Dr. Norbert Cheung's Lecture Series

Level 5 Topic no: 19

Electric Vehicles Developments

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Reference:

C.C. Chan and K.T. Chau, Modern Electric Vehicle Technology, London: Oxford, University Press, 2001

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1. What is an EV?

With ever-increasing concern on energy diversification, energy efficiency, and environmental protection, electric vehicles (EVs), including pure electric vehicle (PEV), hybrid electric vehicle (HEV), and fuel-cell electric vehicle (FEV) are becoming attractive for road transportation. Although some of them have become commercially available, there are many challenges and hence opportunities for EV research and development.

EVs are nothing new; they were invented 178 years ago but lost the competition for dominance to internal combustion engine vehicles (ICEVs). Actually, the first EV was a battery-powered tricycle built by Thomas Davenport in 1834 (Wakefield, 1994). In 1900, among an annual sale of 4200 automobiles in the US, 38% were EVs, 22% ICEVs, and 40% steam-powered vehicles. At that time, EVs were the preferred road transportation among the wealthy elite. Their cost was equivalent to a Rolls Royce of today. A man with an idea that finished off the EVs for good was Ford. His mass-produced Ford Model T could offer a range double or triple that of the EVs but at only a fraction of their cost. By the 1930s, the EVs almost vanished from the scene. The rekindling of interests in EVs started at the outbreak of the energy crisis and oil shortage in the 1970s. Owing to the growing concern over air quality and the possible consequences of the greenhouse effect in the 1980s, the pace of EV development was accelerated.

In general, EVs are classified as the PEV, HEV, and FEV types on the basis of their energy sources and the propulsion devices (Chan and Chau, 2001; Chau, 2010, 2014). In essence, the PEV is purely fed from electricity, while the propulsion is solely driven by the electric motor; the HEV is sourced from both electricity and gasoline/diesel, while the propulsion involves both the electric motor and engine; and the FEV is directly or indirectly sourced from hydrogen, while the propulsion is solely driven by the electric motor. Moreover, in order to distinguish the refueling means, the HEV can be further categorized into the conventional HEV and the gridable HEV. The conventional one is solely refueled with gasoline/diesel in filling stations, whereas the gridable one can be recharged by electricity via charging ports. On the basis of the hybridization level and the operation feature between the electric motor and engine, the conventional HEV can be further split into the micro HEV, mild HEV, and full HEV. Meanwhile, on the basis of the coordination between the electric motor and engine, the gridable HEV can be further split into the plug-in hybrid electric vehicle (PHEV) and range-extended electric vehicle (REV). This classification is depicted in Figure 1.1.

