Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 134 (2016) 165 – 174

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Scientific Conference Transbaltica 2015

Analysis of Parameters Influencing Electric Vehicle Range

Martin Mruzek*, Igor Gajdáč, Ľuboš Kučera, Dalibor Barta

University of Zilina, Univerzitna 1, 01026 Žilina, Slovakia

Abstract

Range is considered as a key parameter of electric vehicles. Increasing electric vehicles range is important for acceptance of electro mobility. Battery capacity is the main parameter influencing electric vehicles range. In order to batteries are the most expensive part of electric vehicle is it suitable to focus on others parameters such a weight, aerodynamic drag coefficient or correct size of motor. Range is not influencing only by the designs parameters such as battery capacity but also important is driver influence. Simulations were created in order to determine how is influencing those factors range. For better accuracy was used real driving cycles.

Peer-review under responsibility of the organizing committee of Transbaltica 2015

Keywords: electric vehicle; range; simulation.

1. Introduction

The range is main parameter for the electric vehicle (EV) especially from the customer side. Range of electric vehicles has long been considered a major barrier in acceptance of electric mobility (Franke et al. 2013). Various factors influencing EV range. The first group of factors influencing EV range is vehicle design and the second is driver influence. The most significant design parameter for EV is the battery capacity. Increasing the amount of batteries is the simplest way to increase EV range. For long journeys could be used range extender (Derollepot et al. 2014; Punov et al. 2008). On the other hand, batteries are the most expensive part of the EV. Hence it is suitable to focus on other design parameters of the vehicle such as the aerodynamic drag coefficient or right designed size of electric motor. Driving style is crucial for range. Aggressive driving significantly decreases the range (Rimkus

* Corresponding author
E-mail address: mruzek@uniza.sk

Peer-review under responsibility of the organizing committee of Transbaltica 2015
doi:10.1016/j.proeng.2016.01.056

2012). Also important is in which conditions EV operates. Big elevation differences and extreme climate conditions decrease range. For find out how much is those parameters influencing EV range were created simulation. The other purpose is improving the experimental EV EDISON (Fig. 1) which was built at the University of Zilina. Based on those simulations analysis we want improve the parameters of the electric vehicle especially in terms of systems that will be able to reduce the driver impact. Curb weight of the experimental vehicle including the battery is 1048 kg. Propulsion provides a compact lightweight all-aluminum, air-cooled asynchronous electric motor AKOE with a nominal output of 16 kW and maximum power of 30 kW, with control unit, CURTIS converter and traction LiFeYPO4 300 Ah batteries with the controller and onboard charger 110-240V/16A. The main part of the vehicle is a tubular steel space frame (Gajdac et al. 2014).

Fig. 1. Experimental vehicle Edison.

2. EV simulation

For simulations was chosen the Software Matlab Simulink. The aim was to create a model of an electric vehicle in which is possible change the components parameters. Electric vehicle model is consisting of several subsystems. Demand power is calculate in dynamic subsystem. Demand power flow is dividing to the particular components in control subsystem. Operation of the battery and the electric motor is modelled in separate subsystems. Input data to the simulation are the driving cycles. The driving cycle represents the speed of vehicle versus time. The fact that most driving cycles are simplified and do not include the resistance of the climb results to creating real driving cycles (Barta et al. 2013). The urban part of the NEDC cycle and two real driving cycles created in Žilina and Prague were selected for parameters comparison. Courses of cycles are shown in Figures 2–4. Elevation profile of the real driving cycles is shown in Figure 5–6.

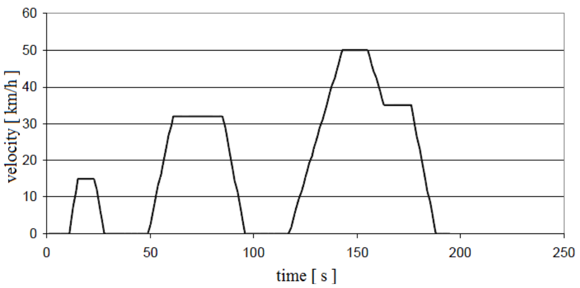

Fig. 2. Urban part of NEDC cycle (Barlow 2009).

