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doi:10.15199/48.2015.05.38

Optimal Design Techniques for Small Electric Car Operating in Common Urban Traffic

***Abstract**. The paper deals with design technique for electric drive of the small e-car. The requirements on electric car (drive) were determined according to European driving cycle ECE15. This normative defines typical city driving cycle and is used for example for definition of consumption for conventional cars. The main goal of the presented design techniques isn't primarily design of the drive as a substitute of conventional drive for middle class car, but design of drive for small low weight car with minimal demands on power and torque of its traction drive. Simultaneously the parameters of the traction drive have to meet all necessary requirements for safety city traffic operation. All these goals are specified according to requirements of typical city traffic operation with the range up to 30 km and with only one person in the car.*

Streszczenie.** W artykule analizowany jest napęd do małego pojazdu elektrycznego w oparciu o europejską dyrektywę ECE15. Celem jest projekt samochodu z minimalnymi wymaganiami dotyczącymi mocy i momentu napedowego. Analizowane są wymagania dla jednoosobowego samochodu o zasięgu 30 km.* ***Optymalny projekt małego samochodu elektrycznego wykorzystywanego w typowym ruchu miejskim

Keywords: electric drive, electric car, induction machine.
Słowa kluczowe: napęd e;lektryczny, samochód elektryczny

Introduction

At the look on the electric cars, currently available on the market, it is obvious that cars producers are trying to substitute conventional cars completely with electrical cars with the same or at least similar parameters (size, max. speed, range, etc.). This fact pushes electric cars prices up to disproportionately level although for needs of most car users are these parameters needless. It is suitable to do not put same demands on electric car like on the car with conventional drive. Cars with conventional drive unit are basically universal cars determined both for daily transportation to work as well as to long distance trip. Therefore, the electric car should be designed especially for everyday short distance transportation where it is better to use its advantages in contrary to conventional car with combustion motor.

Most car users didn't accomplish longer distance than 30 km on their way to work or to regular shopping. Additionally these trips are realized mostly in urban traffic where no high speed is required. These facts have significant influence on final parameters of the whole drive system. In following chapters an individual steps leading to drive system of small electric car design are described. First, the limiting parameters of the drive system are defined according to European normative ECE15. Parameters such as: definition of proper gear ratio of the transmission, definition of the proper size and type of electric machine, design of power converter and estimation of sufficient capacity of the traction accumulator are critical for drive unit design. The European normative ECE15, known as UDC too, represents conditions in which cars commonly operates in urban traffic (small velocities, frequent acceleration from zero speed, etc.) [1], [2].

Vehicle Motion Model

This chapter is focused on finding functional dependences of traction force and power on requirement defined according to ECE15. All significant variables acting on car wheel will be defined according to demands mentioned above [3], [4], [5].

The motion of the car is described in terms of its longitudinal speed with well-known motion equation:

$$m \cdot \vec{a} = \vec{F}_M + \vec{F}_{gravity} + \vec{F}_{rolling} + \vec{F}_{aerodyn} \quad (1)$$

where a is acceleration vector of the car with reduced weight. This reduced weight take into account an inertia mass of wheels, rotors and weight of car. This car is driven by actuating force of an electromotor. The motion of the car is affected by losses:

$F_{gravity}$ – gravity force which depends on angle of road at uphill driving,

$F_{rolling}$ – rolling force which depends on a rolling resistance between wheels and roads,

$F_{gareodyn}$ – aerodynamic force which depends on an air resistance of the car.

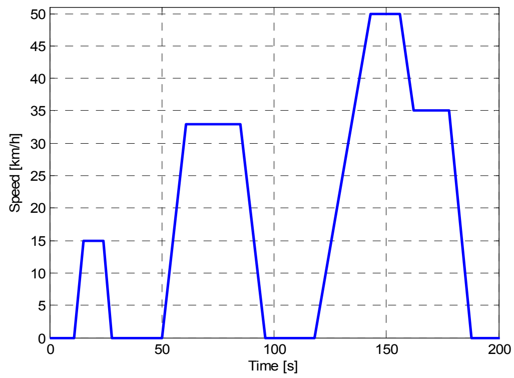

Fig. 1. Required speed of the car model during time (ECE15).

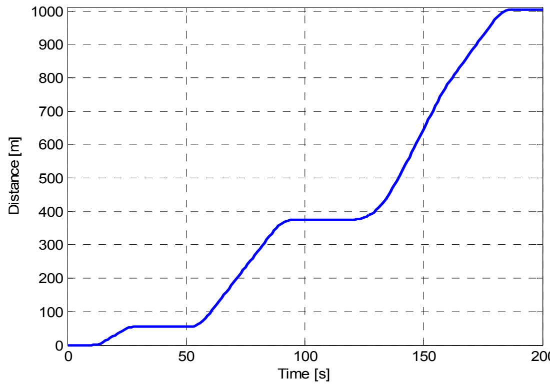

Fig. 2. Required distance of the car model during time.

