Some Myths and Facts of Electric Road Vehicles

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Abstract: This paper presents some facts focusing on some anomalies that appear at road electric vehicles. Application of photovoltaic cells sounds well, but the reality presents something else. Application of electric hub motors is a nice field of research but it is in contradiction with some basic rules of the dynamics of road vehicles. The list can be continued with some other problems that do not match the basic rules of engineering and technical sciences. In this paper I present also, a solar electric vehicle built at our department.

1. INTRODUCTION

Nowadays we can be the witnesses of the renaissance of the electric road vehicles. The reasons are well known: environment protection, climate change, finite resource stocks, and so on. The road vehicle is a mechatronic system. To develop a good car it needs knowledge from the fields of mechanics, electrical engineering and electronics and information technology. Very few specialists can tell about themselves that they are good in all these fields of science and technology. This is the reason that there are research teams containing specialists from wide domains of engineering. The problems appear when a small group of specialists having deep studies in only one field starts to develop something that belongs to other fields and needs some other deep knowledge. The road vehicle engineers learn a lot about the dynamics of the car and something about electric motors and drives. Electrical engineers learn a lot about electric motor and drives but mainly nothing about dynamics of mechanical systems, not speaking about cars. Let suppose there is an institute that has nice results in the domain of electric motors and drives starts to work in a project about electric road vehicles because the government supports this topic. If they do not involve car engineers in their project then it could appears some very interesting solutions, that may work well or not, but the sources are consumed. Of course a kind of “evolution” will select the right solutions, but I ask why are the engineers and specialists trained if their knowledge is not used to avoid unwanted results that might occur. It would be desirable to do the research work and development in an optimistic way, and the myths would not appear. Such kind of anomalies can be the application of photovoltaic cells to be the energy source of a road vehicle or the application of electric hub motors built in the wheel of a road vehicle. In this paper I would like to focus on these two problems, but I think there are several other anomalies and colleagues could speak a lot about their experiences.

2. PHOTOVOLTAIC CELLS

2.1. Solar Energy

The average perpendicular incident power coming from Sun is 1353 W/m^2. This means that energy coming from Sun covers the energy need of the Earth by 20000 times.

2.2. Photovoltaic cells

Without entering deeply into the theory, photovoltaic cell is a semiconductor (e.g. Si) that converts the solar energy to electric energy. As every energy converter the photovoltaic cell also has efficiency. The theoretical value of the efficiency of the photovoltaic cell with one layer is 33.7%, at laboratory circumstances it was reached 25%, and in reality is about 18%. Very expensive multilayer GaAs photovoltaic cells can reach 44% in concentrated light beam.

Fig. 1. Photovoltaic cell. [1]

It means we can get about (200…250) W electric energy from a photovoltaic panel which surface is 1 m^2.

2.3. Power need of the road vehicle

The motor of the road vehicle has to defeat the following forces:

- aero-dynamical force,
- rolling force,
- ramp force,
- inertia force.

The formulas are well known and I do not think it is necessary to present them but we also know the power of the road vehicles. Let take a small passenger electric car:
Smart Fortwo ED (electric drive) 2nd generation [2]:
the continuous power of electric drive $P_{continuous}$=20 kW.

Fig. 2. Smart Fortwo ED. [2]

So to be able to deliver continuously a mechanical power of 20 kW, it means we need about 25 kW of electrical energy - taking into the consideration the losses of electric motor and drive. It would result a solar panel with a surface of 100 m^2 that is enormous big. Using the solar energy to drive a vehicle it gives a special car (Fig. 3) instead of a passenger car (Fig. 2.).

Fig. 3. Sunswift IVy. [3]

What happens if the Sun does not shine? It would need an intermittent energy storage possibility: a battery. We do not have to forget that batteries also have a certain efficiency, for example the efficiency of the lithium-ion battery is between (80…90) % [4].
Moreover we have to realize that the Li resources of the Earth are limited. If we start to produce Li-ion batteries for electric vehicles the stocks will be depleted in 10 to 20 years and some destroyed ecosystems will remain, only. “Li-Ion powered cars are not “Green Cars” but Environmentally Destructive Cars” [5].

