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# FACTORS INFLUENCING THE HYBRID DRIVE OF URBAN PUBLIC TRANSPORT BUSES

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**Abstract**:
The efficiency of each drives is dependent on many factors. Hybrid drives and specially the drives of urban public transport may be affected by other factors given by transport infrastructure or operational conditions. These factors condition the suitable configuration of the individual elements of hybrid drive and the establishment of good control strategy of such drive. The study of influencing factors of the control strategy is the aim of this paper.

***Key words:*** *control strategy, combustion engine, hybrid drive, public transport, bus*

## INTRODUCTION

Previous century was the century with rapid development of industry, the growth of living standards and the related needs for increased mobility of the population. As this development continues and can be expected to continue in the next years and decades, the topic of mobility and passenger transport is actual and adequate.

The population mobility is everyday need to travel to school, to work, for shopping, culture and recreation by every available transport means that enable movement, from walking to air or waterway transport.

### *Importance of public transport*

Individual road passenger transport also plays important role in this problem is growing incredibly fast in recent decades. Expanding individual road passenger transport has positive effects, like convenience and speed of travel, but also produce a lot of negative effects, for example significant increase in emissions, increase of noise, vibration, accidents, congestion, large occupation of land for transport infrastructure (e.g. high demands for parking areas) etc. This problem can be solved only by very good functional public passenger transport which will satisfy the largest possible number of the population and ensure adequate transport services operating in region.

Area covered by transport services can be evaluated by the transport opportunity in terms of time (time position of connections), area (keeping the lines and location of stops), transport capacity (number of connections and capacity of the vehicles), financial costs (tariffs) and added value (comfort, additional services).

Public transport in terms of the size of the area it serves, can be divided into urban, suburban, regional and long distance transport. The most of the passengers has the beginning and the end of its transport routes in areas that are served by urban, suburban or regional services. Therefore, the importance of all three transport modes should not underestimated.

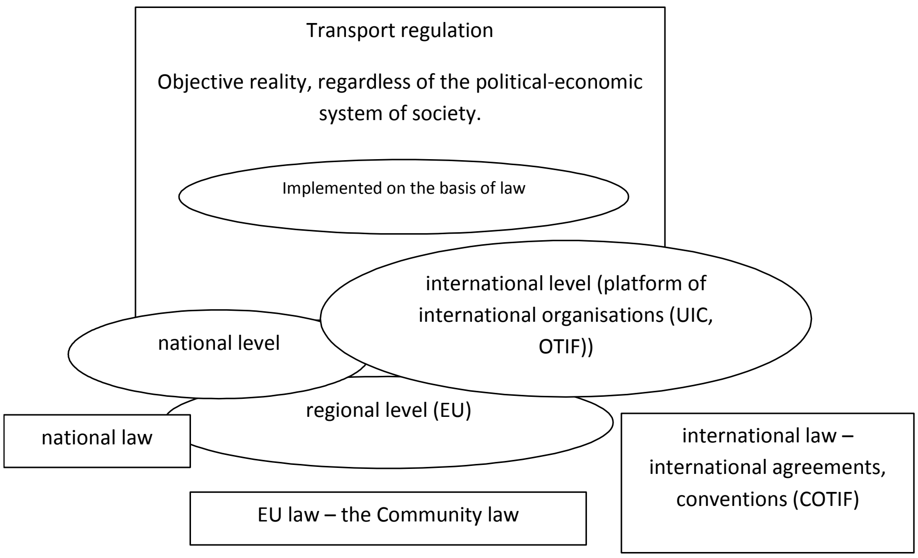


***Fig. 1 Scheme of the legal framework for the regulation transportation in EU Member States***

The main operating area of urban and suburban transport are large agglomerations with high density of the settlement, with large populations and with big transport demand. For the transport outside the suburban area, services are provided by regional transport. Regional transport has different function, as it operates in high density settled suburban and less populated areas away from the big cities.

