2

Types of Electric Vehicles – EV Architecture

2.1 Battery Electric Vehicles

The concept of the battery electric vehicle (EV) is essentially simple and is shown in Figure 2.1. The vehicle consists of an electric battery for energy storage, an electric motor and a controller. The battery is normally recharged from mains electricity via a plug and a battery charging unit that can be either carried on board or fitted at the charging point. The controller will normally control the power supplied to the motor, and hence the vehicle speed, in forward and reverse. This is normally known as a 'two-quadrant controller' – forwards and backwards. It is usually desirable to use regenerative braking both to recoup energy and as a convenient form of frictionless braking. When in addition the controller allows regenerative braking in forward and reverse directions it is known as a 'four-quadrant controller'.[1]

There are a range of EVs of this type which are currently available on the market. At the simplest there are small electric bicycles and tricycles and small commuter vehicles. Several manufacturers have released commercial battery EVs. Two of these, the Nissan Leaf and the Mitsubishi MiEV, are described in further detail in Chapter 14.

2.2 The IC Engine/Electric Hybrid Vehicle

A hybrid vehicle has two or more power sources, which gives a very large number of variants. The most common types of hybrid vehicles combine an IC engine with a battery and an electric motor and generator.

There are two basic arrangements for hybrid vehicles: the series hybrid and the parallel hybrid, which are illustrated in Figures 2.2 and 2.3. In the series hybrid design the vehicle is driven by one or more electric motors supplied directly either from the battery or from the IC-engine-driven generator unit – or from both. In the parallel hybrid the vehicle

[1] The four 'quadrants' being forwards and backwards acceleration, and forwards and backwards braking.

Electric Vehicle Technology Explained, Second Edition. James Larminie and John Lowry.

