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E-REV's HYBRID VEHICLE RANGE MODELING

Filip Polak

Military University of Technology
Faculty of Mechanical Engineering, Institute of Motor Vehicles and Transportation
tel. +48 261 837859, fax: +48 261 839276
Gen. Witold Urbanowicz Street 2, 00-908 Warsaw
e-mail: filip.polak@wat.edu.pl

Abstract

Article presents the influence of battery capacity and electric generator power on a series hybrid vehicle range. Vehicles equipped with increased battery capacity and small power generator are special type of series hybrid vehicles called Extended Range Electric Vehicles – E-REV. The increasing number of hybrid and electric vehicles increases the demand for durable and efficient sources of energy storage for vehicles.

The hybrid vehicle's battery driven range is increased as battery power density is increased and its cost is decreased. This is due to the battery cell cost decreasing and improvement of cell chemistry. That cause higher and higher distance driven on electric mode in hybrid vehicles. First series hybrid vehicle engine power was equal to engine powered the vehicle's wheels. Nowadays, series hybrid vehicles are more electric vehicles with small power generator (piston or turbine engine. In such a constructions, battery is used as an energy buffer and combustion engine is used more as emergency power supply.

To minimize this phenomenon, manufacturers use counteracting solutions that include mounting additional cells in the battery that are switched on when the battery controller identifies a particular battery cell's failure or high degradation. This is due to the deep and shallow discharges of the battery, the numbers of charging and discharging cycles, and the age and technology of battery packs.

AMESim software was used for the simulation of the E-REV hybrid vehicle range. The research was based on modelling the range of the vehicle with different battery capacity works with power generator of different power. By modelling different capacity of battery and power of small generator, it is possible to determine the vehicle range.

Keywords: *battery, simulation model, electric vehicle, E-REV*

1. Introduction

With the tightening of regulations and emission standards, manufacturers are constantly striving to fulfil increasingly stringent emission limits among vehicle manufacturers, including companies producing engines that power mechanical vehicles. In order not to exceed the set limits, manufacturers use different solutions, based on extensive exhaust gas treatment systems. One solution to meet emissions standards is the use of hybrid and electric drive systems.

The advantages of having electric and hybrid systems over exhaust-based systems are, among other advantages, the ability to recover energy while braking a vehicle, allowing for a slightly increased vehicle range, lower CO_2 emissions by turning off an internal combustion engine under conditions where it would not operate efficiently. Optimized internal combustion engines are characterized by lower toxic emissions of exhaust gases [2].

Historically, motorization started from electric propulsion system, combustion engines were used to increase vehicles acceleration and range. Since the combustion engines were developed, they displaced electric propulsion systems. From the end of XX century, when the oil crisis occur and law regulations prefers engines that emit low CO_2, hybrid and electric vehicles are again considered. Thanks to the battery development, the use of electric powered engines is increasing. Noticeable decrease in the cost of production of cells, prolongation of life or even increased safety of use (Fig. 2) [1] has positive influence on electric cars development.

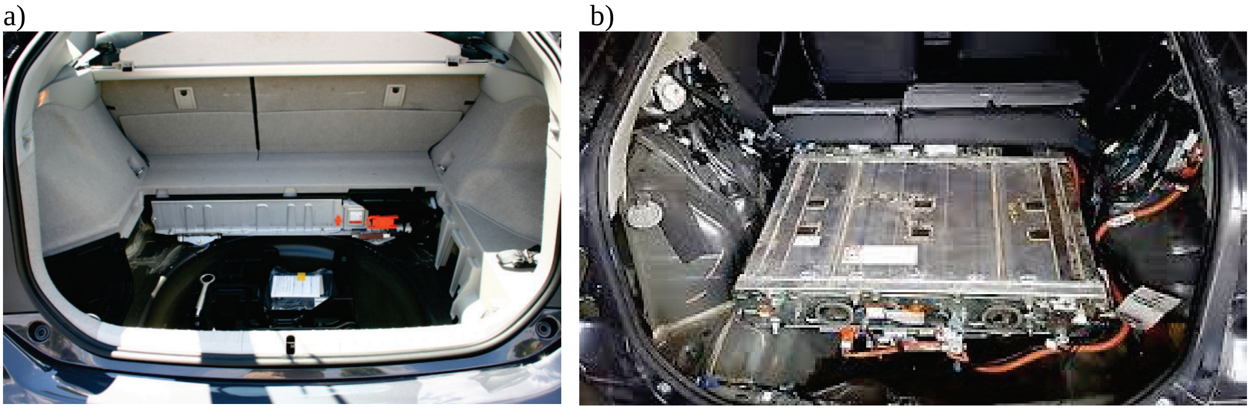

Fig. 1. A view of battery pack: a) Toyota Prius from 2004, b) Toyota Prius Plug-in from 2014 (source: a – author's archive, b – www.egmcartech.com)