European Union's approach to urban, suburban and regional transport is clear - to support the role of local and regional transport, because its benefits should be seen in economic development and employment, reduction in congestion, lower energy consumption, less environmental problems in terms of emissions and noise reducing, reducing social barriers and increasing the quality of life. Achieving these goals helps in making the better use of environmentally friendly kinds of transport, such as green and more efficient public transport, cycling and walking. This requires an integrated approach.

*Transport policy and passenger traffic regulation*

EU transport policy is one of the starting points of realizing the passenger traffic regulation on the national level towards ensuring the adequate, a sustainable, safe mobility and quality of life.

These are implemented on the basis of law. The EU Member States applying duality rights in transport. On Figure 1 is seen the scheme of the legal framework for the regulation transportation in EU Member States.

The subject of transport policy is to modify conditions and relations in transport with tools that would ensure sustainable economic, environmental and social sustainability of transportation. Transport policy, as well as any public policy is not a one-time act. It should be a process with certain phases with formulation, implementation, evaluation of feedback for each of its stages and introduction of new decisions and actions.

The main objectives of the transport policy of the EU are:

1. Economic sustainability:
   - the contribution to economic growth,
   - contribute to increase the availability of employment by transportation and job creation,
   - in the future to reduce and eliminate congestion.
2. Environmental sustainability:
   - contribute to the reduction of greenhouse gases, local emissions and traffic noise,
   - the protection of sensitive areas before transport negatives.
3. Social sustainability:

   Decreasing of accidents,

   To ensure availability of services,

   Social cohesion, including the removal of social and regional disparities,

   To ensure passengers' rights to high quality services,

   Establish and maintain good conditions for employees in the transport sector [3].

One way how to ensure the environmental sustainability of city areas is using of more ecological drives of public transport means, as hybrid and electric drives are.

## FACTORS INFLUENCING HYBRID BUS TECHNOLOGIES

Hybrid-electric vehicles (HEVs) combine the benefits of gasoline engines and electric motors and can be configured to obtain different objectives, such as improved fuel economy, increased power, or additional auxiliary power for electronic devices and power tools.

Hybrid drives can be divided on:

- serial,
- parallel,
- serial-parallel (power split).

In following part of the article will be discus the serial type of hybrid drives used in the hybrid buses.

The main factors influencing the control strategy of hybrid drive of urban public transport buses are represented by:

- operational factors (elevation profile of the city, number of intersections and stops, traffic density, climatic conditions, length of the line route, bus capacity, rush hour traffic, green zones,…),
- technical factors (size of battery pack and combustion engine,…).

*Energy primary sources*

The suitability of the hybrid system is not given only by its use in urban traffic. Composition of primary sources, from which is achieved the electricity in given country also affect the usefulness and suitability of electric hybrid drives. While in the countries with a high proportion of ecology primary sources of energy (solar, water, wind power stations) are the electric drives or electric hybrid drives good applicable, the use of such drives in countries with a high proportion of electric energy produced from fossil fuels is debatable.

