FULLY ELECTRIC VEHICLES IN PRACTICE

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There are already many forms of EVs (electric vehicle) from cheap to premium; from E-bikes to trucks; from demonstrational projects to practically usable cars. We have all heard about their pros, and cons when compared with ICE (internal combustion engine) cars. We are not going to list all these arguments, instead we highlight one of the most important thing: EVs need a different approach. It is possible to reach the same comfort level with an EV but this requires changes in our transportation habits: most importantly, one has to plug the car in right after use, not only when it’s depleted. In this decade there will come a turning point, when the benefits will even out the disadvantages in general, and from then on, the ratio of conventional versus electric car usage will start to change. In many respects EVs tend to outperform ICE cars even today.

Keywords: zero emission, electric cars, battery electric vehicle, emission free transportation

Introduction

The market share of EVs is undoubtedly expanding, but we are still far from the number that would bring changes. Such changes could be the price drop of EVs owing to mass production or the positive environmental impact due to emission reduction. The intermittent nature of renewable energy sources sets new challenges, calling for highly efficient management systems of those sources. In addressing this problem, the beneficial utilization of additional storage resources come into view; thus the massive use of electric vehicles - particularly of vehicle-to-grid (usually referred as gridable vehicles or V2G) – can become a very relevant issue. In case of widespread EV usage, the total intake capacity of EV battery packs could facilitate electrical power system management [1]. Norway, with about 10,000 electric cars registered through December 2012, is the country with the largest EV ownership per capita in the world. Still today no more than 0,3% [2] of the cars has electric drive.

The main barrier in the EV market is undoubtedly the high price of Li-ion batteries. The trends are clearly visible: the prices are dropping from year to year. Some reports say [3], that by 2020 Li-ion battery prices will drop to the one-quarter of today’s price.

People are usually concerned about the high prices of EVs and batteries. But do they calculate the consumption and maintenance costs of their ICE cars? Small-scale repeated disbursements like refueling or motor oil change, are less noticeable and means less of a burden for households/companies than a single but high payment. It is not an easy task to calculate the costs of a vehicle because of the differences in usage, vehicle category, the

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mechanical conditions of the cars, etc. Therefore, a valid comparison between ICEs and EVs is a tough challenge.

In our article we summarize our experiences about EVs in practice, based on the research we have conducted for the automotive industry. Our perspective on EVs also comes from two vehicle conversion projects that we carried out. One of the car was a classical VW beetle with an 7,5 kW AC motor, the other is a Lada 2101, with an 11 kW DC motor.

1. Lada 2101 EV

Our first project started in 2012, with a sudden decision initiated by the Head of Institute Dr. Árpád Bence Palotás. At the Department of Combustion Technology and Thermal Management, an associate professor offered a “donor car” for conversion. The car was a classical Lada 2101 model from 1977. These models don’t have servo braking, which makes them slightly uncomfortable to drive, but makes our work much easier. In the absence of comfort electronics (e.g. servo brakes, power steering, AC) the range of the EV could be higher. For a start, we removed all the unnecessary parts: the original engine, the cooling system, the exhaust system, the gasoline pipes, the fuel tank, the generator and the starter motor. In the following step we constructed the battery cases.

The first test model was equipped with conventional lead-acid batteries. One of our battery packs consisted of 45 Ah capacity batteries by which the car could go only about 20 km. The next solution was 140 Ah capacity lead-acid batteries with a 70 km range. This latter pack added almost 400 kg to the car’s mass. Since the electric motor needs 144 V, the twelve batteries were connected in series. As soon as we had the chance, we changed the rusty chassis to a better one (to a “new” one from 1986), and also the batteries. The new LiFeYPO4 cells were operating at 3.3 V, so the pack consisted of 48 pcs in order to supply the motor. After the last modification, the battery pack was housed in the place of the rear seats. As a result, the modified vehicle is able to transport only two persons at a time (the driver, and one passenger). By this solution, the trunk still remained usable for luggage, and the load of the axels didn’t change much. The range (about 60 km) is lower than expected, probably because of the inefficient electric motor and other powertrain losses. The car is equipped with LiFeYPO4 batteries suitable for EVs. These batteries are robust, and do not tend to overheat, therefore they are an optimal choice for EV use. There are Li-ion based batteries which have higher energy density yet may suffer thermal runaway and cell rupture if overcharged, overheated or injured [4]. In extreme cases, these scenarios might even lead to combustion.