Firs hybrid vehicles had similar combustion and electric engines power. Presently, modern hybrids are design as electric vehicles or series hybrid vehicles with small combustion engine that works as a power generator when battery is depleted.

The simplest solution for increasing range of electric vehicle is to increase the capacity of battery. Because of still low energy density of the batteries, their cost and other properties such as charging time, the battery electric vehicles are still minor part of automotive industry. As the researches of Neubauer [6] and Sandy [5] shows, that every 100 kg of battery need additional 60 kg of vehicle's equipment such as stronger brakes, suspension, battery frame or stronger electric engine to sustain speed and acceleration parameters of a vehicle.

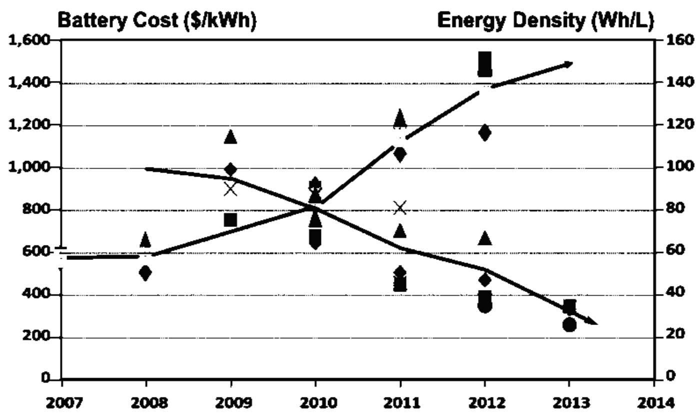

Fig. 2. Increase of battery capacity (upper line) and decrease of battery cells costs (lower line) (source: www.greencarreports.com)

2. Drivetrain's mathematic model

The aim of the study was to compare drivetrains parameters of a vehicle in three cases of the power transmission.

The vehicle's drivetrain model was developed in the AMESim environment of SIEMENS Company. This is a complete computational system for the simulation of multi-mechatronic systems. Fig. 3 shows the main components of model set. Used elements such as vehicle (3) with electric power transmission system, driver model (2) realize selected road test (5). Power transmission system consisted of controller (1); electric engine (4) with engine controller and battery (6).The last element (7) is power generator that is connected with battery. In presented model, there is possibility to take into account parameters such as wind speed and slope angle during test realization.

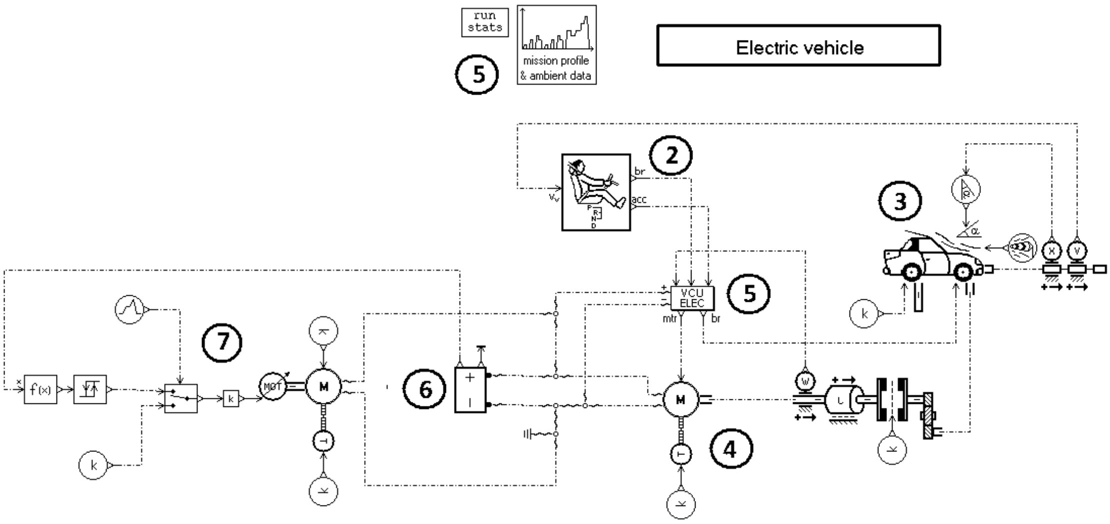

Fig. 3. Model of a vehicle's drivetrain presented in AMESim

During simulations, model of electric vehicle, introduced on a Fig. 3 was used. The chosen vehicle parameters were as follow:

