RANGE AND ACCELERATION ANALYZE OF AN ELECTRIC DRIVEN CITY CAR WITH ADVANCED ENERGY STORAGE

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Abstract

For short distance (neighborhood) city transport of people, electric driven vehicle with advanced energy storage and electronic control system could assure fulfill essential requirements. Range, acceleration ability and grade ability of electric driven small size city vehicle depend on: total vehicle mass, energy storage type and size, vehicle exploitation conditions (motorway, city traffic). Energy storage type and size optimization and full utilization of regenerative braking system leads to significant amount energy saving. Regenerative braking is particularly important in city traffic, where a lot of acceleration/braking cycles occur. Advanced secondary energy source consist of electrochemical battery and stack of supercapacitors. Using supercapacitors as an additional energy source makes it possible to improve battery life cycle and simultaneously to decrease the exploitation costs of electric vehicle. Short charging and discharging times of supercapacitors give ability to quick accept large amount of energy. In order to cooperate with batteries, a power electronic converter is necessary. Knowledge of vehicle energetic parameters could be obtained by model based simulation than verified by research testing. To estimating the energy consumption, energy recovery, range, acceleration and grade ability, simulation in MATLAB environment has been performed applying special low speed vehicle drive cycle based on ECE-15 driving cycle. The results of simulation are presented in this paper.

***Keywords**: electric vehicle, DC motor, supercapacitor, vehicle range, simulation*

1. Introduction

The history of vehicles driven by electric machines in cooperation with lead-acid battery is a long one. The first vehicle of such a type was constructed in 1881. Development of electric starter for internal combustion engines, widely accessibility of hydrocarbons fuel and unfortunately long period of battery recharging caused rapidly stopping of market interest. Currently occurs some renaissance of such vehicles, but only in specific areas – short distance neighborhood vehicles, delivery vehicles, golf carts. City or neighbourhood cars are these that cover daily up to 25 km. Electric vehicles (EV) equipped with high-efficiency electric motors (EM), controllers and power electronics devices provide environment friendly and highly efficient urban transport. EV use secondary energy sources only. EV do not emit harmful substances and additionally have the ability to regenerate energy during braking, thus reducing the negative impact of the developing economy on the natural environment and cultural and historical heritage. They are Zero Emission Vehicles (ZEV), moving with limited velocity (25 km/h) and equipped with necessary systems such as: braking devices, seat belts, lighting, etc. Electrochemical batteries, used as secondary energy sources, have relatively short life cycle. Moreover, frequent states of deep charge/discharge of a battery connected with specific city traffic (stop & go) cause premature use up. Wherever the tractive power is produced by electric machines - in cases of Fuel Cells (FC) vehicles, Hybrid Electric Vehicles (HEVs) as well as EV - energy losses during braking can be reduced due to effective regeneration. Each vehicle in order to move must produce tractive power on its wheels to counteract against the aerodynamic drag force, rolling resistance forces and gravity forces during ascent. Moreover, during accelerating the vehicle must overcome inertia forces. Most of energy delivered to the system during accelerating is consequently lost irrecoverably during braking. Energy regeneration is possible because an electric machine can work in a reversible mode, i.e. as a propulsion electric motor or as a generator in regenerative mode during braking. It is estimated that in intensive urban traffic up to 15% of energy could be saved as a result of regenerative braking. The amount of saveable energy is limited because the braking process takes place in a short time with a large amount of energy emitted. Use of supercapacitors (SCAP) as an additional secondary energy source enables improvement of battery life cycle and simultaneously a decrease in electric (EV) or hybrid electric vehicles (HEV) exploitation costs.

2. Electric City Car

In our case, the small size electric city vehicle was proposed. Vehicle, based on golf cart, have necessary to city traffic equipment, such as: fluid-mechanical brakes, seat belts, lighting, etc. Basis parameters of vehicle are described below and Fig. 1 shows it's scheme.

Vehicle data:

- total mass (with 2 passengers) - 690 kg,
- tire radius – 0.23 m,
- DC motor rated speed – 3900 1/min,
- DC motor speed constant – 89 rad/s,
- DC motor rated torque – 8.2 Nm,
- DC motor armature resistance – 0.0089 ohm,
- Lead-Acid battery nominal voltage – 48 V,
- Lead-Acid battery capacity - 220 Ah,
- supercapacitors stack – 3 modules BPAK052 – capacity 19.44 F.

