Chapter 23
A Review of Electric Vehicle Technologies

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Abstract Electric vehicles (EVs) have gained remarkable attention due to growing concerns over global warming and the depletion of fossil fuels in the last decade. The propulsion system in EVs comprises electric motors, which are fed by energy storage units through power electronic devices. Due to limitations of conventional energy storage systems in terms of cost, sizing, management, energy and power density, it has become necessary to have an energy generating unit along with the energy storage unit. Effective utilization of energy in EVs can be carried out with the incorporation of advanced power electronics technologies. This chapter reviews the various classifications of EVs, electrical propulsion systems, energy storage systems and energy management systems. This chapter also highlights the various issues to be considered for effective electrification in EVs.

Keywords Electric Vehicle · Energy Management System · Energy Storage System

Abbreviations

EV	Electric Vehicle
ICE	Internal Combustion Engines
ICEV	Internal Combustion Engine Vehicle
HEV	Hybrid Electric Vehicle
AEV	All Electric Vehicles
PEC	Power Electronic Converters
BEV	Battery Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
EPS	Electric Propulsion System

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ESS	Energy Storage System
PHEV	Plugin Electric Vehicle
UC	Ultra capacitor
EDLC	Electric Double-layer Capacitors
EMS	Energy Management System
RB	Rule Based
RTO	Real Time Optimizations

23.1 Introduction

Conventional vehicles utilize gasoline/petroleum products such as petrol or diesel as fuel to propel their internal combustion engines (ICEs), which act as the main source for the energy conversion unit. These vehicles emit greenhouse gases such as carbon dioxide, hydrocarbons, carbon monoxide and nitrogen oxide, which pollute the environment globally. In the last decade, the usage of petroleum products in the transportation sector has raised concerns over the depletion of fossil fuels and the problems related to pollution and climate change.

Reduction in the emission of greenhouse gases is seen as the only major remedy for restoring the natural climatic conditions globally. The transportation sector all over the world has seen a paradigm shift towards electrification of vehicles. Electric vehicles (EVs) are expected to be more reliable, affordable, highly energy efficient and safe with zero or reduced emissions. The prominence of electric vehicles under various dimensions is presented in Fig. 23.1. Electric propulsion systems, which are used in EVs, are considered stiff competition for ICEs with the recent advancements in the field of energy sources, power electronics and electrical-driven technology. This chapter presents an overview of the classification of electric vehicles, energy sources energy management system.

ENVIRONMENT	POLITICS	ECONOMY
• Climate Change • Reduction of CO_2 Emissions • Reduction of Noise Emissions	• International Specifications for emission limits • Low Emissions or Emission free zones	• Limited Oil Reserves • Rising Prices for Fossil Fuels
TECHNOLOGY	**SOCIETY**	**INFRASTRUCTURE**
• Merits of electric motors compared to internal Combustion engine • Increase in Efficiency • High Voltage Safety	• Growing Mobility • Demand for Vehicles with Lower Consumption and Emissions	• Comprehensive Infrastructure to supply energy for electric vehicles

Fig. 23.1 Electric vehicle prominence

23.2 Classification of Vehicles

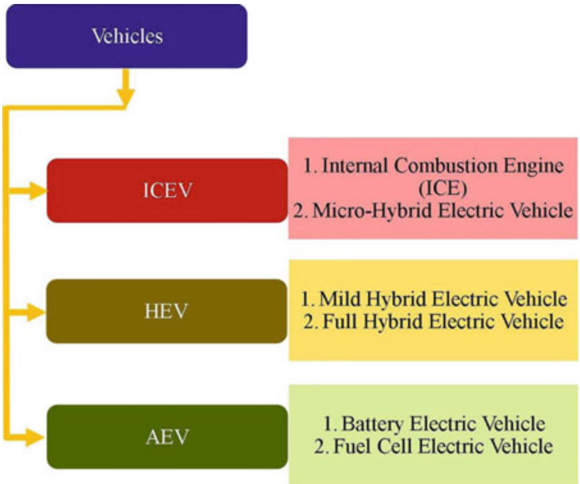
In terms of usage of electrification, the vehicles are categorized into three groups: internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs) and all-electric vehicles (AEVs). Figure 23.2 illustrates the various categories of vehicles.