A model of car dynamics is used for the actuating force determination [6], [7]. The model of the car is actuated on the base of required speed and distance (ECE15) which are shown in Fig. 1 and 2. The actuating force is calculated from the model (see Fig.4) which is based on motion equation (1). The calculated actuating force with an assumption of a flat road is shown in Fig. 3.

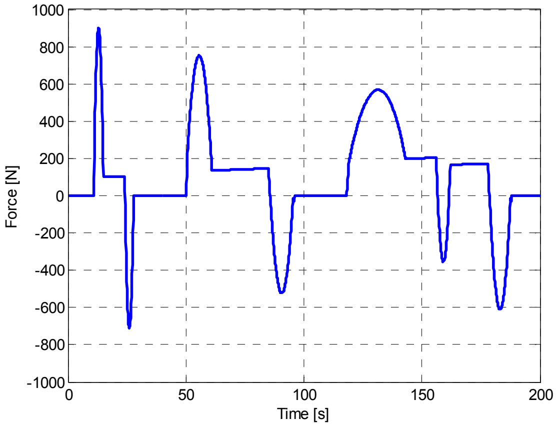

Fig. 3. Calculated actuated force of the car model.

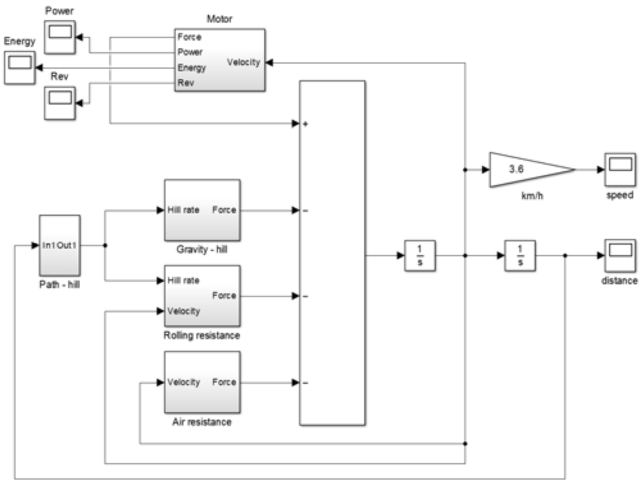

Fig. 4. Matlab/Simulink model of the car dynamic.

Drive Uphill

The model contains the road profile and the uphill drive is assumed too. Several angles of the hill ramp: 0, 2, 4, 6, 8, 10, 12 degrees, were simulated and the results are shown in Fig. 5. The maximal speed of the car is 66 km/h for drive with flat road. The car can drive uphill with angle 12 degrees with maximal speed 24 km/h. The angle of the uphill ramp (12 degrees) can be assumed as uphill limit rate for this car model. According to Fig. 6, it is obvious that maximal power to satisfy desired driving profile at maximal angle is 9 kW. The traction unit of the car has to be designed in terms of this value.

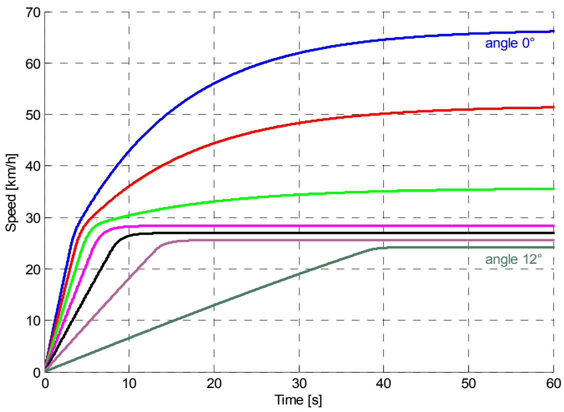

Fig. 5. Speed of car during acceleration to the hill with different hill angle 0, 2, 4, 6, 8, 10, 12 degrees.

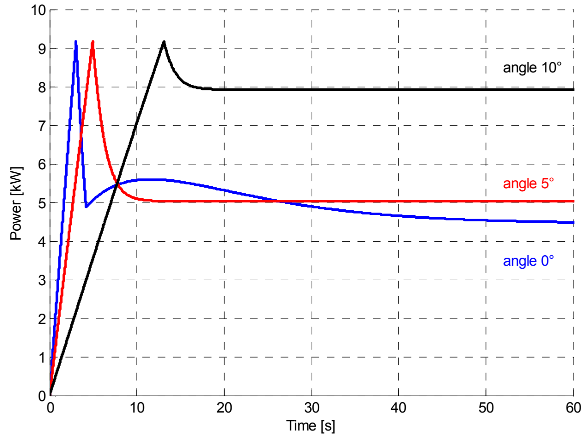

Fig. 6. Power of motor during acceleration to the hill with different hill angle 0, 5, 10 degrees.

Power Analysis

The power analysis of the car model is required for design of the actuating motor and traction accumulator. The consumed and recuperated power was calculated on the base of the car model. The 10% efficiency of the gear box with differential gear was assumed in this model. The results of power analysis are shown in Fig. 7.

