ProVQ™

HYBRID TECHNOLOGY

Electric/Hybrid Vehicles

UK Legislation Related to PHEV

- Health and Safety at Work Act (1974)
- Electricity At Work Act (1989)
  Regulation 12 Means for cutting off the supply and for isolation
  Regulation 13 Precautions for work on equipment made dead
  Regulation 14 Work on or near live conductors
  Regulation 16 Persons to be competent to prevent danger and injury

- Management of Health & Safety at Work Regulations (1992)

No specific UK legislation for High Voltage Vehicles,

Health and Safety at Work Act (1974)

The Act places a general duty to 'ensure so far as is reasonably practicable the health, safety and welfare at work of all their employees'. Employers must comply with the Act. They must:

- provide and maintain safety equipment and safe systems of work
- ensure materials used are properly stored, handled, used and transported
- provide information, training, instruction and supervision - ensure staff are aware of instructions provided by manufacturers and suppliers of equipment
- provide a safe place of employment
- provide a safe working environment
- provide a written safety policy/risk assessment
- look after the health and safety of others, for example the public
- talk to safety representatives

An employer is forbidden to charge his or her employees for any measures which he or she is required to provide in the interests of health and safety i.e. PPE.

Management of Health and Safety at Work Regulations (1992)

Every employer shall make a suitable and sufficient assessment of-
The risks to the health and safety of his employees to which they are exposed whilst they are at work; and the risks to the health and safety of persons not in his employment arising out of or in connection with the conduct by him of his

undertaking, for the purpose of identifying the measures he needs to take to comply with the requirements and prohibitions imposed upon him by or under the relevant statutory provisions.

Health surveillance
Every employer shall ensure that his employees are provided with such health surveillance as is appropriate having regard to the risks to their health and safety which are identified by the assessment.
Capabilities and training
Every employer shall, in entrusting tasks to his employees, take into account their capabilities as regards health and safety and provided with adequate health and safety training when –
A. introduced to the organisation
B. transferred or given different responsibilities
C. introduced to new work equipment, technology, or systems used within the organisation.

Electricity at Work Regulations (1989)

Means for cutting off the supply and for isolation

Where necessary to prevent danger, suitable means shall be available for–

(a) cutting off the supply of electrical energy to any electrical equipment; and
(b) the isolation of any electrical equipment.

Precautions for work on equipment made dead

Adequate precautions shall be taken to prevent electrical equipment, which has been made dead in order to prevent danger while work is carried out on or near that equipment, from becoming electrically charged during that work if danger may thereby arise.

Work on or near live conductors

No person shall be engaged in any work activity on or so near any live conductor (other than one suitably covered with insulating material so as to prevent danger) that danger may arise unless–

(a) it is unreasonable in all the circumstances for it to be dead; and

(b) it is reasonable in all the circumstances for him to be at work on or near it while it is live; and

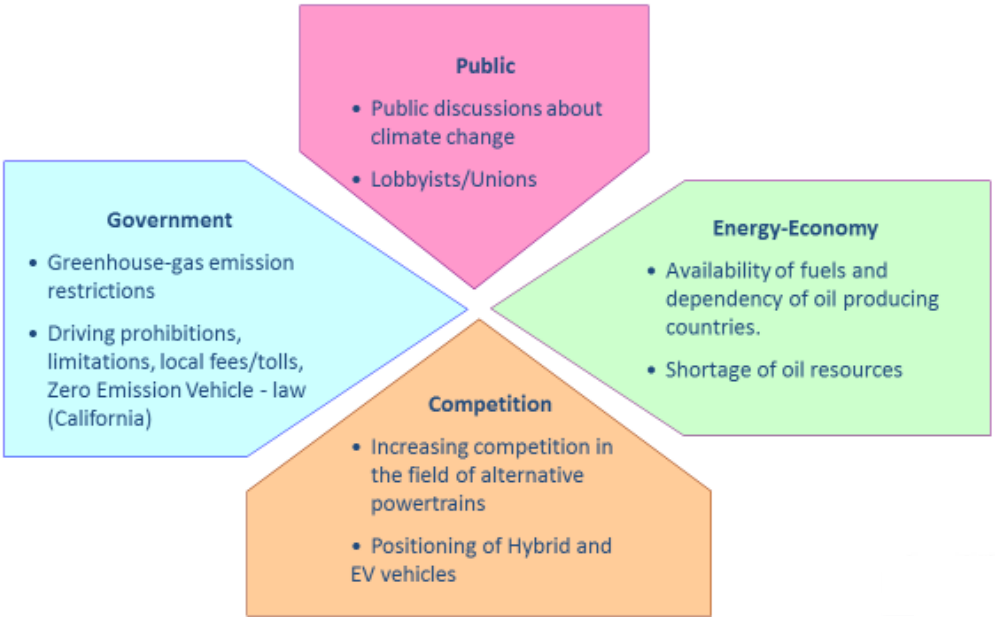
(c) suitable precautions are taken to prevent injury.

Persons to be competent to prevent danger and injury

No person shall be engaged in any work activity where technical knowledge or experience is necessary to prevent danger or, where appropriate, injury, unless he possesses such knowledge or experience, or is under such degree of supervision as may be appropriate having regard to the nature of the work.

Electrification: Motivation

- **Competition, legislation, Energy-economy, customer**



Hybrid and EV Powertrains

Tesla model S

Toyota Mirai

Porsche Panamera Hybrid

Battery Electric vehicle (BEV)
An electric vehicle contains a HV-battery and an electric motor, with no other method of propelling the vehicle.
Depending on the source of the electricity it is charged with, it does not emit any greenhouse gases.