ICEVs use pure mechanical transmission with petrol or diesel as the main fuel. The use of electrical energy is very minimal, and it is mostly used for starting purpose. HEVs use a combination of electrical and mechanical transmission, and both fossil fuels and electrical energy. Various classifications are available with HEVs, which are discussed below. AEVs are pure electric vehicles that consume electric energy and comprise only the electric drive train and transmission. A comparative overview of the three vehicle categories is shown in Fig. 23.3.

23.2.1 Internal Combustion Engine Vehicles (ICEVs)

These vehicles are propelled by transforming chemical energy to heat energy and kinetic energy by use of a combustion chamber. These vehicles are further classified into conventional ICEVs and micro-hybrid EVs. The major difference is that the former operates without an electric vehicle, whereas the later uses one to start the combustion engine. The operating voltage of the electric motor is around 14 V and power is not more than 5kW (Fig. 23.3).

Fig. 23.2 Classification of vehicles



Vehicle	Energy Source	Propulsion System	Merits	Demerits	Observation
ICEV	Petroleum Products	ICE Based Drive	Reliable Durable Better performance Established technology	Harmful emission Poor fuel economy Less Efficient	Fossil fuel depletion Emission rate is high Fuel economy
HEV	Electrical Energy Petroleum Products	EPS and ICE Based Drive	Very Low Emission Higher Fuel Economy Long Electric Driving Range Durability	Costly and Bulky Increased Component Count Complex Control Algorithm	Size and weight Integration of Component Power Management
AEV	Electrical Energy with Charging Hydrogen enriched fuel	EPS Based Drives	Independent from petroleum Zero Emission Energy Efficient	Higher recharging time Slow transient response Sophisticated electronic controllers	Charging station Infrastructure Reliability and cycle life Vehicle performance

Fig. 23.3 Overview of vehicle categories

23.2.2 Hybrid Electric Vehicles (HEV)

These vehicles are propelled by both a combustion engine and an electric motor. Based on the architecture, HEVs are further classified into Mild HEV and Fully HEV. Compared with micro-HEVs, the operating voltage and power of electric motor are 150 V and 7–12 kW in mild-HEVs. However, the rating is high in mild-HEVs, as they can propel the vehicle along with the combustion engine as they use the same shaft.

Fully HEVs have the upper hand in providing better driving performance as they can propel with the use of split power path, that is, they can run either on an electric motor or an ICE or both. This category is further classified into Series Fully HEV, Parallel Fully HEV, Series-Parallel Fully HEV, Complex HEV and Plugin HEV (Fig. 23.4).

Different architectures have different characteristics, which are briefed here. Series Fully HEV comprise of power electronic converters (PECs), which are fed using a battery along with the ICE. With bidirectional operating property of the converter topologies, it is possible to store energy in the battery from the energy generated using the generator. Depending on fuel capacity and generator power, the battery pack can be appropriately designed. It is very much suitable for driving in city conditions. Parallel fully HEVs propel utilizing both electrical power and ICE, along with a mechanical coupler. The vehicles can either run using ICE or EM. These HEVs have better efficiency than series Fully HEVs and can incorporate lower-rated electric motors and batteries as they are very well complimented by ICE. The series-parallel Fully HEVs use two mechanical power couplers as the drive train is powered both electrically and mechanically. These HEVs are costly and complicated even though they incorporate the merits of both parallel and series Fully HEVs. Plug-in hybrid electric vehicles make use of charging infrastructures built to charge the battery from the grid. The charging station and charger configuration are not discussed in the chapter considered. It allows the user to choose the propulsion based on the capacity of the battery installed.