Supercapacitors stack is connected with battery via DC/DC buck-boost energy converter. Average power of supercapacitors stack is 1.38 kW, which means capabilities of 13.8 kJ energy recovery during 10 s. Such kind of supercapacitors is produced for vehicle energetic systems, and is characterized by 10 years life cycle, very low internal resistance and the high number of charge/discharge cycles – 500 000. Total mass of selected devices is 4.37 kg.

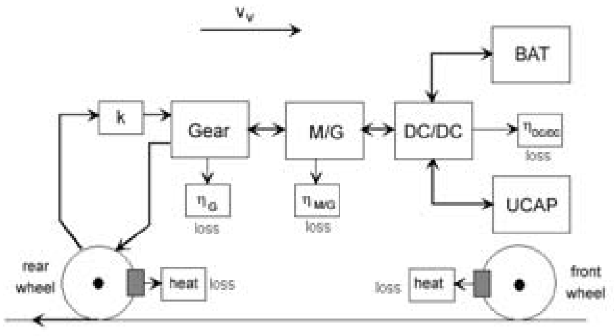

Fig. 1. Rear axle driven electric vehicle scheme

3. Simulation EV parameters

Use of golf cart based EV requires application of special driving cycle with limited speed and particular schedule of stopping the vehicle. For this reason, a new driving cycle was prepared. Driving cycle consists a part of typical European Driving Cycle – ECE15. Duration of cycle is 120s and for time extension this duration should be multiplicated. Maximum vehicle speed in this cycle achieves 32.5 km/h and average vehicle speed is about 11 km/h. Driving cycle typically is performed on a chassis dynamometer; in our case it was simulated.

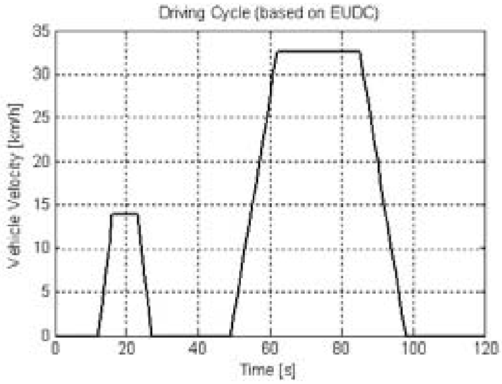

Fig. 2. Modified ECE15 driving cycle for low speed electric vehicles

Vehicle acceleration, maximum velocity and range are the main parameters which are simulated. For this procedure following formulas are prepared.

Tractive effort:

$$F_T = F_r + F_A + F_p + F_{\varpi a} , \tag{1}$$

$$F_T = \mu_{rr} + \frac{1}{2} \rho A C_d v^2 + ma + I \frac{G^2}{\eta_G r^2} a , \tag{2}$$

where:

F_T - tractive effort,
Fr - force due to rolling resistance,
F_A - aerodynamic force,
F_p - acceleration force,
$F_{\omega a}$ - rotational acceleration force,
μ_{rr} - rolling resistance coefficient,
m - total mass of vehicle,
g - gravity,
ρ - air density,
A - vehicle frontal area,
C_d - air drag coefficient,
v - vehicle velocity,
a - linear acceleration,
I - electric motor rotor inertia,
G - gear ratio,
η_G - gear efficiency,
r - tire radius.

Basic DC motor formulas:

$$T = \frac{C_m \Phi U_z}{R_T} - \frac{(C_m \Phi)^2}{R_T} \omega , \tag{3}$$

$$T = C_m \Phi I , \tag{4}$$

where:

T - motor torque,
C_m - motor constant,
Φ - motor flux,
U_z - supply voltage,
R_T - armature coil resistance,
ω - rotor angular velocity,
I - armature current.

For EV range simulation, the computing amount of energy required to moving vehicle during every second of the driving cycle is necessary. Driving cycle is than repeated as far as assumed level of battery discharging (Depth of Discharge - DoD) is attained. The energy flow path between particular vehicle components is characterized by specific efficiency factors. Motor/controller efficiency factor takes into account four different components: copper losses connected with current flow by armature windings an brushes, iron losses for permanently changing magnetization of motor iron cores, friction and ventilation losses and constant losses in field winding and electronic control equipment independent of velocity. Thus electric motor efficiency takes into account all of these losses.

$$\eta_m = k_c T^2 + k_i \omega + k_w \omega^3 + K \,, \tag{5}$$

where:
η_m - motor efficiency,
k_c - copper losses coefficient,
T - motor torque,
k_i - iron losses coefficient,
ω - rotor angular velocity,
k_w - ventilation and friction coefficient,
K - constant losses due to field and electronic.