2.4. Experimental solar vehicle

Students of our department participated at a race organized by company BOSCH at Miskolc, Hungary in 2010. The task it was to build an electric vehicle (an electromobil) powered by electric power tools: six battery powered drills.

Fig. 4. Our students’ team with the vehicle at Bosch Electromobil Race

After the race the vehicle remained at the department.
Two years ago we started to build an electric drive for a general-purpose bicycle:

Fig. 5. Electric drive for a general-purpose bicycle.

Our department started projects in the field of solar energy, and we had the possibility to use a photovoltaic panel and to make some experiments.

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So, last year we started to combine the vehicle built by the students, the electric drive developed for bicycle, and the photovoltaic panel and charger of the department.

Fig. 6. Experimental solar electric vehicle.

The photovoltaic panel has a surface of 0.6 m^2 and it gives 80 Wp at an efficiency of 13.5%.

Fig. 7. The charger.

The MPPT (maximum power point tracking) charger operates at a voltage of 12 V, its rated current is 6 A and the efficiency is 90% [6].
The battery we used is a simple lead-acid starter battery. Its voltage is 12 V, and the capacity is 44 Ah.
The rated parameters of the PM brushed DC motor we used are 12 V, 5 A and the efficiency is about 70%.
It can be observed that the system was designed in such a way that the solar panel should cover the power need of the DC motor. If the DC motor does not operate, the solar panel charges the battery. If the Sun does not shine, the battery powers the DC motor. In spite of the fact that the PM brushed DC motor is suitable to operate as a generator the experimental system was built without using totally this possibility. The electrical drive of the DC motor is a simple one quadrant DC chopper and it lets only some operating area when recharging of battery is possible.

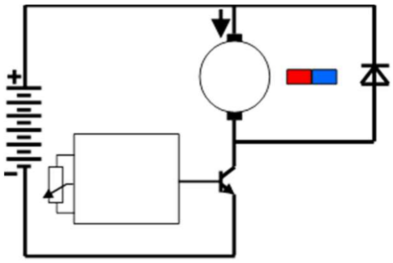


Fig. 8. Simple one quadrant PWM electric drive for PM brushed DC motor

We connected a second diode in antiparallel with the chopper transistor. At higher RPM of the motor the induced voltage could be more than the battery voltage, a reverse current can charge the battery while a negative torque will appear. This means that in case of slopes it will operate as an engine brake meanwhile the battery will be charged.

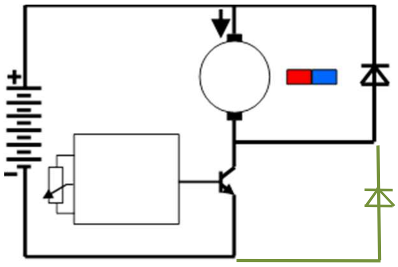


Fig. 9. Our PWM electric drive of the PM brushed DC motor with recharge possibility in certain operation conditions