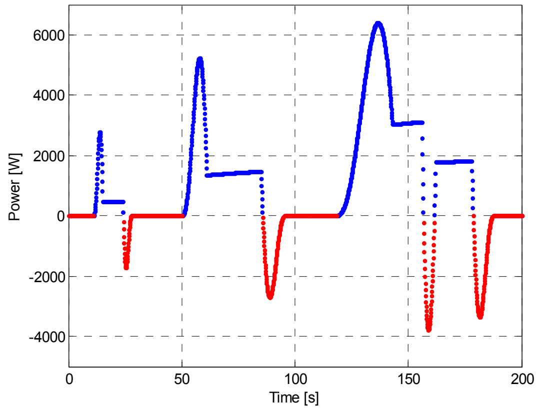

Fig. 7. Power analysis during drive cycle with defined trajectory.

The required power for acceleration is plotted with blue marks and the required brake power is plotted with red marks.

The quantity of consumed energy (blue) and recuperated energy (red) during the drive cycle in assumed trajectory is shown in Fig. 8.

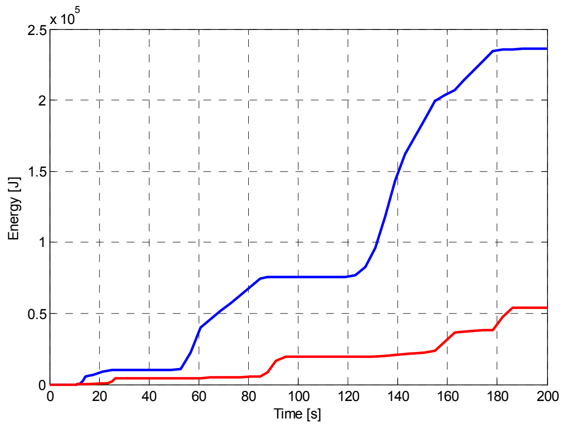

Fig. 8. Consumed (blue) and recuperated (red) energy during ride in assumed trajectory.

In figures above, all necessary parameters of the car are shown. For these parameters the final drive unit has to be designed to ensure safety and reliable operation in urban traffic. From the perspective of the car user is the most important parameter especially acceleration from zero speed (crossroads, etc.) According to Fig. 7. and generally known formula (2), it is obvious that desired power, given by product of force and speed, is zero at zero speed. And its value rises with rising speed. Therefore, the high power of the traction drive isn't relevant for acceleration from zero speed, as is often misunderstood in general public. The highest possible increase of traction force is needed for achieving maximal acceleration from zero speed according to (3).

(2) $$P = F \cdot v$$

(3) $$\Delta F = m \cdot a$$

For further calculation all variables have to be transformed from linear to rotational variables. Car speed and motor *RPM* are related according to:

(4) $$n = \frac{60 \cdot v}{o}$$

where n is motor rotational speed and o is wheel circumference. Torque is given from force on the wheel by:

(5) $$T = F \cdot r$$

where r is wheel radius (0.25 m).

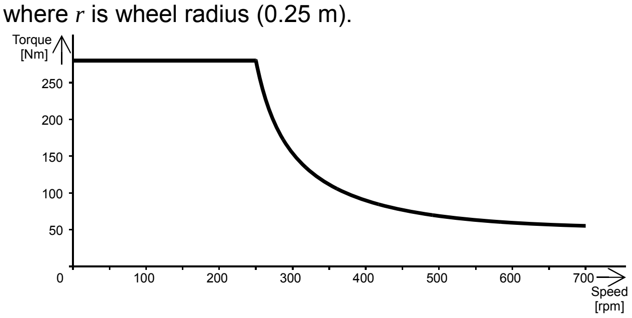

Fig. 9. Desired torque-speed characteristic on car wheel (wheel radius 0.25 m).

Minimal values of torque T = 225 Nm and motor speed *RPM* = 530 rpm are desired according to Fig.1, Fig. 3 and (4), (5). Maximal motor speed 6900 rpm (car speed 65 km/h) is taken into consideration. Desired torque–speed characteristic according to Fig. 3 is shown in Fig. 9.

Appropriate Choice of Electric Machine and Transmission Gear Ratio

Transmission (Gear Box)

Size of the motor is related to nominal torque not to the power. Motor output power can be changed with change of speed, which leads to change of its supply voltage level not to its size (weight). An appropriate choice of the transmission ratio has major impact to total weight of the whole drive system. Weight of the transmission will be always smaller (even for high transmission ratio) than weight of the high torque motor without transmission. The combination of motor and transmission is always beneficial to achieve optimal weight of the whole drive.

If the drive system is designed without transmission than the motor with high nominal torque has to be chosen, as was mentioned before. But size and weight of the motor is directly related to this high value of torque. Even if special synchronous motor with high nominal torque to weight ratio is used, the motor is still unacceptable large and heavy. Another big drawbacks are high Joule losses in winding. Its value is related to product of square current density and winding volume. Motor without transmission and placed directly into wheel is more often used in electric bikes. These motor are DC or synchronous with permanent magnets. Their torque range without overloading is between 5 – 15 Nm. Both types of motors have a pretty good nominal torque to weight ratio. But their weight is still in range of several kilograms. It is not possible to use them as the only auxiliary motor for easier pedaling uphill. The only advantage which motivates producers to such solution is simple assembling and nicer looks of these bike. Even in car, this solution is used for auxiliary drive and not as main traction unit.

