Dr. Norbert Cheung's Series
in
Electrical Engineering

Level 5 Topic no: 25

Auxiliary Units

Contents

Reference:

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

Email: norbert.cheung@polyu.edu.hk **Web Site:** www.ncheung.com

1. EV Auxiliaries

Incorporating all EV auxiliaries relating to electrical energy control, the energy management system (EMS) plays an important role in modern EVs. As shown in Fig. 7.1, the EMS makes use of sensory inputs from various EV subsystems to select the battery charging scheme, to indicate the battery SOC, to predict the remaining driving range, to manage the battery operation, to modulate temperature control inside the EV compartment, to adjust lighting brightness, and to recover regenerative braking energy for battery charging. It should be noted that a major subset of the EMS is called the BMS which handles the battery's indication, measurement, prediction and overall management.

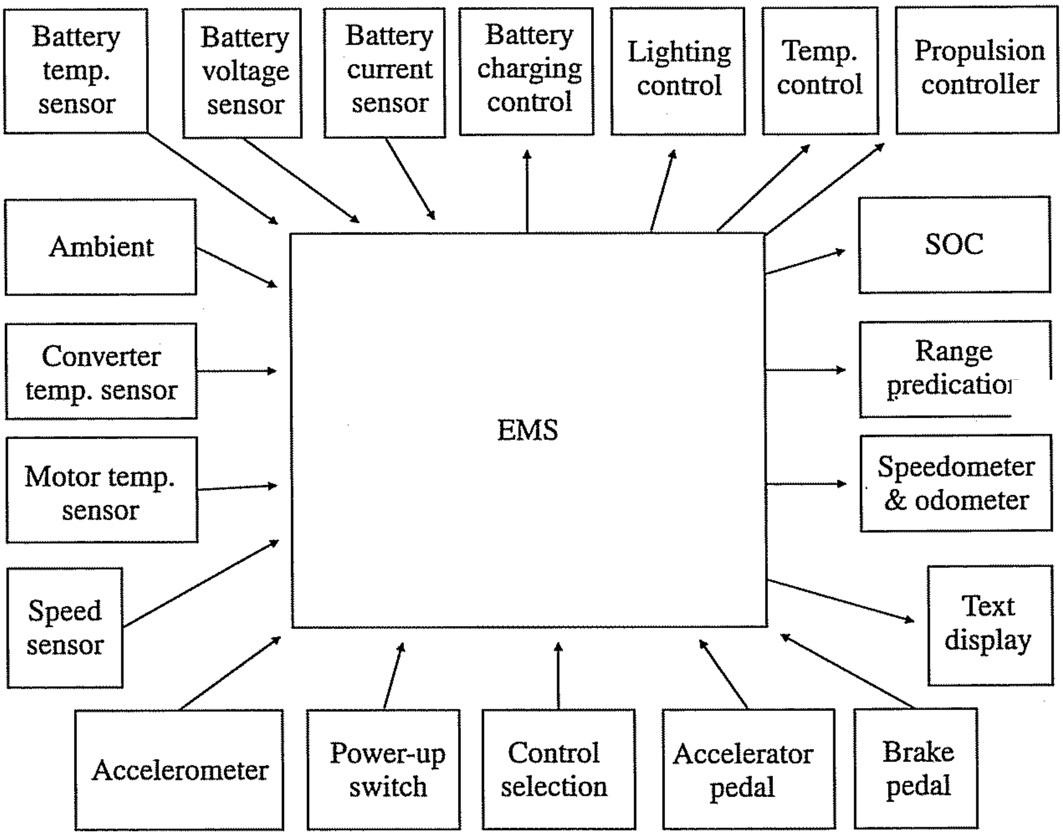


Fig. 7.1. Energy management system for EVs.

2. Battery Chargers

For a practical EV, the battery charger is one of the key auxiliaries, which functions to recharge the discharged batteries of the EV. This EV charger can be on-board or off-board. The on-board one should be designed with small size and lightweight to minimize its drawback to the driving range, hence dedicated to low-power slow-charging purposes. On the other hand, the off-board charger has no limitation on its size and weight, hence it is devoted to offer high-power fast-charging purposes. Modern EVs with the on-board charger can also be recharged through the off-board charger.

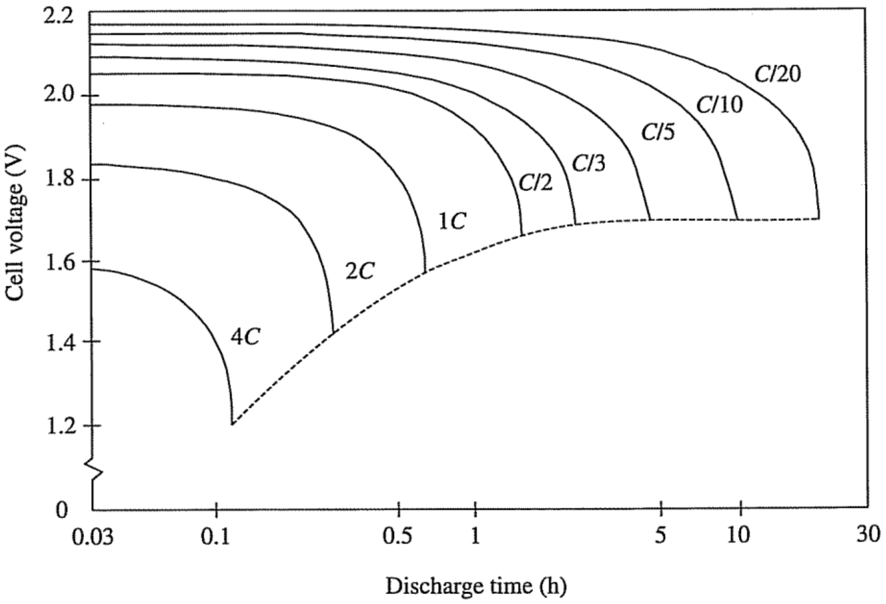


Fig. 7.2. Discharging characteristics (cell voltage vs. time) of a Pb–Acid battery.

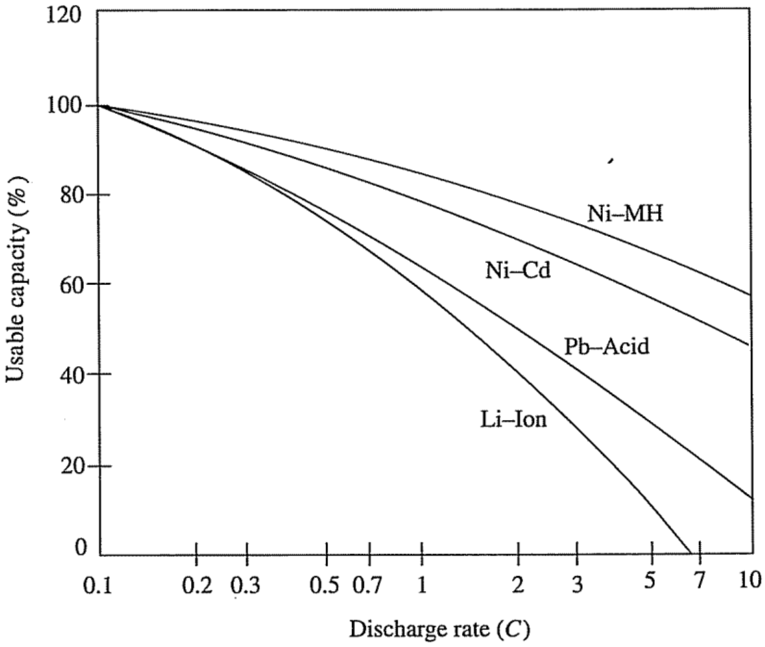


Fig. 7.3. Discharging characteristics (usable capacity vs. C rate) of various batteries.

