Impact of Energy Production Technology on Gas Emission by Electric Hybrid and Electric Vehicles.

Zdeněk Čeřovský*, Pavel Mindl**

* Josef Bozek Research Center of Engine and Automotive Technology
Czech Technical University in Prague, Faculty of Electrical Engineering,
CZ 166 27 Prague 6, Technicka 2, Czech Republic

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Abstract- The production of energy for traction in classical vehicles is performed by petrol or oil combustion. The consequence is green gas production. Paper deals with different power trains of electric hybrid and electric vehicles. Electric hybrid vehicles diminish the fuel consumption by giving to the internal combustion engine (ICE) better working conditions with respect to ICE revolutions and demanded power. The kinetic braking energy recovery is an important feature too. Electric vehicles are usually called "green vehicles". It is true that they do not produce green gas on places where they are driving but it is also true that their traction energy has to be produced with another energy technology used in electric plants. The efficiency of the vehicle powertrain is important. The energy for transportation by vehicles in the world is great. Therefore it is very important what energy production technology for this traction purposes will be used.

Keywords- Gas emissions, Electric vehicles, Electric Energy Production, Energy for Transportation.

1. Introduction

Gas emission and fuel consumption of vehicles influence the environment quality on many places namely in big cities [1,2]. Greenhouse gas emission of internal combustion engines brings ecological problems in towns.

Vehicles using fuel cells are in promising development stadium now.

Hybrid electric vehicles combine electric and internal combustion engine drive. Hybrid electric drives adjust the combustion engine load and revolutions into the point of the best motor efficiency [1,5]. Hybrid electric vehicles cannot exclude the green gas emission on the place where the vehicle is driving but can it diminish significantly. Electric hybrid vehicles find the commercialization on the market of vehicles for long distance service.

Electric vehicle excludes gas emissions on the place where the vehicle is driving fully. Vehicles using batteries are used in several cities for post or food delivery for example. Electric energy can be stored in battery but energy for battery charging is produced on the place where the electric plant is situated.

Electric plants produce green gas emission too. They are different technologies used in electric plants. Some of them are better then the others as concerns the green gas production. The appreciation as concerns electric vehicles is goal of this paper.

2. Basic drive configuration

2.1. Hybrid electric vehicle basic powertrains and their features.

2.1.1 Series hybrid drive

Series hybrid drive in Fig.1 presents a combination of different energy sources. In the picture the energy sources are the combustion engine ICE and the battery. The internal combustion engine propels a generator.

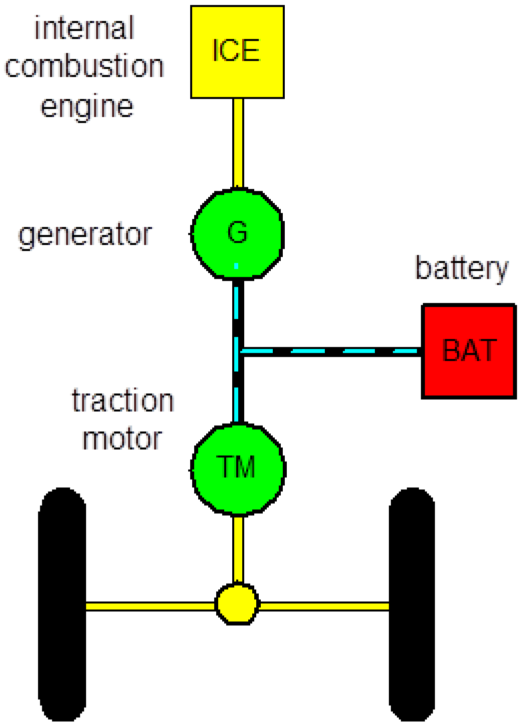

Fig. 1. Series hybrid drive

The electric power of the generator and the battery electric power are summed in the traction motor. There is no mechanical connection between ICE and wheels. Battery acts as energy buffer. Advantage of series hybrid drive is the possibility to operate the ICE in optimal revolutions quite free from the velocity. That results in low specific fuel consumption and in low gas, especially CO_2 emission.

2.1.2 Parallel hybrid drive

Parallel hybrid drive is depicted on Fig. 2. It is a combination of ICE and electric traction motor on the same shaft. Traction motor is supplied by battery and its output is separated from the ICE output. Final traction torque is sum of both motors torques.

Power transmission is more effective than in series hybrid drive because the mechanical ICE output is not transformed in electrical output. But the ICE cannot work in optimal load regime because its speed is not quite free from the car velocity.