Only two possible solutions can be taken into consideration the transmission with fixed gear ratio or multistage transmission. There are two basic demands put on this solution with transmission. First, it is achieving maximal efficiency in wide range of torque and speed and simultaneously lowest dimension and weight for desired torque-speed curve. If we are choosing the gear ratio and nominal torque of the motor, than these two conditions have to be taken into consideration.

If one-stage transmission is used, two conflicting criteria have to be taken into consideration. Using the motor with the least possible nominal torque (small electrical machine), in terms of meeting the desired torque on shaft of the traction wheel, it means using transmission with highest possible gear ratio. Big gear ratio isn't ideal at high velocities, where the maximal motor speed will be difficult to realize due to mechanical limitation of the motor and transmission. Additionally with higher speed rises noise (generated by transmission and motor) and losses in the motor (iron, mechanical). Nevertheless, increase of iron losses isn´t inevitable. In case of using machine, which has possibility to flux weakening at high velocities, it is possible to significantly reduce these losses. This problem is presented only in motors with permanent magnets due to their complicated flux weakening. Choice of the proper gear ratio is compromise between:

- High gear ratio $\Rightarrow$ small size and high rotational speed of the motor at maximal car speed. High efficiency at low speed and high torque.
- Lower gear ratio $\Rightarrow$ not so high rotational speed of motor at maximal car speed. High efficiency at high speed and low torque.

It is obvious that one stage transmission is kind of compromise. The more will be breakdown speed on torque–speed curve distanced from the maximal speed (see Fig. 9), the more will be difficult to realize the transmission with only one stage. In this case it becomes more difficult to find sufficient compromise between conflicting criteria mentioned above. By using two stage transmission where one stage has high gear ratio for ensuring high torque and sufficient efficiency at low velocities. Second stage with lower gear ratio lower motor speed at maximal car speed is useful for reducing iron and mechanical losses in motor.

Using two-stage transmission is always better solution in term of achieving maximal efficiency in wide range of motor velocities regardless of used motor. It represents technological complication (speed shifting, synchronization). We choose one-stage transmission with fixed gear ration to meet all demands on low cost, low speed and simplicity of the whole drive system. It is sufficient solution for such type of electric car.

Electric Machine

Only two types of electric motor come into consideration. Synchronous permanent magnet motor and induction motor with the squirrel cage [8], [9].

Permanent magnet synchronous machine

Pros and cons:

+ Excellent torque to weight ratio

+ High efficiency at high torque
+ Brushless machine
- Problematic flux weakening
- Direct relation between back EMF and motor speed (problematic high voltage at high velocities)
- Unrecoverable iron losses
- Problematic magnet fixing into the rotor
- High and still increasing price of permanent magnets

Due to the fact, that hysteresis losses increase with the speed (eddy current with square of speed), it is appropriate to choose motor with higher torque and lower speed. This machine has excellent torque to weight ratio. Lower maximal motor speed reduces iron and mechanical losses as mentioned above. Drive unit with synchronous machine is very progressive solution despite all already mentioned disadvantages. Lowest weight of the motor is achieved for given torque-speed curve of the drive. High efficiency is than achieved when motor operating with nominal torque [9], [10], [11].

Induction *machine with squirrel cage*

Pros and cons:

+ Lower manufacture cost in comparison with PMSM (No magnet fixing into rotor)
+ Easy to flux weakening at high velocities (no complication with back EMF, reduction of iron losses in stator), this is big advantages especially for independent traction where machine operates in wide range of velocities
- Additional losses in the motor and DC/AC converter caused by magnetizing current
- 3 – 5 times lower torque to weight ratio

The disadvantage of lower torque - weight ratio is possible to eliminate by choosing machine with lower torque and higher speed. Maximal motor speed of the induction motor can be up to 3 times higher in comparison to synchronous.

The disadvantage of presence magnetizing current is compensated with possibility to flux weakening of the motor at high speed. Motor has lower torque but also lower iron losses for lower magnetic flux density. Induction motor operates with higher efficiency at high speed and low torque in comparison to PMSM. Efficiency is lower at nominal speed and nominal torque due to magnetizing current which causes Joule losses in stator winding [12], [13].

At nominal speed and nominal torque is than efficiency lower due to magnetizing current which causes Joule losses in stator winding [12], [13].

Parameter summarization for the both type of machines and choosing of suitable type of motor

The drive unit (motor and transmission) with induction motor will be always heavier. Difference will not be finally so dramatic in terms of mentioned torques to weight ratios. Induction motor with transmission reduces significantly this difference due to motor with lower torque and transmission with higher gear ratio.

Induction motor is several times cheaper than PMSM. And the price of the permanent magnet is still increasing on the market.

The next advantage of induction motor is better immunity for motor overloading, because according to Fig. 3 there is big difference between average and maximal torque. It is more appropriate to choose motor with lower nominal torque and stress the motor by short time overloading.

