4

Electricity Supply

4.1 Normal Existing Domestic and Industrial Electricity Supply

A typical electricity supply route is illustrated in Figure 4.1. Once electricity leaves the power station as AC electricity its voltage is stepped up by a transformer and it is then transmitted by high-voltage AC transmission lines. When it nears its destination the voltage is stepped down again and transmitted to the end user. The transmission and distribution efficiency varies from place to place and country to country. Normally the efficiency of transmission (power transmitted to customer/power fed into network) is better than 0.9. Typical losses in the USA are believed to be 6–8%.

High-efficiency, low-loss electricity transmission is possible using high-voltage transmission lines with voltages of up to 150 000 V. Energy losses can be kept as low as 3% per 1000 km. High-voltage DC technology is only really suited to long-range transmission due to the static inverters that must be used to convert the energy to direct current for transmission. These are expensive devices, in terms of both capital cost and energy losses, although the cost is coming down.

High-voltage transmission lines allow the creation of supergrids in which energy can be transmitted for long distances. These superhighways open up considerable advantages for alternative energy use, for example they allow for solar energy to be created in North Africa and transmitted with low losses to Britain or for electricity from wind energy to be transmitted from areas of high wind to areas of no wind. A high-voltage transmission line used as part of a superhighway is illustrated in Figure 4.2.

In January 2009, the European Commission proposed €300 million to subsidise the development of high-voltage DC links between Ireland, Britain, the Netherlands, Germany, Denmark and Sweden, as part of a wider €1.2 billion package supporting links to offshore wind farms and cross-border interconnectors throughout Europe. Meanwhile the recently founded Union of the Mediterranean has embraced a Mediterranean Solar Plan to import large amounts of concentrating solar power into Europe from North Africa and the Middle East.

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

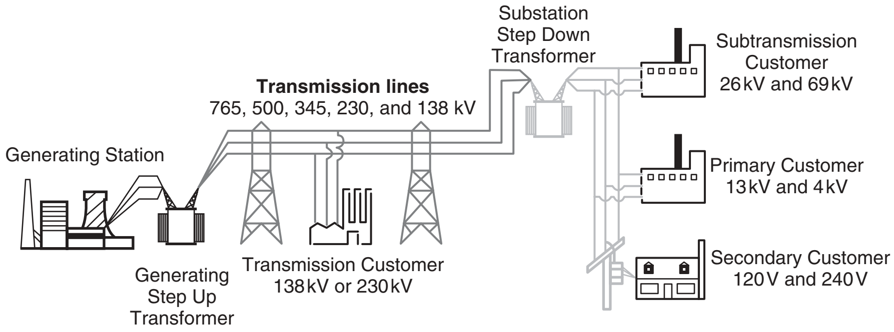

Figure 4.1 Electricity grid in North America. (Source: US DOE, http://en.wikipedia.org/wiki/Electric_power_transmission.)

Figure 4.2 Renewable electricity superhighways (Source: http://en.wikipedia.org/wiki/High-voltage_direct_current)

4.2 Infrastructure Needed for Charging Electric Vehicles

Once electricity has been transmitted to the point of use it has to be supplied to the EVs which will use it. Most buildings in the developed world have electrical sockets available which will typically supply up to 3 kW of power and hence the assumption is that EVs can be charged overnight ready for the next day or during the day while parked at work. For more rapid charging, sockets which transmit greater amounts of power combined with appropriate cabling need to be available. The Nissan Leaf, for example, has a battery capacity of 24 kWh and if this is to recharge 80% of its capacity in 48 minutes then 24 kW of power will need to be available at the socket. For home charging such sockets will need to be fitted. Charging at work will need to be catered for with appropriate sockets being available in the work car park, in public car parks or for street parking.

Inductive charging points are another option and these need to be wired in where the vehicle is parked. Motorway service stations are an interesting example. While it is too early to predict a demand pattern it is not unreasonable to consider100 cars per hour needing a rapid charge. A hundred charging points each supplying 24 kW will create a demand for 2.4 MW. Clearly, considerable planning needs to be done on the likely infrastructure if battery EVs become common.

4.3 Electricity Supply Rails

Electric trains normally take power from supply rails or overhead supply lines. These can either be DC or AC lines. For example, London Underground trains run on DC supply rails: the rail besides the track runs at 420 V and the central rail runs at 210 V. AC supply can be either single phase or multiphase.

