Study of Advancement of Hybrid Vehicle 'Combination of Internal Combustion Engine & Electric Method'

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Abstract: ***In recent years, the mobility industry has quickly transitioned to electric powered transportation. The most well liked option lately has been hybrid electric automobiles, which blend conventional and electric combustion engines. This is because, in contrast to the re-fuelling point system, which is still quite limited in certain nations, longer autonomy and progressively larger re-fuelling networks are to blame. With regard to the thermodynamic models of heat engines used in hybrid electric vehicles and their corresponding configurations for series, parallel, and mixed powertrains. The most significant combustion engine thermal energy models, including the Otto cycles, which are frequently employed in commercial hybrid electric vehicle models, will be covered.***

Keywords: hybrid configuration series, parallel, mixed, micro-hybrid, hybridization, mild-hybrid, full-hybrid, hybrid electric vehicle, thermodynamic models, and ignition engines.

1. Introduction

Nowadays, low pollutant mobility throughout the world is being substantially developed and promoted, especially focusing on the automotive segment. In this regard, the transport sector represents one of the main sources of air pollution, especially by contributing carbon monoxide, unsmoked hydrocarbons and nitrogen oxides (NOx). Because of the increasing importance given to pollution concerns, many efforts have been conducted in recent years to develop different techniques and approaches to minimize gas emissions caused by the mobility sector. At the same time, environmental anti-pollution laws are evolving to address the incoming environmental issues in order to safeguard ecosystems and people's health. Such is the case of the Euro standards, which are regulating key aspects Emission Standards in India. Consequently, unlike the Indian and American automotive markets which have objectives of manufacturing gasoline hybrid vehicles, hybrid solutions with diesel engines have been profusely studied in the Indian market by leading brands such as Maruthi-Suzuki, Bajaj 3 Wheelers.

According to the Automotive Engineers, a hybrid vehicle can be defined as that vehicle with two or more energy storage systems which must provide power to the propellant system either together or independently. Similarly, the heavy dutyhybrid vehicles group indicates that a hybrid vehicle must have at least two energy storage systems and energy converters. In practice, a hybrid electric vehicle combines the great autonomy of conventional vehicles with spark ignition engines, compression ignition engines, fuel cells and solar panels with the speed, performance and environmental advantages of electric vehicles, obtaining an automobile with lower fossil fuel consumption and lower pollutant emissions to the atmosphere.

Driving Range (km)

Table 1: Characteristics of various type of vehicles

Fuel	Compact and Small	Mid and Large
All electric	94–360	320–650
Plug-in hybrid	500–800	480–1000
Fuel cell electric	570	600

Besides the electrical part of an HEV, the conventional combustion layout is still present in current HEV models. The combustion components are expected to have a vital importance in future HEVs, helping to overcome the limitations of purely electric vehicles. In this sense, the combustion system is still necessary for extending the autonomy offered by the electric counterpart. In addition, electricity cost in many countries is still quite high and few competitive with traditional fuel prices. In this context, vehicle manufacturers and researchers have developed many configurations for coupling both systems. The various configurations with the application of a heat engine and an electric traction in an HEV seek significant improvements in autonomy, as the heat engine has the mission of recharging the batteries in a standard configuration and provides the propulsion force in conditions of constant running and overtaking. This studyprovides most typical configurations applied in industrial HEVs. The state of art of the model considered in such applications are studied. This way, this study aims at providing an overall current technological status of HEVs, with emphasis on the vehicle layout and mathematical models.

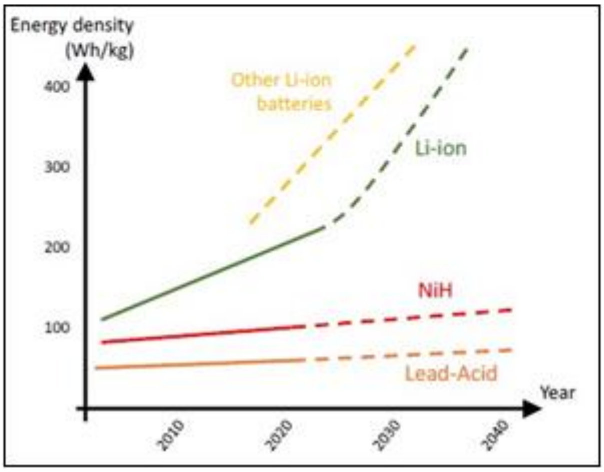

Figure 1: Energy density feature for various typical battery technologies in automotive sector and expected future trends

2. Most Typical Configurations for HEVs

In general, a power train system for a vehicle in general requires meeting a series of characteristics

- High performance.
- Low pollutant emissions from fossil fuels.
- Enough energy storage on board to cover adequate autonomy.
- Sufficient power generation to supply the various requirements in the driving and behavior of a vehicle.

