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ELECTIRCAL DRIVE SYSTEMS FOR ROAD VEHICLES – CONCEPTS, EXAMPLES, ENERGY SAVING

The paper deals with solutions in the field of electric vehicles. Basic architecture of electric vehicles is described, issues of battery charging are outlined. The paper contains technical data on several modern hybrid electric vehicles. The cost-benefit analysis of vehicles' performances is carried out considering ecological and energetical impacts. A new principle of battery charging status intelligent prediction is described.

Присвячено досвіду розробок в галузі електричних транспортних засобів. Надано опис основ архітектури електричних та гібридних транспортних засобів, розглянуті питання зарядження накопичувача енергії. Наведено технічні данні кількох сучасних транспортних засобів. Проведено техніко-економічний аналіз показників транспортних засобів з урахуванням їх впливу у сфері енергетики та екології. Описано новий принцип прогнозу стану заряду накопичувача енергії.

Посвящается анализу разработок в области электрических транспорнтых средств. Дано описание основ архитектуры электрических и гибридных транспортных средств, рассмотрены вопросы заряда накопителя энергии. Приведены технические данные по некоторым современным гибридным автомобилям. Проведен технико-экономический анализ показателей транспортных средств с учетом их влияния в сфере энергетики и экологии. Описан новый принцип прогноза состояния заряда накопителя энергии.

1. Introduction

Limited availability of natural resources and environmental problems caused by pollution have raised a global discussion concerning alternative technologies for individual mobility. There are many concepts available, ranging from vehicles with fully electrified powertrain up to systems using electrical energy for only partly supporting a conventional combustion engine. Battery-based electrical vehicles (BEVs) are examples for the first group, whilst hybrid electrical vehicles (HEV) can be categorized to the latter one. Plug-in hybrid vehicles (PHEV) provide two independent drive concepts. For short distances, driving power will solely be provided by an internal battery, which will be substituted by a conventional combustion engine generator, when battery capacity is low. The authors have chosen to focus their investigation only on BEVs. The idea of electrically powering an automobile is not new and has achieved its peak level in the beginning of the last century. It is quite interesting to note that during this time electric vehicles were seen in advantage compared to gasoline cars. In the early 19th century, they dominated the vehicle registration numbers with a ratio of 3:1 [1]. Fig.1 shows an interesting concept of an electric car, which was presented on 14th April 1900 at the automotive world exhibition in Paris.

It was named after its designer Ferdinand Porsche who was employed at the machine factory Jakob Lohner & Co in Austria. Its front wheels were driven by two single hub motors. The power of the electrical motors was specified with each 2,5 hp at 120rpm. A 44 cell battery with a capacity of 300Ah and a nominal voltage of 80 V allowed a driving range of up to 50km at a maximum speed of 50 km/h. The weight of the vehicle was specified with 1000kg, including the battery with 410kg. The vehicle was far ahead of its time and the principle of hub motors is once more used in modern e-cars.

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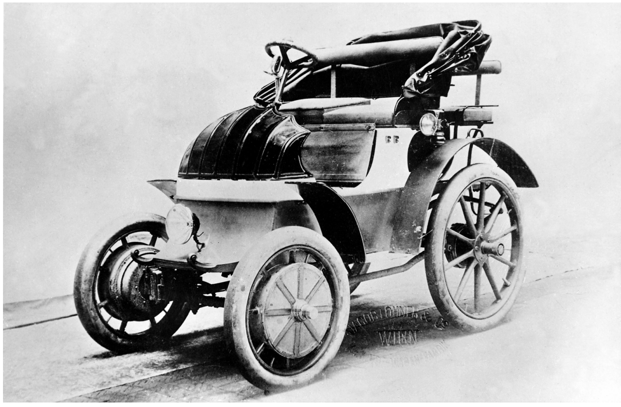


Fig.1. Lohner-Porsche battery driven electrical vehicle [2]

However, in the past, electric vehicles have never been mass produced mainly due to their limitations concerning driving range and missing infrastructure for recharging the batteries. In the past century, oil has been considered as a cheap and nearly unlimited source of energy. Further efforts in the development of improved electrical vehicles have therefore been neglected. Today this situation has changed dramatically. The global demand of oil is continuously increasing and political and economic issues do stroke fears of shortage. The electrification of the automobile is considered as the most promising technology for our mobile future. However, there are still major (technological) challenges, e.g., in terms of maximizing battery capacity and costs, charging time and the provision of a sustainable energy supply.