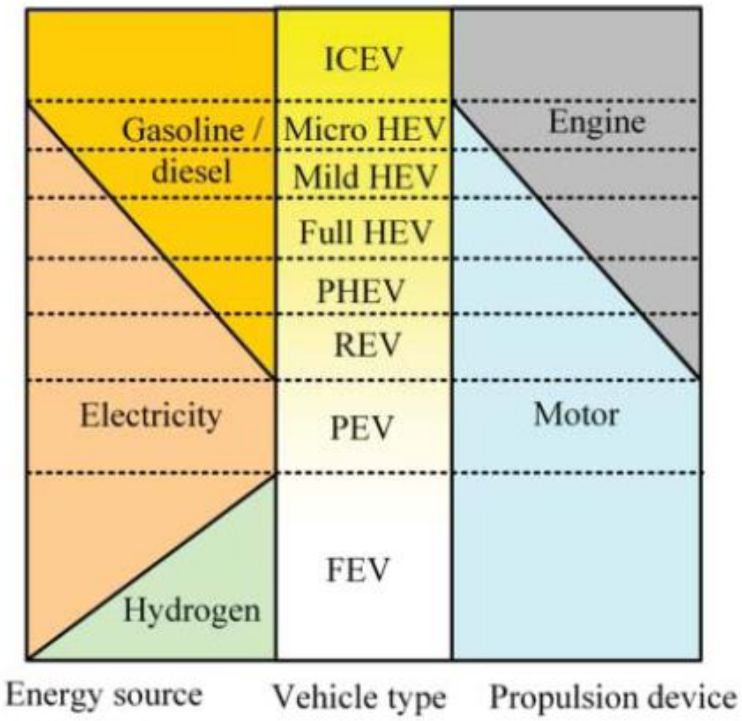


Figure 1.1 Classification of EVs

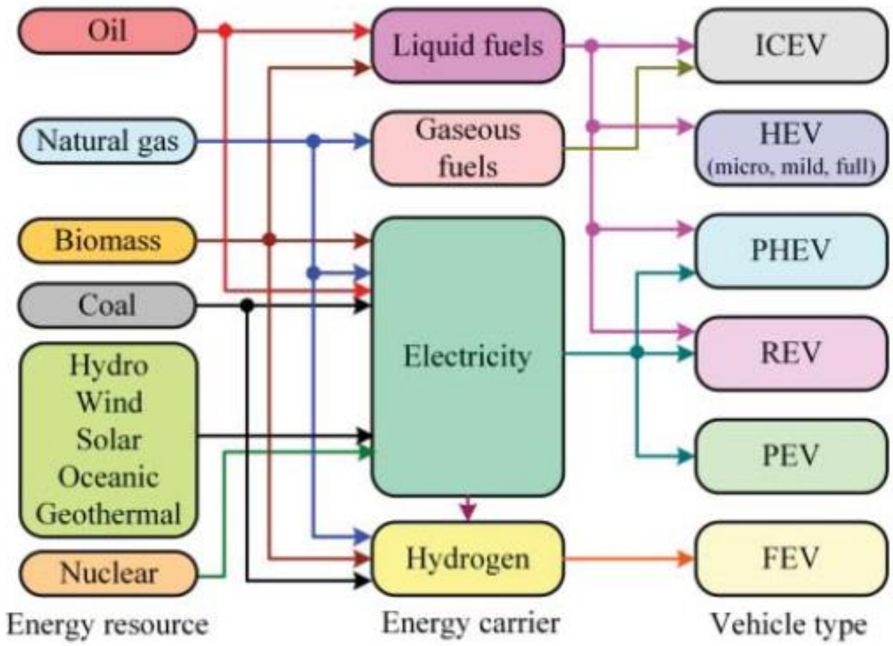


Figure 1.2 Energy diversification of EVs

2. Past Present and Future of EV

In a world where environmental protection and energy conservation are growing concerns, the development of electric vehicle (EV) technology has taken on an accelerated pace to fulfil these needs. Concerning the environment, EVs can provide emission-free urban transportation. Even taking into account the emissions from the power plants needed to fuel the vehicles, the use of EVs can still significantly reduce global air pollution. From the energy aspect, EVs can offer a secure, comprehensive and balanced energy option that is efficient and environmentally friendly, such as the utilization of various kinds of the renewable energies. Furthermore, EVs will be more intelligent to improve traffic safety and road utilization, and will have the potential to have a great impact on energy, environment and transportation as well as hi-tech promotion, new industry creation and economic development (Chan, 2000).

Besides subsystem level improvement and system level optimization, effort should be made at the global level. We need to combine the strength of East and West to solve those EV problems, especially the production cost. For instance, the eastern countries such as China, India, Thailand and Malaysia can readily offer low labour cost while the western countries such as the USA, Germany and France can provide fundraising and high technologies. Japan can also play an important role in the global development of EVs. Hence, by combining low labour cost and hi-tech facilities, the production cost of EVs can be remarkably reduced.

Moreover, the development of EVs is a global issue—how to restructure the global business environment to create a sustainable global market for EVs. For instance, the energy-storage device of ICEVs, the fuel tank, represents only a minor fraction of the total vehicle cost; whereas the energy-storage device of EVs, the battery pack, is the most expensive EV subsystem. Thus, it is natural to sell the fuel tank as part of an ICEV, while it may be more appropriate to lease the battery pack of an EV so that the user just needs to pay for the rental cost and electricity cost. In fact, power utilities can own the batteries, lease them for EV users, and run battery storage business to leverage their electricity generation business, thereby maximizing their profits on storage and generation of electricity, while making EVs more affordable.