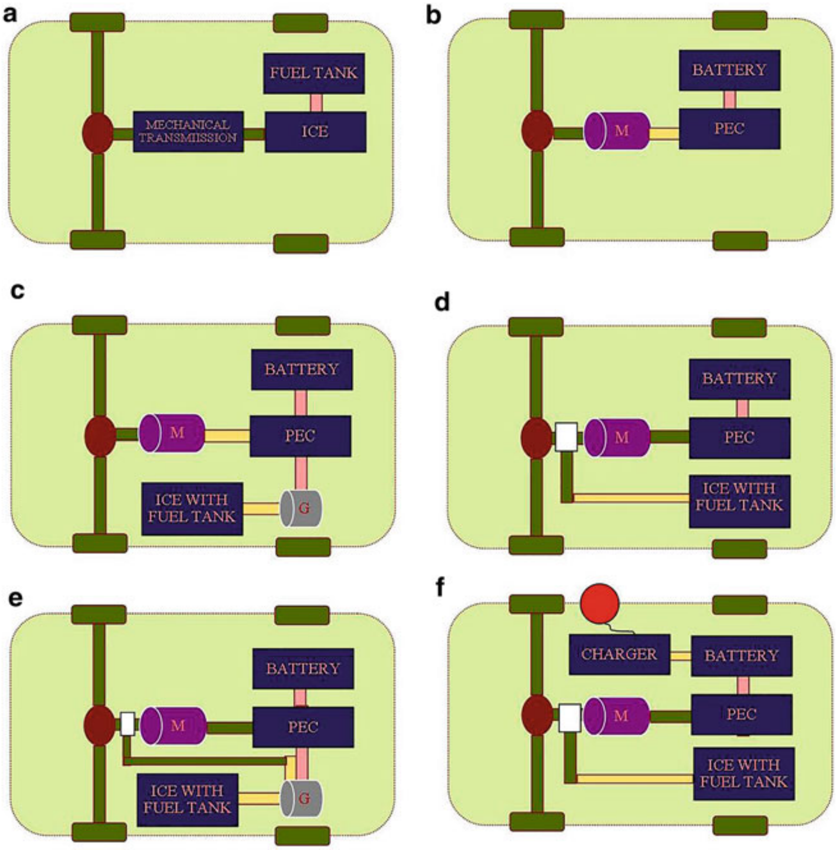


Fig. 23.4 (**a**) ICEV, (**b**) BEV, (**c**) Series HEV, (**d**) Parallel HEV, (**e**) Series-Parallel HEV, (**f**) Plugin- HEV

23.2.3 All-Electric Vehicles

Electric power is the lone source used to propel the vehicle. Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicle (FCEVs) are the classifications of AEVs. BEVs use energy-storing devices, mostly batteries, from which energy is converted using a PEC and fed into the motor. Based on the capacity of the battery installed in the vehicle, the driving range of the vehicle can be calculated. Increasing the battery size would increase the weight of the vehicle, thereby reducing its speed. Frequent charging of the vehicles proved to be a demerit compared with HEVs. The FCEVs comprise energy-generating units along with the battery. Hydrogen is the key component, which is being converted using fuel cell technology. Among various energy-generating systems, fuel cell is comparatively better in terms of integration with other energy-storing systems.

23.3 Electric Propulsion System

The core part of any EV is the electric propulsion system (EPS), which comprises components like the energy storage system (ESS), the power electronic converter, the electric motor and the electronic control unit. Based on the architecture of the EV considered, the integration of these components may differ, and it plays a vital role. In order to compete with ICEV, the EPS should take into account issues such as weight of the vehicle, drive train, durability and flexibility, compact packaging and maintenance. Many researches are taking place to design and implement the integration of electric motor and PEC to provide a better driving range. The integration has to focus on issues such as availability of the right motor at affordable cost, promising battery technology and suitable PEC configuration to support efficient transmission.

