

# Determination of the needed power of an electric motor on the basis of acceleration time of the electric car

M Sapundzhiev<sup>1</sup>, I Evtimov<sup>2</sup> and R Ivanov<sup>2</sup>

<sup>1</sup>Branch Silistra, University of Ruse, 8, Studentska str. 7017 Ruse, Bulgaria

<sup>2</sup>Department Engines and Vehicles, University of Ruse, 8, Studentska str. 7017 Ruse, Bulgaria

milenvs@abv.bg

**Abstract.** The paper presents an upgraded methodology for determination of the electric motor power considering the time for acceleration. The influence of the speed factor of electric motor on the value of needed power at same acceleration time is studied. Some calculations on the basis of real vehicle were made. The numeric and graphical results are given. They show a decrease of needed power with the increase of the speed factor of motor, because the high speed factor allows the use of a larger range of the characteristic with the maximum power of the motor. An experimental verification of methodology was done.

## 1. Introduction

When designing an electric car, the needed power of the electric motor is selected primarily based on the specified maximum speed [1, 7 and 9] but this criterion does not guarantee its acceleration to a certain speed at a set time, as well as a good inserting in the traffic.

This approach typically does not take into account the energy losses for the operation of the ancillary systems of the electric vehicle and the resulting power is considerably less than what is actually needed [2, 3, 4 and 5].

The classic methodology for selecting an electric motor does not take into account the intensity of acceleration, which is also important in the calculation of the electric vehicle traction [6, 8 and 9].

When a more powerful electric motor is used, the maximum speed is determined by the maximum rotation speed of the electric motor [1, 6 and 9].

The problem concerning determination of needed power is also actual in the field of hybrid and converted vehicles [3, 11 and 12]. Usually they resolve that problem using complex modeling and simulation tools [4, 7 and 10].

The main goal of the presented paper is to develop a relatively simple methodology for determination of the needed power of electric motor, based on time for acceleration. Other goals are investigation the influence of different factors on value of needed power and experimental verification the methodology.

## 2. Method of determination the needed power of an electric motor according to a given acceleration time

The existing [6], rather as an idea, approach to determining the power needed to accelerate the electric vehicle to a specified speed at a given time  $t_a$  is based on the following relation



$$t_a = \int_0^{V_b} \frac{\frac{G}{g} \delta_a}{\frac{P}{V_b} - G f_f - \frac{1}{2} k_a S V_b^2} dV + \int_{V_b}^{V_f} \frac{\frac{G}{g} \delta_a}{\frac{P}{V_f} - G f_f - \frac{1}{2} k_a S V_f^2} dV, \tag{1}$$

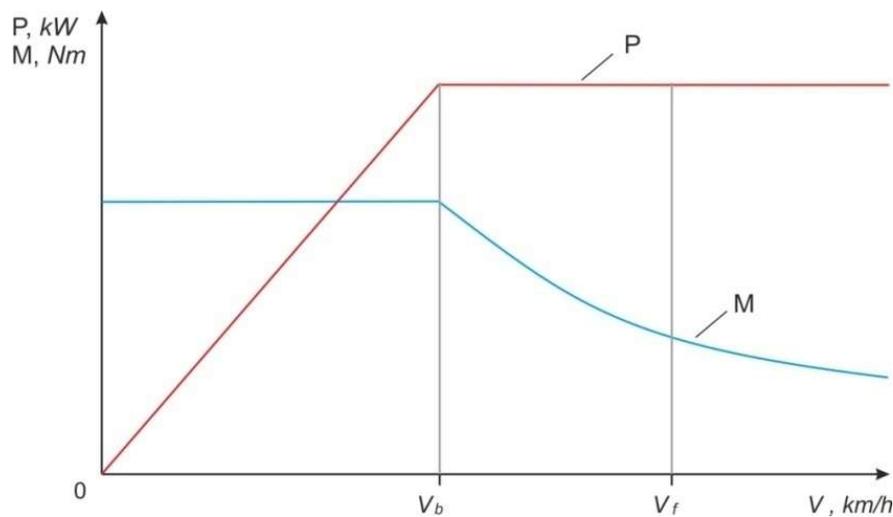
where  $V_f$  is the final speed, km/h;  
 $V_b$  – the base speed, km/h;  
 $f_f$ – the rolling resistance coefficient;  
 $\delta_a$  – the coefficient of influence of the rotating masses of the car;  
 $g$  – the Earth acceleration.  
 $G$ – the weight of the electric car, kN;  
 $k_a = c_x \rho$  – the coefficient of air resistance of the electric car;  
 $c_x$ – the drag coefficient of the electric car;  
 $\rho$ – the air density;  
 $S$ – the front area of the electric car,  $m^2$ ;  
 $P$  – the power of the electric motor, kW;

