Chapter 6
Power Flow in Hybrid Electric Vehicles and Battery Electric Vehicles

S. Madhu, A. Ashwini, and Karanam Vasudha

1 Introduction

Increasing levels of pollution, global warming and population are important concerns as we move towards the current century [1]. To overcome the effects of these problems on the environment and also for the human community, a shift must be required to sustainable transportation [2, 3]. The solutions are – to use a low or zero-emission vehicle, promote the use of public transport, use more and more renewable energy sources for charging, thus becoming less dependent on the depleting fossil fuels. With the interest to reduce the impact of emissions given out by the internal combustion engine vehicles and with the tremendous technological developments happening in the field of battery-operated vehicles, the interests of many researchers are shifting towards Electric vehicles [4]. Various steady developments and cutting-edge technologies are recorded in the past few decades which has led to the recent development of electric vehicles such as Autonomous driverless cars. Electric vehicles have greater advantages in all dimensions. Hence, wide use of electric vehicles (EV) is encouraged for transportation.

Electric vehicles implement modern electric propulsion consisting of electric machines, power electronic converters, electric energy sources, electronic controllers and storage devices. Based on the group of subsystems involved in the process and based on whether they transmit energy to wheels or energy to charge the battery, there are various modes of power flow operation possible. In Hybrid EV (HEV) and some of the Battery Electric Vehicles (BEVs) two power flow paths are possible. Different sets of components are involved in the transmission of energy from the sources to the wheels. These sets of components which operate together in the process are called Powertrain or drivetrains.

S. Madhu (✉) · A. Ashwini · K. Vasudha
BNM Institute of Technology, Bengaluru, Karnataka, India
e-mail: madhus@bnmit.in; ashwinia@bnmit.in; kvasudha@bnmit.in

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2 Types of Electric Vehicles

The vehicles can be classified in various ways, based on propulsion devices, energy sources and energy carriers. The classification based on the propulsion systems is internal combustion engine vehicles, hybrid EVs and all-electric vehicles [5]. The conventional IC engine vehicle has an internal combustion engine for propulsion. The energy sources used here are exhaustible fossil fuels, whereas EV runs on electrical energy derived from batteries, fuel cells and renewable energy sources. The important class of this classification is the Hybrid EVs which are further classified as Series HEV, parallel HEV, Series-parallel HEV and complex HEV. Plug-in EV is another upcoming type of HEVs.

The HEV is classified based on different aspects like the percentage of battery and ICE involvement for driving, power flow path during various modes of operation, etc. The different types of conventional HEV are Micro HEV, Mild HEV and Full HEV. In micro HEV, the battery is used for the start–stop and regenerative braking only. In mild HEV, the battery is used for start, stop, regenerative braking and power assistance. In full HEV, the battery is used for start, stop, regenerative braking, power assistance and electric launch. A more versatile operation is possible in the case of HEV [6].

All EV uses batteries and ultracapacitors as sources. Six types of configurations are existing for power transfer, among them three are widely used viz. battery EVs, Fuel cell EVs and Ultracapacitor EVs.

The design aspects depend on the energy requirement at the wheels and also on the power flow path. In the power flow path, a major amount of energy is required for all the components for its operation and also there is some amount of power loss that is unavoidable. In this regard, the power flow in the vehicle between the energy sources and the wheels is very important to be understood. In this chapter, the main focus is on power flow in HEV and BEV. The power flow in various modes of operation for all types of HEVs and BEVs is explained in the preceding sections.

3 Power Flow in HEVs and BEVs

The energy required for propulsion in HEVs is provided by the IC Engine, fuel tank and battery while in BEVs battery and ultracapacitors are the energy sources. Along with the energy source/s other key components of these EVs are electric motors & generators, power converters and controllers.

The various typical modes of operation are Acceleration of the vehicle, normal driving of the vehicle, light load condition, regenerative braking (deceleration), battery charging during driving, battery charging during standstill. There can be multiple energy sources to deliver the power as per the requirements. Let us consider the sources as 1 and 2 and with 2 as a battery, there can be various modes of operation possible based on power flow path as mentioned below:

- Sources 1 and 2 both supply power to the wheels
- Source 1 or source 2 alone supply power to the wheels
- Source 2 (here Battery) receives power from source 1
- Source 2 receives power from wheels and stores it
- Source 1 supplies power to the wheels and also to source 2
- Source 1 supplies power to the supply 2 and supply 2 to the wheels
- Source 1 supplies power to the wheels and the wheels deliver power to source 2

In the above modes of power flow operation, the power flow path may or may not include the power converters depending on the type of power and the voltage levels at different subsystems. The power requirements to propel the vehicle due to frequent changes in the system requirements as per the drive cycle needs different power flow paths. As per the need during acceleration, deceleration, normal drive, etc. load power may be steady power or dynamic power. The operation of the vehicle with the two supplies operating in coordination favours all the conditions as per the need. The subsystems in any configuration have to be decided based on the types of sources available, the need for power converters and electric motors. In the preceding section, the power flow modes of operation for various configurations are presented. The architecture considered here is typical structures that may vary as per the power levels required, AC or DC power, voltage levels, etc.

Based on the component integration, its location and working we obtain various vehicle designs. The various types of HEVs and BEVs and their architecture are presented in this section.

3.1 Power Flow in HEV

A full hybrid electric vehicle can operate with IC engine mode alone, an electric mode alone or in a combination of both the IC engine and motor together. It requires a complicated transmission system known as electronic variable transmission which is generally a high power device of 50–60 kW with a system voltage of 500–600 V [7, 8]. All the parts of HEV that work together with the IC engine to move the wheels and other parts of the vehicle to move are together referred to as a drivetrain. This includes the transmission, differential, driveshaft, axles and wheels. HEV configuration also increases its performance and an increase in the speed is provided when needed by the vehicle. The ICE can provide energy for charging the batteries and also batteries can regain energy through regenerative braking. Hence, HEVs are predominantly ICE-driven vehicles that can use an electric drivetrain for increasing their performance.

In HEV, the traction power required for the load is delivered together by the IC engine and the electrical motor. The amount of power and direction of power flow depends upon the load demand. Depending upon the architecture, HEV has different modes of operation viz. start-up, acceleration, normal driving, Braking, battery charging, etc. In this section, power flow for various modes of operation for each configuration is presented [7, 9–12].

3.1.1 Series HEV Powertrain and Modes of Operation

Figure 6.1 shows the architecture of a Series Hybrid drivetrain. The mechanical energy from the IC engine is converted into electrical energy by a generator. This power will charge the battery or it gets added with the battery power through the power converter for driving the electric motor. The function of the power converter is to act as a power coupler and control the flow of power from the generator and battery to the motor during acceleration and from the motor to the battery during braking. The IC engine, fuel tank and generator are the primary energy sources while the batteries are energy storage devices.