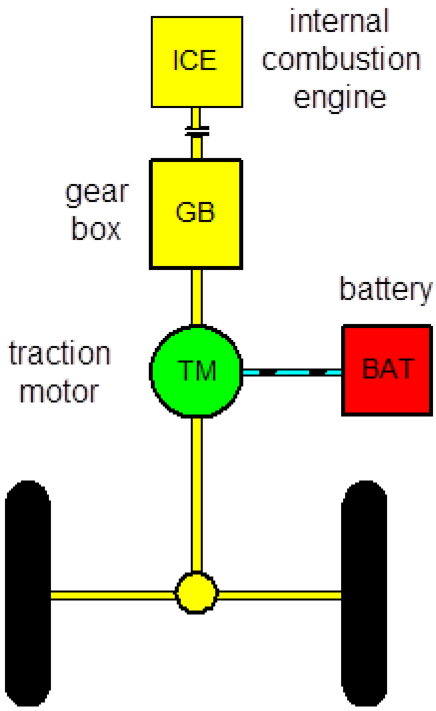

Fig. 2. Parallel hybrid drive.

2.1.3. Electric Power Splitting Drive

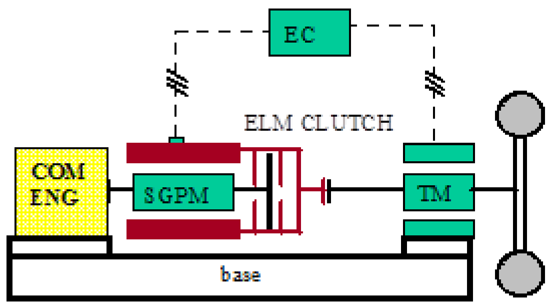

Fig. 3. Physical model of Electric Power Splitting Drive using AC Machines

Model of Electric Power Splitting Drive using AC Machines is depicted on Fig.3. It was implemented in the laboratory of Josef Božek Research Centre of Engine and Automotive Technology at the Czech Technical University in Prague. It is experimental electric hybrid car drive of a small power. [5-11].

The output is 7.5 kW, 0 – 6000 min^{-1} Electronic converters and supercapacitor EC are integrated in the circuit between electric power divider SPGM and traction motor TM. The super capacitor as a peak energy storage is added and has 100F, 56V and 400 A. It is able to accept the kinetic braking energy of the vehicle with mass 1500kg and the velocity 60km/hour. This energy can be regenerated during next speeding up. Principle is as follows. The combustion engine COM ENG drives the electric power divider SGPM. The power divider is a special double rotor synchronous permanent magnet generator. The first rotor is firmly connected with the combustion engine shaft. The second rotor is firmly connected with the traction motor TM and with car wheels. The traction motor is supplied with electric power induced by differential velocity between first and second rotors. Parameters of this electric power (voltage, current and frequency) are changed in electronic converter EC. Power of the combustion engine is divided into two parts. The incoming power $P_1=T_1*\omega_1$ is the power of combustion engine producing torque T_1 at angular velocity ω_1. Torque T_1 is transferred with electromagnetic force to the second rotor, rotating at angular velocity ω_2 which corresponds to the car velocity. Power transmitted to car wheels by this torque is therefore $Pm=T_1*\omega_2$. Remaining power is induced by magnetic field into the electric winding arranged on the second rotor. Neglecting losses this power is $P_{el}=P_1-P_m=T_1*(\omega_1-\omega_2)$. Power P_{el} is transferred via electronic converter in EC to the traction motor TM and finally added to power P_m on car wheels. Incoming power P_1 from combustion engine is by this technique divided into two parts P_m and P_{el}. Combustion engine can rotate with angular velocity which does not depend from the car velocity. That results in low specific fuel consumption and in low gas, especially CO_2, emission for any traction load and car velocity.

2.2. Electric storage devices and their features.

Attribute	Ni-MH	Li-Ion
Energy Density (Wh/kg)	<70	~150
Power Density (W/kg)	1600	>3000
Volumetric Energy Density (Wh/L)	200	>300
Cost ($/kWh)	35	30-35
Self Discharge (% / month)	20	2-5
In/Out Efficiency (%)	90	> 95
Temperature Range (°C)	-10 to +40	-30 to +50
Cycle Life: EV (# cycles)	~1000	1000-3000
Cycle Life: HEV (# cycles)	300,000	300,000[2]
Calendar Life (years)	> 10	>10

Fig. 4. Comparison between Ni-MH and Li-Ion batteries properties.