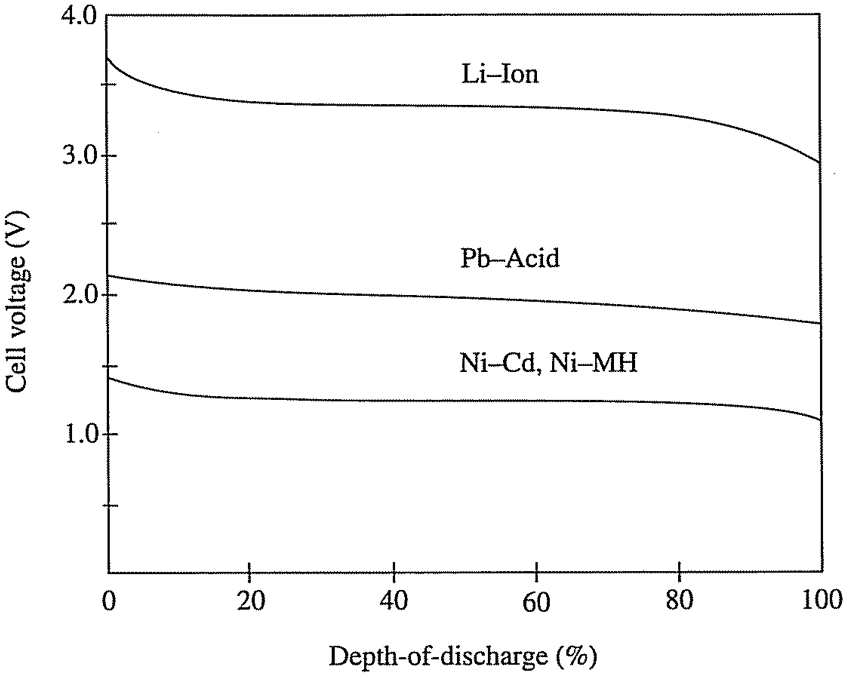


Fig. 7.4. Discharging characteristics (cell voltage vs. DOD) of various batteries.

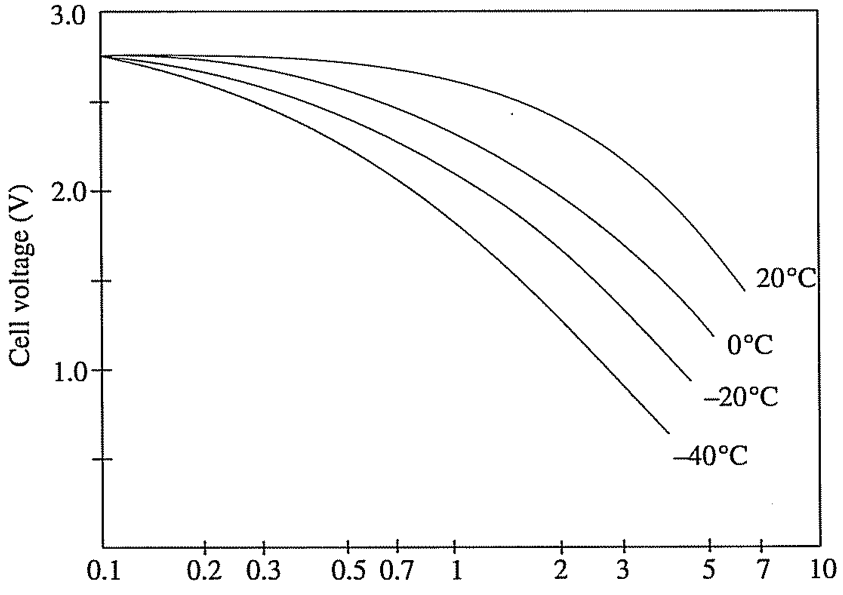


Fig. 7.5. Discharging characteristics (cell voltage vs. *C* rate) of a Pb–Acid battery at various temperatures.

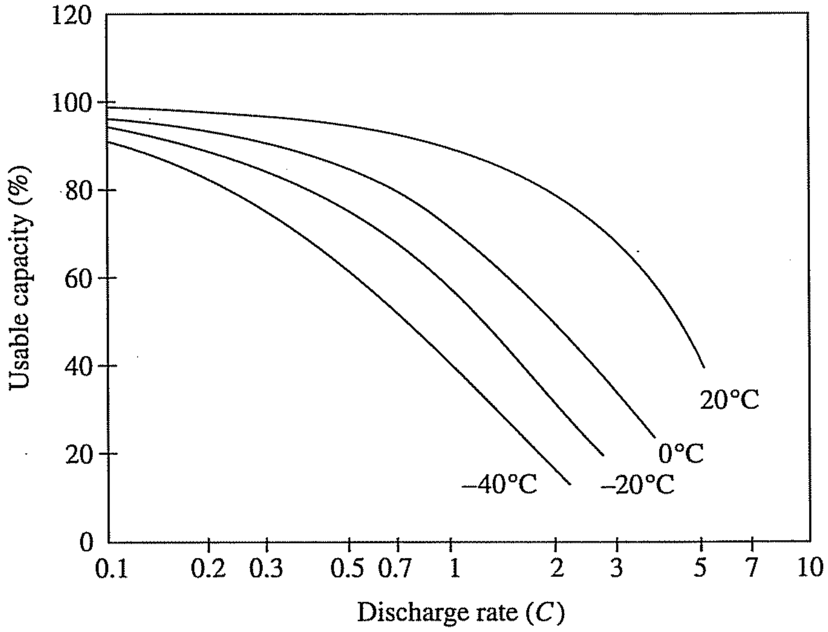


Fig. 7.6. Discharging characteristics (usable capacity vs. *C* rate) of a Pb–Acid battery at various temperatures.