Based on the power flow there are four modes of operation in series HEV.

1. **Start-up/normal driving/acceleration mode:** Fig. 6.2a shows the power flow diagram during starting or normal driving or acceleration. In this mode, the electrical energy to the drive motor is supplied by both the battery and IC engine through the converter. The output of the motor is then delivered to the wheels via transmission.
2. **Light load mode:** Fig. 6.2b shows the power flow diagram at light load conditions. In this mode, the output of the IC engine is more than the power required for the propulsion of the vehicle. The additional electrical energy generated is hence used for battery charging. This continues till the battery is charged to its full capacity.
3. **Braking/deceleration mode:** Fig. 6.2c shows the power flow diagram when the vehicle is braking or decelerating. In this mode, the motor behaves like a generator to convert the kinetic energy of the wheels into electrical energy. This electrical output from the generator is used to charge the energy storage device through the power converter.
4. **Battery charging/standstill mode:** Fig. 6.2d shows the power flow diagram when the vehicle is at rest. In this mode, the IC engine continues charging the battery through the generator even if the vehicle stops or comes to a standstill position.

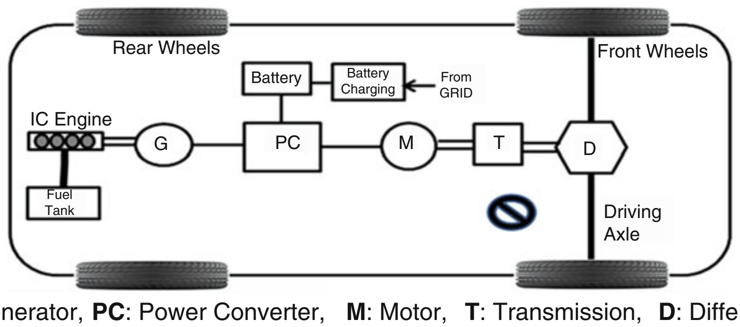


Fig. 6.1 Architecture of Series HEV configurations. *G* Generator, *PC* Power converter, *M* Motor, *T* Transmission, *D* Differential

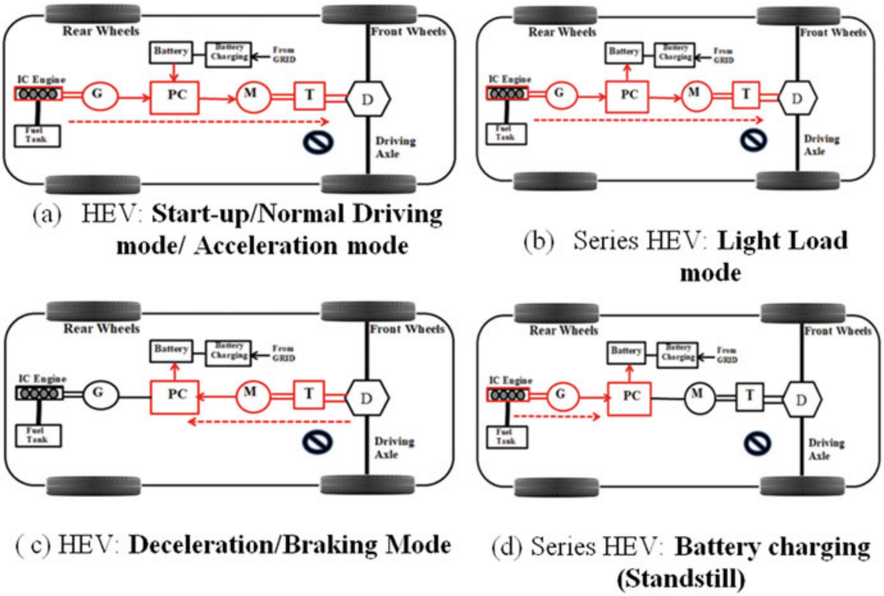


Fig. 6.2 Different power flow modes in series HEV

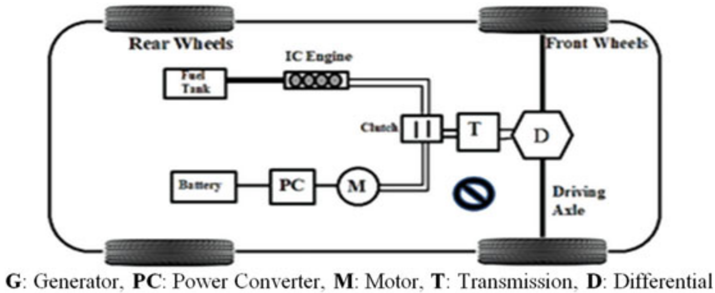


Fig. 6.3 Architecture of parallel HEV configurations. *G* Generator, *PC* Power converter, *M* Motor, *T* Transmission, *D* Differential

3.1.2 Parallel HEV Powertrain and Modes of Operation

Figure 6.3 shows the architecture of the Parallel Hybrid drivetrain. The IC engine and the electrical motor are coupled to drive the wheels through a mechanical coupler or a clutch. The power to drive the wheels is delivered either by the motor or IC engine or both. The IC engine is the primary power source while the motor can also work as a generator for charging the battery during braking/deceleration and absorbs power from the ICE when its power output is more than the power needed for traction.

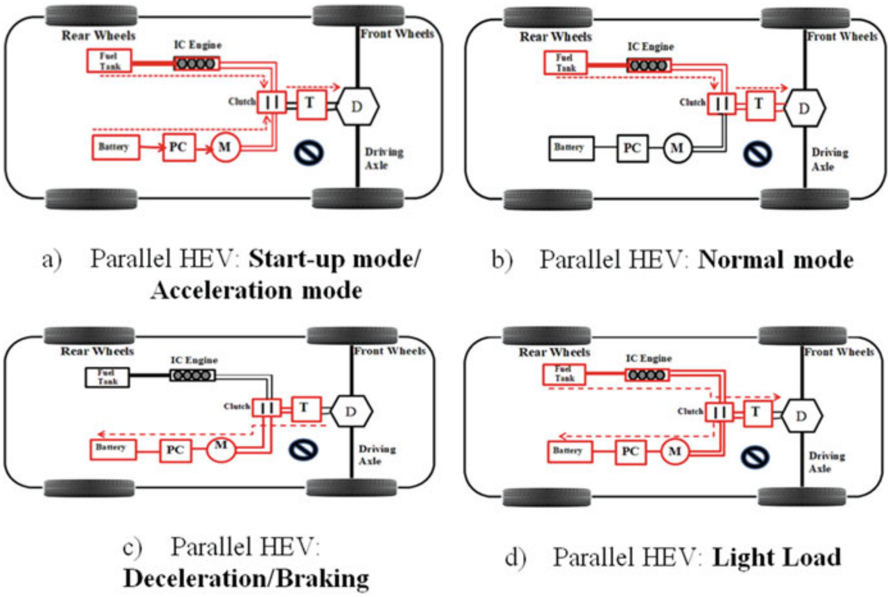


Fig. 6.4 Power flow modes in parallel HEV

Based on the power flow there are four modes of operation in Parallel HEV.