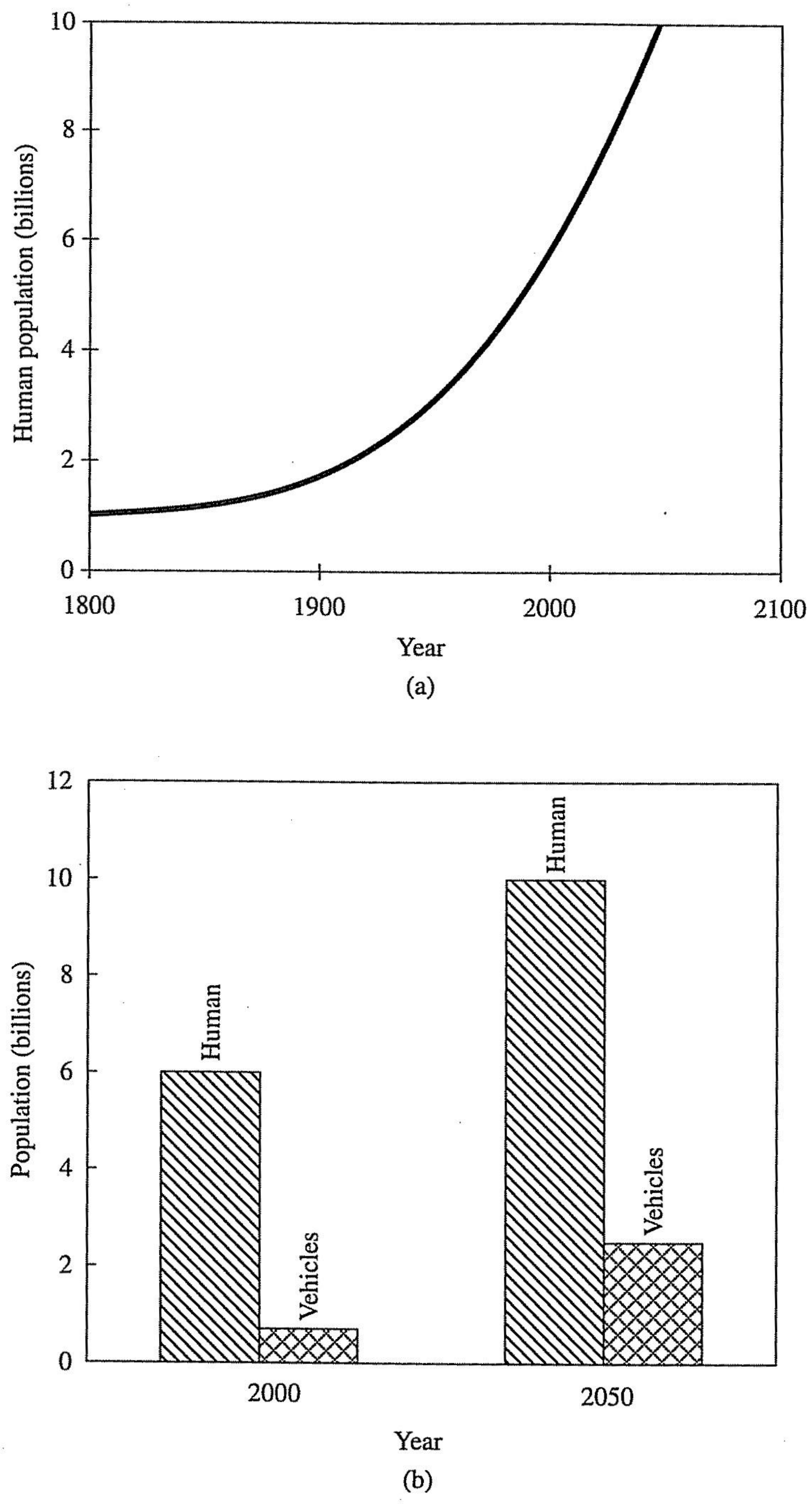


Fig. 1.1. Growth of population and vehicles.

Survey of trends of various technologies from the Elevctric Vehicel Symposium (EVS)

DC – DC motor; IM – Induction Motor;
PM – Permanent Magnet Brushless Motor;
SR – Switched Reluctance Motor

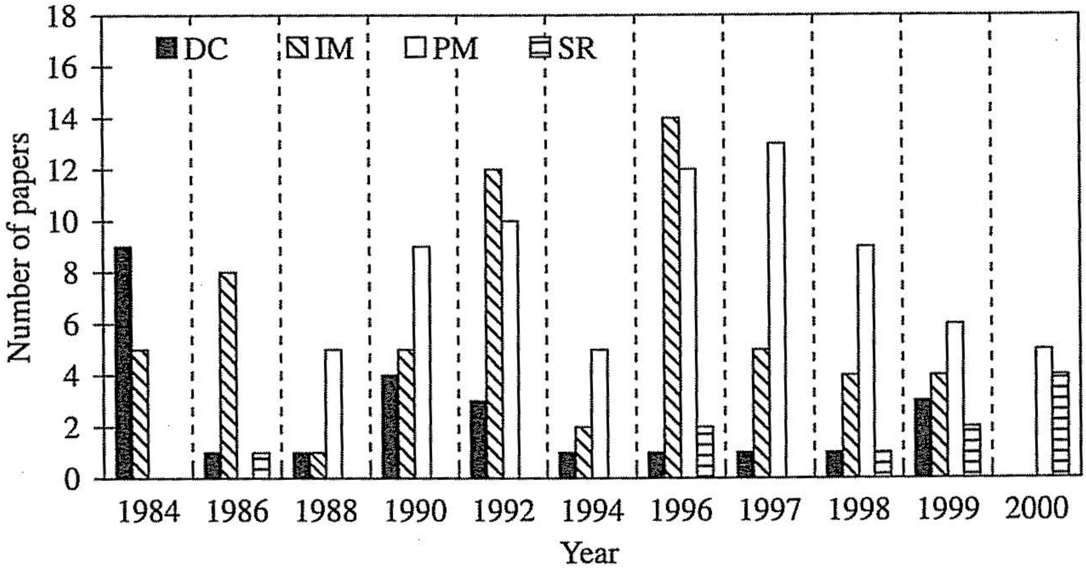


Fig. 1.2. Survey on motor drives in EVS proceedings.

