Short Classification of the Alternative Powertrains for Vehicles

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Abstract. This article deals with the different alternative vehicle powertrain designs. It compares them by addressing their most prominent advantages and disadvantages based on the available literature research, and classifies them. The aim of this classification is to better understand the possible positive and negative sides of the wide adoption of such an alternative propulsion which is dictated by the strict emissions norms. Additionally, other technological means that can be implemented in the alternative powertrains (alternative fuels, ICE combustion strategies, propulsion topologies, and others) to further help in creating the transport sector climate neutral, are briefly discussed.

INTRODUCTION

In the context of strict CO_2 emission regulations being applied in the European Union [1] the automotive branch found it necessary to look for alternative propulsion types for the new European fleet that guarantee low to zero onboard emissions. Indeed, following the trend, many electric vehicles and hybrid electric vehicles are currently designed and produced or planned to be produced for this particular market, which in 2020 became the biggest electric vehicle market in the world [2]. The expected results from the Green Deal in the spheres of clean energy and sustainable transportation however, are certainly not to be achieved by immediate actions [3, 4] – the transition to non-polluting and environmentally friendly transport is planned to be gradual with a number of different existing technologies being bettered and also emerging technologies being developed in the process. This most surely suggest that the internal combustion engine (ICE) should be advanced as it still has many positive aspects – the excellent know-how available due to being the most widespread power generator in vehicles, the low production price and the high energy density, to name a few. Thus, ICE-based propulsion is going to remain an intrinsic vehicle component, especially in cases where electrification is for the near future hardly justified, such as in heavy-duty trucks and other heavy utility vehicles [5].

At the same time along with battery and plug-in hybrid electric vehicles, the fuel cell (FC) hybrid is also gaining momentum on the market as hydrogen fuel and hydrogen delivery infrastructure are a crucial part of the plan for decarbonization of Europe [3]. Hydrogen produced by renewable energy is believed to be a good substitute for fossil fuels especially when electrification is not relevant, moreover it can be applied in electricity load balancing. For that reason, the aim of this article is to be as a contribution to the European efforts in lowering the vehicles' emissions by reviewing the various alternative powertrains, describing their advantages, disadvantages, and most appropriate application, and also to briefly mention other technological means that can amplify the desired effect from the implementation of such powertrains in a wider range.

HYBRID ELECTRIC VEHICLES

Hybridization is an important step in the development of vehicles toward lower fuel consumption, lower onboard emissions and more dynamic driving characteristics. The first mass-produced hybrid electric vehicle (HEV) and simultaneously the most successful one is the Toyota Prius, which was launched in Japan in the late nineties [6]. Obviously, it took a very long period of time since the inception of the automobile for the engineers and manufacturers around the globe to provide a viable hybrid model to the public. This is due to the higher complexity that such vehicles possess in comparison to conventional ICE-driven ones. The energy management strategy, the hybridization rate, and the hybridization topology are the features that all play a key role in unfolding the fuel-saving potential of HEVs. The various combinations of these three features define the strengths and weaknesses of each specific hybrid model. In this publication the HEVs are classified depending on the hybridization rate, the positions of the electric machine, and the hybridization topology.

Hybridization Rate and Position of the Electric Machine

Based on the hybridization rate HEVs can be divided in three main types, listed in Table 1. Micro hybrids have a small integrated starter motor which shuts down the engine when the vehicle stops and then starts it up when the vehicle moves again – start/stop system. During motion the vehicle is propelled in all times by the ICE [7]. Mild hybrids on the other hand possess a more powerful electric motor which enhances the vehicle by adding not only the stop/start option to be used when idling, but also torque assistance when accelerating and energy regeneration when braking. Despite this, the electric system still does not enable the vehicle to move solely on electric mode. Mild hybrids utilize higher voltage electrical systems, typically of 48 or 90V, they incorporate a small battery pack, and the estimated benefit in terms of onboard CO_2 reduction in comparison to ICE-driven vehicles is about 10% [8, 9]. As of 2021 the examples of mild HEVs are numerous and include models from the Mercedes C, E and S classes, Audi A3 to A8 series, and BMW 3 series among others.

Full HEVs encompass all the functions of the mild hybrid but they have more powerful electric motors, significantly bigger battery capacity, and higher cost than micro and mild HEVs, as the motor can be used as the sole propulsion for very short trips up to 10 km. The ICE is downsized and the energy management strategy is generally more sophisticated, which ensures fuel efficiency increase of up to 40% compared to non-hybrid ICE-driven vehicles. The Toyota Prius is the best example of such an automobile.