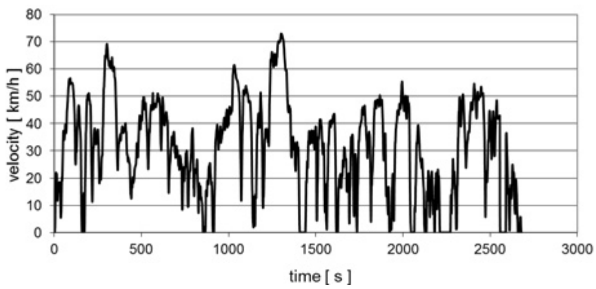

Fig. 3. Real driving cycle Zilna.

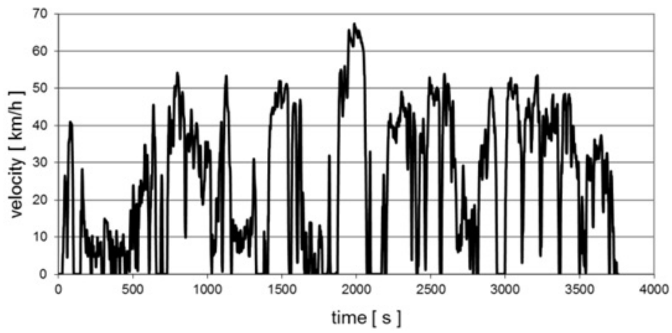

Fig. 4. Real driving cycle Prague.

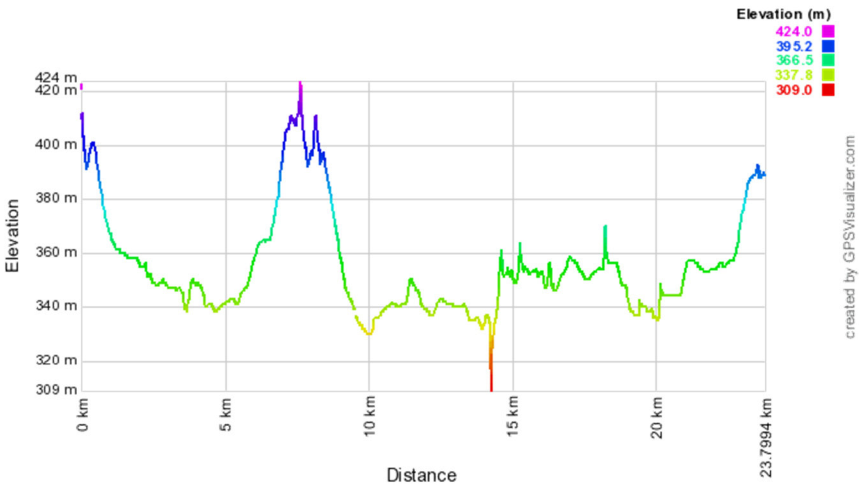

Fig. 5. Elevation profile of Zilina cycle.

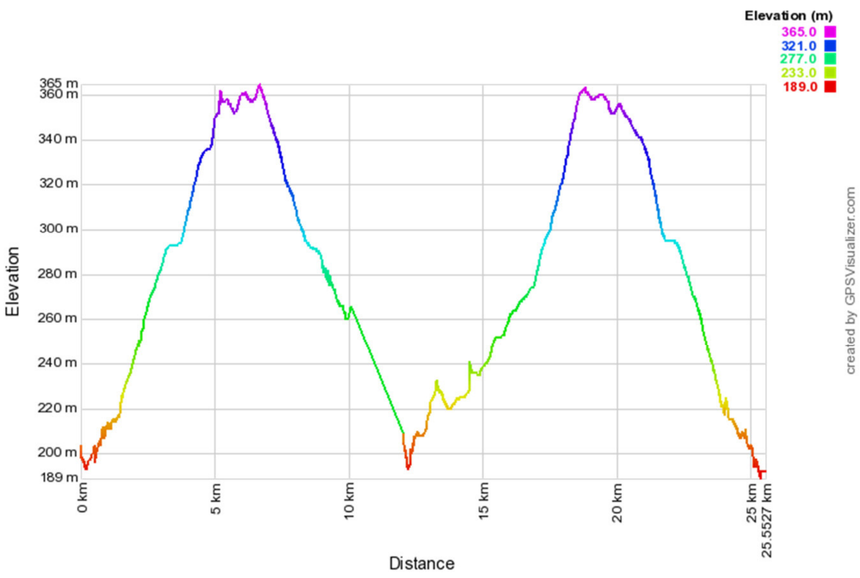

Fig. 6. Elevation profile of Prague cycle.