The electric motor required a specific support, which needed unique design and construction. After the first tests we had faced a shaft coupling problem, which we managed to sort out later on with the modification of the original axis joiner. The nominal power of the original petrol engine was 44 kW, at 5600 RPM (Lada SOHC 1200 cm³) and the maximal torque was 89 Nm at 3400 RPM [5]. In the lower RPM range the ICE has much less power. The built in electric motor has only 11 kW of nominal power, but even at zero RPM it can produce almost three times its nominal power for a short period of time. So, it is considered a dynamic car for city use. The top speed is also defined by the power and the maximal RPM of the motor, and since it’s only 3500 RPM and 11 kW; the maximal speed is about 90 km/h.
The efficiency of our electric motor is more than 80–85%, which is still considered low in terms of electric drives. The ICE has about 20–30% efficiency, and the remaining energy dissipates in the form of heat. In cold seasons the heat loss from ICE can be used for heating the inside of the car, but for EVs, another solution has to be found, since there are no overheating parts. Still there is no heating system in our converted cars, but basically any electric heater with slight modification could do.

We installed a 5-speed transmission system (OEM part) in the car, so the drivetrain beside the engine, remained intact. The gearbox can be used in the same way as in the original car. Along with that, there is another operational option: owing to the different characteristics of the electric motor one can drive the car as an automatic, only using the brake and gas pedals in the fourth ratio. At red lights, no one has to concern about stalling, because there is no minimal RPM, neither any need for clutching.

A voltage converter was also placed under the hood. The original 12 V system had remained intact (windshield-wipers, headlamps, brake lights etc.), so in the absence of a generator this modification was necessary. Another small 12 V battery was also added to power the BMS system.

The BMS (battery management system) is a small, printed circuit, usually on the top of each battery. These devices are used to monitor the voltage and the temperature of each battery in order to avoid overheating, overcharging or discharging under a certain limit. There are feedbacks from the electronics through meters, and through an USB port. Another important action of the BMS is to balance the battery pack at the end of the charging procedure. Since the batteries are connected in series, the same current flows through every one of them, but the voltage may differ at the pins of each cell. When one of the cells (usually the one in the best condition) reaches the preset voltage value, the BMS takes it out from the charging chain, and continues charging the others. By this method, all of the cells in the pack reach the same voltage, regardless of their condition. Cell balancing is one of the most important thing, to preserve the consistency of the batteries [6].

Above the motor there is the automatic charger specified for Li-ion batteries. It communicates with the above mentioned BMS system, and has variable power output. Strangely it has maximum of 5 kW input on single phase! In order to exploit the maximal performance of the charger, we changed the plug to an AC (three-phase) 3X32 A
connector. Still only one phase is being active, but now we are able to connect the unit to a high performance socket. There is also a converter cable which allows us to plug the charger in any conventional, single-phase 230 V socket if we reduce the performance below the capability of the specific network (usually to 2 kW).

2. VW Beetle 1300 EV

Our second car conversion project started in May, 2013. The base was an original VW 1300 from 1969. Considerable metalwork and a complete paint job was needed, since the model had rusty parts. VW Beetles are quite popular targets for conversion, therefore we have found a complete EV conversion kit for the car, and ordered it from the US. The kit consisted of a 7.5 kW AC motor, a motor controller (including the inverter), a converter for the 12 V system, a motor mounting system, cables, and several smaller gadgets.

In this case too, the original drivetrain remained intact; we placed the electric motor at the same spot where the ICE had been. Since the rotation direction of the new motor can be changed with a switch, the use of the gearbox is only optional, still we kept it. The car has the original 4-speed transmission, but in practice only the second and the fourth gear is used.