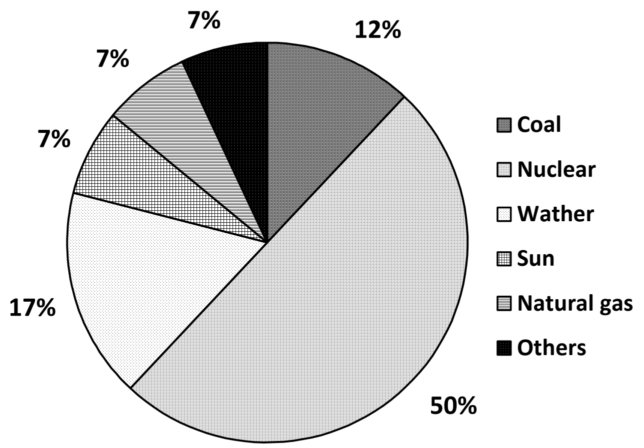


***Fig. 2 Primary power sources of Slovakia***
Source: [4]

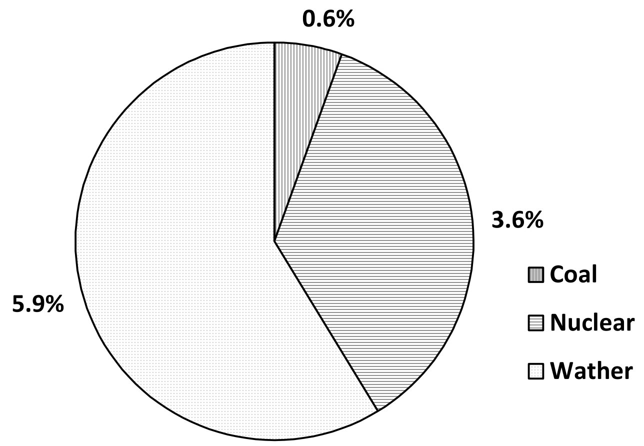


***Fig. 3 Primary power sources of Switzerland***
Source: [1]

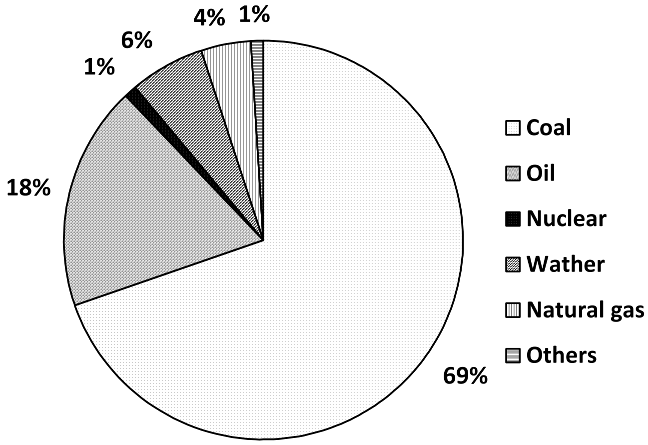


***Fig. 4 Primary power sources of China***
Source: [6]

Proportion of individual primary sources of electricity in selected countries show Figures 2, 3 and 4. For example, the main source of electricity in Slovakia represent nuclear power plants together with ecological water, solar and wind power stations and only 20% of electricity is generated by thermal power stations producing monitored harmful emissions. In Switzerland, the proportion of electricity generated by thermal power stations is only 5.5%, but in China it is 92%. It means, that the real production of emissions from "ecological drives" (electric and hybrid vehicles) is very different and depends on the proportion of primary sources of electric energy.

### *Operational factors*

Elevation profile of the city, number of intersections and stops, traffic density - rush hour traffic, climatic conditions, length of the line route, occupancy, green zones etc. are the main operational factors.

### *Green zones*

Green, or low emission zones are areas where access by vehicles is limited by their emissions. They are implemented to improve air quality. Green zones grow especially in big and green oriented cities. In the future some cities plans implement zero emission zones. The Figure 5 shows the reduction of the Black Carbon Mass concentration in Leipzig -Mitte from 2010-2013, always in the second half of the year [2].

### *Rush hour traffic*

The Figure 6 shows how the number of transported passengers over the course of 24 hours in three variants: for the way from the estates to city center, from city center to estates and ideal distribution of traveling passengers during the day.

The diagram shows three peak hours: morning peak, afternoon peak and cultural evening peak. The first (and highest peak) is in the morning between 7:00 and 8:30 when there are nearly three times as many trips in progress when compared with the average hour. The second peak is in the afternoon between 16:00 and 17:00. Both peaks are driven by education related trips. The busiest day of the week in terms of the number of trips was Friday with 150 trips per person per year.