3. Coasting and braking impact

From the perspective of energy intensity is the coasting of a vehicle best solution for example for the deceleration on the entrance to the village or at stopping on the intersection. That means it is better to use kinetic energy of the vehicle and avoid braking. Figure 7 shows the change of coasting course of EV EDISON with different weight during deceleration from 90 to 50 km.h^{-1}.

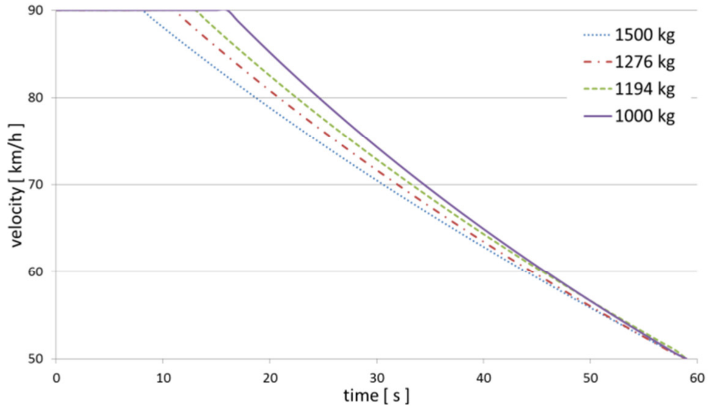

Fig. 7. Coasting analysis.

The advantage of electric vehicles is that they allow the braking energy recovery. This fact was analyzed. Identical acceleration from the speed of 50 to 90 km.h^{-1} and driving constant speed 90 km.h^{-1} on the beginning of maneuvers was assumed. The analysis compared two maneuvers. The first one, when the EV slows down before speed limit road sign by coasting from the speed 90 to 50 km.h^{-1} and in the second case by use braking from 90 to 50 km.h^{-1} during the time of 12 seconds. Vehicle passes 2500 m in both cases (Fig. 8).

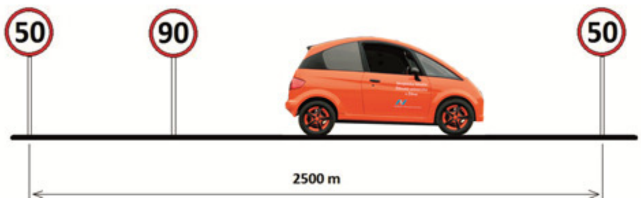

Fig. 8. Driving maneuver.

Table 1. Energy demand to pass maneuver.

Energy demand for maneuver in kWh by	Vehicle weight [kg]			
	1500	1276	1194	1000
Coasting	0.27493	0.25310	0.24630	0.22726
Braking without recuperation	0.36730	0.33181	0.31884	0.28814
100% recuperation efficiency	0.29377	0.27076	0.26240	0.24261
80% recuperation efficiency	0.30849	0.28297	0.27369	0.25171
60% recuperation efficiency	0.32321	0.29518	0.28498	0.26082
40% recuperation efficiency	0.33794	0.30739	0.29627	0.26993
20% recuperation efficiency	0.35267	0.31960	0.30755	0.27903
10% recuperation efficiency	0.36003	0.32570	0.31320	0.28358

The comparison of the demanded energy for passing maneuver by coasting and by braking is shown in table 1. Because it is not possible to use all of the recuperated energy, it was calculated how much will change the amount of energy to pass the maneuver at different efficiency of recuperation. As shown in Table 1, the deceleration by coasting is the most energy efficient. It is true also in the case that we will use recuperated energy up to 100%. During driving not every driver is able to estimate the right moment for using coasting. For reducing vehicle energy consumption would be suitable to use a signalizing device which will signalize the right moment for decelerating by coasting to driver. Such device would need the information of the vehicle weight, current speed and vehicle position eventually system for recognizing traffic signs.

