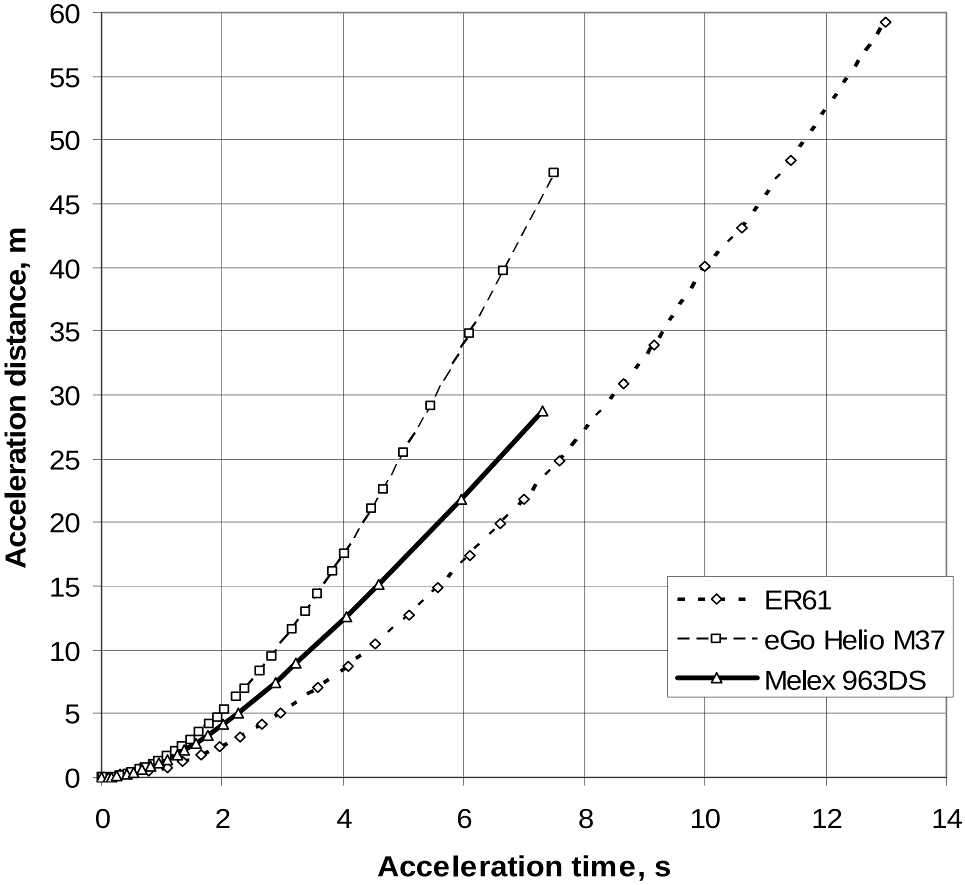

Fig. 3. **Acceleration distance for electric motor vehicles**

Conclusions

1. Various slow-moving vehicles are available in the Latvian market, yet their popularity is limited by the high price of these vehicles.
2. The largest specific power or 12.50 $kW \cdot t^{-1}$ belongs to the electric moped, which ensures the highest indicators of dynamics for it – the acceleration time to reach a speed of 15 $km \cdot h^{-1}$ is achieved in 1.77 s.
3. The longest acceleration time or 4.62 s is required for the electric bicycle ER61 to reach a speed of 15 $km \cdot h^{-1}$ due to its low specific power indicator.
4. Irrespective of the relatively small engine power, the electric motor vehicles showed sufficiently good dynamic characteristics owing to their excellent engine power and torque curves.
5. The optimum average speed of the electric motor vehicles studied is (0.7-0.8) $v_{\max}$ which ensures the largest distance of driving for the electric motor vehicles.

6. In the technical characteristics, the producers of slow-moving electric motor vehicles have showed on average 10 % larger speed of driving than it was achieved in the experiments.
7. The best indicators of dynamics were observed for the electric moped eGO Helio M37; it reaches the maximum speed of driving in 7.49 seconds.
8. The dynamics of the electric shopping cars is the lowest among the vehicles studied, yet, given the specifics of using these vehicles, the maximum acceleration is achieved in less than two seconds, which is sufficient.

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INVESTIGATION OF ELECTRIC CAR ACCELERATION CHARACTERISTICS PERFORMING ON-ROAD TESTS

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Abstract. Use of electric cars have several potential benefits compared to conventional internal combustion automobiles, for example, a significant reduction of urban air pollution, less dependence on foreign oil etc. Despite these benefits, several problems limit widespread application of electric cars. Electric cars are significantly more expensive than conventional internal combustion (IC) engine vehicles due to the additional cost of their battery pack. However, battery prices are coming down and expected to drop further. Other factors deterring the adoption of electric cars are the lack of public recharging infrastructure and the driver's unfamiliarity with the electric car dynamic characteristics compared with vehicles powered by IC engines.

This article deals with the electric car *Fiat Fiorino Elettrica HC-S* acceleration characteristic studies testing the car on real road. The car's acceleration intensity was determined using the scientific radar *Stalker ATS* on 1 km long road section with fully charged batteries without load, with a partially (25 – 30 %) charged batteries without load and with fully charged batteries and a 500 kg load. A time to run the car from 0 to 95 km per hour, and from 50 to 90 km per hour was measured. Speed curves according to the travelled distance were obtained. It was found that without load electric car acceleration time with 30 % charged batteries was only 1.9 – 2.5 % higher than with fully charged batteries. Loading the car, the time increases by approximately 34 %. Acceleration distance was even greater and reached 39 %.

Keywords: electric car, acceleration run, acceleration intensity, scientific radar.

Introduction

World energy resources are limited, but environmental pollution is increasing. One of the major energy consumers and polluters of environment is the road transport. According to different scenarios world energy resources may be sufficient for only next 40 to 60 years [1; 2].

Consequently, there is a need to introduce new vehicles that are environmentally friendly and consume less fossil fuel. One of such vehicle types is electro vehicle. Using of them may localize the production, utilization, and exploitation pollution, as well as it is possible to use various forms of energy:

- electricity produced from renewable resources – solar, wind, and hydro energy;

- energy derived from renewable resources by energy transfer to electricity – biogas or biofuels produced electricity in cogeneration plants;
- energy from non-renewable natural resources or environmentally harmful resources – nuclear, coal or oil energy.

Depending on the type of energy, i.e., on how the electricity is produced, electric car will be more or less environmentally friendly.

Significant electric vehicle exploitation parameter is the dynamic behaviour that allows to judge about the following features:

- electric cars fitness for road traffic, the ability to integrate into the traffic flow;
- identification of the most cost-effective driving speed to ensure maximum mileage per charge;
- ability to safely perform dynamic manoeuvres, such as the run-up and overtaking.

Materials and methods

Investigation of electric car acceleration characteristics was carried out in cooperation with the public limited company *Latvenergo AS* using their electric car *Fiat Fiorino Elettrica HC-S.*

Fiorino is conceived for build-up urban environments and small cities. It combines performance, agility and comfort with the load capacity, ease of loading and unloading, reliability and productivity of a light commercial vehicle. The car's main technical parameters [3]:

- category – M1;
- motor – asynchronous, nominal power 30 kW, maximal power (peak) 60 kW;
- brakes – energy recovery;
- recharging socket – 230 VAC – 16 A – 3 kW;
- battery – lithium up to 31.1 kWh;
- grade ability – 24 %;
- transmission – direct drive;
- maximum speed – up to 115 $km \cdot h^{-1}$;
- distance of run with a single full charge (range ECE 101 cycle) 100 km;
- coupe heating system with a fossil fuel.

The car's acceleration intensity was determined using the scientific radar *Stalker ATS* (See Fig. 1) on 1 km long road section.

Fig. 1. **Electric car *Fiat Fiorino Elettrica HC-S* and scientific radar *Stalker ATS***

The *Stalker Acceleration Testing System* (*STATS*) is the combination of the *Stalker ATS Professional Radar Gun* and the powerful *Stalker ATS* software program. It is a portable and accurate system for testing and analyzing vehicle performance. *STATS* provide a detailed picture of the dynamics of acceleration. It is the ultimate tool for racers and manufacturers to test and tune products for maximum performance. The *ATS* gun measures the speed of the vehicle at precise intervals, and then sends those speed samples to the computer.

The *Stalker ATS* software program saves the speed data, assigns time information, and then calculates distance and acceleration rates for each data sample. This data is then saved as a file on the computer's hard drive. Since speed, time, distance and acceleration are mathematically related, having any two of these measurements means the other components can be derived with absolute accuracy.

The radar's main technical parameters [4]:

- speed range: 1 – 480 $km \cdot h^{-1}$;
- accuracy: ±1.069 $km \cdot h^{-1}$;

- target acquisition time: 0.01 s;
- maximal range for cars: 1.82 km;
- weight: 1.45 kg;
- RS-232 communication system.

Before the experiment a full battery charge was performed under laboratory conditions. Experiments were carried out on a flat and straight asphalt road surface with an average rolling resistance coefficient from 0.018 to 0.020. Road surface was dry, ambient temperature +15 ºC. Wind speed didn’t exceed 2.8 $m \cdot s^{-1}$. Going to the experiment site, the car travelled 12 km.

Starting the experiment the radar was placed 5 meters behind the car. Two operators participated in the experiment. One worked with the radar, which is connected to a portable computer, the second has driven the car. Operators communicated through portable radio set. After the radar operator commands, the car driver started the car’s sharp run-up, pressing the accelerator pedal all the way. Experiment was performed from 0 $km \cdot h^{-1}$ until maximum speed was achieved. After the test car returned to starting position and the next experiment repetition was carried out.

The experiment was repeated to determine the driving dynamics from 50 to 90 $km \cdot h^{-1}$. Driving started 100 – 150 meters before the radar so that crossing the radar detection area a steady speed of 50 $km \cdot h^{-1}$ was reached. After that the run-up to 90 $km \cdot h^{-1}$ was performed.

Each experiment was repeated 5 times. If during the test another car appeared on the road and disturbed the radar measurements, the experiment was repeated. From all five repetitions three were selected with the closest data, i.e., with the highest correlation between experimental series data points. Average values were calculated from at least 3 repetitions if correlation between the series data points was at least 0.995, i.e., above 99.5 %. After that curves $v = f(t)$, $s = f(t)$, $v = f(s)$ were constructed.

Experiments were carried out with fully charged batteries without load, with a partially (about 25 – 30 % of maximal capacity) charged batteries without load and with fully charged batteries and a 500 kg load.

The block diagram of experiments is shown in Figure 2. Electric vehicle tests were carried out in two stages, because with a single charge is not possible to provide a full cycle of the experiment and come back to the laboratory. In the first stage experiments with fully charged and partially charged batteries were performed, in the second stage – recharging batteries and loading the car with 500 kg weight, thus achieving a gross weight of the car.

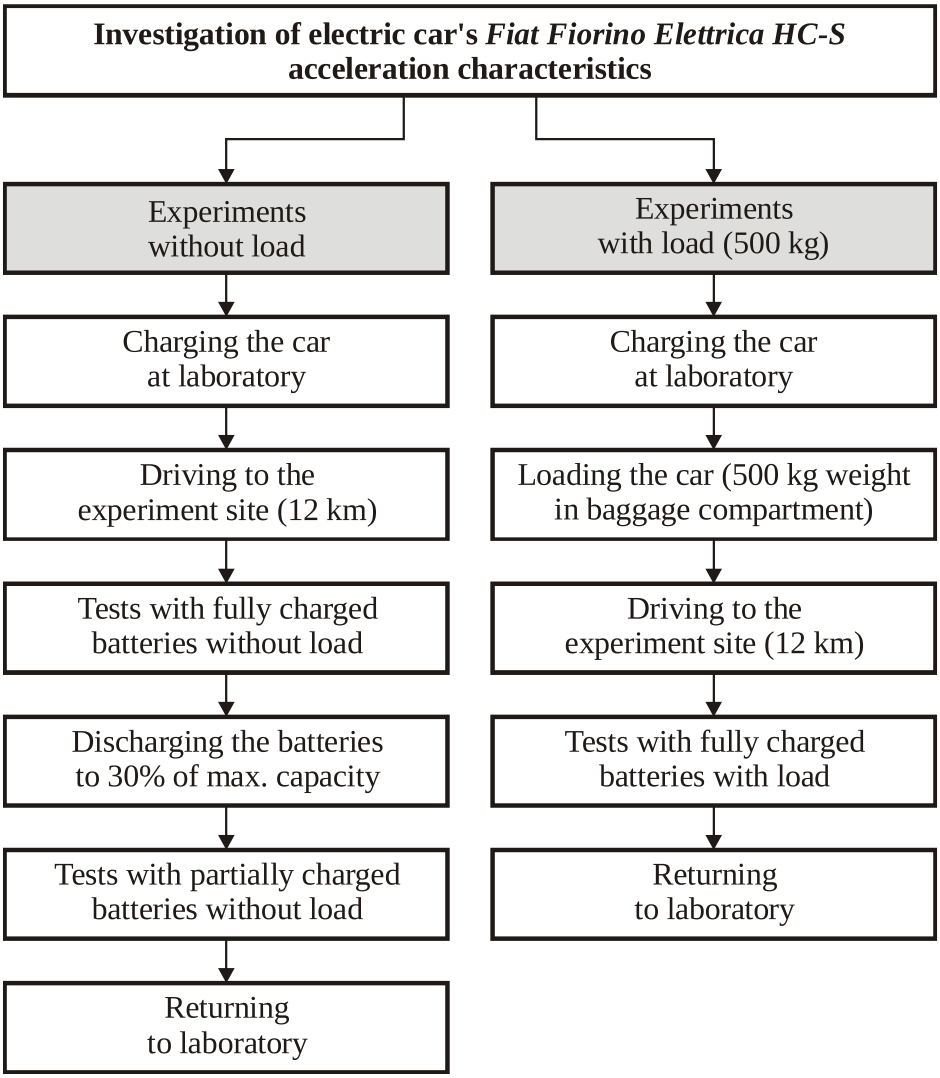

Fig. 2. **Block diagram of experiments**

Results and discussion

Acceleration characteristics, testing the car with fully charged batteries without load, are shown in Figure 3. As the maximum speed of 100 $km \cdot h^{-1}$ in any of the tests was not achieved, the speed 95 $km \cdot h^{-1}$ was chosen for comparison, which was reached also driving with the load and partially charged batteries. Data processing showed that the speed of 95 $km \cdot h^{-1}$ is achieved in 24.13 seconds, this time driving 421.15 meters long distance.

Figure 4 shows the acceleration characteristics, testing the car with partially (25 – 30 %) charged batteries without load.

The speed of 95 $km \cdot h^{-1}$ is achieved in 24.58 seconds during 431.45 meters long distance.

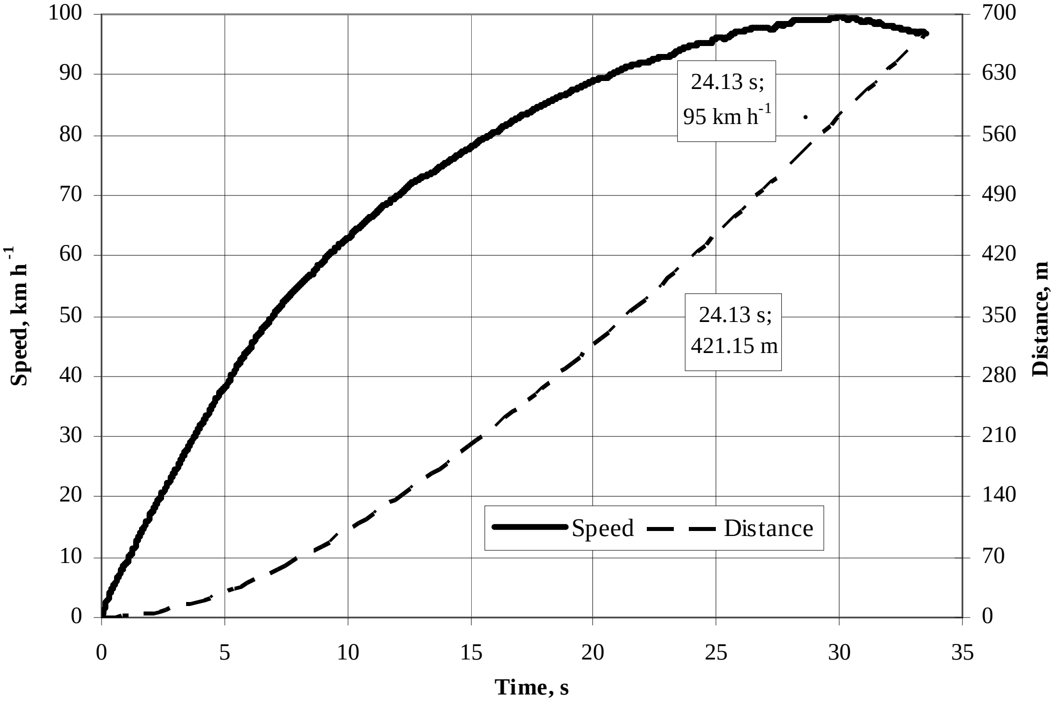

Fig. 3. **Acceleration characteristics, testing the car with fully charged batteries without load**

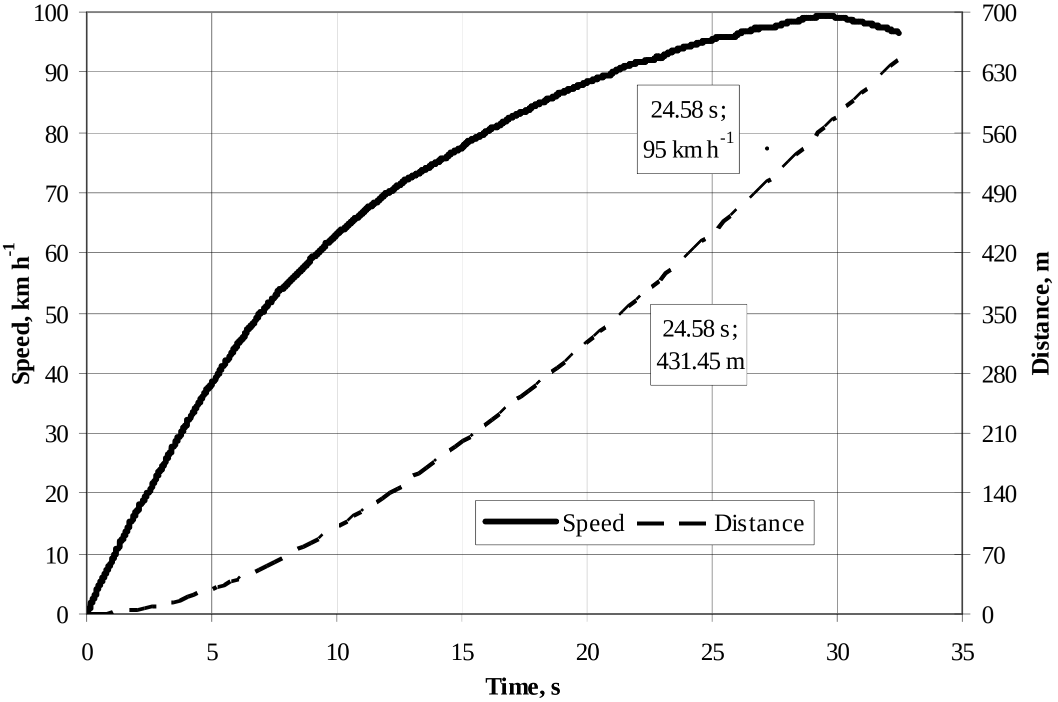

Fig. 4. **Acceleration characteristics, testing the car with partially (25 – 30 %) charged batteries without load**

Acceleration characteristics, testing the car with fully charged batteries and a 500 kg load, are shown in Figure 5. The speed of 95 km·h^{-1} is achieved in 32.90 seconds during 588.00 meters long distance.

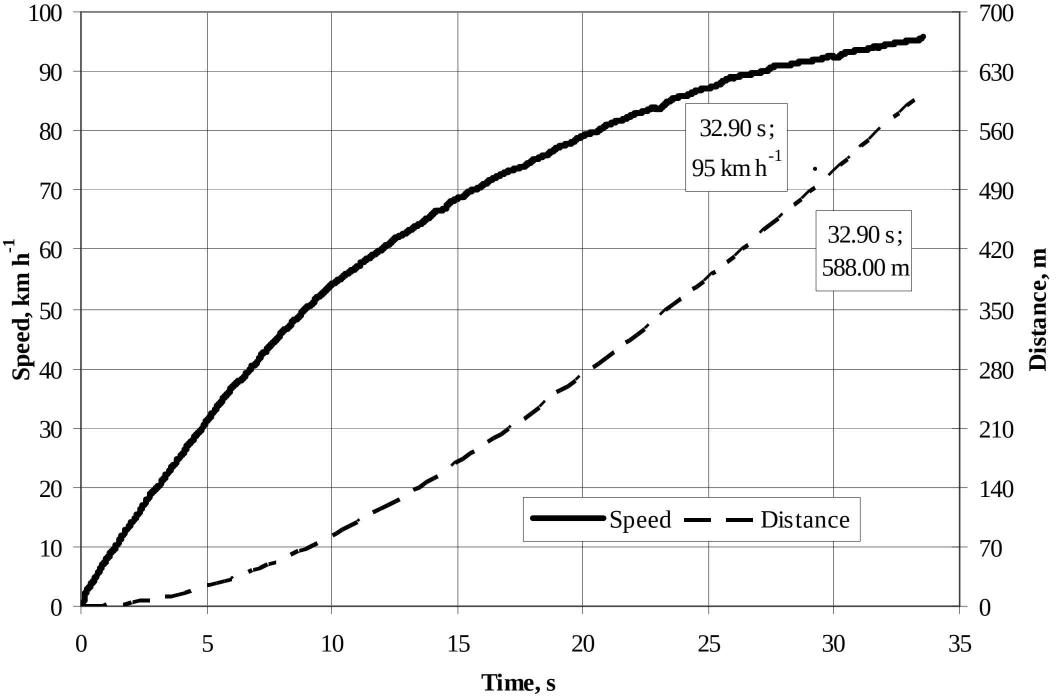

Fig. 5. **Acceleration characteristics, testing the car with fully charged batteries and a 500 kg load**

Due to the fact that the acceleration is regulated by the Electronic Control Unit of electric vehicle, the run-up (speed and distance) curves in the covering range of speeds accelerating from 0 to 95 km per hour, and from 50 to 90 km per hour are very similar and differ by less than 3 %. All the above-mentioned test mode results are summarized in Table 1.

Without load and with 30 % charged batteries electric car acceleration time from 0 to 95 km·h^{-1} and from 50 to 90 km·h^{-1} was accordingly only 1.9 % and 2.5 % higher than with fully charged batteries, but acceleration distance – in average 2.4 % longer. Loading the car, the time increased by approximately 34 %. Acceleration distance was even greater and reached 39 %.

For comparison, petrol-powered *Fiat Fiorino Combi 1.4 Euro 5* (1368 cm^3, 54 kW) from 0 to 100 km·h^{-1} accelerates in 16.6 seconds, while gas-powered – in 17.5 seconds [5; 6]. Of course, in such view electric car is much less dynamic, but that comparison is not really correct, since the maximum speed for the petrol car is 155 km·h^{-1} and accelerating to

100 km·h^{-1} is far from the maximum speed, while for the electric car this speed is close to maximum. Therefore, more objective would be to make a comparison, for example, accelerating up to 80 km·h^{-1}. This was confirmed by additional experiment, in which the car *Renault Trafic 2.0 DCI* was tested. Although the car's engine is 3 times more powerful than the *Fiat Fiorino Elettrica HC-S*, *Renault* up to 80 km·h^{-1} accelerates in 14.05 seconds, but *Fiat* – in 15.72 seconds, i.e., the difference is not huge.