Fuel Cell Electric Vehicle (FCEV)
Fuel Cell Electric Vehicles are electric vehicles. Additionally to other types of electric vehicle, they have a tank for hydrogen and a fuel cell which generates power using the reaction between the hydrogen and oxygen from the atmosphere. The only emission is water. A small lithium-Ion battery acts as a buffer due to the delay in the fuel cell reacting to demand.

(Plug-In-) Hybrid Electric Vehicles (HEV / PHEV)
A hybrid electric vehicle has to have at least two energy transforming units and two independent energy storing units.
Hybrid electric vehicles can improve efficiency by changing the operation point of the combustion engine and provide Electric only drive capability.

Electric Vehicles (EV's)

When talking about Electric Vehicles (EVs) or Electrically Chargeable Vehicles (ECVs) we usually mean any vehicles that are powered, partially or fully, by a battery that can be directly plugged into the mains.

In terms of EVs we recognize the following:

Pure-Electric Vehicles (PEVs) are powered by a battery alone. With a single charge, their range extends up to 100 miles (figure from 2015). However, when they were tested for this project, it was found not to be the case.

Extended-Range Electric Vehicles (E-REVs) are similar to PEVs but with a shorter battery life of 50 miles. However, range is extended by an ICE (Internal Combustion Engine) generator providing extra miles of mobility.

Plug-in Hybrid Electric Vehicles (PHEVs) are equipped with an internal combustion engine (ICE) but also a battery with range of 10–30 miles. After the battery is completely used up, the vehicle draws from the benefits of the hybrid engine.

Hybrid Electric Vehicles (HEVs) cannot have their battery charged externally. So, charging is done by regenerative braking system. They are powered by a battery and/or ICE (Internal Combustion Engine). The power source is selected by the vehicle, depending on speed, engine load and battery charge.

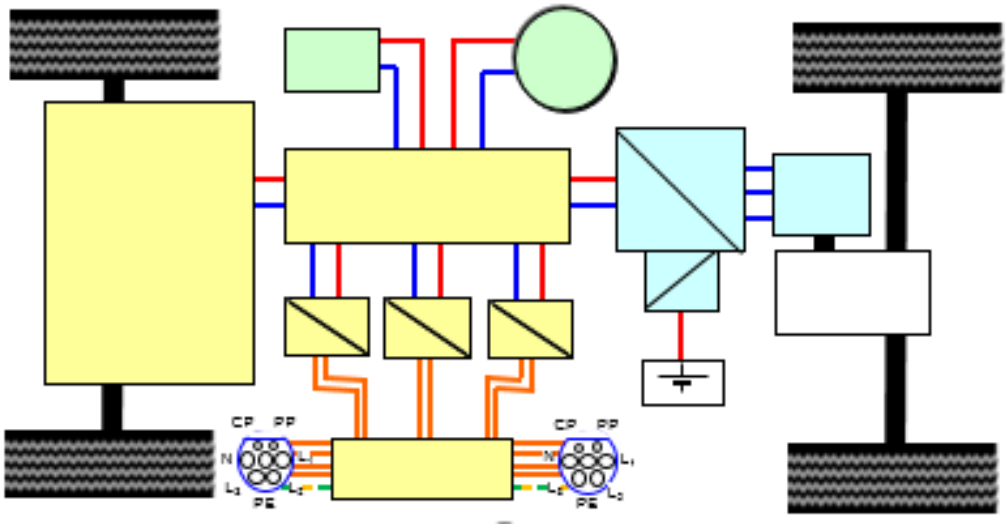
A phrase often used in connection with EVs "range anxiety"; meaning the fear about the distance the EV can drive and worries about that it may not be enough to reach the destination.

The average individual journey in the UK is less than 10 miles. At the time of writing this, EV sales are increasing. During 2014, over 75,000 new EVs were registered in the EU, which is around a 40% increase. The trends are expected to develop in the near future.

Drive Systems – Electric Vehicle

One or more electric motors power the wheels. The energy is stored by the battery. The Inverter transforms direct current into alternating current while the car is accelerating by converting energy from the HV battery and delivering it to the electric motor. If the driver is pushing the brake or is driving down a mountain, the electric motor works as a generator. Now, the inverter transforms alternating current into direct current and charges the battery.

One disadvantage of today's electric vehicles is the time to charge.
High performance cars like the Tesla Model S can get up to 500 km with one charge. Recharging can take a long time though. To recharge for 200 km range, you need about 20 Minutes of charging time.