4. Impact of acceleration

The vehicle acceleration is the most energy demanding maneuver. Four accelerations were chosen for comparison as it is shown in Figure 9. Acceleration 1 is the slowest one, acceleration 4 is the fastest.

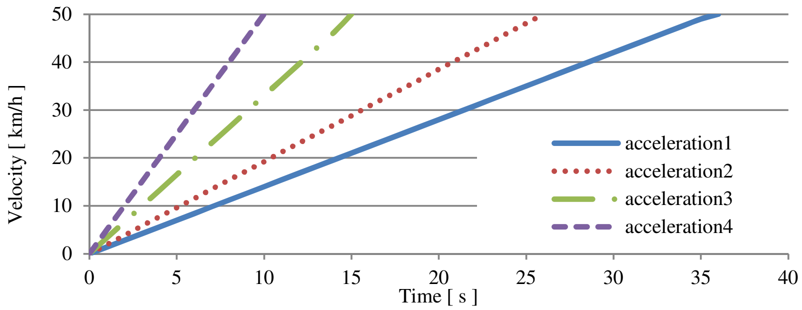

Fig. 9. Accelerations.

Vehicle passes the longest distance when acceleration is the lowest (Table 2). It is necessary to take into account equal distance at all 4 accelerations in order to compare energy intensity. The acceleration 1 with longest distance was taken as reference. It means that if at the accelerations 2–4 the vehicle reaches the speed 50 km/h then it is moving by constant speed until the reference distance of the slowest acceleration1 is achieved.

Table 2. Accelerations parameters.

	t [s]	Distance [m]
acceleration 1	36	251.9
acceleration 2	26	180.6
acceleration 3	15	103.2
acceleration 4	10	69.44

From the viewpoint of energy intensity the difference between the fastest and slowest acceleration is 4% at the vehicle weight 1000 kg, and 2.7% at weight of 1500 kg as can be seen in Tables 3 and 4.

Table 3. Demanded energy for acceleration.

m = 1500 kg			*m* = 1276 kg		
Acceleration	kWh	Difference %	Acceleration	kWh	Difference %
1	0.06227		1	0.05335	
2	0.06289	0.99258	2	0.05399	1.18803
3	0.06364	2.14524	3	0.05473	2.52789
4	0.06401	2.72351	4	0.05510	3.18091

Table 4. Demanded energy for acceleration.

m = 1194 kg			*m* = 1000 kg		
Acceleration	kWh	Difference %	Acceleration	kWh	Difference %
1	0.05009		1	0.04237	
2	0.05073	1.26638	2	0.04301	1.50422
3	0.05147	2.69104	3	0.04375	3.1677
4	0.05185	3.39671	4	0.04413	3.99771

The previous results indicate that the considerable influence to the acceleration has electric motor efficiency given by electric motor efficiency map (Figure 10).

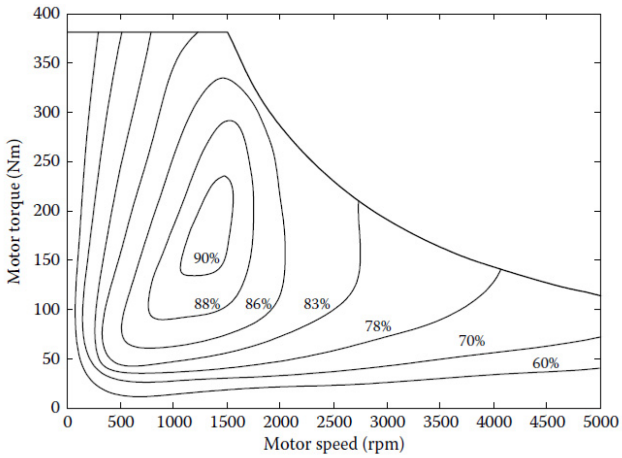

Fig. 10. Efficiency map of electric motor (Ehsani 2010).

