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COMPARISION OD TWO TYPES OF HYBRID ELECTRIC VEHICLE: BATTERY-FUELCELL AND FUELCELL-ULTRACAPACITOR

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The aim of this paper is to determine which configuration of hybrid electric vehicle is more efficient in a context where both configurations are fesabile and may represent viable solutions for developing a transportation system with zero emissions. Study of the two proposed configurations was chosen for further development perspective. At present, on the market are available with high performance fuel cells or batteries and ultracapacitors. The desire to have a transportation system that does not pollute, led to improvement of equipment that have appeared over 100 years ago.

Keywords: hybrid electric vehicle, battery, fuelcell, ultracapacitor.

1. Introduction

Increasing consumption of fossil fuels worldwide has led to drastic reduction of such natural resource. In addition, excess consumption has led to air pollution and especially in decreasing the quality of life on Earth. These adverse effects on human, stimulated scientists to resume development and improvement of technologies and equipment abandoned behind more than 100 years given the appearance of the ICE (internal combustion engine). The paradox is that the resumption of research and development of transport technology considered obsolete was generated by the effects of ICE. Battery power was first certified under this name in 1748 by Benjamin Franklin and in 1800, Alessandro Volta invented the voltaic cell discovering the first method of electricity generation. In 1830 there were already electric vehicles with unchargeable batteries [1]. An electric vehicle battery was the first car that has exceeded the 60mph (mile per hour) barrier. The total decline in vehicle construction using electric battery was reached in 1910 when the ICE acquired a growing success. Fuelcell discovered by William Grove shortly before 1840, was abandoned until the early 1960's when it was adopted for use in special applications, the most significant being space programs. Electrochemical double layer principle was discovered by physicist Helmholtz in 1850. He noted that applying a potential difference on the two

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electrodes in contact with an electrolyte, ions in the electrolyte regrouped on the surface of the electrode and electrolyte interface. At present the development of transportation systems with zero emissions and accessible to the great majority of people is vital. Fuel cell electric vehicles and battery electric vehicles are the only ZEV (Zero Emissions Vehicle) that can replace vehicles with ICE [2]. Maximum efficiency of internal combustion engine is 30% because it is limited by Carnot cycle. Medium efficiency of an totally electric vehicle is at least 60%. This means that almost half of the amount of pollution produced in current transport to disappear. Hence the emphasis is on development of energy sources used in electric traction and especially hybrid energy sources. The hybrid sources manage to combine performances of the fuelcells, ultracapacitors and batteries.

2. System configuration

It is proposed to compare the system battery-fuelcell with fuelcell-ultracapacitor because batteries and fuelcells are only two significant sources in electric traction. Thus through hybridization of these two primary sources it is trying to obtain high performance without lowering existing vehicle performance. The study was done considering the efficiency of the proposed systems in most unfavorable case of the 4 cycles of speed, namely: NEC (European Normalized Cycle) which corresponds to a route in Europe, UF3 corresponding to a totally urban route, R3 corresponding to a half-urban halh-highway and A2 corresponding an highway route. Speed variation during the UF3 cycle can be seen in Figure 1 [5]. All cycles considered unfolds speed for 20 minutes in vehicle speed varies depending on the area where is the travel route. Since most light-duty vehicles are used in cities, the efficiency of the two studied systems should be considered for UF3 cycle. As can be seen from the diagram UF3 cycle, it requires a large number of starts and stops, which require at maximum the energy sources.

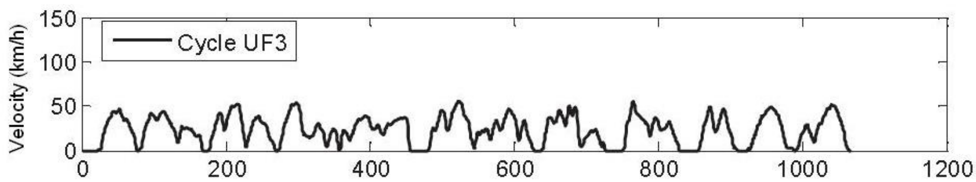


Fig. 1. UF3 considered velocity cycle

2.1. Hybrid system baterie-fuelcell

The energy system battery-fuelcell have the battery as primary power source. It is considered a Li-Ion battery with high efficiency and is available on the market in modular and very compact construction special purpose for electric traction. Compared with other types, Li-Ion batteries have the best ratio energy density - volume. In addition, because rapid reversibility they charge and discharged faster than lead-acid batteries and NiMH [3]. Although Li-Ion batteries have a high efficiency and stationary discharge rate is very low about 5% per month, to obtain a 60kW power to wheel requires a large number of cells. However both efficiency at charge and efficiency at discharge depends of SOC (state of charge). Therefore, the battery hybridization with a fuelcell that replace one third of power needs during periods of start-up or when the vehicle climb a ramp and power consumption is greatest, is one solution that can increase battery life by reducing the stress. Another advantage is the decrease of battery charge times because it can be charged both from recuperative braking and fuelcell. Block diagram of the proposed system is represented in Figure 2.