A plug-in HEV (PHEV) is a type of full HEV that can be charged from the grid through a plug and has even larger electrical components, thus making them suitable for mid-length suburban trips. This makes the technology also applicable for buses and heavy-duty trucks. Depending on the used topology, the electrical powertrain system in PHEVs is used for range extending, or for the only vehicle propulsion at all times (series – discussed later in the article) [10].

TABLE 1. Different hybridization rate of HEVs and its important features [7-11].

Hybridization rate	EV mode range, km	Estimated reduction of CO_2 emissions, %	Electric motor Electric power, kW
Micro HEV	0	approx. 5	belt 2-5 kW
Mild HEV	0	approx. 10	belt/crankshaft 10-15 kW
Full HEV	10 >10 for PHEV	15-20 >20 for PHEV	belt/crankshaft 15-100 kW

Hybrid architectures can also be classified into five groups from P0 to P4, depending on the position of the electric machine in the driveline of the vehicle – Fig. 1. The P0 architecture, known as Belt-Integrated-Starter-Generator (B-ISG), is realized mainly on micro and mild hybrids for the start/stop option and limited electric power assistance. The P1 configuration – with a directly connected crankshaft ISG or a flywheel ISG that replaces the conventional starter and alternator – incorporates a larger electric machine located between the flywheel and the transmission used for regenerative braking, acceleration assist, stop/start function, and also provides higher torque than P0 due to the lack of belt slip. Nevertheless, the integration cost is higher compared to P0 [12].

In configuration P2 the electric machine is mounted between the engine and the transmission and is decoupled from the ICE which allows for higher energy regeneration efficiency compared to P1 due to the lack of engine friction losses. The motor-generator is placed between the transmission and the final drive through a gear mesh in P3 configuration, while in the P4 one – at the drive axle or at the wheel hubs, thus allowing for even better efficiency as the amount of friction losses is lower. However, in P3 and P4 a larger and more expensive electric machine is necessary to achieve pure electric drive, since there is no torque amplification by the transmission [12].

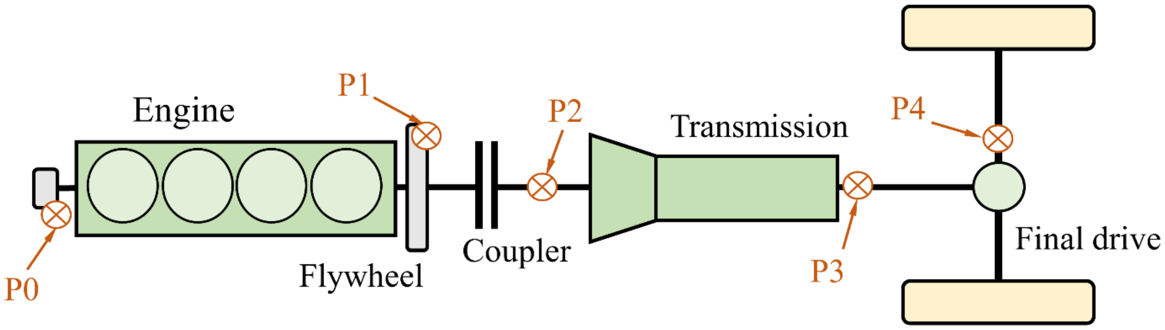

FIGURE 1. Simple schematic of the motor-generator placement in HEV according to the P0-P4 classification.

Hybridization Topology

Based on the topology HEVs are divided in three main types: series, parallel, and parallel-series. Their most prominent features are shown in Table 2 and Fig. 2.

Series HEVs use electric traction motors which can be placed on either of the axles or on all of them and are powered by the batteries and the generator – Fig. 2 a). This allows the ICE to work in the best efficiency field, as it is not coupled to the drive shaft. The traction motor (motor/generator-MG in the figure) has a wider working range than the ICE, therefore the topology may not include a transmission. This, however, results in a need for good sizing of the traction motor, in order for it to well respond to the dynamical driving scenarios. Additionally, the electric motors may be more efficient than the ICE, but the energy transitions from the ICE to the final drive (mechanical-electrical-mechanical) lowers the overall efficiency [13].

Series HEVs use smaller engines than those in conventional vehicles and are PHEV in terms of hybridization rate. Generally, the engine provides less than 50% of the peak power demand and it is rather used as a range extender to the pure electrical drive since the batteries have low energy density [7]. A good example of such a topology realized in a massively-produced vehicle is BMW i3 with a range extender. Currently, this type of HEV is still very unpopular with heavy-duty transportation due to the high weight and cost of the battery pack.