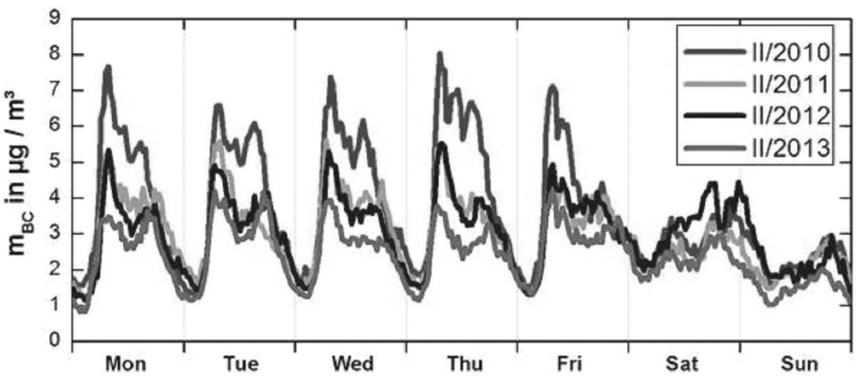


***Fig. 5 Influence of Low emission zone in Leipzig between 2010-2013***
Source: [5]

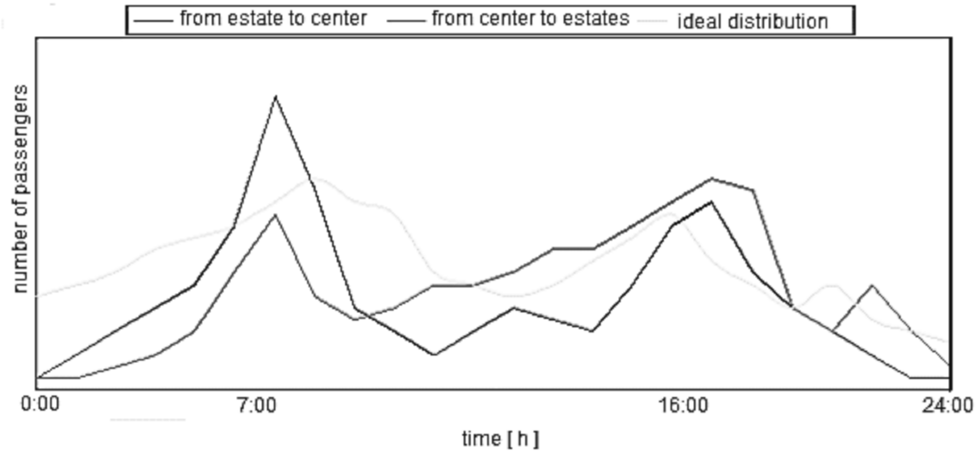


***Fig. 6 Number of transported passengers over the course of 24 hours***

***Table 1***
***Comparison of the energy consumption of the bus operating on different line routs***

| Line | | 21 | 21 back | 27 | 27 back | 31 | 31 back |
|---|---|---|---|---|---|---|---|
| E | [kWh] | 10.01 | 10.66 | 23.35 | 15.16 | 18.27 | 14.81 |
| Erek | [kWh] | 6.17 | 5.34 | 9.95 | 11.33 | 9.78 | 8.03 |
| E com | [kWh/km] | 1.122913 | 1.213024 | 1.503932 | 1.106136 | 1.333207 | 1.205665 |