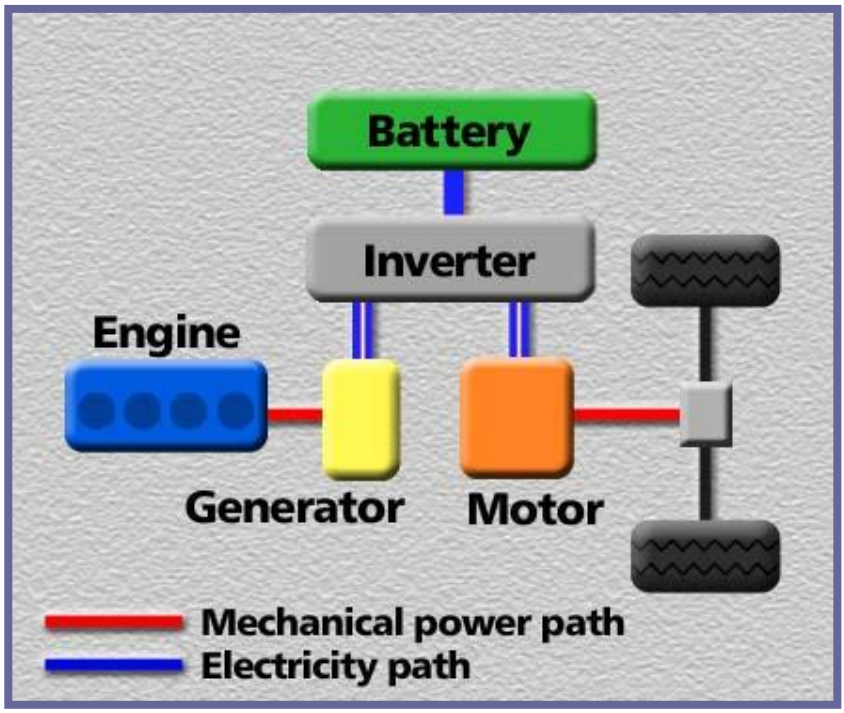
Electric/Hybrid Vehicles

This is the principle of using two power sources to drive the vehicle In its practical form, it has over the last decade or so produced a number of models which generally use similar principles. As battery technology has improved, plug-in vehicles which can store electricity from domestic mains has made the prospect of entirely electric vehicles more likely. The infrastructure for such vehicles is not in place

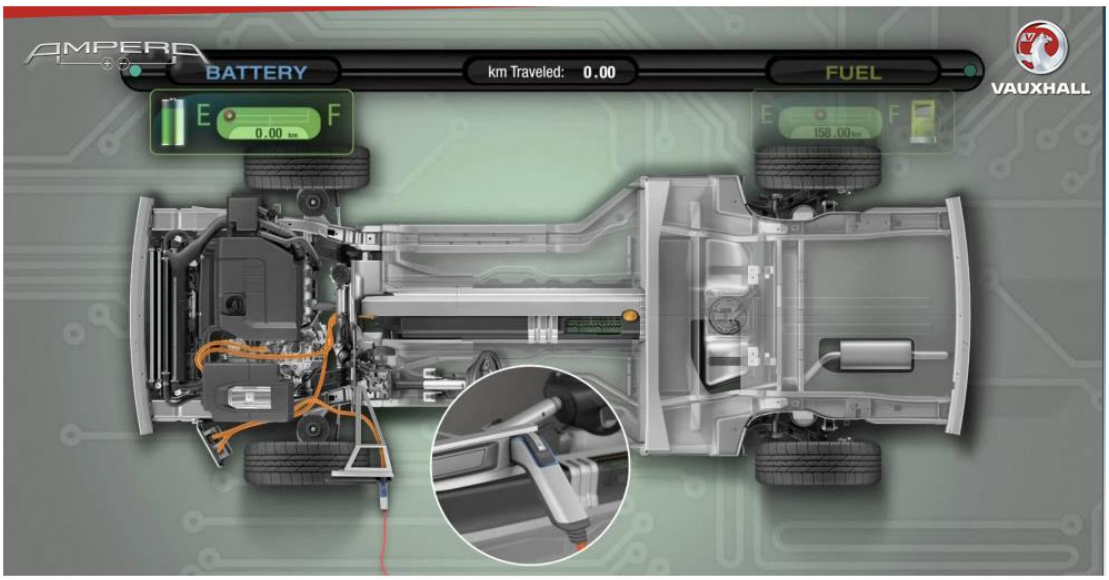
Recuperating energy.

When a vehicle's brakes are applied the kinetic energy of the vehicle is converted into heat energy by the friction generated between the disc and pad. The hybrid vehicle has the ability to take some of this energy to generate and store it as electricity. The stored energy is then used to drive the vehicle which reduces the energy required from the engine. The result is a more energy efficient system which gives an reduction in fuel consumption.

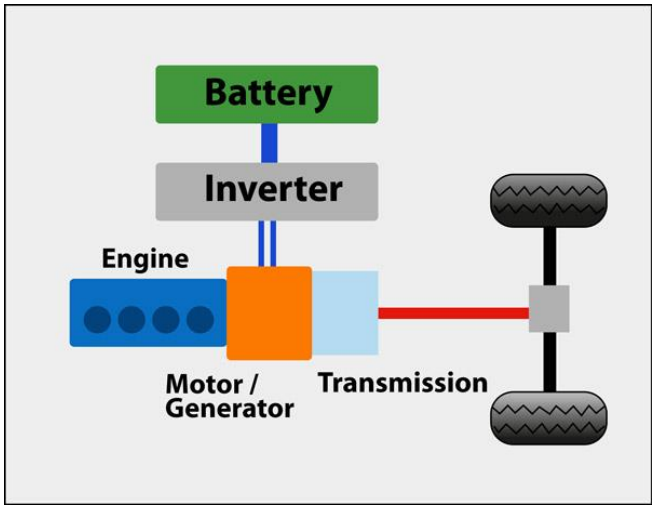
There are basically three types of hybrid system.



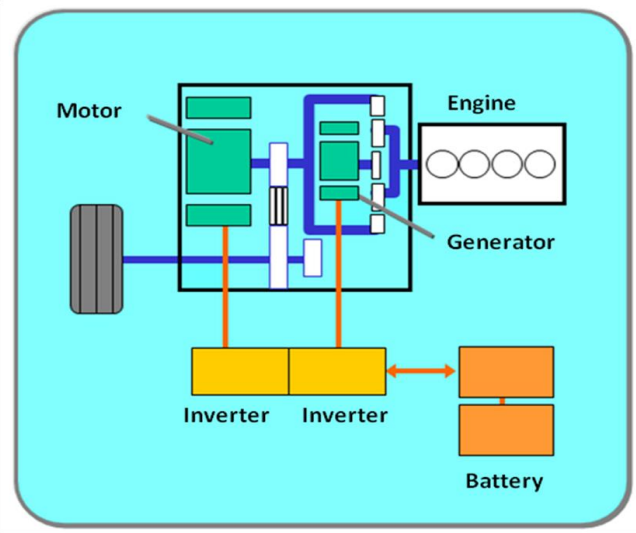
1 series hybrid.
This system has been used for many years in trains. The engine drives a generator which charges the battery. The battery is then used to drive the vehicle's electric motor. The Vauxhall ampere uses this system and also has a domestic mains plug-in giving it a 40 mile zero emission range.