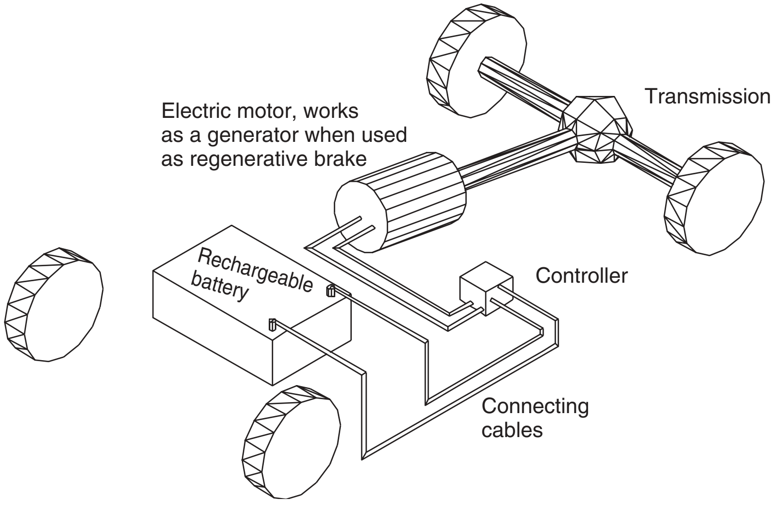

Figure 2.1 Rechargeable battery electric vehicle

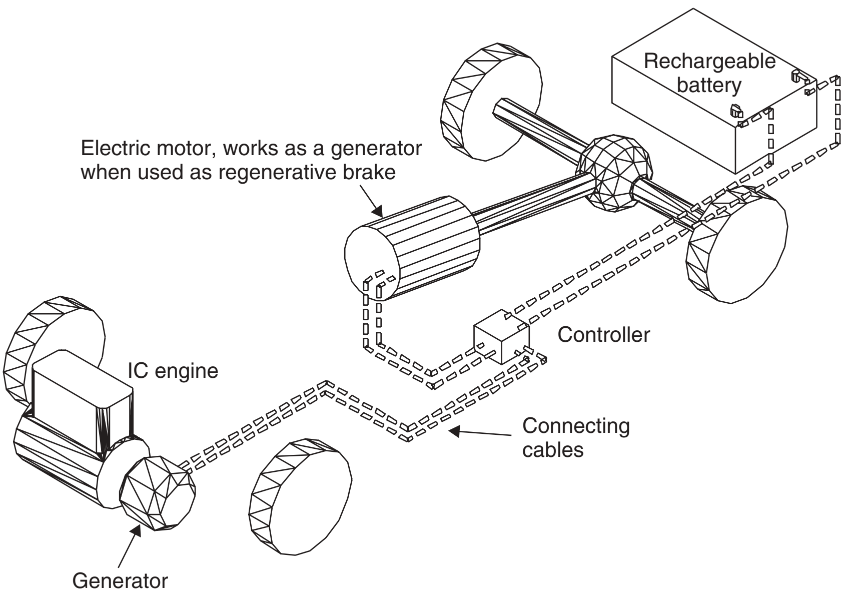

Figure 2.2 Series hybrid vehicle layout. In rechargeable hybrids the battery can also be charged from mains electricity

can be driven either by the engine working directly through a transmission system, or by one or more electric motors working via the transmission or coupled directly to the wheels – or both by the electric motor and the IC engine at once. There are different arrangements for the parallel hybrid system. Figure 2.4 shows a parallel hybrid in which

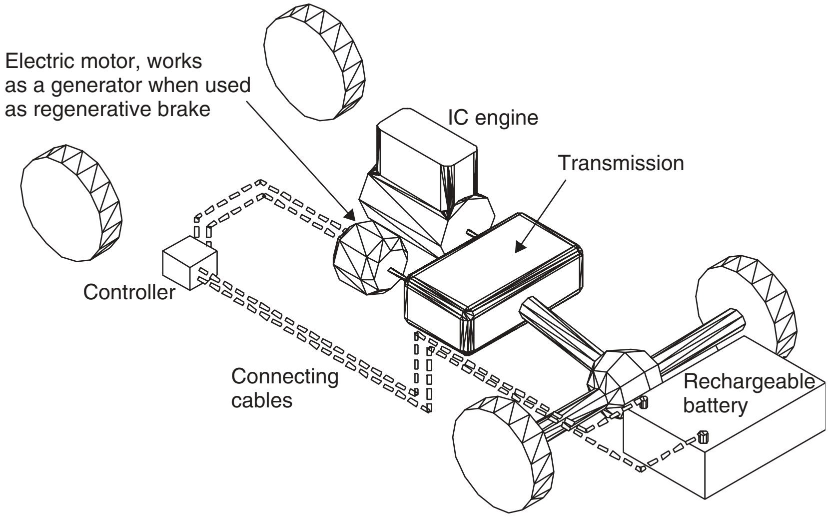

Figure 2.3 Parallel hybrid vehicle layout. In rechargeable hybrids the battery can also be charged from mains electricity

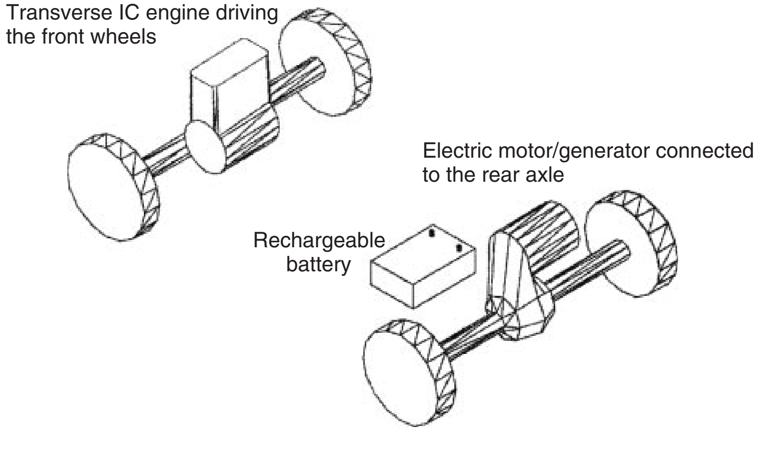

Figure 2.4 Parallel hybrid system with the IC engine driving the front axle, and electric power driving the rear wheels

the engine can drive the front wheels through the front axle, the electric motor driving the rear wheels.