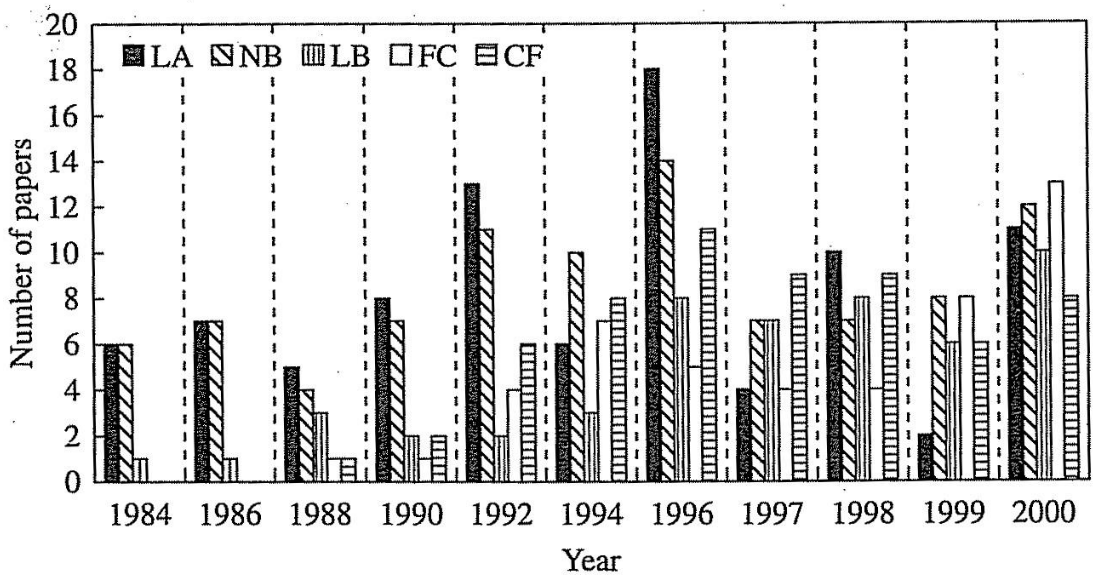


Fig. 1.3. Survey on energy sources in EVS proceedings.

LA – Lead Acid Battery; NB – Nickel Based Battery; LB Lithium Based Battery; FC – Fuel Cell Battery; CF – Capacitor/Flywheel

CEV – Conversion EV; Purpose Built EV;
HEV – Hybrid EV

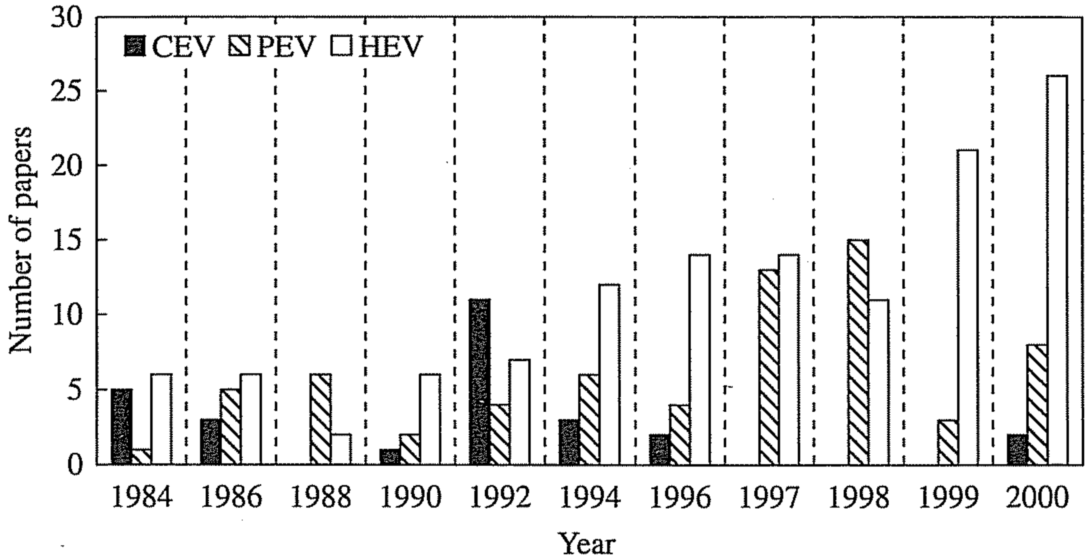


Fig. 1.4. Survey on EV types in EVS proceedings.

