Energy consumption of auxiliary systems of electric cars

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Abstract. The paper analyzes the power demand of the auxiliary systems of electric cars. On the basis of existing electric cars an analysis of energy consumption of different auxiliary systems is done. As a result possibilities for rational use of these systems have been proposed, which can increase the mileage per one charge of the battery.

1 Introduction

An important characteristic of energy performance of the electric car is the distance covered for one charge of the battery [1-3]. Usually, in the technical specification of electric cars, producers give an operational range which is not precisely detailed about the conditions of motion (in city or inter-city traffic, air temperature, use of the auxiliary systems, etc.). For the owners it is very important to know as best as possible the remaining travel distance and impact of auxiliary systems on energy consumption and distance [4-7]. That knowledge will ensure a calm and comfortable trip regardless of the limited energy autonomy of electric cars.

The goal of the paper is to analyze the impact of different auxiliary systems of electric cars on the travel distance in different running conditions and comfort (such as temperature in the car, using lights, audio system, etc.).

2 Exposition

2.1. Fundamentals of electric car energy consumption

The main purpose of the energy accumulated in the battery is to supply the electric motor and to ensure the electric car motion in different running conditions. In addition, the battery also has to supply the auxiliary systems, which guarantee safety (lights, horn, window cleaner etc.) and comfort (climate control, media etc.). During the trip, the value of the specific energy consumption (in Wh/km or kWh/100km) can be different. Depending on the skills and needs of the driver, energy consumption can be 2 times higher than the one indicated in the technical specification of the electric car.

In the general case, the specific energy consumption can be determined theoretically by following the equation

$$E_{100} = \frac{100}{3{,}6\eta_M\,\eta_E}\left[\left(f_o + 5.10^{-7}V^2\right)G + k_B\,S\frac{V^2}{13}\right] + E_{AS_{100}}, \frac{\text{kWh}}{100\,\text{km}}, \quad (1)$$

where f_o is the rolling resistance coefficient at low speed; V – car speed, km/h; G –car weight, kN; k_B – coefficient of aerodynamic resistance, kNs^2/m^4; S – the front area of the car, m^2; η_M – the efficiency coefficient of transmission; η_E – the efficiency coefficient of the electric motor and power electronics; E_{AS100} – the specific energy consumption of auxiliary systems, kWh/100km.

Coefficient k_B is calculated as

$$k_B = 0{,}5.10^{-3}\rho\, c_x, \text{kN}\,\text{s}^2/\text{m}^4, \quad (2)$$

where ρ is air density, kg/m^3; c_x – drag coefficient.

The change of the air temperature t from +40 to –20 °C causes a change in its density from 1,127 to 1,395 kg/m^3 [8] and at high speed it can increase the energy consumption by over 10%. The value of the air density can be evaluated with good accuracy (deviation of not more than 0,5% at low temperature) using the equation

$$\rho = 2.10^{-5}\,t^2 - 0{,}0048t + 1{,}2926, \text{kg/m}^3. \quad (3)$$

Mechanical losses in the transmission vary within wide limits and depend on the electric motor load. The efficiency coefficient η_M can be evaluated with good accuracy using the approach, proposed in [1]. The losses in the electric motor and power electronics η_E also depend on thhe working conditions and load. The product of both coefficients varies between 90 – 95%, but can decrease by 50% under some running conditions [9]. It is necessary to have the characteristics of the elements of electric drive, not only at nominal load (whose value is given in the technical specifications), but also at particular load. Some of the researchers assign these two types of losses to the so called drive train losses [3].

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DOI: 10.1051/matecconf/201713306002

Auxiliary systems have great impact on energy consumption– the second part E_{AS100} of equation (1). The approach for their assessment has to be very accurate, especially when the maximal power of these devices is in use, to ensure exact determination of travel distance.

The power supply of auxiliary systems is realized by the second (operational) battery at a voltage of 12V. It can be recharged from the traction battery through DC/DC convertor. The losses during this transformation have to be taken into account by introducing a coefficient marked as η_{DC}. Finally, the specific consumption of the auxiliary systems can be represented as

$$E_{AS_{100}} = \frac{1}{\eta_{DC}}\left(E_{CC} + E_L + E_{WCS} + E_{OS}\right), \frac{\text{kWh}}{100\text{km}}, \quad (4)$$

where η_{DC} is the efficiency coefficient of the convertor between two batteries; E_{CC} – the specific energy consumption of climate control system; E_L – the specific energy consumption of lights and horn; E_{WCS} – the specific energy consumption of windows cleaning system; E_{OS} – the specific energy consumption of other systems as SRS, ABS, TC ESP, electric windows open system etc.

