Hybrid Electric Vehicle (HEV): Reasons, Concepts, and Issues

By

B. Chehroudi, PhD
Chief Scientist, Raytheon

U. S. Environmental Protection Agency (EPA) estimates that vehicle emissions contribute between 1/3 to 1/2 of the total U.S. atmospheric emissions for CO, NO_X , and Hydrocarbons (HC). California law requires that two percent of cars sold in this state be zero-emission vehicles by 1998 (zero for non-methane organic compound (NMOG), CO, and NO_X), increasing up to 10% for the year 2003 and after. The 10 % rule applies individually to every car manufacturer that sells more than 5000 cars per year in California. Under this condition no vehicle using combustion engine can reach such a low level. The only choice appears to be electric vehicle. Other states and some European cities are also considering similar requirements. Although electric vehicles do not emit pollutants by themselves, some level of pollution is created by the power station generating the needed electricity to recharge these vehicles. However, the overall effect is a cleaner environment as compared with the usage of the current internal combustion engines. This is particularly true if the power stations use nuclear, hydro, natural gas, wind or solar energy.

HEVs can be better understood after a brief discussion of electric vehicles. In its basic design, an electric vehicle uses an electric motor, instead of the combustion engine, to provide the required torque to rotate the wheels. The electrical energy comes from the battery storage. Batteries store and deliver electrical energy chemically by initiating and reversing chemical reactions, which accept electrons to form chemical products. The major issue here is battery's low specific energy (i.e. energy per unit mass) ranging from 30 to 120 Wh/kg (for different kinds) as compared with the high value of about 12,000 Wh/kg for the gasoline fuel. The implication is that electric vehicles have lower travel range than equivalent gasoline-fueled ones. It is for this reason that various types of HEV's have been demonstrated and/or being developed. There are other issues with the battery energy storage worth mentioning. They are generally heavy, expensive, low cycle-life (must be replaced every 40,000 kilometers or so), 6 to 8 hours recharge time (depending on battery), and lose capacity at low ambient temperature (emergency charge in about 2 hours, however).

There are basically two major types of HEVs based on the manner in which the auxiliary power unit (APU), such as a small spark-ignition or diesel engine, is incorporated in the system. In what is called as a "series" design the APU is connected to a generator to provide the electricity for the battery pack and the electric motor. Only electric motor is physically connected to the shaft to drive the wheels. In a "parallel" design, however, both the APU and the electric motor can drive the wheels and most of them do not need a generator because the electric motor can also function as a generator to recharge the battery. In this case, for example, the APU can be used for highway driving and the power from the electric motor for accelerating. There is also a third type of the HEV design that combines the best of the series and parallel configurations. This, being a subset of the parallel design, is sometimes called a "combined" or a "series/parallel" design. Here, the APU can directly drive the wheels and has the ability to charge the energy storage component through a generator.

There are some advantages and disadvantages of series and parallel designs as follows. For series design, inherent in the process of conversion of mechanical-to-electrical and back to mechanical energy are losses resulting from each of the energy conversion processes. Also, total combined efficiency of the generator/electric motor must be at least as good as the conventional gearbox for series design have some uses. Additionally, if maximum power is needed for a long time, both the generator and the APU must be rated at this power value. This is not a desirable feature for a passenger HEV car. However, on the advantage side, the engine is never operated at idle and runs mostly under optimum condition, therefore emissions are minimized. There is also more flexibility in positioning engine and other vehicle components with series design. For parallel design, improved efficiency is achieved because mechanical energy of the engine is directly connected to the drive axle. As generator is not required for parallel design, the weight and cost are reduced. Also, vehicle has more power because both the APU and the electric motor can provide power simultaneously.

Under intense R&D work are many other technologies pertaining to different components of the HEVs to make them even more efficient and so-called “green”. For example, for energy storage, there are batteries of different kinds (Lead-Acid, Nickel Cadmium, Nickel Metal Hydride, Lithium-Polymer, and Lithium-Ion), flywheels (or electromechanical batteries, convert electrical energy into kinetic energy of rotation of the flywheel), and ultracapacitors. Regenerative braking is used to usefully convert some of the kinetic energy of the wheels at the time the car must be slowed or stopped into electric energy stored in some form of battery. This stored electricity can then be used in place of, or added to, the vehicle’s generator, further decreasing the engine’s fuel consumption and emission.

In one very promising type of HEV, fuel cell is used as the axially power unit. A fuel cell is an energy conversion device that directly converts the chemical energy to electrical energy. This is achieved through separate introduction of hydrogen fuel and oxygen (or air) from the catalyst-coated anode and cathode sides, respectively, separated by a suitably selected electrolyte. On the anode side, electrons are removed from the fuel molecules in presence of the catalyst and routed through the external wire connected to the cathode. Ions, however, are passed through the electrolyte towards the cathode to catalyticaly react with oxygen producing water. Fuel cells can deliver efficiencies from 40 to 60 percent as compared to an averaged value of 15-20 percent for the internal combustion engines. Some key engineering and economic issues will delay widespread use of this technology. Fuel cells and related issues will be discussed in future publication of the Powertrain International.

Although HEVs, in general, are just as safe and crashworthy as today’s gasoline-powered cars (since they must satisfy the same federal motor vehicle standards), there are environmental, health, and safety issues related to some specific components that need further research and regulations. For further in-depth information on this subject the reader is invited to visit http://www.hev.doe.gov/ and in particular the references cited therein.

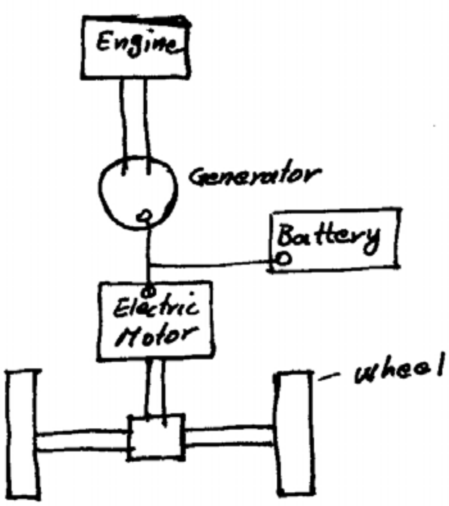

Figure 1: Series HEV

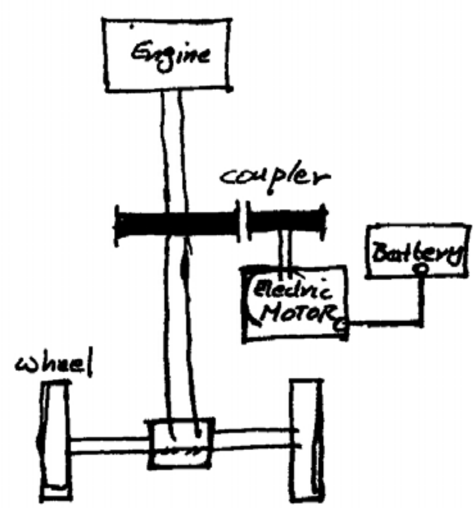

Figure 2: Parallel HEV