23.4 Energy Storage System

Energy storage systems consist of both energy sources and energy storing devices, which are attracting the power industries as they help reduce the emission of greenhouse gases. With the advancement of ESS technologies, EV is considered an alternative to ICE, thereby replacing fossil fuels with renewable energy technologies.

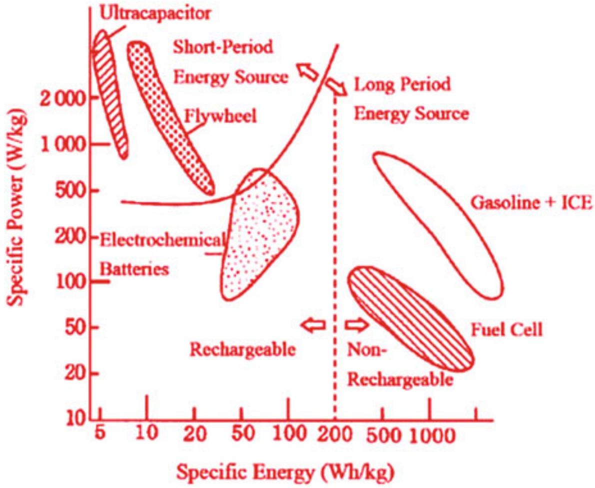
ESS includes energy-generating devices such as fuel cells and other storing devices such as batteries, ultracapacitors and flywheel. ESS can be classified into rechargeable and non-rechargeable technologies.

The operating range of the EV is directly dependent on these technologies and they are illustrated in Fig. 23.5. Comparison of the various technologies is given in Fig. 23.6.

23.4.1 Battery

A battery is a storage device that is made up of electrochemical cells that convert stored chemical energy into electrical energy. Battery capacity and state of charge are the main characteristics of battery, which should be taken into consideration while designing an EV. Other characteristics include high energy density, flexibility, modularity and affordability. Battery requirement is different for different types of EV. BEVs require high-energy-density batteries, HEVs require high-power-density batteries and PHEVs require intermediate battery capacity with energy density like that of a BEV and power density like that of an HEV.

Fig. 23.5 ESS in terms of power and energy



Characteristics	Battery	Ultra Capacitor	Fuel Cell	Flywheel
Mechanism	Chemical	Electrostatic	Chemical	Mechanical
Energy Density	High	Low	Very High	Low
Power Density	Low	Very high	Moderate	High
Charging Time	Hours	Seconds	-	Minutes
Discharging Time	Hours	Seconds	-	Minutes
Life	3-5 years	> 10 years	10 –20 years	> 20 years
Efficiency (%)	75-85	85-95	40-60	80-90
Environmental Issues	Disposal	Less	Very Less	Very Less

Fig. 23.6 Comparison of ESS technologies

23.4.2 Ultracapacitor

An ultracapacitor (UC) or super capacitor and a normal capacitor are similar in built, but the former has higher capacitance than a regular capacitor. The ultracapacitor's characteristics include maintenance-free operation, longer operation cycle life and insensitive to environment temperature variation. The three types of UC technologies established so far are electric double-layer capacitors (EDLC)—carbon/carbon, pseudo-capacitors and hybrid capacitors.

The difference between those UCs is in their energy storage mechanisms and the electrode materials used. In EVTs, ultracapacitors can be used as primary energy devices for power delivery during starting, acceleration and hill climbing, as well as for recovery of braking energy during regenerative braking. It can downsize as well as extend the life of a battery and reduce maintenance and replacement costs.

23.4.3 Flywheel

Flywheel is a storage device that stores and delivers mechanical energy in the form of rotational kinetic energy as well as electrical energy. Limitations of using a flywheel in EVs are that they are heavy weight and costly. Recent advancement in frictionless magnetic bearing, carbon-fibre composite materials, manufacturing technique and sophisticated power electronic controllers has accelerated the development of flywheel energy storage.