2.2. Distribution of the total energy consumption of the electric car

An analysis of the distribution of the total energy used can be done on the basis of an existing example. Fig. 1 presents a real picture of the energy consumption of the Tesla Roadster electric car with different values of the speed. The climate control does not work [3].

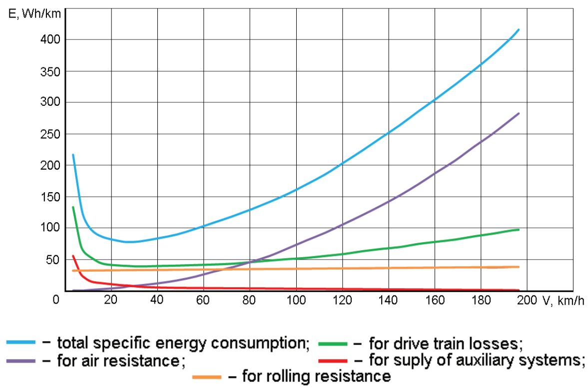

Fig. 1. Distribution the total specific energy consumption of Tesla Roadster vs car speed

The ratio between the different parts of the total specific energy consumption changes with the increase of car speed. At low speed most significant is the part of energy consumption for drive train losses and supply of the auxiliary systems. Higher energy consumption in slow motion is caused by the low values of the efficiency coefficients η_M and η_E. At high speed, the energy spent for air resistance becomes the largest.

The energy spent for rolling resistance is changed within short limits, because of the small impact of the speed on the coefficient *f*.

In fact, in motion the most variable parts of the energy can be those spent for air resistance and supply of auxiliary systems. The last part depends on the atmospheric conditions such as rain, snow, wind etc.

The curves shown in Fig.1 are well represented by the following regression models:

- total specific energy consumption

$$E = 4.10^{-10}V^6 - 3.10^{-7}V^5 + 7.10^{-5}V^4 - \\ - 0{,}009V^3 + 0{,}5715V^2 - 16{,}313V + 234{,}92; \quad (5)$$

- specific energy consumption for drive train losses

$$E = 3.10^{-10}V^6 - 2.10^{-7}V^5 + 5.10^{-5}V^4 - \\ - 0{,}0057V^3 + 0{,}358V^2 - 10{,}26V + 139{,}27; \quad (6)$$

- specific energy consumption for rolling resistance

$$E = 0{,}0297V + 32{,}278; \quad (7)$$

- specific energy consumption for air resistance

$$E = 1.10^{-6}V^3 + 0{,}007V^2 + 0{,}0035V + 86{,}22; \quad (8)$$

- specific energy consumption for supply of auxiliary systems

$$E = 121{,}1\ V^{-0{,}794}. \quad (9)$$

2.3. Energy consumption of auxiliary systems

Approximately, the energy consumption of the auxiliary systems presented as a percentage of the energy accumulated in the main (traction) battery is shown in Table 1 [5, 7].

Table 1. Energy consumption of some auxiliary systems

Auxiliary systems	Part of traction battery energy, %
Climate control: – cooling; – heating.	 Up to 30% Up to 35%
Power steering	Up to 5%
Braking system	Up to 5%
Other (lights, media, locks etc.)	Up to 5%

The information presented in Table 1 is more general and does not include all operational conditions of electric cars. This is the reason to make a review of the impact different factors on energy consumption of each auxiliary system.

Climate control system

The normal internal temperature of the air in the compartment has to be 20-23 °C. To maintain these limits, the energy consumption of climate control depends on the temperature difference in and out of the car. Table 2 presents an example of the needed power of control system at different internal temperatures and high external temperature [5].

Table 2. Needed power for supply of the climate control system as a function of internal temperature in the compartment

External air temperature, °C	Internal temperature, °C	Needed power, kW
43	21	1,5 – 2
43	25	1
43	29	0,5

The maximum value of the power supply of climate control can achieve 3 – 5 kW for some models of car. As heat device they use an electric heater or a thermo pump. In Fig. 2 the impact of power consumption of 2 kW (working climate control) on the travel distance is illustrated for Tesla Roadster electric car [3].