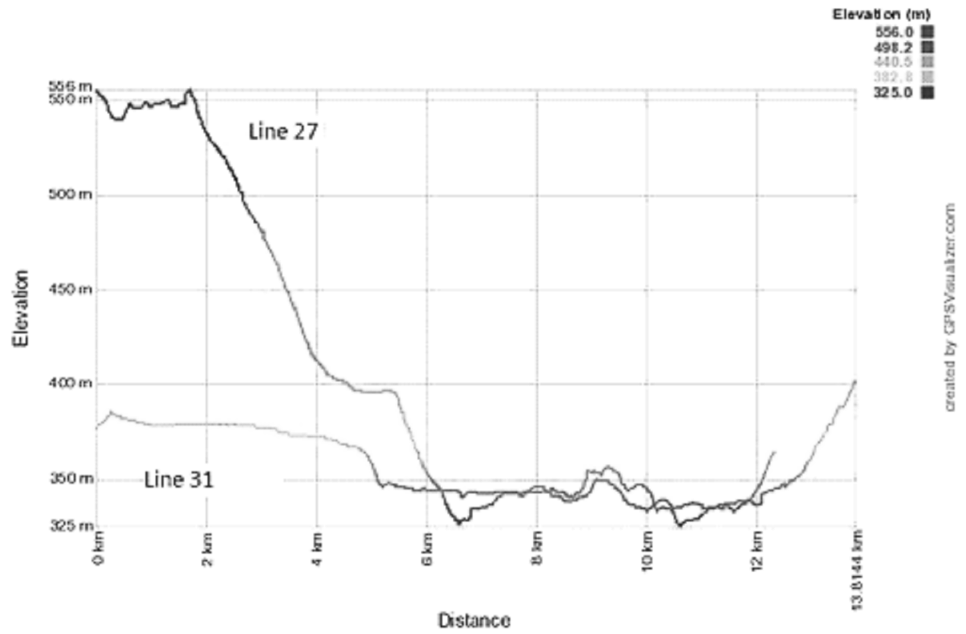


***Fig. 7 Elevation profiles comparison of route line 27 and 31***

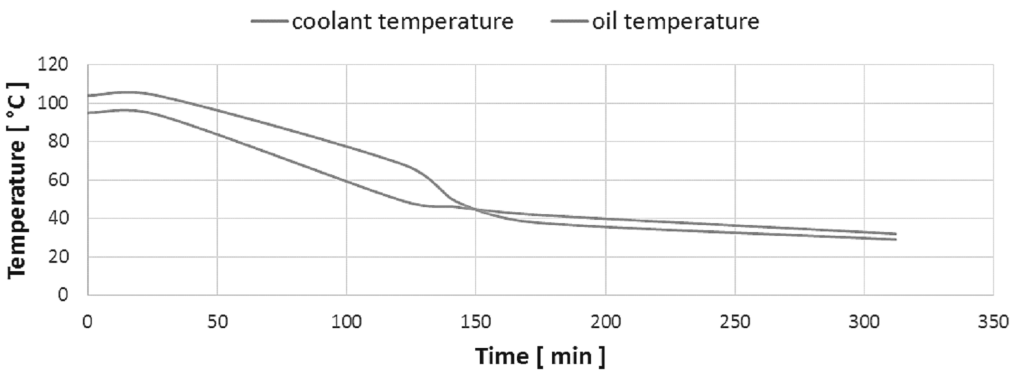


***Fig. 8 Drop of the coolant and oil temperature of SI engine cooling at an external temperature of 0° C***

Depending on the traffic situation can the energy demands on the bus propulsion change very significantly. Higher number of stops and starts in the green zone at the traffic jam cause higher demands on the capacity of the batteries.

*Line route terrain profile*

The place where hybrid bus operates has a major effect on the power consumption. Elevation profile of the terrain has the biggest impact on the consumption. The advantage of the hybrid city bus versus conventional bus is the possibility of recovery of energy when going downhill. The number of intersections where the vehicle has to stop directly impacts the energy consumption. This can be affected by the green waves at traffic lights to ensure the free flow of traffic. Significant impact on the energy consumption of the vehicle also has a density of traffic especially during rush hour. It should be noted that in several cities special lanes for buses to suppress this effect were established.

In the following table Table 1 can be seen the results of the energy consumption simulation of various bus lines (21, 27, 31) operated in Zilina city. Simulated was the driving of the bus with mass of 10 540 kg at 50% occupancy on real driving cycle. As shown in Figure 7 the lines have a different elevation profile and have a different proportion of driving in the city center. The measurements were performed during rush hour.

*Climatic conditions*

Climatic conditions are other important operating parameter. Low temperatures below zero have unfavourable impact not only on the efficiency of the battery but also of the internal combustion engine. The Lithium batteries are the most often used batteries in the hybrid vehicles applications. The poor performance of these batteries at low temperatures is caused by significantly increase of the internal resistance. The advantage is that the vehicle of the public transport starts its driving in the morning from the depot where the batteries can be preheated before drive and so keep their full performance. It is possible to use the heat emitted from the traction motor or eventually from the combustion engine for maintaining the proper operating temperature of the batteries. The internal combustion engine is more often started and stopped in the serial hybrid vehicle. If the temperature of the combustion engine decreases bellow optimum the fuel consumption will increase and equally will increase the production of the emissions due to low temperature of catalytic converter. The drop of the coolant and oil temperature of spark ignition engine of 1.4 $cm^3$ which could be used as a part of the bus hybrid drive can be seen in the Figure 8. This factor is on the boundary of technical and operational factors.