This vehicle is able to regenerate the kinetic energy into the batteries. In this case, the wheels rotate the main-shaft via the gearbox and the electric motor works as a generator. The force of the generator-mode can be adjusted, and also switched off.

Regeneration of the break horsepower in favor of range extension could be a great improvement, but it would entail a set of other serious modifications. It would need the alteration of the brake system, which we didn’t want to change, for authorization issues. Stopping the vehicle that weights more than one ton in a short period of time would release a huge amount of energy, which should be stored immediately. The batteries couldn’t handle such a sudden energy shock, so an ultra-capacitor [7] would be required for absorption.

Since the vehicle is run by a 72 V motor, we installed 24 batteries, and connected them in series. There are nine 300 Ah LiFeYPO4 cells in the front and 15 more behind the rear seats (Figure 2). One cell weights about 10.5 kg [6]; with this pack the weight of the vehicle increased to 1040 kg (measured data), which is not considered high among today’s cars.

Figure 2. 9 LiFeYPO4 batteries in the trunk (left); 15 cells behind the rear seats (left)
The Beetle has a 3 kW charger, and a conventional 230 V connector, so it can be basically plugged in anywhere, where there is electricity. If the power grid is obsolete or in poor condition, the input of the charger can be reduced to avoid the overloading of the fuse.

Neither the motor nor the charger requires active cooling, however after the first tests we have noticed the overheating of the motor controller. In case of controller overheating, the software regulates the power output so the motor receives less and less current with rising temperature. As a solution, we installed a custom active cooler, which turned out to be oversized - a bigger passive one would have been sufficient.

Summary

At the University of Miskolc our small team of two PhD students for EV conversions led by Prof. Palotas was formed. It started as a hobby project and was originally financed from the savings from other R&D projects at the Faculty of Materials Science and Engineering. Later on (over the years) the projects attracted direct and indirect subsidies, which helped the Department and the University. Our three member ad-hoc team designed all the steps necessary to convert the two old gasoline powered passenger cars to fully electric ones.

A summary of the technical data can be seen in the Table 1. These specifications are the most important characteristics of an EV. All other vehicle related data can be looked up in the vehicle’s original data sheet, since we did not modify the chassis, the 12 V system, the brakes, the suspension, and the drivetrain.

Table 1

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Lada 2101 EV</th>
<th>VW 1300 EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric motor</td>
<td>11 kW – DC – 144 V</td>
<td>7.5 kW – AC – 72 V</td>
</tr>
<tr>
<td>Battery type</td>
<td>90 Ah LiFeYPO4</td>
<td>300 Ah LiFeYPO4</td>
</tr>
<tr>
<td>Number of batteries</td>
<td>48 pcs</td>
<td>24 pcs</td>
</tr>
<tr>
<td>Total energy in battery pack</td>
<td>14 kWh</td>
<td>24 kWh</td>
</tr>
<tr>
<td>Battery pack weight</td>
<td>150 kg</td>
<td>250 kg</td>
</tr>
</tbody>
</table>
The range of the Lada 2101EV turned out to be less than we expected. This may be due to the low efficiency of the electric motor and drivetrain losses. Based on our practical experiences, both of the cars are perfectly usable for everyday transportation. The average range necessary per day (in Hungary) is about 36 km [7], which can be covered with ease using the vehicles. Once the cars are completed, the maintenance costs are minimal, and the cost per km is about the one-third of those of ICE cars. All equipment required for EV car conversion are available at the stores, and the procedure can be carried out without a professional repair shop.

The authorization of converted vehicles is very difficult. In compliance with the European standards, several tests and experts opinions are required for traffic verification, which could triple the price of conversion. We have managed to use and test the vehicles with a temporary number plate, which entails several limitations like a defined set of drivers and a fixed number of uses.

There are public concerns about the higher risk of accidents due to noiseless operation, but in practice this is not a real problem. Modern ICE cars with appropriate exhaust-, and insulation systems have the same noise level as EVs. Our converted cars are far from confirming the general assumption that electric cars could be slow and circumstantial. These are fast cars, relaxing to drive, and enjoyable to look out of to see the curious faces from the pavements.

Acknowledgment

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