The powertrain is defined as the junction of an energy source and the energy converter or also referred to as a power source. For example, gasoline and ICE, hydrogen-fuel cells and an electric motor, batteries and electric motor, etc. the overall energy flows in a hybrid powertrain. There is the possibility of operating two powertrains according to load requirements. In the case of the vehicle with gasoline hybridization comprising ICE, battery system and electric motor, the path 1 indicated in Figure 2. Through this energy path, the propulsion mode with ICE is only applied when the batteries are almost discharged and the ICE is not able to charge them, or also when the batteries have been fully charged and the ICE is able to supply the power demand of the vehicle. In contrast, the path 2 corresponds to the purely electric mode, in which the ICE is switched off, for example, at low speed or in zero pollutant emission zones. The path 2 can be conducted in reverse mode when the batteries are charged from the ICE.

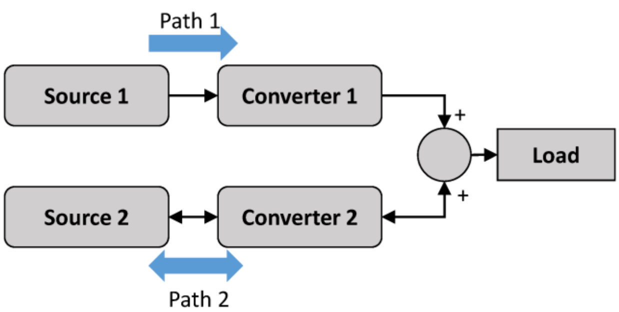

Figure 2: Energy flows in a hybrid power train

The transmission of an HEV lacks a conventional gearbox. In contrast, the centralpart in the transmission of such vehicles is the epicycloid gear, also called planetary, from where the movement to the intermediate sprockets is transferred. Figure-3 schematically illustrates a typical transmission for a hybrid vehicle.

The movement towards the differential assembly is through the intermediate sprockets while the backward movement is achieved by reversing the direction of the electric motor.

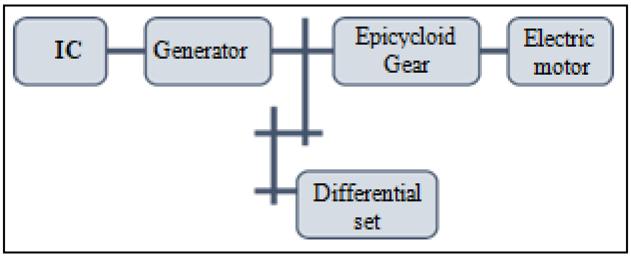

Figure 3: Schematic diagram of typical hybrid transmission

3. Classification by Vehicle Hybridization Level

In essence, the hybridization concept refers to HEVs and mentions the level at which a vehicle could be considered as purely electric. Roughly speaking, the hybridization level determines the importance of the electric and combustion systems of an HEV. The hybridization of an HEV could be conceived from two different point of views Hybridization of the propulsion system this classification comprises those vehicles that have at the same time an electric traction system and another based on a heat engine. Therefore, both systems have the ability, either independently or in combination, to propel the automobile. Propulsion system hybridization vehicles are composed of a heat and electric motor, but the latter is only used for starting and keeping the vehicle at low speeds over short distances. Hybridization of the power supply system: in this case, the vehicles have more than one type of energy system, which could be either production or storage, being at least one of them purely electric. Intuitively, this configuration must count with at least an electric motor. The hybridization system with power supply combines an electrical system and a fuel that serves to increase the autonomy, but the tractor system will be electric, being the function of the heat engine to recharge the batteries when they are running out. This model is also valid for fuel-cell electric vehicles, in which the electric energy is produced through fuel cells that convert hydrogen to electrical energy.