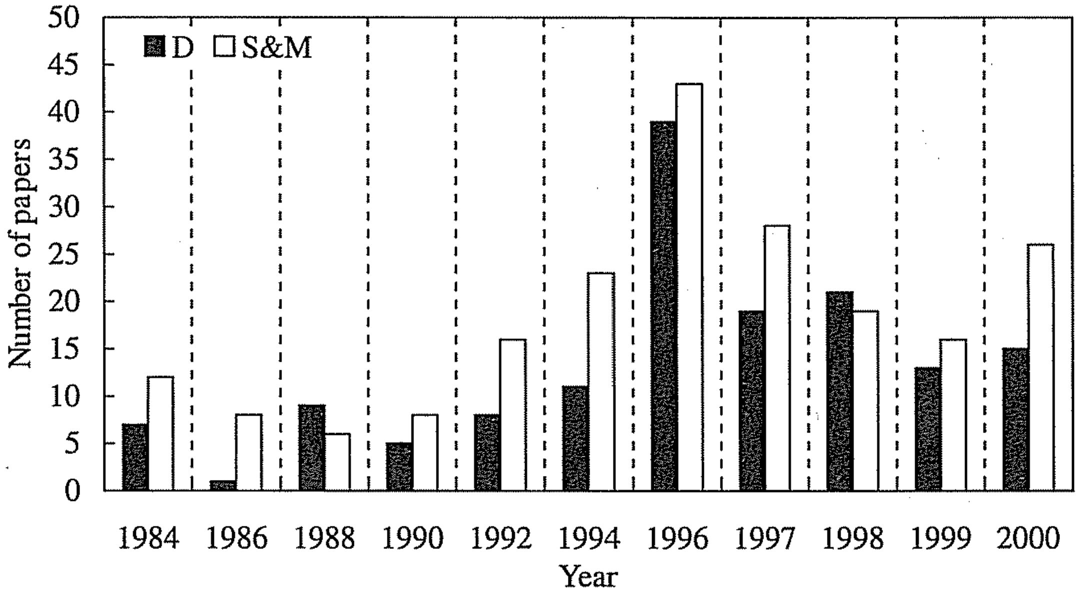


Fig. 1.5. Survey on EV commercialization in EVS proceedings.

D – Demonstration Only; S&M – Standardization and Marketing

3 Engineering Philosophy of EV

The modern EV concept is summarized as follows:

- The EV is a road vehicle based on modern electric propulsion which consists of the electric motor, power converter and energy source, and it has its own distinct characteristics;
- The EV is not just a car but a new system for our society, realizing clean and efficient road transportation;
- The EV system is an intelligent system which can readily be integrated with modern transportation networks;
- EV design involves the integration of art and engineering;
- EV operating conditions and duty cycles must be newly defined;
- EV users' expectations must be studied, hence appropriate education must be conducted.

Engineering Issues:

- To identify the niche market and environment;
- To determine the design philosophy;
- To determine the technical specifications including the driving cycle;
- To determine the infrastructure required including the recycling of batteries;
- To determine the overall system configuration—EV, HEV or fuel cell EV configurations;
- To determine the chassis and body;
- To determine the energy source—generation or storage, single or hybrid;
- To determine the propulsion system—motor, converter and transmission types, single or multiple motors, gearless or geared, mounting methods, and ICE systems in case of an HEV;
- To determine the specifications of electric propulsion (power, torque, speed) and energy source (capacity, voltage, current) according to various driving cycles; for example, Fig. 1.7 shows that the torque-speed requirement of Federal Urban Driving Schedule (FUDS) is very different from that of Federal Highway Driving Schedule (FHDS);
- To adopt intelligent energy management system;
- To analyse the interaction of EV subsystems by using the quality function matrix, hence understanding the degree of interaction that affects the cost, performance and safety;
- To optimize the efficiency of the motor drive according to the selected driving pattern and operating conditions;
- To optimize the overall system using computer simulation.