At a speed of 25 km/h, the travel distance per one charge of the battery decreases approximately 2 times when the climate control of 2 kW works. The curves are well represented by the following regression models:

• travel distance without working climate control

$$L = -9.10^{-10}V^6 + 6.10^{-7}V^5 - 0{,}0002V^4 + \\ + 0{,}0228V^3 - 1{,}6088V^2 + 50{,}131V + 116{,}1; \qquad (10)$$

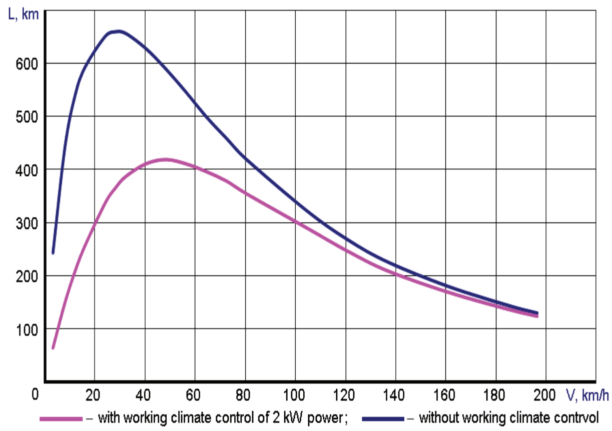

Fig 2. Impact of climate control power consumption of 2 kW on the distance per one charge of battery for Tesla Roadster electric car.

• travel distance with working climate control of 2 kW power

$$L = -4.10^{-6}V^4 + 0{,}0018V^3 - 0{,}3157V^2 + \\ + 19{,}881V + 10{,}837. \qquad (11)$$

There is not much research on the impact of the external air temperature on energy consumption. In [10] a Canadian company, on the basis of over 7000 travels in the whole of North America, has made a generalization of the average energy consumption of Nissan Leaf electric car (Fig. 3).

The curve from Fig. 3 is well represented by the regression model

$$E = 8.10^{-9}t^6 - 3.10^{-6}t^5 + 0{,}0001t^4 + 0{,}0028t^3 - \\ - 0{,}0546t^2 - 2{,}7979t + 206{,}22. \qquad (12)$$

The same data is shown in Fig.4 as impact on the travel distance L [11]. The respective regression model is

$$L = 6.10^{-8}t^6 - 4.10^{-7}t^5 - 0{,}0001t^4 - 0{,}0004t^3 + \\ + 0{,}0544t^2 + 1{,}3326t + 99{,}995. \qquad (13)$$

It is obvious that the external air temperature has a significant impact on the energy consumption of an electric car. The explanation for this is connected with the energy for heating or cooling but also with the efficiency of the battery at different temperatures. Taking into account these two factors, one can see an optimal external air temperature at which the energy consumption is minimal and travel distance is maximal (Fig. 3, 4). This optimal value is approximately 20 °C.

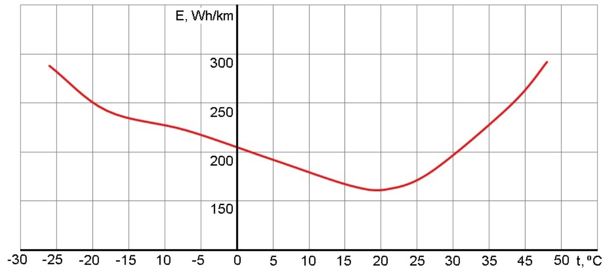

Fig. 3. Impact of the external air temperature on the specific energy consumption of a Nissan Leaf electric car.

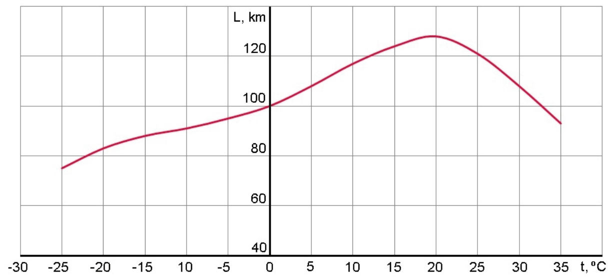

Fig. 4. Impact of the external air temperature on the travel distance of a Nissan Leaf electric car.

Light system, light signalization and horn

The energy consumption of the light system and signalization depend on a twenty-four-hour period – if the trip is realized in the day or at night. That is particularly important for long and short front lights. The usage of elements of light system and signalization, during 100 km travel, are presented in Table 3. The data from different sources [4, 6] was processed and summarized.

