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A review of micro and mild hybrid systems

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Abstract

The CO₂ legislation has become more restrictive over time, and to reach the goals imposed by this legislation the automotive industry saw in the hybrid vehicles a solution. Technologies like micro, mild, full and plug in hybrids emerged in order to achieve the imposed goals. This article will provide an overview of the status of micro and mild hybrid technology and is intended to show that this type of technologies is a necessary step until the barriers are not exceeded and purely electric vehicles become the mainstream.

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Keywords: Electric machine; Hybrid electric vehicle; Internal combustion engine; Micro hybrid; Mild hybrid; Efficiency

1. Introduction

The environmental impact, and deplete of global oil reserves, lead to stringent emission regulations around the world, has obliged car manufactures to improve vehicle efficiency and research for equivalent solutions that are not just economically viable but also environmentally friendly [1–6].

In recent years, a huge effort from the industries, resulted in a variety of innovations to face this challenge, developing solutions like turbocharges, engine downsize, valve timing variation or cylinders deactivation to improve fuel efficiency and catalytic converters or exhaust gas recirculation to reduce the Nox emission [7–10]. But despite those efforts to accomplish the legislation, the manufactures need new and drastic solutions like hybrid powertrain architectures. Hybrid electric vehicles (HEVs) are vehicles that use internal combustion engines (ICE) in combination with one or more electric machines (EM) connected to a battery or directly to an electric generator providing propulsion to the wheels together or separately. The development of the hybrid vehicles is a challenge as it is necessary to combine mechanical, electrical and electronic technologies to obtain a vehicle with better efficiency than the conventional ICE vehicles and better initial price and mileage range than the electric vehicles (EVs) [11,12].

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Nomenclature

EM	Electric machine
EVs	Electric vehicles
HEVs	Hybrid electric vehicles
ICE	Internal combustion engine
PHVs	Plug in hybrid vehicles
SoC	State of charge

1.1. Why HEVs are necessary?

For 2021, the European target for new vehicles is 95 g of CO₂ per km. This represents a 30% reduction in relation to 2010. This reduction ratio is a common target in other countries like US, China, Japan and many others [13]. The answer to this numbers seems to be very easy: the car manufactures can start to sell full electric cars and the emission number for new cars drops to zero, but it is not that simple.

The electric cars are not ready to be sold in large scale; despite the zero-emission achieved, they have many disadvantages for which an answer need to be found: high initial cost, short driving range, long charging time, and reduced cargo and passenger space are some of these disadvantages. On the other hand, the ICEs dominate the ground transport due to their long driving range and an initial low-cost, despite the improvements reached in recent years [14]. Despite the improve the thermal efficiencies up to 30% for compression-ignition engines and 25% for spark-ignition engines, they can hardly operate at their peak efficiencies [6,15]. The efficiency of the ICEs is mostly affected by the thermal energy losses within the engine itself, the inertia effects and a highly dynamic utilization due to road cycles (variations on the vehicle speed and torque request) [13].

Therefore, new solutions need to be developed to meet the targets established while not compromising the performance of the vehicles.

HEVs are one of the solutions able to compensate some of these disadvantages of the ICE vehicles and EVs. This combine in a powertrain an ICE and an additional propulsion system, constituted by an electric energy storage unit, an EM and a device which couples together the electric and thermal drivelines. The combination of the two propulsion systems allows the vehicles achieve better efficiency by introducing a greater flexibility in engine use, and continue ensuring the fulfilment of the power request [16,17].

1.2. HEVs classification

HEVs can be classified essentially based on architecture. There are three types of HEVs configurations currently in the automotive industry. The dissimilarities that separate HEVs into these categories diverge in the design of the power flow from the sources of energy to the transmission. Power flow in the series HEV is passed down to the transmission over a single path (electrical path). Parallel HEVs allow power flow through two paths (electrical and mechanical path) [16–20].

On terms of architecture, the HEVs are divided into the following paths:

- On the series HEVs a generator is placed in series with the ICE, producing electric energy to one or more electric motors for traction of the vehicle. This HEV configuration does not allow direct mechanical connection between the internal combustion engine and the propelling wheels. Consequently, the internal combustion engine can be controlled independently of the vehicle power demand and close to its peak-efficiency region. Series HEVs tend to have high efficiency engine operation. This benefit is quickly outweighed by the fact that they often require very powerful and expensive batteries, with a high energy density to operate. The powerful batteries are needed because in most cases, the motor may have to produce 50% of the required total power demand [13,17,20–22].
- On the parallel HEV configuration, both ICE and EM can work independently or together to provide traction. In this configuration, the ICE is mechanically connected to the transmission, while the EM is used to support the ICE during accelerations. Depending on the power of the EM, it can also be used as the vehicle's unique

source of power at idle and during the starts. The possibility of direct energy flow from the ICE to the wheels allows the parallel HEV to shift to the most efficient point of operation using the ICE. This is due to the parallel connection between the electric motor and the internal combustion engine, which implies that the capabilities of the ICE and the electric motor can be changed without modifying vehicle's total driving capacity [13,17,20–22].