2. Concepts of electrcal passenger cars

2.1. Architecture of E-cars

The basic architecture of an electrical passenger car is presented in Fig.2. Of course, there are possible variations of this architecture but the presented structure seems to be quite common. First of all, the conventional combustion engine is replaced by one or more electrical motors which are directly driving the wheels. Neither manual nor automatic shift gear boxes are in use. The motors get their electrical energy from high voltage batteries or battery packs via power electronic inverters, which are or should be able to recover electrical energy during deceleration phases. For the high voltage electrical components and wires in a car, particular safety measures are to be implemented. Besides the high voltage components and wire network, there is still a common low voltage (12V) DC system and wire network (because of safety reasons), which supplies all the well-known common electrical components and systems of the car. Some components will have to be implemented in a different way compared to a conventional vehicle, in particular the heating and air conditioning (HVAC) system as well as the break force amplifier. Conventional cars make use of the thermal energy of a combustion engine for heating and the air-conditioning system is mechanically driven by the motor. In e-cars, heating and air conditioning will have to be implemented electrically (consuming energy out of the high voltage battery).

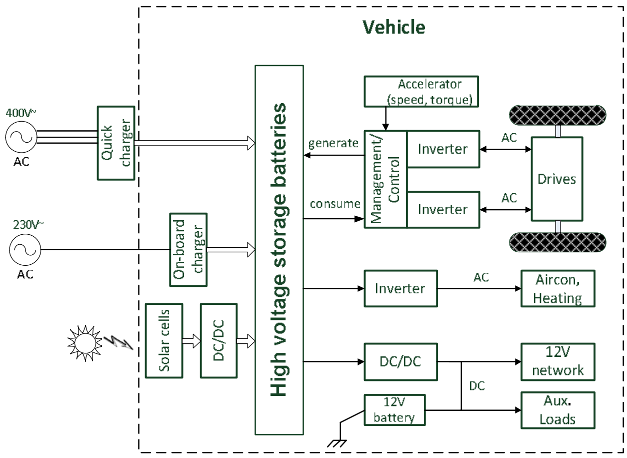


Fig.2. Basic architecture of a modern electric passenger car

For charging the batteries there are the following concepts: Standard charging of the high voltage battery from conventional 230 V supply is usually done via an on-board electronic charger system. Quick charging from 400 V AC might require external electronic chargers. In future both charger types might be able to transfer energy back from the vehicle's battery into the power grid. Therefore in future, electric vehicles may play an important role in intelligent power distribution and storage concepts. Charging of the low voltage battery is done by transferring energy from the high voltage battery via an electronic DC/DC converter. An interesting but not yet decided question will be whether it will make sense to equip standard e-cars with solar cells. In this case, an additional DC/DC converter is necessary to charge either the high or the low voltage battery. A closer look to the high voltage battery reveals different possible types. Lead-based high voltage batteries are mostly out of use because of their very limited life-time and number of charging cycles, as well as very high weight. Other possible types are Redox-flow-batteries and ZEBRA batteries. Currently in most e-cars different types of Li-ion batteries (lithium-based batteries) are used. Common to lithium-based batteries is that the whole system consists of a huge number (stack) of cells. Since lithium-based batteries may by no means be overcharged, a safe and intelligent battery management and charging system, often taking into account the parameters of single cells or at least of subsets of cells, is essential. A closer look to the electrical drives of the car shows that mostly AC motors are in use. This can be either a single motor for all driven wheels, or so called hub-based motors (each driven wheel has its own motor). Therefore one or more DC/AC converters are necessary in combination with intelligent management and control units. The electronic converters are switched frequency inverters whose basic functionality and architecture are well-known from other intelligent controlled AC drive applications. The energy efficiency ratio of the power inverters are of extreme importance, as there is a continuous energy flow forth and back between high voltage battery and motor(s). Efficiency rates of 95% or better are envisaged. As Fig. 2 shows, besides the high power drive inverters, quite an additional number of DC/DC, AC/DC and DC/AC converters can be found in electrical vehicles. Power electronics are therefore a major field of development and source of value generation in e-cars.

a

b

Fig.3. Examples of modern electrical vehicles: (a) Mitsubishi i-MiEV, (b) Tesla Roadster

2.2. Examples of modern electric vehicles

Most car producers are working on the development of electrical vehicles to supplement their product portfolio. However, only a few are already commercially available on the market. Fig.3 shows two examples from entirely different vehicle categories. Table 1 details their specifications.