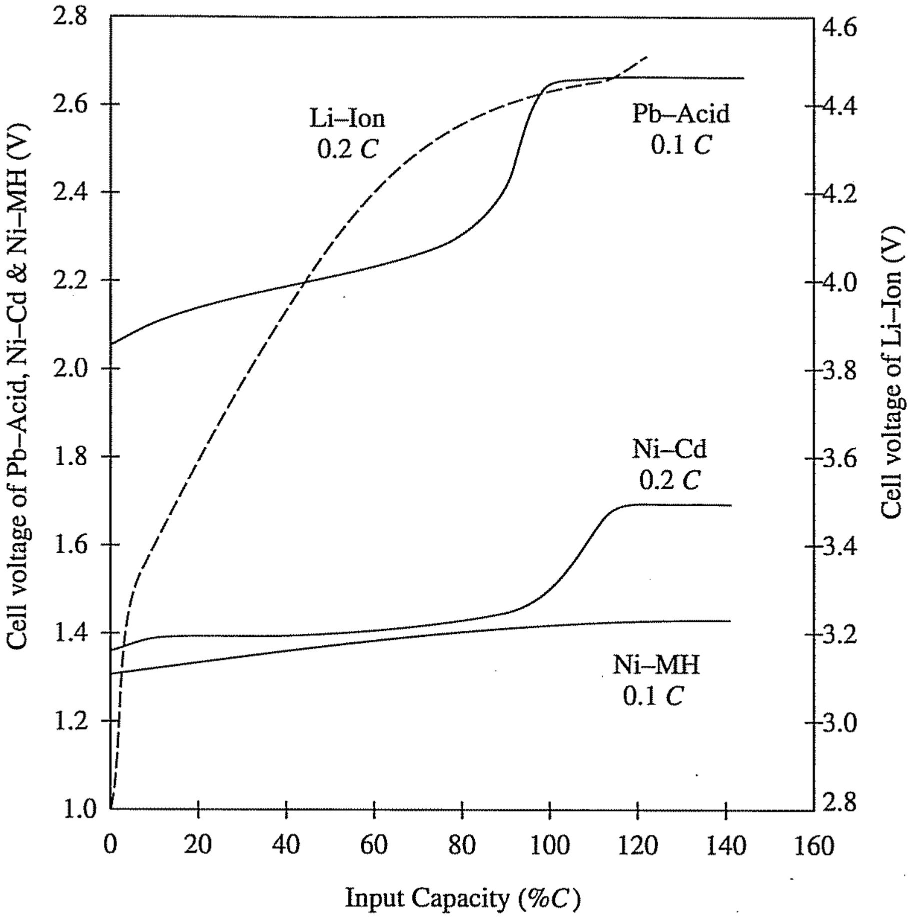


Fig. 7.7. Charging characteristics (cell voltage vs. input capacity) of various batteries.

In general, there are many methods to charge EV batteries because of their different charging characteristics. The key criterion for effective charging is to recharge the battery to its full capacity without causing extended overcharge or excessive temperature. Otherwise, the presence of over-voltage or overheating may result in permanently deteriorating the battery's performance and life, or even causing serious safety hazard. According to the selection of charging voltages and currents, the charging methods for EV batteries can roughly be classified as:

- controlled voltage charging
- controlled current charging and
- controlled voltage and current charging.

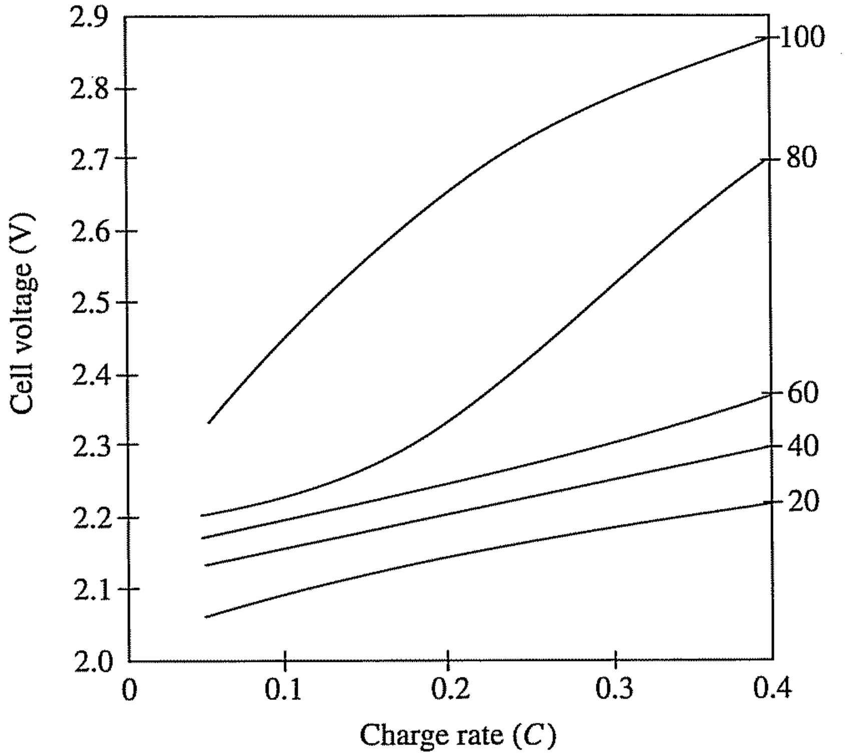


Fig. 7.8. Charging characteristics (cell voltage vs. *C* rate) of a Pb–Acid battery.

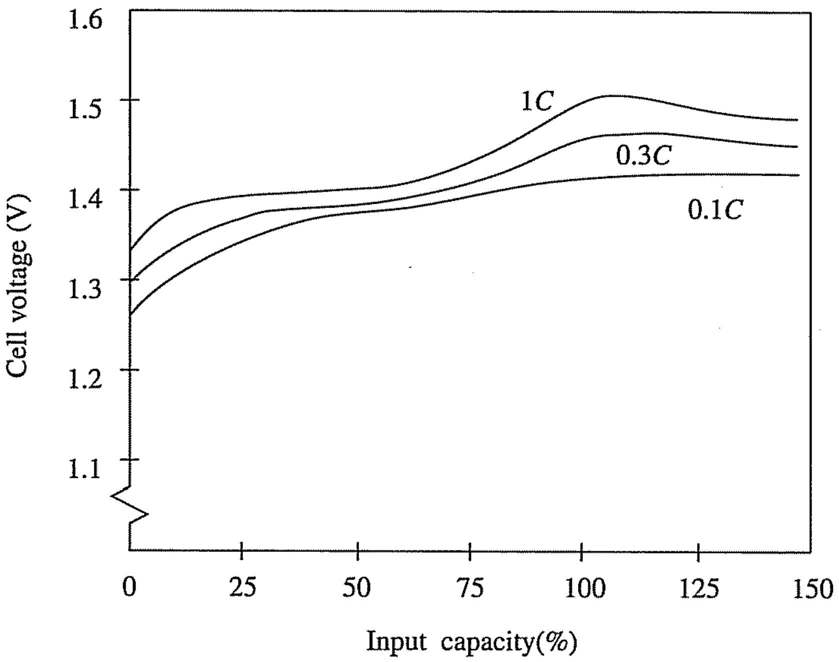


Fig. 7.12. Charging characteristics (cell voltage vs. input capacity) of a Ni–MH battery.

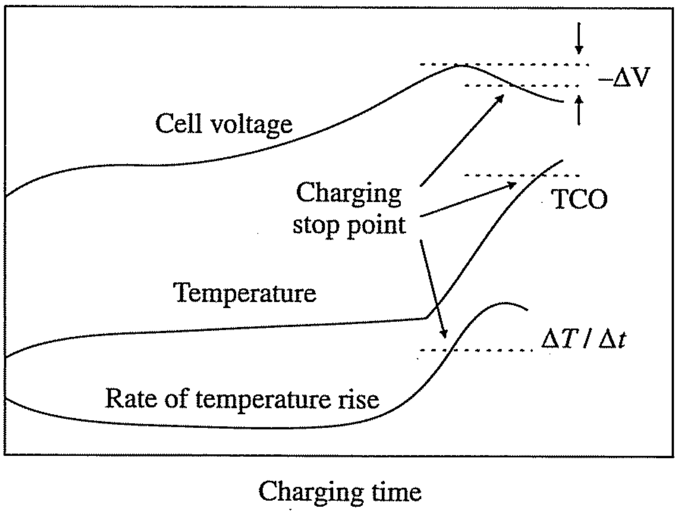
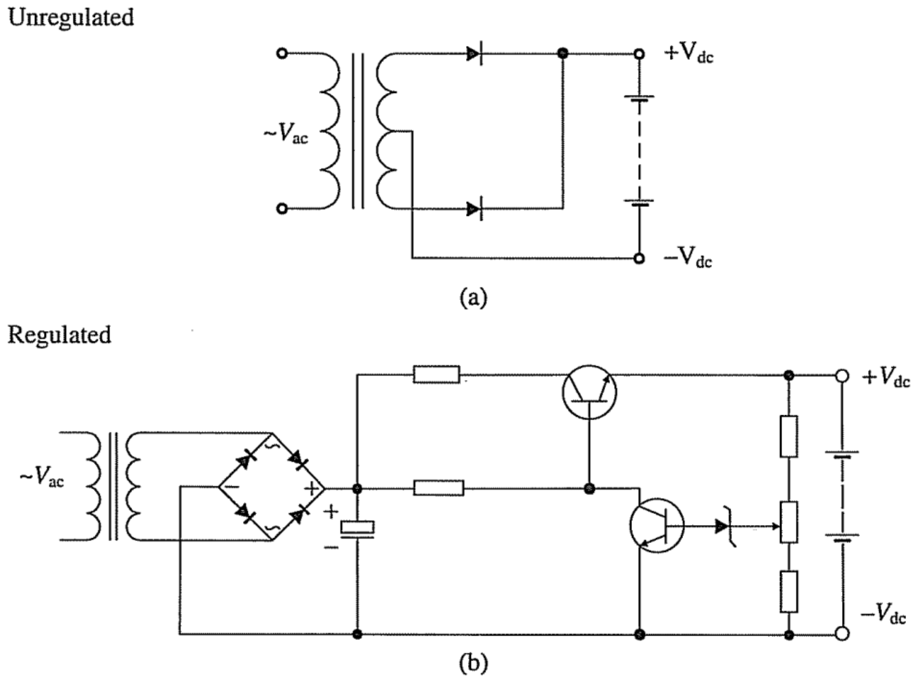