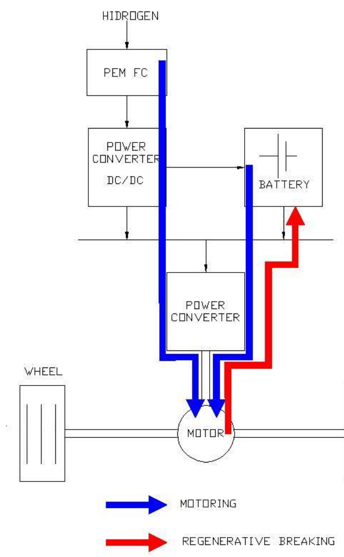


Fig. 2. Block diagram and power flow for battery-fuelcell system

As we can see, the fuelcell is connected to the main voltage bus of the vehicle through a power converter. The power converter is designed to adapt fuelcell voltage to the voltage of main bus and for purpose to charge the battery when vehicle is stationary or in recuperative breaking. Considering equipment and materials available on the market, to get 60kW power to wheel, energy system should be approximately 75kW. It was considered transmission system output $\eta_{drivetrain}$=0.85 and bidirectional power converter output which supplies engine hauling η_{pc}= 0.93. Fuelcell power will be:

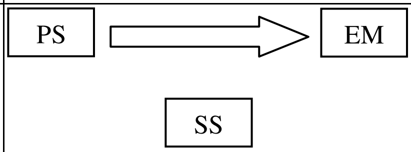
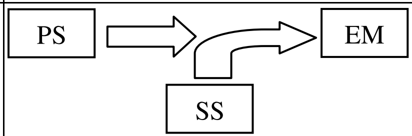
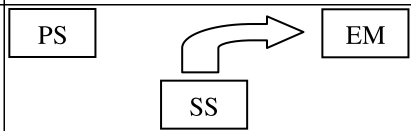
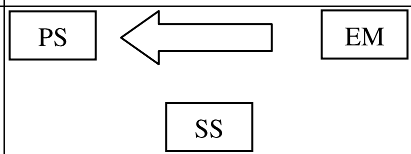
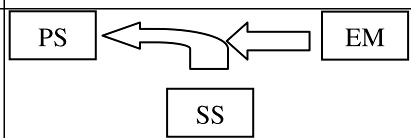
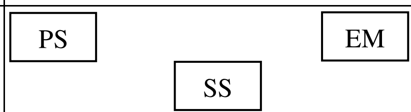
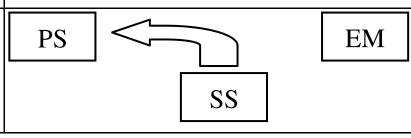
$$P_{fuelcell} = \frac{60kW}{\eta_{drivetrain} \cdot \eta_{pc}} - P_{battery}\,, \tag{1}$$

Knowing that the total power of energy source is 75kW result that $P_{fuelcell}$= 25kW.

Power flows from energy source to the electric motor (EM) and from generator (EM) to battery is presented, depending on case, in the table below. The significance of notations that occurs in table is: P_{EM}-electric motor power, P_{PS}-primary source power, P_{SS}-secondary source.

Table 1

Power flow in battery – fuelcell electric vehicles

Drive state	**Power**	**Diagram of power flow**	**Description**
Traction	$P_{EM}>0$ $P_{PS}>0$ $P_{SS}=0$		Primary source only supplies energy to elctric motor
	$P_{EM}>0$ $P_{PS}>0$ $P_{SS}>0$		Primary and secondary sources both supplies energy to electric motor
	$P_{EM}>0$ $P_{PS}=0$ $P_{SS}>0$		Secondary source only supplies energy to electric motor
Braking	$P_{EM}<0$ $P_{PS}<0$ $P_{SS}=0$		Primary source is charged by recuperative breaking
	$P_{EM}<0$ $P_{PS}>0$ $P_{SS}<0$		Primary source is charged by recuperative breaking and secondary source
Stopping	$P_{EM}=0$ $P_{PS}=0$ $P_{SS}=0$		Power flows is zero
	$P_{EM}=0$ $P_{PS}>0$ $P_{SS}<0$		Secondary source charge primary source