TABLE 2. Different HEV topologies and their advantages and disadvantages [9, 13, 14].

Topology	Advantages	Disadvantages
Series	• No mechanical connection between ICE and drive wheels. • No need for multigear transmission. • Simple control strategy.	• Twofold energy transition from the ICE to the drive wheels. • As the electric motor is the only source of propelling, it should be well-sized. • High weight and high cost of batteries.
Parallel	• No energy form conversion in comparison to series hybrids. • Compactness, since no additional generator is needed and the traction motor is smaller than in series.	• Wider speed and torque working region for the ICE since its mechanically coupled with the drive wheels, thus lower efficiency. • More complex design and energy management strategy than series.
Parallel-series (power-split)	• Combines the advantages of both the above-mentioned topology types depending on the operating mode.	• The electrical path generates higher efficiency loses due to the energy transition. • Very high complexity of the design and the energy management strategy. Higher system weight.

In parallel HEVs both the ICE and the motor/generator are mechanically connected to the output shaft in such a manner that they can work both simultaneously to propel the vehicle – Fig. 2 b). The powers from the ICE and MG are coupled together through a mechanical coupler. The electric machine works as a generator at low power demand and assisting the ICE as a motor at high power demand, hence enabling the engine to work with better efficiency than in conventional automobiles. The engine is generally bigger and the electric motor smaller than those used in the series configuration.

The series-parallel (also known as power-split) configuration combines the advantages of both series and parallel topologies – Fig. 2 c). A power split device (consisting of planetary gears) allows the vehicle to operate through the electrical or mechanical path, or when the energy management and state of charge of the battery enable it, operate through both paths [15]. Nevertheless, such a powertrain is significantly more complex than the parallel and series topologies alone. The available literature indicates that all three configurations of HEV consume less fuel and emit less onboard CO_2 than standard ICE-driven vehicles [9, 13, 14, 16]. Power-split hybrids show better fuel economy in most of driving regimes than the other two topologies as well [17]. This is, of course, at the expense of higher propulsion complexity, higher vehicle weight, and higher price in comparison to ICE-driven vehicles of the same power range.

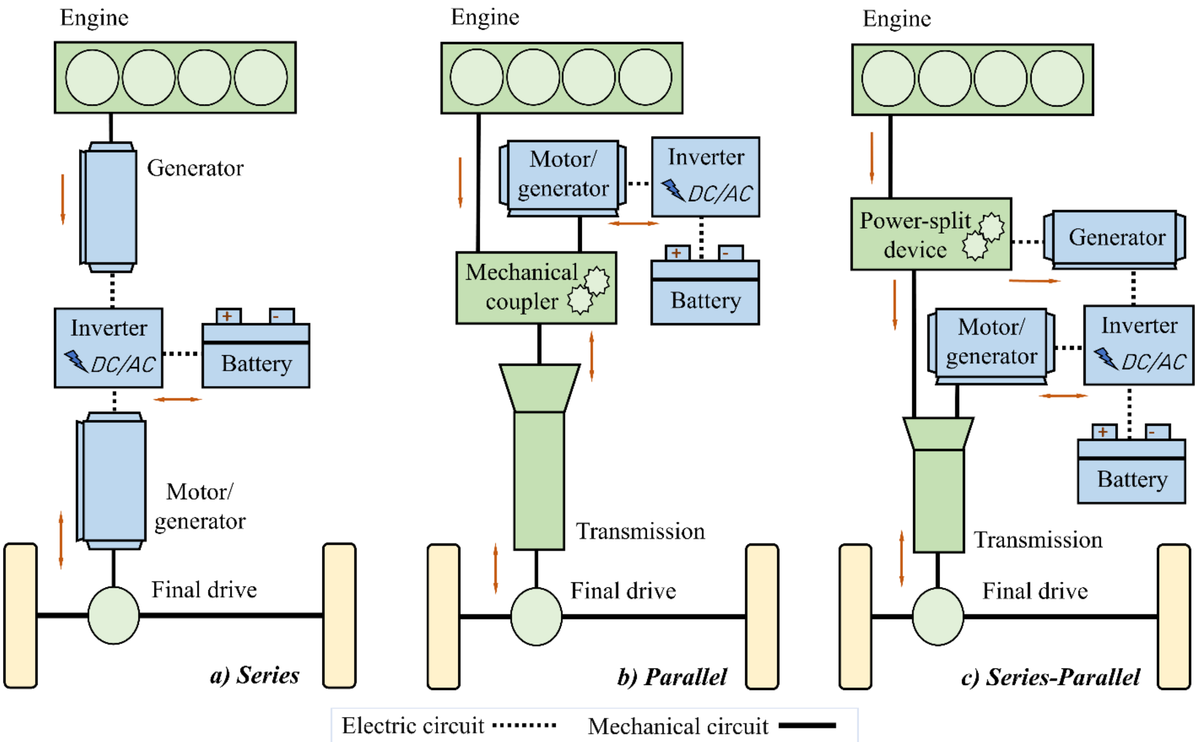

FIGURE 2. Simple schematics of the hybridization topologies for hybrid electric vehicles: a) series, b) parallel, c) series-parallel.