Fig. 7.13. Charging control methods for a Ni–MH battery.

Depending on whether the battery charger is installed inside or outside the EV, it is generally classified as on-board or off-board. The on-board charger is designed with a low charging rate, and is dedicated to charge the battery for a long period of time (typically 5–8 h). Due to the limitation of allowable payload and space of the EV, the on-board charger needs to be lightweight (typically less than 5 kg) and compact. Since both the charger and the BMS (which functions to monitor the battery's voltage, temperature and SOC) are inside the vehicle, they can easily communicate to each other based on the internal wiring network. The corresponding charging method is predefined to suit the battery used in the EV. On the other hand, the off-board charger is designed with a high charging rate, and has virtually no limitation on its weight and size. Since the off-board charger and the BMS are physically separated, they should have a reliable communication by wiring cables or wireless radios. Based on the information of the battery's type, voltage, temperature and SOC supplied by the BMS, the off-board charge will adopt a proper charging method to charge the battery without any excessive overcharge and overheating.



(a)

(b)

Fig. 7.14. Basic charger circuits.

Table 7.1 Standard power levels of conductive chargers

Level 1 Convenience Plugs into a common grounded wall outlet	1-phase 120 V ac, 15 A* ac 1.44 kW (max)
Level 2 Private/public Requires EV supply equipment installation	1-phase 208–240 V ac, 30–60 A ac 14.4 kW (max)
Level 3 Opportunity Requires commercial equipment installation	3-phase 208–600 V dc, 400 A dc 240 kW (max)**

*Receptacle rating (maximum continuous current of 12 A).
**Maximum allowed by standards.

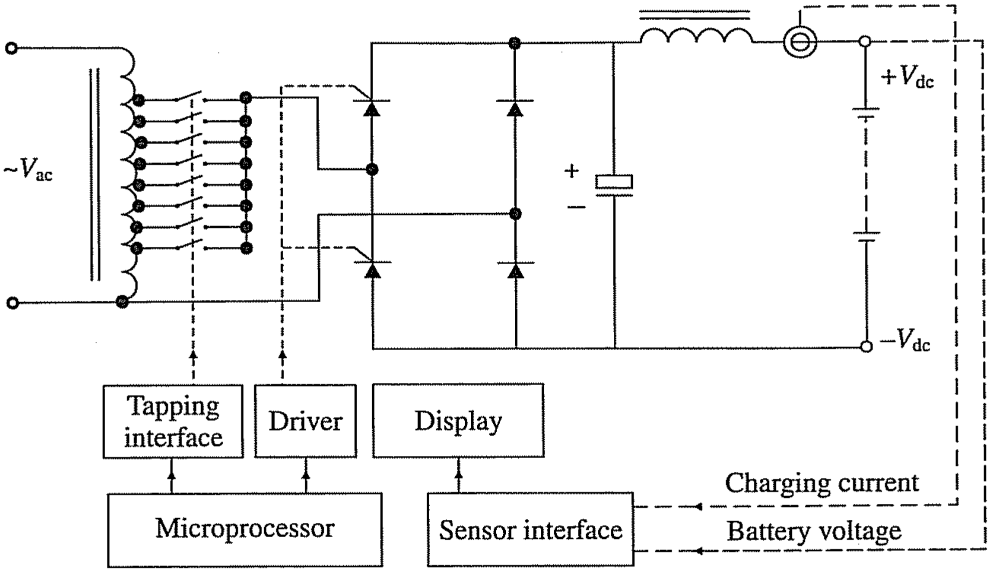


Fig. 7.15. Microprocessor based charger circuit.

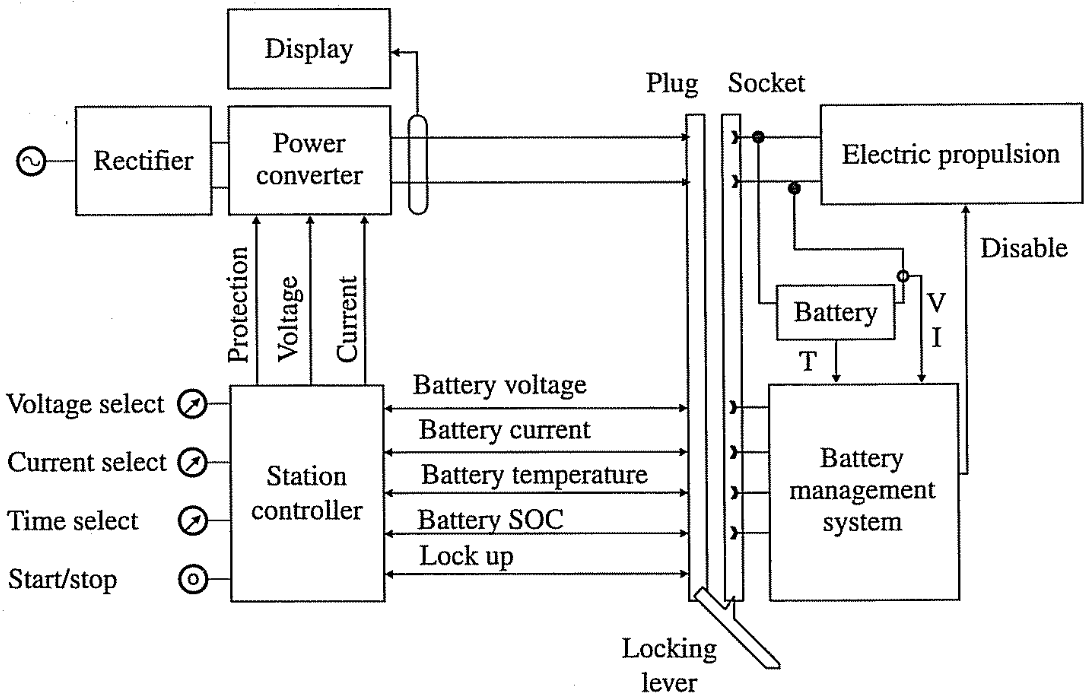


Fig. 7.16. Arrangement of an off-board conductive charger.