2. Parallel hybrid

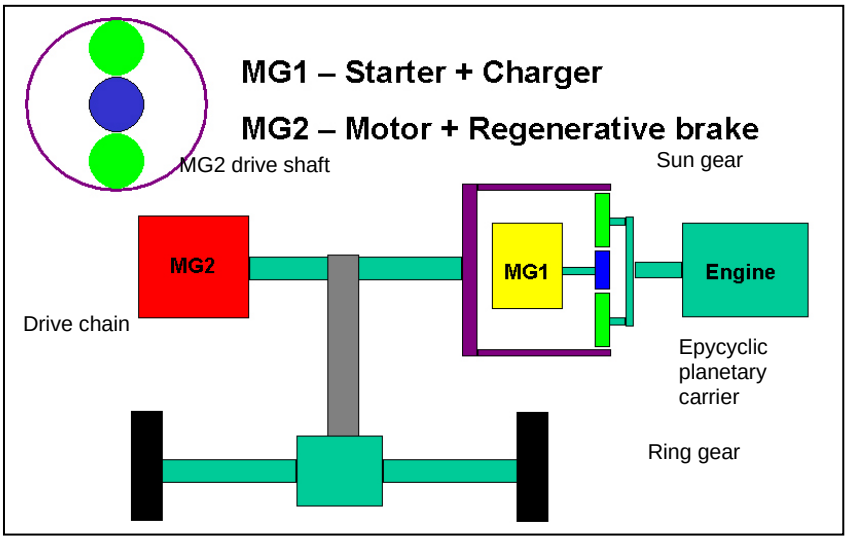


3. Series parallel



The most common type of Hybrid on the road is the series parallel system. Most people thing of Hybrids as Eco friendly but in the case of 5 litre Lexus it used as a power enhancing device which gives high acceleration by using the electric motor to work with the petrol engine. More and more manufacturers are using the hybrid system but by far the most common vehicle on the road is the Toyota Prius.

It was 1997 when the first Hybrid powered Toyota Prius took to the roads in Japan, and yet over a decade on very few technicians throughout our industry have a clear idea as to how this pioneering vehicle works. This is of no great surprise due to the vast majority of hybrid vehicles still being serviced and maintained by the Toyota dealer network, and with voltages in excess of 500 volts throughout the power train no wonder the majority of us in the aftermarket shy away from working on these vehicles.
So how does it work



In the diagram you will see there are 3 main boxes. These are the Engine, MG1 and MG2. The engine should need no explanation but MG1 and MG2 may well. MG1 stands for Motor / Generator number 1. MG2 rather logically is therefore Motor / Generator number 2. The main points to bear in mind with both of the MG units are, if we supply electricity to either of these they will rotate as driven motors. Equally, if we supply torque to these items, as they are driven, they will generate electricity.

MG1, when acting as a motor, performs the roll of the starter motor on a conventional vehicle. When it performs its roll as a generator, it is the engine driven generator.

MG2 on the other hand, when acting as a motor, physically provides torque to the driven road wheels through a drive chain and when it acts as a generator, acts as a brake to the driven wheels – converting torque into electricity.

Starting the engine

If at this stage we assume the vehicle to be stationary, it would be fair to say the wheels would not be turning. As the wheels are not turning the drive chain would not be rotating, the MG2 drive shaft would not be turning and the epycyclic ring gear would not be turning. Now through thinking about the operation of a the epycyclic gear train, if we hold the ring gear and yet turn the sun gear (through supplying electricity to MG1) the planetary carrier would begin winding its way around the centre of the ring gear. Now that the planetary carrier is rotating, the crankshaft would rotate and, providing we supply the engine with fuel and ignition, the engine will start.

Engine running, vehicle stationary

Now that the engine is running, the planetary carrier will be rotating at engine speed. In this instance the THS system allows MG1 to freewheel (it is rotating but in an electrical open circuit state therefore preventing current generation). As the sun gear is able to rotate freely and yet there will be a mechanical resistance from MG2 preventing the ring gear from rotating, the only items

being driven by the engine will be the sun and planetary carrier rotating internally inside the epycyclic gear train.

Transmitting drive from the engine to the road wheels

Bearing in mind that there will be no drive transmitted to the road wheels when MG1 is able to freewheel – (as it takes far less torque to rotate the sun than the ring gear), if the THS system applies sufficient electrical force to load the sun gear up to a point where it is easier for the ring gear to rotate than for the sun gear to turn, the vehicle will start to move. By simply varying the load on the sun gear the THS system is able to control the gear ratio of the gearbox infinitely, therefore creating the characteristics of the typical CVT when driving the vehicle. At the same time that all of this is occurring it is additionally possible to vary the engine speed and therefore torque output, allowing the performance of the vehicle to be adjusted though controlling engine speed and the load on MG1 simultaneously. Further more, as at this point the THS is electrically loading up MG1, MG1 will now be generating electricity. This electricity can be diverted to either the high voltage nickel metal hydride battery or MG2 and any electricity diverted to MG2 will provide the energy for MG2 to generate torque. This torque via the drive chain is diverted to the driven wheels, hence providing a second source of drive making this vehicle a true hybrid.