Other Hybridization Technologies

There are other hybrid technologies that also utilize an ICE and also store the kinetic energy from braking thus offering lower fuel consumption than conventional automobiles. The flywheel hybrid vehicle (FHV) for example is a parallel topology hybrid which uses a flywheel energy storage system (FESS) instead of a battery. Such systems offer faster charging/deploying of energy in comparison to batteries since they do not transfer the regenerated energy into chemical form. Moreover, flywheels can discharge up to 97% of the stored energy, thus they do not have deep discharge limitations, they are less dependent on extreme temperatures, and cycle life as well [18]. Usually, such systems are mechanically coupled to the output shaft of the vehicle through a continuously variable transmission (CVT), but this topology is too heavy, large and costly. The company Williams Hybrid Power proposed an electrical configuration used in racing cars and public vehicle transport, where the MG harvests the energy from braking and transfers it into rotating kinetic energy to spin the flywheel – Fig. 3 a). Such a novel system is more compact, light-weight and easy to build than the mechanically coupled one. The efficiency loss and financial cost are lower, and the flywheel may recover as much as half of the energy which is otherwise released as heat while braking. Certainly, FESS have disadvantages – the stored amount depends on the size and maximum rotating speed of the flywheel, and it cannot store the energy for long periods of time, unlike batteries [19].

In Figure 3 – b) is illustrated a hydraulic hybrid topology. They hydraulic pump/motor (HPM) is used to as a pump to store high pressure working fluid (nitrogen gas or oil) in a high-pressure reservoir (accumulator) during regenerative braking [20]. Then the stored energy is applied during acceleration and driving at low vehicle velocities – HPM works as a motor and the working fluid flows form the high-pressure to the low-pressure tank. The operation regimes of HPM as motor coincide with the low efficiency regions of the ICE, therefore improving the efficiency of the hybrid in the same manner as in HEV and FHV. Such a system has high power density, can regenerate up to 75% of the braking energy, in comparison to 30% for batteries, and has a long lifetime. The hydraulic components of HHV are also cheaper and easier to maintain than electric HEV components [21]. The system however, requires a lot of volume for the hydraulic reservoirs to store reasonable amounts of system working fluid, thus it is most suitable for large vehicle such as the heavy-duty ones. Similar to HEV, HHV can utilize a series, parallel or power-split topology, in Fig. 3 b) a parallel one is presented.

TABLE 3. Other hybridization technologies with ICE [18-21].

Technology	Advantages	Disadvantages	Applicability
Flywheel hybrid - FHV	• Fast charging/discharging of energy, little maintenance. • Can dispense up to 97% of the stored energy. • Less dependent on deep discharge, extreme temperatures and number of cycles compared to batteries.	• Storage amount dependent on size and rotating speed. • Inability to store energy for long periods of time due to eventually halting rotation. • Generally high price.	Racing and public transport – vehicles which brake and accelerate frequently.
Hydraulic hybrid - HHV	• Regenerates and dispenses up to around 75% of the energy from braking. • Fast charging/discharging of energy, little maintenance, low cost, long lifetime.	• High noise and large system volume. • Lower energy density than batteries.	Light-duty and heavy-duty vehicles, military vehicles, buses – larger vehicles that have more available volume for the hydraulic reservoirs.

Alternative Technologies for Better ICE Ecology

It is argued that some fuels need to be phased out, not ICEs. And indeed, there are many suitable replacements of conventional fuels – biodiesels, methanol, ethanol, natural gas and hydrogen. Biodiesels made from vegetable oils and residues and animal fat residues for example are added to conventional diesel fuel in order to reduce soot and carbon oxide formation [22, 23]. Similarly, because of the possibility to be produced by renewable biomass resources, the biodegradability, and the lower lifecycle emissions due to consumption of CO_2 by the feedstock crops, methanol and ethanol are other popular alternative fuels They are used particularly in spark-ignition engines owing to their similar characteristics to those of gasoline [24-26]. Hydrogen is also implemented in gas-fuel cycles by injecting it in the inlet manifold of the engine to improve its economic and ecological parameters [27]. Direct hydrogen injection (pure hydrogen engine) has also been extensively researched recently as it is considered more beneficial than gas-fuel cycles because it achieves higher efficiency and emissions only of nitrogen oxides [28]. Currently, all alternative fuels face obstacles for their widespread utilization mostly due to lack of sufficient amounts of production feedstock, hydrogen in particular suffers from absent delivery infrastructure and the complicated storage technologies.