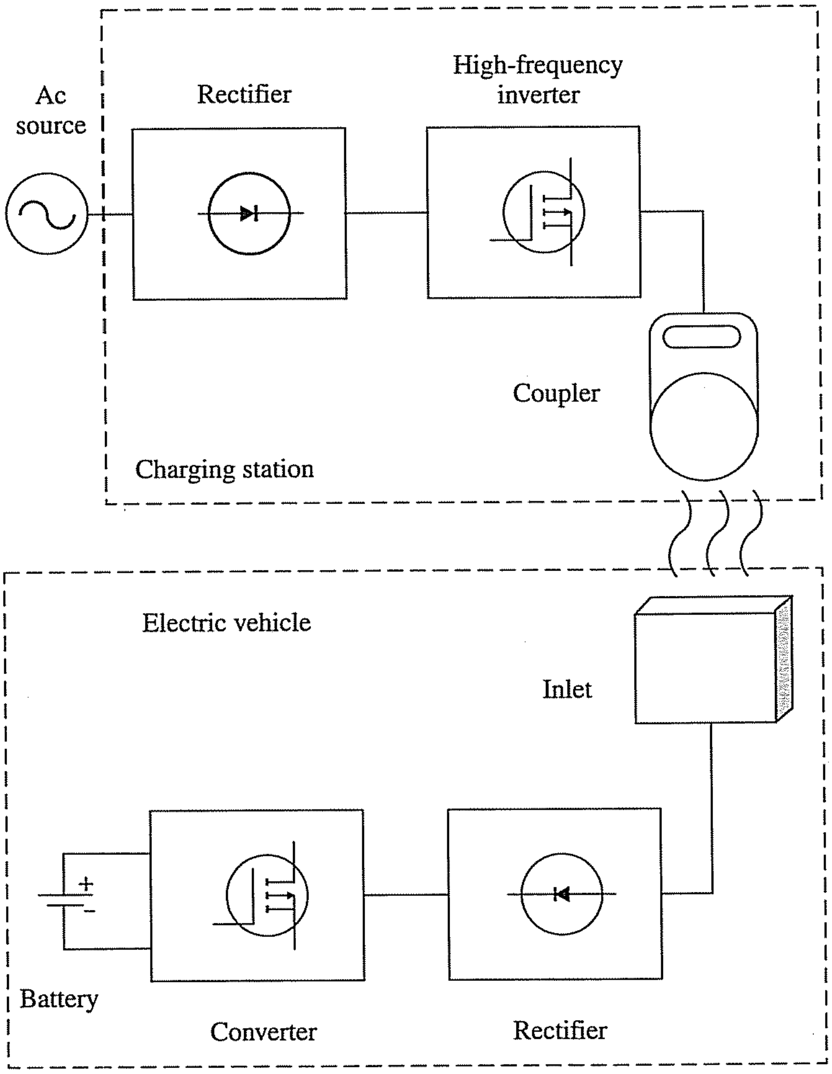


Fig. 7.17. Principle of inductive charging.

Inductive charger

Inductive charging allows electrical energy being transferred from chargers to EVs by induction. As shown in Fig. 7.17, the principle of inductive charging is based on the magnetic coupling between two windings of a high-frequency transformer. One of the windings is installed in the charger terminal while the other is embedded in the EV. Firstly, the main ac supply with a frequency of 50–60 Hz is rectified and converted to a high-frequency ac power of 80–300 kHz within the charger module, then the high-frequency ac power is transferred to the EV side by induction, and finally this high-frequency ac power is converted to dc power for battery charging. The whole process is free from any metallic contacts between the charger and the EV, hence providing a very convenient way for battery charging.

3. Battery Management System

Table 7.2 Main tasks of a BMS

Tasks	Input sensing	Output control
Prevention of battery overcharge	Battery voltage, current and temperature	Battery charger
Avoidance of battery over-discharge	Battery voltage, current and temperature	Power converter of electric motor
Control of battery temperature	Battery temperature	Cooling or heating device
Balancing of module voltages and temperatures	Battery voltage and temperature	Battery balancing unit
Prediction of SOC and residual driving range	Battery voltage, current and temperature	Display unit
Battery diagnosis	Battery voltage, current and temperature	Off-line analysing unit (PC)

Similar to the fuel gauge of ICEVs, the SOC indicator functions to provide the EV driver accurate information on how much energy content remained in the battery. Hence, the driver can plan the future driving range before recharging. Theoretically, the SOC is defined as:

$$\mathrm{SOC} = \frac{C_{\mathrm{r}}}{C_{\mathrm{t}}} \times 100\%,$$

where C_{r} and C_{t} are respectively the residual and total usable coulometric capacity in Ah of the battery. In general, as shown in Table 7.3, C_{t} is significantly affected by the discharging rate or current I. Thus, practically, the SOC is defined as:

$$\mathrm{SOC}_I = \frac{C_{\mathrm{r}I}}{C_{\mathrm{t}I}} \times 100\%,$$

where SOC_I, $C_{\mathrm{r}I}$ and $C_{\mathrm{t}I}$ are the SOC, residual capacity and total usable capacity at a constant discharging current I, respectively.

Having formulated C_{tI} with respect to I, we need to know C_{rI} to deduce the SOC. There are many methods that have been developed to measure C_{rI} or to directly indicate the SOC. Those viable methods are the specific gravity, open-circuit voltage (OCV), constant-current voltage and coulometric capacity measurements:

(1) Specific gravity—it is applicable to those batteries that the specific gravity of the electrolyte depends on the concentration of the electrolyte, hence the SOC. The specific gravity measurement is generally based on a hydrometer. Although this method can yield a reasonable accuracy on the SOC estimation, it is impractical for continual battery operation nor the sealed type battery. Also, the specific gravity measurement needs a lengthy stabilisation period after charging or discharging because of the slow diffusion rate of the electrolyte.

(2) Open-circuit voltage (OCV)—it is a simple and convenient method, but is applicable to those batteries that the OCV significantly varies with the battery SOC. Figure 7.19 shows a typical linear relationship between the OCV and the SOC of a Pb–Acid battery at the $C/10$ rate, whereas Fig. 7.20 is a nonlinear relationship between the OCV and the SOC of a Li-Ion battery at the $C/10$ rate. The key drawback of this method is due to the fact that the OCV generally needs a lengthy stabilization period (typically 12 h) after charging or discharging.

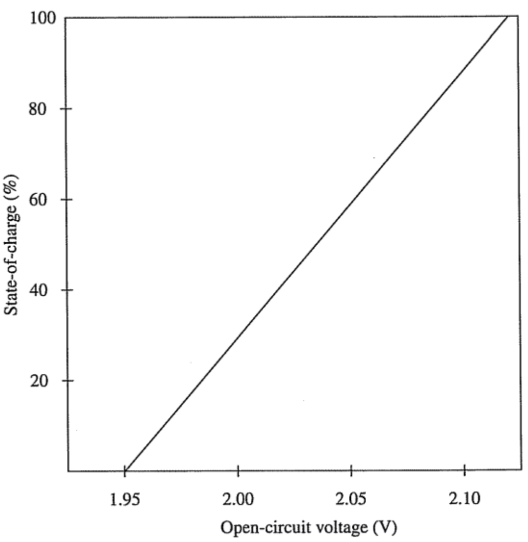


Fig. 7.19. SOC vs. OCV of a Pb–Acid battery.

