CHAPTER EIGHT

Hybrid Electrical Vehicles

Introduction

A hybrid electric vehicle (HEV) has two types of energy storage units, electricity and fuel. Electricity means that a battery (sometimes assisted by ultra-caps) is used to store the energy, and that an electromotor (from now on called *motor*) will be used as traction motor.

Fuel means that a tank is required, and that an Internal Combustion Engine (ICE, from now on called *engine*) is used to generate mechanical power, *or* that a fuel cell will be used to convert fuel to electrical energy. In the latter case, traction will be performed by the electromotor only. In the first case, the vehicle will have both an engine and a motor.

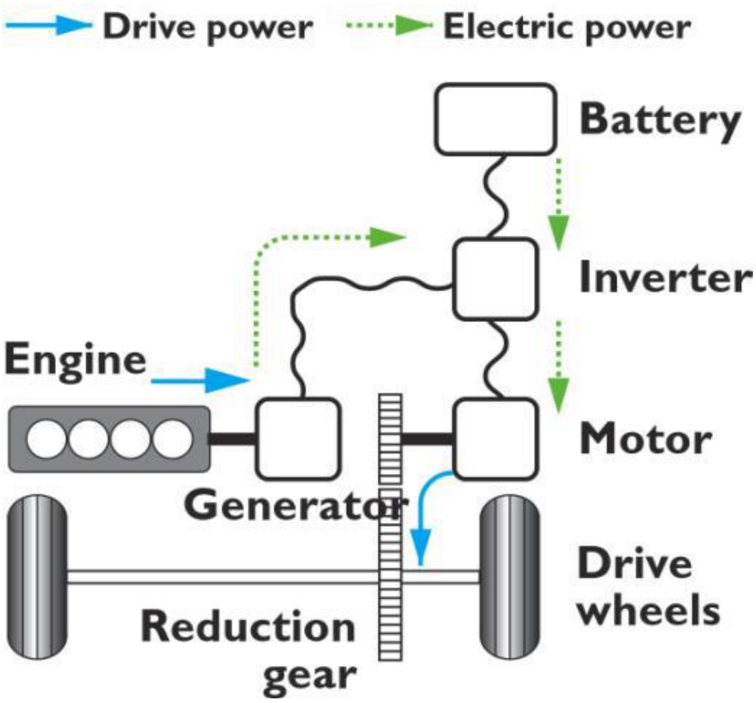
- ***Motors*** are the "work horses" of Hybrid Electric Vehicle drive systems. The electric traction motor drives the wheels of the vehicle.

  A main advantage of an electromotor (Motor) is the possibility to function as generator. In all HEV systems, mechanical braking energy is regenerated. The maximum operational braking torque is less than the maximum traction torque; there is always a mechanical braking system integrated in a car.
- ***The battery pack*** in a HEV has a much higher voltage than the SIL automotive 12 Volts battery, in order to reduce the currents and the I2R losses.
- ***Accessories*** such as power steering and air conditioning are powered by electric motors instead of being attached to the combustion engine. This allows efficiency gains as the accessories can run at a constant speed or can be switched off, regardless of how fast the combustion engine is running. Especially in long haul trucks, electrical power steering saves a lot of energy.

1. Types by drive-train structure

1.1. Series hybrid

In a series hybrid system, the combustion engine drives an electric generator (usually a three-phase alternator plus rectifier) instead of directly driving the wheels. The electric motor is the only means of providing power to the wheels. The generator both charges a battery and powers an electric motor that moves the vehicle. When large amounts of power are required, the motor draws electricity from both the batteries and the generator.