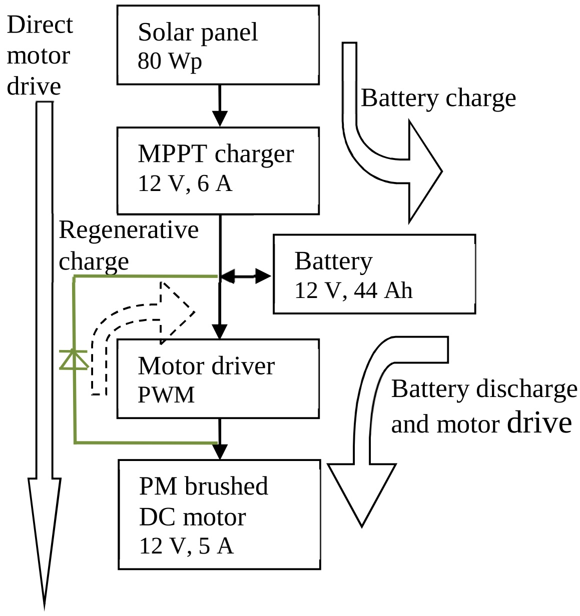
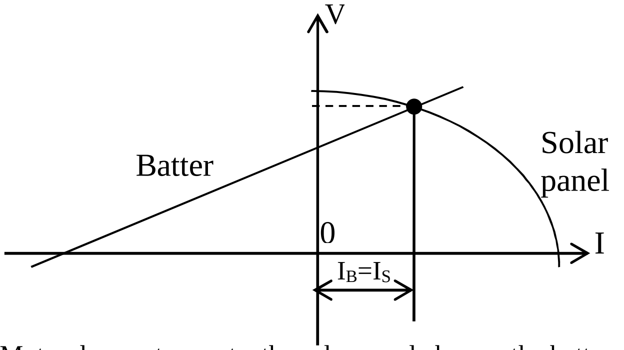
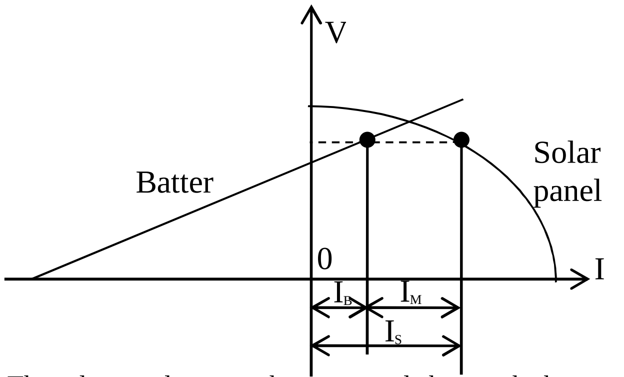


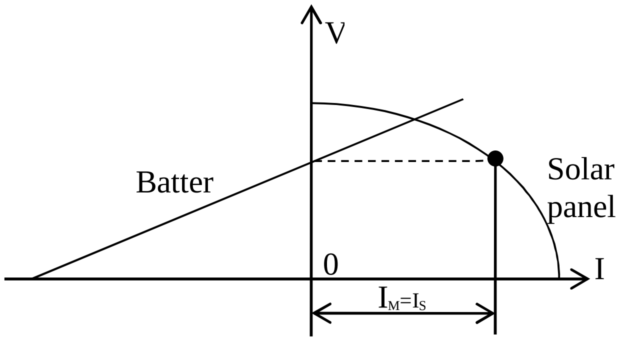
Fig. 10. Energetic block diagram



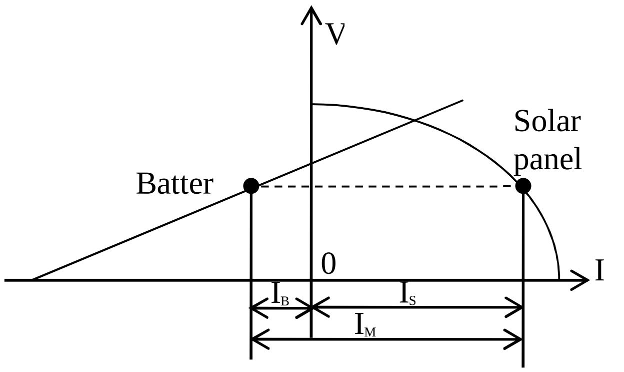
a) Motor does not operate, the solar panel charges the battery



b) The solar panel powers the motor and charges the battery



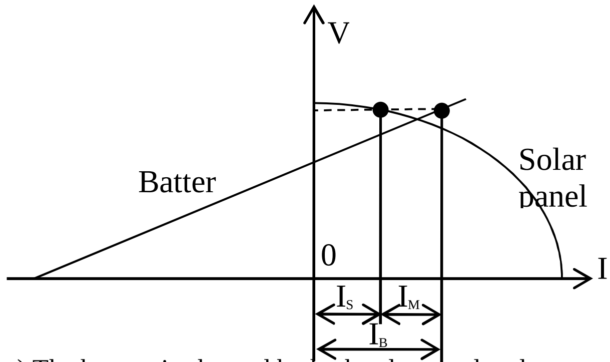
c) The solar panel powers only the motor, the battery is not charged