Figures 2.2–2.4 show the hybrids as non-rechargeable hybrids, in which case the hybrid EV will need to run entirely from fossil fuel.

An alternative is to use rechargeable hybrids which normally have much larger batteries to give the vehicle an effective range when working from the battery alone. Both series and parallel hybrid designs allow for regenerative braking – for the drive motor to work as a generator and simultaneously slow down the vehicle and charge the battery.

The series hybrid traditionally is used only in specialist applications. For example, the diesel-powered railway engine is nearly always a series hybrid, as are some ships. Some special all-terrain vehicles are series hybrids, with a separately controlled electric motor in each wheel. The main disadvantage of the series hybrid is that power from the engine cannot be transmitted mechanically to the wheels but must pass through both the generator and the motors.

The parallel hybrid, on the other hand, has scope for very wide application. The electric machines can be much smaller and cheaper, because they do not have to convert all the energy. There are various ways in which a parallel hybrid vehicle can be used. In the simplest it can run on electricity from the batteries, for example in a city where exhaust emissions are undesirable, or it can be powered solely by the IC engine, for example when travelling outside the city. Alternatively, and more usefully, a parallel hybrid vehicle can use the IC engine and batteries in combination, continually optimising the efficiency of the IC engine. A popular arrangement is to obtain the basic power to run the vehicle, normally around 50% of peak power requirements, from the IC engine, and to take additional power from the electric motor and battery, recharging the battery from the engine generator when the battery is not needed. Using modern control techniques the engine speed and torque can be controlled to minimise exhaust emissions and maximise fuel economy.

In parallel hybrid systems it is useful to define a variable called the 'degree of hybridisation' as follows:

$$\mathrm{DOH} = \frac{\text{electric motor power}}{\text{electric motor power} + \text{IC engine power}}$$

The greater the degree of hybridisation, the greater the scope for using a smaller IC engine, and having it operate at near its optimum efficiency for a greater proportion of the time.

Hybrid vehicles are more expensive than conventional vehicles; however, there are some savings which can be made. In the series arrangement there is no need for a gearbox, transmission can be simplified and the differential can be eliminated by using a pair of motors fitted on opposite wheels. In both series and parallel arrangements the conventional battery starter arrangement can be eliminated.

There are several hybrid vehicles currently on the market and this is a sector that is set to grow rapidly in the years ahead. The Toyota Prius, which was shown in Figure 1.14, is a non-rechargeable hybrid. A nickel metal hydride battery is used. At startup or at low speeds the Prius is powered solely by the electric motor, avoiding the use of the IC engine when it is at its most polluting and least efficient. This car uses regenerative braking and has a high overall fuel economy of about 56.5 mpg (US) or 68 mpg (UK).[2] The Prius has a top speed of 160 kph (100 mph) and accelerates to 100 kph (62 mph) in 13.4 seconds. The Prius battery is only charged from the engine and does not use an external socket. It is therefore refuelled with petrol only, in the conventional way. In addition, it seats four people in comfort, and the luggage space is almost unaffected by the somewhat larger than normal battery. The fully automatic transmission system is a further attraction of this car that has brought electric cars well within the reach of ordinary people making the variety of journeys they expect their cars to cope with.

[2] Further details appear in Table 14.9 of the final chapter.

The Prius mainly has the characteristics of a parallel hybrid, as in Figure 2.3, in that the IC engine can directly power the vehicle. However, it does have a separate motor and generator, can operate in series mode and is not a 'pure' parallel hybrid. It has a fairly complex 'power splitter' gearbox, based on epicyclic gears, that allows power from both the electric motor and the IC engine, in almost any proportion, to be sent to the wheels or gearbox. Power can also be sent from the wheels to the generator for regenerative braking.