23.5 Energy Management

A major challenge in EVs is the development of control and management of power from energy sources to the PEC and from the PEC to various loads. Based on the architecture of the EVs, the energy source may be a single- or multi-input source. Integration of such hybrid sources with the PEC involves understanding of control of PEC components as well as the overall control of the EV for a better driving profile and range. An energy management system (EMS) manages all possible energy resources to feed the power to the ESSs in EVs. An EMS involves low-level component control and high-level supervisory control. This high-level controller usually comprises event-based or time-based conditions that coordinate the component-level operation. There are two classes of control, that is, rule-based (RB) control and optimization approaches control, which are shown in Fig. 23.7.

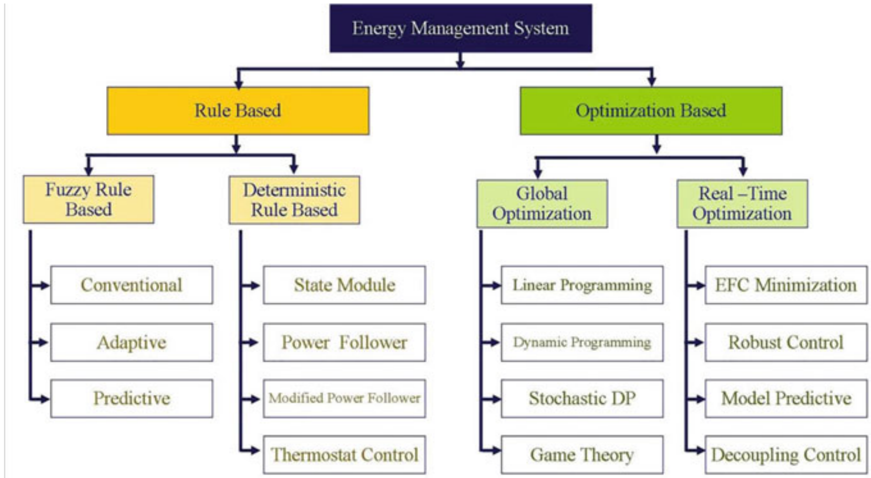


Fig. 23.7 Control and power management strategies of EVs

Rule-based control (RB) is the control system based on human expertise (engineering knowledge), heuristic, intuition, even mathematical model, predefined driving cycles and load-levelling strategy on vehicles. RB control can be divided into deterministic rule-based methods and fuzzy rule-based methods. Deterministic rule-based use looks up tables (not real-time data) to design deterministic rules. It can be subdivided again into thermostat (on/off) control strategy, power follower (baseline) control strategy, modified power follower (baseline) strategy and state machine-based strategy. However, fuzzy rule-based methods use real-time parameters and suboptimal power split, which are non-linear data and linguistic knowledge to calculate optimal output.

Optimization approach control is based on analytical or numerical operations, which are able, obviously, to minimize the cost function. Optimization approach control can be further classified into global optimization and real-time optimization methods (RTO). Global optimization is based on knowledge of future and past power demands to minimize the cost function through fuel efficiency (fuel consumption) and emissions over a fixed driving cycle. It is useful in design and comparison purposes if implemented together with rule-based strategies. There are a lot of strategies that are categorized under global optimization, for example, linear programming, control theory approach, optimal control, dynamic programming (DP), stochastic DP, genetic algorithm and adaptive fuzzy RB, while real-time optimization consists of equivalent fuel consumption minimization, decoupling control, robust control approach and optimal predictive control. Real-time optimization is based on the system variable at the current data, which is instantaneous cost function. Real-time optimization comprises equivalent fuel consumption minimization strategy (ECMS), decoupling control, robust control approach and optimal predictive control. These control strategies include the drivability of the vehicle.

23.6 Conclusion

This chapter reviews the drive train architecture of EVs with current updates on energy storage as well as energy generation units. It also presents the various electrical drives that can be adopted in EVs. The EMS of an EV is briefed up to introductory level. A comparison with ICEVs is carried out and it can be seen that EVs are the only alternative for reducing emission of greenhouse gases. A few pitfalls seen with AEVs can be seen as opportunities for further research and development.

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