The train takes electric current from a rail or wire mounted on insulators. The current is collected from steel shoes which are in contact with the supply rail running parallel to the track. The shoes which are connected to the train move as the train moves. Alternatively, the current can be collected from overhead lines.

The supply rails normally use direct current. There is a choice between using a three-rail or a four-rail system. In the three-rail system the rail runs at several hundred volts and the current is returned via the normal running rails. In the four-rail system as used on the London Underground the current is returned through the fourth rail. The most common DC voltages are 600 and 750 V for trams and underground trains of metros and 1500, 650/750 V third rail for the former Southern Region in Britain, and 3 kV overhead. The lower voltages are often used with third- or fourth-rail systems, whereas voltages above 1 kV are normally limited to overhead wiring for safety reasons. A pickup for a DC third rail is illustrated in Figure 4.3. Most third-rail systems are used with a DC supply. Overhead systems are used with either DC or AC supply. The Tyne and Wear

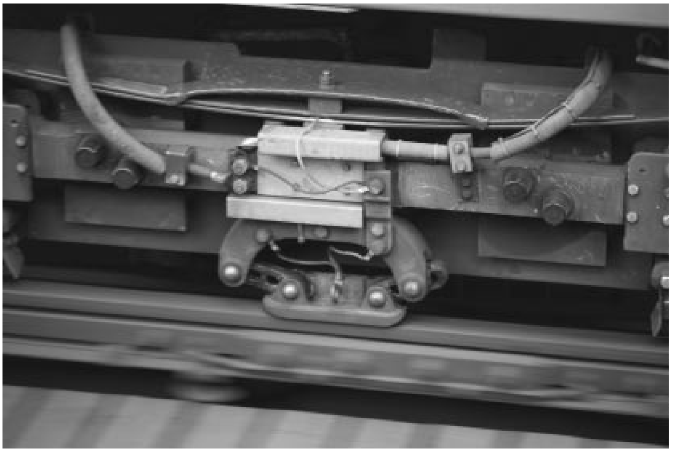

Figure 4.3 Third-rail contact shoe of Chicago ‘L’ car. (Source: http://en.wikipedia.org/wiki/Third_rail.)

Figure 4.4 Overhead pantograph. (Source: http://en.wikipedia.org/wiki/Pantograph_(rail).)

metro system, for example, uses 1500 V DC whereas the overhead system for the French TGV is electrified at 25 kV, 50 Hz. The 700 Series Shinkansen is supplied with electricity at 25 kV, 60 Hz from a pantograph. A pantograph pickup is illustrated in Figure 4.4.

4.4 Inductive Power Transfer for Moving Vehicles

Power supply to electric road vehicles is a concept which has not been deeply explored. Most of us are familiar with dodgems in which power is supplied from an overhead grid and is earthed to the floor, but outside the fairground this is rarely seen. Some work has been done on inductive power transfer (IPT) for vehicles on the move and it is a concept which could usefully be developed. The idea of using inductive power for supplying vehicles on the move was invented by Nikkola Tesla (Patent number 514972, filing date 2 January 1892, issue date 20 February 1894). An up-to-date system was conceived by the University of Auckland, New Zealand, and the development of an IPT product is being carried out commercially by a company called Wampfler Ltd, which owns the patent.

IPT is a contactless power supply system that would allow electrical energy to be safely supplied to vehicles without any mechanical contact. IPT works by the same principle as a transformer. The primary circuit lies on the track while the pickup is the secondary. In a regular transformer the air gap between primary and secondary is very small and the frequency is low, 50/60 Hz. With IPT the air gap is large but the operating frequency is raised to 15 000 Hz to compensate. With the large air gap the system becomes insensitive to positional tolerances of the pickup on the track. Multiple loads may also be operated at the same time. The track power supply generates the high-frequency alternating current in the track cable. The special shape of the pickup is most effective at capturing the magnetic field generated by the track conductors. The captured AC magnetic field produces electrical energy in the pickup coil and the pickup regulator converts the high-frequency AC power to DC power while regulating the power to the load. If required the direct current can be converted back to alternating current at a chosen frequency using an inverter.