Reverse

Reverse is the easiest one of all to understand. All that needs to occur in this instance is for the energising of the 3 phases in MG2 to be reversed. This will cause the motor to rotate backwards, and as it is mechanically linked to the driven wheels, if the motor turns backwards so will the driven wheels – hence the vehicle will reverse.

Regenerative braking

As with a conventional vehicle, if the driver wishes the vehicle to slow down, the driver will push on the brake pedal. Where the difference lie between a conventional vehicle and a Toyota hybrid is what happens when the driver presses the brake pedal. With the THS, when the driver presses the brake pedal, the driver is really informing the THS that he wishes the car to decelerate. In this instance the car will slow the vehicle down using 2 methods. The first option is for MG2 to be electrically converted into a generator. As MG2 is mechanically connected to the driven wheels, if MG2 applies a load to the wheels the wheels will naturally begin turning at a slower rate. If the wheels turn at a slower rate the vehicle will naturally slow down. This is known as regenerative braking. At the same time as this occurring the THS system calculates the difference between the rate of deceleration desired by the driver and the rate of deceleration generated through regenerative braking, and the difference in force will be applied to the pads

and discs through the hydraulic braking system. It is this ability to generate electricity without the need to burn fuel that allows a hybrid vehicle to generate the high MPG's they do – especially in stop start conditions. The more electricity generated for free, the more that can be supplied to MG2 to drive the car along and the fewer loads placed upon the engine for any given level of vehicle performance reducing fuel consumption overall.

Hybrid Inverter Assembly

The Boost Converter

This assembly boosts voltage. This means that the voltages actually supplied to the motor assemblies, Motor Generator 1 and Motor Generator 2 (MG1 and 2) are at a much higher level that that applied by the high voltage battery. You will see in diagram 1 that the voltage output by the battery is 201V and yet the voltage applied to the motors is up to a maximum of 500V. The question is; how does it do it?

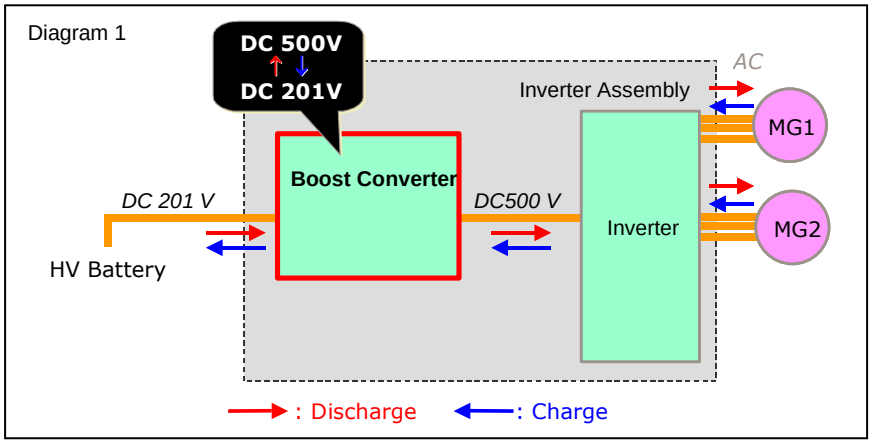
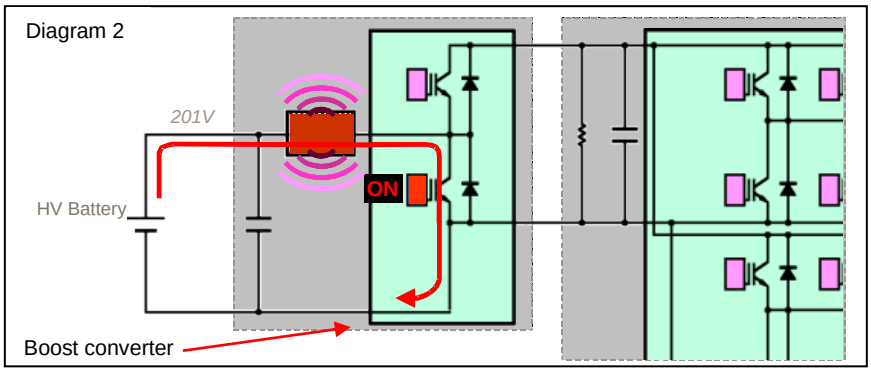


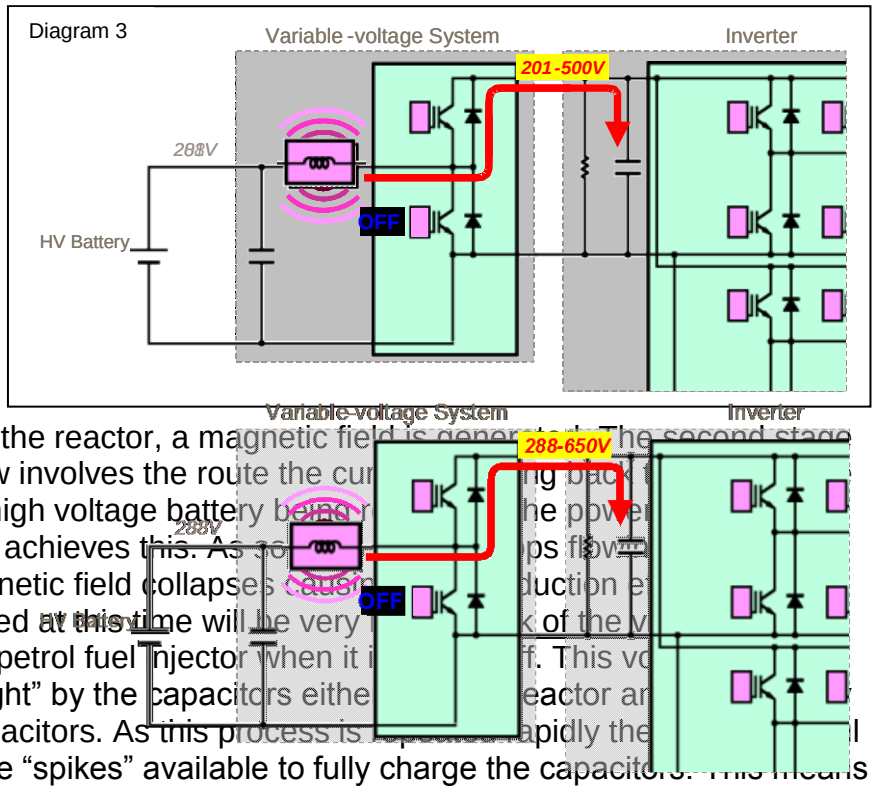
Diagram 2 shows the boost converter circuitry – you will see there isn't a great deal in there:

- A reactor (coil of wire)
- 2 power transistors
- 2 capacitors (although strictly speaking the second capacitor is found inside the inverter but its function is key to the boost converter).



The first stage in the voltage boost process is when the power transistor (shown in Diagram 2) is turned on, allowing current to flow through it. You will see current travels from the positive terminal of the high voltage battery, through a winding (the reactor), through the power transistor and then back to the negative terminal of the high voltage battery. As this current passes through the reactor, a magnetic field is gener[illegible]. The second stage of operation now involves the route the cur[illegible]ng back [illegible] terminal of the high voltage battery being [illegible]he pow[illegible] being turned off achieves this. As so[illegible]ps flow[illegible] reactor the magnetic field collapses caus[illegible]duction e[illegible] voltage generated at this time will be very [illegible]k of the v[illegible] generated by a petrol fuel injector when it i[illegible]f. This vo[illegible] effectively “caught” by the capacitors eithe[illegible]eactor ar[illegible] charges the capacitors. As this process is [illegible]apidly the[illegible]l supply of voltage “spikes” available to fully charge the capacitors. This means that the capacitor to the right of the power transistors (see diagram 3) acts like an energy store ready to be applied to the motors and allows them to generate the fantastic levels of torque that they are capable of generating. (MG2 on a Prius can generate 400Nm of torque from a standstill!).

Diagram 3



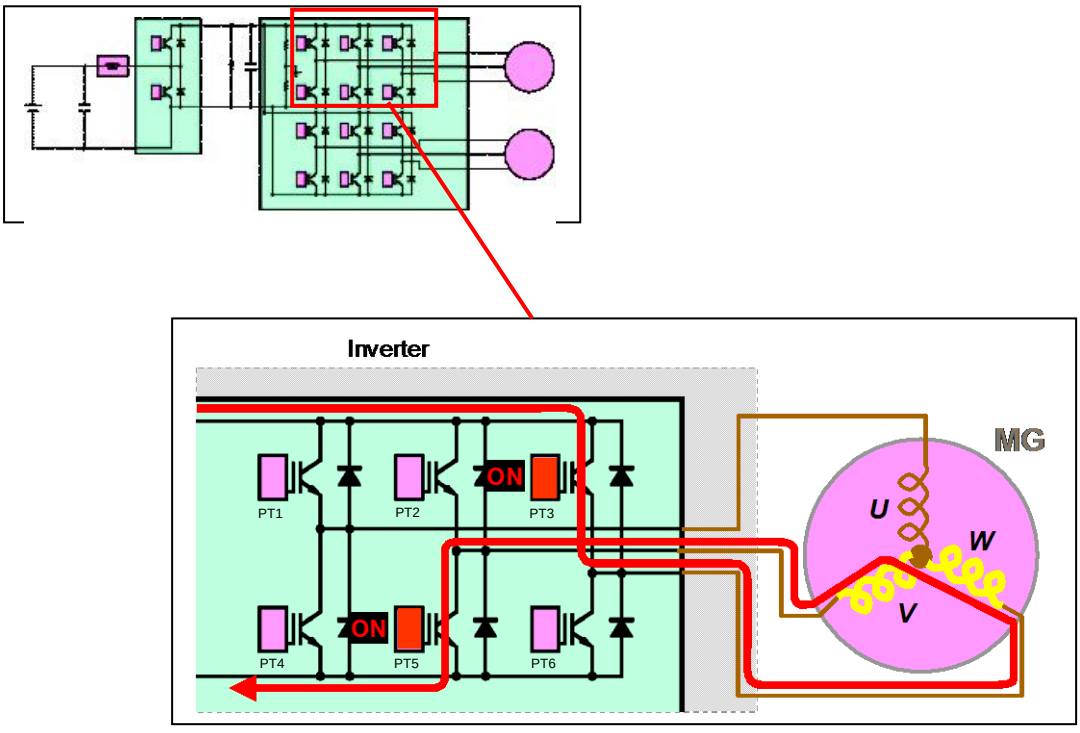
The Inverter

The inverter changes DC to AC and AC back to DC (inversion).