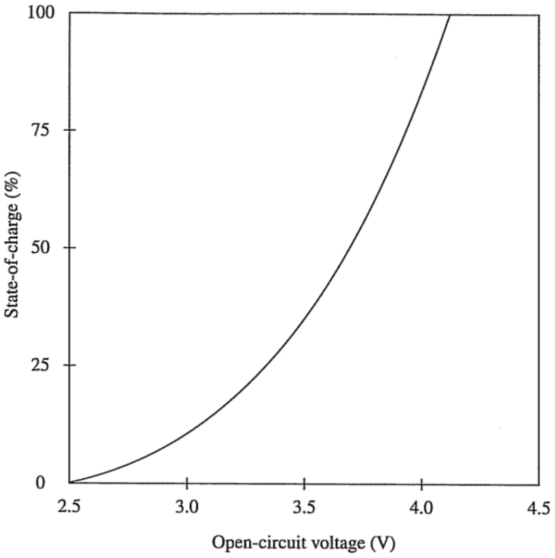


Fig. 7.20. SOC vs. OCV of a Li–Ion battery.

(3) Constant-current voltage—provided that the load current is constant, the load voltage is directly proportional to the OCV, hence estimating the battery SOC. However, this constant-current situation is impractical for variable-load applications such as EVs.

(4) Coulometric capacity—it simply counts the Ah that has been taken out or put into the battery. It can be applied to estimate the SOC of all batteries provided that the total usable coulometric capacity as represented by a Peukert equation is known. This method does provide reasonable accuracy for short-term estimation of the battery SOC; however, it suffers from the accumulation of errors over a long period of estimation.

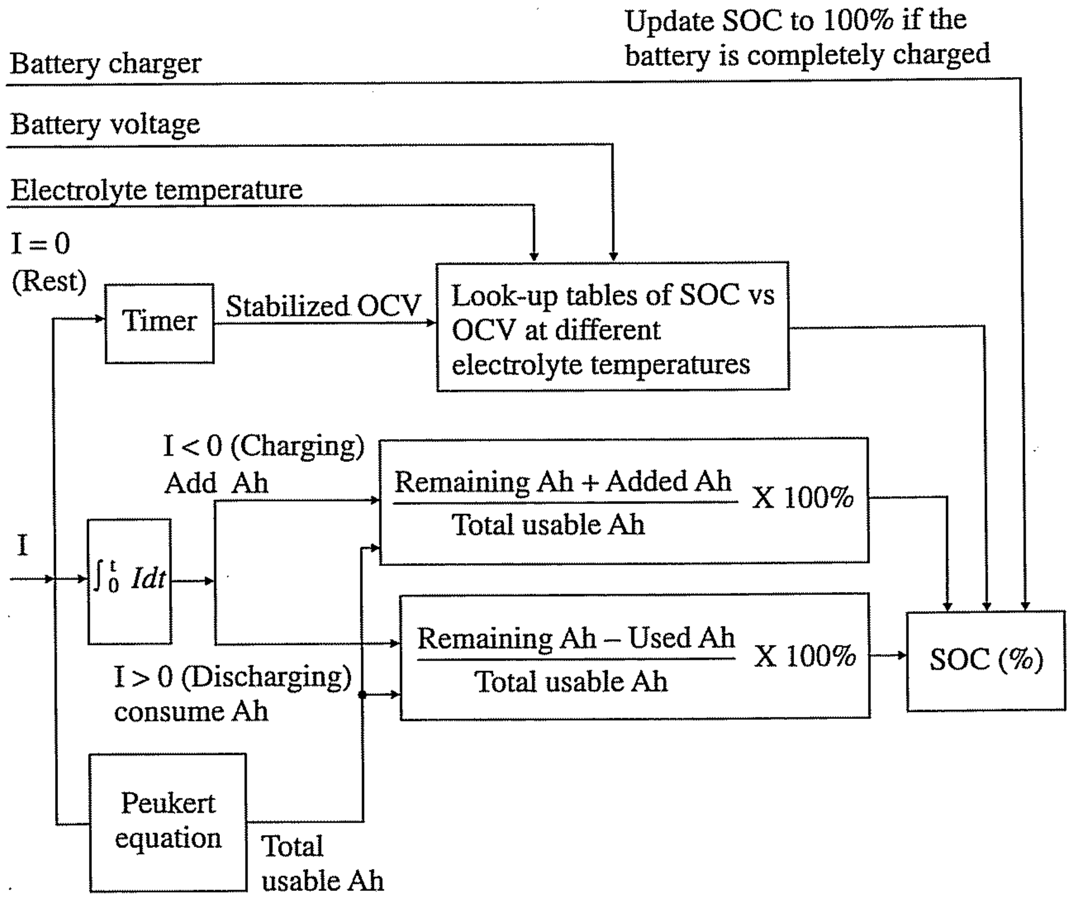


Fig. 7.21. Combined approach for SOC indication.

4. Air Conditioner

Taking into account the factors of EV operation, the EV air-conditioners should satisfy the following requirements:

- high efficiency
- compact size
- lightweight
- low cost
- low acoustic noise and
- workable in all-weather conditions.

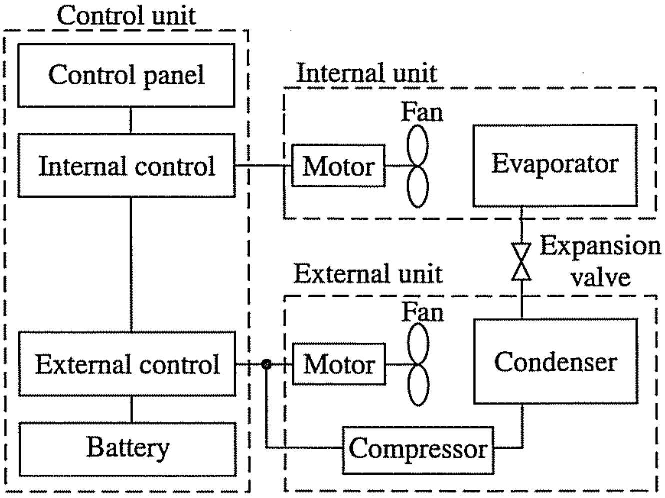


Fig. 7.27. Principle of an EV air-conditioner.