Table 1

Summary of acceleration parameters in all test modes

No.	**Test mode**	**Test results**				
		Acceleration time from 0 to 95 km·h^{-1}, s	**Acceleration distance from 0 to 95 km·h^{-1}, m**	**Speed at 500 m mark, km·h^{-1}**	**Acceleration time from 50 to 90 km·h^{-1}, s**	**Acceleration distance from 50 to 90 km·h^{-1}, m**
1.	Fully charged batteries without load	24.13	421.15	97.67	13.86	283.95
2.	Partially (25 – 30 %) charged batteries without load	24.58	431.45	97.55	14.21	290.79
3.	Fully charged batteries and a 500 kg load	32.90	588.00	92.10	18.37	377.21

Conclusions

1. In experiments with a fully charged batteries without load car *Fiat Fiorino Elettrica HC-S* shows enough good dynamic performance, accelerating to 95 km·h^{-1} in 24.13 seconds, to 80 km·h^{-1} – in 15.72 seconds, and to 50 km·h^{-1} (that is important for driving in the city) – in 7.07 seconds.
2. Electric car's dynamics with partially discharged batteries is close to fully charged batteries. Acceleration time from 0 to 95 km·h^{-1} and from 50 to 90 km·h^{-1} was accordingly only 1.9 % and 2.5 % higher than with fully charged batteries.
3. Loading the car, the acceleration time increased by approximately 34 %, but acceleration distance – by 39 %.
4. Considering that the tested electric car's maximum speed is close to 100 km·h^{-1}, for comparison with the internal combustion engine vehicles it's recommended to choose a lower speed, for example, 80 km·h^{-1}, when the entire vehicle dynamics has not yet been spent.

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RESEARCH OF RUNNING DISTANCES OF ELECTRIC VEHICLES IN URBAN AND EXTRA URBAN REGIMES

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Abstract. In order to research the running distance of an electrical vehicle in urban and extra urban regimes in dependence on the vehicle load Fiat Fiorino Elettrico HC-S was used. The car running distance was determined using the scientific data logger HOLUX GPSport245. The maximal driving distance of the electric vehicle with full charged battery in urban regime without load reached 99 km and the average driving speed 30.69 $km \cdot h^{-1}$, but with load the driving distance reached 90.7 km and the driving average speed 28.03 $km \cdot h^{-1}$. The maximal driving distance of the electric vehicle with full charged battery in extra urban regime with a driver and one passenger reached 95 km and the average driving speed 63.72 $km \cdot h^{-1}$. The running distances of the electric vehicle largely depend on the battery type, its condition (new or used), vehicle load and driving regime.

Key words: electric vehicle, running distance.

Introduction

Nowadays, a great part of manufacturers offer their own range of electric vehicle models. As of March 2012 series production models available in some countries include the Tesla Roadster, REVAi, Buddy, Mitsubishi MiEV, Tazzari Zero, Nissan Leaf, Smart ED and others. Cars with internal combustion engines can be considered to have indefinite range, as they can be refuelled very quickly almost anywhere. Electric cars often have less maximum range on one charge than cars powered by fossil fuels, and they can take considerable time to recharge. Running distances of electric vehicles largely depend on the battery type, its condition (new or used), vehicle load and driving mode. This is a reason why many automakers marketed electric vehicles as "daily drivers" suitable for city trips and other short hauls. The technical information of the manufacturers is often of electric performance parameters indicating a car that is not loaded with passengers or load. In addition, the distance parameters are obtained under laboratory conditions, which correspond to the real situation on the road. These parameters are obtained under laboratory conditions that are not fully compatible with the realities on the road. In this investigation a small duty electrical truck Fiat Fiorino Elettrica HC-S with a gross weight of up to 3500 kg was used. The main purpose of the experiments is to determinate the electric vehicle running distance in urban and extra-urban regimes.

Materials and Methods

The investigation in electric car acceleration characteristics was carried out in cooperation with the public limited company Latvenergo AS using their electric car Fiat Fiorino Elettrica HC-S. Fiorino is provided for build-up urban environments and small cities. It combines performance, agility and comfort with the load capacity, ease of loading and unloading, reliability and productivity of a light commercial vehicle. The experiments have been performed in urban and extra urban regimes of Jelgava. In order to research the running distance of electrical vehicle (Fig. 1) in urban and extra urban regimes in dependence on the vehicle load Fiat Fiorino Elettrico HC-S was used. The experiments were carried out with fully charged batteries in urban regime without load and a 500 kg load, but in extra urban regime without load.

The main technical parameters of the car [1]:

- category – M1;
- motor – asynchronous, nominal power 30 kW, maximal power (peak) 60 kW;
- brakes – energy recovery;
- recharging socket – 230 VAC, 16 A, 3 kW;
- battery – lithium up to 31.1 kWh;
- grade ability – 24 %;
- transmission – direct drive;
- maximum speed – up to 115 $km \cdot h^{-1}$;
- distance of run with a single full charge (range ECE 101 cycle) 100 km.

Fig. 1. **Experimental electric vehicle *Fiat Fiorino Elettrico HC-S***

The experiments were performed on asphalt road surface with an average rolling resistance coefficient from 0.018 to 0.022 and with a fully charged battery. The experiments were carried out at time when the road surface was dry and the ambient temperature +10 – 20 °C. Wind speed did not exceed 3 m·s^{-1}. The electric driving experiments are carried out in the center of Jelgava, which is more heavily loaded.

The experiments were carried out continuously, without significant car stop, except when required by the traffic conditions. For the electric vehicle battery discharged level illustration the indicator on the vehicle dash-board was used (Fig. 2).

Fig. 2. **Charging position of electric vehicle battery indicator:**

1-7 – vourious charging position of battery indicator; 8 – minimum volume of battery charge level; 9 – batteries fully discharged; 10 – warning lamp; 11 – battery warning lamp; 12 – battery voltage.

If the charge indicator has reached the red zone (see the 2nd Fig. 8), the average electric remaining mileage is 15 miles. At this moment, the yellow light illuminates, this shows some remaining mileage. If the electric vehicle was used further the vehicle speed reduction or dynamic parameters did not decrease. When the batteries are fully discharged the indicator is in the red area at the bottom line (see the 2nd Fig. 9), the yellow warning signal turns on and the electric vehicle stops to work. Charging the electric vehicle batteries approximately for 2 hours the batteries can be charged to the extent when the electric vehicle can take 30 – 35 km mileage.

The urban route of the experiment was incorporate of 28 controllable and 3 uncontrollable junctions. The urban route distance of the experiment was 14.6 km, but the extra urban was 45 km. The urban route is shown in Figure 3. The experiment route contains different driving intensity where the driving speed changes from 50 till 70 km·h^{-1}.

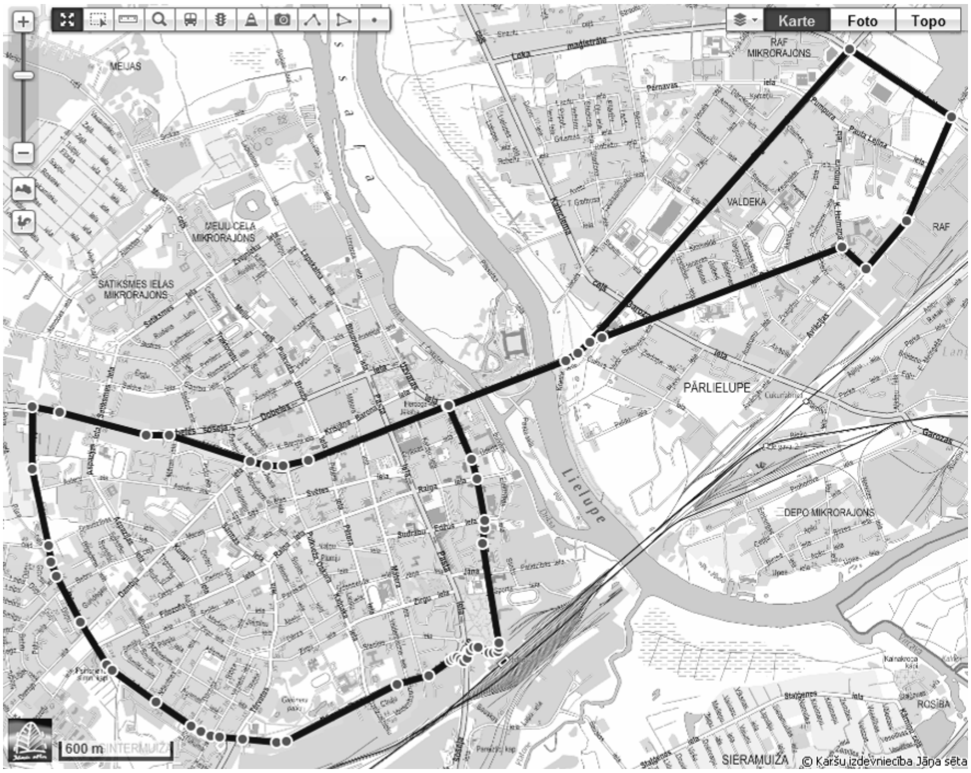

Fig. 3. **Experiment route in urban regime**

Using the universal data collection and processing logger HOLUX GPSport245 [2], the electric car running distance, speed and time in urban and extra urban regimes of Jelgava is measured. After the experiment the mileage is compared with the odometer values.

The logger technical parameters [2]:

- weight – 72 g with battery;
- memory – RAM: 64KB;
- display – 128 × 128 dots;
- IO interface – Mini-USB charging;
- adaptor – input 100 – 240 VAC, 0.5 A max, DC output 5 V/1 A thought Mini-USB;
- function – save log data and 200,000 waypoints, show speed, time, routes, log, G-finder;
- environment temperature – operating temp. -10 ºC to 60 ºC, storage temp. -20 ºC to 70 ºC.

Each measurement was repeated three times [3] till fully discharged batteries. From all three repetitions the average values were calculated if the correlation level between the series data points was at least ($\alpha = 0.95$, $P = 0.05$, $t = \pm 3\sigma$).

Results and Discussion

Changing the electric vehicle load and the experiment route different driving distances and average driving speeds are acquired. The electric car different driving speed and load changes during the experiments in urban and extra urban regimes are shown in Figure 4.

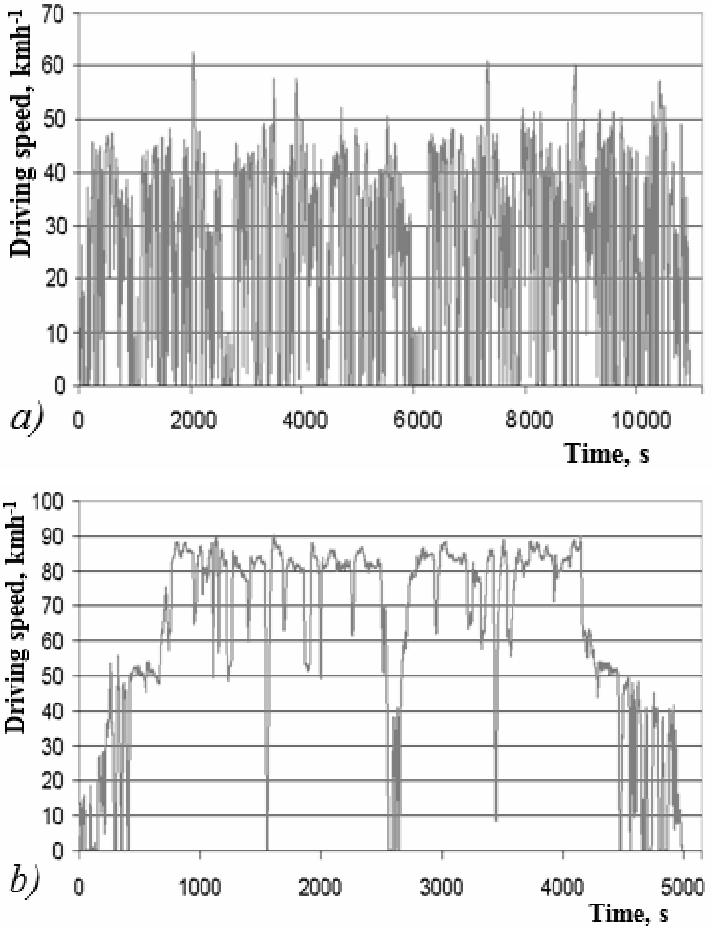

Fig. 4. **Driving speed diagram of electric car:**
a – driving speed in urban regime; b – driving speed in extra urban regime

Fig. 4a describes that the most cases of the experiment speeds did not exceed 50 km·h^{-1} in urban regime. At one stage of the experiment route the driving speed increased till 70 km·h^{-1}. Fig 4b describes the average speed in extra urban route and movement and stops of the electric vehicle.

The odometer average value indication compliance with the discharge indicator at urban and extra urban mode is summarized in Table 1. If the electric vehicle batteries are fully charged their summary voltages do not exceed 300 V, but if the batteries are discharged the summary voltage decreases till 250 V.

Table 1

Odometer value indication compliance with the discharge indicator

No	**Position of Indicator (Fig. 2)**	**Urban running regime**		**Extra urban running regime**	
		Running distance from beginning of experiment, km	**Voltage according to dash-board, V**	**Running distance from beginning of experiment, km**	**Voltage according to dash-board, V**
1.	1.	0.0	296.9	0.0	293.4
2.	2.	11.5	283.9	12.3	285.9
3.	3.	25.0	276.5	24.3	276.0
4.	4.	37.0	272.4	36.7	268.4
5.	5.	50.5	264.7	52.0	260.7
6.	6.	61.0	261.5	64.3	258.2
7.	7.	72.5	259.1	76.7	257.2
8.	8. light illuminate	81.5	256.4	86.7	252.4
9.	Experiment finish	**90.5**	254.3	**95.0**	251.4

In all experiment replicates the batteries charge indicator marks achievement of the mileage is not differing by more than ± 1 km, which allows a sufficiently accurate assessment of the remaining electric vehicle millage.

In Table 2 the parameters of all three experimental repetitions and their average values are shown. After the complete series of the experiments conducted, data were collected and compared with the experiments in other mileage modes.

Table 2

Summary of exploitation parameters

No	**Urban running regime (with load)**			**Extra urban running regime**		
	Running distance, km according to odometer/ logger	**Average speed, km·h^{-1}**	**Driving time**	**Running distance, km according to odometer/ logger**	**Average speed, km·h^{-1}**	**Driving time**
1.	95/91.9	28.13	3 h 10 min	100/97.27	68.24	1h 25min
2.	86/83.3	26.27	2 h 54 min	92/88.36	60.06	1h 30 min
3.	91/81.1	29.68	3h 15 min	93/90.40	62.87	1h 26 min
Average	90.7/85.4	28.03	3 h 6 min	95/92.01	63.72	1h 27 min

The average running distance and average speeds of the two routes, testing the electric vehicle with fully charged batteries with load and without it, are shown in Figure 5. According to the image it is seen that in the experiments at different movement modes with load, and in extra-urban traffic the electric vehicle has similar tendencies as the internal combustion engine vehicle. The only difference – in the urban traffic the electric engine vehicle has a little more mileage that is not characterized to an internal combustion engine vehicle.

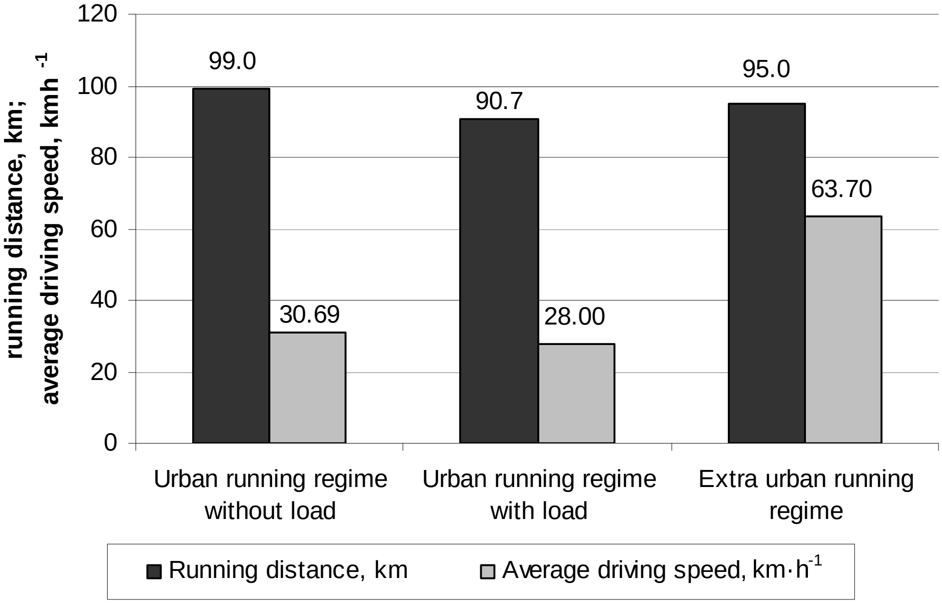

Fig. 5. **Electric vehicle parameters of running distance at different route regimes**

The maximal running distance of the electric vehicle Fiat Fiorino Elettrica HC-S with full charged battery in urban regime without load reaches 99 km and the average driving speed 30.69 km·h^{-1}, but with load the driving distance reaches 90.7 km and the driving average speed 28.03 km·h^{-1}. The maximal running distance of the electric vehicle with full charged battery in extra urban regime with a driver and one passenger reaches 95 km and the average driving speed 63.72 km·h^{-1}. Due to the fact that the exploitation parameters are regulated by the Electronic Control Unit of the electric vehicle the average running distance of the electric vehicle at all experimental modes was within 90 to 100 km.

Because of the full electric vehicle load, the mileage has decreased about 8.4 % in comparison with urban mode without load (driver and passenger – 150 kg). This is due to the resistance of inertia to overcome in the vehicle run-up mode with the load that reduces the electric vehicle mileage.

A similar trend should be observed with heavier batteries, for example, lead-acid batteries.

Conclusions

1. In the experiments with fully charged batteries without load the car Fiat Fiorino Elettrica HC-S shows enough good dynamic performance in urban regime and the electric car dynamics with partially discharged batteries is close to fully charged batteries.
2. Loading the car, the running distance decreased by approximately 8.4 %, but the average speed – till 8.7 %.
3. The maximal running distance of the electric vehicle Fiat Fiorino Elettrica HC-S with full charged batteries in urban regime with load reached 99 km and the average driving speed 30.69 km·h^{-1}, but with load the driving distance reached 90.7 km and the driving average speed 28.03 km·h^{-1}.
4. The maximal running distance of the electric vehicle with a full charged battery in extra urban regime with a driver and one passenger reached 95 km and the average driving speed 63.72 km·h^{-1}.

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STUDY OF ENERGETIC BALANCE OF REGENERATIVE ELECTRIC VEHICLE IN A CITY DRIVING CYCLE

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Abstract. The article describes the research of electrical system for the electric vehicle Melex 963 of city driving cycle. Vehicle intended for use in airports and aerodromes, national parks, hotel complexes, tourist trips and for passenger transport in manufacturing areas. The lead-acid batteries (nominal voltage 48 V) and electric motor (nominal power 3.9 kW) with a 16:1 gear and specific power 3.44 $kW \cdot t^{-1}$ are used. The battery charge and discharge curves at constant current and the load were measured for three city drive cycles. The speed and acceleration were logged with the GPS data logger device.

Keywords: electric vehicle, regenerative braking, city cycle run.

Introduction

With the more stringent regulations on emissions and fuel economy, global warming, and constraints on energy resources, the electric, hybrid, and fuel cell vehicles have attracted more and more attention by automakers, governments, and customers. The need to reduce fossil fuel consumption and emissions in automobiles and other vehicles predominately powered by internal combustion engines is well known. If fuel cell vehicles go into production in the near future, their degree of hybridization will significantly impact the vehicle price due to high manufacturing and material costs of fuel cells and batteries. Vehicles powered by electric motors attempt to address these needs. The global optimization of energy management systems are based on knowledge of the future driving conditions, as provided by scheduled driving cycles. In this approach, two main constraints must be accounted for:

- very limited a priori knowledge of the future driving conditions is available during the actual operation;
- the charge of the reversible energy source must be sustained without external sources, but based only upon fuel conversion or regenerative braking during the vehicle operation [1].

For many hybrids and electric vehicles the regenerative battery charging is used, when the braking energy is converted into electrical energy and therefore recharges the battery.

In literature it is noted that up to 60 % of braking energy can be recovered, it depends on the total mass of vehicle [2]. Similarly, in city modes, at low speeds, significantly more energy can be recover, the less impact on the aerodinamic properties and more brake are used [3]. Regenerative braking is the energy recovery benefit of hybrid vehicles. The former is strictly through regenerative braking while the latter uses the energy recovered through regenerative braking and steady speed driving when vehicle energy conversion is optimal [4].

In the experiments electric vehicle Melex 963 was used, which has such a regenerative energy recovery method implemented in SepEx motor controller. The vehicle has lead-acid batteries with nominal voltage 48 V, 190 Ah at 75 A discharge rate, 3.9 kW electric motor with a 16:1 gear and $3.44\ \mathrm{kW \cdot t^{-1}}$ specific power. Total mass of the vehicle during the experiments was 912 kg.

Materials and methods

Fig. 1. shows the main power components and the experimental setup on the test vehicle.

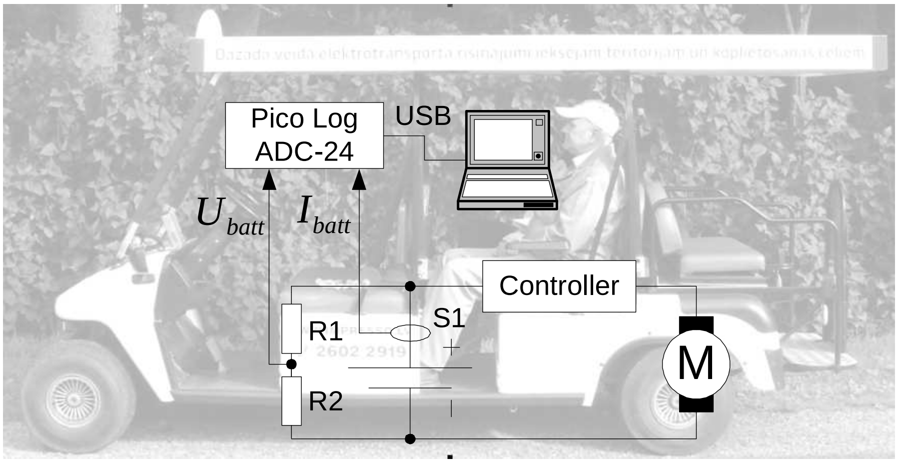

Fig. 1. **The main power components and the experimental setup on Melex 963**

During the test runs battery voltage and current were measured. The current measurements were performed using Hall-type current transducer S1 placed at the positive lead before motor controller and other consumers; voltage was measured at the leads of batteries using voltage divider R1-R2. APPA32 was used as a current sensing device with voltage output, 100 A measurement range was set, accuracy ±(2 % + 2 A) = ±4 A, which corresponds to 0…1 V ±40 mV voltage output. Coefficient of the voltage divider was (46.99 ±0.027 kΩ)/(1.178 ±0.0027 kΩ) = 27.35.

Error of resistor values in the voltage divider output was neglected. The measured data were acquired using Pico ADC-24 logger and a portable PC. The measurement voltage range of the data acquiring unit for current was set to -1250…+1250 ±1.3 mV and for voltage -2500…+2500 ±5.4 mV, conversion time of both signals 60 ms. The total maximum measurement error for I_{batt} was 4.1 A or 4.1 % of measurement range (including partial errors of the current transducer and logging device), maximum error for U_{batt} was ±0.15 V or 0.3 % of nominal battery voltage (accuracy of the logging device and voltage divider). The data logging interval for both signal was set to 1 s.

GPS data (current coordinates and speed) were logged independently using Holux GPSport245 logger based on MediaTek MT3318 GPS chip, which provides 3 m position accuracy. Speed is calculated from the time and coordinate difference by the GPS logger device. Speed accuracy is not specified, but it can be evaluated from error difference of two concurrent position measurements. The Holux GPSport245 logs position and speed data with 1 s interval. The ambient temperature during all tests was 5 – 8 °C. Batteries were charged to 51 V open circuit voltage before each test. Three test runs were performed in Jelgava on a route shown in Fig. 2.