Highest energy consumption according with table above, is at traction when both battery and fuelcell feed power to traction electric motor. This consumption corresponds UF3 cycle speed. Since the vehicle starts and stops so often, it will be equipped with an recuperative braking system. The power recovered at breaking P_{regen} can be calculate with equation [4]:

$$P_{regen} = -e_{regen} \cdot M_{GrVeh} \cdot a \cdot v, \tag{2}$$

where e_{regen} is the regenerative braking efficiency, M_{GrVeh} is the gross vehicle mass, a is the acceleration and v is the velocity. Regenerative braking systems can increase the driving range of electric vehicles by 10 to 15%. For the recovery of braking energy through regenerative breaking system in battery stack, the type of Li-Ion battery should to be fast charging because exist the possibility that during braking and fuel cell to recharge the batteries. Because fuel cell efficiency is up 60%, overall efficiency of the system will be less than battery faradic efficiency (92%). Considering and recovered energy from recuperative braking, the efficiency of battery-fuelcell system can reach 80%.

2.2. Hybrid system fuelcell-ultracapacitor

In this energy system, fuelcell is the primary element and ultracapacitor is secondary element. Block diagram and power flow for this system is shown in Figure 3 and Table 2. Similar with battery-fuelcell system, fuelcell is connected to the main bus vehicle through a power converter. This system contains in addition a bidirectional power converter to adjust the ultracapacitors voltage to the main bus voltage.

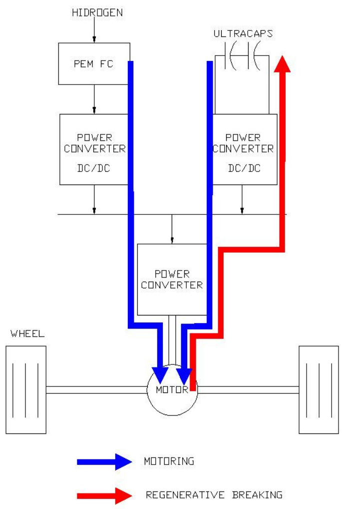
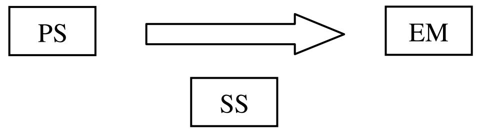
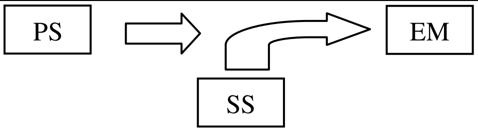
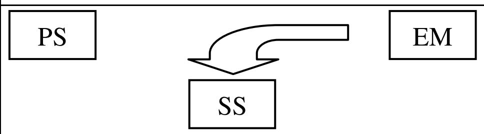
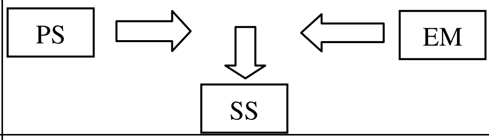
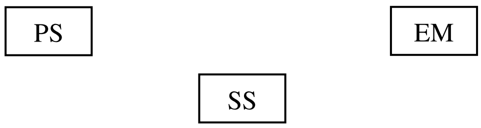


Fig. 3. Block diagram and power flow for fuelcell-ultracapacitor system

Table 2

Power flow in fuelcell – ultracapacitor (UC) electric vehicles

Drive state	**Power**	**Diagram of power flow**	**Description**
Traction	P_{EM}>0 P_{PS}>0 P_{SS}=0		PS only supplies energy to EM
	P_{EM}>0 P_{PS}>0 P_{SS}>0		PS and SS both supplies energy to EM
Braking	P_{EM}<0 P_{PS}=0 P_{SS}<0		SS is charged by recuperative breaking
	P_{EM}<0 P_{PS}>0 P_{SS}<0		SS is charged by recuperative breaking and PS
Stopping	P_{EM}=0 P_{PS}=0 P_{SS}=0		Power flows is zero