The right side of the equation contains two parts. The idea may be illustrated in figure 1 - the change in torque and power of the electric motor vs the speed of the electric car. The first part of the equation (1) refers to the speed section from 0 to  $V_b$ , and the second from  $V_b$  to  $V_f$ .

The figure depicts the operation of the electric motor when driving an electric car with a transmission with constant gear ratio - starting and accelerating to speed  $V_f$ . If a gearbox with manual gearshift is used to drive the wheels, the interruption of the power flow can be compensated by the higher torque and the higher acceleration at the low gears.

In fact, it is difficult to find an analytical solution to equation (1), so [6] proposes a number of assumptions and simplifications.

The resistive forces acting on the electric car in acceleration mode on a straight, horizontal road are rolling resistance, air resistance and acceleration resistance.



**Figure 1.** The electric motor torque  $M$  and power  $P$  in function of car speed  $V$

Assuming that the power for overcome the rolling  $P_f$  and air resistances  $P_a$  are not dependent on the curve of the motor torque but only on the speed of motion, then  $P_f$  and  $P_a$  can be presented separately and after integration [6] are expressed by the equations:

– the power to overcome rolling resistance

$$P_f = \frac{2}{3} G f_f V_f ; \quad (2)$$

– the power to overcome air resistance

$$P_e = \frac{1}{5} k_e S V_f^2 . \quad (3)$$

The coefficients 2/3 and 1/5 are a result of the integration and used simplifications [6]. After  $P_f$  and  $P_e$  are presented separately, in equation (1) remains the acceleration time of the electric vehicle, expressed by relation of the speed and the mass to the power.

After integration, the acceleration time  $t_a$  of the electric car can be represented as

$$t_a = \frac{\delta_a G}{2 g P_a} (V_f^2 + V_b^2) \quad (4)$$

After remaking of (4), the average power needed during the acceleration time of the electric vehicle is equal to

$$P_a = \frac{\delta_a G}{2 g t_a} (V_f^2 + V_b^2) \quad (5)$$

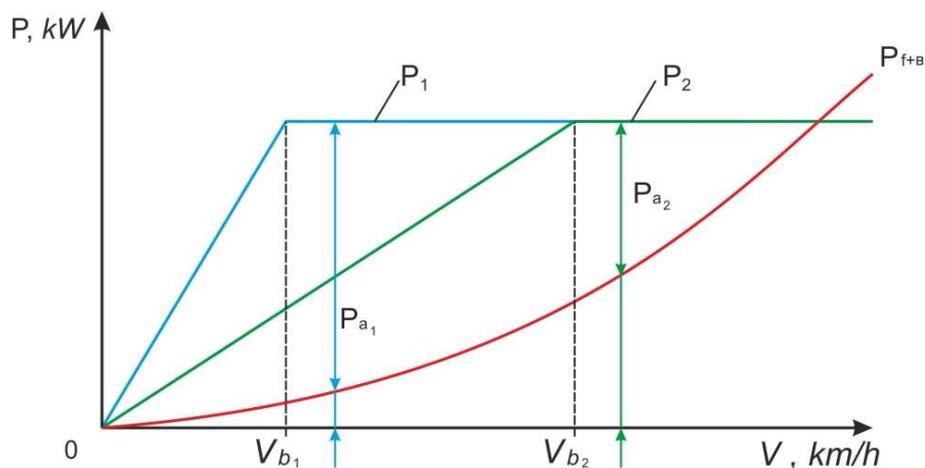
Equation (5) expresses approximately the needed power  $P_a$  according to the intensity of the electric car acceleration, due to the different character in the two speed sections of the electric motor characteristic.