1. **Start-up/acceleration:** Fig. 6.4a shows the power flow diagram during starting or acceleration. In this operating mode, both the motor and the ICE supply power to drive the wheels via transmission. Typically, the energy distribution for propulsion is 80–20% for IC engines and electric motor.
2. **Normal driving:** Fig. 6.4b shows the power flow diagram during normal driving conditions. In this mode, the power for driving the wheels is delivered only by the ICE and the motor will be in standstill condition.
3. **Deceleration/braking:** Fig. 6.4c shows the power flow diagram during braking/ deceleration. In this mode, the generator action is provided by the motor itself and the available kinetic energy at the wheels is converted into electrical energy. This energy is then used to supply charge to the battery through the power converter.
4. **Light load and battery charging:** Fig. 6.4d shows the power flow diagram at light load condition. In this mode, IC Engine delivers the power required to drive the wheels as well as charges the battery through the electric motor and power converter.

3.1.3 Series-Parallel HEV Powertrain and Modes of Operation

Figure 6.5 shows the architecture of the Series-Parallel Hybrid drivetrain. This configuration employs both mechanical and electrical power couplers. It has the

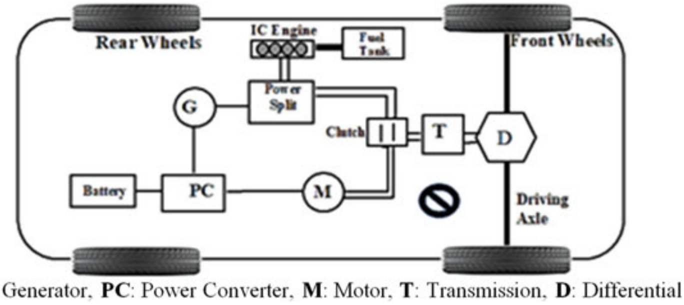


Fig. 6.5 Architecture of series-parallel HEV configurations. *G* Generator, *PC* Power converter, *M* Motor, *T* Transmission, *D* Differential

characteristics of series and parallel HEVs. It allows more operating modes than that of series or parallel drive alone.

Based on the power flow there are 12 modes of operation in Series-parallel HEV. As this system involves the characteristics of both series and parallel hybrid systems, several operating modes are possible which can be classified under two categories viz. ICE dominated and EM dominated. This mode is also called Dual-mode HEV [13].

The operating modes under the ICE dominant system are:

1. **Start-up:** Fig. 6.6a shows the power flow diagram at the start. In this mode, the battery alone offers the power required for driving the vehicle and the IC engine is in off condition.
2. **Acceleration:** Fig. 6.6b shows the power flow diagram during acceleration. In this operating mode, the electric motor and the IC engine share the traction power to drive the wheels.
3. **Normal driving:** Fig. 6.6c shows the power flow diagram during the normal driving condition. In this operating mode, the power required for propulsion is delivered only by the ICE and the electric motor in the off condition.
4. **Deceleration/braking:** Fig. 6.6d shows the power flow diagram during deceleration or braking. In this mode, kinetic energy at the wheels is transformed into electrical energy by the motor working like a generator and charges the battery through a power converter.
5. **Battery charging while driving:** Fig. 6.6e shows the power flow diagram of the battery charging while driving. In this mode, the IC engine delivers the power required for both traction and battery charging.
6. **Battery charging during standstill:** Fig. 6.6f shows the power flow diagram of the battery charging when the vehicle is at rest. In this mode, when the vehicle halts, the ICE charges the battery through the power converter.

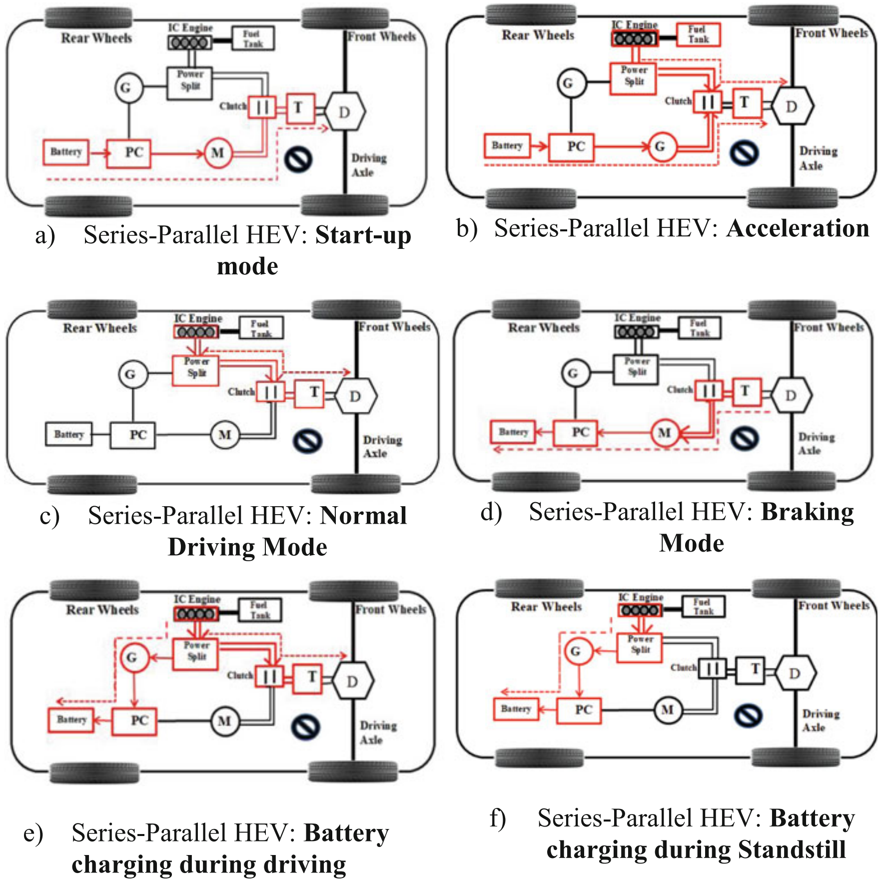


Fig. 6.6 Power flow modes in series-parallel HEV (ICE dominant)

The operating modes under EM dominated system are:

1. **Start-up:** Fig. 6.7a shows the power flow diagram at the start. In this mode, the battery alone supplies the required power for driving the vehicle whereas the ICE is in the off state.
2. **Acceleration:** Fig. 6.7b shows the power flow diagram during acceleration. In this mode, mechanical energy from the IC engine is transferred to the wheels along with a part being transmitted through the generator and motor. Also, energy from the battery is transmitted through the electric motor.
3. **Normal driving:** Fig. 6.7c shows the power flow diagram during the normal driving condition. In this mode, the IC engine delivers the required power to the wheels directly and also through the generator. So, in this operation, the battery is not used.