For the separately excited DC motor applied in simulated vehicle efficiency map was prepared (Fig. 3).

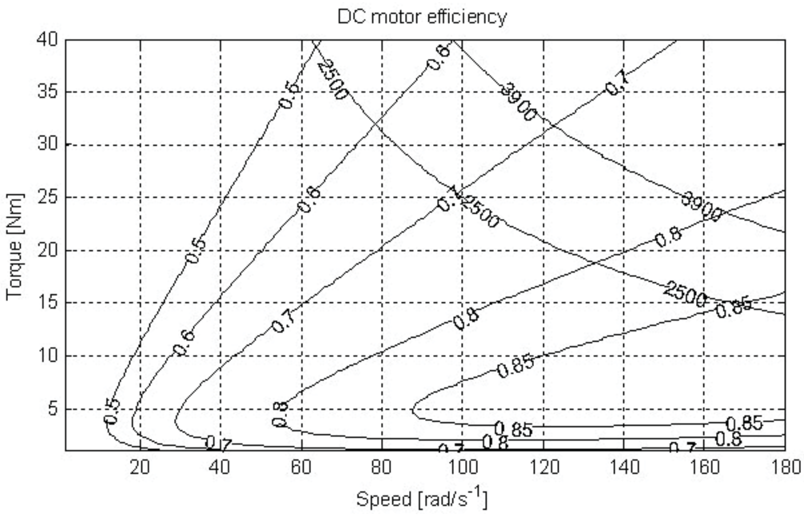

Fig. 3. Separately excited DC motor (3.9 kW) efficiency map

Typical modeling procedure for electric vehicle range consists of:
- computing of vehicle acceleration taking into account vehicle velocity on the present moment and velocity in previous computing step (previous second),
- computing of vehicle tractive effort and tractive power,
- computing of DC motor power consider motor and gear efficiency,
- computing of motor angular velocity and torque on the shaft,
- supplementary power consumed by vehicle have to be taken into account,
- computing of current raised from the battery, supporting on the Peukert model of battery,
- computing of battery discharge level (DoD).

This procedure is repeated until assumed level of DoD is attained. Simulated vehicle range until DoD achieve 0.9 (90% discharging battery) is illustrated in Fig. 4. This range is 37.881 km and 104 driving cycles simulation duration that is 3 hours and 28 minutes.

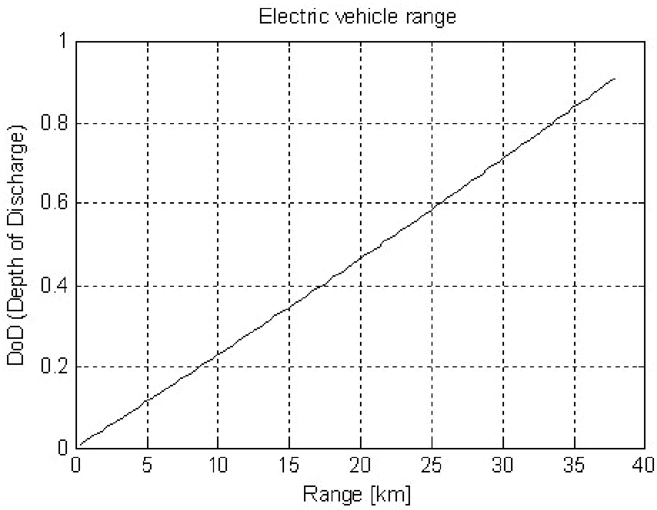

Fig. 4. Electric vehicle range plot until DoD achieve value 0.9

Positive (during vehicle propulsion) and negative (during regenerative braking) power of DC motor is presented in Fig. 5. Relatively inconsiderable amount of recuperated energy results from small vehicle mass and velocity – both have main impact on vehicle kinetic energy, which could be acquired during braking.