Comparing slow and fast of acceleration of EV from 0 to 50 km/h, can be said that:

During the fastest acceleration vehicle achieve 50 km/h speed in 10 seconds. Hence EV is going 13 seconds constant speed 50 km/h. If the torque and revolutions of an electric motor is in the area of high efficiency during these 13 seconds of constant speed of 50 km/h then could be this acceleration the least energy-intensive.

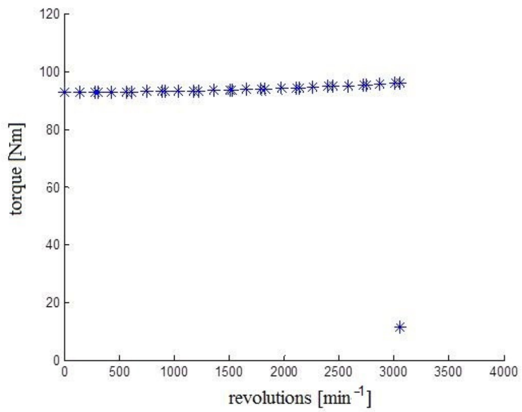

Fig. 11. Motor operations points – fast acceleration.

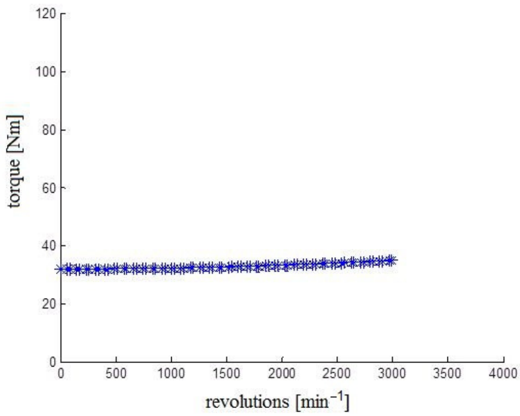

Fig. 12. Motor operations points – slow acceleration.

The following figures Fig. 11 and 12 show the operating points where the electric motor of EV EDISON loaded on the weight of 1276 kg operates at the fastest and slowest acceleration. As seen at Fig. 11, at the fastest acceleration 4 is the torque of electric motor between 92.8 to 96 Nm and after reaching of the speed 50 km/h is the electric motor torque 11.3 Nm at 3056 rpm for a period of 13 seconds. In the Fig. 12 there is shown the lowest acceleration where the torque ranges from 31.8 to 34.9 Nm.

5. Battery and weight impact

The simplest way to increase EV range is the using batteries with higher capacity. Based on the real driving cycles and the urban part of NEDC cycle was created the simulation of EV range with different battery packs. It was calculated with an electric car of a total weight of 600 kg without batteries, 75 kg of passenger weight and 25 kg of baggage. Four battery packs with different capacity were compared. In the table 5 you can see how much the total weight of EV increase by using of different battery packs.

Table 5. Battery packs comparison.

battery pack [kWh]	capacity [Ah]	weight [kg]	EV weight [kg]
24kWh	300	240	540
20.8kWh	260	225	485
16kWh	200	182.5	382.5
8kWh	100	80	180

The following figure Fig. 13 shows how the EV range simulated on the real driving cycle of Zilina change depending on different loads and various battery packs (24, 20.8, 16 and 8 kWh).

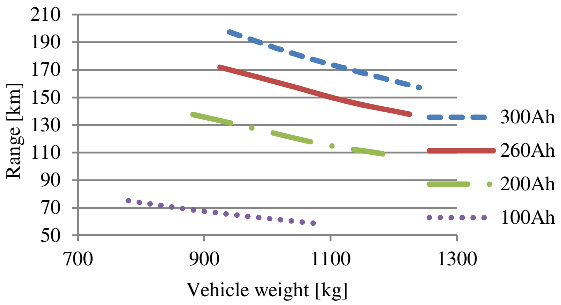

Fig. 13. Battery and load comparison on Zilina cycle.