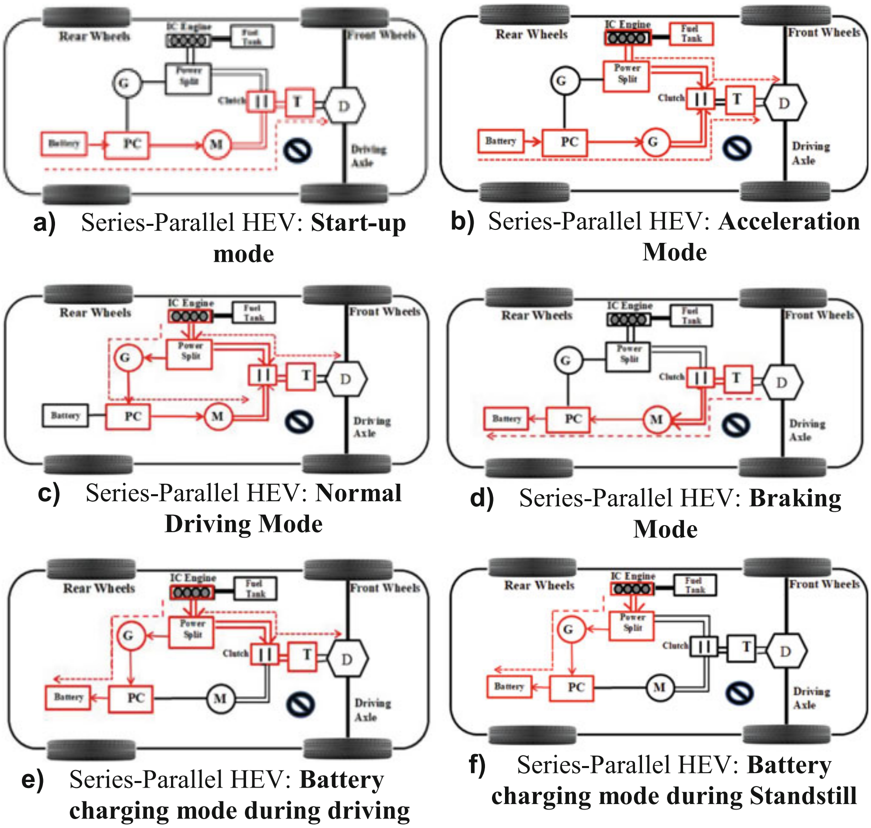


Fig. 6.7 Power flow modes in series-parallel HEV (electric motor dominant)

4. **Braking/deceleration:** Fig. 6.7d shows the power flow diagram during deceleration or braking. In this mode of operation, the kinetic energy at the wheels is transformed into electrical energy by the motor working like a generator and charges the battery via a power converter.
5. **Battery charging while driving:** Fig. 6.7e shows the power flow diagram of the battery charging while driving. In this mode, the IC engine delivers the power required for both traction and battery charging.
6. **Battery charging during standstill:** Fig. 6.7f shows the power flow diagram of charging the battery during standstill. In this operating mode, when the vehicle comes to rest, the ICE charges the battery through the power converter.

3.1.4 Complex HEV Powertrain and Modes of Operation

Figure 6.8 shows the architecture of the Complex Hybrid drivetrain. This configuration is similar to a series-parallel hybrid electric vehicle as it has both generator and motor. Generally, dual axle transmission is employed by which both the front and the rear wheels are driven. A power converter is connected between the battery and motor/generator to provide electrical coupling and facilitate bi-directional power flow.

The configuration in Complex HEV is of two types viz. Front hybrid Rear electric and Front electric Rear hybrid which is based on the placing of propulsion devices. Here both the front wheels and the rear wheels are driven by two subsystems. Based on the power flow, both have six modes of operation.

In **Front Hybrid Rear Electric (F-H-R-E) dual axle complex HEV**, there is a hybrid system of IC engine & motor connected to the front wheel transmission and a pure electric motor connected to rear wheel transmission. The modes of power flow operation are:

1. **Start-up:** Fig. 6.9a shows the power flow diagram during starting. In this mode, the required traction power for starting is supplied by the battery to both the motors connected to the front and rear transmission through the power converters whereas the ICE is in the off condition.
2. **Full-throttle Acceleration:** Fig. 6.9b shows the power flow diagram during acceleration. In this mode, the ICE and front-wheel motor drive the front wheel while the second motor drives the rear wheel.
3. **Normal driving/battery charging:** Fig. 6.9c shows the power flow diagram during normal driving conditions. In this operating mode, the IC engine supplies the driving power to the front wheels and part of the energy is used to charge the battery. So, in normal driving, only front wheels are used to drive the system while the rear transmission is inactive.
4. **Light load:** Fig. 6.9d shows the power flow diagram during the light load operation. In this mode, the power is delivered to the front wheels by the front motor while the rear motor and IC engine are in the off state.