DC to AC

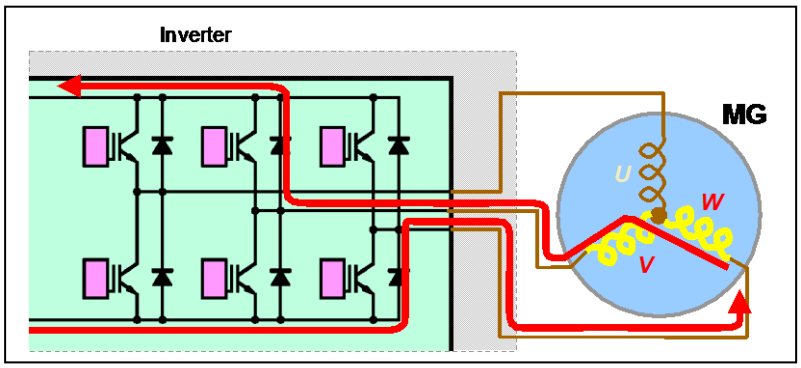
You will see in diagram 4 that the inverter is made up of several banks of diodes and power transistors (technically called IGBT's - Insulated Gate Bipolar Transistors). It is through the accurate switching of these transistors that current is supplied to the motor generator windings. The diagram shows PT3 and PT5 energised; current is able to pass through the W and V windings of the MG (Motor Generator) creating the magnetic fields necessary to rotate the motor partially. To rotate the motor further, the next pair of phases needs to be powered up. This is effected by powering up PT1 and PT6 which then allow current to flow through windings U and W. The process is repeated by powering up PT2 and PT4 which then allows current to flow through windings V and U. Through this process occurring rapidly, the motor will rotate at the speed dictated by the frequency at which the pairs of transistors are switched.

Diagram 4



AC to DC

Diagram 5

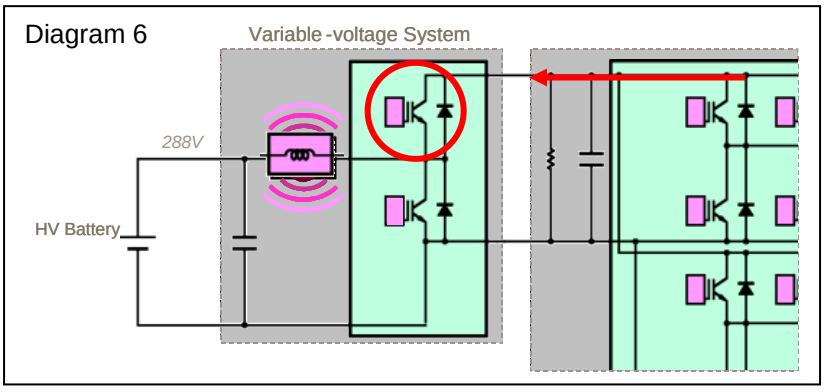


AC to DC conversion is more straightforward. As magnetic flux from the permanent magnets (located inside the stators of the motor generators) passes over their respective U, V and W coils, an AC voltage will be generated. As you will see from diagram 5, as the voltage pushes current out from the windings the current will be diverted automatically back to the positive side of the boost converter, and back to the battery. Follow the path for yourself; whichever way the voltage is applied from the windings inducing that voltage, the diodes will rectify that current through the layout – similar to that of a rectifier in an alternator.

Varying the load from the motor generator while it is acting as a generator

You may remember that the load MG1 applies to it's sun gear is key to the amount of drive that will be output from the transaxle assembly when the engine is running (see previous hybrid article). This is controlled by another power transistor that so far has not been mentioned. Diagram 6 shows current from the motor generators flowing back (in the direction of the arrow shown).

Diagram 6



Current is only able to flow providing is has a complete path. You will see there is a transistor in the path of the current back to the boost converter / battery. Current is only going to flow providing this transistor is powered up. If it is not, there is going to be no flow of current. If there is no route for current to flow – the circuit incomplete, the lines of magnetic flux will effectively do nothing as the rotor rotates, leading to no load (negative torque) being applied by the motor generators. It is only when current has a path that there will be any load applied. This means therefore, if the transistor highlighted in diagram 6 is switched in a controlled

manner – using duty cycle / open cyclic ratio, the system can control when current is able to flow and so vary the load of the MG's whilst they are acting as generators.

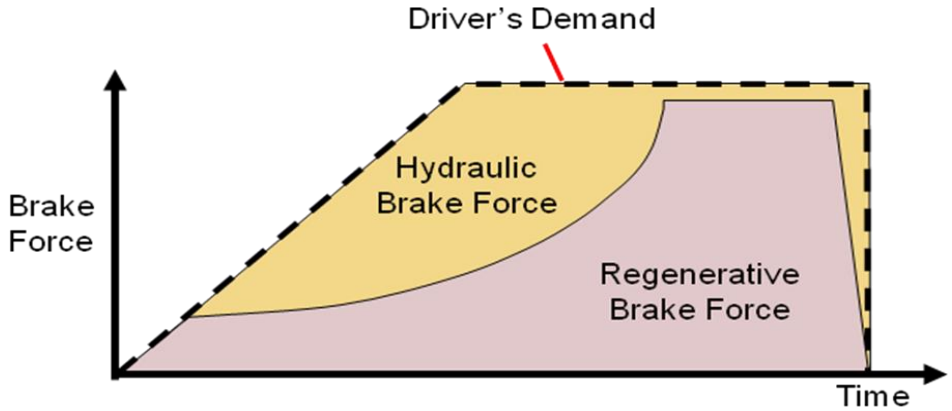
NB - Duty cycle

Duty cycle is a digital control sequence that provides (near) analogue control. Imagine a light switch. It has 2 states – fully on and fully off. Imagine if you were able to switch it on and off very rapidly (1000 times a second), it would be possible to dim the brightness of the bulb that it is switching through limiting the amount of time current is able to pass though the switch. If you were then able to control the amount of time the light switch is in the on position and in the off position while you are still flicking it on and off very rapidly you would be able to control the amount of current able to pass through it very accurately – in effect turning your basic light switch into a dimmer. Duty cycle or O.C.R. is exactly this, the switch is a transistor and your finger is the E.C.U. switching on and off the supply or earth path from/to the transistor therefore regulating how much current is able to pass through the transistor, hence producing a level of near analogue control – clever!