Many companies are now bringing out vehicles that are true parallel hybrids. The Honda Insight is a good example. Some notable examples do *not* use the gearbox, as shown in Figure 2.3, to combine the engine and electric motor power, but rather use another set of wheels. Figure 2.5 shows the principle of the Daimler Chrysler SUV hybrid. The electric machine is adjacent to the gearbox behind the engine and drives a shaft leading forward to the front axle. This can be used in 'motor mode' to increase the tractive power of the vehicle. It can also be used in 'generator mode', for example when braking.

In vehicles such as the Chevrolet Volt, the vehicle battery can be charged from a separate electrical supply, such as the mains, while the vehicle is not in use. It carries a larger battery than non-rechargeable hybrids and can run for up to 40 miles (64 km) using the battery alone. When the initial pure EV battery capacity drops below a pre-established threshold from full charge and while the Volt is operating as a series hybrid, the Volt's control system will select the most optimally efficient drive mode to improve performance and boost high-speed efficiency. At certain loads and speeds, namely 30–70 mph (48–112 kph), the IC engine may at times be engaged mechanically via a clutch to an output split planetary gearset and assist the traction motor to propel the Volt. Therefore, the Volt can operate as a pure EV, a series hybrid or a parallel hybrid depending on the battery's state of charge (SOC) and operating conditions. The Chevrolet Volt is discussed in more detail in Chapter 14.

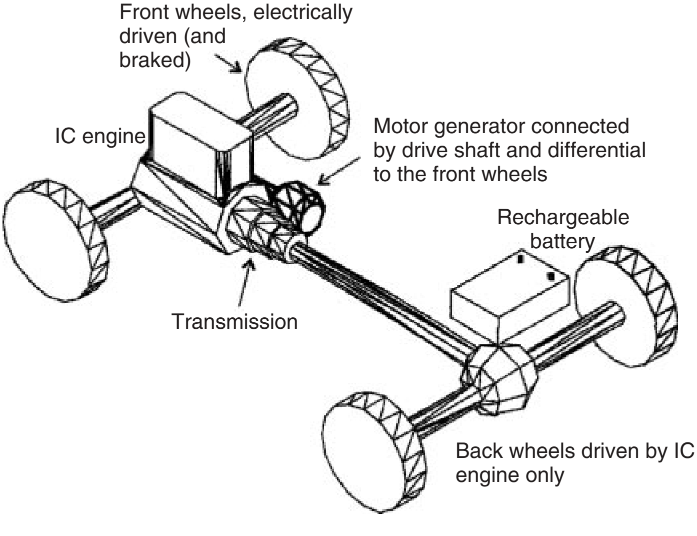

Figure 2.5 Parallel hybrid arrangement similar to that used in the DaimlerChrysler SUV hybrid

2.3 Fuelled EVs

The basic principle of EVs using fuel is much the same as with the battery EV, but with a fuel cell or metal air battery replacing the rechargeable electric battery.

Although invented in about 1840, fuel cells are an unfamiliar technology for most people; they are considered in some detail in Chapter 5.

As we will see later in Chapter 5, a major issue with fuel cells is that, generally, they require hydrogen fuel. This can be stored on board, though this is not easy. An alternative is to make the hydrogen from a fuel such as methanol. This is the approach taken with the Necar 5, which has an onboard reformer. The car can simply be refuelled with methanol in the same way as a normal vehicle is filled up with petrol. The car has a top speed of 150 kph and an overall fuel consumption of 5 l/100 km of methanol. Another fuel cell vehicle of note is the Honda FCX Clarity, which was shown in Figure 1.16. The basic arrangement for the FCX Clarity is shown in Figure 2.6. The vehicle is discussed in further detail in Chapter 15. As the vehicle uses a lithium ion battery working in conjunction with the fuel cell it may also be described as a fuel cell electric battery hybrid!

Public service vehicles such as buses can more conveniently use novel fuels such as hydrogen, because they only fill up at one place. Buses are a very promising early application of fuel cells, as shown in Figure 1.17. A further example of a fuel cell bus is discussed in Chapter 15.