Electric vehicles have the highest potential to cut down CO_2 emissions. The main problem is to develop electric energy storage which will have volume, energy content and mass equivalent near to actual fuel tank. In recent time there are large sums of money invested into the research of batteries as modern energy storage. Short survey of battery possibilities gives Fig.4 and Fig.5. On Fig.4 Ni-MH and Li-Ion batteries are compared in usable energy density, power density, volumetric energy density, cost, cycle life and others. On Fig.5 dependence of specific power against specific energy of different battery types is depicted.

From figures it can be seen that Li-Ion battery delivers twice the energy density than Ni-MH. But when we compare usable energy density of batteries with petrol energy density which is 2.39 kWh/kg we see a great difference

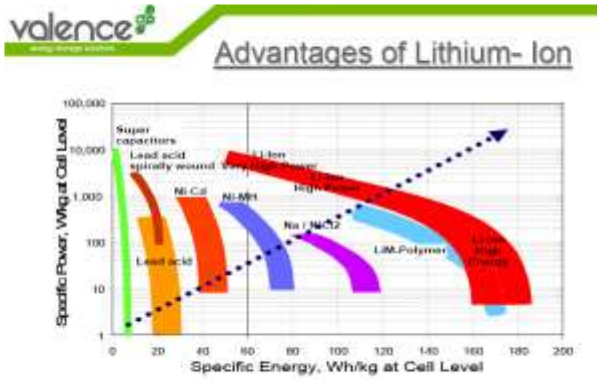

Fig. 5. Specific power against specific energy at the cell level.

When we shall calculate that energy content in 1kg of petrol can be used only with 28% efficiency of ICE we get petrol usable energy density 669 Wh/kg.

The better efficiency of electric powertrain helps to equilibrate this difference a little.

3. How electric hybrid vehicles diminish the fuel consumption.

The efficiency of an internal combustion engine is changing with load and revolutions. For example a real efficiency curve (lower curve 5*η %) as function of revolutions with respect to the load torque (upper curve) are depicted on Fig. 6. The efficiency in optimal working regime is 145/5=33%.

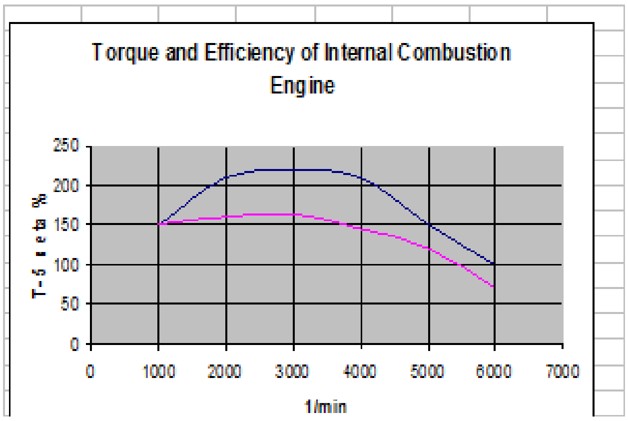

Fig. 6. ICE torque and efficiency versus IEC revolutions

What is the real average efficiency during real driving is no so easy to find out. Measurements or simulations on real road with respect to real velocity must be done. The working conditions of the ICE are much better in electric hybrid cars than in conventional cars generally. For this reason simulations or measurements must be done too.

As example simulations were done with the mathematical model of Electric Power Splitting Drive Using AC Machines developed in the university laboratory. Measured parameters and features obtained in the laboratory [5,6,11,18] were used for the simulation.

The mathematical model of a conventional car and hybrid electric car with electric power divider was established in Ref. [19,20].

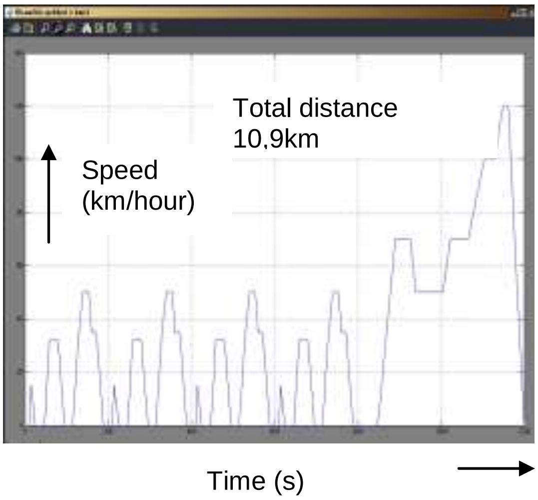

Fig. 7 New European Driving Cycle

Comparisons of this art are usually done on different standard driving cycles. Standard driving cycle represents a driving pattern of a certain geographic region (North America, Europe, Asia-Pacific). These driving cycles are used for evaluation and comparison of car's performance, fuel consumption, pollution production, efficiencies etc.