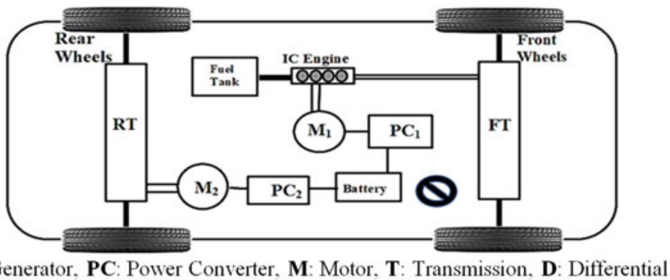
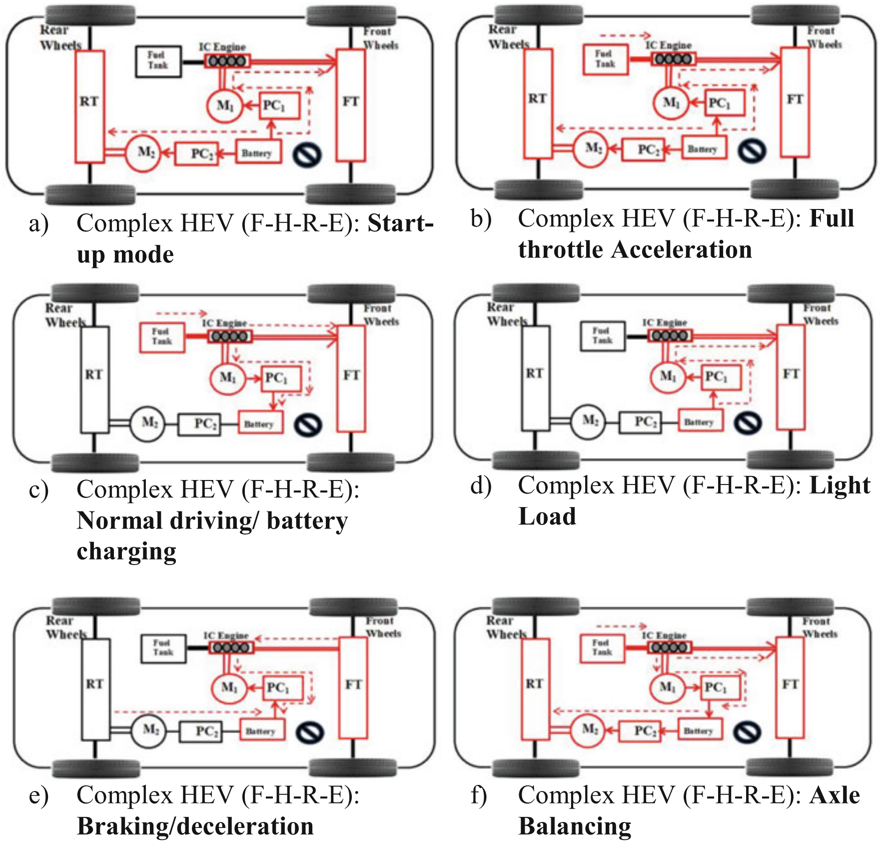


Fig. 6.8 Architecture of different HEV configurations. *G* Generator, *PC* Power converter, *M* Motor, *T* Transmission, *D* Differential



a) Complex HEV (F-H-R-E): **Start-up mode**

b) Complex HEV (F-H-R-E): **Full throttle Acceleration**

c) Complex HEV (F-H-R-E): **Normal driving/ battery charging**

d) Complex HEV (F-H-R-E): **Light Load**

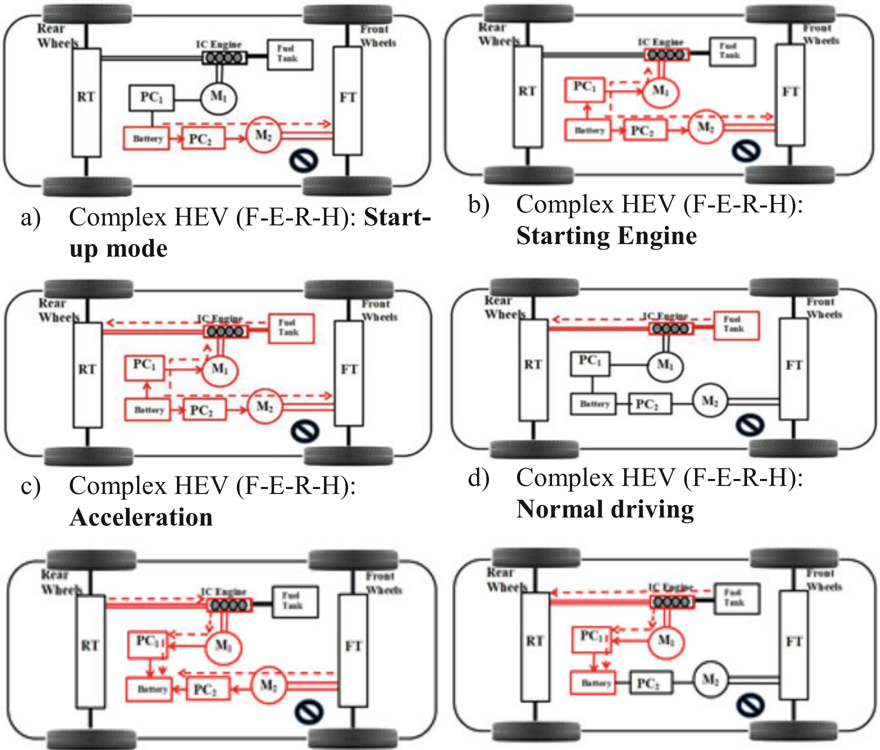
e) Complex HEV (F-H-R-E): **Braking/deceleration**

f) Complex HEV (F-H-R-E): **Axle Balancing**

Fig. 6.9 Power flow modes in front hybrid rear electric (F-H-R-E) dual axle complex HEV

5. **Braking/deceleration:** Fig. 6.9e shows the power flow diagram during deceleration or braking. In this mode, motors at the front wheel transmission and rear-wheel transmission act as generators and charge the battery simultaneously.
6. **Axle balancing:** Fig. 6.9f shows the power flow diagram during axle balancing. This is a unique operating model. If the front wheel is undergoing sliding or due to bad road, there is a sliding force in the front wheels. To overcome this an equal and opposite force can be extracted or put in the rear wheel thereby balancing the sliding force. Such system can balance itself and can move in difficult terrains as well.

In the **Front Electric Rear Hybrid (F-E-R-H) dual axle complex HEV**, a pure electric motor is coupled to the front wheel transmission while there is a hybrid system of IC engine and a motor connected to rear wheel transmission. The modes of power flow operation are:



a) Complex HEV (F-E-R-H): **Start-up mode**

b) Complex HEV (F-E-R-H): **Starting Engine**

c) Complex HEV (F-E-R-H): **Acceleration**

d) Complex HEV (F-E-R-H): **Normal driving**

e) Complex HEV (F-E-R-H): **Braking/deceleration**

f) Complex HEV (F-E-R-H): **Axle Balancing**

Fig. 6.10 Power Flow modes in Front Electric Rear Hybrid (F-E-R-H) dual axle complex HEV

1. **Start-up:** Fig. 6.10a shows the power flow diagram during starting. In this mode, the required traction power for starting is supplied only to the front transmission by the front motor connected to the battery via power converter while the IC engine and rear motor are in the off condition.
2. **Starting engine:** Fig. 6.10b shows the power flow diagram during the start of the IC engine. The second motor works as an integrated starter generator to start the IC engine as cranking.
3. **Acceleration:** Fig. 6.10c shows the power flow diagram during acceleration. In this mode, the front-wheel motor propels the front wheel whereas the rear-wheel motor and ICE drive the rear wheel.
4. **Normal driving:** Fig. 6.10d shows the power flow diagram during normal driving. In this mode, the IC engine delivers power to the rear transmission to drive the rear wheels. So, in normal driving, only rear wheels are used to drive the system while the front transmission is inactive.