– vehicle's mass: 1695 kg,
– electric engine power: 60 kW,
– battery single cell capacity: 2.3 Ah,
– nominal battery voltage: 330 V.

A key element of the mathematical model was the connection of different battery capacity and different generator power. For this purpose, the three different $LiFePO_4$ battery architecture and power generators were compiled.

3. Simulation test

Simulation test consisted of passing a NEDC road test by a vehicle with different types of battery size and combustion engine with current/power generator. NEDC test was selected for the study, due to Regulation ECE R83.03, EU directive 98/68 EC. It is standard test procedure for testing vehicles up to 3500 kg.

Average vehicle speed during the test was about 16 km/h. The vehicle was required to perform the test repeatedly from 100% state of charge, until the battery was discharged up to 30% SOC. After that power generator was turned on, charging process was started to reach 99% of SOC, and test was continued. Power generator was set to run for total time of 5 hours. This time was limited by the fuel tank capacity of the power generator. Test end when battery reaches 10% SOC and power generator working time was exceeded.

Vehicles battery consisted of single 2.3 Ah cell with different connection architecture. Cells were connected in series and parallel. Single branch of cells consisted of 100 cells connected in series. Parallel connection of branches increased capacity of the battery.

Three variants were tested:

1) 100Sx20P battery architecture, without power generator,
2) 100Sx14P and power generator of 6 kVA,
3) 100Sx10P and power generator of 20 kVA.

Every battery has nominal 330 V (100 x 3.33 V) and each branch weight was 14 kg. Batteries architecture was selected in respect of mass of the battery. BEV vehicle has 100Sx20P what gave 280 kg of battery mass (46 Ah @ 330 V). Other battery branches were combined with power generators to not exceed 280 kg. In second variant small 6-kVA power generator of 100 kg was combined with 13 branches of total mass 182 kg (30 Ah @ 330 V). In third variant, power generator of 20-kVA weight was about 150 kg and was set with 10 branches of battery (23 Ah @ 330 V).

The obtained results of the comparison of selected parameters of the propulsion system and vehicle performance are presented in Fig. 4 and 5.

The difference ratio of the number of cycles of the road test (Fig. 4a), between different power transmission battery and power generator sets is shown as a numbers of passed NEDC road test. Numbers of cycles are as follow: 9 for battery only drive, 28 for 6 kVA E-REV and 69 cycles for 20-kVA E-REV system.

Figure 4b present the range of vehicles. For a vehicle without Range Extender, range was limited to 110 km. Vehicle with 6 kVA generator enable to drive on a distance of 310 km and 20 kVA Range Extender vehicle has 750 km of range. This is mainly caused by high energy density, and even small efficiency of power generator gave higher volumetric energy density than cells of the battery. Because battery in such structure works as energy buffer. Power of the vehicle depends on the power of engine powering the wheels.