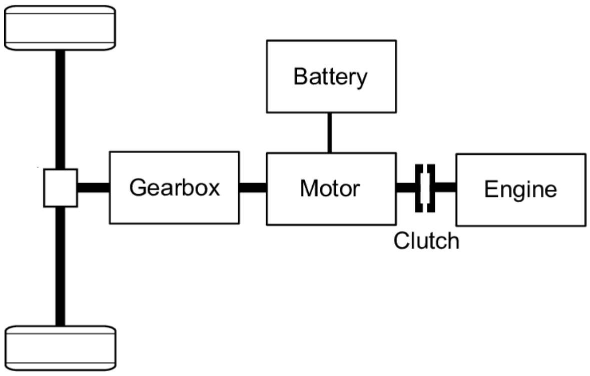

Figure 4: Typical architecture of an HEV with full-hybridization level

3.1 Micro-Hybrid

The vehicles in this classification encompass the alternator and the start button in the same set. A small electric motor is other key feature of this kind of vehicles. In this sense, the engine only serves to charge the battery system as much as possible during braking phases, besides providing the so-called 'Stop and Start' service, which is devoted on restoring the heat engine before starting the running. In this sense, any automobile thatprovides such kind of capability could be encompassed into this category. One highlight ofthe 'Stop and Start' service is the moment during which the engine is put on below 6 km/h, and starts automatically with the help of the electric motor when it needs to accelerate again.

3.2 Mild-Hybrid

In the second category, the mild-hybrid vehicles have a more powerful electric motorand are usually equipped with a higher capacity battery system. This configuration allowsthe electric system supports the heat engine even during acceleration. However, the electriccounterpart is still only able to partially fulfill the function of ICE, because it lacks thesufficiently capacity for propelling the vehicle by itself.In this kind of HEV, the electricsystem is also used to start the propulsion of the vehicle and initialize the whole traction system. This type of hybridization system allows to recover the kinetic energy of the vehicle through the braking phase with reversible electrical components, in the same way the gasoline economy is favorable because it typically ranges from 20% to 25%.

3.3 Full-Hybrid

In this category, the vehicles typically encompass a heat engine (MEP-MEC) and an electric motor both connected to the transmission. Additionally, this scheme incorporates agenerator and a high capacity battery. The full hybrid vehicles usually can operate under pure-electric mode up to 30 or 40 km/h, beyond that, the electric system needs to be supported by the heat engine. During acceleration, the electric motor supports the thermal system, whereas in braking and retention the kinetic energy is transformed into electricity and stored in batteries. The electric motor is also useful during starting processes, which makes this configuration very suitable for long trips with frequent start-stop transitions. Both systems are mechanically connected with the wheels, allowing to circulate in electric mode, being the most efficient solution allowing to reduce the gasoline consumption by 45%. The Toyota Prius supposes a notorious example of this kind of hybridization level. This vehicle uses a permanent electric motor coupled to the transmission and a petrol engine that gives movement to a generator, also incorporating a 200 V battery located at the rear. The size of the heat engine can be reduced, applying the concept of downsizing and large capacity battery.

3.4 Plug-in-Hybrid

The vehicles within this category present an architecture very similar to the full-hybrid level. However, the plug-in-hybrid has the capability of being connected to an upscale electric grid. This way, the battery system can be recharged from the traction system during breaking stages or directly from the electric system. One interesting feature of this kind of vehicle is the possibility of exploiting the on-board storage system for grid supporting tasks. For example, the vehicle batteries could be exploited as storage facilities in smart homes through bidirectional chargers, thus supporting the labor of onsite renewable generators on pursuing a more efficient energy management in dwellings.

Figure 5: Vehicle- to- homecapability

4. Classification by Architecture

The HEVs are often classified attending to their architecture. This classification attends to the on-board system layout, components and interconnection and enabled energy paths among them. Subsequent sections describe the different categories within this classification approach.

4.1 Series Configuration

The vehicle is driven entirely by the electric motor, which is moved by a heat engine with fuel supply. Figure-6 shows a schematic diagram of this architecture. The mechanical output of the ICE is first converted into electricity by a generator then, this energy could be destined to charge the batteries or propel the wheels through the electric motor, which also allows to capture the energy during braking. Thereby the ICE is mechanically decoupled to the transmission system.The vehicle generally works at those operating points by which consumption and emissions are minimal. By this configuration, the battery system acts an accumulator facility that can store the excess of energy thus allowing to disconnect the ICE momentarily. This principle is normally handled by energy management programs, which continuously control the state of charge of the batteries on pursuing a fuel consumption reduction.