- Series–Parallel HEV configuration requires two electric machines. One acts as generator and the other acts as a motor. The connection between the generator and the ICE is done using a planetary energy splitting device. This device allows the vehicle to operate as parallel HEV and series HEV. The series–parallel configuration offers the advantage and possibility of having the ICE decoupled from the vehicle transmission, thus making it possible for the vehicle to be powered using only the electric motors. This also offers the possibility of operating the ICE around its maximum efficiency [13,17,20–23] (see Fig. 1).

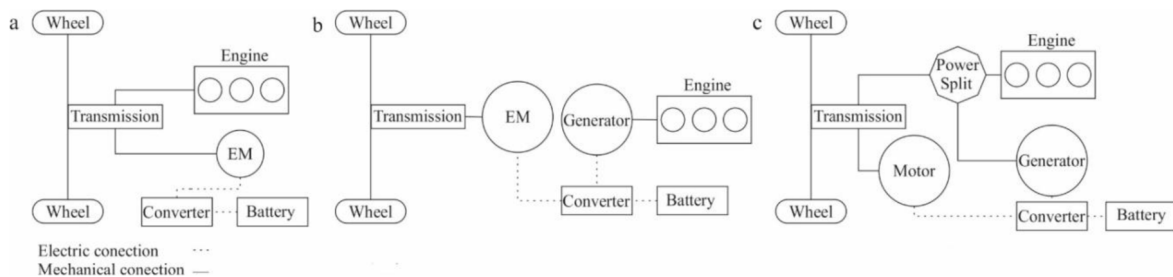


Fig. 1. (a) Parallel HEV architecture; (b) Series HEV architecture; (c) Series–parallel HEV architecture.

2. Parallel HEVs and series–parallel HEVs

Parallel and series–parallel configurations, due to their reduced weight, size and cost are the most used. This configuration presents a better perspective of development and is becoming mainstream [11,21,24]. These two configurations can be categorized according to the degree of hybridization. Degree of hybridization depends upon the power supplied by IC engine and electric motor. The most common is the one in which the ICE is the most powerful source of power and the electric motor only turns on when a boost is needed, but another management strategy can be used, such as, both ICE and electric motor share equal loads, or the HEV can run only with the electric motor system operating.

Degree of hybridization is the ratio of power developed by an electric motor in a hybrid vehicle to the total power consumed by the vehicle hybridization. According to the degree of hybridization the vehicles can be classified as Micro, Mild, Full or Plug-in Hybrid [13,17,25].

- Micro HEVs have a degree of hybridization of less than 5%. The electric motor, in the form of a small integrated starter/generator, is used to shut down the engine when the vehicle comes to a complete stop and start it up when the driver releases the brake pedal. Once in motion, the vehicle is propelled by ICE and the EM does not provide additional torque to the vehicle, the fuel efficiency increase around 5 to 10% with the use of a micro HEVs system [13,19,25].
- Mild HEVs are very similar to a micro HEV, but with an increased size of the EM of up to 10% of the ICE power and a battery which permits power assist during vehicle propulsion. Typical fuel efficiency increases for mild HEVs are in the range of 20%–30% for real-world driving situation when compared with a non-hybrid [13,19,25].
- Full HEVs, the EM and batteries are significantly bigger than those of the micro HEVs and mild HEVs. As such, depending on the vehicles power demand, the electric motor can be used as the sole power source. Compared to micro HEVs and mild HEVs, full HEVs have much smaller engines and require more sophisticated energy management systems. Typical fuel efficiency increases for full HEVs are around 30%–50% for real-world driving compared to a non-hybrid [13,19,25].

- Plug in HEVs (PHEVs) essentially possess the same configuration as full HEVs but with the addition of an external electric grid charging plug, much bigger electrical components (electric motor and battery) and a downsized engine. Owing to the high capacity electrical components, PHEVs can run on electric power for long periods of time [13,19,25].

3. Micro HEVs and mild HEVs

The two main differences between micro and mild HEVs are the torque that they can or not deliver to the vehicle, the micro HEVs does not have the capacity to do it because the EM is typically used to add the start and stop functionality to the vehicle, and power the vehicle accessories like the power steering, air conditioning, lights and other systems that usually consume energy from the engine. The EM is smaller when compared to a mild hybrid, usually has up to 2.5 kW, and works with 12 V. Recent developments in the converters and capacitors storage allow the micro hybrid to work with different voltages without the necessity of complex and expensive electric modifications on cars electric system [13,22,25].