Other ICE enhancing technologies are such that process the exhaust gasses to further extract energy from their pressure or heat. In turbocompounding for example, the exhaust gasses are put through a power turbine which has its output shaft connected mechanically to the engine's crankshaft, or to a generator, to achieve greater fuel economy. Mechanical turbocompounding has been used in commercial heavy-duty diesel engines for a long time already and is expected to grow in popularity in the next decade [29]. The power turbine can be added in series or parallel to the turbocharger, or alternatively, as a part of it.

About 40% of the energy of the fuel is lost as heat which makes waste heat recovery systems very intriguing. An example of such systems is the thermoelectric generator (TEG) system, working based on the Seebeck effect and taking advantage of silent operation, no moving parts and high reliability. It is mounted in the vehicle's exhaust gas system and charges a battery by converting the temperature differences into electrical energy [11]. The Rankine cycle (RC) is the most promising means for energy recovery from exhaust heat – a working fluid is evaporated and expanded to generate electricity, and then condensed and put through the cycle once again. The system is most notably used in heavy-duty diesel engines where there is enough space and waste heat for its realization. Up to around 14% cycle efficiency had been reported [30]. The main disadvantage of systems that regenerate energy from waste heat is the higher complexity and higher cost that they bring to the vehicle.

The combustion process taking place inside the cylinders of ICEs can also be optimized for lower emissions of harmful chemicals, by adopting advanced combustion strategies – homogenous charge compression ignition (HCCI) and reactivity-controlled compression ignition (RCCI). HCCI has the potential to lower and curb emissions of particular matter (PM) and nitrogen oxides (NOx), but it needs to adopt a multiple injection strategy and high EGR for best thermal efficiency. However, the high emissions of hydrocarbons (HC) and carbon oxide (CO) and the harsh combustion phase control makes for very scarce practical implementation of the technology. RCCI, on the other hand, is a dual-fuel method which similarly to HCCI reduces the level of PM and NOx, but also has higher thermal efficiency than diesel-fuelled engines and significantly better combustion phase control than HCCI. Nevertheless, the emissions in RCCI of HC and CO, even though lower in comparison to HCCI, are still higher than in conventional single-fuel combustion strategies [31]. These two advanced technologies have great potential and with the resolution of the difficulties they face, they could easily be applied in many types of vehicles, especially in such that operate in urban areas where the pollution of PM and NOx is the highest.

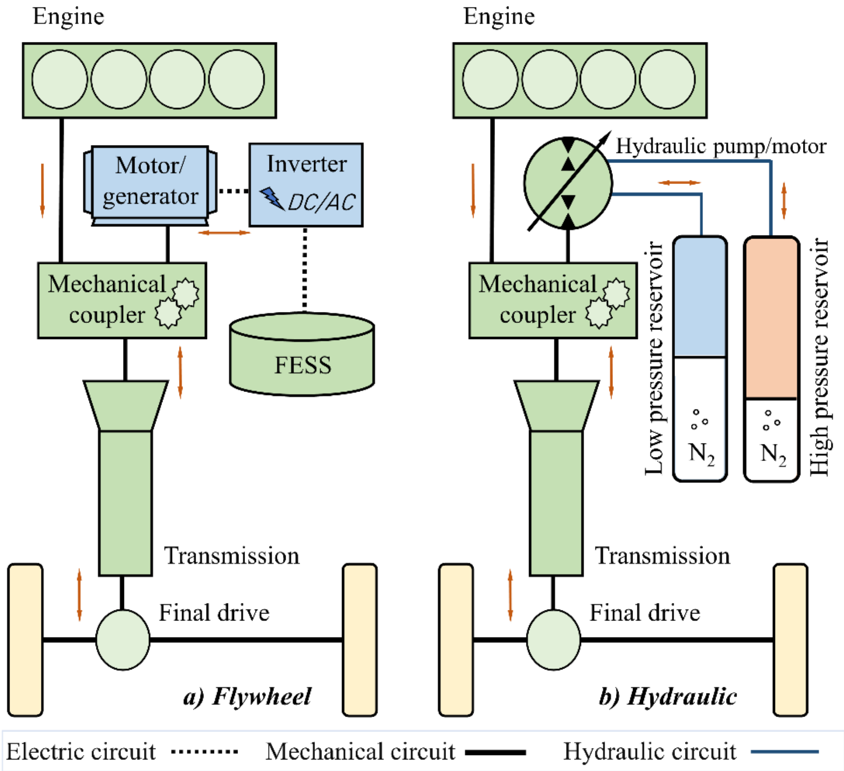

FIGURE 3. Simple schematics of other hybridization technologies linked in a parallel topology: a) flywheel hybrid, b) hydraulic hybrid.