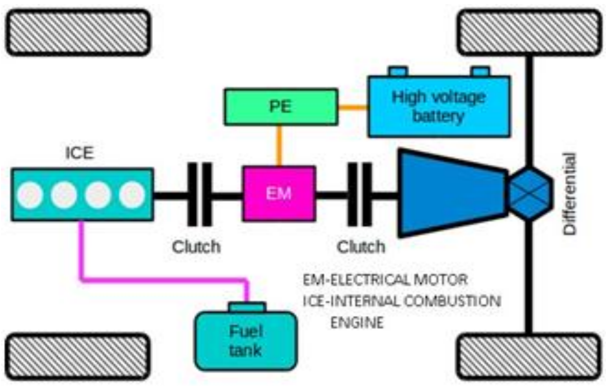

Figure 7: Parallel configuration of an HEV.

4.2 Parallel Configuration

By this configuration, both the heat and electric engines can propel the transmission systems. An electric hybrid vehicle with the parallel configuration has the ICE and electric motor coupled to the final drive axle of the wheels via clutches. Moreover, this configuration allows the ICE and electric motor to supply power to drive the wheels in combined or isolated modes. This way, both systems work in parallel. Figure-7 shows the schematic diagram of the parallel configuration for HEVs. This configuration supposes a remarkable simplification of the series architecture as the electric generator is no longer necessary. In this sense, the electric motor could work in reverse mode, converting the kinetic energy of the transmission system to electricity which is stored in batteries.

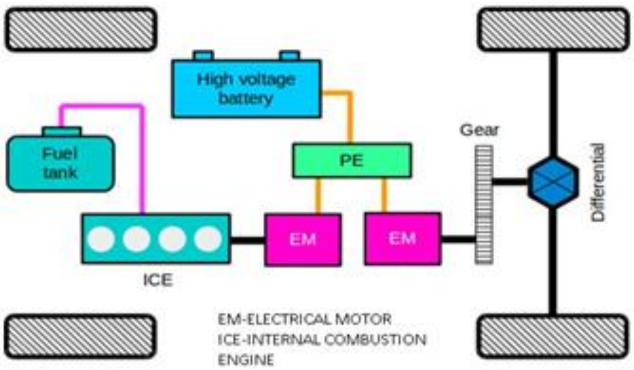

Figure 7: Parallel configuration of an HEV

4.3 Mixed Configuration

In essence, this configuration combines both previous architectures on a whole. Thisway, the vehicle could be propelled in this case through the ICE, the electric motor or both systems at once. The heat engine is directly connected to the transmission system and is mechanically coupled to the electric system through a differential set, which mechanically couples both electric and heat systems. The electric system is composed by a motor and a generator, which allows to convert the excess of energy produced by the ICE during braking into electricity to be stored in batteries. By far, this configuration is more complex than the others, but allows to gather all the advantages obtained with series and parallel configurations. Figure8 presents a diagram of the mixed configuration for HEVs.

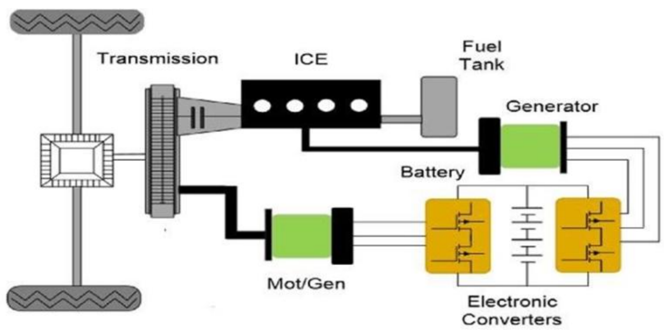

Figure 8: Mixed configuration of an HEV

5. Thermodynamic Models for HEVs

In this section, the most common thermodynamic processes in HEVs and the mathematical formulations usually considered for modeling them are reviewed. In this sense, thermodynamic processes in an HEV are frequently modeled by thermal cycles, thus allowing a simplification of their conceptualization making their analysis and optimization significantly simpler. In addition, the analysis of the thermodynamic cycles will allow an understanding of the fundamental trends for the design of the engines. Subsequentsections describe the most usual thermodynamic cycles in HEVs, i.e. Otto cycle.