The both types of machines have different features causing varying efficiency in the various operating modes. Synchronous machine has better efficiency at high torque and lover speed and induction at higher speed and lower torque. These modes can be partly covered by choosing motor and transmission. Due to demands on low manufacture price, simple and reliable solution of the drive unit and simultaneously in terms of low desired maximal values of torque and motor power, the solution of drive unit with induction motor and transmission was finally chosen.

Design techniques (prototyping and modification) of the induction *motor*

First, number of poles has to be chosen according to following facts:

• As mentioned before size of motor is given with value of nominal torque not with motor power. Higher power can be achieved with increasing speed of the motor that means with increasing frequency of stator voltages at the same level of excitation. Advantage of higher power of the motor with lower number of poles is useless due to possibility to change the frequency.

• Torque to weight ratio is almost independent on number of poles. Motor with more poles has better transition of the magnetic induction in stator, which leads to torque increase. The difference is significant especially between two and four poles motor.

• At the same torque and power is necessarily for higher number of poles to increase excitation which leads to higher iron losses.

Definition of the final number of poles is compromise between higher torque and iron loses for multiple-poles motor and for low-pole motor it is vice versa.

Compromise solution of this problem is a four pole motor according to our experience in this field. Deign technique for concrete motor is described in chapter *Practical calculation*.

Three Phase DC/AC Converter and Traction Accumulator

DC/AC Converter

Design of DC/AC inverter according to specification in chapter *Vehicle Motion Model* is very simple. Voltage level set at 50 V (safe touch voltage) is chosen for maximal safety. There are no limitation on transistor maximal current due to low output power 9 kW. Low voltage level allows using MOSFET transistors with low conductive and switching losses. For conventional cars with power up to 100 kW, it is not realizable with voltage level of 50 V due to high value of currents.

Accumulator

For design of traction accumulator it is necessary to define requirements on its capacity and current at given voltage level (maximal power). According to Fig. 8, it is clearly defined desired energy for one traffic kilometer. Desired amount of energy is given by subtracting the value of blue curve from the value of red curve in the end-point. For considered distance approx. 30 km is desired energy E = 1.54 kW/h. This value has to be increased of losses in motor (efficiency approx. 0.87) and in traction inverter (efficiency approx. 0.96). The total amount of stored energy in accumulator is E = 1.85 kW/h. Calculation with specific accumulator together with traction inverter and motor are described in chapter *Practical calculation*. Losses generated on inner resistance of accumulator are negligible due to low inner resistance of chosen type of accumulator, see chapter *Practical calculation*.

Practical Calculation

Motor and Transmission

There are two ways how to solve modification of the already chosen motor. First, we can design completely new motor or use motor with appropriate torque, which is commonly available on the market, and then only rewind the motor. Second solution reduces significantly motor cost and it will be further analyzed.

Standard motor from EMP company M90-4X was chosen. It is 4 pole motor with weight 17 kg, which has to be rewound to desired voltage level and nominal point. Nominal torque is 15 Nm. For net supplying f = 50 Hz at nominal torque and speed (n_r = 1400 rpm, f_{slip} = 3.3 Hz) is output power 2.2 kW.

At low speed (drive uphill) it is possible to rise magnetic flux density in the motor (overexcited motor). And if the slip frequency is increased simultaneously, toque about 28 Nm is achieved for short time. In this mode is speed limited via software up to 3000 rpm. Than the output power can't exceed 9 kW.

In overexcited state provides motor torque 28 Nm but according to calculation from chapter *Vehicle Motion Model* torque T_{max} = 225 Nm (n_{max} = 530 rpm) is desired. Than minimal gear ratio is given:

$$i = \frac{225Nm}{28Nm} = 8.3 \qquad (6)$$

Due to sufficient reserve in torque and in terms of maximal acceptable speed gear ratio i = 10 is chosen.

Considering maximal car speed approx. 65 km/h (drive with flat road) and wheel radius r = 0.25 m the wheel rotation speed is 690 rpm. The maximal motor rotation speed is 6900 rpm. It was practical verified that rotor is sufficiently dimensioned to such value. For maximal speed 65 km/h and zero climb and still air, the output power 4.5 kW (6 Nm) is needed according the calculation to overcome aero dynamical and friction forces.

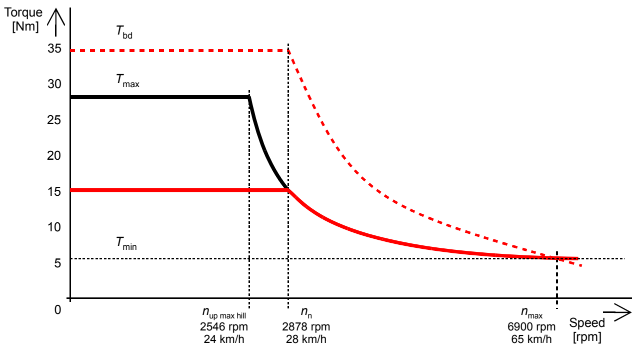

Fig. 10. New nominal point of the motor.