The calculations show that the maximal energy consumption of a light system using conventional lamps in night travel is about 150 Wh/100km. The usage of LED-lamps decreases the consumption 2,2 – 3,8 times [2, 4, 6, 12, 13].

In the specialized literature there is no information concerning the time of use and energy consumption of the horn. Probably, this is because the value of the energy used is insignificant.

Table 3. Statistical data for the use of the elements of the light system and signalization.

Elements	Working time, min/100 km	Power consumption for car with conventional lamps, W	Power consumption for electric car with LED-lamps, W
Daily lights	116,5	40	8
Long lights	9,8*	60	34,4
Short lights	97,6*	55	54
Left blinker	5,8	21	6,9
Right blinker	4,6	21	6,9
Stop-lights	18,9	21	5,6
Stop-lights (central position)	18,9	21	3
Rear-lights	107,4	5	1,7
Registration table lights	107,4	5	0,5
Reverse motion light	0,9	21	5,2
* - night time driving only			

Audio system

Energy consumption depends on the power characteristic and the time the system is used. Usually, built-in systems have a power supply of about 200 W. The time during which the audio system is used varies within wide limits and corresponds to the driver and passenger(s) needs.

The actual energy consumption also depends on the sound level. Some authors [9], in simulation models, give an average power supply of 20 W for the audio system and use a ratio of approximately 75% of travel time.

Windows cleaning system and seat heating

This system uses electric motors with maximum power of 30-50 W. The time of use strongly depends on the weather (if there is rainfall or snowfall).

The average consumption of the seat heating system is 30 W and the mean ratio of use – 5% of the time [9].

Other systems

The main systems included in this group are: the system of passive and active safety – SRS; Anti-lock Braking System – ABS; Traction Control System – TC; Dynamic Stability System – ESP; systems for opening and closing of door windows and roof. The biggest consumers in this group are the systems for active safety, but the value of energy depends on driving style.

Internal losses in traction battery

Depending on the battery type, during idle time (no traction) the additional losses can present for the maintenance of the working temperature. For example, natrium-nikelhidrid batteries work at a temperature of approximately 300 °C and permanent consumption power of 60 – 80 W for temperature maintenance. If the capacity of the battery is 18 kWh after 10 days of idle time it will be fully discharged.

Internal losses of the Lithium-ion batteries depend on the number of the connected cells and Battery Management System – BMS.

Every battery has a limited period of exploitation. To extend that period the power electronics controls charge/discharge the process. This means that only part of the battery capacity can be used – full charge and discharge are unavailable. This is done to provide for the possibility of accumulation of the regenerative braking energy.

2.4. Impact of regeneration on travel distance

Regeneration of electric energy is possible during the braking process. Depending on the running conditions and route characteristics, the maximuml value of regenerative energy varies from 10 to 25% in city conditions [14, 15]. The experimental results [14, 15] show that braking deceleration within the limits of 2 – 3 m/s^2 can ensure efficiency of regenerative braking of up to 90% and minimal transformation of kinetic energy to heat and friction in mechanical braking system (Fig. 5).

At bigger decelerations, the battery cannot receive regenerative energy, the mechanical braking system is switched on and the two systems work together to provide the required deceleration (Fig. 6).

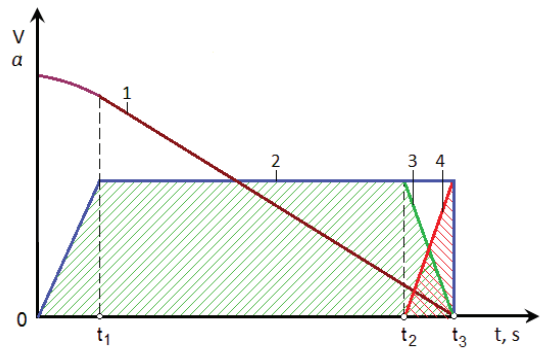

Fig. 5. Example of regenerative braking:
1 – car speed; 2, 3 – deceleration, realized only by regenerative braking; 4 – deceleration, realized only by mechanical braking system.

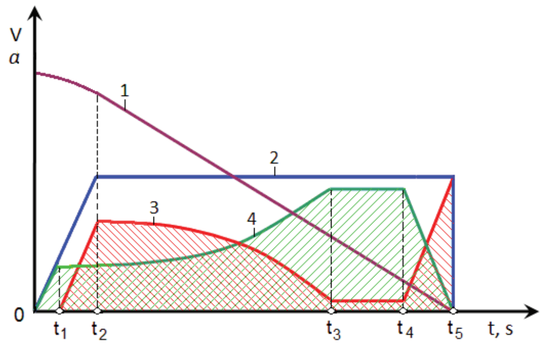

Fig. 6. Interaction of the two braking systems during formation of constant deceleration: 1 – car speed; 2 – total deceleration; 3 – deceleration, realized by mechanical braking system; 4 – deceleration, realized by regenerative braking.