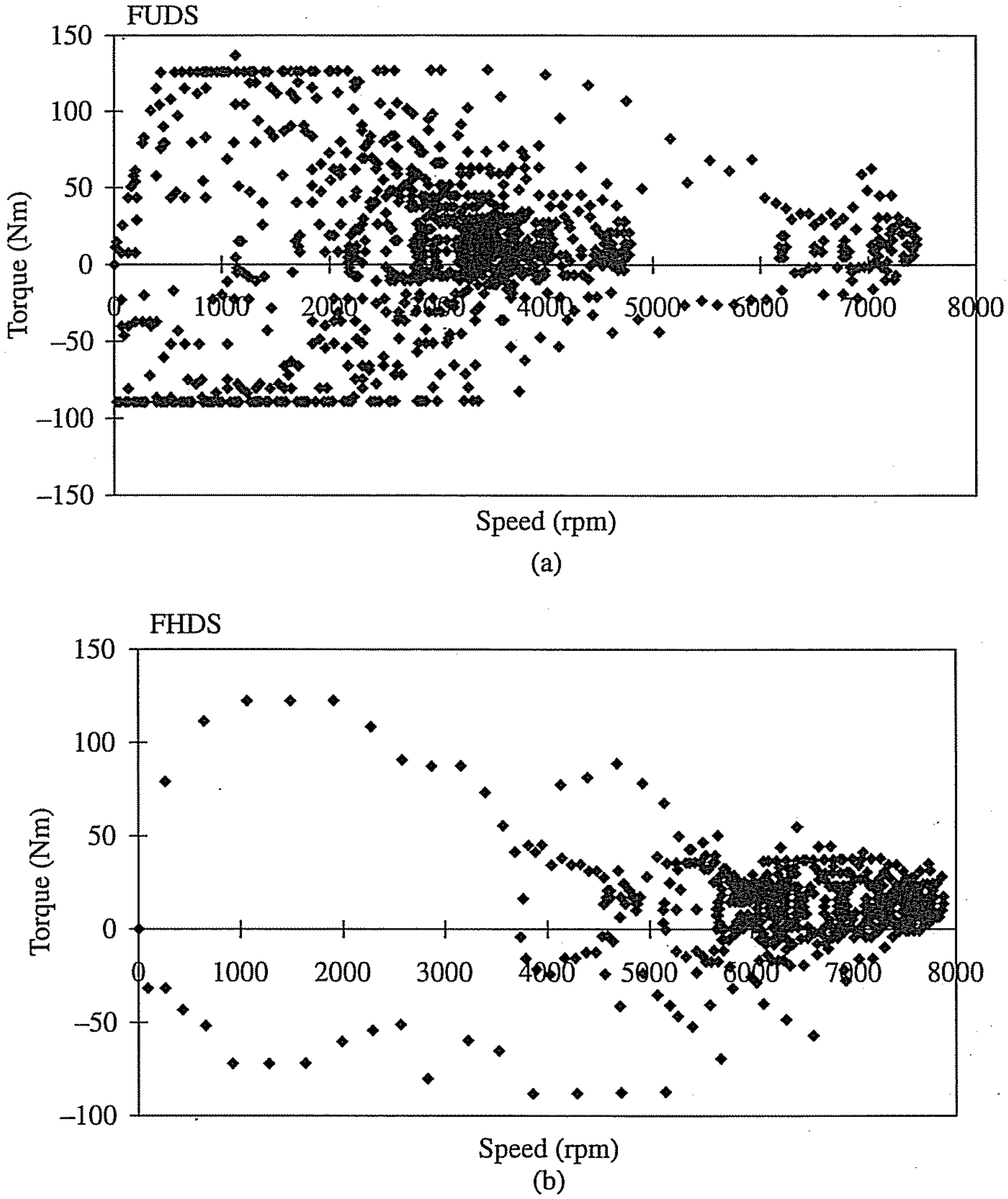


Fig. 1.7. Torque-speed requirements of typical driving cycles.

Electric Propulsion Requirements

Motor drives are the core technology for EVs that convert the on-board electrical energy to the desired mechanical motion. Meanwhile, electric machines are the key element of motor drive technology. The requirements of electric machines for EVs are much more demanding than that for industrial applications. These requirements are summarized as follows (Zhu and Howe, 2007; Chau, 2009):

- High torque density and high power density
- Wide speed range, covering low-speed creeping and high-speed cruising
- High efficiency over wide torque and speed ranges
- Wide constant-power operating capability
- High torque capability for electric launch and hill climbing
- High intermittent overload capability for overtaking
- High reliability and robustness for vehicular environment
- Low acoustic noise
- Reasonable cost

When the electric machine needs to work with the engine for various HEVs, there are some additional requirements:

- High-efficiency power generation over a wide speed range
- Good voltage regulation over wide speed generation
- Capable of being integrated with the engine