The efficiency of the EV with mass parameters mentioned above at using of two battery packs of 8 kWh and 24 kWh was studied. EV used 8 kWh battery pack reached the range of approximately 70 km in the city traffic. EV used 24 kWh battery pack reached the range of approximately 200 km. In case of use the EV for approximately 70 km daily looks the use of 24 kWh battery pack as a less efficient than using of 8 kWh. For a better comparison shows the Table 6 how many km can pass EV on 1 kWh of energy.

Table 6. Energy per km.

battery pack kWh	range km/kWh
24	8.223542
20.8	8.263462
16	8.596063
8	9.389875

Figure 14 shows changes of EV range on the real driving cycle Prague.
The following figure Fig. 15 shows changes of EV range on the urban part of the NEDC cycle.

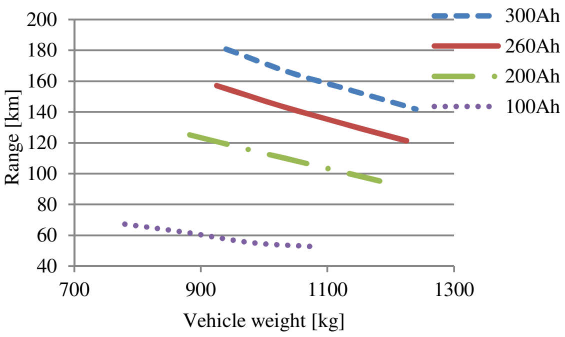

Fig. 14. Battery and load comparison on Prague cycle.

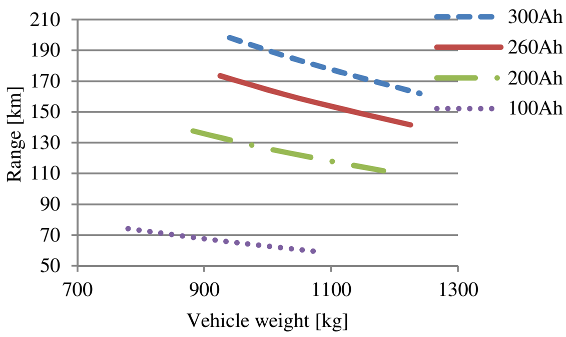

Fig. 15. Battery and load comparison on NEDC cycle.

6. Body shape impact

The power of the vehicle or its range directly affects the driving resistances. For example the air resistance depends on the shape of the body and increases quadratically with speed. The more aerodynamic is the vehicle body the smaller is the aerodynamic drag coefficient c_x. In the Fig. 16 is shown the dependence of aerodynamic drag coefficient on the EV range at various driving cycles. The curves were calculated for the EV mass of 900 kg and the 24 kWh battery pack.

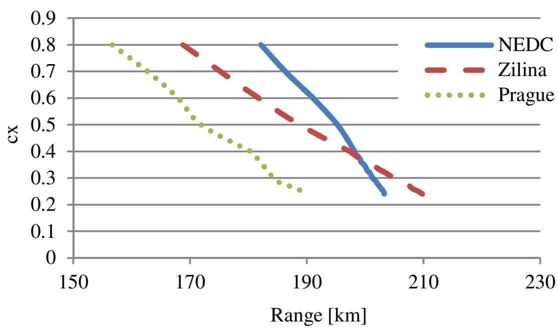

Fig. 16. C_x coefficient influence.

7. Electric motor size impact

The right sized electric motor influences the range of EV too. Figures 17 to 19 show the results of the range comparison of EV with two different electric motors and with different capacity of batteries simulated on real driving cycles Zilina, Prague and on the urban part of NEDC cycle. Considered was the electric vehicle EV1 with the weight of 410 kg without the battery pack and without the electric motor. For this vehicle was combine an electric motor with a nominal output of 15 kW and a peak power of 30 kW and an electric motor with a nominal power of 30 kW and 60 kW peak power. The mass of the motor 15/30 kW with inverter was 100 kg. The mass of the motor 30/60 kW was 180 kg.