BATTERY ELECTRIC VEHICLES

Battery electric vehicles (BEVs), or also known as pure electric vehicles (PEVs) utilize only an electric propulsion powered by a battery pack, or alternatively by a hybrid storage system incorporating a battery pack and supercapacitors, or a battery pack and FESS. BEVs do not have an exhaust gas pipe, the electric powertrain occupies significantly less space than the powertrains of conventional and hybrid vehicles, and they also emit less vibrations and noise. They produce zero onboard emissions, thus are considered more ecological than conventional and hybrid vehicles, yet the production of batteries leaves a serious carbon footprint. Nonetheless, the overall lifecycle well-to-wheels emissions of BEVs are lower when renewable energy is applied [32].

A simple schematic of the typical powertrain design for BEVs is shown in Fig. 4 a). The motor/generator can either be DC, or AC, therefore it is powered by the battery pack in motor mode either through a voltage converter, or an inverter. In generator mode the MG regenerates braking energy and charges the electrical storage system.

Some of the drive schemes in modern passenger electric cars are the same as the ones in ICE-driven cars. The classical layout (front motor and rear-wheel drive) is used only in some hybrids and electric cars that are converted from vehicles having an engine. Front-wheel drive is mainly used in compact urban electric cars, with the electric motor, power and control electronics located in the front part and the battery, as it is with other modern electric cars, most frequently located in the floor of the chassis.

Electric vehicles built on completely new platforms such as Volkswagen ID, if they are not in four-wheel drive variant, use a drive via a single electric motor located at the rear axle. This layout allows better utilization of the engine power during acceleration. The improved traction properties and stability when launching, cornering, and braking in regeneration mode determine the wide use of electric cars with a single rear axle electric motor.

The topology with an ICE located centrally or at the rear axle of the vehicle is not applied in contemporary passenger cars, only occasionally in some sports cars. This is due to the low load on the front axle, and thus the resulting poor stability of the vehicle. Additionally, this topology eliminates the space of the back trunk and the back passenger seats. This is not the case with electric cars where the weight distribution along the length of the car is very good, as the battery is in the chassis floor, and the electric motor is more compact, which guarantees easier mounting and more free space compared to the ICE. The electric motor can be located at a lower level than the ICE so that there is enough place above it for the trunk and the rear seat arrangement. This type of propulsion topology has good traction performance on all road surface types and with different number of passengers.

Particularly promising for electric cars is the usage of a distributed drive through separate (individual) motors for each wheel. The advantages of such a drive are expressed in a faster and more accurate response to the torque control and independent control of the electric motor of each wheel, thus ensuring better dynamics and energy efficiency of the electric vehicles [33, 34]. Moreover, if two MGs are connected through fixed gears to the wheels there is no need for a conventional final drive with a differential. Alternatively, the in-wheel (hubmotor) drive almost entirely abandons mechanical gearing by installing the MG inside the wheel, in this way further simplifying the powertrain. Only a thin planetary gearset may be placed coupled with the motor to enhance its torque [13]. The MG in all electrical propulsions is controlled by a controller device that operates according to the energy management strategy and the driving conditions.

FUEL CELL ELECTRIC VEHICLES

Another alternative powertrain vehicle which is essentially a BEV, is the fuel cell electric vehicle (FCEV or FCHEV) that uses a FC instead of an ICE as main power generator. Fuel cells have high efficiency (up to 65% electrical) and can process different types of fuels to generate electricity with low to no onboard emissions, low noise and vibrations, and relatively low maintenance. However, the major disadvantages of FCs are the very high cost because of the precious metals applied, the low power density, owing to slow response times in energy dispensing, and the hardships associated with hydrogen production and delivery when it is used as fuel [35].