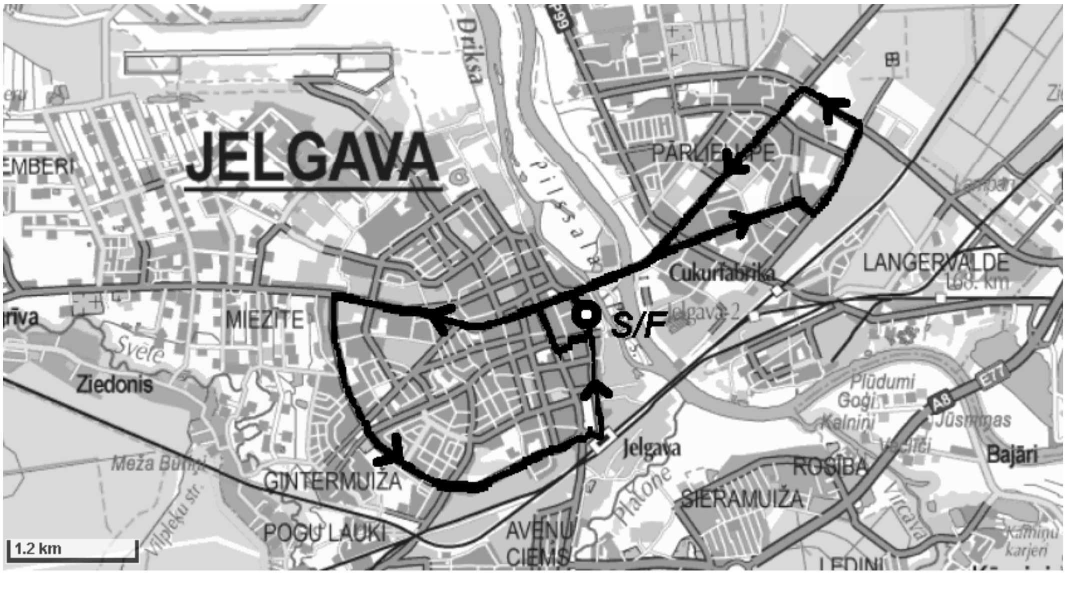

Fig. 2. **Route of the performed test runs:** 2 laps, total distance: 30.94 km

As the electrical and GPS signals were logged using different devices and consequently they have different time basis the synchronization is required. Taking into account comparatively large logging interval, synchronization was done by visually aligning the speed and current consumption curves.

Results and discussion

Electricity is being considered as an alternative to petroleum fuels as an energy source. A pure battery electric vehicle is considered a more efficient alternative to hydrogen fuel propelled vehicle as there is no need to convert energy into electricity since the electricity stored in the battery can power the electric motor. Besides an all electric car is easier and cheaper to produce than a comparable fuel-cell vehicle. The main barriers to the development electric cars are the lack of storage systems capable of providing driving ranges and speed comparable to those of conventional vehicles. The low energy capacity of batteries makes the electric car less competitive than internal combustion engines using gasoline. Yet, as technology improves, cost effective batteries will become available.

Fig. 3. shows the overview of the test run 1 including momentary speed, distance, voltage and current of the battery.

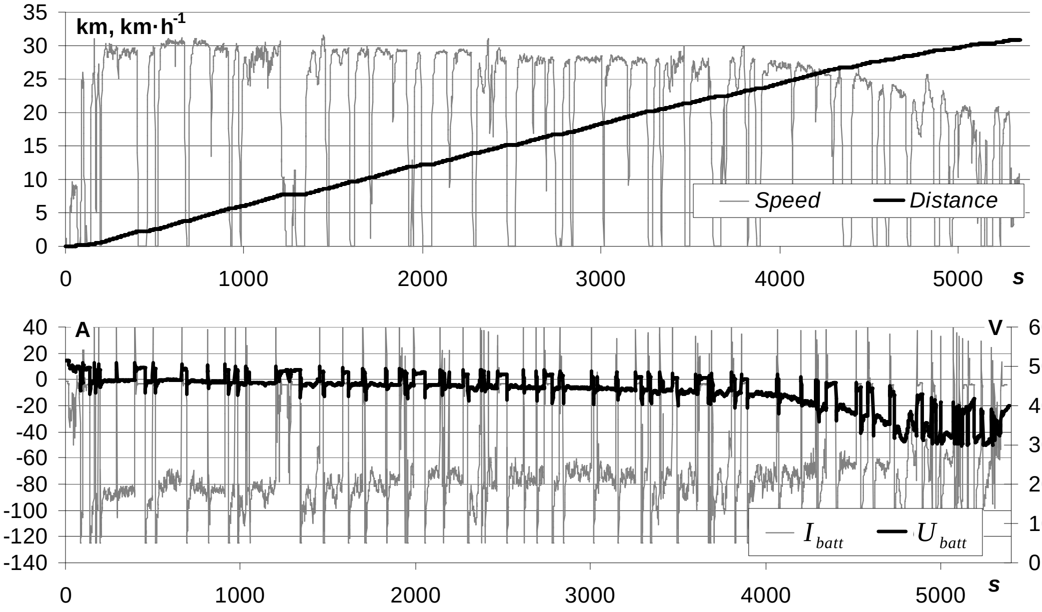

Fig. 3. **Overview of the test run 1**

As the voltage and current measurements were performed directly on the battery total consumed energy is calculated and also the energy acquired from electrical braking and used for the battery charging can be evaluated. The idle current with the vehicle control electronics and low beams turned on is 1.4 – 2.4 A, which is within the limits of measurement error. Total time of the run is 5346 s, at the end of the run open circuit voltage of the battery was 40 V. Changes in voltage correspond to a typical lead-acid battery discharge curve, and consequently the momentary speed decreases as well.

Table 1 summarizes the main statistics for all runs.

Table 1

Statistical summary of three test runs

Run	**Distance, km**	**Total time, s**	**Average speed, km·h^{-1}**	**Energy consumed, kWh**	**Energy regenerated, kWh**	**Energy regenerated, %**
1	30.94	5346	20.84	3.88	0.06	1.6
2		5738	19.41	3.66	0.06	1.6
3		6121	18.20	3.47	0.07	2.1

The energy flow in the battery was calculated using formula (1) by taking into account that measurement interval is constant.

$$W = \sum_{t=0}^{t_n} \frac{U_{batt}(t) I_{batt}(t) \Delta t}{3.6 \cdot 10^{-6}}, \tag{1}$$

where W – energy, kWh;

U_{batt} – measured battery voltage, V;

I_{batt} – measured battery current, A;

Δt – measurement interval, 1 s.

Energy inflow and outflow were calculated separately using positive and negative I_{batt}. The calculations show that only 1.6 – 2.1 % of consumed energy is regenerated during electrical braking and used for battery charging.

Typical start-stop cycles are shown in Fig. 4. The battery discharge current ($I_{batt} < 0$) increases with positive acceleration. During travelling at constant speed I_{batt} changes insignificantly, but at the braking points 1 and 2 battery current becomes positive and begins charge.

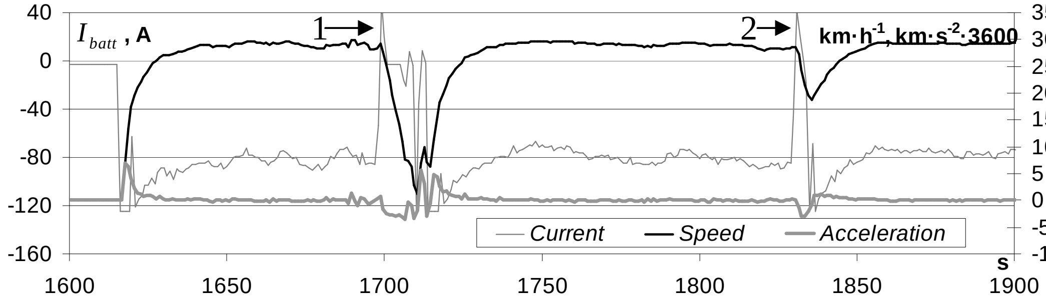

Fig. 4. **Battery current dependence on acceleration**

The histogram of battery power for the three test runs is shown in Fig. 5. As the period of observation is 1 s, histogram value for each point at horizontal axis shows the time in seconds when the corresponding power was applied to the battery for charge and discharge. The largest value is for idle state of the vehicle (low beams and electronics are turned on).

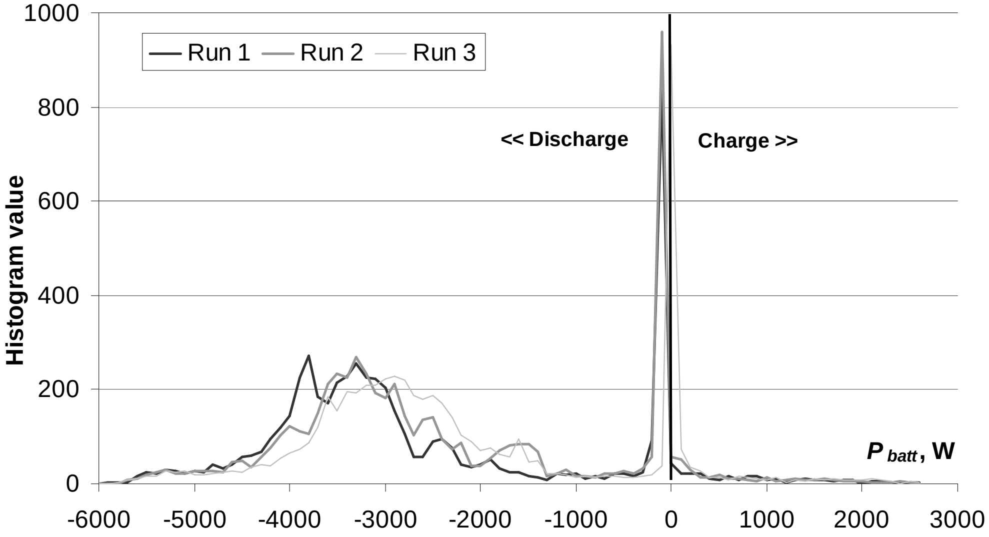

Fig. 5. **Histogram of battery power**

The most of the travel time the vehicle consumed power close to motor nominal. Battery power ranged from 3.1 to 3.9 kW varied from 25 to 37 % depending on the run. There was no load applied to batteries for 15 % of total time due to stops during the run. Battery charging with the braking energy (positive power on the graph) occurred only in 5 % of the total time for the run 1 and 3 and 4 % for run 2.

Conclusions

1. Three city-cycle test runs were performed on the Melex 963 electric vehicle on the same route in order to determine portion of regenerated energy during the electrical braking. Total distance of the test run was 30.94 km. The experimental data was logged with 1 s interval; both electrical (battery voltage and current) and moving (speed, absolute position) parameters were measured.
2. Experiments show, that regenerated energy fraction increased with the drop of the average speed.
3. Battery charging with the braking energy occurred only in 4 – 5 % of the total city-cycle drive time and 1.6 – 2.1 % of the consumed energy was regenerated. The same percentage of total travelling distance can be expected.
4. More tests with different factors that can affect the performance of battery, regenerative braking controller and drive e.g. varying mass, ambient temperature, relief, different average speeds, disabled regenerative braking etc. should be performed.

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INVESTIGATION OF DYNAMICAL AND EXPLOITATION PARAMETERS OF SLOW MOVING ELECTRIC CAR ON CHASSIS DYNAMOMETER

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Abstract. Because of extinction of fossil fuels and increasing pollution of atmosphere scientists and authorities are more and more searching for how to decrease the dependency on fossil fuels. As known, fossil fuels make hazardous emissions. One of the ways how to decrease the impact on environment is to make more efficient internal combustion engines (less consumption; less emission). Another way is to establish alternative fuels (biofuels) or alternative drive (electric drive) of vehicles. A number of regulations have been worked out to increase the specific weight of alternative fuels of total consumption in transport. Electric energy in commercial vehicles is used already for a long time (trolleys, trams, trains) but exploitation of electric vehicles as transport of physical persons is coming more and more topical during the recent years. Electric motor vehicles are more expensive than conventional internal combustion engine vehicles due to the costs of batteries. Expenses of batteries are decreasing and recharging infrastructure is progressing. If amortization costs are ignored then direct driving costs with electric motor vehicle are frequently lower in comparison with internal combustion engine vehicles. The article deals with the low-speed electric motor vehicle *Melex 963DS* dynamical and experimental parameter studies on the power stand *Mustang MD1750*. The dynamical parameters - power, torque, acceleration time and acceleration distance up to 30 $\text{km}\cdot\text{h}^{-1}$ were determined. The exploitation parameters to determine are autonomy, driving time, charging time and charging energy. All parameters, except spin-up curves, were determined with different load regimes and with fully charged batteries. The maximum obtained electric motor power is 5.02 kW at 1858 rpm and maximum achieved torque is 34.54 N·m at 1132 rpm. Acceleration time and distance changes with a load and is from 102 to 155 seconds and from 666 to 1146 meters without load and with 150 % load. The results show that load has no considerable impact on the exploitation parameters of the vehicle driving it on power stand and the difference in autonomy driving the vehicle without load in comparison with overload of 150 % is only 2.623 km, difference in driving time is 00:01:20 h, difference in charging time 00:00:40 h and difference in charging energy 0.03 kWh.

Keywords: slow-moving electric motor vehicle, acceleration time, acceleration distance, charging energy, charging time, driving time, power curve, torque curve, chassis dynamometer.

Introduction

Emission standards for vehicles in many countries are based upon the *United Nations Economic Commission for Europe* (UN ECE) standards commonly referred as *Euro* standard. Current emission standards in the EU countries are referred to as *Euro1* up to *Euro5*, whereas *Euro5* comprises the strictest emission standard. Internal combustion engine vehicles produce such hazardous gases as nitrogen oxides (NO_x), carbon oxides (CO, CO_2), hydrocarbons (HC), charcoal fumes, smuts, sulfur dioxide (SO_2), benzene and lead. In Fig. 1 Euro limits for diesel fuelled commercial vehicles are described, whereas *Euro5* comprises the strictest emission standard [1]. The *Euro6* standard is worked out and it is planned that this standard will become effective in September, 2014.

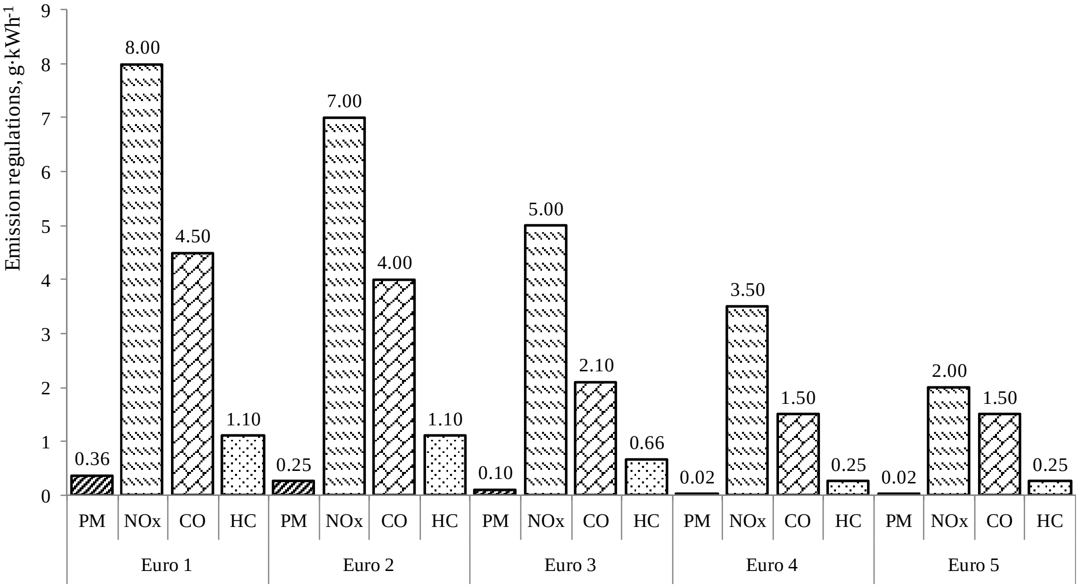

Fig. 1. **Past and current emission legislation broken down to more relevant emission categories**: PM – particulate matter; NO_x – nitrogen oxides; CO – carbon monoxides; HC – hydrocarbon

One of the ways to decrease air pollution by transport is to make more stringent desires anent on emission standards (evolution *Euro1* to *Euro5*, *Euro6*), that makes engine manufacturers to work out more and more effective and environment friendly engines. But, as known, each new product requests for investments and permanent research. The second way to decrease air pollution by direct operation of transport is to exploit electric motor vehicles.

As the electric motor vehicles during direct exploitation make no hazardous emissions (exhaust gases) exploitation of them is one of the alternatives to decrease air pollution in urban areas (cities, agglomerations). Besides that, electric motor vehicles make no noise that is important, for example, in crossings, parking-places, residential areas etc.

The above mentioned reasons to exploit electric motor vehicles are connected with direct impact on humans. Another reason to exploit them is connected with resources of fossil fuels.

At present the combustion of coal, natural gas and crude oil gives about 90 % of the total amount of energy consumption. Calculations have shown that resources of coal will be enough for 250 years, crude oil for 40 years and natural gas for 65 years. The next lack of fossil fuels (coal, peat, petroleum products, natural gas etc.) is hazardous emissions [2].

Depending on the way how the energy is obtained, electric transport is more or less environmentally friendly, especially in urban areas (trams, trolleys, trains, buses, taxi, operative transport, trip transport and private transport), and makes no hazards, such as emissions and noise made by internal combustion engines.

Electricity as a transport fuel could [3]:

- decrease the oil dependence, as electricity is a widely-available energy vector that is produced from several primary energy carriers;
- improve the energy efficiency through higher efficiency of an electric drive train;
- decrease the CO_2 emissions of the transport sector along with the expected continuing increase in the share of renewable energy sources in the EU power generation mix, supported by emission capping through the EU Emission Trading Scheme;
- provide for innovative vehicle solutions requiring less resources and allowing better vehicle utility optimisation.

Significant electric motor vehicle exploitation parameters are the dynamic behaviour and exploitation parameters.

Materials and methods

The experimental research was made on a slow–moving electric motor vehicle *Melex 963DS*.

Slow-moving electric motor vehicles can be classified into 2 groups [4]:

- vehicles that can take part in road traffic – electric bicycles, mopeds, single-seat electric shopping cars, and certified tourist automobiles;
- vehicles that are not certified for road traffic – golf electric cars, hearses, electric trucks for closed territories.

In Latvia, 10 slow-moving electric motor vehicles produced by the Melex Company are presently used for tourist transportation in Riga, Sigulda and Jurmala and are certified for road traffic. The slow moving electric motor vehicle *Melex 963DS* main technical parameters are [5]:

- category – L7e;
- motor – asynchronous, maximal power 3.9 kW at 3200 rpm, 48 V, SepEx;
- weight/gross weight – 762/1212 kg;
- specific power – 3.22 $kW \cdot t^{-1}$;
- brakes – hydraulic, energy recovery up to 5 %;
- recharging socket – 230 VAC; 16 A;
- battery – heavy duty deep cycle lead acid up to 31.1 kWh;
- transmission – direct drive;
- maximum speed – up to 32 $km \cdot h^{-1}$;
- distance of run with a single full charge – up to 65 km;

Investigation of slow moving electric motor vehicle dynamical and exploitation characteristics was carried out on the Chassis Dynamometer *Mustang MD-1750* at the *Scientific Laboratory of Biofuels* of the Motor Vehicle Institute of the Faculty of Engineering (Jelgava, P.Lejina Street 2).

Fig. 2. **Slow–moving electric motor vehicle *Melex 963DS* on power stand**

Mustang MD-1750 is a stationary chassis dynamometer that allows to perform tests of technical diagnosis of light ground motor vehicles with single axis drive. The power stand is equipped with the necessary additional tools to determine the engine speed as well as after rotation speed of rollers the actual driving speed of the vehicle and overdriven distance are determined. In parallel with the above mentioned parameters a line of other parameters can be registered, for example, ambient temperature, air relative humidity and air pressure, engine power and torque, acceleration intensity etc. [6].

The stand management is provided by MD 7000 management platform. On the stand it is possible to perform the following tests: power test, constant load test, constant power stand, constant speed tests, manual load test, road simulation tests, acceleration test, emission test, quarter mile test etc.

The chassis dynamometer *Mustang MD1750* main technical parameters are as follows [6; 7]:

- speed range: 1 – 360 km·h^{-1};
- maximum power: 1286 kW (1750 HP);
- maximum absorption power: 294 kW (400 HP);
- rated accuracy of the load cell: ± 0.1 %;
- maxium load on rollers: 4540 kg;
- diameter of rollers: 1.27 m;
- width of rollers: 0.7112 m;
- air requirements: 5.5 bar.
- power requirements: 230 V; 60 Hz; 40 A.

Before the experiments a full battery charge was performed under laboratory conditions. The roller surface was dry; temperature in the laboratory was +17 to +18 ℃.

The slow-moving electric motor vehicle *Melex 963DS* tests were carried out in a number of stages that could be divided into two groups: dynamical and exploitation parameters. If the first parameters could be established with a single charge of batteries, then the exploitation parameters take a lot of time, because with fully charged batteries one measurement could be taken and batteries have to be recharged. The experiment duration occurs till the driving speed drops down by the speed of 5 km·h^{-1}.

Dynamical parameters

The experiment was repeated to determine the driving dynamics from 0 to 30 km·h^{-1}, i.e., acceleration time from 0 to 30 km·h^{-1} (seconds) and acceleration distance from 0 to 30 km·h^{-1} (meters) in the following load regimes: without load, with 50 % load, with 100 % load and with 150 % of load.

Exploitation parameters

The exploitation parameters to determine are autonomy with fully charged batteries (km), driving time (hours), charging time (hours) and charging energy (kWh). These parameters were determined in the following load and speed regimes: maximal starting speed (fully pressed accelerator pedal) without load, with 50 %, 100 % and 150 % load and with starting speed 20 km·h^{-1} (partially pressed accelerator pedal) with 100 % load. The last regime was selected to determine if there is some impact of the driving speed on autonomy.

Load regimes

The experiments were carried out with the following load regimes:

- without load (762 kg);
- 50 % of load (987 kg);
- 100 % of load (1212 kg);
- 150 % of load (1437 kg);

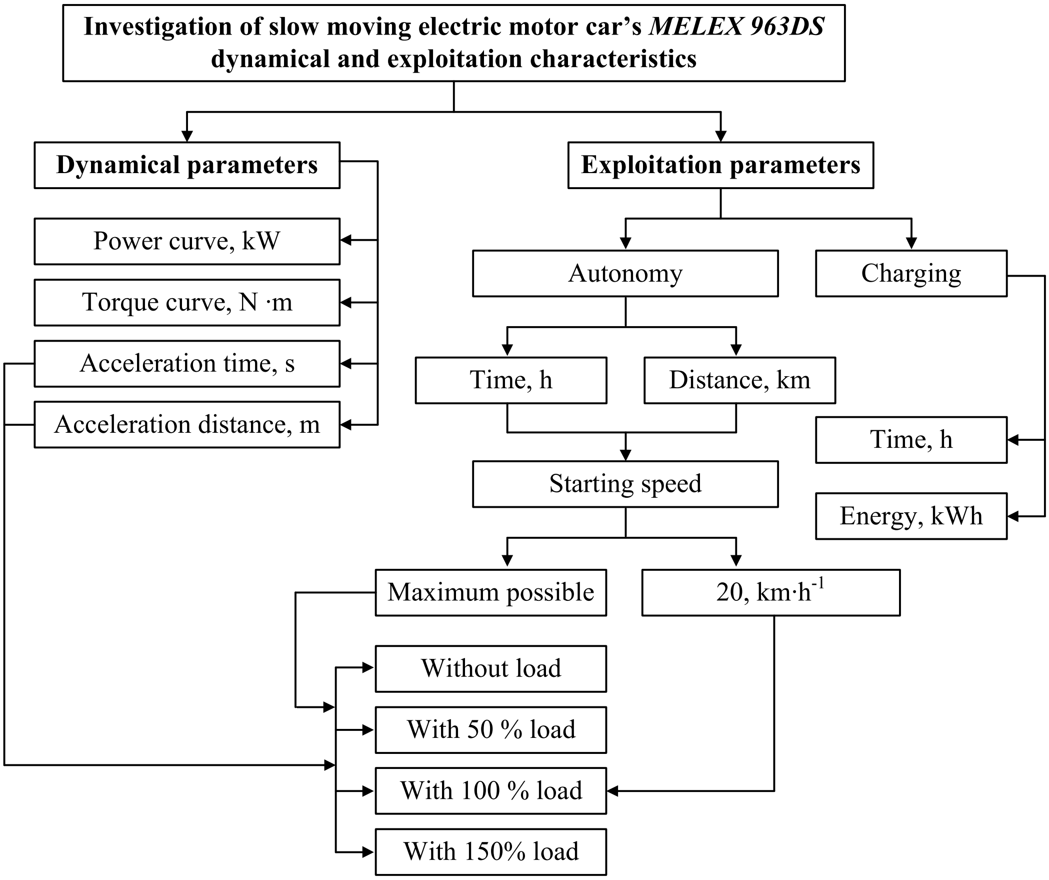

Fig. 3. **Block diagram of experiments**

According to literature [8], each measurement was repeated 3 times ($\alpha = 0.95$; $p = 0.05$; $t = \pm 3\sigma$). If some of the measurements are too originate, they were repeated one more time. After that electric motor spin-up curves and acceleration columns were constructed. The block diagram of the experiments is shown in Figure 3.