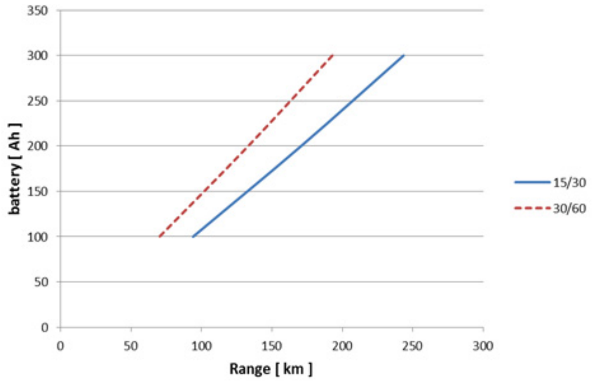

Fig. 17. EV1, Zilina.

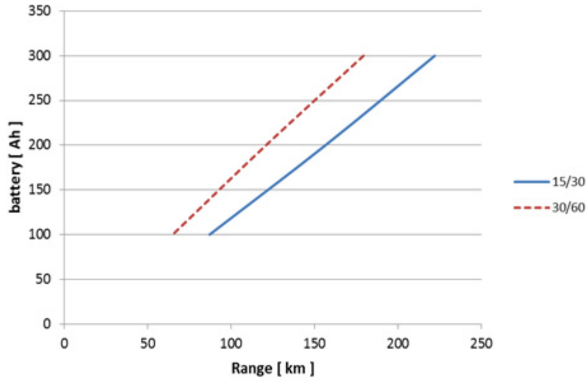

Fig. 18. EV1, Prague.

The figures 20 to 22 show the results for the electric vehicle EV2 with doubled mass of 810 kg without battery and without electric motor. The same combination of the electric motors, wheels and the gear ratio as in the first case were used for the simulation.

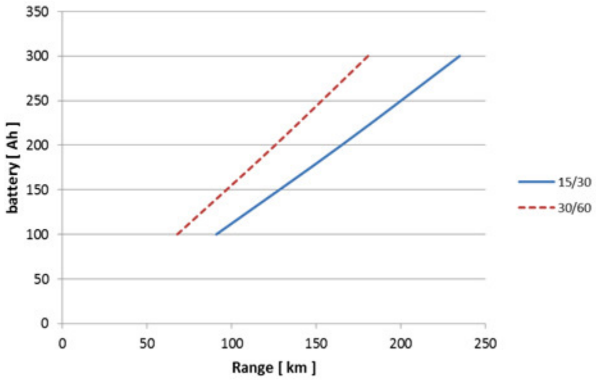

Fig. 19. EV1, NEDC.

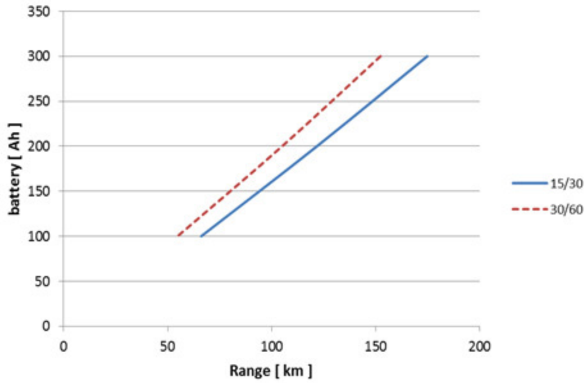

Fig. 20. EV2, Zilina.

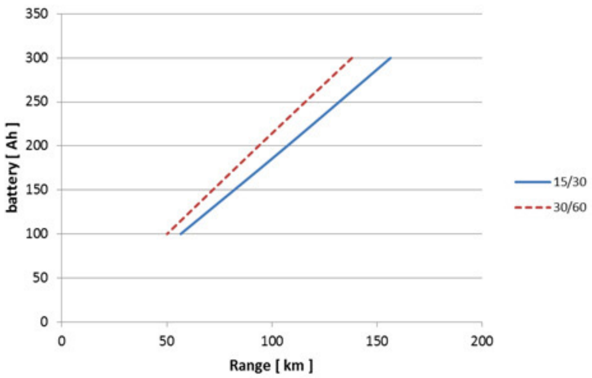

Fig. 21. EV2, Prague.