The most widely used fuel cell in such a powertrain is the proton exchange membrane fuel cell (PEMFC). It has a compact design with a solid proton exchange polymer membrane for an electrolyte which has good mechanical and thermal stability. It also processes gaseous hydrogen with high purity (99.99 %) as fuel. It operates at low temperature and pressure and has relatively fast start-up times, hence it is ideal for automotive applications. A typical schematic of this powertrain is presented in Fig. 4 b). The fuel cell supplies DC voltage through a converter to a DC MG, or through an inverter to AC MG. Additional buck/boost DC/DC converters are used to charge the battery pack and the supercapacitors. Supercapacitors may be used in addition to the battery to assist the propulsion in transient dynamic regimes, as they have good power density.

Yet again Toyota pioneered a new technology on the automotive market - the Toyota Mirai which is by far the most well-known commercially-available FCEV. Other models include the Hyundai Nexo and the Honda Clarity FC. They all utilize pure gaseous hydrogen stored in a carbon-fibre reservoir under 70 MPa pressure. There is also ongoing research for implementation of the technology in other vehicles such as forklifts, carts, buses and heavy-duty vehicles [36]. PEMFC is especially envisioned to be the main power generator of future road heavy-duty transportation, due to the comparable driving ranges and fuelling times of systems incorporating a PEMFC to the ones of conventional ICE-driven vehicles. Nevertheless, the issues with hydrogen production, storage and delivery also need serious addressing.

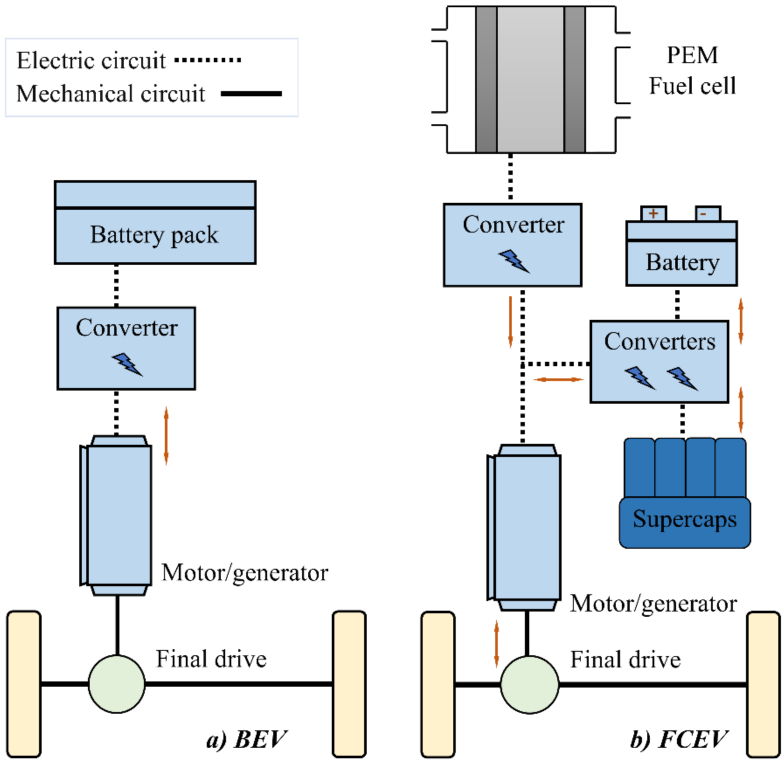

FIGURE 4. Simple schematics of electric vehicles: a) battery electric vehicle, b) fuel cell electric vehicle.

Possibilities for FCEV with Other Types of FC

Other FC technologies that can be applied in a vehicle's powertrain are direct methanol FC (DMFC) and solid oxide FC (SOFC). DMFCs, that are a subcategory of PEMFC, are limited to about 40% efficiency and also have lower power density than PEMFC, but they use a widespread fuel – methanol, which can be produced from a variety of methods, including environmentally friendly ones. DMFC systems are used in small vehicles such as forklifts.