### *Occupancy*

Impact of bus occupancy on the energy intensity of drive is seen in Table 2. The values given in the table are the outcome of simulations serial hybrid drive of the bus operating in Zilina on the route 21 in both directions. As can be seen the consumed energy is directly dependent on the occupancy of the bus. The higher occupancy the higher consumption. However higher occupancy also allows to recuperate more energy from the drive.

***Table 2***
***Impact of bus occupancy on the energy intensity of drive***

| Line | | 21 there | | | 21 back | | |
|---|---|---|---|---|---|---|---|
| Occupany | | 100% | 50% | 25% | 100% | 50% | 25% |
| m | [kg] | 13225 | 10450 | 9100 | 13225 | 10450 | 9100 |
| E | [kWh] | 12.54 | 10.01 | 8.78 | 13.35 | 10.66 | 9.35 |
| Erek | [kWh] | 7.88 | 6.17 | 5.34 | 6.81 | 5.34 | 4.63 |
| % Erek | [%] | 62.84 | 61.68 | 60.87 | 51.03 | 50.15 | 49.54 |

***Table 3***
***Occupancy influence for coasting distance***

| occupancy | 100% | 50% | 25% |
|---|---|---|---|
| weight | 13225 | 10450 | 9100 |
| distance | 582.2 | 567.7 | 557.9 |

Occupancy also influences bus coasting distance which is often using in city traffic. Impact of bus occupancy to coasting can be seen in the Table 3. Figure 9 shows the course of coasting for 50% occupancy of the bus.

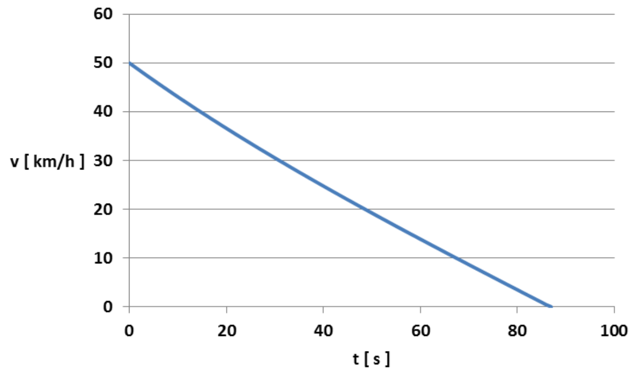


***Fig. 9 Course of coasting for 50% bus occupancy***

## TECHNICAL FACTORS

Technical parameters of the electric motor, size of battery pack and power of combustion engine are the basic technical factors influencing the control strategy of a hybrid drive.

### *Size of hybrid drive components*

Public transport buses usually have a fixed route throughout the day. Distance that the vehicle travels during the day and also the approximate occupancy is therefore known. It is also possible to determine how many miles the vehicle needs to pass on pure electric power in the case of green zones, which affects the size and number of batteries. With this knowledge it is able to configure the hybrid drive to operate as efficiently as possible. One of the assumptions is that the bus will start from the depot with fully charged battery and will return back to the depot with the SOC as low as possible so that the bus can be charged again in depot. This helps reduce the formation of local emissions in cities which is highly desirable.