5.1 Otto Cycle

This cycle is associated with the ignition process that happens in the heat engine. In the literature, this cycle is also called Spark ignition. Figure 9 shows the p/V scheme of the Otto cycle whose main steps are:

Adiabatic compression (1–2): Compression of the working fluid, the piston has to perform the work W1.

Contribution of heat at constant volume (2–3): instantaneous introduction of the heat Q1 isprovided.

Adiabatic expansion (3–4): Expansion, which is corresponding to theW_2work, per-formed by the working fluid.

Extraction of heat at constant volume (4–0): instantaneous extraction of Q_2 heat.

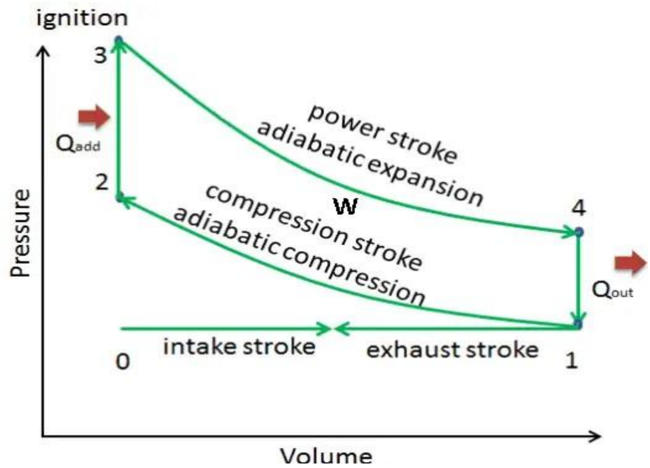

Figure 9: P/V diagram of the Otto cycle

In the engines of four strokes (4T), the extraction of heat occurs in the exhaust phase, from the opening of the exhaust valve (4–1–0). In addition, the mixture of the air–fuel fluidis introduced into the intake stroke (0–1). This process is graphically represented in the horizontal dashed line of the p/V diagram of Figure 9. Theoretically the processes (1–0and0–1) between them are cancelled out, in such away that a loss or gain of zero heat is generated, so that the p/V diagram of the ideal Otto cycle only considers the closed cycle. Similarly, the work in this phase is zero, $W_{2-3} = 0$ the heat supply is performed at constant Q_1 volume.

The mathematical model described above for the Otto cycle responds to ideal conditions. In practice, performing of heat engines may be far away to these ideal conditions mainly due to the following reasons

- Heat loss through the walls, caused by the need to have a cooling system for the ignition engines organs.
- Need to anticipate ignition with respect to death point, because combustion is not instantaneous and a certain time is needed.
- Exhaust opening advance, due to the inertia of the valves and gas masses.
- Loss of pumping work during the exhaust and intake stroke.

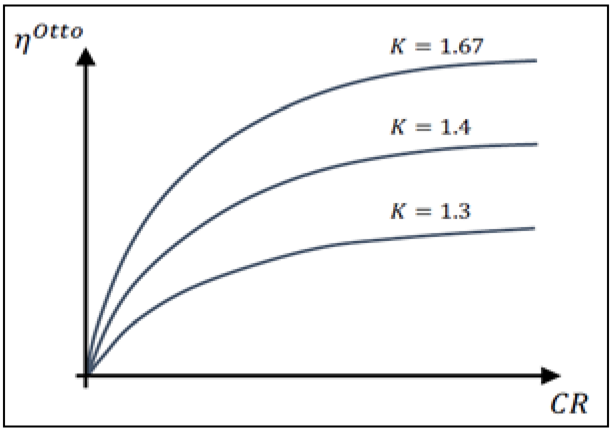

Figure 10: Thermal efficiency of the Otto cycle as function of the specific- heat and compression ratios.

6. Conclusions

This study has presented a descriptive of typical configurations and architectures for hybrid electric vehicles. Accordingly, the different configurations have been classified attending to different criteria. The main advantages and disadvantages of each architecture have been identified and highlighted with the aim of serving as a valuable contribution to related research and academic purposes. On the other hand, the usual thermodynamic cycle that are typically exploited in HEVs have been developed. Thus, Otto cycle have been mathematically elaborated.

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