5. **Braking/deceleration:** Fig. 6.10e shows the power flow diagram during deceleration or braking. In this mode, the motors at the front wheels and rear wheels act as generators, extracting the power from the wheels and charging the battery simultaneously.
6. **Battery charging:** Fig. 6.10f shows the power flow diagram during normal driving. In this mode, the IC engine delivers power to the rear transmission to drive the rear wheels and some amount of energy is used to charge the battery. So, in normal driving, only rear wheels are used to drive the system while the front transmission is inactive.

3.2 Power Flow in Battery Electric Vehicles

A BEV is a system integrating three types of subsystems viz. energy source, traction and support device. The energy subsystem comprises of a battery source, energy management and refuelling system. The traction system comprises a power electronics converter, motor and its controller, propulsion system and driving wheels. The auxiliary system consists of a power supply, power and temperature controllers [11]. The BEV is relatively flexible because of the absence of many mechanical components which are present in ICE vehicles. The only moving part in BEV is the motor which requires a power supply to operate and it can be placed at various locations in the BEV. The motor will run with the supply given to it through the electrical wires. Due to such flexibility, various configurations are possible to be implemented.

BEV uses batteries and ultracapacitors as sources. Six types of configurations are existing for power transfer in BEV's among them three are widely used viz. BEV with longitudinal front-wheel drive, Fixed gear and No clutch, Transverse front-wheel drive, dual motor drive, In-wheel motor drive, Outer rotor motor drive [11, 14]. In this chapter, BEV with longitudinal front-wheel drive architecture is considered to explain the modes of operation. The power flow in Battery Electric Vehicles can be explained with seven modes of operation indicating the power flow. Among these modes, G2V and V2G are popular, along with these two new modes H2V and V4G are also discussed. EVs can store energy in their batteries and Bidirectional DC–DC converters play a major role in the charging and discharging process of Batteries. However, here charge controller operation is not focused and it is assumed that the charge controller is an integral part of the Energy Storage System (ESS) [15–18].

1. **Grid-to-Vehicle (G2V):** In the G2V mode, power flow will be from the grid to the charger and then to the EV battery. This mode is used to charge batteries and is shown in Fig. 6.11a.
2. **Vehicle-to-Grid (V2G):** When there is a requirement for power in the grid, the battery has to supply power to the grid. In this mode, power flows in the reverse

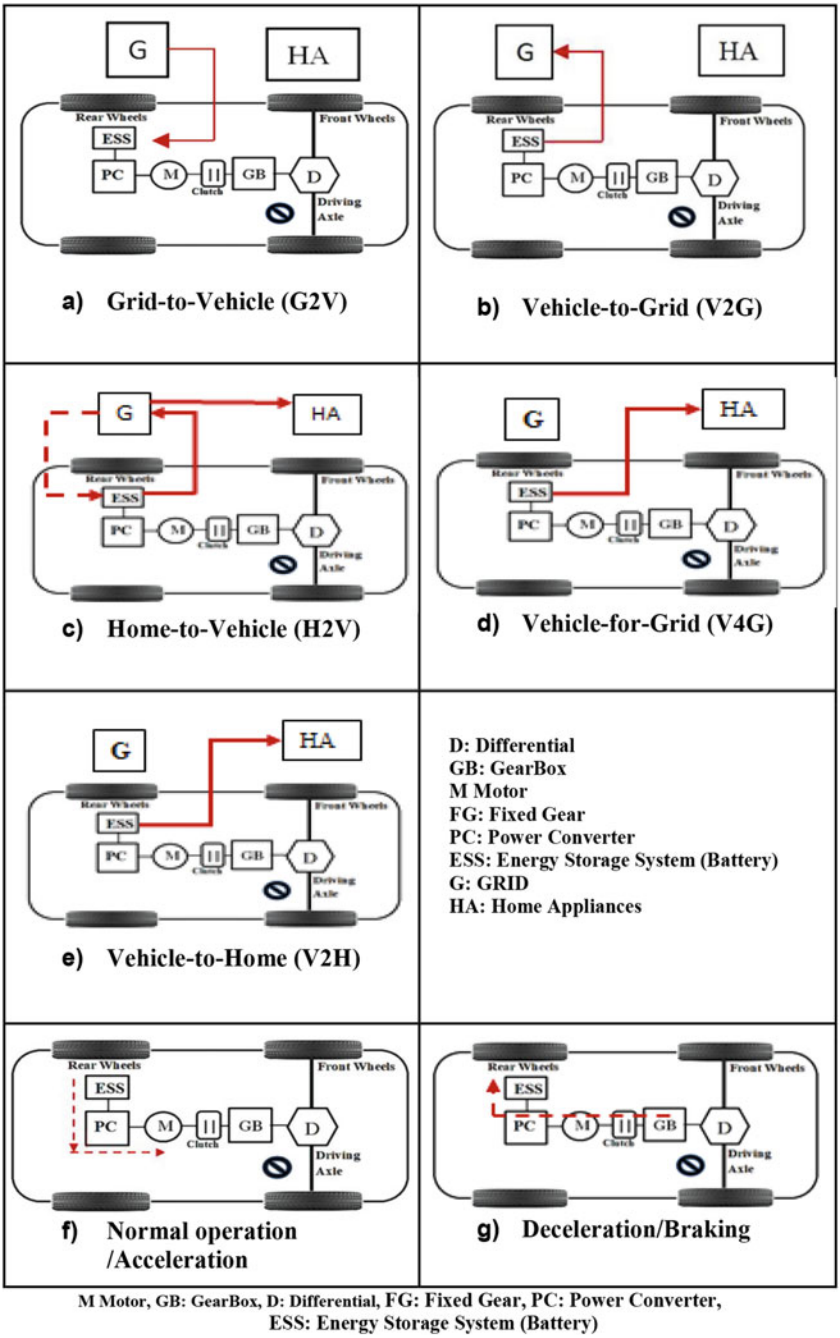


Fig. 6.11 Power flow modes in battery electric vehicles. *M* Motor, *GB* Gear box, *D* Differential, *FG* Fixed gear, *PC* Power converter, *ESS* Energy storage system (battery)

direction from the battery to the grid via the controller and the control during the mode will be taken care of by the power grid manager. Figure 6.11b shows the power flow path for this operating mode.