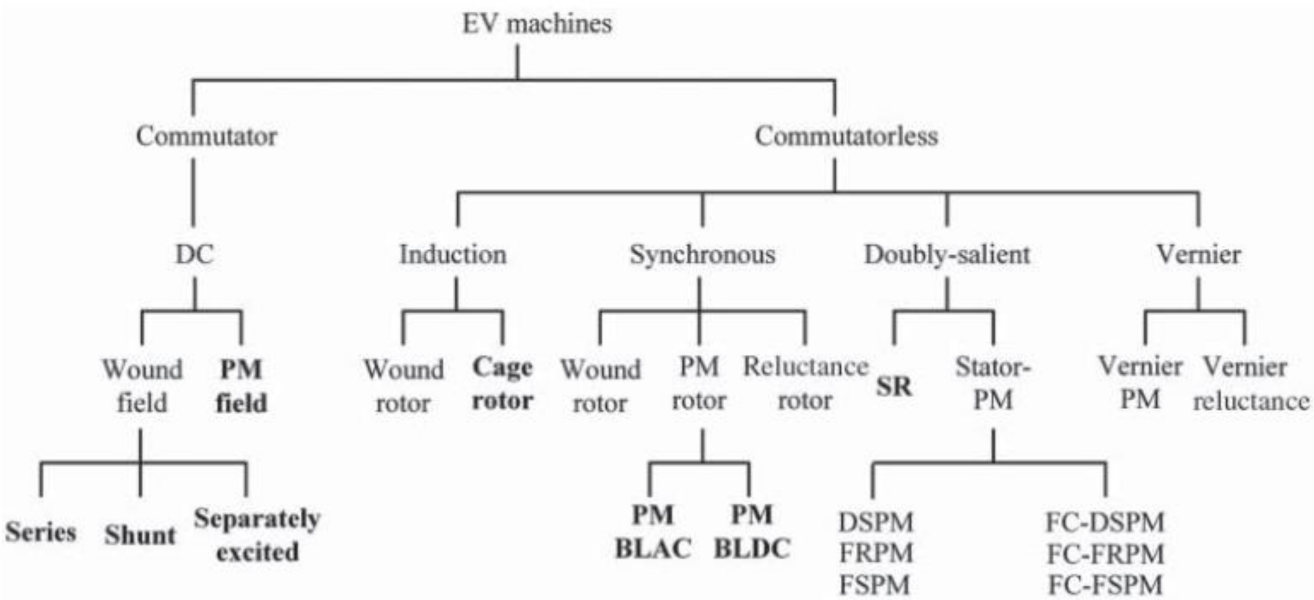


Figure 1.5 Classification of EV machines

Energy Source Requirements

- High specific energy and energy density;
- High specific power and power density;
- Fast charging and deep discharging capabilities;
- Long cycle and service lives;
- Low self discharging rate and high charging efficiency;
- Safety and cost effectiveness;
- Maintenance free;
- Environmental sound and recyclable.

System Optimization Requirements

- to optimize the system energy flow;
- to predict the remaining available energy and hence the residual driving range;
- to suggest more efficient driving behaviour;
- to direct regenerative energy from braking to receptive energy sources such as batteries;
- to modulate temperature control in response to external climate;
- to adjust lighting brightness in response to external environment;
- to propose a suitable battery charging algorithm;
- to analyse the operation history of the energy source, especially the battery;
- to diagnose any incorrect operation or defective components of the energy source.

In summary, the system-level simulation and optimization of EVs should consider the following key issues:

- As the interactions among various subsystems greatly affect the performance of EVs, the significance of those interactions should be analysed and taken into account.
- As the model accuracy is usually coherent with the model complexity but may be contradictory to the model usability, trade-offs among the accuracy, complexity and usability as well as simulation time should be considered.
- As the system voltage generally causes contradictory issues for EV design, including the battery weight, motor drive voltage and current ratings, acceleration performance, driving range and safety, it should be optimized on the system level.
- In order to increase the driving range, multiple energy sources may be adopted for modern EVs. The corresponding combination and hybridization ratio should be optimized on the basis of the vehicle performance and cost.
- Since EVs generally adopt fixed gearing, the gear ratio can greatly affect the vehicle performance and driveability. An optimal ratio should be determined through iterative optimization under different driving profiles.