IPT may be used continuously to supply electrical energy along a predetermined track to people movers such as monorails, duo-rails or elevators, as well as theme park rides. The main features of the IPT system are:

- **Efficiency:** The track power supply and vehicle pickup work with an efficiency of up to 96%. Both track and pickup systems are resonant so that losses and harmonics are minimised.
- **Power:** Large amounts of power may be transferred. Power ranges of 30–1000 kW are possible.
- **Large air gap:** Power may be transferred across air gaps of 100 mm and more.
- **Multiple independent loads:** Using intelligent control, any number of vehicles may be operated independently and simultaneously on a system.
- **Long tracks:** IPT works with track lengths of up to several kilometres in length, which may be repeated for even longer systems.
- **Maintenance:** No brush wear or moving parts ensure that the IPT system is virtually maintenance free.
- **Data transfer:** Signal and data transfer is possible with IPT with minimal additional hardware. An integrated power and data system is currently being developed.
- **Speed:** With conductor bar, festoon or cable reel systems, speed is a limiting factor. With IPT the speed of operation is unlimited.
- **Safety:** All components are fully enclosed and insulated. Hence the system is fully touch-proof.
- **Sensitive environments:** The fact that no carbon dust, other wear or sparks are generated makes IPT suitable for sensitive or hazardous environments.

An example of an inductively powered monorail system is shown in Figure 4.5 and a cross-section of the pickup given in Figure 4.6. The company, Wampfler, have built a test track at its headquarters in Weil am Rhein in Germany. To date, the system is claimed to be the largest IPT system constructed, having a total capacity of 150 kW and a track

Figure 4.5 Inductively powered monorail system (Reproduced by kind permission of Department of Electrical and Computer Engineering the University of Auckland)

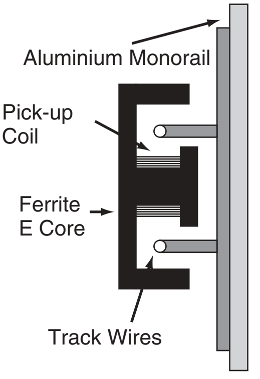

Figure 4.6 Cross-section of inductive pickup (Reproduced by kind permission of Department of Electrical and Computer Engineering the University of Auckland)

length of nearly 400 m. Power is transferred to a total of six pickups on a test vehicle each having a power capability of 25 kW and an air gap of 120 mm. Taking into account the track cable and the track supports, this allows a positional tolerance of movement of the pickup of 50 mm in all directions. Since the IPT test vehicle requires a peak power no greater than 10 kW, the excess power is returned via the conductor bar for regeneration into the mains. The test track will be used as a basis for the development of the product range and for the continued analysis of cost optimisation.

The IPT system could be used for buses and cars. It can operate with either an enclosed-style pickup or with a flat roadway-style pickup. The track conductors may be buried in the roadway or in the charging station platform and a flat pickup is used as an energy collector. The flat construction allows large lateral tolerances. The energy transfer is totally contactless and intervention free.

In the future many other application areas can be covered using IPT, including trams and underground trains.

The IPT system is also potentially applicable to hybrid vehicles. The use of EVs, which take power from supply rails within cities and on motorways, could itself cause a revolution in electric transport.

4.5 Battery Swapping

One way to charge EV batteries is to charge the battery when it is removed from the vehicle and replace it with a fully charged one. Batteries could be stored and charged in a warehouse, for example when they are waiting to be put in a vehicle. Denmark has recently introduced a battery swapping station in which lithium ion batteries weighing around 250 kg can be replaced in specially designed cars in around 5 minutes. Another battery swapping system is being tried in Japan for use on electric taxis.

The logistics of the scheme may prove slightly complex and it is perhaps better suited to taxis where the number and usage patterns can be predicted. It would allow an electric taxi to be used continuously throughout a 24 hour period.

In order to make battery swapping a viable option for cars and vans several problems would need to be solved. Firstly, there would need to be considerable space devoted to storing and charging the batteries. Secondly, vehicles would need to be designed to allow batteries to be swapped quickly and easily. Thirdly, quality control on the batteries would be needed to ensure the recharged batteries would hold sufficient energy for onward journeys. As future batteries are developed with greater specific energy and energy efficiencies the scheme would be easier to manage as recharging would be less frequent and the storage warehouse would not need to be so large.

Further Reading

Wikipedia (2012) http://en.wikipedia.org/wiki/Electric_power_transmission (accessed 2 April 2012).

Wikipedia (2012) http://en.wikipedia.org/wiki/High-voltage_direct_current (accessed 2 April 2012).

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