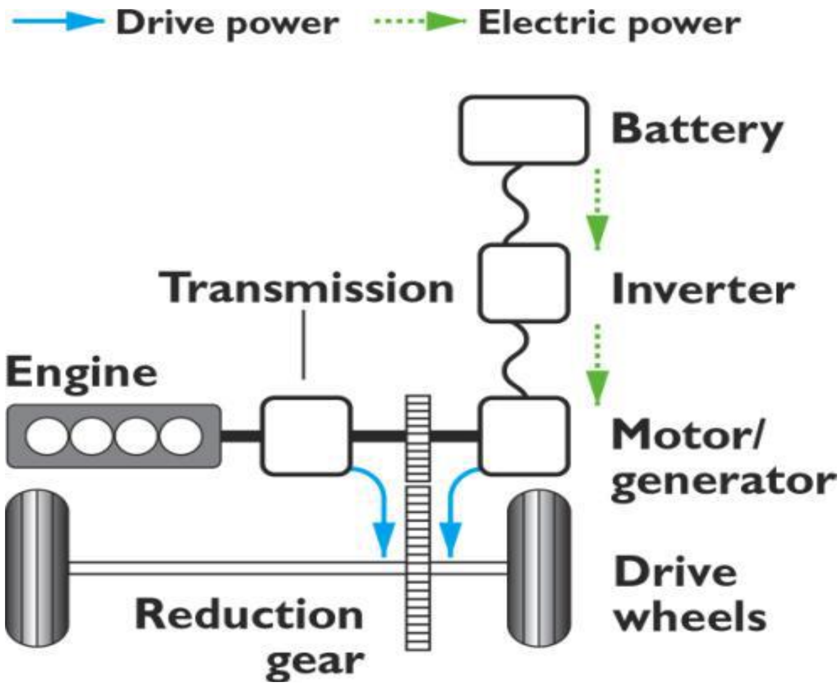


***<u>Advantages of series hybrid vehicles</u>*:**

1. There is no mechanical link between the combustion engine and the wheels. The engine-generator group can be located everywhere.
2. There are no conventional mechanical transmission elements (gearbox, transmission shafts). Separate electric wheel motors can be implemented easily.
3. The combustion engine can operate in a narrow rpm range (its most efficient range), even as the car changes speed.
4. Series hybrids are relatively the most efficient during stop-and-go city driving.

1.2. Parallel hybrid

Parallel hybrid systems have both an internal combustion engine (ICE) and an electric motor in parallel connected to a mechanical transmission.



☒ **Operation Modes:**

The parallel configuration supports diverse operating modes:

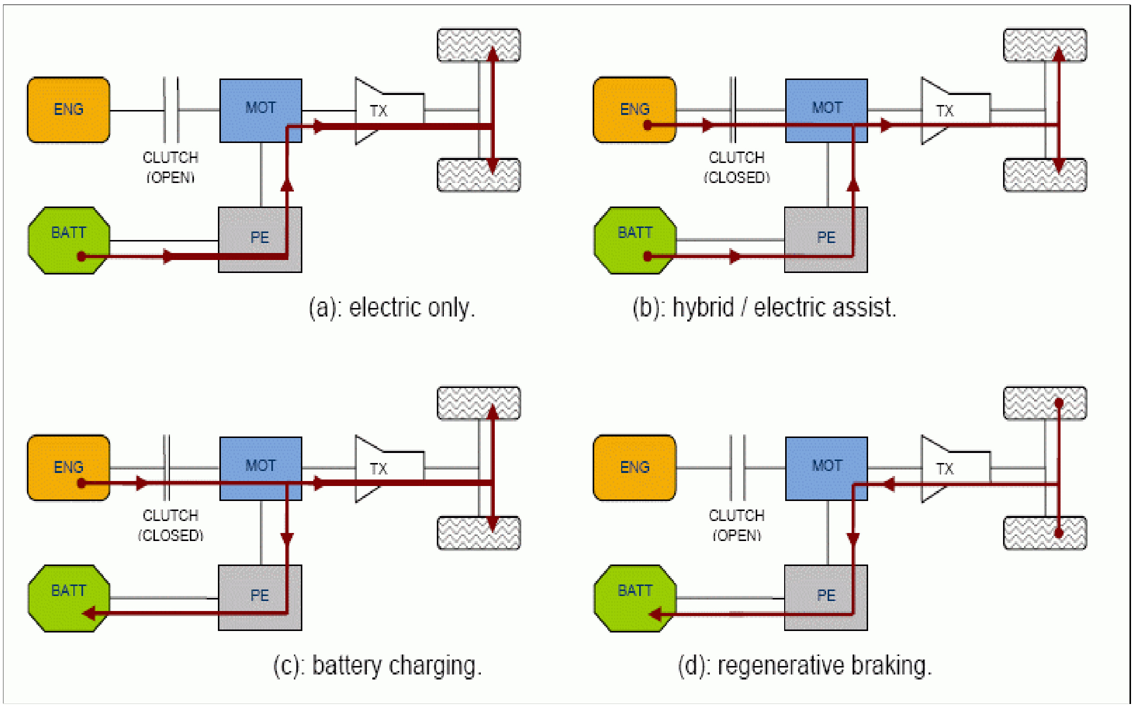
(a) Electric power only: Up to speeds of usually 40 km/h, the electric motor works with only the energy of the batteries, which are not recharged by the ICE. This is the usual way of operating around the city, as well as in reverse gear, since during reverse gear the speed is limited.

(b) ICE power only: At speeds superior to 40 km/h, only the heat engine operates. This is the normal operating way at the road.

(b) ICE + electric power: if more energy is needed (during acceleration or at high speed), the electric motor starts working in parallel to the heat engine, achieving greater power

(c) ICE + battery charging: if less power is required, excess of energy is used to charge the batteries. Operating the engine at higher torque than necessary, it runs at a higher efficiency.