3. **Home-to-Vehicle (H2V):** In this mode based on the power consumed by home appliances two ways of power flow are possible. H2V is a modified form of G2V and V2G.

   (a) H2V combined with G2V
   (b) H2V combined with V2G

   These two modes help in avoiding overcurrent tripping in the circuit breaker which is installed in the house The power flow diagrams for the modes are shown in Fig. 6.11c.
4. **Vehicle-for-Grid (V4G):** When EV is non-operating in G2V mode and V2G modes it can be used for reactive power compensation acting as an active power filter for the appliances connected in-home as shown in Fig. 6.11d. However, this mode can also be combined with V2G or G2V modes, in that case, power flow to or from the battery will be limited.
5. **Vehicle-to-Home (V2H):** In case of power outages when emergency power is required then EV batteries can be used as offline UPS to deliver power by operating in this mode as shown in Fig. 6.11e.
6. **Normal operation/Acceleration:** When the EV is in motion during starting, normal operation and during acceleration, this mode comes into the picture. The power flow will be from battery to power converter then to motor as shown in Fig. 6.11f.
7. **Deceleration/Braking:** When the motor vehicle slows down by applying brakes or during stopping, Electric Vehicles are to be operated in this mode and the power flow path is as shown in Fig. 6.11g.

3.3 Power Flow in Fuel Cell HEV (FCHEV)

The fuel cells are the prime supplier of energy in fuel cell EV (FCEV). These cells use their chemical reactions to generate electricity and the electrical motor for propelling the vehicle. The fuel cells cannot be considered as the main source of energy for BEV since fuel cells cannot have regenerative energy. Therefore, batteries are usually adopted as the other energy source.

The fuel cell generates the electric power and this power is given to the motor to drive the wheels. Excess energy, if any, can be stored in the batteries. The fuel cells have higher efficiency with low emissions of carbon. The power density of the fuel cells is suitable for EV applications. A typical powertrain configuration of Fuel cell EV is as shown in Fig. 6.12. There are various energy management techniques that help to monitor the system and focus on important aspects such as energy losses, fuel economy and efficiency [5, 19].

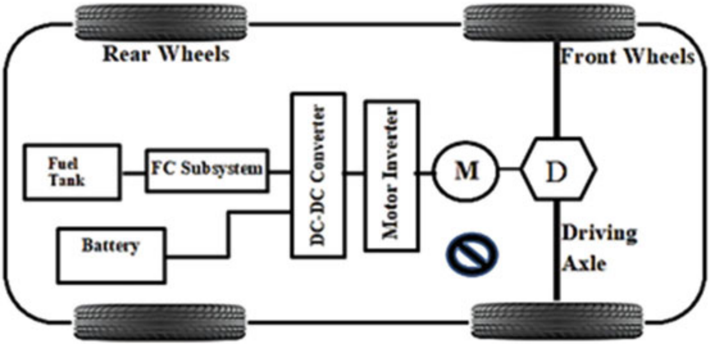


Fig. 6.12 Configuration of FCEV

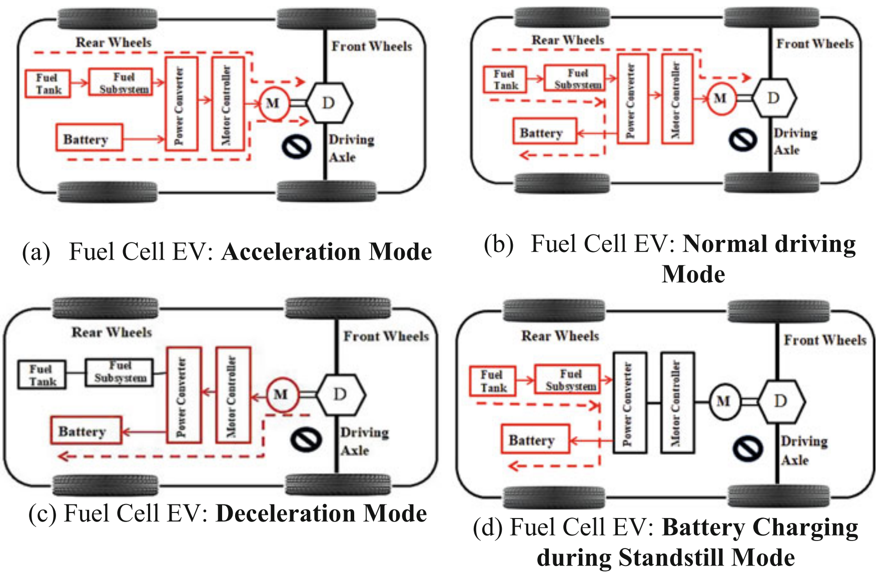


Fig. 6.13 Power flow modes in Fuel Cell HEV

Fuel cell hybrid electric vehicles operate majorly in 3 operating modes as explained below. Other than these modes there is one more least popular method called battery charging mode. Power flow in all these four modes is discussed with diagrams [20, 21].

1. **Acceleration mode:** During acceleration our starting motor requires more power hence both fuel cell and battery will provide power. The fuel cell will be operating with its full rating remaining power will be supplied by the battery as shown in Fig. 6.13a.

2. **Normal operation:** In this mode of operation the motor will demand power depending on the speed operated by the user. If the power demand by the motor is the same as the rated power of the fuel cell, then the fuel cell supplies power to the motor alone. If the demand from the motor is less than the rated power of the fuel cell then the fuel cell provides the power to the motor and the remaining power will charge the battery as the fuel cell has to operate at its rated power always. Power flow for both the cases is shown in Fig. 6.13b.
3. **Deceleration:** During deceleration, the motor operates as a generator and supplies power for the battery. Hence this power charges the battery as shown in Fig. 6.13c.
4. **Battery charging mode:** In this mode of operation the electric motor does not receive power from the fuel cell as well as battery and the vehicle remain in a halt position. However, the battery can be charged through the fuel cell in this mode as shown in Fig. 6.13d. Hence it is called battery charging mode.