Results and discussion

In the first stage the dynamical parameters of the low-moving electric motor vehicle were determined. As seen from Fig. 4, the maximum power of the slow-moving electric motor vehicle is 5.02 kW at engine speed 1858 rpm. Because of the specific character of the power stand it is not possible to determine the maximum torque of the electric motor. As known, electric motors expand their maximum torque already from small revs, but because of power stand delay, it is determined only from 1000 rpm and the maximum obtained torque registered by the power stand were 34.54 N·m at 1132 rpm.

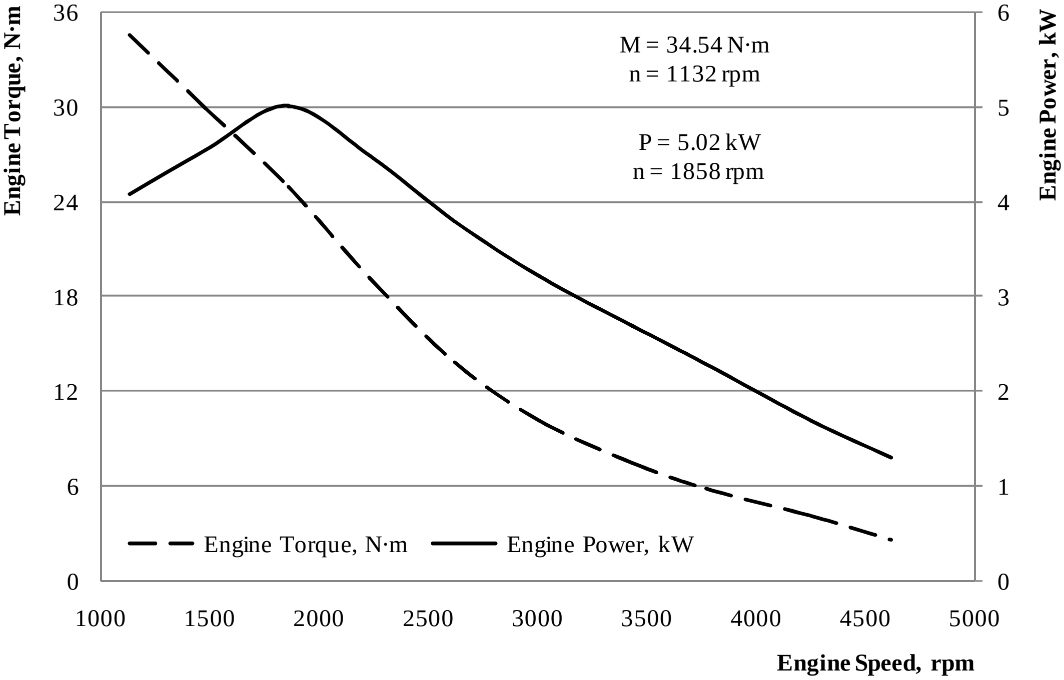

Fig. 4. **Electric motor spin-up curves**

Figure 5 shows the acceleration dynamics testing the slow-moving electric motor vehicle with four load regimes.

As seen from Figure 5, the speed 30 $\text{km}\cdot\text{h}^{-1}$ without load is attained in 102 ± 3 seconds, with 50 % load in 117 ± 10 seconds, with 100 % load in 133 ± 9 seconds and with 150 % load in 152 ± 19 seconds.

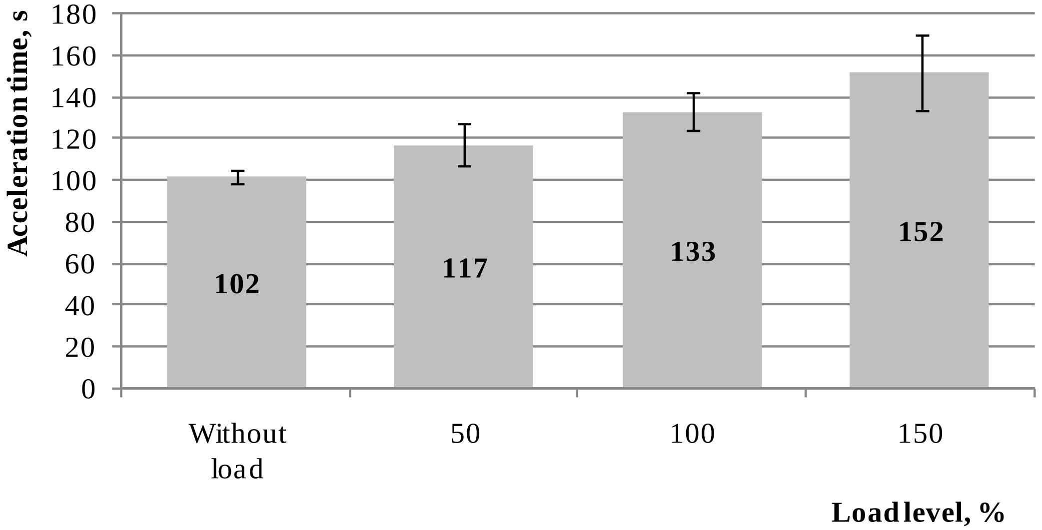

Fig. 5. **Acceleration time up to 30 km·h^{-1} speed**

Figure 6 shows the acceleration distance during the speed 30 km·h^{-1} is attained. From Figure 6 it is seen that the speed 30 km·h^{-1} without load is attained during 666 ± 29 m, with 50 % load during 794 ± 24 m, with 100 % load during 922 ± 45 m and with 150 % load during 1146 ± 49 m.

In Figures 5 and 6 there are also error bars depicted that, according to Gauss (normal) distribution, characterize ± 3 standard errors.

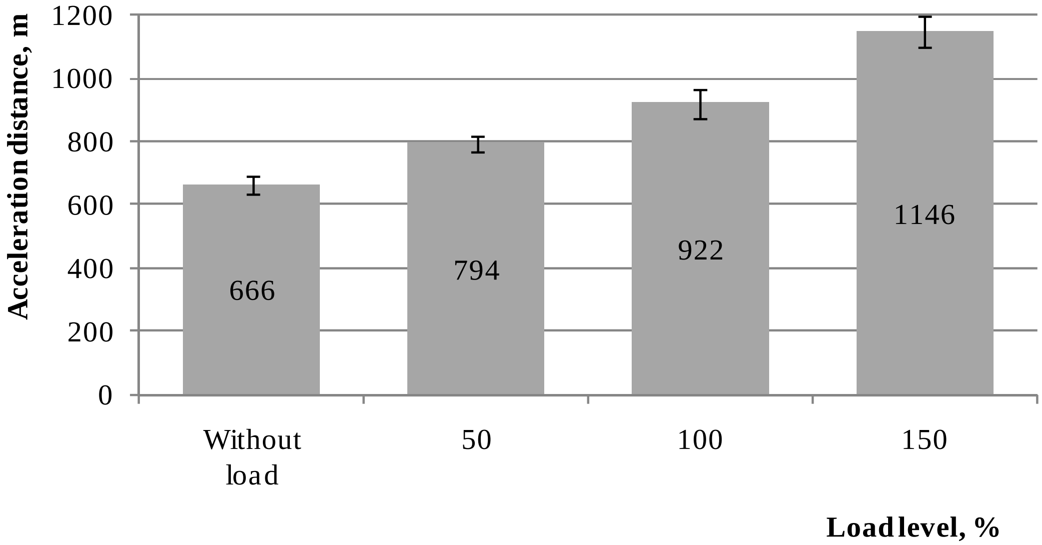

Fig. 5. **Acceleration distance up to 30 km·h^{-1} speed**

During determination of the exploitation parameters of the slow-moving electric motor vehicle intraday one drive was performed. The results are summarized in Table 1.

Table 1

Summary of exploitation parameters

Load level	**Distance, km**	**Driving time, h**	**Charging time, h**	**Charging energy, kWh**
Without load	47.820 ± 0.085	2:12:00 ± 0:04:35	7:44:40 ± 0:20:53	9.09 ± 0.47
50 %	46.859 ± 0.475	2:02:40 ± 0:14:00	7:34:00 ± 0:17:35	7.67 ± 0.63
100 %	45.364 ± 0.095	2:02:40 ± 0:02:00	7:37:00 ± 0:18:05	8.68 ± 0.36
100 %, v_o = 20 km·h^{-1}	50.071 ± 2.147	3:10:40 ± 0:15:43	8:39:00 ± 0:22:31	9.50 ± 0.51
150 %	45.197 ± 0.781	2:10:40 ± 0:03:36	7:44:00 ± 0:18:44	9.06 ± 0.28

As seen from Table 1, the exploitation parameters do not differ much depending on the load regime. If we compare the exploitation parameters of the low-speed electric motor vehicle operating with extreme load regimes (without load and with 150 % load), it is seen that the difference of autonomy is 2.623 km (2.09 %), of driving time 00:01:20 h (1.01 %), of charging time 00:00:40 h (0.14 %) and of charging energy 0.03 kWh (1.33 %). These results stimulate to suppose, that on the power stand load does not have so big influence on autonomy than on the road because of the specific driving regime on the road (crossing, pedestrian crossings, traffic lights, wind etc. conditions) that allows changing the driving speed.

In order to clarify what impact on the exploitation parameters the starting speed has, several drives were carried out with different starting speeds. If in general research the exploitation parameters were determined with maximum possible speed and different loads, than for comparison the starting speed was selected 20 km·h^{-1} and load 100 %. As it is seen the reduction of the starting speed of drive to 20 km·h^{-1} allows to increase autonomy for 4.707 km (9.40 %), but wherewith the driving time increases of 1:08:00 h (35.66 %), charging time of 1:02:00 h (11.95 %) and charging energy of 0.82 kWh (8.63 %) in average.

Conclusions

1. The maximum power of the slow-moving electric motor vehicle is 5.02 kW at 1858 rpm and maximum achieved torque is 34.54 N·m at 1132 rpm. Having regard of the power stand delay the achieved torque could not be considered as veritable.
2. The acceleration time up to 30 km·h^{-1} depending on the load varies from 102 ± 3 seconds (without load) to 152 ± 19 seconds (150 % load).
3. The acceleration distance up to 30 km·h^{-1} depending on the load varies from 666 ± 29 m (without load) to 1146 ± 49 m (150 % load).
4. The driving distance till full discharge of batteries varies from 45.197 ± 0.781 km (150 % load) to 47.820 ± 0.085 km (without load).

5. The driving time till full discharge of batteries practically does not depend on the load and is within 2:02:40 to 2:12:00 hours.
6. The charging time also does not depend on the load and is within 7:34:00 to 7:44:40 hours.
7. The charging energy depending on the load varies from 7.67 (50 % load) to 9.09 (without load) kWh.
8. Decreasing the maximum starting driving speed to 20 km·h^{-1}, the driving distance increases for 4.707 km (9.40 %), driving time for 1:08:00 h (35.66 %), charging time of 1:02:00 h (11.95 %) and charging energy of 0.82 kWh (8.63 %) in average in comparison with the same data when the starting speed is selected as the maximum possible.

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MELEX 963DS ELECTRIC VEHICLE DRIVING RANGE WITH PARTIAL CHARGE

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Abstract. A slow moving electric vehicle Melex 963DS is made for carrying up to 6 passengers. It is equipped with 8 six volt acid batteries and outer charger. With full charge, the vehicle has a range of approximately 64.91 km. In this study, partial charging regimes are studied. It is important to know the range from a half an hour and other partial charging modes, because there is no option to fill batteries like internal combustion engine with fuel and towing the vehicle can damage the electric motor. The experiments were carried out on a chassis dynamometer Mustang MD-1750 for road condition simulation and measuring the distance, REV logger for measuring the consumed energy from a charger and a data logger GRAPHTEC GL-220 for measuring the energy consumption from batteries. Melex was driven with maximal speed, Melex was stopped when the batteries reached voltage 40 V and a partial charge was done. After that, the vehicle was driven again in the same conditions. Each experiment was repeated 3 times. The vehicle on average managed 6.39 km with 30 min, 12.24 km with 1 h, 24.97 km with 2 h and 47.32 km with 4 h charge.

Keywords: partial charge, driving range, electric vehicle.

Introduction

Electric vehicles are getting more popular but still there are many unanswered questions. Despite, electric automobiles have been in use for over a century, their popularity has experienced few popularity and decline waves. Also the battery technology has improved over the last decade, but still it cannot satisfy the internal combustion engine users with driving range. The most popular electric vehicles in Latvia are bicycles, then slow moving vehicles and 12 electric automobiles [1]. This research is about a scenario when the electric vehicle has drained its batteries and needs a partial charge to reach the destination. There are 11 charging stations in Latvia that can charge 45 vehicles simultaneously [2]. Most stations are with free charging but paid parking space. This limits the driving range, but private house owners can charge their electric vehicle at home, an advantage compared to fuel users.

The test object Melex 963DS is a slow moving electric vehicle constructed to carry up to 6 passengers and is used for sightseeing tours in Sigulda, Latvia. Because of hilly environment batteries are drained faster and a charge is being done as soon as possible, to be able to continue tours all day long. The only reference point is an on-board battery gauge that shows energy left into the batteries. Because tours are performed in the Gauja National Park, Latvia, the electric vehicle is suited for work with no emission gasses, quiet operation, high torque and easy maintenance.

The charging mode can be described with: charging time (h), charging voltage (V), charging current (A), charging type (partial/full), charging phase (main/final) and consumed energy (kWh). This vehicle charging is done by an external charger that is connected to a standard household socket.

Materials and methods

The experiment object is a slow moving electric vehicle Melex 963DS which is made for carrying up to 6 passengers and is certified for road traffic (see Fig. 1).

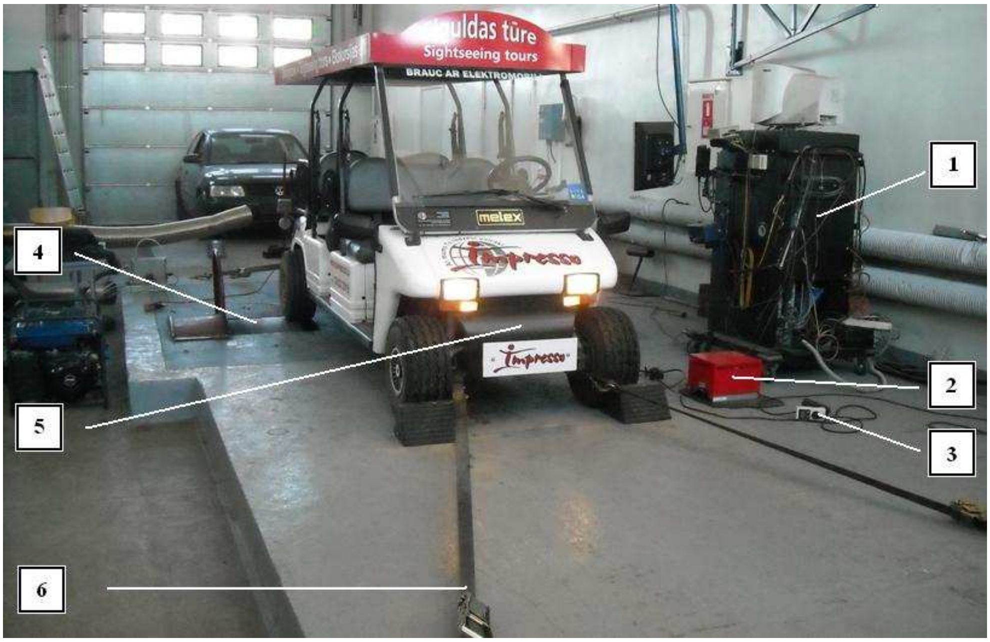

Fig. 1. **Melex 963DS on a chassis dynamometer:** 1 – control platform, 2 – charger, 3 – REV logger, 4 – chassis dynamometer rolls, 5 – experiment object, 6 – straps

Specifications of the vehicle [3]:

- first registration 03.07. 2008.;
- 8 six volt acid batteries and external charger 48 V 30 A;
- maximal power 3.9 kW;
- maximal speed 8.9 $m \cdot s^{-1}$;
- mass equipped 762 kg;
- gross mass 1212 kg;

- direct drive transmission;
- length 3.66 m;
- width 1.335 m;
- wheel base 2.5 m;
- double A-frame with springs suspension;
- vehicle body – plastic.

The Mustang MD-1750 chassis dynamometer consists of mechanical, electro-mechanical, and electronic modules, that simulate road loads to get repeatable and valid data for road simulation, performance, emission and driving cycle tests. The roller surface was dry; temperature in the laboratory was +18…+19 ºC. Specifications of the chassis dynamometer [4]:

- maximal power 1750 hp;
- maximal speed 100.56 $m \cdot s^{-1}$;
- roller diameter 1.27 m;
- face length 0.71 m;
- maximum absorption power: 294 kW;
- maximal load on rollers 4540 kg;
- Closed Loop Digital Controller with WindowsXP based software controls.

The automobile must be fixed on the chassis dynamometer with straps from front and back, to keep the automobile in place (see Fig. 1). Inertial rolling stand operates with the automobile driving wheels proportionally to the driving speed, imitating driving conditions. The air and rolling resistance sum must be entered in the chassis dynamometer control platform. The control platform also allows changing the vehicle mass and road grade. Because the wheel inner diameter was smaller than the chassis dynamometer inner track width, flanges were made to increase the width and fit on rollers.

REV logger (190-276 V, 20 mA-16 A, 5-3680 W, ±0.01 kWh) was used for total consumed energy measurement in a charge.

GRAPHTEC midi LOGGER GL220 was used to gather the data both when charging and driving. This device allows monitoring measurable values during experiments. Specifications of the data logger [5]:

- 10 analog input channels;
- built-in Flash memory (2 gigabytes);
- display size 4.3 inch TFT colour LCD (WQVGA: 480 × 272 dots);
- display formats - Waveform + Digital, Waveform, Calculation + Digital, Expanded digital;
- operating environment 0-45 ºC, 5-85 % RH;

- power source- AC adapter (100 to 240 V, 50/60 Hz), DC (8.5 to 24 V DC, max. 26.4 V);
- external dimensions (W×D×H) approx. 194 × 117 × 42 mm;
- weight approx. 520 g (Excluding AC adapter and battery pack).

Block diagram of the experiments is given in Fig. 2.

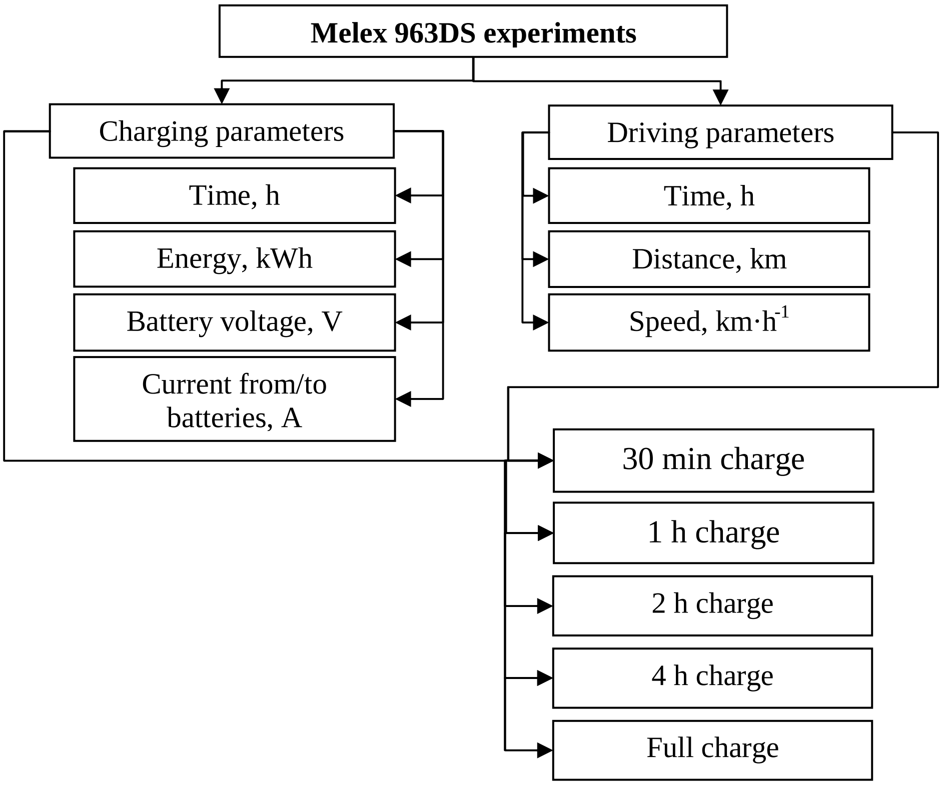

Fig. 2. **Block diagram of experiments**

At first the electric vehicle was placed on a chassis dynamometer, strapped, attached loggers and tested. Then a full charge was done. After that the vehicle was driven with maximal speed (fully pressed acceleration pedal), monitoring the battery voltage. When the battery voltage reached 40 V, the experiment was stopped, all data were saved in the loggers. Then a partial charge was done. After defined time, charging was stopped and the vehicle was driven again with maximal speed until the battery voltage reached 40 V. Each partial charge experiment was repeated 3 times. After that the vehicle was fully charged and left to sit for 24 hours. Then the next partial charge regime was carried out. The experiments were carried out with the lights switched on- mandatory in Latvia all year long. Partial charge was always done after draining batteries with voltage 40 V, this value was obtained in on-road experiments.

Results and discussion

The experiment results are summarized in Table 1. All partial charging points have linear relevance.

Table 1

Experiment results for Melex 963DS

Charge type	Distance, km	Consumed energy, kWh	Drive time	Battery voltage before experiments, V
Full charge	65.00	9.90	2h 17min	50.90
	62.42	10.37	2h 13min	51.09
	67.31	10.12	2h 32min	50.90
Average	**64.91**	**10.13**	**2h 21min**	**50.96**
30 min charge	8.14	0.72	19min	50.40
	5.80	0.71	14min	49.80
	5.23	0.71	13min	49.50
Average	**6.39**	**0.71**	**15min**	**49.90**
1 h charge	14.37	1.39	32min	50.20
	11.23	1.29	27min	49.80
	11.12	1.26	26min	49.92
Average	**12.24**	**1.31**	**28min**	**49.97**
2 h charge	26.72	2.58	58min	51.00
	25.20	2.58	59min	50.80
	22.99	2.67	53min	50.90
Average	**24.97**	**2.61**	**57min**	**50.90**
4 h charge	51.13	4.93	1h 53min	51,00
	47.16	5.03	1h 44min	51,20
	43.67	4.86	1h 39min	50,88
Average	**47.32**	**4.94**	**1h 45min**	**51.03**

The charging characteristics for a full charge are shown in Fig. 3. Drained batteries without load have 43.88 V, maximal voltage was 61.86 V. The current at the start was 34.49 A and was slowly decreasing until reaching the lowest value 8.76 A. The current does not increase gradually at the start, like for the electric automobile Fiat Fiorino [6], even contrariwise – the first 11 minutes the current is noticeably higher, but the average power output 769 W (charger power 1440 W) is not enough for overloading household electricity connection.