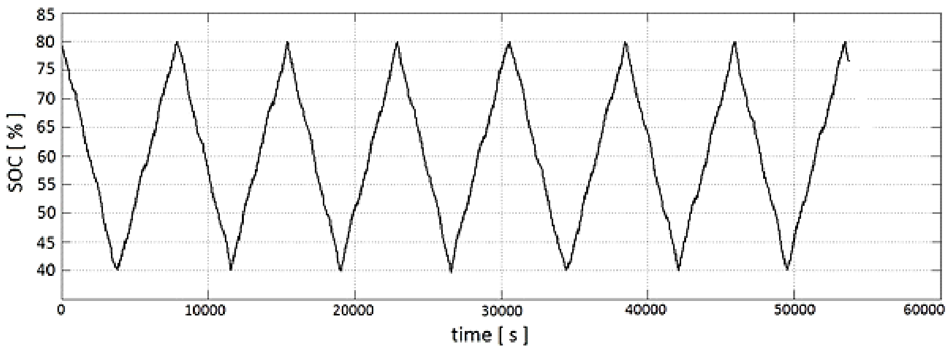


***Fig. 10 Course of battery charging: ICE 2200 $cm^3$, Battery 100 Ah***

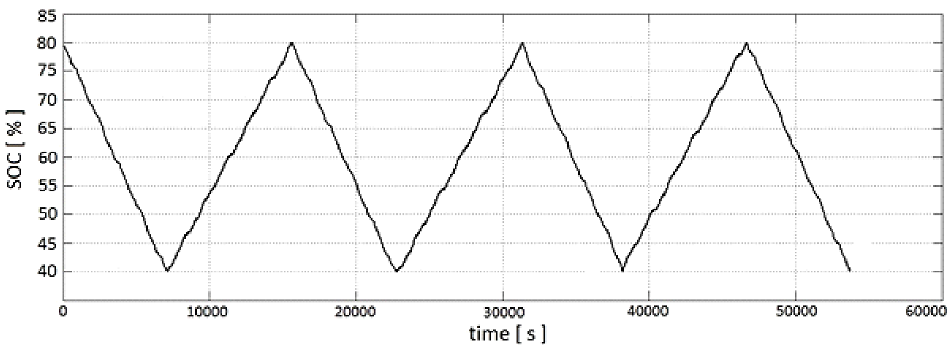


***Fig. 11 Course of battery charging: ICE 2200 $cm^3$, Battery 200 Ah***

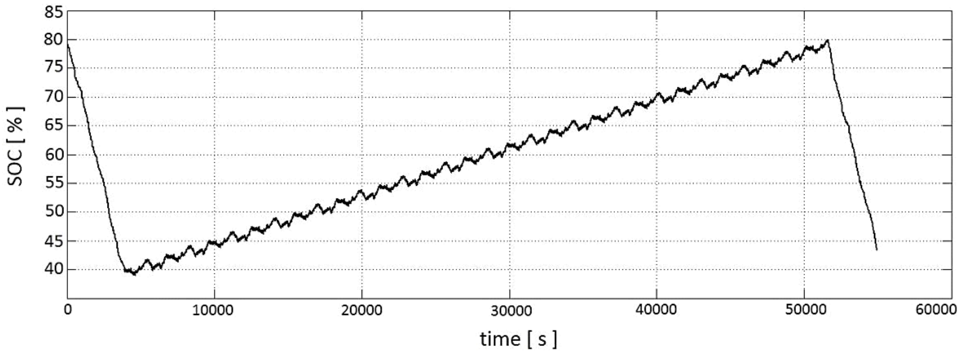


***Fig. 12 Course of battery charging: ICE 1003 cm$^3$, Battery 100 Ah***

Figure 10-12 shows the simulation results of the serial hybrid drive bus at the real route with various size of battery pack. In the case of short low-emission zones, it may be selected battery pack with a lower capacity.

When selecting the internal combustion engine, it is necessary to ensure its dimensioning to at least the average measured power. Internal combustion engine with insufficient power would charge the batteries during all the day, see Figure 12. It would not allow driving on pure electric propulsion in low-emission (green) zones.

## CONCLUSION

As shown this study the suitable configuration of the individual elements of hybrid drive and the establishment of good control strategy of such drive can be set only at respecting of typical conditions of individual city as elevation profile, the size of the zero emission operating area or number of stops. It is also good to respect the local climatic conditions and in view of this fact use all technical possibilities to maintain ideal battery conditions. The set of control strategy on the lowest level of battery state of charge before arriving the depot enable ensure the lowest local emissions load.

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