3.4 Ultra Capacitor Electric Vehicles (UCEV)

One of the major concerns is supplying for the peak power needs in EV. Ultracapacitors (UC) are used in two-wheeler along with other energy sources in such systems which need both continuous supply, peak power demands and also for low power discharges. In the EVs which implement Ultracapacitors, it will have ICE and/or Battery which acts as the primary source of energy and the Ultracapacitors act as the secondary power source [7, 21]. In the life cycle of the vehicle drive, it has to satisfy the needs of short duration events many times for which such combination is suitable. Even the UC will have an increased life span without any constraint on the depth of discharge. Such combinations also help in the overall reduction in size. The UC-based vehicle offers greater advantages such as operation during peak power, has a longer life cycle, tolerates surges during operation of the battery and provides high magnitude power. The combination of UC with any other primary source has high stability. Figure 6.14 shows the configuration of UC-based electric vehicles. The power flow modes in UCEV are shown in Fig. 6.14. The UC can also be implemented along with both the ICE and the battery. As per the power conversion needs, various power converters can be implemented at different points in the power flow path. A typical structure with UC and battery is shown in Fig. 6.14. Also, the various modes of operations are indicated in the figure such as acceleration, normal driving mode, deceleration and battery charging under a standstill.

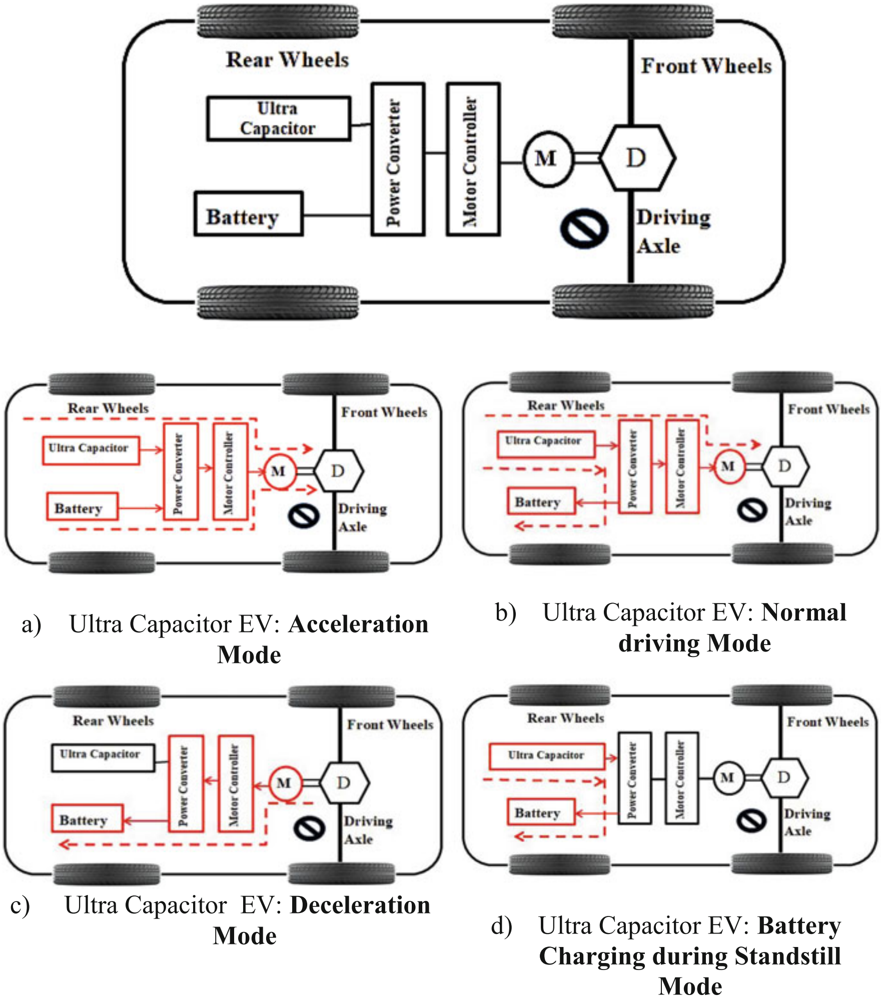


Fig. 6.14 Power flow modes in Ultra Capacitor electric vehicles

4 Current Trends and Technology

The various configurations under HEV and BEV have their advantages and challenges. Wide R&D is being done to improvise the configuration for efficient energy utilisation and reduce the power losses during transmission. A constant and a common trend is still not observed due to the regional variations and road conditions. Previous surveys indicate that the widely used HEV architecture is Parallel configuration and then combined HEV (series-parallel & complex). The reason behind this trend is in the parallel configuration it is possible to reduce the size and rating of both the propelling devices and in complex HEV configuration it is possible to operate in

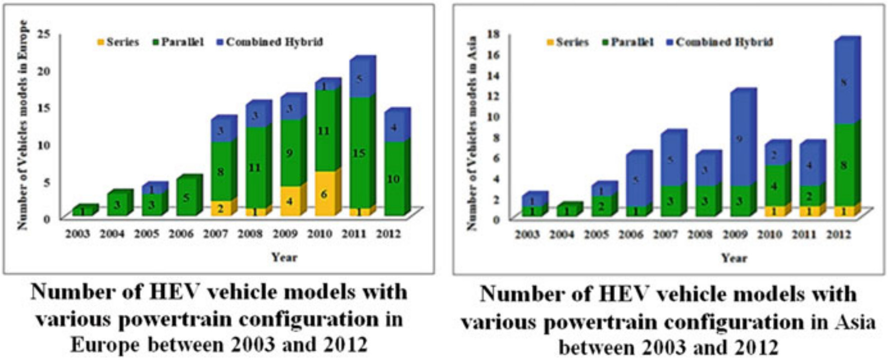


Fig. 6.15 Different HEV powertrain architectures in Europe and Asia

both series and parallel modes. The graph in Fig. 6.15 shows the implementation of various HEV configurations in Europe and Asia in various electric vehicle models [12, 22].

Based on the chemical composition, different types of fuel cells are emerging resulting in higher energy efficiency. Due to advances in research towards different types of fuels used in fuel cells, a fuel cell-powered vehicle with a longer driving range and less battery chagrin time can be obtained.

5 Conclusion

In this chapter, the architecture of different configurations of BEV's and HEV's are briefly presented. The various power flow modes of series, parallel, series-parallel, complex HEVs, fuel cell HEV and also for BEV are discussed with the support of power flow diagrams for each mode in all the types. BEVs use battery, fuel cell or ultracapacitor as energy storage systems and the HEV uses IC Engine along with the batteries. HEV's provide high efficiency compared to BEVs. It has been observed that the widely implemented configuration is parallel HEV structure because of its strengths and flexibility. FCHEV and UCEV are also gaining focus due to the developments happening in fuel cell technology and energy supply during peak requirements.

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