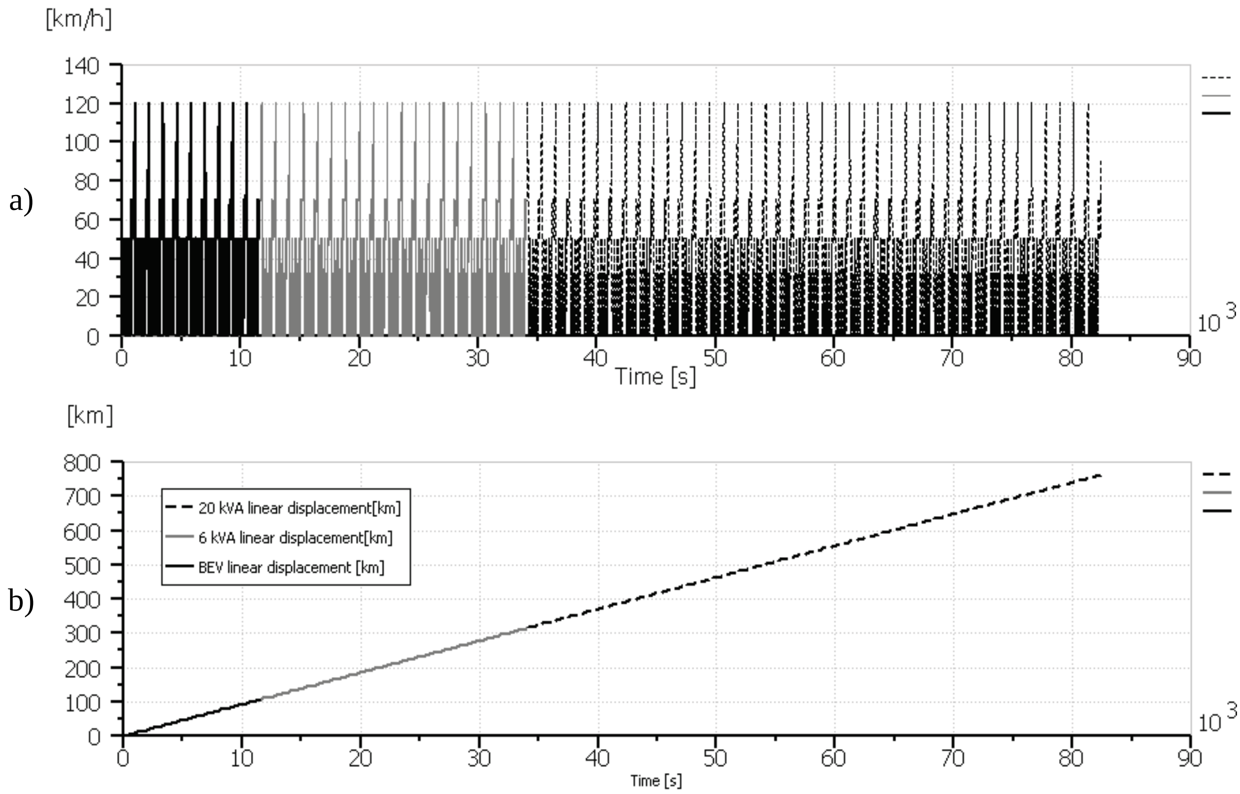

Fig. 4. Vehicle's range investigation: a) NEDC test profile and number of overcomes road tests, b) range of the vehicle (tine vs. range characteristic) during examination, black line –BEV, grey line – 6 kVA E-REV, black dotted – 20 kVA E-REV

Figure 5a shows the charging status of the battery. In the presented model, battery is continuously discharged from 100% SOC to 10% SOC during 3.2 hour of test, executing nine NEDC cycles. In 6-kVA E-REV system, because of smaller number of battery branches installed in vehicle, discharging process took faster – after 2-hour battery SOC was 30%, but E-REV system started charging process and vehicle continued the test. Charging process lasts 4.4 hour. During that time, linear displacement of the vehicle was about 150 km. For 20-kVA, charging time was about 20 min. The vehicle displacement was 750 km. Simulation results corresponding with experiments described in [3] and [4].

Charging time might be shorter, but vehicle should stop the test and wait until battery charge process will end. As long as the power generated by E-REV system is higher than power needed to sustain the test speed and acceleration. Those stages are visible as a saw shape of the 6-kVA test variant (Fig. 5a). Vehicle during acceleration consume more power than can be actually produced ant then SOC is decreasing despite power generator is charging the battery. When power demands are lower than energy produced by power generator, charging process continue.

For 6-kVA generator 13-14 cycles of NEDC test must be repeated to charge the battery. 20-kVA generator energy surplus enable to charge the battery in time of one NEDC cycle – about 20 min. Because battery capacity is smallest over three variants, discharging process need 4 NEDC cycles (about 80 min.). After that, charging process starts again. For 6-kVA generator only one full charging cycle was possible, for 20 kVA – 13 charging steps (Fig. 5b). It is possible to increase fuel tank and increase time of power generator work. This can easily increase the range of the vehicle.