The characteristics for a drive with fully charged batteries are shown in Fig. 4. Voltage drop is noticeable at the end of the drive and has a similar tendency as speed in Fig. 5 (both charts are for the same drive). Maximal voltage at start is 50.9 V. Maximal current from batteries was 104.54 A at the start and lowest 31.2 A at the end. Average current was 47.96 A. At the same point when the voltage starts to drop, the current values become discursive, what can be described as vehicle attempts to maintain maximal speed.

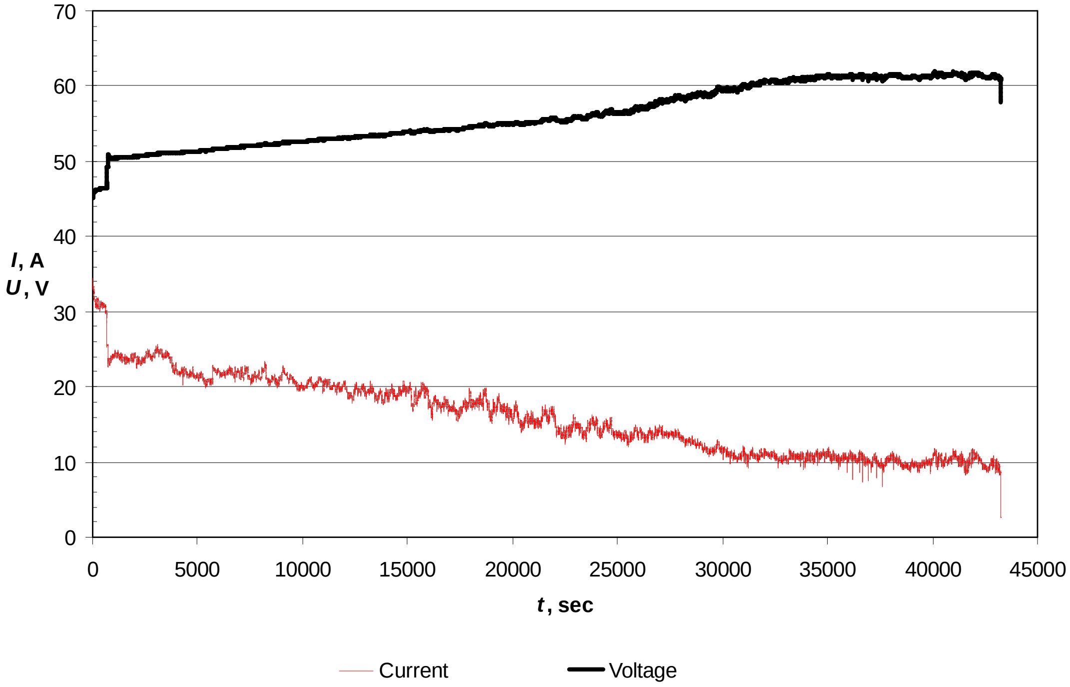

Fig. 3. **Characteristics for a full charge**

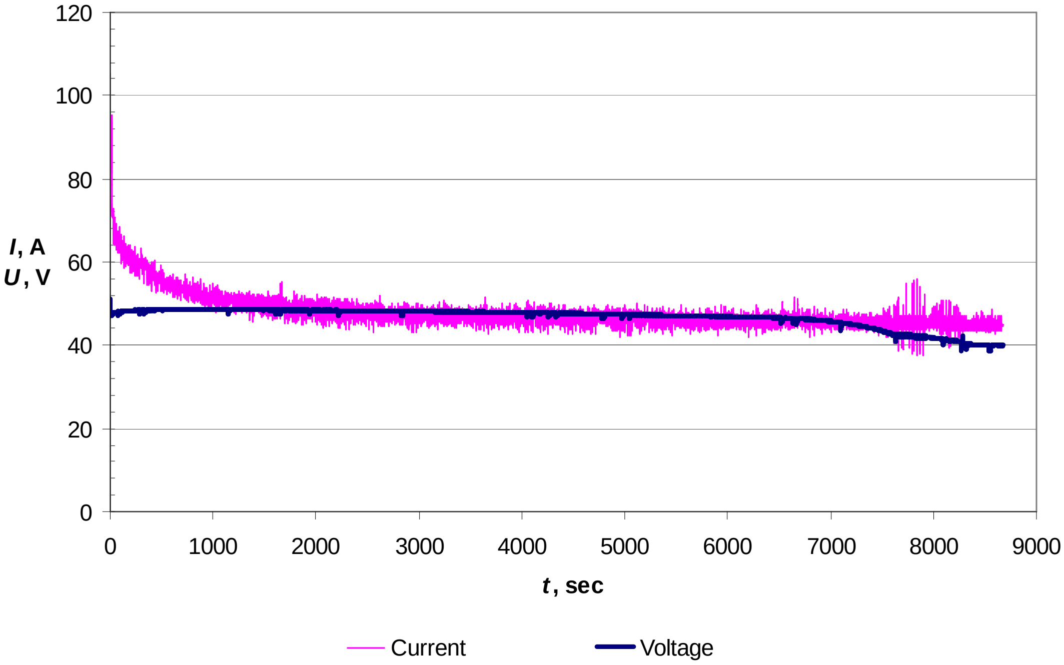

Fig. 4. **Characteristics for a drive with charged batteries**

Fig. 5 shows the screen from a chassis dynamometer control platform program for a full charge drive. The chart line for speed shows the maximal value of 8.06 $m \cdot s^{-1}$, speed at the end is 6.67 $m \cdot s^{-1}$. These speed characteristics are the same for all drives, also with partial charge. The graph also shows steady regime – there are no spikes.

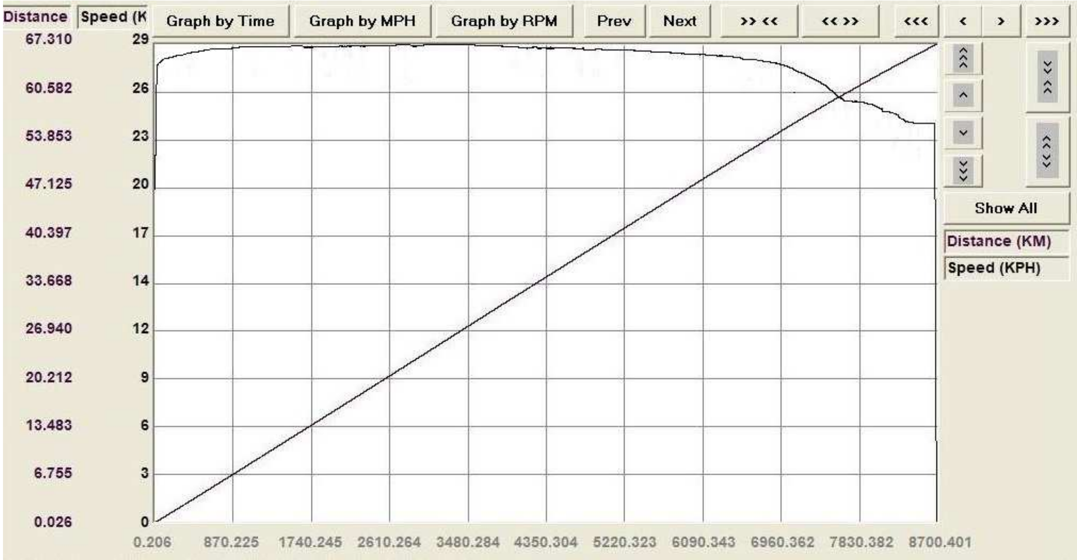

Fig. 5. **Mustang Dynamometer PowerDynePC screen**

Compared to other full driving range experiments on a chassis dynamometer [7] with Melex 963DS, the values differ because of the battery state: previous tests were done with batteries before utilization, but this experiment with new batteries, also the level of discharge differs.

By the international standard IEC61851-1 for electrical connectors and charging modes for electric vehicles that has introduced 4 charging modes [8], Melex 963DS charging regime complies with charging mode 1 – slow charging from a household socket.

Conclusions

1. Full battery charge takes around 11 hours, 10.13 kWh and costs 1.58 euro. Full charge gives driving range of 64.91±2.82 km.
2. For Melex 963DS 30 min charge after batteries have been drained, gives driving range of 6.39±1.78 km or 10 % of full range.
3. For Melex 963DS 1h charge after batteries have been drained, gives driving range of 12.24±2.13 km or 19 % of full range.
4. For Melex 963DS 2h charge after batteries have been drained, gives driving range of 24.97±2.17 km or 38 % of full range.

5. For Melex 963DS 4 h charge after batteries have been drained, gives driving range of 47.32±2.31 km or 73 % of full range.
6. Onboard battery gage shows empty batteries even after 4 hour charge that gives 73 % of full driving range.
7. Without battery resting and normalizing, each partial charge gives less driving range, for 30 min and 1 h charge around 20 % decrease, and for 2 h and 4 h – 10 % decrease.
8. Obtained driving ranges on a chassis dynamometer are bigger than on-road values, because of constant load and speed regime that rarely can be achieved in on-road conditions.

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INVESTIGATION OF ELECTRIC BICYCLE ACCELERATION CHARACTERISTICS

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Abstract. This article deals with five different electric bicycle (power from 0.2 to 1.0 kW) acceleration characteristic studies testing them on real road conditions. The measurements were carried out using the scientific radar *Stalker ATS* on two various flat and straight 300 m long asphalt road sections with fully charged batteries under different test modes depending on the electric bicycle type. The investigation results show that the maximum speed and run-up dynamics of electric bicycles are mainly determined by electromotor power, but they are also affected by the weight of the bike, the gear ratio from the motor to the wheels and other parameters. If the electric bicycle has several gears, the character of acceleration in the first seconds is similar, only the maximum achievable speed for each gear differs. Pedalling at the beginning of the run improves the acceleration of the bike, but not the maximum attainable speed.

Keywords: electric vehicle, electric bicycle, acceleration run, scientific radar.

Introduction

During the last few decades negative environmental impact of the gasoline and diesel fuelled vehicles has led to renewed interest in an electric transportation infrastructure. Electric vehicles (EVs) are vehicles that are equipped with electric motors for propulsion.

The main types of electric vehicles are: rechargeable battery vehicles, hybrid vehicles, and electric vehicles that can be refuelled using fuel cells. Rechargeable battery vehicles can also be divided into several different categories. For example, there are electric bicycles or e-bikes, the low speed vehicles that form a class of vehicles with maximum speeds up to 40 $km \cdot h^{-1}$, and conventional road vehicles using rechargeable batteries [1; 2].

The main barriers to the large scale deployment of EVs are:

- high cost of the vehicle, batteries and service;
- limited driving range on a single charge;
- very little or no public charging infrastructure available;
- limited number of EVs currently on roads and hence limited data and experience regarding their performance [3].

Electric bicycles are probably the most popular type of rechargeable battery vehicles. It is estimated that there are approximately 150 million e-bike users in China and nearly 1 million electric bicycles are sold in Europe each year starting from 2010. China is also the country where the most of researches concerning electric bicycle evolution, as well as the common e-bike user gender, age, income level and daily habits are carried out [4; 5].

There are many different electric bicycle manufacturers and types, with a very wide range of power methods: hub motors in the front or back wheels, and drives on the pedal cranks are the most common variations. In most European and North American countries it is becoming a standard regulation that these bikes must be of the "pedal-assist" type. This means that they cannot be powered by the electric motor alone. However, the regulatory situation is very changeable and depends also on local regulations [1].

A significant electric vehicle exploitation parameter is the dynamic behaviour that allows to judge about the following features:

- electric vehicle fitness for road or walkway traffic;
- identification of the most cost-effective driving speed to ensure maximum mileage per charge;
- ability to safely perform dynamic manoeuvres [6].

The purpose of this study is to compare the different power electric bicycle run-up dynamics, performing measurements in different modes depending on the electric bicycle type, for example, using different gears, with or without a passenger, with or without the assistance of pedals.

Materials and methods

Five different electric bicycles were used during this investigation. They are named accordingly EB1, EB2, ..., EB5, adding the nominal motor power (See Table 1).

Table 1

Main technical parameters of electric bicycles

No.	Conventional name of electric bicycle in experiments	Nominal motor power, W	Bicycle weight with batteries, kg	Bicycle weight with batteries and a driver, kg	Power-to-weight factor, $W \cdot kg^{-1}$
1.	EB1-1000	1000	39.5	121.5	8.23
2.	EB2-500	500	68.5	150.5	3.32
		500	68.5	230.5*	2.17*
3.	EB3-250	250	31.0	113.0	2.21
4.	EB4-200	200	35.8	117.8	1.70
5.	EB5-200	200	37.5	119.5	1.67

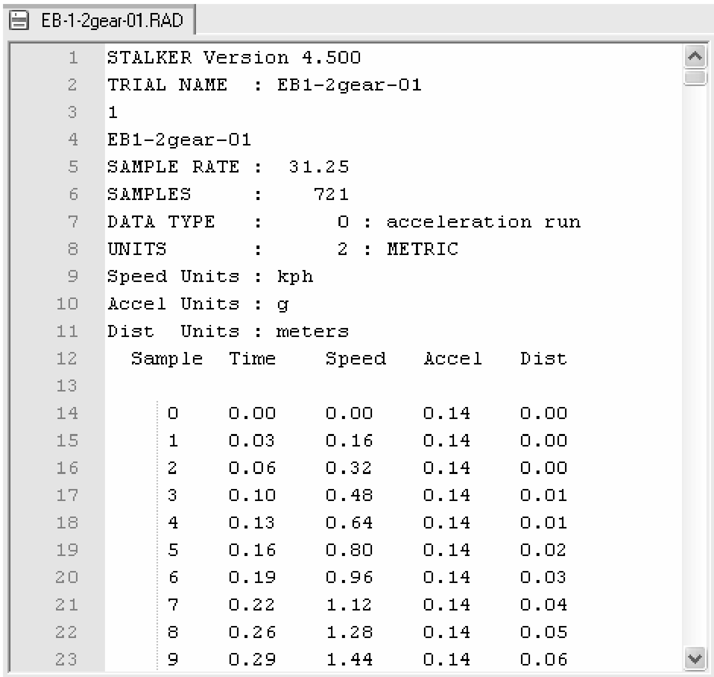
* – *electric bicycle EB2-500 was tested also with a passenger*

The acceleration intensity of electric bicycles was determined using the scientific radar *Stalker ATS* on different calendar days and on two various flat and straight 300 m long asphalt road sections with an average rolling resistance coefficient from 0.018 to 0.020. The road surface during the experiments was dry, ambient temperature +15 ± 2 ºC, wind speed did not exceed 2.5 $m \cdot s^{-1}$. Before the experiments a full charge of batteries was performed under laboratory conditions and the electric bicycles were transported to the experiment site by a van.

The scientific radar main technical parameters [7]:

- measurement speed range: 1 – 480 $km \cdot h^{-1}$;
- accuracy: ± 1.069 $km \cdot h^{-1}$;
- target acquisition time: 0.01 s;
- maximal measurement range: 1.82 km;
- weight: 1.45 kg;
- RS-232 communication system.

The *Stalker ATS* software program saves the speed data, assigns the time information, and then calculates the distance and acceleration rates for each data sample. These data are then saved as a file on the computer hard drive in *.RAD* format with speed, acceleration, and distance fixation step after every 0.03 seconds (See Fig. 1).



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STALKER Version 4.500
TRIAL NAME   : EB1-2gear-01
1
EB1-2gear-01
SAMPLE RATE :  31.25
SAMPLES     :    721
DATA TYPE   :      0 : acceleration run
UNITS       :      2 : METRIC
Speed Units : kph
Accel Units : g
Dist  Units : meters
  Sample  Time    Speed   Accel   Dist