For nominal excitation is motor breakdown torque T_{bd} = 34.5 Nm. If we consider that the breakdown torque is depended on square of speed than its value decreases more steeply during flux weakening. Therefore the nominal point of the drive is chosen so that breakdown torque at maximal speed was equal to desired T_{min} = 6 Nm. Than for calculation of the minimal possible rotation speed in nominal point under the requirement on torque at maximal rotational speed we get:

$$n_n = \sqrt{\frac{T_{min}}{T_{bd}}} \cdot n_{max} = \sqrt{\frac{6}{34.5}} \cdot 6900 = 2878 \text{ rpm}. \qquad (7)$$

For nominal point is rotational speed chosen approx. 2900 rpm. Equation (8) is used for verification of motor output power in nominal point:

$$P_n = \frac{2\pi n_n}{60} \cdot T_n = \frac{2\pi \cdot 2900}{60} \cdot 15 = 4555 \text{ W}. \qquad (8)$$

According to (8) it is obvious that the output power was increased from 2200 W only with increasing of speed in nominal point (without torque overloading) from prior 1400 rpm to 2900 rpm.

Motor Rewinding

Motor has to be rewound due to lower voltage level and new nominal parameters. While maintaining slip frequency f_{slip} = 3.33 Hz is synchronous frequency in new nominal point given by:

$$f_s' = 2\frac{n_n}{60} + f_{slip} = 2\frac{2900}{60} + 3.33 = 100 \text{ Hz}. \qquad (9)$$

DC voltage link is V_D = 50 V (due to safe voltage level in whole drive). By using suitable PWM modulation is maximal value of first harmonic of phase to phase voltage equal to V_D. Motor coils are in delta connection, it means, that for new synchronous frequency is stator voltage k-times lower according to (11). Effective value of the new phase to phase voltage is:

$$V_{p-p_{RMS}} = \frac{V_D}{\sqrt{2}} = \frac{50}{\sqrt{2}} = 35.4 \text{ V}, \qquad (10)$$

$$k = \frac{f_s'}{f_s} \cdot \frac{V_{p_{RMS}}}{V_{p-p_{RMS}}} = \frac{100}{50} \cdot \frac{230}{35.4} = 13. \qquad (11)$$

According to (11), it is clear that the number of turns has to be reduced 13-times for the same excitation level on which was motor designed at net supplying.

The amplitude of magnetic current is than 13 times higher as well as the active current component. The amplitude of stator current is than higher.

$$P = 3V_{p_{RMS}} I_{p_{RMS}} \cos\varphi \qquad (12)$$

$$I_{p_{RMS}} = \frac{P}{3 \cdot U_{p_{RMS}} \cos\varphi \cdot \eta} = \frac{2200}{3 \cdot 230 \cdot 0.81 . 0.8} = 4.9 \text{ A}. \qquad (13)$$

Effective value of phase current for rewound motor is given by:

$$I'_{p_{RMS}} = I_{p_{RMS}} k = 4.9 \cdot 13 = 63.7 \text{ A}. \qquad (14)$$

Finally, it means that for same current density has to be use wire with 13 times higher cross size or more wires connected in parallel. The total effective conductor size of stator winding remains unchanged, because the conductor size k–times increased but the number of turn of winding k–times decreased.

Three Phase Traction DC/AC Inverter

For design of traction inverter is important to specify the desired transistor current. Assuming effective (RMS) value of the rewound motor phase current I'_{PRMS} = 63.7 A. Due to delta connected motor the inverter has to be dimensioned in terms of peak to peak value of the motor current:

$$I'_{P-P_{RMS}} = I'_{P_{RMS}} \cdot \sqrt{3} \qquad (15)$$

Effective value of this current $I'_{P\text{-}PRMS}$ = 110.3 A is according to (15). Transistor has to be designed to maximal value of the current (with sufficient reserve):

$$I'_{P-P\max} = I'_{P-P_{RMS}} \cdot \sqrt{2} \qquad (16)$$

The amplitude of the phase to phase current $I'_{P\text{-}Psmax}$ = 156 A is valid for torque T = 15 Nm at non-excite mode. When overloading motor is the torque T = 28 Nm, and current $I'_{P\text{-}Pmax}$ is increased with ratio 28 : 15. According to (17) is amplitude of the phase to phase current in over-excited mode $I''_{P\text{-}Pmax}$ = 291 A. On this value is than transistor designed (some reserve should be taken into consideration)

(17) $$I''_{P-P_{\max}} = \frac{28}{15} \cdot I'_{P-P_{\max}}$$

Design and construction of the power part (PCBs) of the inverter for a maximal achievable efficiency has to be taken into consideration. Efficiency is significant and important parameter for all inverters used in independent traction. Very suitable basic device of this inverter is transistor MOSFET IRF4110, with very low $R_{DS(on)}$ = 4.3 mΩ, reducing conductive losses. Maximal continuous current of this transistor is 120 A and is limited only by capability of the transistor package [14]. Breakdown voltage V_{DSS} = 100 V gives voltage reserve 50 V due to DC voltage level of the inverter V_D = 50 V. Possible voltage overshoots (caused by parasitic induction and high slopes of di/dt) at switching can't exceed the breakdown voltage of transistor. The main factor reducing parasitic induction is proper geometrical placement of semiconductor devices. Mutual distance of the device on PCB has to be strongly minimized and non-inductive capacitor has to be connected as close as possible to them. Double-sided PCB is necessary for minimizing parasitic inductances. The top and bottom transistors should be placed against themselves on the both sides of PCB (see Fig. 11 and Fig. 12). The area between source pin of top transistor and drain pin of bottom transistor is massively and widely poured due to minimizing parasitic induction. For achieving desired current $I_{P,max}$ = 291 A four transistors have to be connected in parallel. Than the theoretical current capability of one switch (four transistors) is 480 A. In comparison with $I_{P,max}$ = 291 A provides one switch sufficient current reserve.