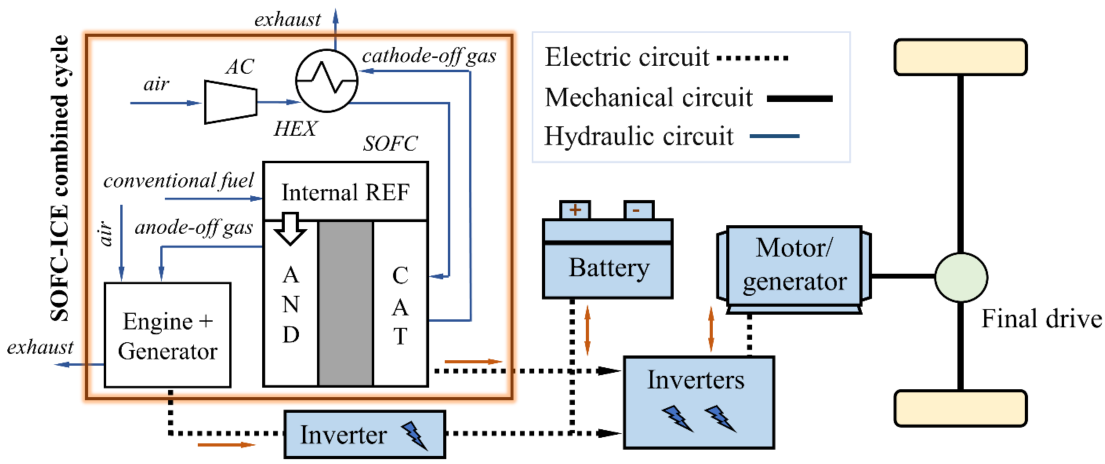

FIGURE 5. Schematic of a powertrain with SOFC-ICE combined cycle for main propulsion.

Of more serious interest are solid oxide fuel cells. They have a solid ceramic electrolyte and work at very high temperatures – up to 1200 °C – this provides them with the possibility to process internally conventional hydrocarbon fuels. The anode outlet gasses of the SOFC are combustible which also allows for an ICE or a gas turbine to process them and thus additionally increase the efficiency to reach 85% in cogeneration. In Figure 5 is shown a schematic of a concept SOFC-ICE hybrid vehicle. Such a powertrain makes it possible to significantly lower harmful emissions in comparison to conventional systems while having higher efficiency and applying a widespread fuel (diesel, gasoline, natural gas) [37]. The disadvantages of such a system are its complexity, very high cost and severe thermal management. It could be most beneficial in heavy-duty vehicles. SOFCs can also be utilized as auxiliary power units in heavy-duty transportation for power generation during idling [38].

CONCLUSIONS

Based on the analysis of the available literature on various alternative powertrains and powertrain technologies for application in vehicles, Table 4 was prepared, emphasizing on the advantages and disadvantages of the most popular alternative propulsion systems over conventional ICE-driven powertrains. It is evident that all of them produce less or no onboard emissions, and also have higher efficiency, due to braking energy regeneration and dynamic energy management depending on the driving mode. HEVs and FCEVs have higher powertrain complexity than conventional vehicles, while all of the alternative technologies are generally more expensive. There are also concerns regarding the driving range and battery lifecycle of BEVs, while the better establishment of FCEVs on the market is hindered by the lack of infrastructure and storage facilities for hydrogen produced by renewable recourses. Generally, alternative powertrain technologies have a great potential to replace conventional ones as it is the intention in the plans of the European Commission, but a lot of research and development mostly of the BEV and FCEV technologies needs to be done in order to make them more competitive in terms of cost, range, and reliability, in order to penetrate deeper in the sector and become better suited for all types of vehicles.

TABLE 4. Advantages and disadvantages of alternative powertrains over conventional ICE powertrain.

Type	Advantages	Disadvantages	Applicability
HEV	• Lower onboard emissions. • Utilizing regenerative braking. • High efficiency of the electric propulsion. • Possibility of applying different propulsion based on the driving conditions.	• Higher weight due to batteries. • Higher system complexity and more complex energy management strategy.	In all types of vehicles, preferably in urban-type passenger ones.
BEV	• Zero onboard emissions. • High efficiency of the electric propulsion. • Lack of transmission or use of a smaller one. • Simple energy management strategy.	• Higher weight due to batteries. • Long recharging times and limited driving ranges. • Performance more vulnerable in extreme conditions in comparison to ICEs. • Battery life concerns and high price.	Can be applied in all types of vehicles, but most suitable for small urban-type passenger ones for small trips.
FCEV	• Lower to zero onboard emissions. • High efficiency of the FC and the electric propulsion. • Fast fuel recharging and satisfactory drive ranges.	• Higher system complexity and more complex energy management strategy. • Lack of facilities for fuel production, storage and delivery, complex fuel storage and handling. • High price.	In all types of vehicles, preferably in heavy-duty ones.

ACKNOWLEDGEMENTS

This study was funded by the project "Passenger cars efficiency improvement by means of optimized operation engine-turbocharger" № КП-06-Франкофония/3 within the frame of bilateral program BNSF-AUF session 2018, and was also funded by project BG05M2OP001-1.001-0008 "National Centre for Mechatronics and Clean Technologies" Operational Program Executive Agency, Ministry of Education and Science, Bulgaria.

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