     0    0.00    0.00    0.14    0.00
     1    0.03    0.16    0.14    0.00
     2    0.06    0.32    0.14    0.00
     3    0.10    0.48    0.14    0.01
     4    0.13    0.64    0.14    0.01
     5    0.16    0.80    0.14    0.02
     6    0.19    0.96    0.14    0.03
     7    0.22    1.12    0.14    0.04
     8    0.26    1.28    0.14    0.05
     9    0.29    1.44    0.14    0.06
```

Fig. 1. **Example of electric bicycle acceleration measurement data storing**

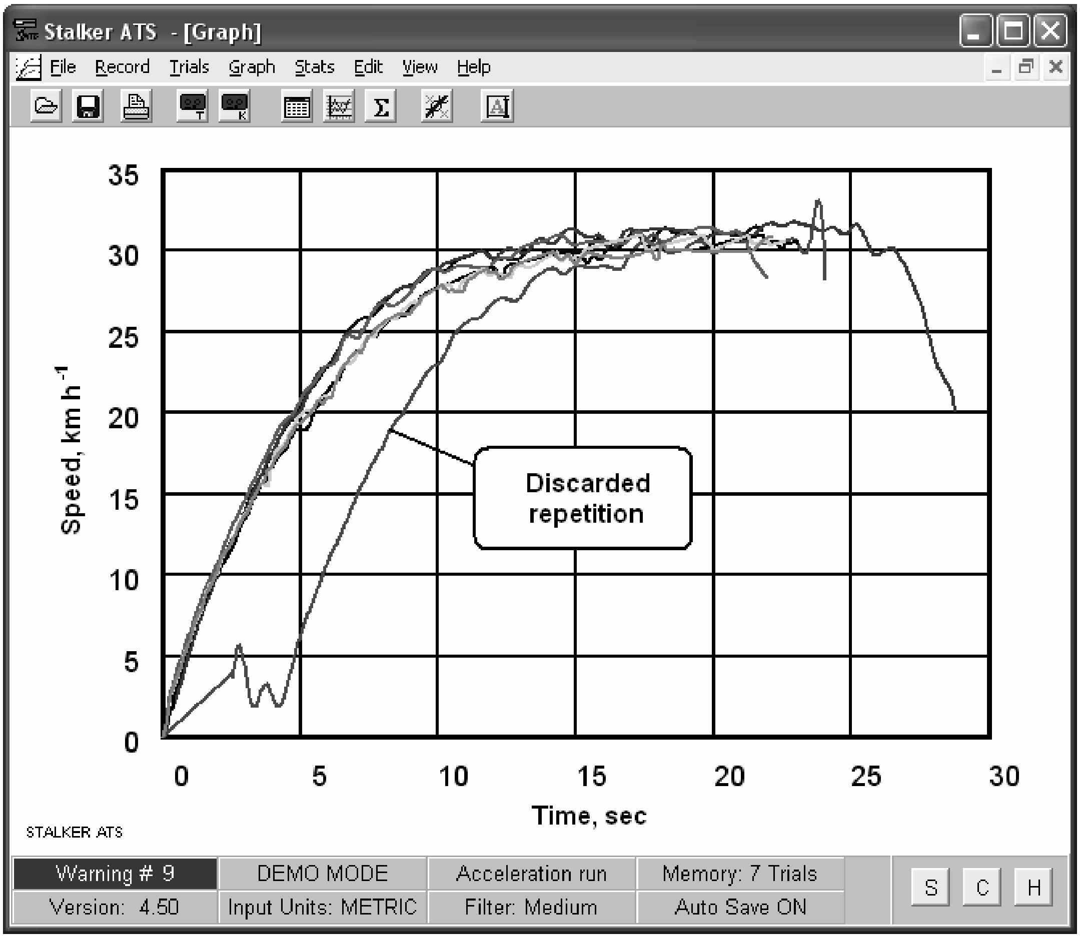
Starting the experiment the radar was placed straight behind the e-bike (See Fig. 2). Two operators have participated in the experiment. One worked with the radar, which is connected to a portable computer, the second rode the bicycle.

Fig. 2. **Electric bicycle acceleration measurement using scientific radar *Stalker ATS***

After the radar operator commands, the bicycle driver started sharp run-up, holding the accelerator throttle in maximum position all the way. The experiment was performed from 0 km·h^{-1} until maximum speed was achieved. After the test the bicycle returned to the starting position and the next experiment repetition was carried out.

Each experiment was repeated at least 5 times on each test day. If during the test a car or any other vehicle appeared on the road and disturbed the radar measurements, the experiment was repeated. If already in the radar *Stalker ATS* software distortion of curves was seen, these repetitions also were discarded. An example of discarded repetition is shown in Fig. 3.

From all repetitions in each test mode three to six were selected with the closest data, i.e., with the highest correlation between experimental series data points. Average values were calculated from at least 3 repetitions if correlation between the series data points was at least 0.995, i.e., above 99.5 %. After that the curves $v = f(t)$ and $s = f(t)$ were constructed.



Discarded repetition

Warning # 9

DEMO MODE

Acceleration run

Memory: 7 Trials

Version: 4.50

Input Units: METRIC

Filter: Medium

Auto Save ON

Fig. 3. **Raw radar data and example of discarded repetition**

The experiments with electric bicycles EB1-1000, EB3-250 and EB5-200 were carried out performing simple run-up, i.e., only holding the accelerator throttle in maximum position all the way. The bicycle EB4-200 additionally was tested using pedal assistance – half a turn starting acceleration.

EB2-500 electric bicycle run-up studies were performed using 3 different gears or driving modes and additionally, accelerating on the 3rd gear, also with a passenger.

Results and discussion

Acceleration characteristics, testing all bicycles, are shown in Fig. 4-6. As the maximum speeds and acceleration times of the electric bicycles were different, the two different points were chosen for comparison – the time and distance until the bicycles reach the speed of 15 km h^{-1}, and the achieved speed and travelled distance during 15 seconds acceleration.

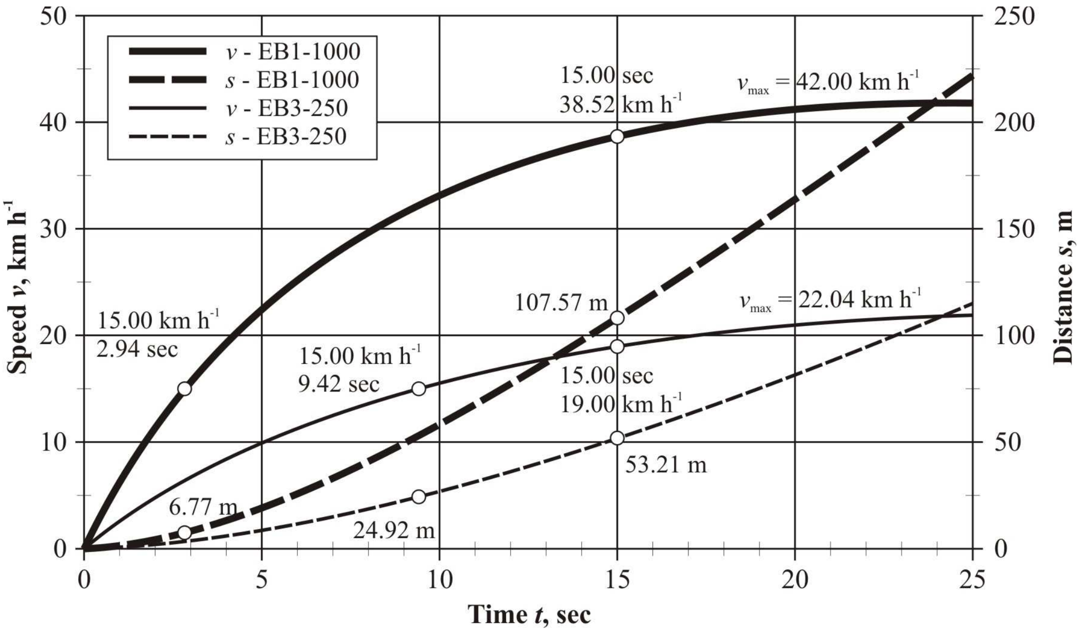


Fig. 4. **Acceleration characteristics testing EB1-1000 and EB3-250 electric bicycles**

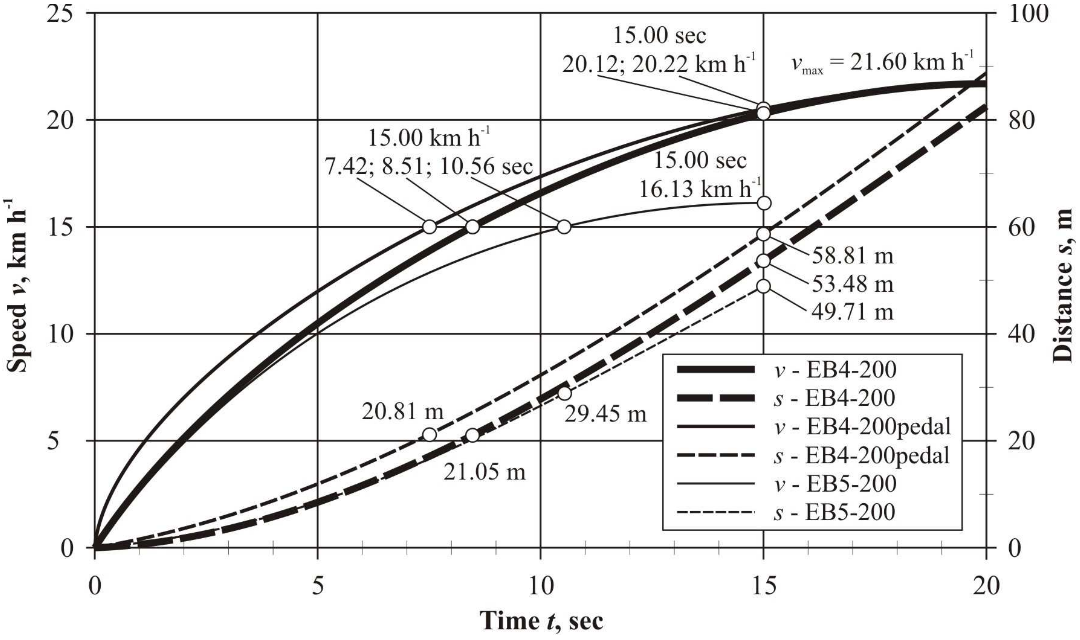


Fig. 5. **Acceleration characteristics testing EB4-200 and EB5-200 electric bicycles**

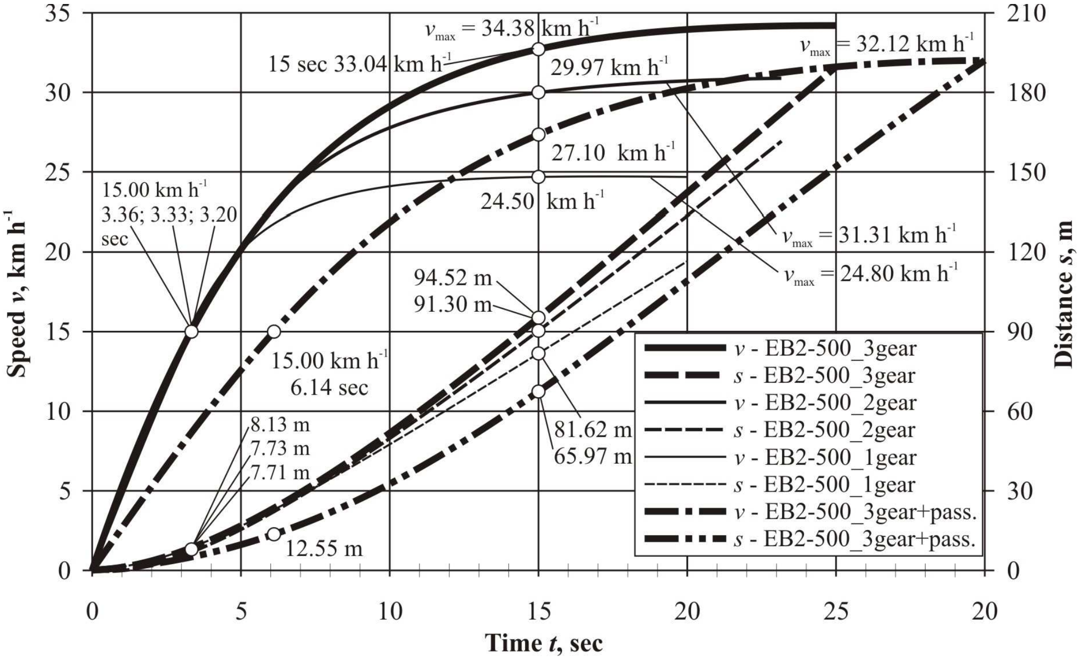


Fig. 6. **Acceleration characteristics testing EB2-500 electric bicycle**

All the above-mentioned test mode results are summarized in Table 2.

Table 2

Summary of acceleration parameters in all test modes

No.	**Test bicycle and mode**	**Test results**				
		Maximum speed, km h^{-1}	**Acceleration time from 0 to 15 km h^{-1}, s**	**Acceleration distance from 0 to 15 km h^{-1}, m**	**Speed after 15 sec acceleration, km h^{-1}**	**Distance after 15 sec acceleration, m**
1.	EB1-1000	42.00	2.94	6.77	38.52	107.57
2.	EB2-500 1st gear	24.80	3.20	7.71	24.50	81.62
3.	EB2-500 2nd gear	31.31	3.33	7.73	29.97	91.30
4.	EB2-500 3rd gear	34.38	3.36	8.13	33.04	94.52
5.	EB2-500 3rd gear and passenger	32.12	6.14	12.55	27.10	65.97
6.	EB3-250	22.04	9.42	24.92	19.00	53.21
7.	EB4-200 without pedal assistance	21.60	8.51	21.05	20.12	53.48
8.	EB4-200 with pedal assistance	21.60	7.42	20.81	20.22	58.81
9.	EB5-200	16.13	10.56	29.45	16.13	49.71

Even before starting the tests, it was clear that the electric bicycles with higher motor power will develop higher maximum speed and starting driving will be more dynamic. In general, it was also confirmed in the tests, but there were exceptions.

For example, the same motor power electric bicycles EB4-200 and EB5-200 develop a top speed with a 34 % difference. Small cutoff can be described by differences in the bicycle weight, consequently by the power-to-weight factor (See Table 1), but in this case the key factors were different gear ratios of the bicycles from the motor to the wheels (for example, the bicycle EB5-200 was with a smaller tire size), EB5-200 electric motor depreciation and thus lower efficiency.

Differences in gear ratios and tire sizes were also the main cause that explains EB3-250 and EB2-500 (running at first gear) similar maximum speeds. At the same time, the highest EB2-500 motor power ensures that the speed of 15 $km \cdot h^{-1}$ was reached about 3 times faster and in a shorter road section, compared to EB3-250.

According to the Latvian law regulations bicycles equipped with an electromotor with a power higher than 250 W or developing greater speed than 25 $km \cdot h^{-1}$, are classified as mopeds. The experiments show that such a distinction is correct, because the electric bicycles, like the tested E1-1000 and EB2-500 driving on sidewalks (that is allowed for ordinary bicycles) can be dangerous for e-bike drivers themselves and pedestrians, as well as for car drivers when the road intersects with walkways. Bicycles that during 15 seconds can reach speeds up to 30 $km \cdot h^{-1}$, covering this time almost 100 m distance, may surprise other traffic participants unprepared.

Analyzing the electric bicycle EB2-500 run-up dynamics, it can be concluded that at the first 5 seconds it accelerates equally regardless of the used gear, reaching the speed about 20 $km \cdot h^{-1}$. The following nature of run-up curves is different because each gear ratio is designed for another maximum speed.

Accelerating at the third gear and with 80 kg passenger up to 15 $km \cdot h^{-1}$, the e-bike speed increase takes 83 % longer time and 54 % longer distance. By increasing the speed, the acceleration difference is not so perceptible, and the maximum speed difference is only 7 %. This leads to the conclusion that also without a passenger a heavier cyclist at start-up will accelerate significantly slower. The EB4-200 test results show that using the pedals assistance as much as half a turn at the beginning of the run-up, the bike is about 15 % more dynamic, but the maximum speed is not affected.

Conclusions

1. The maximum speed and run-up dynamics of electric bicycles are mainly determined by the motor power, but they are also affected by the weight of the bike, the gear ratio from the motor to the wheels and the efficiency coefficient of the motor and transmission.
2. Driving bicycles equipped with an electromotor larger than 250 W along the walkways is undesirable because their high dynamic characteristics may endanger cyclists, pedestrians and car drivers.
3. If the electric bicycle has several gears, the character of acceleration in the first seconds is similar, only the maximum achievable speed for each gear differs.
4. Heavier electric bicycle cyclist has to consider with the reduction of dynamics, particularly in the first movement seconds, or he has to buy a more powerful e-bike.
5. Pedalling at the beginning of the run improves the acceleration of the bike, but not the maximum attainable speed.

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4. ALTERNATIVE ENERGY FOR CHARGING ELECTRIC VEHICLES AND THE RESEARCH OF INFRASTRUCTURE

In Latvia, the infrastructure for electric vehicles is limited, which can hinder the wide introduction of such vehicles. The key elements of infrastructure for electric vehicles, which contribute to the popularity of electric vehicles and ensure a convenient use of such vehicles, are as follows:

- a firm or dealer selling electric vehicles;
- possibilities to buy electric vehicle units;
- quality maintenance and repairs of electric vehicles during the warranty period;
- charging points at locations of electric vehicles and public charging points;
- battery replacement stations, possibilities for the replacement and maintenance of batteries;
- recycling of batteries and possibilities to buy batteries.

To charge electric vehicles, alternative sources of energy may be exploited, for instance, solar and wind power. Such a battery charging station powered on solar and wind energy was designed and established at the Faculty of Engineering of Latvia University of Agriculture. An examination of the parameters of this battery charging station running on alternative energy was carried out.

At the battery charging station, electric vehicles with an electric capacity of less than 1600 W can be charged.

Besides, the first electric vehicle charging point in Jelgava was opened in the yard of the Faculty of Engineering. The results of research on these infrastructural elements and their parameters are summarised in this chapter.

COMPOSITION OF ALTERNATIVE ENERGY BATTERY CHARGING STATION

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Abstract. The paper focuses on the composition of a battery charging station. The proposed charging station can be used for charging batteries of electric bicycles, using solar radiation as the main source of energy. The station contains 10 photovoltaic panels with total maximal power up to 2000 Watts. The harvested energy is accumulated in local batteries (24 V 300 Ah). During a regular summer day it is possible to charge up to 19 (12 Ah 36 V) electrical bicycle batteries. The key features of the proposed battery charging station are an adjustable photovoltaic panel angle for efficient use of solar energy and protection of parked bicycles against precipitation. The paper contains detailed information about the already built prototype of the proposed charging station. The constructed alternative energy battery charging station is completely autonomous.

Key word: photovoltaic modules, alternative energy, power station, battery charging station.

Introduction

The photovoltaic panel optimal operating mode is dependent on the position to the sun. Optimal position of photovoltaic panels to the sun is when their surface is perpendicular to the sunrays. In order to make the panel surface perpendicular to the sunrays, an adjustable photovoltaic panel angle is needed, which varies depending on the season [1]. In summer time, when the sun is higher above the horizon, the photovoltaic panels need to be adjusted in 45° angle, but in winter time, when the sun position is lower above the horizon, the photovoltaic panels need to be adjusted from 45° to 90° angle. Generally in the autumn and springtime the photovoltaic panel pitch angle matches with the latitude, in our case 57°. We need to add 10-15 degrees (67-72°) in wintertime, but take 10-15 degrees (42-47°) in summer. In order to locate the photovoltaic panels perpendicular to the sun rays, the panel alignment should also be changed in the course of the day, to compensate variation of the height of the sun to the horizon.

The solar charging station construction is used in two ways.

- Stations those are intended for the cities. These stations are mostly set as an architectural object to align in urban areas. Urban area is highly dense and it is very complicated to equip photovoltaic panels with a system which follows the sun. In general these photovoltaic panels are equipped with a system where only the pitch angle can be changed when the seasons change.

- Stations that are created to produce electricity effectively. These solar stations are equipped with a system that follows the sun. In general, these stations are created in areas with low building density and other objects that cast shadows.

From the description above, it can be concluded that for the optimum solar energy production, the construction should be with moving parts, to which attach photovoltaic panels, and it must be sufficiently strong and stable to withstand the local climatic conditions. The key features of the proposed battery charging station are an adjustable photovoltaic panel angle for efficient use of solar energy and protection of parked bicycles against precipitation.

Materials and methods

The alternative energy charging station had to be placed in the yard of the Faculty of Engineering of the Latvia University of Agriculture. It was necessary to determine the optimal placement of the station within limited area. Conformity to the existing infrastructure and potential shadowing by the buildings and trees had to be evaluated.

There were carried out experiments in March of 2012 about the shadowed areas of the faculty yard green area. It is important for determination of the alternative energy battery charging station position on the green area, to receive as much possible radiation from the sun during the whole year, thereby improving the efficiency of the station.

The lengths of the shadows are shown in Fig. 1. In March of 2012 at 9 o’clock the shadows from the buildings 1, 2 and 4 reach the center of the green area 5. In March of 2012 at 12 o’clock the shadows from the building 4 and trees do not reach the center of the green area 5.

To consider the sun height changes and increase of daytime, lengths of the shadows from the west in the afternoon are shown in Fig. 2. In March of 2012 afternoon the shadow lengths from buildings 1 and 4 and trees do not reach the centre of the green area 5.

Earth is doing 1 rotation around the sun in a year, and its axis direction remains fixed in universe by 23.45 degrees at normal against the rotation plate [2]. The degree between the direction towards the sun and equatorial plate is called declination δ and is a seasonal change measure [3].

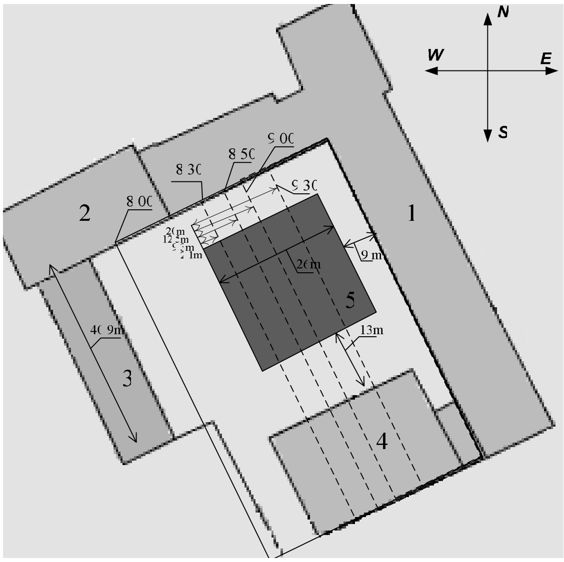

Fig. 1. **Shadow measurement on March 23 (in the morning):** 1 – old building, 2 –new building, 3 – garages, 4 – workrooms, 5 – green area

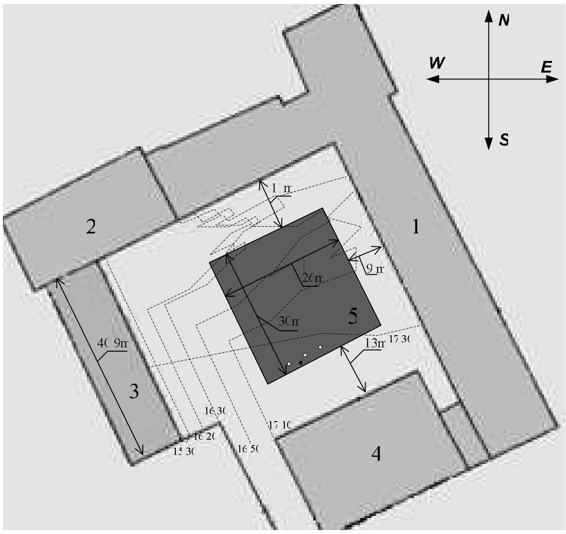

Fig. 2. **Shadow measurement on March 23 (afternoon)**

In the northern hemisphere δ changes from + 23.45° on July 21 (summer solstice period), to – 23.45° on December 21 (winter solstice period) [2].

The highest point of the sun at midday can be determinated using the following equation:

$$\alpha_n = 90° - \varphi + \delta\,, \tag{1}$$

where α_n – degree of sun position at midday;

φ – degree of latitude (Jelgava 56.39 lat. degrees);

δ – declination.

Using the equation (1), it is possible to determine the sun altitude at midday for every season:

- in summer (on June 21)
  $\alpha_n = 90^o - \varphi + \delta = 90 - 56.39 + 23.45 = 57.06$;
- in winter (on December 21)
  $\alpha_n = 90^o - \varphi - \delta = 90 - 56.39 - 23.45 = 10.16$;
- in spring (21.03), in the autumn (21.09)
  $\alpha_n = 90^o - \varphi + \delta = 90 - 56.39 + 0 = 33.61$.

Fig. 3 a schematically shows the movement of the sun and the station location, Fig. 3, b shows the solar height of the summer solstice (at midday). Choosing the location of charging stations should take into account the fact that the time of the so-called solar time does not coincide with the local time zone respectively, standard time (recorded clock) is different from solar time [4]. This difference is defined as the time equation.

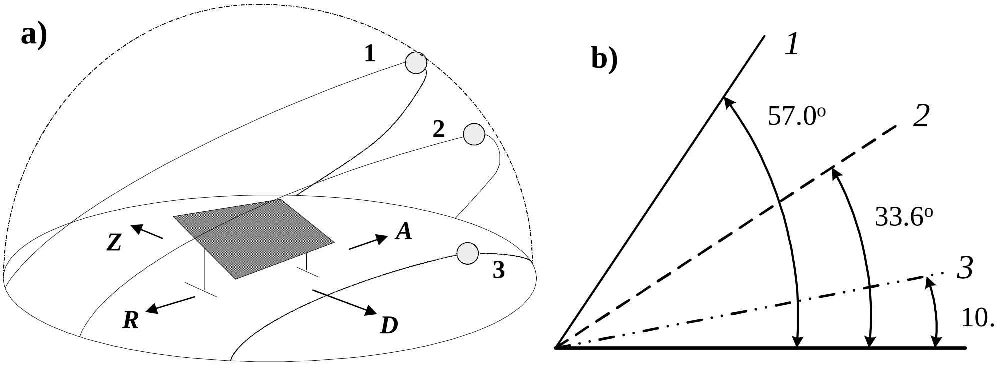

Fig. 3. **Position of the sun:** *a* – position of the sun during the solstice; *b* – highest point of the sun at midday; 1 – summer solstice; 2 – autumn solstice; 3 – winter solstice

The time equation value is constantly changing because the sun motion is not constant during the year. These irregularities are due to the Earth motion in the orbit with variable speed, and solar motion characteristics. Because of these two reasons, the time equation value can reach 16 minutes [5]. Therefore, several authors allow displacement of solar photovoltaic from the south a few degrees.

The recommended position of the alternative energy battery charging station is shown in Fig. 4. Because the alternative energy battery charging station was designed as canopy and only one plane is regulated, the station is located 10-15 degrees to the west, to absorb the sun radiation more effectively during summer time.

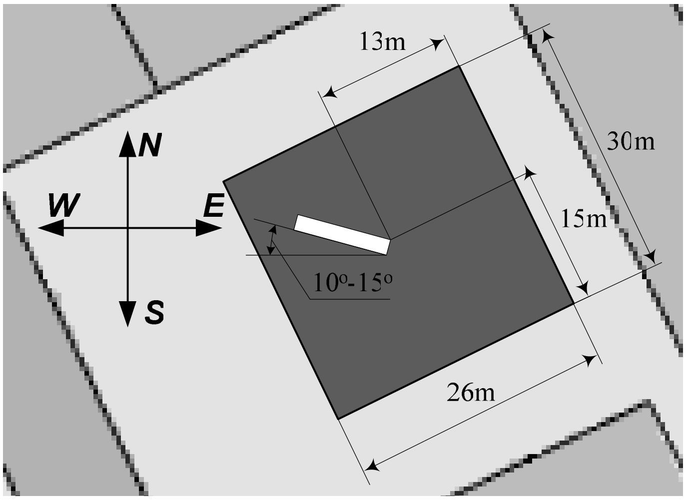

Fig. 4. **Position of alternative energy battery charging station**

Results and discussion

The prototype of the photovoltaic energy battery charging station contains 10 photovoltaic panels. The total area of the panels is 15 m^2. The construction weight without solar panels (photovoltaic panels) is about 380 kg. The frame is fixed to the central beam, which is hinged on two vertical stands. The vertical stands are secured by bolts to the concrete foundation. The solar station frame is shown in Fig. 5.

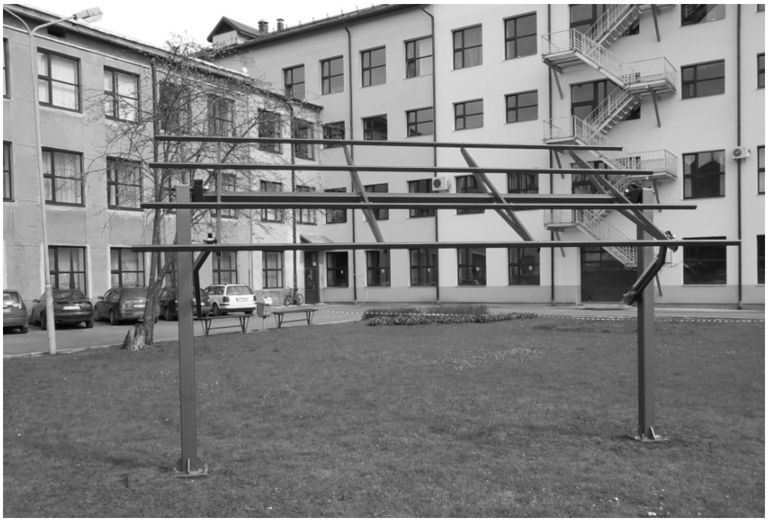

Fig. 5. **Frame of alternative energy charging station**

The frame and the central beam are made from square profile steel tubes, sized accordingly 50×30×3 mm and 120×80×4 mm, steel standard S235JR. The vertical stands are made from square profile steel tube, size 120×120×6 mm, steel standard S355J2H.

The dimensions of the solar station are the following:

- width – 5.02 m;
- height – 3.04-3.60 m (depending on frame positioning angle);
- depth – 0.97-2.02 m (depending on frame positioning angle).

The angle adjustment mechanism (Fig. 6) contains two square profile levers, which are hinged to the frame and fixed to the vertical stands. The angle is being adjusted using threaded rods and the desired position secured by bolts.

Fig. 6. **Angle adjustment mechanism of the solar station**

The panels are fixed on the frame by metallic clamps (Fig. 7). The charging station is designed to adjust from 27-63 degrees. If necessary, the adjustment mechanism can be equipped with an automatic angle adjustment mechanism.

Fig. 7. **Photovoltaic module attachments**

The solar station design was guided by the following criteria:

- ability to withstand wind and snow loads;
- allowing simple adjustment of the inclination angle for photovoltaic panels;
- architectonically fit for the location.

The constructed battery charging station is made with adjustable photovoltaic panel angle for efficient use of solar energy and protection of parked bicycles against precipitation.

Conclusions

1. The alternative energy battery charging station prototype can be used for efficient use of solar energy and protection of parked bicycles against precipitation.
2. It is important for stations located in city yards to be constructed in places where there is less shadowing from buildings and trees.
3. The charging station turning angle depends largely on the season and location latitude, in summer time when the sun is higher above the horizon the photovoltaic panels need to be adjusted in the angle 45°, but in winter time when the sun position is lower above the horizon – in 45° to 90° angle.
4. Because the alternative energy battery charging station was designed as the frame and only one plane is regulated, the station is located 10-15 degrees to the west to absorb the sun radiation more effectively during summer time.

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ENERGETIC BALANCE OF AUTONOMOUS HYBRID RENEWABLE ENERGY BASED EV CHARGING STATION IN WINTER CONDITIONS