Simulations were performed on New European Driving Cycle NEDC. The NEDC is shown in Fig. 7. Parameters of compared cars and results of simulation are shown in Table.1 and Table.2.

Table 1. Simulation results

Simulation results	**First case. Hybrid electric car**	**Second case. Conventional car**
Vehicle type, manufacturer	**Model**	**Škoda Fabia 1.2HTP**
Driving Cycle	**NEDC**	**NEDC**
Total mass (kg)	1450	1120
Specific Consumption during total NEDC (l/100km)	5.1	5.9
Total emissions CO_2 (g)	1333	1540
Specific emissions (g/km)	122.9	142

Table 2. Hybridization effect

Hybridization effect	percentage
Specific Consumption during total NEDC (l/100km) decrease	13,6 %
Total emissions CO_2 (g) decrease	13,4 %
Specific emissions (g/km) decrease	13,4 %

Two cases are shown. In both of them the New European Driving Cycle was simulated.

Case first: Hybrid electric car with electric power divider. The mass of the car respects the additional mass of electric part of the powertrain.

Case second: Conventional car Škoda Fabia 1.2 HTP.

The results shown in Table.1 allow to make following conclusions: When comparing fuel consumption and CO_2 emissions between hybrid car with electric power divider versus conventional car of the same class (that means the same primary ICE engine power and respecting additional mass of the electric powertrain machines), we can conclude that the fuel consumption and CO_2 emissions are significantly lower at the hybrid car.

Hybridization of such cars brings not only fuel savings but also is much more environmentally friendly.

4. How different energy production technologies influence CO_2 production by electric vehicles.

When speaking on vehicle CO_2 production then usually only the production of vehicle itself is taken in account. At classical vehicles with ICE it is necessary to add to the CO_2 produced by the ICE itself also the quantity of CO_2 that was necessary to produce the fuel from crude oil for example and to transport it into the vehicle tank. At electric vehicles also the quantity of CO_2 that originated in production of electric energy to charge the battery must be taken into account. These quantities are produced on another place than on the road or street in a town. They were produced using different technologies. Only this attitude is objective. From this point of view it does not exist "green vehicle" that is vehicle which is free from green gas production.

In the reality it is important to determine what quantity of CO_2 pro 100km driving must be accepted. Only papers giving these numbers can be objective for future mobility solution with the minimum of green gas or CO_2 production. This paper tries to do first steps in this direction.

4.1 Layout of CO_2 production by different human activities.

The total greenhouse gases production is caused not only by cars but in general by men activities on whole Earth. The result from all resources is shown in Fig.8 which shows the world production of CO_2 [2].

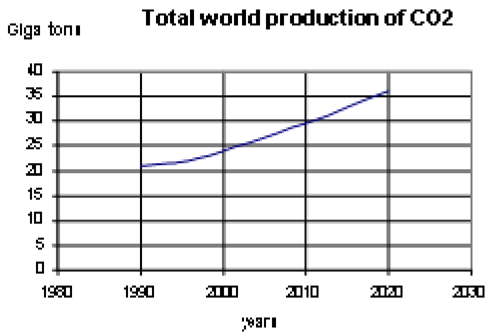

Fig. 8. World production of CO2

If the present and future trends may be sustainable we come to conclusion that it is a duty of men to accept regulation of this dangerous development. These problems are so serious that they became very important theme of international discussions. Table 3 shows that transport and energy production represent approximately a half of the total European world production of CO_2. [24]. High quantities of CO_2 may be the reason or may influence the Earth climate which is changing evidently.

Table 3. CO_2 production in Europe by different human activities.

Energy production	28 %
Transport	21 %
Industry	20 %
Households	17%
Agriculture	10 %
Others	4 %

The verification that the climate is changing and becomes warmer gives observation all over the planet of massive glacier melting or observation that ocean levels are rising. Another question is: What is the reason of temperature rise? There exist two possible answers:

- The measured temperature rise is natural climate change between glacial cycles.
- The measured temperature rise is caused by human activities.

These two answers are discussed for many years. Present consensus of majority scientific personalities is, that the temperature rise which coincides with the time period beginning after the Second World War, is caused by human activities.