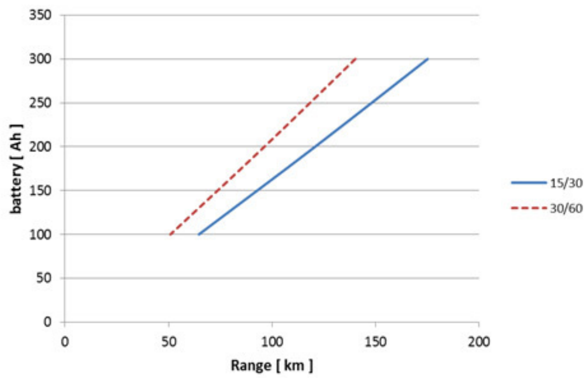

Fig. 22. EV2, NEDC.

The results of both simulations show how sizing of electric motor may affect the range. In all cases it was more suitable to use the electric motor with the power of 15/30 kW. In the case of heavier vehicle EV2 is the difference between ranges not so significant especially on the real driving cycles where the higher demanded power peaks are.

8. Conclusions

From the simulations results that the vehicle weight and size of the battery pack have the main impact on the range. Vehicle weight increases directly with battery capacity. In the case that the electric vehicle has high capacity battery pack and is used for short distances for example EV with 24 kWh battery pack for 70 km range the vehicle is less efficient than the same vehicle with 8 kWh battery pack. In this case the EV with smaller battery pack is more efficient because of 1.17 km higher range achieved from 1 kW of energy. Significant impact on the range has also driving style. It is better to use coasting when the traffic it enable instead using recuperation braking. Using coasting is still more efficient than recuperation braking even if the energy from braking would be completely re-use for driving. During acceleration it is most important the fact how long the motor operates in the area with high efficiency. The right designed electric motor size influence its using in the area with highest efficiency. The result from the comparison of vehicles operating in urban traffic where the speed rarely exceeds 50 km/h is that the aerodynamic drag coefficient has not a major impact to the range.

Acknowledgements

This paper is supported by the following project: University Science Park of the University of Zilina (ITMS: 26220220184) supported by the Research&Development Operational Program funded by the European Regional Development Fund.

This contribution was created within the framework of the project VEGA 1/0721/13 Electric and hybrid vehicles energy balance, which is supported by the Ministry of Education of the Slovak Republic.

References

Barlow, T. J.; Latham, S.; McCrae, I. S.; Boulter, P. G. 2009. *A reference book of driving cycles for use in the measurement of road vehicle emissions.* TRL Limited.

Barta, D.; Galikova, J. 2013. *Kolesové vozidla – trolejbusy a alternatívne pohony*. Zilinska univerzita, Zilina.

Derollepot, R.; Weiss, C.; Kolli, Z.; Franke, T.; Trigui, R.; Chlond, B.; Armoogum, J.; Stark, J.; Klementschitz, R.; Baumann, M.; Pelissier, S. 2014. *Optimizing components size of an Extended Range Electric Vehicle according to the use specifications.* Transport Research Arena 2014, Paris.

Ehsani, M.; Gao, Y.; Emadi, A. 2010. *Modern Electric, Hybrid Electric and Fuel Cell Vehicles*. CRC Press, Florida.

Franke, T.; Neumann, I. Buhler, F.; Cocoron, P.; Krems, J. F. K. 2012. *Experiencing range in an electric vehicle -understanding psychological barriers.* Applied Psychology: An International Review, 61(3): 368–391.

Gajdac, I.; Mikita, M.; Kucera, L. 2014. *EDISON project elektromobilu na Zilinskej univerzite.* ai magazine, 94 p.

Punov, P., Evtimov, T. 2008. Possibilities of using a standalone ECU for gasoline engine control in test bed running conditions. *Trans and MOTAUTO'08*, Sozopol, Bulgaria, vol. 1, p. 31–34.

Rimkus, A.; Melaika, M.; Pukalskas, S.; Nagurnas, S. 2012. Research of hydrogen influence for gas bus ecological and economic parameters. *Transport Means 2012 – 16th international conference*, October 25–26, 2012, Kaunas University of Technology, Lithuania. Kaunas, p. 13–16.