2.3. Energy Consideration and Ecological footprint

Electric vehicles are considered as promising alternative since they do not produce any tailpipe emissions during operation. However, they may cause

1. Technical data [6-7]

	Mitsubishi i-MiEV	Tesla Roadster
Acceleration 0-100km/h [s]	15.9	3.9
Battery [V/Ah]	330/48	375/150
Empty weight [kg]	1,110	1,235
Maximum speed [km/h]	130	201
Power [kW]	49	215
Price (excl. VAT) [€]	~29,000	~84,000
Range [km]	150	394
Torque [Nm]	180	370

additional power grid load, green-house gases and pollutions for the generation of electricity required for battery charging. Electric vehicles do therefore increase electric power use. However, if managed correctly, that power can be fully provided using the power plants we have available today [3,4]. General predictions of CO_2 emissions for BEVs, which determine the environmental impact, are considered impossible due to the variation of each country's energy mix. An electrical vehicle may be only operated emission free, when the electricity is produced by renewable sources. Another source of pollutants is the production of the vehicle components. However, latter ones are only little in meaning during the whole life cycle of the vehicle. The authors will therefore not further consider them. Literature points out that one electric vehicle increases the electricity consumption of a household in industrialized countries by about 50 % [3].

Introducing a large number of electrical vehicles therefore induces new challenges concerning the infrastructure of charging stations as well as the power grid. The total amount of energy E_{tot} required to move a vehicle can be expressed with equation

$$E_{rot} = \frac{E_{res}}{\eta_{trans}\eta_{motor}\eta_{fuel}}, \quad (1)$$

where E_{res} – mechanical efficiency to move the vehicle [MJ/km]; η_{trans} – transmission efficiency; η_{motor} – electric motor efficiency; η_{fuel} – fuel efficiency.

In terms of an BEV, the fuel supply efficiency can be further expressed with equation

$$\eta_{fuel} = \eta_{charging}\eta_{grid}\eta_{power}\eta_{res,...}, \quad (2)$$

where $\eta_{charging}$ – efficiency of charging and discharging the battery; η_{grid} – efficiency of the electrical distribution grid; η_{power} – efficiency of the power plant; η_{res} – efficiency of mining or farming of energy resources.

Fig. graphically compares different types of vehicles according to their CO_2 emissions. Equations (1) and (2) have been separated according to their Well-to-Tank (WtT) and Tank-to-Wheel (TtW) emissions. The sum of WtT and TtW therefore equals again the Well-to-Wheel (WtW) performance, including all energy relevant steps beginning with the extraction of the energy resource up to the physical movement of the vehicle. Fig.4 shows that electric vehicles are in average cleaner than other vehicles during operation. A car using conventional gasoline emits in average more than twice as much CO_2.

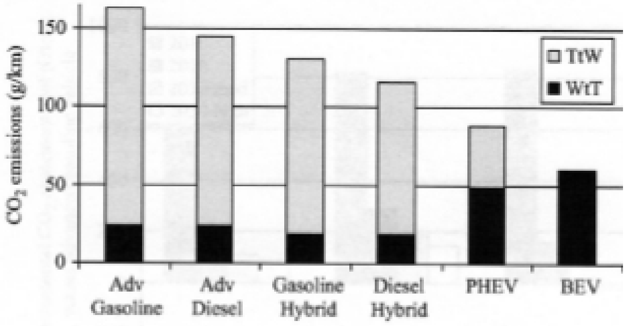


Fig.4. Well-to-Wheel CO_2 emissions [4]

It is assumed that BEVs even get cleaner over time, because the proportion of renewable energy sources is supposed to rise in future. Fig.4 can however only be considered as indicative, since it assumes averaged values of CO_2 intensity for electricity production within Europe. The European country with the lowest CO_2 rate emits 54g CO_2 per kWh, whilst the country with the highest CO_2 emissions produces 1,333g CO_2 per kWh [4]. Literature points out that a two-wheeler BEV in France causes about 5g CO_2/km while the same vehicle in India would pollute the environment with about 35g CO_2/km [5]. France derives nearly 80 % of its power capacity from nuclear plants which is in contrast e.g. to India, whose power generation is extremely CO_2 intensive.

3. Electrical scooters and bikes (pedelecs) at Reutlingen university

Electric mobility is considered to be one of the most significant concepts for future locomotion. It is therefore important to introduce this technology to students in an early stage. Reutlingen University has introduced a fleet of electric two-wheelers as an environmental friendly alternative to commute between 2 University sites which are located in Reutlingen at a distance of about 8 km in between.

3.1. Infrastructure

The fleet consists of two different types of two-wheelers, electric scooters and electric bikes (Pedelecs), whereas five vehicles are available of each group.

The Electric scooters, are German products by the company GUF. The Pedelecs type "Centurion E-Fire" are incorporating the new Bosch Pedelec drive. Their engines support pedaling up to a velocity of 25 km/h. In Germany, no driver's license is required to drive with Pedelecs and they are also permitted on bicycle traffic lanes. 1 technically compares the vehicles. Fig.5 shows the electric two wheelers on campus.