After replacing with (2), (3) and (5) in equation (1) it becomes as follows

$$P = \frac{\delta_a G}{2 t_a g} (V_f^2 + V_b^2) + \frac{2}{3} G f_f V_f + \frac{1}{5} k_e S V_f^2 . \quad (6)$$

Relation (6) allows, though not very accurately, to determine the power needed of the electric motor based on a given acceleration time.

Figure 2 shows a theoretical comparison of the characteristics of electric motors of equal power which  $V_b$  is reached at different speeds. It can be seen that with increasing speed, the share distribution of resistance power is changed - the power needed to overcome rolling and air resistance increases and the acceleration power is reduced. It is also clear that the electric motor with lower base speed  $V_{b1}$  has a higher power reserve for acceleration from 0 to the moment when the speed is equal to  $V_{b2}$ .



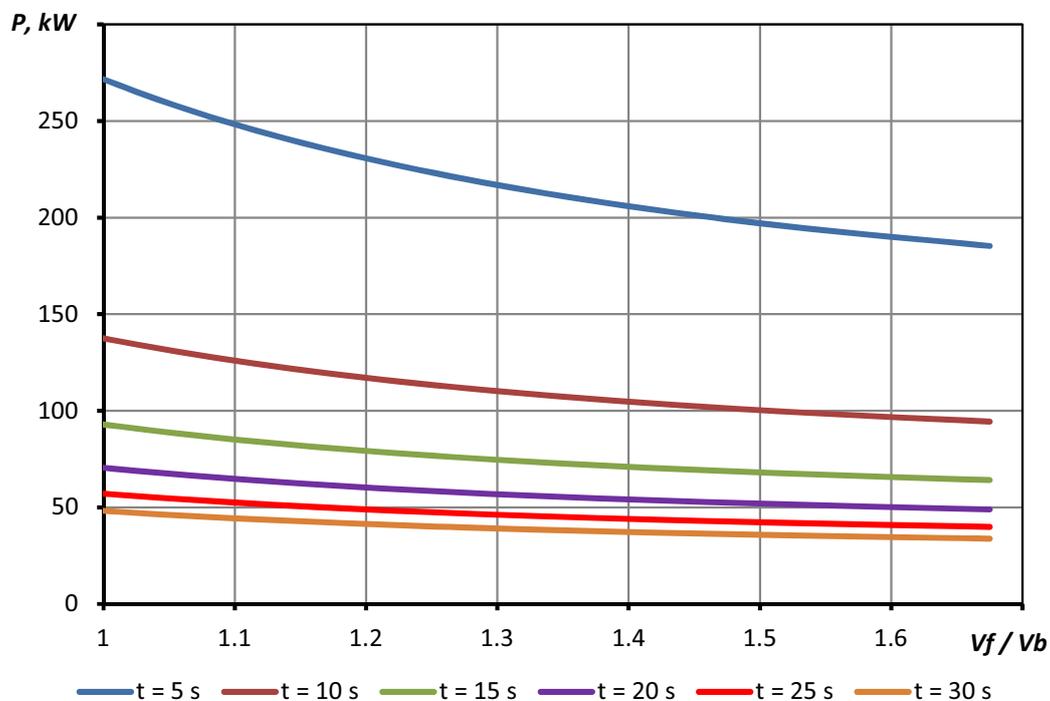
**Figure 2.** Comparison of the distribution of car resistance power for two electric motors with different base speeds:  $V_{b1}$  and  $V_{b2}$  – the base speeds of two motors;  $P_1$  and  $P_2$  – maximal power of motors;  $P_{f+B}$  – full resistance power of the car;  $P_{a1}$  and  $P_{a2}$  power for acceleration