In this case the fuelcell will be sized for a power of 50kW. Ultracapacitors will be sized to be able to stored all the energy recovered through recuperative braking. This energy can be calculated with equation (2). A light-duty vehicle has an average 1200kg. The efficiency of recuperative breaking system is an average of 60%. A vehicle brake from 50km/h and has a negative acceleration of 5m/s^2, produces a maximum power of 42kW in the breaking period. This means that ultracapacitors must be designed to absorb a power of 25kW during the breaking period. Stored energy can be express as:

$$E_{uc} = \int_0^t V_{UC} I_{UC} dt = \int_0^t P_{fr} dt = \int_0^v C V_{UC} dV_{UC} = \frac{1}{2} C V_{UC}^2, \qquad (3)$$

where is V_{UC} ultracapacitor voltage, I_{UC} is the current that flows through it, C is the capacity and P_{fr} is produced in braking power. If UF3 speed cycle, fuelcell-ultracapacitor system perform very efficient because the large number of starts is compensated by energy recovery in ultracapacitor. Fuelcell will be overloaded only at the first start (PEM>0, PPS>0, PSS=0 in Table 2) when ultracapacitors are not charged. Because the maximum efficiency of fuelcell is 60% is difficult to achieve an overall efficiency of the system greater than this value.

2.3. Power management system

A very important role in the efficiency of hybrid systems have the energy management system [6] as can be seen in Figure 3. If power management system is properly designed, global system efficiency is maximum.

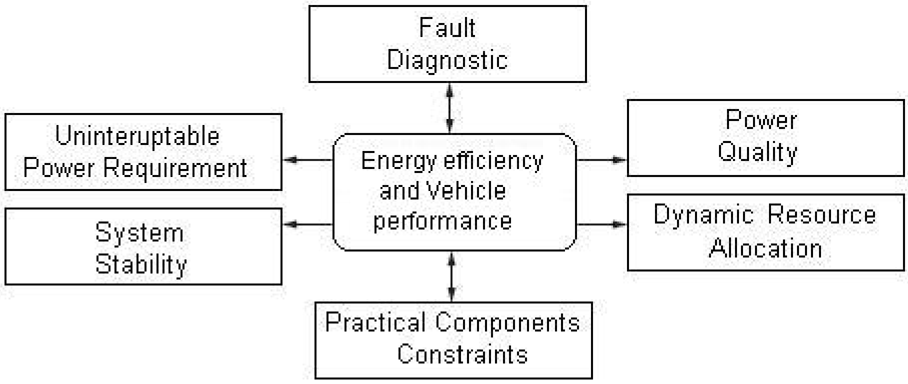


Fig. 3 Block diagram for power management system

Power management system must manage the system so the power needed to electric motor is always satisfied, the power available in secondary source to be maintained in the region of maximum efficiency and operation of main power source to be always in the region of maximum efficiency [7].

3. Conclusions

The two energy systems proposed are achievable and feaseble to future development. While these vehicles itself are type ZEV, in atmosphere are emited polluted substances as a result of electricity production necessary for charge the battery or obtaining hydrogen. Currently being built electric vehicles with batteries that offer a range of about 200km on a full charge of the battery but the price is relatively high. The main disadvantage is the low autonomy compared with ICE vehicles and then the time required for charging the battery. Therefore hybridization of primary energy sources is the solution to obtain a competitive price/quality ratio. Battery as primary energy source, in parallel with a fuelcell provide increased vehicle autonomy, reduce power, volume and stress of the battery. In this case the fuelcell provide the additional power necessary for traction. Furthermore fuelcell charge the battery in parallel with regenerative brake system or when the vehicle is stationary, reducing the time necessary for charge the battery. As you saw an energy system battery-fuelcell commanded by a performant energy management system can reach 80% efficiency which means an efficiency of 2.66 times better than the ICE.

Vehicles equipped with fuelcells possess high autonomy and high cost and relatively low power due to peripherical of fuelcells stack. Pumps, fans, heaters, ducts have a high volume, are not modular which makes difficult to install a large power system in a light-duty vehicle. Besides storage facilities require large volumes of hydrogen for high power fuelcells. Therefore hybridization of fuelcell with an ultracapacitor is the best solution to improve ergonomics of the vehicle because the fuelcell power and volume decreases. Ultracapacitors possesses high power density up to 5kW/kg making them ideal for storing energy produced by regenerative braking system. The power to the electric motor being high, the ultracapacitor discharge the amount of energy stored and as result the chemical and electrical stress of fuelcell significantly decreases, increasing the life period and making possible fuelcell operation in the area of maximum efficiency. The efficiency of this system is however lower than the battery-fuelcell system, few cases exceeded 60% efficiency.

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