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Abstract. The paper presents an experimental research on energetic balance of an autonomous hybrid renewable energy based electric vehicle (EV) charging station. The experimental charge station is located in the central part of Latvia in Jelgava city. The station is built using standard small-scale hybrid power system equipment: 24 V 300 Ah lead-acid battery, 2 kW photovoltaic array, 300 W wind generator, hybrid charge controller and 1.6 kW inverter. The station is capable to perform mode 1 EV charging (220 V, 50 Hz, up to 1.6 kW). The aim of the research is to evaluate the operation possibilities, technical self-consumption and overall energy balance of the renewable resources based station during a winter period. Analysis on available power for EV charging, self-consumption and affecting environment factors during a 6-day period is performed. The time period was chosen to include days with temperatures below and above zero and various levels of solar irradiation. Conclusions about possibilities and usefulness of winter-period exploitation are given.

Key words: renewable resources, electric vehicle charging station, winter conditions.

Introduction

Recent developments and overall cost reduction of renewable energy equipment allow considering autonomous renewable energy based power supply systems as an alternative to a power grid connection. One of the cases where such autonomous power systems can be effectively used is the electric vehicle (EV) charging infrastructure in remote places without power grid coverage or with low quality connections e.g. intercity roads, remote rural places, tourist sites, national parks etc [6]. Technical and economical effectiveness of renewable energy generators is affected by annual weather conditions. In winter months in central part of Latvia average minimum air temperature is –6 °C [3], and additional heating of electrical equipment may be necessary. A crucial part in every autonomous power system is energy storage equipment or batteries. One of the most cost-effective energy storage technologies for stationary backup and standalone power system applications nowadays is lead-acid chemical battery technology with a cost of 50–150 EUR per kWh and lifespan up to 2,000 cycles with 70% depth of discharge [4, 5]. It is well-known fact that operating lead-acid batteries at higher temperature will reduce the life and operating at lower temperature will reduce the efficiency [1]. Also there is a risk of electrolyte freezing for VRLA batteries at low discharge rates when specific gravity of electrolyte can become less than 1,100 and the electrolyte will freeze at approximately – 6.7 °C [2]. Therefore operating conditions should also be taken into account for the batteries. The aim of the research is to evaluate operation possibilities, technical self-consumption and overall energy balance of small-scale autonomous hybrid wind-solar EV charging station during winter period in Latvia by using only of-the-shelf equipment available currently on market.

Materials and methods

The experiments were performed on standalone small-scale electrical hybrid power system (HPS) designed for off-grid low power EV charging. A simplified electrical circuit of the experimental setup is shown in Fig. 1.

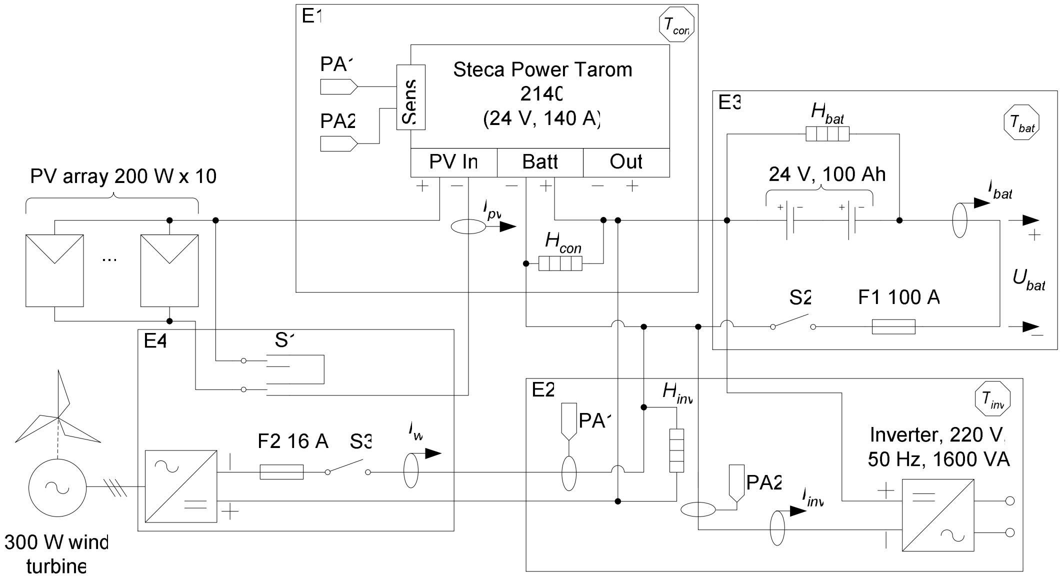

Fig. 1. **Experimental setup, measured parameters**: I_{pv} – current from photovoltaic array; I_{bat} – battery current (below 0 – discharge, above 0 – charge); I_w – current from wind generator; I_{inv} – current to inverter; U_{bat} – system voltage; T_{con}, T_{bat}, T_{inv} – temperatures in enclosures; H_{con}, H_{bat}, H_{inv} – heater states in enclosures

The system uses the central DC bus topology with parallel connection of generator, load and battery with nominal system voltage 24 V. The main components of the system are 2 kW PV array (10 Kioto KPV 195 PE modules) positioned to the South at 62.88° tilt to the horizon, Senwey Energy 300 W wind generator with 3-blade turbine, permanent magnet synchronous machine and dedicated charge controller (see Fig. 2 and 3), two series-connected ABT TM12-510W 12 V 100 Ah VRLA (Valve Regulated Lead Acid) batteries, hybrid solar charge controller Steca Power Tarom 2,140 and MeanWell TN/TS-1500 sine wave inverter. Maximum system output for EV charging is 1,600 VA.

Fig. 2. **Two kilowatts PV array of 10 Kioto KPV 195 PE modules**

Fig. 3. **Vaisala weather station MAWS201 and 300 W wind generator**

The equipment is arranged in 4 enclosures. E1 houses hybrid solar charge controller; E2 contains inverter, circuit breakers and energy meters for AC 220 V EV charging and current sensors for the hybrid charge controller; enclosure E3 is for battery placement; E4 contains charge controller for wind generator. The enclosures are made of 1.5 mm steel sheets, sizes of the enclosures (W×H×D) in millimeters are 360 × 330 × 190 (E1), 650 × 450 × 200 (E2) and 700 × 550 × 450 (E3).

The enclosures are placed in a closed yard under PV modules array and thus effects of solar radiation and wind are minimal (see Fig. 4).

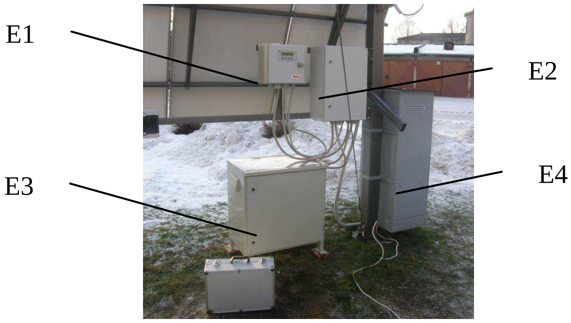

Fig. 4. **Placement of enclosures of electrical equipment**: E1 – solar charge controller; E2 – inverter; E3 – VRLA batteries; E4 – dedicated wind turbine charge controller

A number of parameters of HPS are used for data analyzing. Along with the electric measurements meteorological data is used. In our case a portable Vaisala weather station MAWS201 is used to get the meteorological information (see Fig. 3).

The Vaisala weather station is a real-time data source that is used in a variety of weather observation activities. In the current experiments wind speed, temperature and irradiation measurements are used. Station communication interface to other devices is RS-232. To connect station with PC in a long distance (approximately 60 m) a RS-232 to RS-485 interface converter was used. The RS-485 to USB converter is placed between RS485 terminal and PC for virtual serial port connection which in its turn can be easily used in software for data acquisition. The data from weather station is obtained every minute and stored in database server, which is in the same LAN where PC stands. For the data transferring and database interfacing purposes special software was developed. Experimental data flow diagram is depicted in Fig. 4.

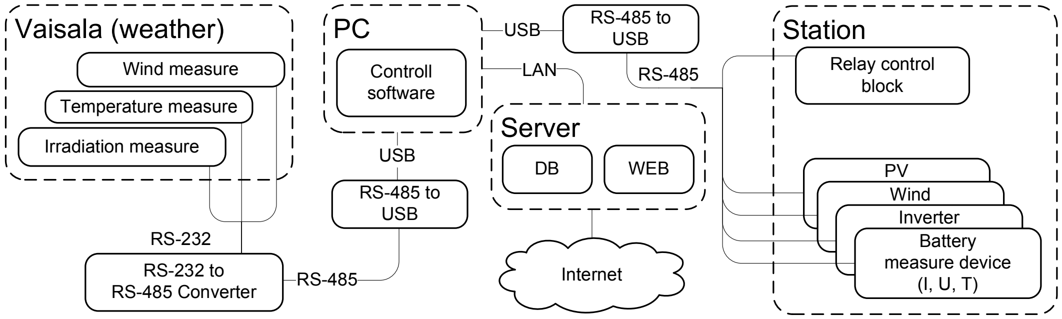

Fig. 4. **Experimental data flow diagram**

An embedded device for HPS current, voltage and temperature measurements (IUT) was developed. The device is based on PIC24F microcontroller can read data from sensors and provides communication with master PC. For current measurement HTFS 200-P Hall-effect contactless current transducer with current depended analog voltage output is used. Voltage divider directly connected to voltage source is used for voltage measurement. The electrical measurements are filtered using moving average filter with 1 s period, thus it is possible to filter transients caused by load switching and solar charge controller switching regulation, which is performed at 20 Hz. Integrated digital sensor TSIC 506F used for measurement of temperature (see Table 1).

Table 1

Accuracies of sensors

Source	**Measurement**	**Accuracy +/-**	**Unit**
Vaisala station	temperature	0.3	°C
	wind speed	0.3	$m \cdot s^{-1}$
	irradiation	0.2	$W \cdot m^{-2}$
IUT device	voltage	0.1	V
	current	0.2	A
	temperature	0.1	°C

Three IUT devices are placed in enclosures. The placement of electrical measurement sensors is shown in Fig. 1. In addition enclosures E1–E3 are equipped with heaters for temperature regulation to maintain operating conditions of the housed equipment. One relay control device with three outputs is used for heater management (executing commands from PC and turning on and off the relays); this device is placed in enclosure E2. Temperature sensors are placed in the center of each enclosure to get average readings, but heaters are installed as close as possible to lower part of enclosures in order to achieve better convection. It should be noted that due to sizes of E1 and E2 it was not possible to fully avoid the effect of direct heater radiation on temperature sensor readings. IUT and relay control devices are interconnected with master using RS-485 network. A RS-485 to USB converter is used at the PC side. All measurements data is stored in database server with one-minute interval synchronously with meteorological measurements. Power and energy for further data analysis is calculated by integration of product of system voltage and currents in various parts of the circuit. The master PC also runs a control algorithm, performs current monitoring and relay switching. Progress of experiments and data logged on server can be accessed trough WEB.

The self-consumption of the power system equipment consists of electrical self-consumption and energy needed for regulation of enclosures internal temperature. In this research heating is considered as only temperature regulation option in winter period for climatic conditions of Latvia.

Consumption needed for heating is expressed in heat loss per K according to (1).

$$Q = \frac{A}{\alpha_t^{-1} + \delta \cdot \lambda_d^{-1} + \alpha_A^{-1}} \ [\mathrm{W \cdot K^{-1}}], \tag{1}$$

where A – total area of walls of enclosure, $\mathrm{m^2}$;

α_t – internal surface conductance for the wall, 8.7 $\mathrm{W\,K^{-1}\,m^{-2}}$;

α_A – external surface conductance for the wall, 23 $\mathrm{W \cdot K^{-1}\,m^{-2}}$;

δ – thickness of walls, m;

λ – thermal conductivity of walls, $\mathrm{W\,(K\,m)^{-1}}$.

The calculated heat loses per °K are 3.15 W for controller enclosure, 6.47 W for inverter enclosure and 11.96 W for battery enclosure. The heat loses are significantly larger than self-consumption of electrical equipment (less than 1 W for controllers and inverter).

Heaters and internal temperature control mode for each enclosure was selected taking into consideration heat losses and operation conditions of the housed equipment.

According to datasheets Power Tarom 2140 should not be operated below –15 °C, but TN/TS-1500 inverter – below 0 °C, so keeping these temperature levels in enclosures is mandatory for normal operation of equipment. For batteries minimum charge temperature is –15 C, but discharge temperature –20 °C.

Operating conditions, calculated temperatures and selected heaters are summarized in Table 2.

Temperature control algorithm is performed from master PC (Fig. 4). For the temperature control in all enclosures thermostats are used with setpoints shown in Table 2.

Additional temperature control logic was added for batteries. As in Fig. 5, battery capacity at different discharge rates decreases by 0.7–1.6% with ambient temperature decrease by 1 °C. In absolute terms for the case study it is 1.1 Ah per degree or approximately 26 Wh with nominal battery voltage at 1 h discharge rate. The temperature effect on lead-acid batteries is studied in more detail in [1].

Table 2

Operating temperature in enclosures, selected heaters and thermostat setpoints

Enc.	Housed equipment	Operating temperature, °C	Heater type/power at 24 V	Max. ambient/internal temperature difference, °C	Min. ambient temperature for selected heaters, °C	Thermostat On/Off temperature, °C
E1	Steca Power Tarom 2140 solar charge controller	-15…60	Ni-Cr heating wire with ceramic coating, 16 W	5.0	-20	1/3
E2	MeanWell TN/TS-1500 sine wave inverter	0…60	Incandescent lamp, 60 W	9.0	-9	1/3
E3	ABT TM12-510W batteries, 24 V, 100 Ah	-10…60 (charge) -20…60 (discharge)	Incandescent lamp, 60 W	4.8	-14.8 (charge) -24.8 (discharge)	-9/-7

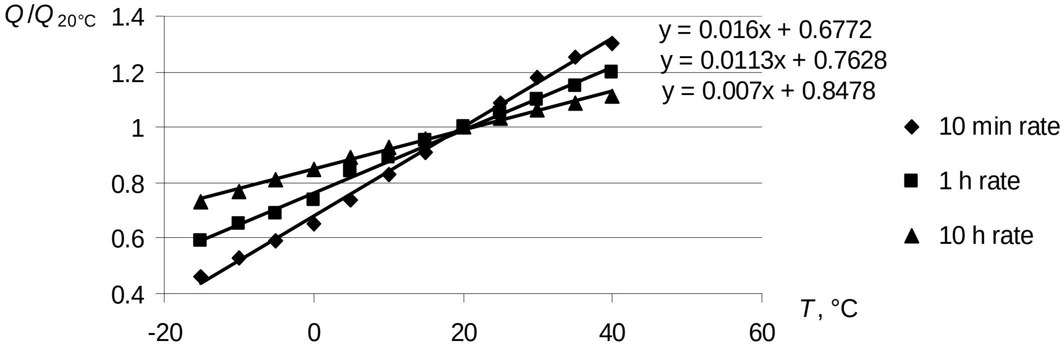

Fig. 5. **Temperature effect on capacity of TM12-510W expressed in relation to nominal capacity at 20 °C**
(information from manufacturer’s datasheet)

The control algorithm is shown in Fig. 6.

In order to maximize capacity of the battery the temperature the control algorithm turns on heater in enclosure E3 when excess energy is available from photovoltaic array and/or wind generator.

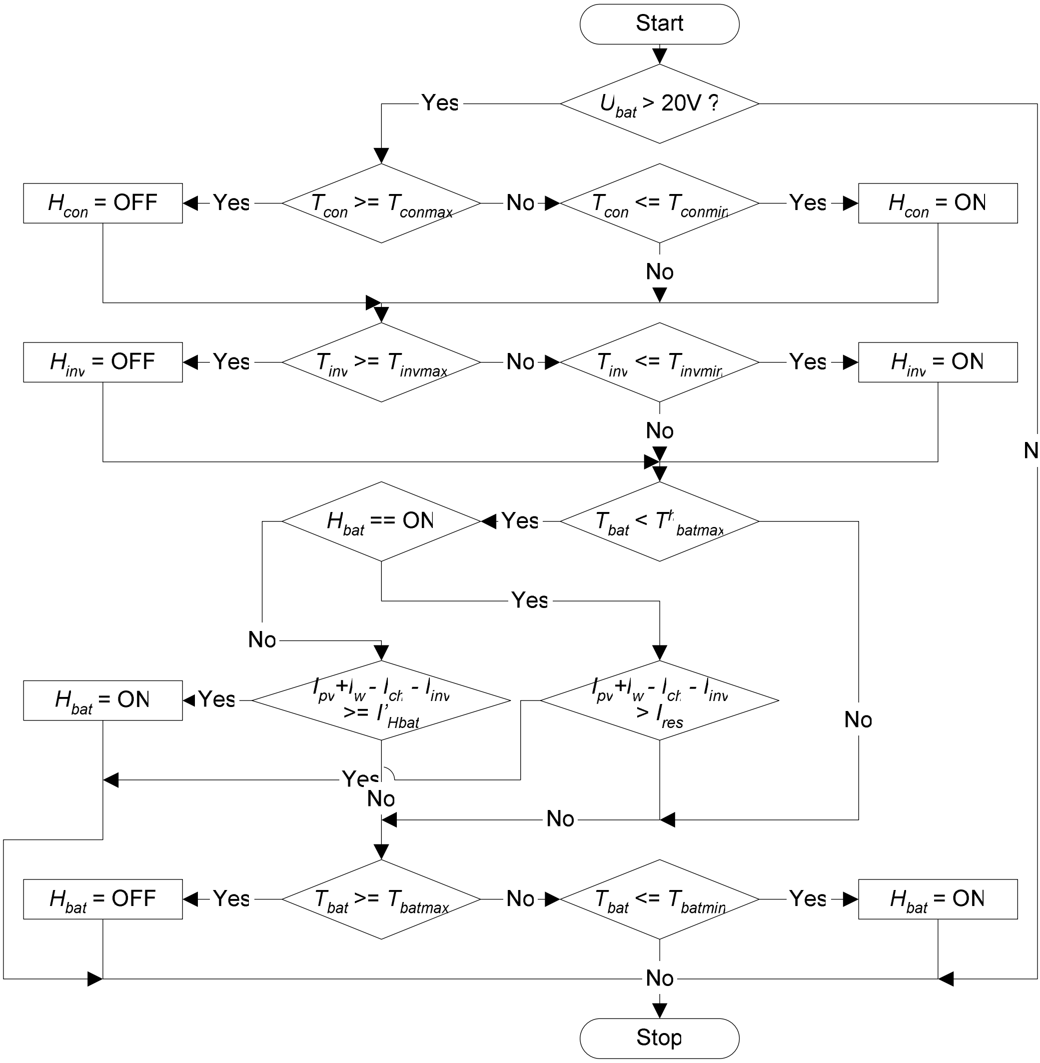

Fig. 6. **Temperature control algorithm**

If heater H_{bat} is not turned on yet, available power expressed with currents (voltage is constant for all system components) $I_{pv} + I_w - I_{ch} - I_{inv}$ is compared against calculated current for battery heater I'_{Hbat} to find if there is enough current to turn the heater on. I'_{Hbat} for given voltage is calculated using heater's U-I curve. If H_{bat} is already on, the algorithm checks if available current is more than reserved current I_{res} for self-consumption of the rest of the equipment.

If available current decreases, H_{bat} is turned off. I_{res} was set to 0.5 A for the experiments. Maximum temperature allowed in enclosure is 20 °C as it is nominal ambient temperature for the selected battery model. No heating is performed in any enclosure, if battery voltage drops below 20 V.

Results and discussions

The experiments were performed continuously in a 6-day period from February 6th to February 13th. Experiments were started with fully charged battery. Operating temperature in enclosures was maintained according to algorithm in Fig. 6 during the period of experiments, except day 3 when experiment on heating transient process was carried out. Meteorological data affecting operation of HPS during the period of experiments is shown in Fig. 7. Average ambient temperature was –0.6 °C, total solar irradiation on horizontal surface was 6 kWh·m^{-2}, but average wind speed – 2.5 m s^{-2}, which according to manufacturer's datasheet is the cut-in speed or the wind turbine.

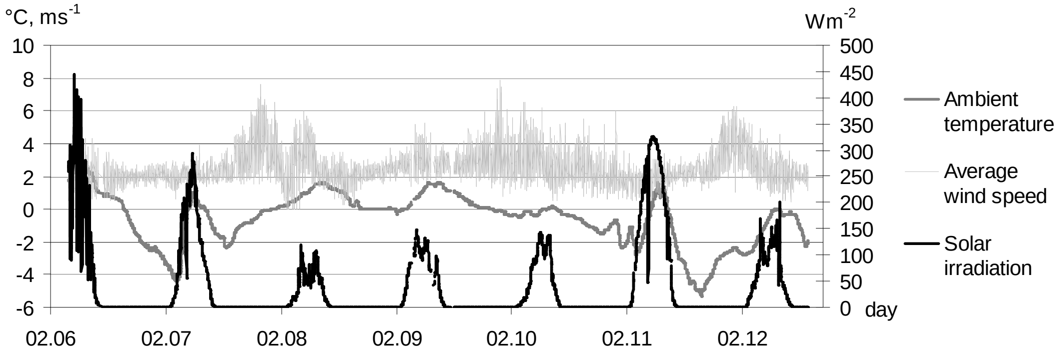

Fig. 7. **Temperature, wind speed and solar irradiation during experiments**

The wind charge controller used in the experiments is operating as a switch and has no voltage step-up function. The controller begins charging only when rotation speed of the wind turbine is enough to raise the output voltage to level required for 12 cells lead-acid battery charging (27–28 V). In conjunction with proportionally greater power of the solar panel array this results in a decrease of the effectiveness of wind generator in the hybrid small-scale standalone power system. This is despite of fact that special hybrid solar charge controller with a remote sensor (Steca HS200) was used for external current sources. Fig. 8 shows the use of wind energy for battery charging during various meteorological conditions. The scenario shown in the figure confirms the main idea of using wind generator in a solar power system – with a decrease of solar radiation in cloudy conditions as a rule wind speed increases yet overall low wind speeds resulted in minimal wind generator output (<0.1 kWh) during the period of experiments.

Before the period of experiments a test was performed to evaluate the real performance of heaters under changing operating voltage conditions, when the batteries are constantly discharged. After transient process the test showed that difference between ambient and internal temperature of enclosures was 7.3 °C for E1, 12.7 °C for E2 and 4.8 °C for E3.

Temperature difference for E3 confirmed the theoretical calculations, but E1 showed 2.3 °C and E2 – 3.7 °C greater temperatures, which can be explained with relatively small sizes of enclosures and close distance between heater and sensor. It should be noted that wind effect during the tests was minimal. Performance of heaters allows to safely use the system for EV charging at temperature down to –10 °C, but operation of controlling equipment (without using inverter for charging) down to –20 °C. Total power consumption for heating (including battery enclosure) will be 123 W or 3 kWh of energy per day at nominal system voltage, but if heating is used to keep operating temperature for controller and inverter only – 69 W and 1.7 kWh respectively. This can be decreased by additional heat insulation of enclosures.

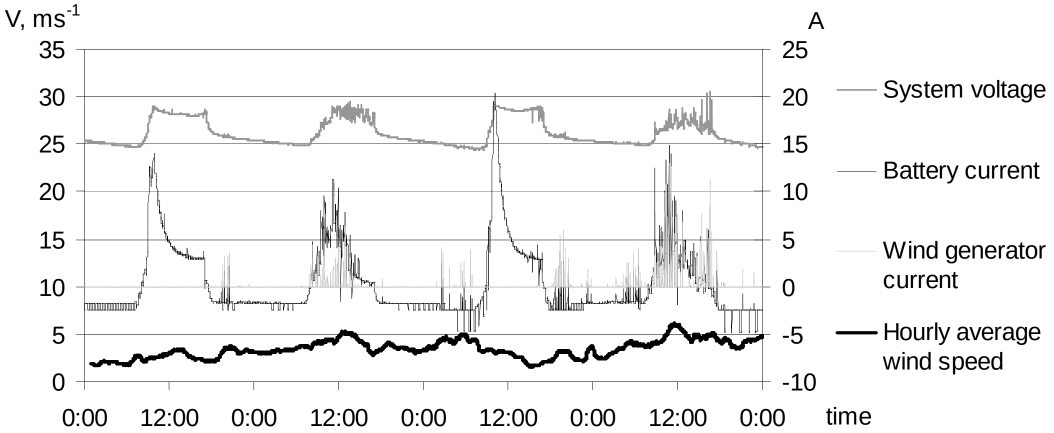

Fig. 8. **Use of wind energy for battery charging during various meteorological conditions**

Available instant solar horizontal irradiation (*I_s*), ambient temperature (*T_a*), system voltage (*U_{batt}*) and dynamic of internal temperatures of each enclosure for a day with average temperature –1.8 °C are given in Fig. 9. Experiments in daylight confirmed that temperature in enclosures is significantly affected by indirect solar irradiation; with the heaters turned off it was 3–10 °C above ambient temperature depending on the size of enclosure and solar irradiation.

During a night temperature in enclosures E1 and E2 was controlled by thermostat, but during daylight battery enclosure E3 was additionally heated using excess energy from photovoltaic panels when it was available. Thus temperature in E3 was 8.1 °C (10 °C above ambient) when the heater was turned off with decrease of solar irradiation and 0.1 °C (0.5 °C above ambient) at its closest point to ambient temperature, allowing to save up to 0.8% of battery capacity in the worst case.

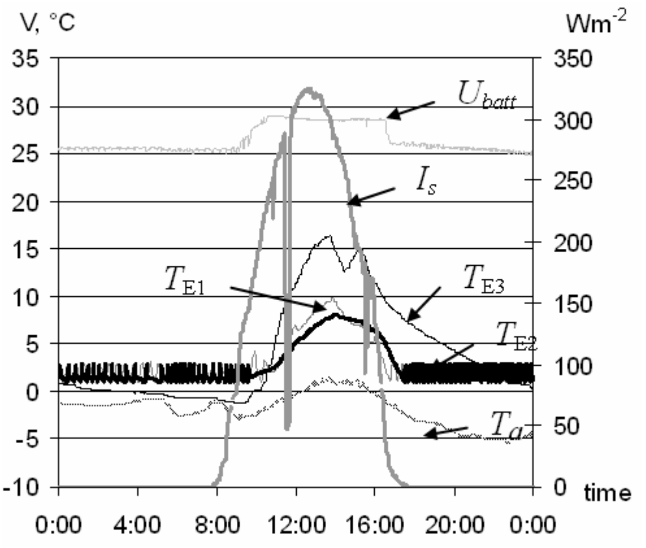

Fig. 9. **Daily temperature parameter dynamics**

Total produced energy during the period of experiments was 19.7 kWh, 1.8 kWh of which was used for heating of equipment, which was mandatory. In addition 2 kWh of total 17.9 kWh excess energy was used for heating batteries. Energy used for heating depending on daily average temperature is summarized in Fig. 10.

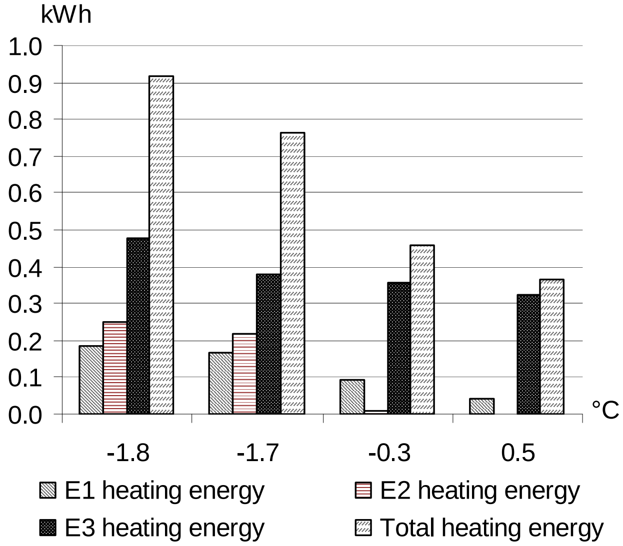

Fig. 10. **Heating energy depending on daily average temperature**

Assuming the worst-case energy amount needed for heating controlling equipment (1.7 kWh per day) it can be concluded that discussed HPS can be operated at temperatures down to –10 °C, but it will take approximately a half of total energy produced for self-consumption during typical winter weather conditions. For longer period of time and depending on EV charging intensity this will lead to negative energy balance. It should be noted that the same controlling equipment with the same self-consumption can be used with up to 3.5 kW PV array, thus optimal sizing of generating equipment can improve the energetic balance.

It should be noted that only standard enclosures without heat insulation were used and arrangement of electrical equipment depending on its function was chosen: DC controlling and AC power equipment in separate enclosures and dedicated enclosure for chemical batteries. Alternatively in order to save the heating energy, electrical equipment could also be placed in common enclosure, but batteries due to necessity of ventilation and different heat regulation algorithm should be operated only in a separate enclosure in all cases.

Conclusions

1. Proposed small-scale autonomous hybrid power system for off-grid low power electric vehicle charging using off-the-shelf components can be fully operated at temperature down to –10 °C, but operation of controlling equipment (without charging function) down to –20 °C.
2. Total worst-case power consumption for maintaining normal operational conditions for controlling and power conversion equipment is 69 W or 1.7 kWh of energy per day at nominal system voltage. This can be decreased by additional heat insulation of enclosures, but ventilation, electrical and fire issues should be considered.
3. Excess energy can be effectively used for additional heating of main lead-acid batteries thus increasing efficiency of the batteries, which is strongly affected by ambient temperature, but longer experiments with full charge/discharge cycles of batteries are needed to fully evaluate effects of environmental conditions, schedule of energy usage for electric vehicle charging and overall economical reasonability.
4. Mutual sizing of power generating equipment is essential for small-scale hybrid power systems. Output of smaller generator can be used fully only in periods with significant decrease in primary generator output as it was in our case with primary 2 kW photovoltaic array and 300 W generator. Besides optimal power sizing of the generators the problem could be partially solved by using power converters with maximum power point tracking and voltage step-up functions.