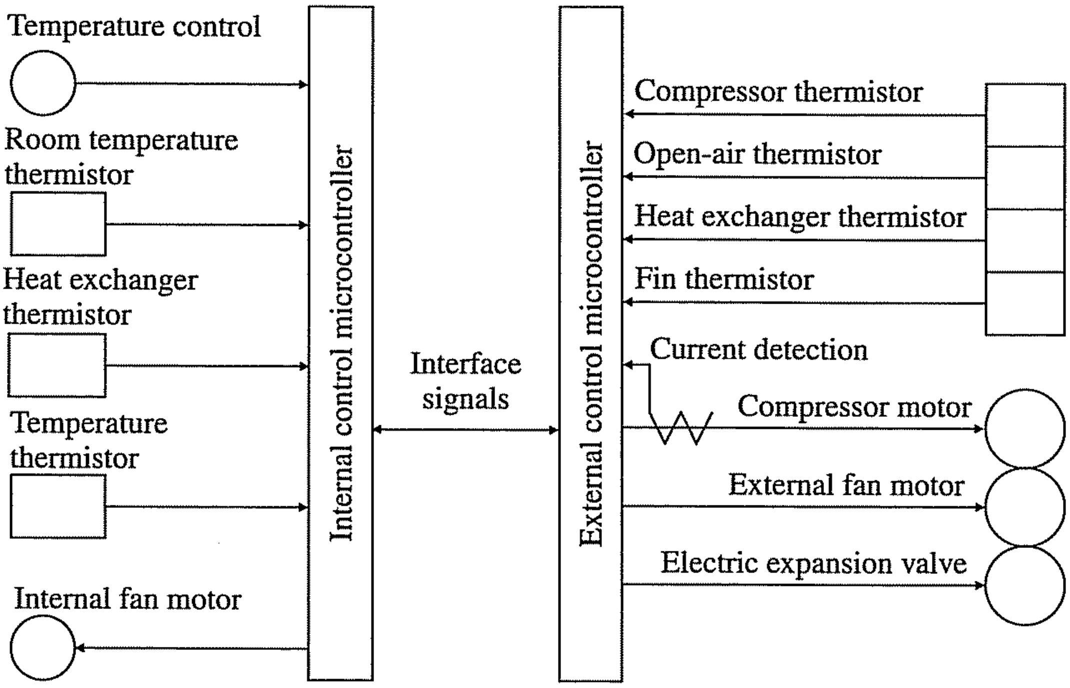


Fig. 7.28. Control schematic of an EV air-conditioner.

The basic drawback of air-conditioners for EV application is high energy consumption because it generally needs 2–4 kW for cooling or heating the whole vehicle compartment. Recently, one new idea has been proposed, namely cooling or heating the vehicle occupant directly, rather than the whole compartment.

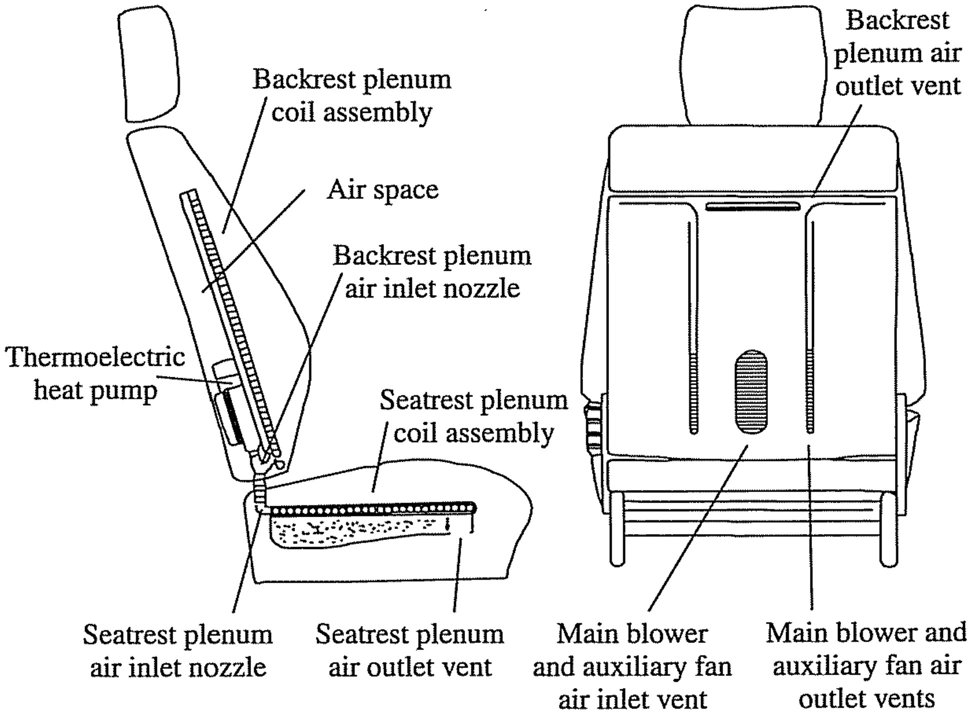


Fig. 7.29. Schematic of an EV variable temperature seat.

5. Electric Power Steering

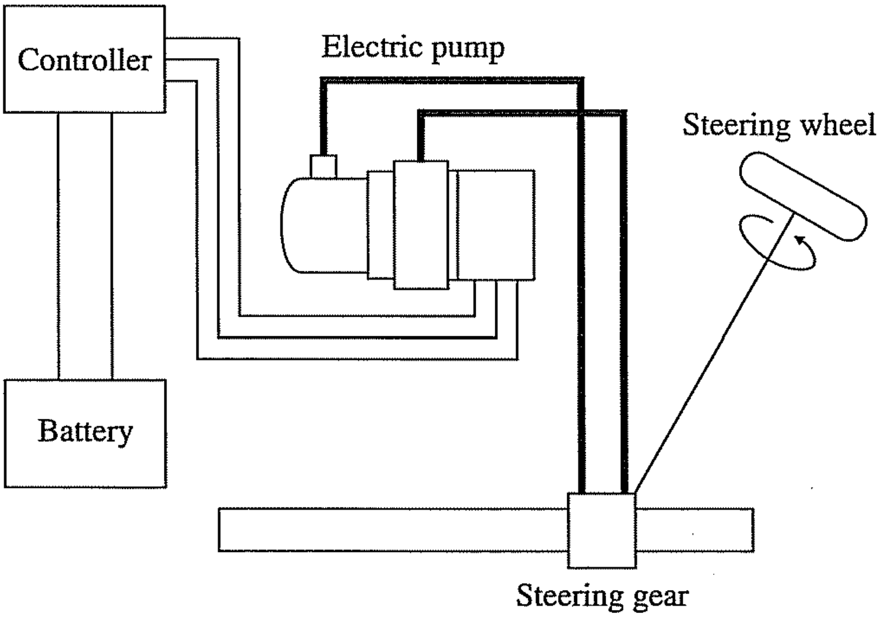


Fig. 7.30. Schematic of an electrohydraulic power steering unit.

By eliminating the hydraulic pump, the electric direct-driving (loosely termed electric) power steering unit directly employs an electric motor to generate the steering torque. Figure 7.31 shows this electric power steering unit which mainly consists of the electric motor, torque sensor, controller and reduction gear (Ijiri,

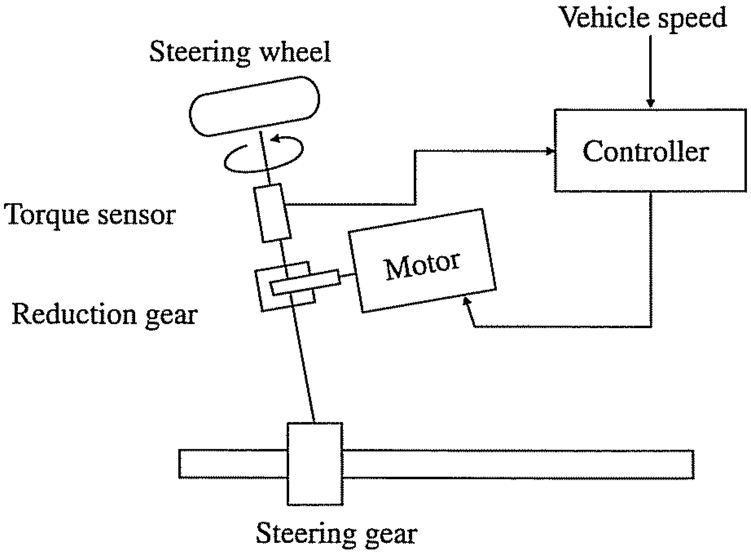


Fig. 7.31. Schematic of an electric power steering unit.