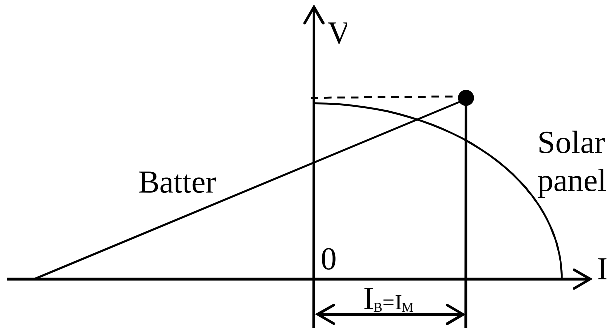
d) Both solar panel and battery powers the motor, the battery is discharged

Fig. 11. Different operating points of the system

In Fig. 11. there are presented different operating cases (B=battery, S=Solar panel and M=motor). If the motor does not operate (a) the whole current of the solar panel charges the battery. If the motor operates at low power the battery maybe gets some charging current (b), or maybe not (c). If the motor operates at high power, the solar panel is not able to deliver enough current and the battery recovres the differences and it starts to discharge. In Fig. 12. there are presented cases when the RPM of the DC motor is so high that can recharge the battery shared with the solar panel (a) or only by itself (b).



a) The battery is charged by both solar panel and motor



b) The battery is charged only by DC motor at high RPM

Fig. 12. Regenerative operations of the system

The energetic strategy of the system has been resolved. We started to develop the electronic circuit of the electric drive of the motor. The PWM signal is obtained by comparing a triangle signal and a DC signal. The triangle signal comes from an astable multivibrator, while the DC signal comes from a simple potentiometer that divides the voltage of the battery. The output of the comparator drives a Totem Pole circuit. The output of the Totem Pole drives the gate of a Power MOSFET. The Power MOSFET is connected in series with the DC motor. A flyback diode is connected antiparallel with the DC motor to protect the Power MOSFET from the induced voltages when it is switched off. A diode connected antiprallel with the Power MOSFET is added to give the possibility of the regenerative braking at high RPM. There are also built in some protection elements in the circuit. If the temperature of the Power MOSFET or the temperature of the motor increase to higher values the electronic drive will switch off the power suplly of the DC motor. The diagram of the electric circuit is presented in Fig. 13., and the printed circuit board of the electric circuit is presented in Fig. 14.

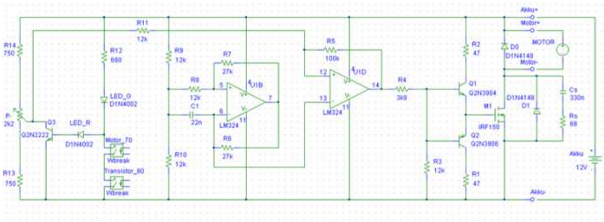


Fig. 13. The electric circuit of PWM controller.

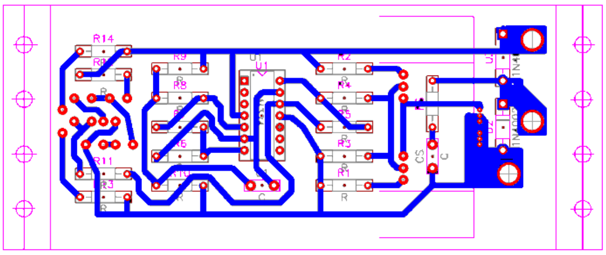


Fig. 14. The PCB of PWM controller.

The characteristics of the PM brushed DC motor are presented in the Fig. 15.