DOI: 10.1051/matecconf/201713306002

To improve the usage of regenerative energy traction system super capacitors (especially in buses) are often build-in.

3 Conclusions

On the basis of the analysis of the impact of the running conditions and auxiliary systems on the energy consumption of an electric car, the following conclusions can be formulated:

1. The minimal energy consumption of electric cars is realized at lower speed – up to 40 km/h. These values are significantly lower than the respective ones for conventional cars - approximately 65 km/h.

2. At low speed, for example 5 km/h (heavy traffic and jams), the energy consumption can be equal to that one at 100 *km/h*. The reason for this are the low efficiency of the drive train and energy consumption for supply of the auxiliary systems at low speed motion.

3. At high speed – over 50 km/h – the impact of the auxiliary systems in total energy consumption decrease, the energy consumption spent for air resistance becomes dominant.

4. At some values of speed and weather conditions, the energy consumption for the supply of auxiliary systems can decrease twice travel distance of the car.

5. The minimal energy consumption of auxiliary systems is realized at an external air temperature of 20 °C, at which the biggest travel distance is achieved.

6. The light system and signalization consume about 1% of total energy consumption of an electric car.

The authors would like to thank the Scientific Research Fund of the University of Ruse, Project 2017-FT-01 for the financial support.

References

1. R. Ivanov, I. Evtimov, M. Sapundjiev, A model for investigation of energy characteristic of an electric car, *Electric vehicles EM`15*, 131-137, (in Bulgarian), (2015)
2. E. Schaltz. Electrical Vehicle Design and Modeling, *Electric Vehicles – Modelling and Simulations*, 496, (2011)
3. EV Energy Consumption, www.solarjourneyusa.com/EVdistanceAnalysis5.php
4. B. Schoettle, M. Sivak, Y. Fujiyama. Leds and power consumption of exterior automotive lighting: implications for gasoline and electric vehicles. Report No. UMTRI-2008-48, 18 (2008)
5. EV Auxiliary Systems Impacts, http://avt.inl.gov/sites/default/files/pdf/fsev/auxiliary.pdf
6. M. Vražić, O. Barić, P. Virtič. Auxiliary systems consumption in electric vehicle. Przegląd elektrotechniczny, **12**, 172-175 (2014)
7. A. Santiangeli, C. Fiori, F. Zuccari, A. Dell'Era, F. Orecchini, A. D'Orazio. Experimental analysis of the auxiliaries consumption in the energy balance of a pre-series plug-in hybrid-electric vehicle. *Energy Procedia*, **45**, 779-788 (2014).
8. Air - Density and Specific Weight, http://www.engineeringtoolbox.com/air-density-specific-weight-d_600.html
9. A. Duce, P. Egede, G. Öhlschläger, T. Dettmer, H. Althaus, T. Bütler, E. Szczechowicz, *Guidelines for the LCA of electric vehicles*, 158, http://www.elcar-project.eu/fileadmin/dokumente/Guideline_versions/eLCAr_guidelines.pdf (2013)
10. Real-World Nissan LEAF Fleet Data Reveals, http://insideevs.com/real-world-nissan-leaf-fleet-data-reveals
11. Do electric cars work in cold weather? Get the Facts, http://blog.ucsusa.org/dave-reichmuth/electric-cars-cold-weather-temperatures
12. P. Mashkov, B. Gyoch. Thermal loading investigation of led bulbs for automotive headlights. *SR RU&SU*, **55**(4), 66-80, (in Bulgarian), (2016)
13. P. Mashkov, B. Gyoch, R. Ivanov, An investigation on characteristics of led bulbs for car headlights, *BulTrans-2016*, 118-123, (in Bulgarian), (2016)
14. I. Evtimov, R. Ivanov, G. Kadikyanov, Investigation of electric bicycle's regenerative braking, *BulTrans-2012*, 217-221, (in Bulgarian) (2012)
15. D. Mammosser, M. Boisvert, P. Micheau, Designing regenerative braking strategies for electric vehicles with an efficiency map, *21ème Congres Francais de Mecanique*, 6 (2013)