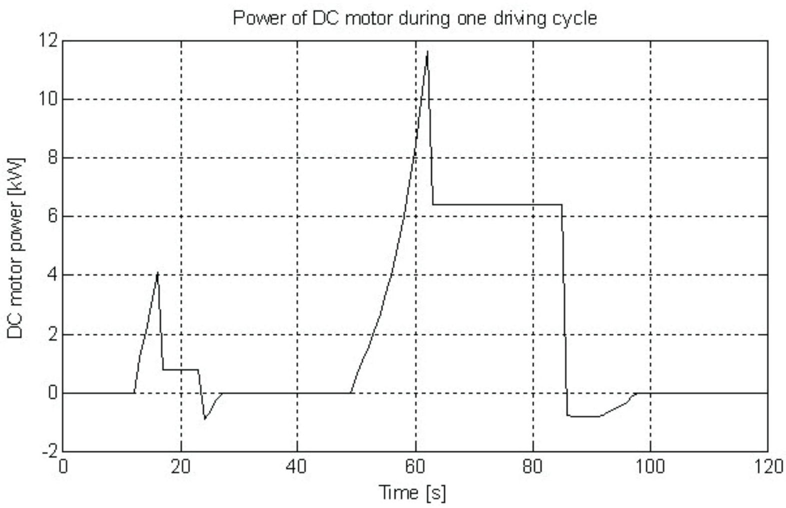

Fig. 5. DC motor power during one driving cycle

Typical modeling procedure for electric vehicle acceleration and maximum velocity consists of:

- calculate motor torque, taking into account current supply voltage,
- computing value of motor base angular speed, below this value motor operate with constant torque and over this value motor operate with constant power,
- computing maximum save torque based on maximum armature current,
- converting tractive effort formula, calculate vehicle speed in every second for both modes: constant torque and constant power,
- repeat above calculation until vehicle velocity stops growing.

As a result of simulation, the vehicle velocity during 20 s period is presented in Fig. 6. It is noticeable that constant torque mode is switched to constant power mode after 6.5 s simulation duration.

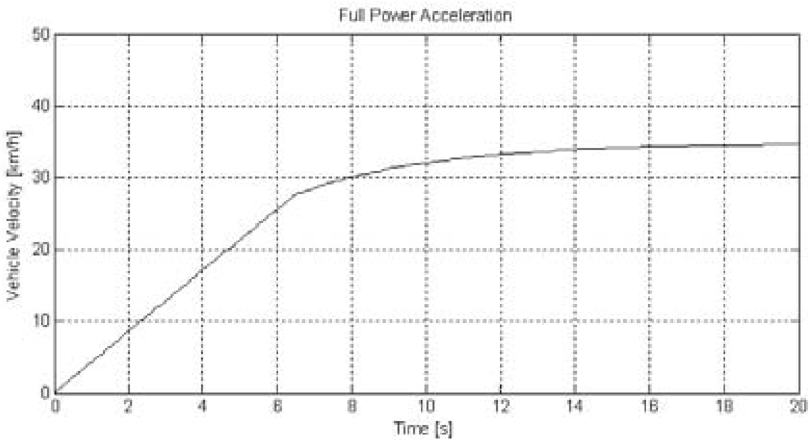

Fig. 6. Vehicle acceleration and maximum velocity plot

Consequently, distance travelled by vehicle during 20 s simulation is illustrated in Fig. 7.

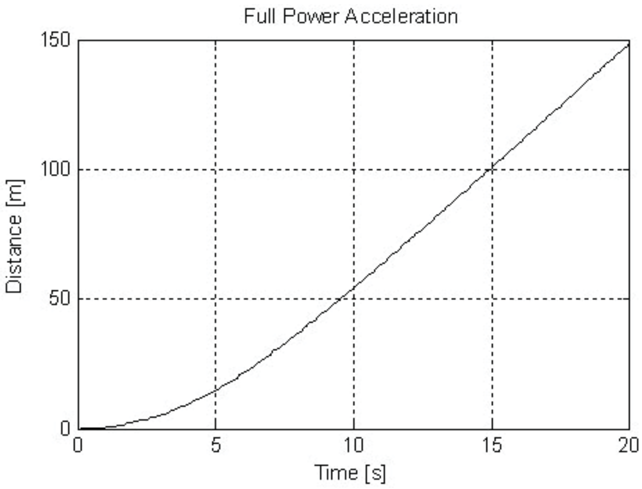

Fig. 7. Electric vehicle distance achieved during acceleration

Through modelling and simulation methodology, performance and many others parameters of vehicle can be predicted. Computer simulation in research and development phase helps to choice a proper solution. In consequence simulation methods lead to save costs in compare with status when the solution is achieved on experimental way.

4. Conclusions

Small size, golf cart based electric vehicles, equipped in necessary safety devices can drive up to 35 km/h. Such velocity in connection with comparatively small mass of vehicle causes small amount of energy to be recuperate. It is estimated that in city traffic amount of recuperated energy could be 5 to 15 % total energy consumed by vehicle. Computer simulations in R&D phase save time and costs for new vehicle construction developing.

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