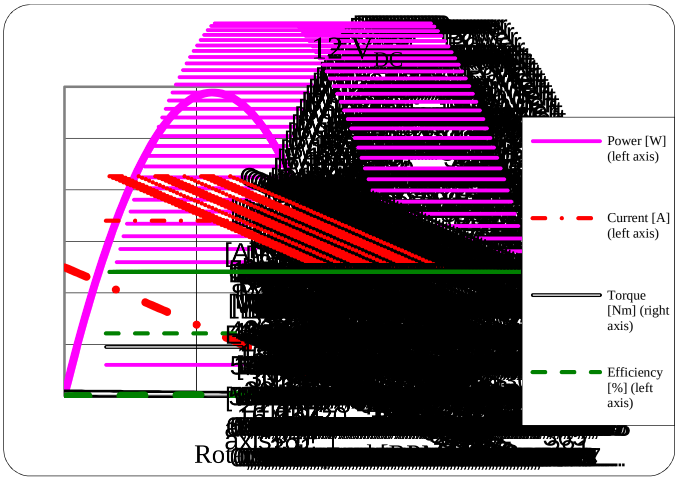


Fig. 15. PM brushed DC motor characteristics

From Fig. 15. it can be concluded that the maximal torque of the motor is at very low speed. This is advantageous because it gives very good starting behaviour, but also means high values of the currnet and the efficiency is small. So we have to deal with heating problems. The power reaches its maximum at the midle value of the speed, but here the efficiency of the motor is still very small and the problem of heating still persists. The highest value of the efficiency is at 4000 RPM close to the maximum value of the speed. This could be a good operating point, but here both the torque and the power of the motor are rather small.

There are also some mechanical constrains to be taken into consideration. The shaft speed of the DC motor is 4000 RPM. This corresponds about an 80 km/h speed of the vehicle if the shaft of the DC motor is connected directly to the shaft of wheel. At a such kind of speed the power needed to drive the vehicle would be much higher than what the DC motor could deliver.

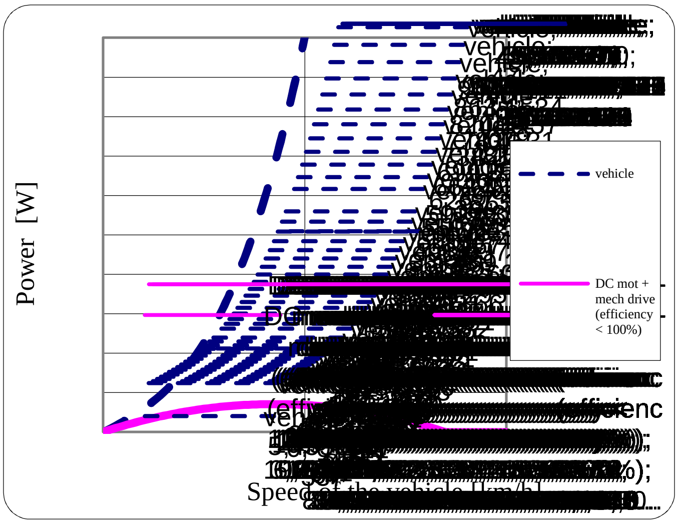


Fig. 16. Power need by vehicle and delivered by DC motor versus the speed

A transmission had to be built in between the DC motor and the shaft of the wheel. The ratio was chosen to be 15, because in this case the power characteristics of the DC motor intersects the power characteristics of the vehicle at an operating point that corresponds to approximately 4000 RPM. This high value of the transmission rate results a rather low maximum speed of the vehicle. This is the maximum that could be obtained from a single 80 Wp solar panel.