A special charging station will be installed on campus. A software portal was developed to enable vehicle booking. It also monitors the user's profile. Bookings can also be done via internet. With each rental process, the user has to sign a confirmation. Simultaneously, data such as user number, specific vehicle and mileage will be acquired. Due to limited battery capacities, the permitted driving range has to be correlated to the rental time. Users are allowed to book the vehicles half-day (8:00 to 13:00 or 13:00 to 18:00 pm) or full-day (8:00 to 18:00). In case of issuing a two-wheeler half-day, users are allowed to drive 20 km. Otherwise they may drive the vehicle until the battery is empty. In this way, time-consuming charging during the day and the resulting unavailability of the vehicles shall be avoided.

1. Comparision of the two-wheeler's technical data

	GUF GECO2	Centurion E-Fire
Type	Electric scooter	Electric bike/Pedelec
Motor power [W]	2500	250
Battery voltage [V]	48	36
Battery capacity [Ah]	45 (lead) 34,5 (lithium)	8
Charging time [h]	6	1,5 (quick charge) 8 (normal charge)
Maximum velocity [km/h]	45	Not specified; Pedal support up to 25
Maximum range [km]	60	145
Weight [kg]	130 (lead battery) 85 (lithium battery)	22
Price (excl. VAT) [€]	~2300 (lead battery) ~4100 (lithium battery)	~2200
Type of driving license	EU class M	None

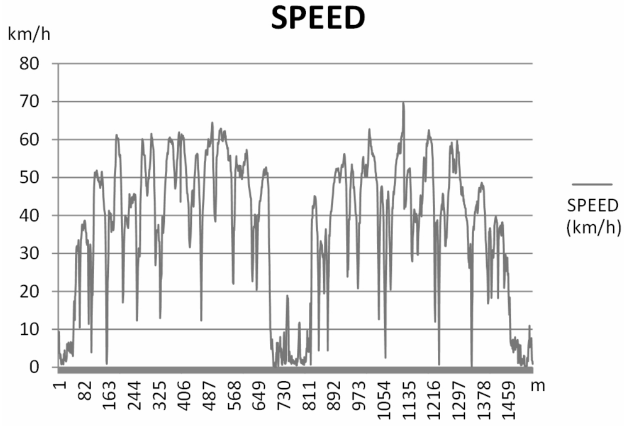

a


b

Fig.5. Electric two-wheelers at Reutlingen University: Electric scooter (a), Pedelec (b)

3.2. Intelligent prediction of battery charging status and remaining driving distance

The scope of this research project at Reutlingen University is the development of an intelligent system for range estimation of electric two-wheelers. Currently, it is difficult for a user to predict the remaining driving range of the battery. Usually, a two-wheeler only provides a display of little accuracy to indicate the battery voltage level. This only allows poor performance in estimating battery capacity and does not visually display any nonlinear discharge of the battery. Latter effect dominates on hilly tracks. The higher the driving load the less the battery voltage. To solve these problems, the range prediction shall be supported by GPS data (elevation, velocity, acceleration) of a driven route. This is shown in Fig.6.



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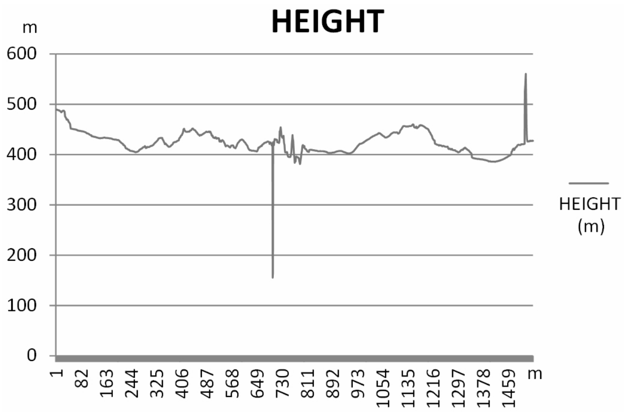

b

Fig.6. GPS Profile of the route between the main campus and the RBZ: Speed profile (a), Elevation profile (b)

This supersedes any technical modifications of the vehicle, once the system characteristics (power consumption and battery characteristics) have been determined. Generally, those parameters are known by the vehicle manufacturer and can be directly put into the predictive system. Therefore a data logger (based on an Arduino microcontroller evaluation board) will be used to monitor battery voltage and current consumption. In combination with the GPS data, this information can be used to determine the system characteristics.

In future, the microcontroller board will be extended by a GPS receiver in order to have all the required functionality combined within one device.

4. Conclusion

Recently, electrical vehicles have been enjoying more and more popularity. Additionally, the range of available products has been continuously increasing. Continuous improvements in technology (such as novel drive concepts and advances in power electronics) have raised the public opinion of these products towards modern and agile tools for locomotion.

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