Zinc–air batteries produced by the Electric Fuel Transportation Company (EFTC) have been tested in vehicles both in the USA and in Europe. The company's stated mission is to bring about the deployment of commercial numbers of zinc–air electric buses. During the summer of 2001 a zero-emission zinc–air transport bus completed tests at sites in New York state and later in the year was demonstrated in Nevada. In Germany, a government-funded consortium of industrial firms is developing a zero-emission delivery vehicle based on EFTC's zinc–air batteries.

Metal–air batteries (described in Chapter 3) are a variation on fuel cells. They are refuelled by replacing the metal electrodes, which can be recycled. Zinc–air batteries are a particularly promising battery in this class.

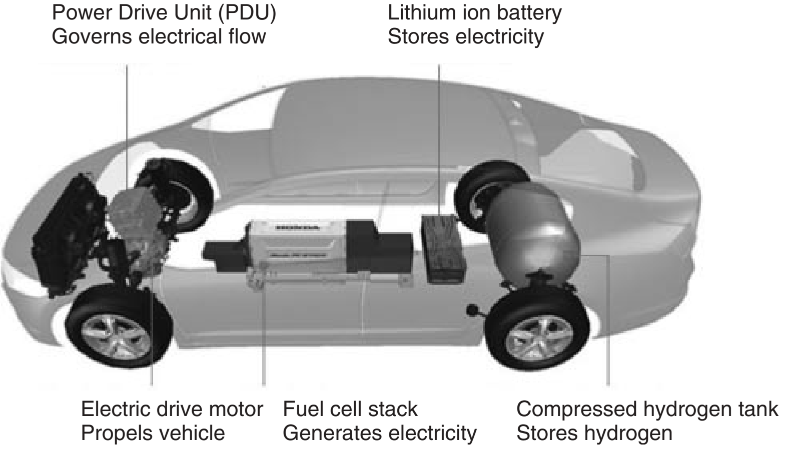

Figure 2.6 Basic arrangement for the Honda FCX Clarity (Courtesy of Honda)

2.4 EVs using Supply Lines

Both the trolleybus and the tram are well known, and at one time were widely used as a means of city transport. They were a cost-effective, zero-emission form of city transport and are still used in some cities. Normally electricity is supplied by overhead lines and a small battery is used on the trolleybus to give it a limited range without using the supply lines.

It is now difficult to see why most of these have been withdrawn from service. It must be remembered that at the time when it became fashionable to remove trams and trolleybuses from service, cost was a more important criterion than environmental considerations and worries about greenhouse gases. Fossil fuel was cheap and overhead wires were considered unsightly, inflexible, expensive and a maintenance burden. Trams in particular were considered to impede the progress of the all-important private motor car. Today, when IC engine vehicles are clogging up and polluting towns and cities, the criteria have changed again. EVs powered by supply lines could make a useful impact on modern transport and the concept should not be overlooked by designers, although most of this book is devoted to free-ranging vehicles.

2.5 EVs which use Flywheels or Supercapacitors

There have been various alternative energy storage devices including the flywheel and supercapacitors. As a general rule both of these devices have high specific powers, which means that they can take in and give out energy very quickly. Although they can do this, the amount of energy they can store is currently rather small. In other words, although they have a good *power* density, they have a poor *energy* density. The principle of the flywheel and the supercapacitor are considered in more detail in Chapter 3.

A novel EV using a flywheel as an energy storage device was designed by British engineer John Parry. The vehicle is essentially a tram in which the flywheel is speeded up by an electric motor. Power to achieve this is supplied when the tram rests while picking up passengers at one of its frequent stations. The tram is driven from the flywheel by an infinitely variable cone and ball gearbox. The tram is decelerated by using the gearbox to accelerate the flywheel and hence transfer the kinetic energy of the vehicle to the kinetic energy of the flywheel – an effective form of regenerative braking. The inventor has proposed fitting both the flywheel and gearbox to a conventional battery-powered car. The advantage of this is that batteries do not readily take up and give out energy quickly, whereas a flywheel can. Secondly, the arrangement can be made to give a reasonably high efficiency of regeneration, which will help to reduce the battery mass.