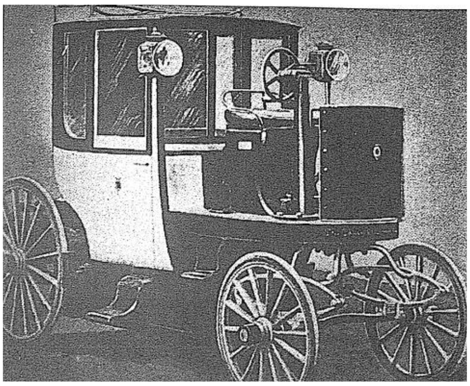
4. Historical Developments

- 1801 – The first steam powered carriage
- 1834 – The first battery powered electric vehicle. A Tricycle, by Thomas Davenport.
- 1838 – The first electric powered locomotive, by Robert Davidson.
- 1874 – The first rechargeable battery powered electric vehicle, by David Solomons.
- 1885 – The first petrol powered Internal Combustion Engine Vehicle (ICEV).
- In 1900, annual sales of 4200 vehicles, 38% were EV, 22% were ICEV, 40% were steam powered.
- 1911 Kettering invented the first electric starter.
- In 1909, Model T Ford was mass produced, and was sold for

US$850.

- In 1929, Model T Ford was selling for US$260.
- In 1930, EV was vanished from the market.

Morris & Salom Electrobat, 1895

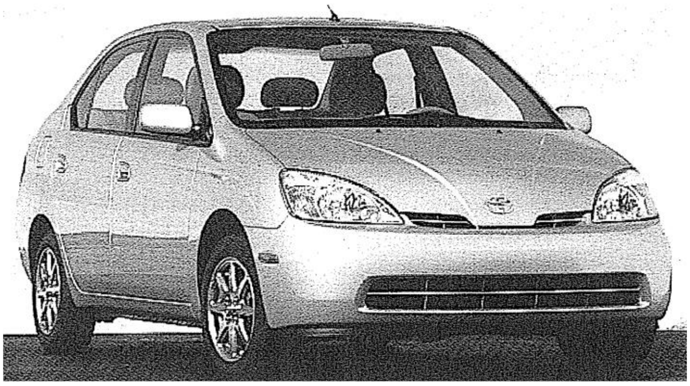


London's Electrical Taxi, 1897

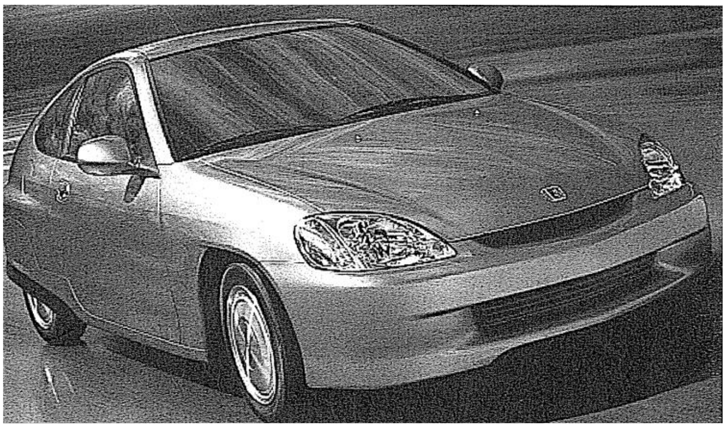
4. Modern EV Developments

GM EVI, 0-96km/h in 9s, 120km/h top speed

Fuel Cell vehicle, 400km range, 150km/h top speed



Toyota Pruis, the 1st generation hybrid car

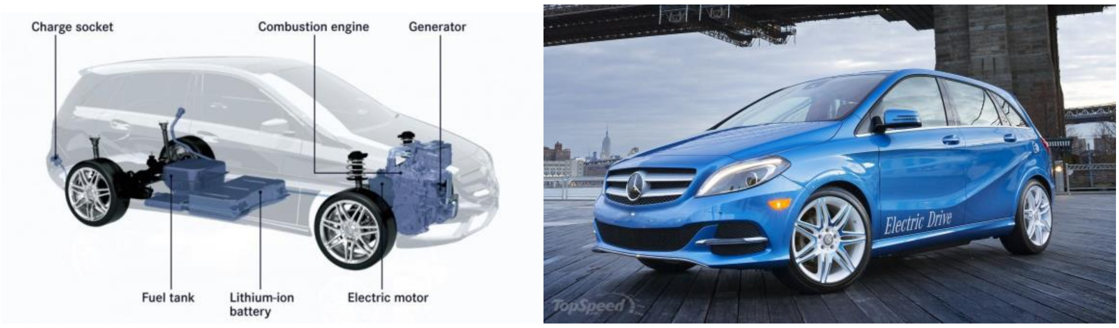


Honda Insight, the hybrid car

Pure Electric Vehicle Sub-Compacts

Mitsubishi miev

Nissan Leaf



Mercedes Class B Electric

Tesler Model S

BYD S6 Electric Taxi

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