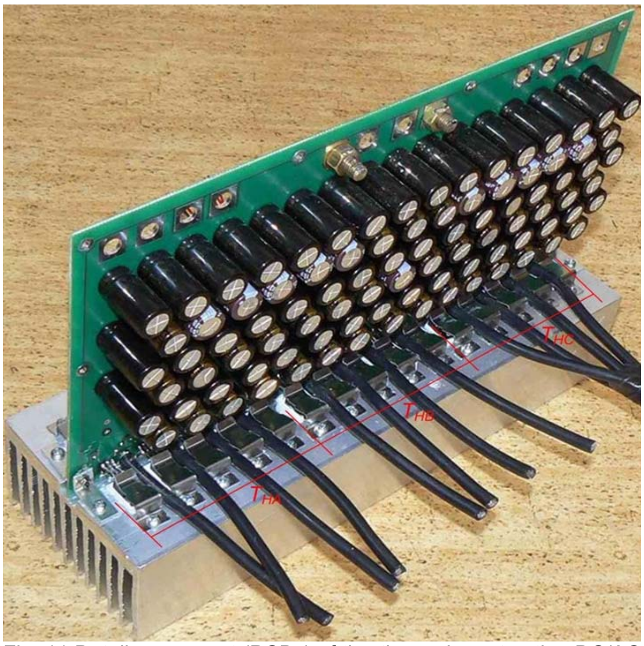

Fig. 11 Detail power part (PCBs) of the three phase traction DC/AC inverter.

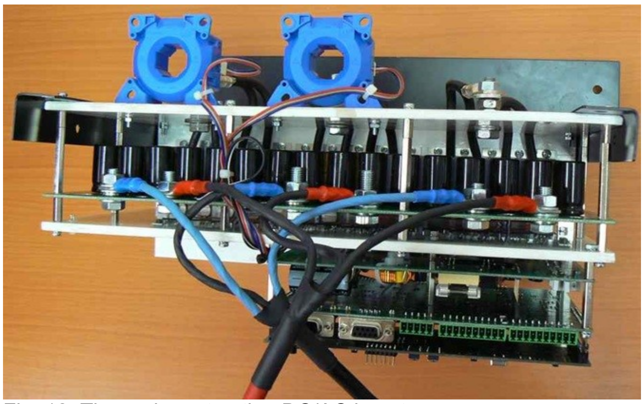

Fig. 12. Three phase traction DC/AC inverter.

Accumulator

As mentioned before, the minimal stored energy for considered car range is about E = 1.85 kW/h and simultaneously the accumulator has to be able to provide maximal power 9 kW. The most appropriate basic unit for accumulator are Li-FE-Po cells [15, 16]. These are very progressive types of cells based on Li-Ion technology. They have 10 times lower inner resistance in comparison witch classical Li-Ion accumulators. Therefore, they are able to absorb or provide higher values of charging current (10 A) and discharging current (70 A). There is no need to use ultra-capacitor for covering power peaks. In traction drives is important that the accumulator is able to quickly absorb recuperating energy because the drive recuperates highest value of energy just in the beginning of breaking. Li-Fe-Po cells have higher life time but higher weight too in comparison with classical Li-Ion cells. Accumulators with Li-Fe-Po cells are suitable for electric or hybrid cars due to their capability to quickly absorb and provide energy (current). One 3.3 V cells is able to store energy of 2.3 Ah. For achieving desired voltage level of the accumulator 15 cells are connected in series. If we take sufficient energy reserve into consideration, than total stored energy of the accumulator is about E = 2.2 kW/h which is ensured by 290 cells. The accumulator pack is made from 19 branches connected in parallel witch 15 in series connected cells in each branch, see Fig. 13.

Voltage of the whole battery is 49.5 V and the capacity 43.7 Ah. Short time maximal peak is about 65 kW (theoretical value highly depended on age of the cells) which provides sufficient reserve for desired 9 kW.

The whole electric system of the drivetrain is shown in Fig. 14.

Fig. 13. Traction accumulator.

Fig. 14. Traction drive.

Simulations of the Electric Car Assuming Calculated Motor

The calculated actuating force could drive the car model with required speed on the flat road. This actuating force is recalculated to a torque of an actuated motor [17], [18]. The model of this car assumed a gearbox with gear ration 10. The torque of the actuated motor is shown in Fig. 15. The motor speed during assumed trajectory is shown in Fig. 16.