Experimental vehicles using ultracapacitors (also considered in Chapter 3) to store energy have also been tested; often they are used as part of a hybrid vehicle. The main source of power can be an IC engine, or it can be used with a fuel cell. The MAN bus, for example, uses a diesel engine; the purpose of the capacitor is to allow the recovery of kinetic energy when the vehicle slows down, and to increase the available peak power during times of rapid acceleration, thus allowing a smaller engine or fuel cell to power the vehicle.

Energy stores such as capacitors and flywheels can be used in a wide range of hybrids. Energy providers which can be used in hybrid vehicles include rechargeable batteries, fuelled batteries or fuel cells, solar power, IC engines, supply lines, flywheels and

Figure 2.7 ‘Parry People Mover’ chassis. The enclosed flywheel can be clearly seen in the middle of the vehicle (Photograph kindly supplied by Parry People Movers Ltd)

capacitors. Any two or more of these can be used together to form a hybrid EV, giving over 21 combinations of hybrids with two energy sources. If three or more energy sources are combined, there are even more combinations. Certainly there is plenty of scope for imagination in the use of hybrid combinations.

A photograph of a flywheel and purely mechanical transmission used on the Parry People Mover is shown in Figure 2.7.

2.6 Solar-Powered Vehicles

Solar-powered vehicles such as the Honda Dream, which won the 1996 World Solar Challenge, are expensive and only work effectively in areas of high sunshine. The Honda Dream Solar car achieved average speeds across Australia, from Darwin to Adelaide, of 85 kph (50 mph). While it is unlikely that a car of this nature would be a practical proposition as a vehicle for everyday use, efficiencies of solar photovoltaic cells are rising all the time while their cost is decreasing. The concept of using solar cells, which can be wrapped to the surface of the car, to keep the batteries of a commuter vehicle topped up is a perfectly feasible idea, and as the cost falls and the efficiency increases this may one day prove a practical proposition.

2.7 Vehicles using Linear Motors

A linear motor is an electric motor that has had its stator and rotor 'unrolled' so that instead of producing rotary motion due to torque it produces linear motion due to the force along its length. The linear motor is discussed in more detail in Chapter 7.

Linear motors combined with magnetic levitation are becoming increasingly important due to their use in Maglev trains.

2.8 EVs for the Future

The future of EVs, of course, remains to be written. However, the need for vehicles that minimise damage to the environment is urgent. Much of the technology to produce such vehicles has been developed and the cost, currently high in many cases, is likely to drop with increasing demand, which will allow quantity production. This has certainly proved true already in the case of the lithium ion battery.

The following chapters describe the key technologies that are the basis of EVs now and in the future: batteries and other energy stores (Chapter 3), fuel cells (Chapter 5), hydrogen supply (Chapter 6) and electric motors (Chapter 7). Once the basic concepts are understood, their incorporation into vehicles can be addressed. A very important aspect of this is vehicle performance modelling, and so Chapter 8 is devoted to this topic. The subsequent chapters address the important topics of the design of safe and stable vehicles, and of the 'comfort facilities' that are essential in a modern car. Finally, the environmental impact of EVs needs to be honestly addressed – to what extent do they really reduce the environmental damage done by our love of personal mobility?

The prospect of cities and towns using zero-emission vehicles is a real one, as is the use of vehicles that use electrical technology to reduce fuel consumption. It is up to engineers, scientists and designers to make this a reality.

Further Reading

The following two books have good summaries of the history of electric vehicles:

Wakefield, E.H. (1994) *History of the Electric Automobile*, The Society of Automobile Engineers, Warrendale, PA.

Westbrook, M.H. (2001) *The Electric Car*, The Institution of Electrical Engineers, London.