Using the described approach to determine the needed power of an electric motor based on the acceleration time, the calculations were done for an electric car with the following parameters:  $G = 15,89 \text{ kN}$ ;  $f_0 = 0,012$ ;  $k_a = 0,0002 \text{ kNs}^2/\text{m}^4$ ;  $S = 2,35 \text{ m}^2$ . The power needed for acceleration from 0 to  $V_f = 100 \text{ km/h}$  at different values of  $t_a$  is calculated. Several variants of different times ( $t_a = 5 - 30 \text{ s}$ ) and different base angular speed of electric motor ( $\omega_b = 200 \dots 335 \text{ rad/s}$ ) are considered. The results of the calculations are presented in table 1 and figure 3.

From the calculated results, it can be seen that as the acceleration time of the electric car increases, the needed power of the electric motor decreases. The same results are represented on figure 3 in function of speed factor  $V_f/V_b$ .

**Table 1.** Needed power of the electric motor at different values of acceleration time  $t_a$  of electric car to  $100 \text{ km/h}$  and different values of base speed of motor  $\omega_b$

$P\omega_b$	$t_a = 5\text{s}$	$t_a = 10\text{s}$	$t_a = 15\text{s}$	$t_a = 20\text{s}$	$t_a = 25\text{s}$	$t_a = 30\text{s}$
$P_{200}$	185,3 kW	94,4 kW	64,1 kW	48,9 kW	39,9 kW	33,8 kW
$P_{220}$	195,3 kW	99,4 kW	67,5 kW	51,5 kW	41,9 kW	35,5 kW
$P_{240}$	206,3 kW	104,9 kW	71,1 kW	54,2 kW	44,1 kW	37,3 kW
$P_{260}$	218,3 kW	110,9 kW	75,1 kW	57,2 kW	46,5 kW	39,3 kW
$P_{280}$	231,2 kW	117,3 kW	79,4 kW	60,4 kW	49,0 kW	41,5 kW
$P_{300}$	245,0 kW	124,3 kW	84,0 kW	63,9 kW	51,8 kW	43,8 kW
$P_{320}$	259,8 kW	131,7 kW	89,0 kW	67,6 kW	54,8 kW	46,2 kW
$P_{335}$	271,6 kW	137,5 kW	92,9 kW	70,5 kW	57,1 kW	48,2 kW