(d) Regenerative breaking: While braking or decelerating,



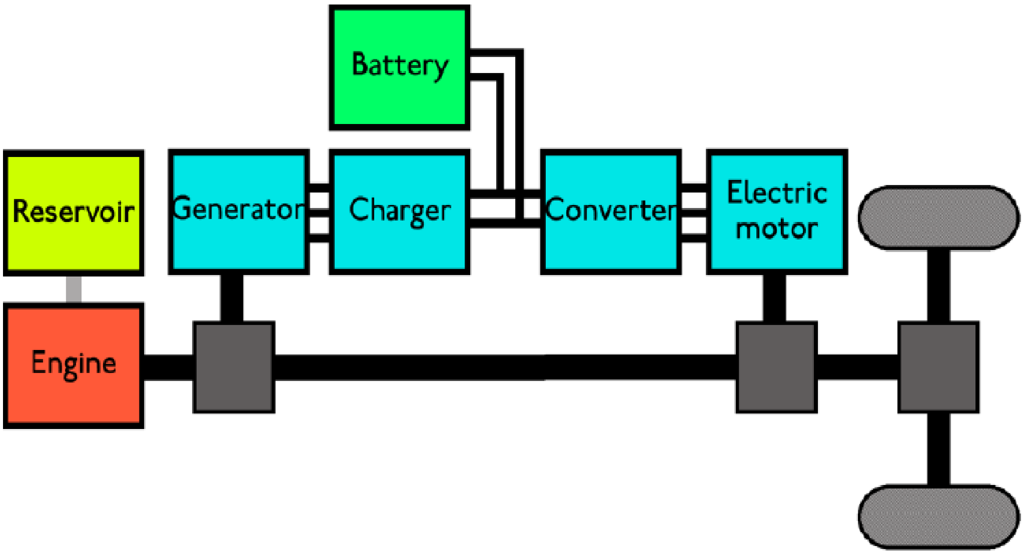
***Advantages of parallel hybrid vehicles*:**

1. Total efficiency is higher during cruising and long-distance highway driving.
2. Large flexibility to switch between electric and ICE power
3. Compared to series hybrids, the electromotor can be designed less powerful than the ICE, as it is assisting traction. Only one electrical motor/generator is required.

1.3. Combined hybrid

Combined hybrid systems have features of both series and parallel hybrids. There is a *double connection between the engine and the drive axle: mechanical and electrical*. This split power path allows interconnecting mechanical and electrical power, at some cost in complexity.

Power-split devices are incorporated in the power-train. The power to the wheels can be either mechanical or electrical or both. This is also the case in parallel hybrids. But the main principle behind the combined system is the *decoupling of the power supplied by the engine from the power demanded by the driver*.



Simplified structure of a combined hybrid electric vehicle

***Advantages of combined hybrid vehicles*:**

1. Maximum flexibility to switch between electric and ICE power
2. Decoupling of the power supplied by the engine from the power demanded by the driver allows for a smaller, lighter, and more efficient ICE design.

2. Types by degree of hybridization

Parallel and combined hybrids can be categorized depending upon how balanced the different portions are at providing motive power. In some cases, the combustion engine is the dominant portion; the electric motor turns on only when a boost is needed. Others can run with just the electric system operating.

2.1. Strong hybrid (= full hybrid): A full hybrid EV can run on just the engine, just the batteries, or a combination of both. A large, high-capacity battery pack is needed for battery-only operation.

2.2. Medium hybrid (= motor assist hybrid): Motor assist hybrids use the engine for primary power, with a torque-boosting electric motor connected in *parallel* to a largely conventional power-train. EV mode is only possible for a very limited period of time, and this is not a standard mode. Compared to full hybrids, the amount of electrical power needed is smaller, thus the size of the battery system can be reduced.

2.3. **Mild hybrid/micro hybrid (= start/stop systems with energy recuperation)**: Mild hybrids are essentially conventional vehicles with oversized starter motors, allowing the engine to be turned off whenever the car is coasting, braking, or stopped, yet restart quickly and cleanly.

2.4. **Plug-in hybrid (= grid connected hybrid = vehicle to grid V2G)**: A plug-in hybrid electric vehicle (PHEV) is a *full hybrid*, able to run in electric-only mode, with larger batteries and the ability to recharge from the electric power grid. Their main benefit is that they can be gasoline-independent for daily commuting, but also have the extended range of a hybrid for long trips.

3. Types by nature of the power source

3.1. **Electric-internal combustion engine hybrid:** There are many ways to create an electric-internal combustion hybrid. The variety of electric-ICE designs can be differentiated by how the electric and combustion portions of the power-train connect, at what times each portion is in operation, and what percent of the power is provided by each hybrid component.

3.2. **Fuel cell hybrid:** Fuel cell vehicles have a series hybrid configuration. They are often fitted with a battery or super capacitor to deliver peak acceleration power and to reduce the size and power constraints on the fuel cell.

3.3. **Human power and environmental power hybrids:** Many land and water vehicles use human power combined with a further power source. Common are parallel hybrids, e.g. a boat being rowed and also having a sail set, or motorized bicycles. In addition, some series hybrids exist. Such vehicles can be tribrid vehicles, combining at the same time three power sources e.g. from on-board solar cells, from grid-charged batteries, and from pedals.

3.4. **Pneumatic hybrid:** Compressed air can also power a hybrid car with a gasoline compressor to provide the power.

3.5. **Hydraulic hybrid:** A hydraulic hybrid vehicle uses hydraulic and mechanical components instead of electrical ones. A variable displacement pump replaces the motor/generator, and a hydraulic accumulator (which stores energy as highly compressed nitrogen gas) replaces the batteries. The hydraulic accumulator, which is essentially a pressure tank, is potentially cheaper and more durable than batteries.