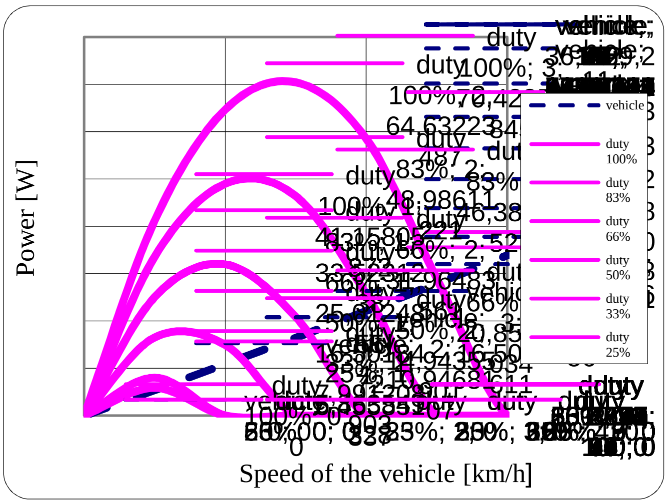


Fig. 17. The power versus speed of the vehicle and the electric drive

3. ELECTRIC HUB MOTORS

3.1. Electric motors

There are several kinds of electric motors that convert the electrical energy to mechanical energy. Because of the quite bad energy density and the limited capacity of energy storage of the battery it is very recommended to use such kind of electric motor that has permanent magnets (PM) instead of electric excitation windings, for example brushless direct current (BLDC) motor or PM synchronous motor. It is well known that nowadays there are very good magnets as the SmCo or NdFeB, but they have very bad mechanical and chemical characteristics, due to their materials and manufacturing process. These permanent magnets give strong magnetic field, but they can crack or break very easy. Also they are very sensible to corrosion. So, the PM should be protected against mechanical shocks and chemical agents.

3.2. Road vehicle wheels and the suspension

The suspension contains a spring that holds the car body. Its function is also to keep the wheel on road when the vehicle runs on a road which surface is not smooth. To be able to fulfil this task it is important the mass of the wheel should be low as possible. The masses and the spring of the suspension form an oscillating system. If the mass of the wheel is too big and there is a bump on the road it could happen the wheel will jump. This means it will lose the mechanical contact with the road and the vehicle would not be controlled for a certain period of time. If the spring is too strong then the car is not comfortable enough for the passengers.

3.3. Electric hub motors

The trend to build in the PM electric motor in the wheel is not suitable because:

- the mass of the wheel will increase and
- the PM gets a lot of mechanical shocks.

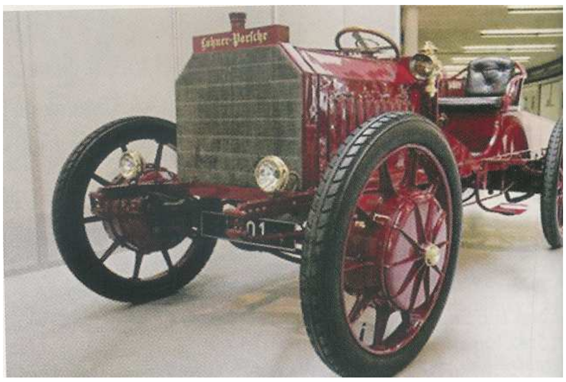
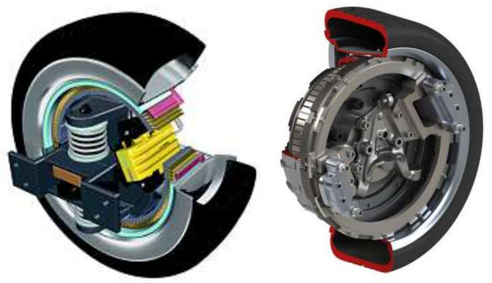


Fig. 18. Electric hub motor at a Lohner-Porsche car from 1900 [7].

Of course there are special cases when an electric hub motor can be applied very well. Good examples are the trolleys working in a smooth industrial area, railway vehicles or special racing cars, where it can be ensured the smoothness of the road surface.

[10]



a) b)

Fig. 19. Electric hub motor developed
a) by Siemens [8] and b) by Protean Electric [9].

4. CONCLUSIONS

The car is a complex system. Development of parts of the car can be done in a way to take into consideration knowledge from different areas of technical sciences and engineering. The photovoltaic cells are not enough to power a passenger car. The electric hub motors does not match the requirements of the dynamics of the suspension.

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