**Figure 3.** Needed power  $P$  of the electric motor vs the speed factor  $V_f/V_b$

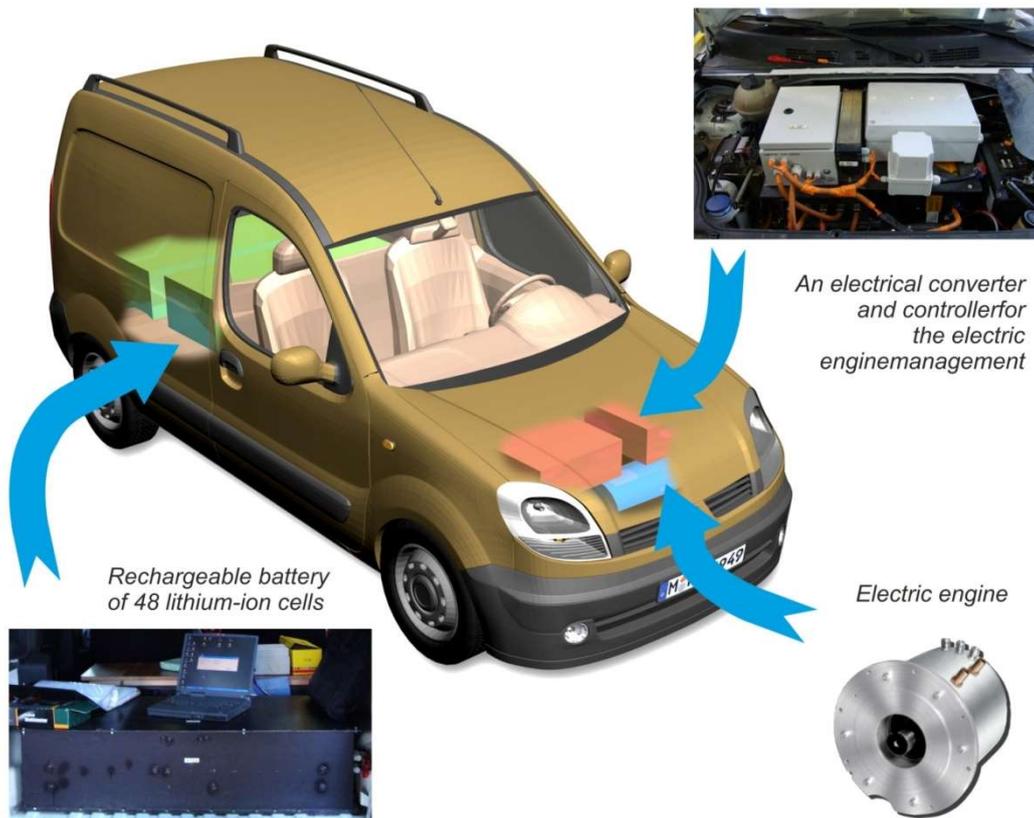
Decreasing of the needed power is also observed when  $V_b$  is reached at a lower angular speed. Therefore, the relationship between the two  $V_f/V_b$  speeds, or the so called speed factor, has a significant impact on the power needed by the electric motor.

At the same maximum speed, electric motors with a higher speed factor have better acceleration performance. The high  $V_f/V_b$  allows the use of a larger range of the characteristic with the maximum power of the motor (see figure 2).

Using this upgraded approach to determine the needed power for a given acceleration time, provides the possibility for a more reasoned determination of the necessary parameters of the motor - power, maximum and basic angular speed.

### 3. Experimental verification

Several experiments were done for verification the theoretical calculations made following the above described methodology. A converted car Citroen Berlingo to electric was used. It has the same parameters as used in calculations. Figure 4 shows the structure of the converted electric vehicle and figure 5 - the electric car in the test area.



**Figure 4.** Structure of the converted electric vehicle on the base of Citroen Berlingo

The electric parameters during tests were registered by a multi-channel measuring and recording system, and then analyzed by a computer programme. The frequency of measurements was 0,1s for electric quantities. The accuracy for the voltage and the current is 0,1%

For the speed and time measurement a "fifth" wheel system of Peiseler was used. The accuracy for the distance is 0,2%. A transducer with 500 impulses for a rotation is built in the "fifth" wheel.



**Figure 5.** The converted vehicle, equipped with "fifth" wheel during the tests

In the tests, the highest registered peak power of the electric motor was in the range of 47 - 51 kW.

Using the described method of theoretical determination of the needed power on the base of acceleration time, the result was  $P = 44,3kW$  at the experimentally obtained acceleration time of 29s. The theoretical result is 6 - 13% less than the highest registered power in the tests. Taking into account the complex of road test and simplifications in theoretical methodology, the accuracy is satisfied.

#### 4. Conclusions

1. The upgraded approach to determine the needed power of the electric motor based on the acceleration time of the electric car allows a more reasoned selection of the electric motor and the necessary parameters such as maximum power, maximum and basic angular speed.

2. The increase in the speed factor reduces the necessary power, at equal acceleration times of the electric vehicle. The effect of the base speed, as an electric motor's characteristic, on the acceleration properties of the electric car was investigated. Higher speed factor allows the use of a larger range of the motor characteristic with maximum power. At the same maximum speed, electric motors with lower base speed have better accelerating properties, because a larger relative share of the power is used for acceleration of the electric car.

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