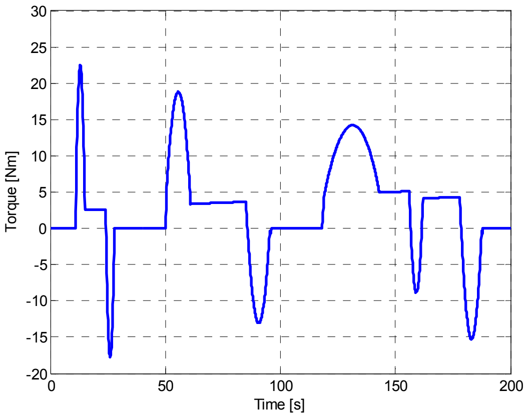

Fig. 15. Torque of actuated motor with gear ratio 10.

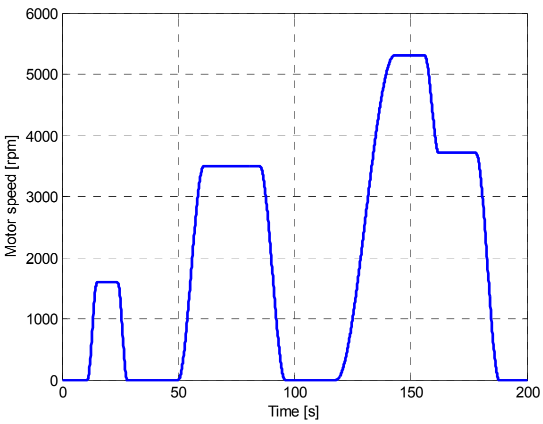

Fig. 16. Calculated motor speed during drive in assumed trajectory.

Ride to the Real Hill to Brno University of Technology

This simulation presents the ride to Brno University of Technology, it is shown in Fig. 17. This path is about 2 km long and we expect maximal torque from motor. The simulation results are shown in Fig. 18, 19 and 20.

Fig. 17. Path to Brno University of Technology.

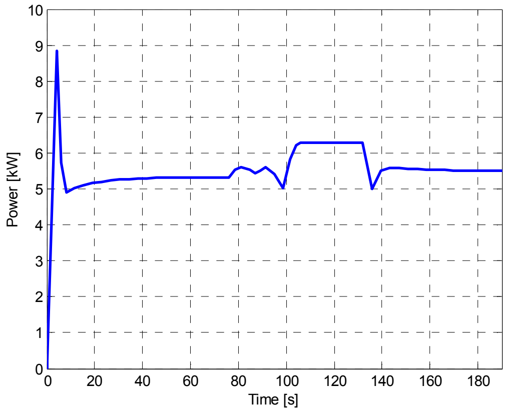

Fig. 18. Actuating power during drive to Brno University of Technology.

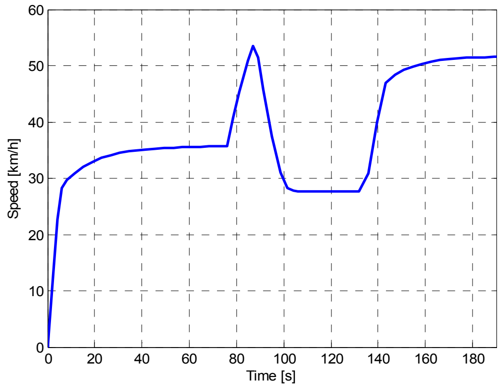

Fig. 19. Maximal speed during drive to Brno University of Technology.

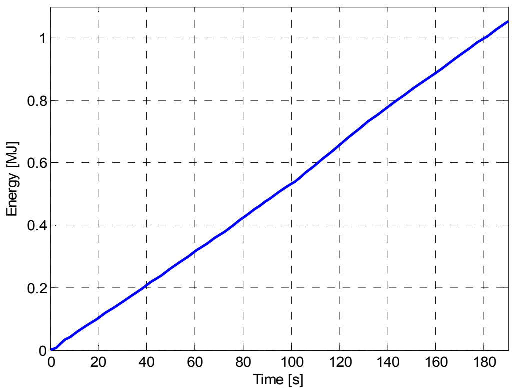

Fig. 20. Energy consumption during drive to Brno University of Technology.

Conclusion

Design of the small electric car is described in this paper. Design is optimized to minimal manufacture cost while maintaining safety operation of the car in urban traffic. Current prices of the electric cars components don’t allow produce electric car comparable with conventional cars at the same price. Therefore a lot of attention has to be paid on minimizing manufacture price when designing electric car (drive unit, components, simple conception, etc.) Results show that is possible to produce small car with small output power which is able to sufficiently satisfy all common user´s needs. The electric car is based on platform of small car JAWA Chic with combustion engine. After replacement of all component of former combustion drive unit for desired electrical drive system is the total weight of the electric car with driver 500 kg.

Acknowledgement

Authors gratefully acknowledge financial support from the Ministry of Education, Youth and Sports under projects No. LO1210 – „Energy for Sustainable Development (EN-PUR)“ and No. CZ.1.07/2.3.00/30.005 of Brno University of Technology solved in the Centre for Research and Utilization of Renewable Energy.

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