A lot of research has been done in order to make the EM work with 48 V and with this makes the EM more efficient. The improvement from 12 V to 48 V makes the EM capable of recovering more energy in short periods of time, for example, from braking action. With this improvements in DC/DC converters the micro hybrid can use 48 V EM without losing the capacity of interacting and using the electrical systems of the vehicle [26].

Thanks to the power necessities of a micro hybrid, the EM can have a compact design, this means that there is no need for changes in the structure of the car or in the ICE. Typically, the EM replaces the vehicles alternator that is connected to the engine by a belt. The battery is another advantage for micro hybrid since they use lead–acid batteries, a type of cheap and well-developed batteries. Due to the comparatively low cost of integration, this technology will be used in significant quantities in the coming years and will have an important role in meeting CO₂ target (see Fig. 2).

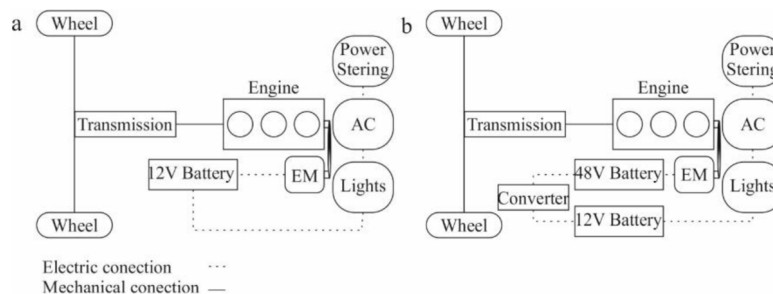


Fig. 2. (a) Micro hybrid HEVs 12 V configuration; (b) Micro hybrid HEVs 48 V configuration.

In terms of configuration the mild hybrid systems are more complex, the system can have an EM coupled to the crankshaft that works as motor and generator or can be a combination with an EM coupled to the transmission with a EM coupled with the ICE as in the micro hybrid. These kinds of systems provide 10–20 kW power and 200–250 N m torque. The mild hybrid vehicle can work with high voltages but for safety reasons the majority of under development systems works with 48 V that are replacing the 42 V mild hybrids introduced 15 years ago [13,17,25,27].

The exponential growth of this technology depends not only of the demand for fuel-efficient vehicles but also goes along with the development of many other technologies that allow making vehicles more efficient without compromise the safety, comfort and affordable price. Technologies like the dual clutch systems or power split planetary systems, improve the flexibility to the implementation of different control strategies to make the best balance of the torque delivery to the vehicle and the state of charge (SoC) from the batteries [28,29].

The mild hybrid energy is managed by a DC/DC converter that balances the SoC from the common 12 V lead–acid battery and the battery used to supply the EM when acting as a motor and supply power to the vehicle. The mild hybrid systems can use ultracapacitors or batteries based on lithium. As well in the micro hybrid systems on the mild hybrid the EM can be a permanent magnet synchronous motor, induction motor or switched reluctance motor (SRM), but due the combination of efficiency, robustness and the ability to be controlled make the SRM the most used motor in the under development and recently developed systems [30–32] (see Fig. 3).

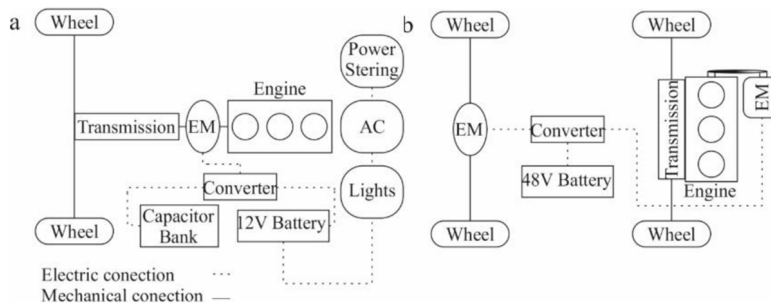


Fig. 3. (a) Mild hybrid HEVs configuration with one EM; (b) Mild hybrid HEVs configuration with two EM.

4. Conclusions

After this research, it is clear that the manufactures are investing in technologies to make the vehicles more efficient and able to meet the emission targets set by the governments. There is special care in the characterization of the different architectures that we can find in HEVs. Despite the advantages brought by the Full hybrid and Electric vehicles, it is noticeable that, given their high cost, these will not be a mainstream solution in the near future. On the other hand, the micro and mild HEVs are technologies that will be increasingly incorporated in commercial vehicles. After this review, control strategies are one of the main focuses of study and development for manufacturers and researchers in the area of HEV's.

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