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ANALYSIS ON ELECTRIC VEHICLE CHARGING INFRASTRUCTURE IN LATVIA

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Abstract. The paper contains a review of electric vehicle charging infrastructure in Latvia. Electric vehicles are only gaining popularity in Latvia, but it is essential to develop the exploitation infrastructure, because without it, users can rely only on individually available resources. In March of 2012 there are only 10 public charging points in Latvia, 8 are in the capital Riga. The other two are within 50 km range from Riga – in Jelgava and Jurmala. Choosing the best exploitation infrastructure for Latvia will mean lower costs, balanced charging points, bigger electric vehicle independence, security for new users of technology and faster integration. Before the development of the electric vehicle market in Latvia has gained speed and serious infrastructure has been built, there is still time to learn from success and mistakes made in other countries and choose the most suitable way of creation of charging infrastructure. Significance of a unified marking standard for equipped parking spaces and charging stations is discussed. The authors review the necessity of simple and straightforward user interface.

Keywords: charging point, electric vehicle, infrastructure.

Introduction

Use of electrically powered means of transportation in Latvia predates hype that started around the year 2009 concerning a new generation of electric passenger vehicles. Electric trams were introduced in year 1901. In 1914, there were 14 lines of electrical trams in Riga, with the total length of 50 km, carrying 52.1 million passengers yearly [1]. Off course, a tram does not need a charging infrastructure but it is a great demonstrator of the use of electrically powered means of transportation. The technology demonstrates comfort, reliability, ecological and economical points. In 1980’s the price for tickets for public transportation was the following – bus 5 kopecks, trolleybus 4 and tram only 3 [2].

Electrical forklifts were widely used in factories in warehouses since their introduction in 1906 [3]. With zero emissions it is an irreplaceable tool in closed areas and a great demonstrator of technology. Electric motors and controllers, used in forklifts are a popular source of components for enthusiasts of internal combustion vehicle (ICE) converters to electrical vehicles [4].

The industrial charging infrastructure for forklifts in Latvia exists for many years. The experience obtained by its maintainers and users should be used when developing a new charging infrastructure for modern electrical vehicles.

More and more strict laws are introduced for emission gasses and waste water. Cities are struggling with smog and noise. People are used to personal transportation for longer than a century, but there is always a prediction ahead, that oil resources will run out despite exploring new reserves. The Earth’s population and wealth are growing, so there is the need for transportation. The political situation and oil demand causes the fuel prices to grow. That leads to more activity in fuel alternative field.

In 2010 almost 60 % of the electric energy, produced by the largest electricity supplier “Latvenergo” in Latvia came from renewable resources - mainly from hydroelectric power stations [5].

Electric energy can be considered as a natural resource of Latvia. If an atomic power plant in Lithuania will be built, it may have a major impact on the energetic independence of the Baltic States from the current supplier. To increase the economical independence of Latvia, consumption of oil products and natural gas should be replaced by electricity. In the field of transportation it means replacement of the current, ICE powered fleet with electrical one. Currently the demand for electrical vehicles in the Western world exceeds the production capacity. Only few producers are ready to supply EV’s. Currently they are Mitsubishi, PSA and Renault-Nissan. To give the best experience to the customers, only countries with developing charging infrastructure are served. It is a job of NGO, municipalities and government institutions to show that a specific country has strong and serious intentions for developing of charging infrastructure.

Current situation of charging infrastructure

Development of a public EV charging infrastructure in Latvia is beginning. At the moment, there is not much to charge. Currently, there are only two officially registered M1 and N1 class electric vehicles in Latvia. Around 500 electrical bicycles and 25 slow moving EV’s, used in the Zoo, hospitals and golf courses are charged in private charging points [6].

The NGO “BIMAB” – Zero Emission Mobility Support Society was founded in 2009 to develop sustainable mobility in Latvia [7]. In cooperation with the local producer of electrical power “Latvenergo’ on September, 2011, a map and list public charging points were presented [8].

The public charging points in Latvia on April, 2012 are listed in Table 1.

Table 1

Public Charging Points

Address	Parking	Charging	Connections
Brivibas gatve 299, Riga	Free	Paid	1
Jomas iela 4, Jurmala	Free	Free	4
Eksporta iela 3a, Riga	Paid	Paid	1
Stacijas laukums 4, Riga	Paid	Free	10
Z. A. Meierovica bulvaris 8, Riga	Paid	Free	10
Elizabetes iela 55, Riga	Paid	Free	5
Baznicas iela 20/22, Riga	Paid	Free	5
J. Cakstes bulvāris 5, Jelgava	Free	Free	4
Dzirnavu iela 67, Riga	Paid	Free	2
Lielgabala iela 4, Riga	Paid	Free	2

In total 10 public EV charging points so far are introduced in Latvia. Most of them are located in the capital Riga. One charging point is located in the city Jurmala (25 km from the capital), near the administrating building of “Latvenergo”. It has a free charging and parking space. This charging point is the only one with IEC-62196; 32 A/230 V/50 Hz (21 kW) type connector, used for electric automobile fast charging. There are sockets for 4 electric vehicles. The other charging point outside the capital is located in the city Jelgava, at the Faculty of Engineering of the Latvia University of Agriculture (45 km from the capital Riga). It is capable to serve 3 bicycles and 1 car simultaneously. Parking and charging are for free, but this service is not available twenty-four hours a day because of the closed territory during the night time.

The first public charging point in Latvia was opened in October, 2010, at the petrol station “Kursi”, Brivibas street 299, shown in Figure 1 [9]. It was developed by the local producer “Eltus” [10].

Fig. 1. **Charging point at Brivibas street 299, Riga [9]**

There are 6 charging points in Riga. One is near the Old Gertrudes Church for 5 vehicles. Free charging, but parking requires payment. The second is not far from the city center, in Old Riga. Charging is for free, but there is a parking fee. Ten vehicles can be parked there. The third is near the Riga Passenger Port, it can serve one vehicle and both, charging and parking, are not for free. Another charging point is near the Latvian National Museum of Art. It has free charging, but paid parking spaces for 5 vehicles. Another big electric vehicle charging point for 10 vehicles is near the Central Railway Station. Here also there is paid parking and free charging.

Currently, there are no agreements for unified marking of the charging points in Latvia. An example of marking at Europark parking is shown in Figure 2.

Fig. 2. **Marking of charging point at Europark parking [11]**

Future development

The public limited company “Latvenergo” is the biggest energy power supply enterprise in Latvia. It has been estimated that the first level extension could consist of 50 charging points in the biggest cities (12 in the capital Riga) and could cost around 2.5 million EUR [12]. The possible locations are shown in Figure 3. Charging points could be located near malls, state enterprises, housing estates, the city center, near catering establishments and along highways. There is a commitment to develop up to 500 charging points in Latvia till 2020 [13].

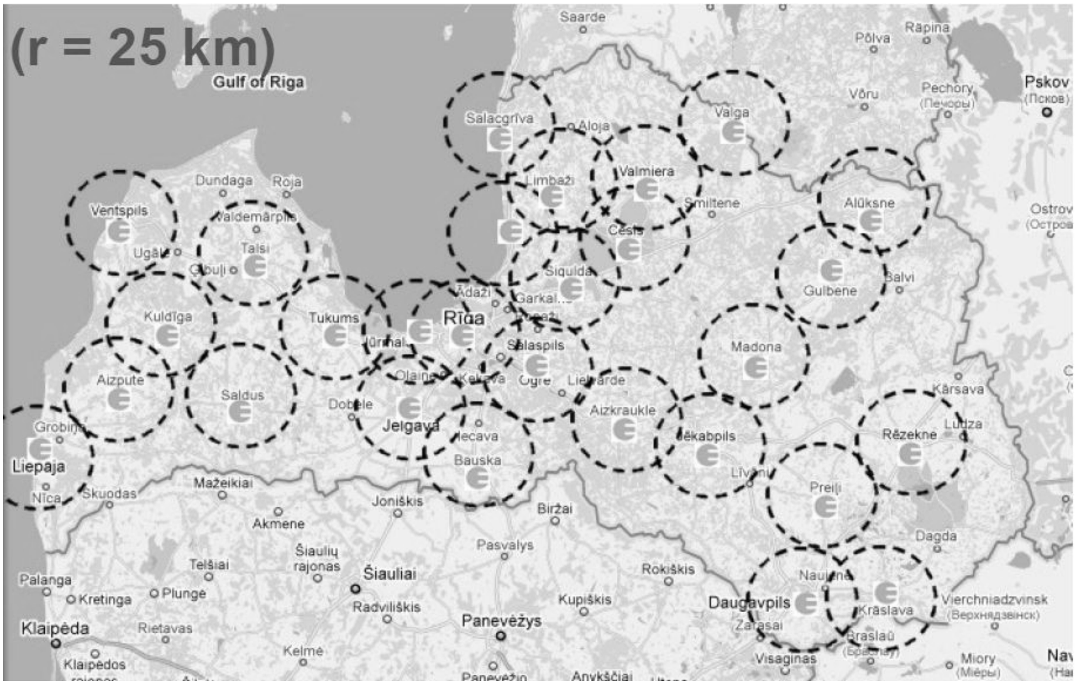

Fig. 3. **Plans for location of charging points by Latvenergo [12]**

If the market will develop successfully, many car manufactures will offer EV’s via the local dealers. To fulfill their contracts, the dealerships will develop their own public charging points, including the designated ones for fast charge with direct current.

In the middle of 2012 financial support from the Latvian Government program KPFI will be available for development of the EV park and charging infrastructure. The total amount is 3.5 million LVL.

The KPFI program is funded by selling CO_2 quotas, according to the Kyoto protocol [14].

There was an immediate public reaction after this announcement, in the form of willingness to purchase EV at few dealerships of the current EV producers. Unfortunately, in Latvia there is no commercial offer of EV from the world’s leading producers. Probably, it can be wise to direct the available funding in the development of the charging infrastructure.

Local production of charging equipment

The first public charging point in Latvia, located at the petrol station “Kursi” at Brivibas street 299, was equipped with locally manufactured charging equipment. It was supplied by the company “Eltus”.

The charging device type M2 Universal is shown in Figure 4.

Fig. 4. **Charging device Eltus M2 Universal [10]**

The main features are listed in Table 2.

Table 2

Technical Characteristics, Eltus M2 Universal

AC Power Input	400 VAC, 32A Max, Three Phase
AC Power Output	Three Phase, 400 V, 32 A (22 kW)
	Single Phase, 230 V, 16 A (3.7 kW)
Charging Connections	Three Phase according IEC-62196 (Mennekes)
	Single Phase – Country Specific (Schuko)
Overcurrent Protection	Cut-off 40A per phase
Leakage Current Protection	30mA, optional programmable auto retry
Cable Type Detection	Yes, on IEC-62196
Energy metering	Class 1, resolution 0.1 $\mathrm{KW\cdot h^{-1}}$
Local Area Network	RS-485, Ethernet
Wireless Local Network	Zig-Bee, according 802.15.4 (optional)
Wide Area Network	GSM/GPRS commercial network
RFID Smart Card Reader	ISO-14443, ISO-15693 or both (optional)
Electrical Compliance	2006/95/EC (Low Voltage directive)
	2004/108/EC (EMC directive)
Operating Temperature	-30 ºC to +50 ºC
Operating Humidity	< 95 %
Dimensions	1400 mm × 180mm × 120 mm
Weight (including packaging)	25 kg

The company “Eltus” was founded in 2010 in collaboration with the Kurland Business incubator in Latvia and a private investor. The company is located in the city Liepaja.

The project launched electric charging point prototype and test unit development for electric and plug-in hybrid electric cars. After finishing the pilot project in 2011, the manufacturer is now starting serial production of the charging points [10].

In northern Europe countries a lot of cars are equipped with engine heaters with external power supply. In some parking places there are sockets for this purpose (see Fig. 5).

Fig. 5. **Sockets for engine heating in town Nokia, Finland**

Currently, there are more than a million engine heating stations already in place [15]. These engine heating stations are used for a short period of time and are not planned for big electrical loads (16 A fuse), so only slow charging is available. If the owner of those parking places allows free long-time charging, then there will already be a simple infrastructure for charging electric vehicles. But there are very few electric vehicles in Finland- the Finns do not believe they would survive their harsh winters. Latvia should also encourage companies for a simple electric vehicle infrastructure nearby their social buildings.

Conclusions

1. All 10 electric vehicle charging stations are located densely in the central part of Latvia, but are not well recognizable among Latvians.
2. All charging stations are different, because of the lack of standards for marking and charging.
3. The infrastructure is developing at a moderate rate due to social activists despite the lack of governmental support.

4. The main supplier of electrical power “Latvenergo” has announced commitment to develop a large network of charging points till 2020.
5. Financial support for charging infrastructure development from the Government funded program in the total amount of 3.5 million Lats will be available in 2012.
6. Latvia has the technology for creation of a modern and complicated electric vehicle infrastructure.
7. A basic charging infrastructure can be created using simple solutions and equipment.

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SUMMARY

1. By introducing electric motor vehicles in Latvia, fossil energy resources can be saved, and electricity can be domestically produced without consuming oil products. Electric automobiles in cities and urban areas can compete with fossil energy automobiles, especially in cases when they are designed to ensure certain parameters of exploitation.
2. Using of fossil fuels in automobiles, the lowest cost or 9.62 EUR $(100 \text{ km})^{-1}$ was obtained for a 5 year old automobile running on compressed gas owing to its low purchase and fuel costs. Among electric motor vehicles, the highest efficiency or 11.94 LVL $(100 \text{ km})^{-1}$ was obtained for a 5 year old automobile that was converted to electric power. Purchasing a used electric automobile is relatively expensive. An economic effect of 12.17 LVL $(100 \text{ km})^{-1}$ for a new electric automobile is possible only in case if its batteries are rented and there is no need to replace them during repair, however, such a service will not be available in Latvia over the next years due to a need for large government subsidies.
3. The total CO emissions from cars in Latvia – 1289.73 t per year – are 4.74 times greater than those from lorries. Regardless of the wide use of diesel engine lorries and their large engine capacities, NO_x emissions from these automobiles are only 13 % greater than those from cars. If 10 % of conventional cars were replaced with electric drive cars in Latvia, the following ecological effects in relation to emission reductions would be achieved: 1289.73 t of CO, 112.43 t of $CH+NO_x$, 97.20 t of C_nH_m, 155.11 t of NO_x, and 6.18 t of PM a year.
4. The electric vehicle electric energy costs depend on the kind of the charging place and the price for electric energy at it. The cheapest charging is at home conditions. From the point of view of energy costs the cheapest are electric bicycles without exceeding 0.36 EUR per 100 km. The costs of the internal combustion motor automobile are three times higher than of the analogous internal combustion motor automobile – 9.81 EUR per 100 km. The energy costs depend on the tariffs in the country and fuel prices and they can essentially differ from the research results in Latvia.
5. From the study results it is clear that the electric vehicle battery full charge needs 7 hours, with electricity connection that can provide 12 – 13 A, 230 V, 50 Hz alternating current, that means that a regular

household connection is used near to its maximal current. Charging an electrical automobile at home means reducing other household electricity consumer total power used simultaneously. With growing of the electric vehicle popularity, there will be increased electricity network load expected, that can lead to the necessity for household connection power upgrade.

6. The electric motor has an important role for improvement of the dynamic properties of electric cars. The study shows that using higher power electric motors, both – the dynamic and operational performance – are better. The battery capacity determines the distance that the car can make between charging. The battery charging time is important.
7. Irrespective of the relatively small engine power, the electric motor vehicles showed sufficiently good dynamic characteristics owing to their excellent engine power and torque curves. The optimum average speed of the electric motor vehicles studied is (0.7 – 0.8) $v_{\max}$ which ensures the largest distance of driving for the electric motor vehicles. In the technical characteristics, the producers of slow-moving electric motor vehicles have showed on average 10 % higher speed of driving than it was achieved in the experiments.
8. The electric car regenerated energy fraction increased with the drop of the average speed. Battery charging with the braking energy occurred only in 4 – 5 % of the total city-cycle drive time and 1.6 – 2.1 % of the consumed energy was regenerated. The same percentage of total travelling distance can be expected.
9. Full battery charge for slow moving vehicles with the total mass less than 800 kg takes around 11 hours, 10.13 kWh and costs 1.58 EUR. The obtained driving ranges on a chassis dynamometer are bigger than on-road values, because of the constant load and speed regime that rarely can be achieved in on-road conditions.
10. The maximum speed and run-up dynamics of electric bicycles are mainly determined by the motor power, but they are also affected by the weight of the bike, the gear ratio from the motor to the wheels and the efficiency coefficient of the motor and transmission. Driving bicycles equipped with an electromotor larger than 250 W along the walkways is undesirable because their high dynamic characteristics may endanger cyclists, pedestrians and car drivers. Pedalling at the beginning of the run improves the acceleration of the bike, but not the maximum attainable speed.

11. The alternative energy battery charging station prototype can be used for efficient use of solar energy. It is important for stations located in city yards to be constructed in places where there is less shadowing from buildings and trees. The charging station turning angle depends largely on the season and location latitude, in summer time when the sun is higher above the horizon the photovoltaic panels need to be adjusted in the angle 45°, but in winter time when the sun position is lower above the horizon – in 45° to 90° angles. If the alternative energy battery charging station is designed as the frame and only one plane is regulated, the station is located 10 – 15 degrees to the west to absorb the sun radiation more effectively during summer time.
12. The proposed small-scale autonomous hybrid power system for off-grid low power electric vehicle charging using off-the-shelf components can be fully operated at temperature down to –10 °C, but operation of controlling equipment (without the charging function) down to –20 °C. Excess energy can be effectively used for additional heating of main lead-acid batteries thus increasing the efficiency of the batteries, which is strongly affected by the ambient temperature. Mutual sizing of power generating equipment is essential for small-scale hybrid power systems. The output of a smaller generator can be used fully only in periods with significant decrease in the primary generator output.
13. All electric vehicle charging stations are located densely in the central part of Latvia, but are not well recognizable among Latvians. The infrastructure is developing at a moderate rate due to social activists despite the lack of governmental support. Latvia has the technology for creation of a modern and complicated electric vehicle infrastructure. A basic charging infrastructure can be created using simple solutions and equipment.
14. In Latvia there are favourable conditions for development and usage of electric vehicles. For promotion of the development government support is needed in the form of different projects as well as understanding and interest of the potential users in the specifics of application, spheres, sustainability and potential of electric vehicles.