It is not quite sure what is true. But engineering conclusion following these arguments may be: The measured temperature rise is dangerous. The measured consequences are so important that it would be irresponsible to close our eyes before them. Climate change and temperature rise are already here and represent one of the greatest environmental, social and economic threat. May be that it is not quite clear if the man-made emissions alone cause these change but it is clear that the society has scientific and economic power to avoid making the problem worse. Therefore it is the reasonable solution and it is the priority to cut down carbon emissions. Our challenge is to find solution in the field of transportation. One of the possibilities lies in electric and hybrid electric transportation technology together with effective electric production technologies.

4.2 Differences of CO_2 production in different electric plants and influence on electric cars parameters.

Table 4. Source for electricity production

	Emissions kg/kWh
EU Mix	650 g
Autrian electricity Mix	440 g
French electricity Mix	162 g
Phtovoltaic	100 g
Hydro Power	40g
Wind Power	20g

Different technologies of electric power stations produce different CO_2 quantities pro one kWh. Some short survey is shown in the Table 4. [21,22].

EU Mix means the mix of different electric power stations in EU like goal, nuclear, gas and water electric power stations. They are present 27% nuclear, 20% renewable and 53% fossil electric plants.

Austrian Electricity Mix is much lower in CO_2 production because the mix is composed from more electric power stations with hydro technology then is usual in EU.

French electricity Mix seems to be the best. It is composed from 75% nuclear, 20% renewable and 5% fossil electric power stations.

Let us compare electro mobile charged from different electric plants with automobile with internal combustion engine.

The usual energy need for 100 km is in case of electro mobile 15-20kWh/100 km. Classical automobiles with internal combustion engine with consumption 7 l petrol/100km or 5 l petrol/100km produce 180 gCO_2/km resp. 140 gCO_2/km. It is calculated with CO_2 needed to produce petrol from oil and to transport fuel into the car tank. Let us compare how much gCO_2/km will be produced by charging batteries of electrical cars when the charging will be done from different electrical plants. By using the Table 4 and calculating with electric consumption of electric cars 20kWh/100km we get results shown on Fig. 9.

5. Conclusion

The advantages of electro mobiles together with new electricity production technologies for environment improvement are quite evident. They bring an important new possibility how to diminish the world CO_2 production. The present disadvantages of electric cars are two. The first is the restricted operating range with one battery charging. The second is the rather long charging time. Present state of art improves both mentioned disadvantages. [21-23]. Nevertheless the electric hybrid vehicle conception can in this time solve both mentioned problem on a higher level and ensure the lower fuel consumption as well.

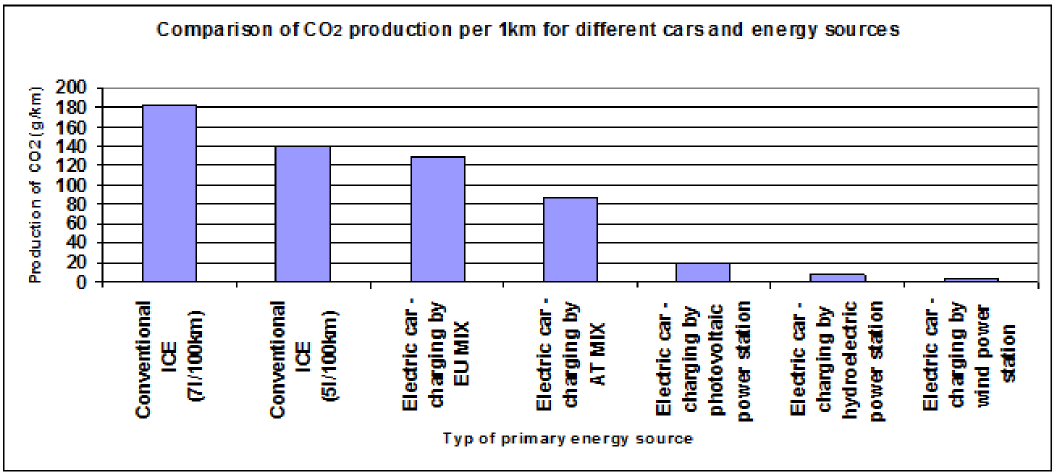

Fig. 9. Comparison of the total CO_2 production for 1 km by different types of vehicles.

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Abbreviation and Acronyms

BAT	battery
ELM	electromagnetic
G	generator
GB	gear box
ICE	Internal combustion engine
NEDC	new European driving cycle
P_1	ICE power
P_m	power transmitted to the car
P_{el}	electric power
T_1	ICE torque
SGPM	Synchronous generator with permanent magnets
TM	traction motor
ω_1	ICE angular velocity
ω_2	power divider second rotor angular velocity