6. Regenerative Braking

Since the regenerative-hydraulic hybrid braking system is unique to EVs or absent in conventional ICEVs, the coordination between regenerative braking and hydraulic braking is a key issue (Ogura *et al.*, 1997). Moreover, some special requirements should also be taken into consideration:

(1) In order to keep the EV driver having a smooth brake feel, the hydraulic braking torque has to be controllable according to the changes of the regenerative braking torque so that the total braking torque is the value expected by the driver. Also, the control of hydraulic braking should not affect the brake pedal stroke and therefore no abnormal feel is experienced by the driver.

(2) Since there is no engine to drive the pump for the production of hydraulic braking torque in EVs, an electric pump assisted hydraulic booster is usually needed. Instead of directly transmitting the hydraulic pressure generated by the driver's brake pedal operation to the wheel cylinders, the hydraulic brak-

ing torque is electrically controlled. Therefore, this regenerative-hydraulic hybrid braking system should be guaranteed with a fail-safe mechanism. To improve the reliability and satisfy the safety standard, a dual circuit arrangement is generally adopted. In case one circuit fails, the other circuit must be able to provide the necessary braking function.

(3) In order to stably brake the vehicle, the braking force distribution between the front and rear wheels has to be well balanced. Moreover, the maximum braking torque to the front and rear wheels should be kept lower than the maximum allowable value (depending on the rolling resistance coefficient) to prevent from skidding.

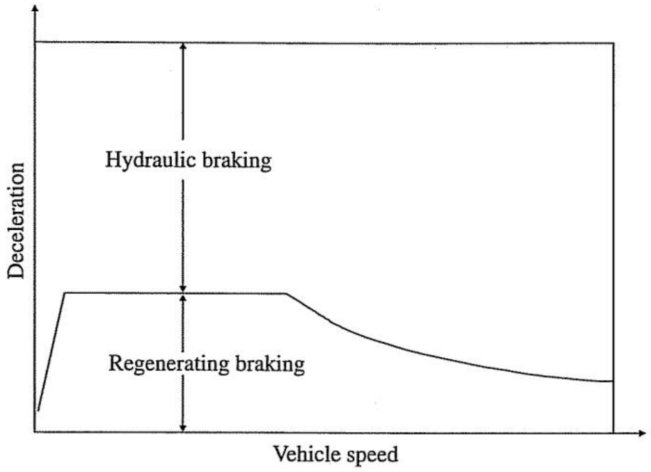


Fig. 7.36. Regenerative and hydraulic braking.

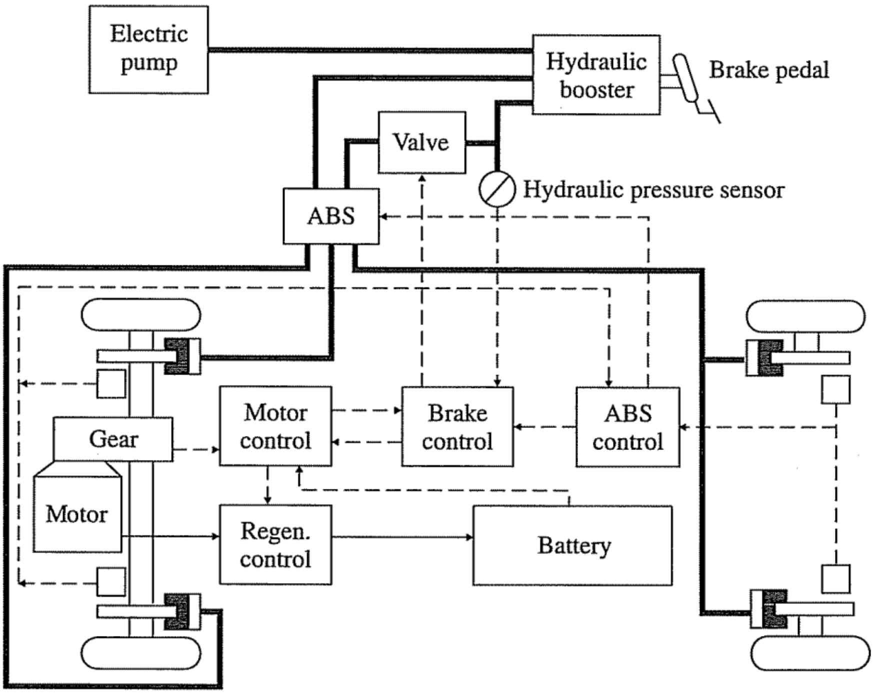


Fig. 7.37. Configuration of a regenerative-hydraulic braking system.

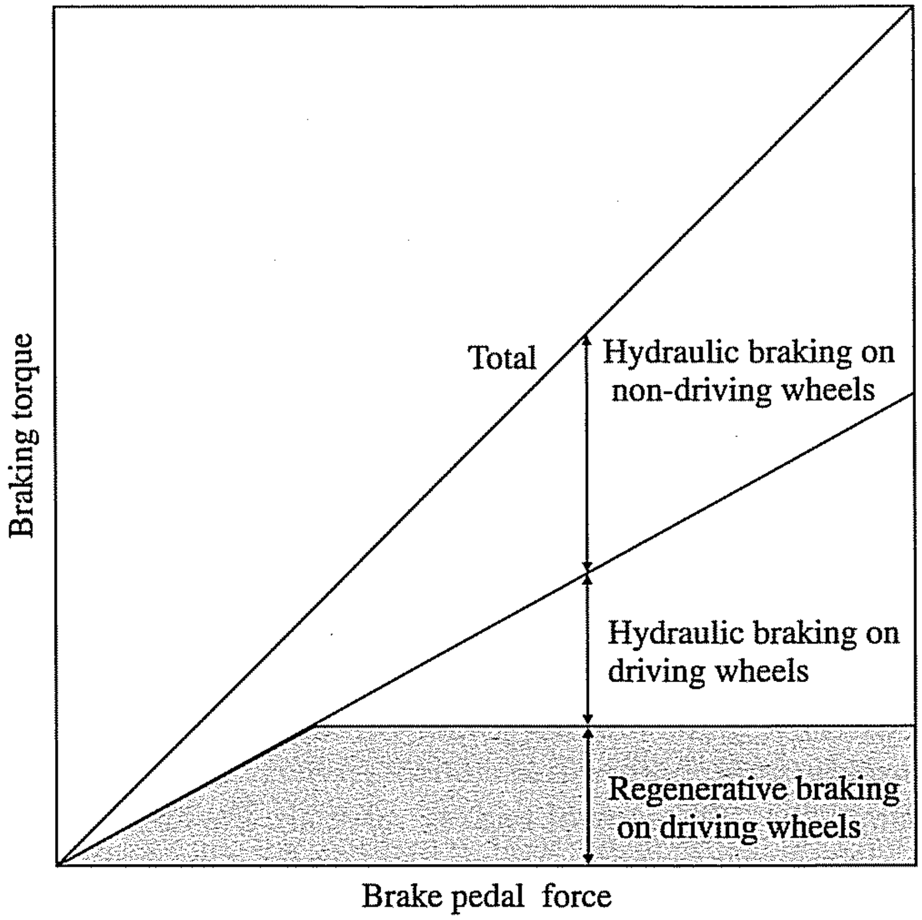


Fig. 7.38. Distribution of regenerative and hydraulic braking torques.

During the whole regenerative braking process, the kinetic energy cannot be fully converted into the electrical energy for battery charging. The corresponding losses along the regenerative energy flow include the aerodynamic loss, rolling resistance loss, braking system loss, motor loss, device loss and charging loss. Nevertheless, modern EVs can generally benefit over 20% energy saving when employing regenerative braking.

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