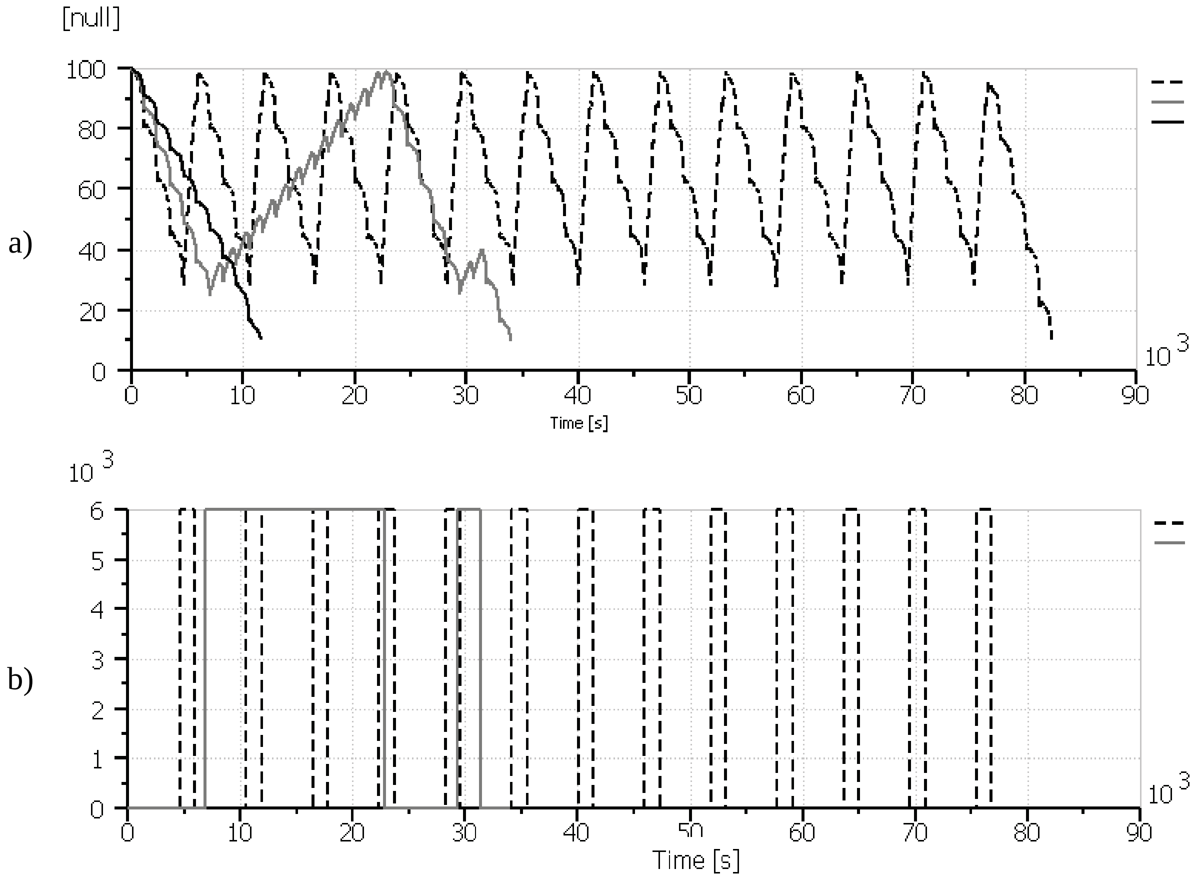

Fig. 5. Charging processes: a) SOC% of battery, b) charging cycles and their duration, black line –BEV, grey line – 6 kVA E-REV, black dotted – 20 kVA E-REV

In above calculations, power generator was turned on when battery capacity reach programmed level. It is possible to set different limits, even constant work of the power generator – that could decrease the power of the generator for charging. Power generators were selected from one producer's design series. Different types of power generators with different power can cover all range of the vehicles' types. In addition, they can be installed in vehicles as presently different types of combustion engines are installed in one model of the car.

4. Conclusions

1. Because of still insufficient batteries chemistry, presently it is not recommended to use only electrochemical source of energy in cars.
2. Adding small combustion power generator can significantly increase the range of the vehicle, because energy density of the fuel, gasoline or Diesel, is much higher even if weight and volume

of power generator is consider in the calculations.

3. The dependence of the battery capacity and the power generator of the vehicle are limited to the manufacturers design series of such equipment.
4. To increase more the range of the vehicle it is possible to increase the fuel tank capacity. Small power generator that works in continuous mode can ensure approximate range in compare to higher power system working occasionally.

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