Electronically controlled braking systems - ECB

This system is not limited just to hybrids it can also be found on other vehicles with conventional drive trains.

As previously discussed one of the methods used to recover energy by a hybrid vehicle is through a process called regenerative braking.



Cooperative Control (example)

Regenerative braking is when the motor used to drive the car along is electrically converted into a generator. As the wheels drive the generators, the vehicle decelerates due to the negative torque applied to the wheels, and at the same time, electricity is generated for free (no petrol burnt). The problem with regenerative braking is that it's level of braking performance and reactivity is far less than what can be provided by a conventional hydraulic

system. This means the braking performance deficit needs to be supplemented from somewhere else. This lack of braking performance is supplemented by a hydraulic system called ECB. A conventional braking system cannot be fitted, as the amount of braking performance deficit will vary depending upon the speed of the vehicle and the rate of deceleration that the driver desires. This means a hydraulic system needs to be in place that is able to vary the amount of hydraulic pressure provided by the system throughout a single braking manoeuvre. The question is; how does it do it?

Fig 1

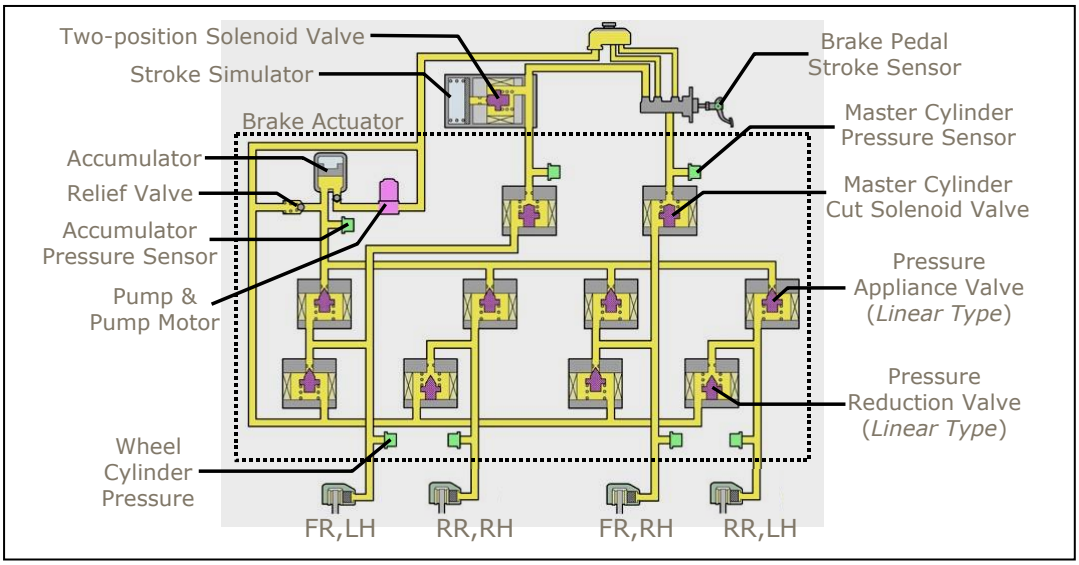
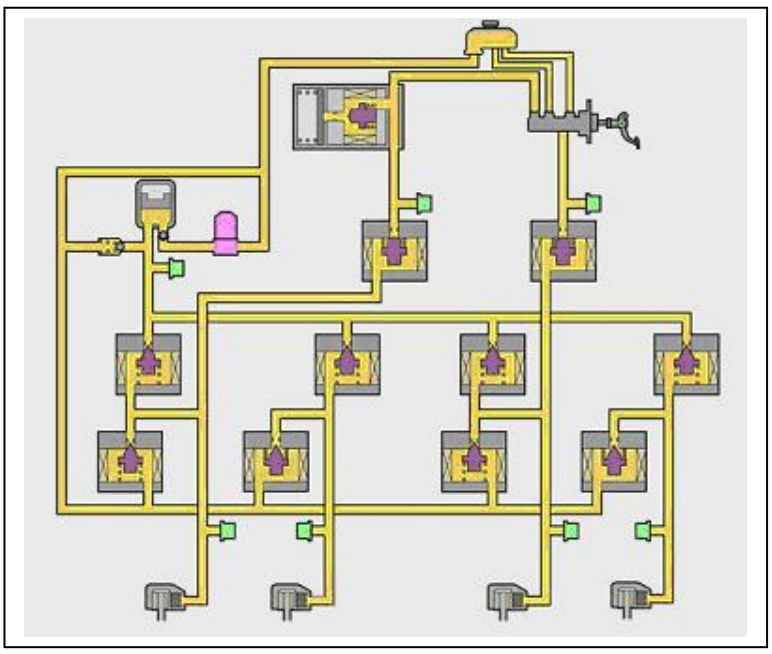


Figure 1 shows the layout making up the ECB system. The point to start in your road to understanding this system is through looking at the area where the pump is located. As the pump is operated, brake fluid can be drawn out of the master cylinder (top right of fig 1). The fluid is then pushed into the accumulator past a one-way valve. This means that any fluid trapped in the accumulator is kept under pressure. You will see that this fluid under pressure is directly applied to the top of the four pressure appliance valves located horizontally though the middle of the diagram with the one on the far right of figure 1 is labelled. The accumulator pressure is monitored at this point by the ECB ECU, which receives the pressure signal from the accumulator pressure sensor.

Fig 2

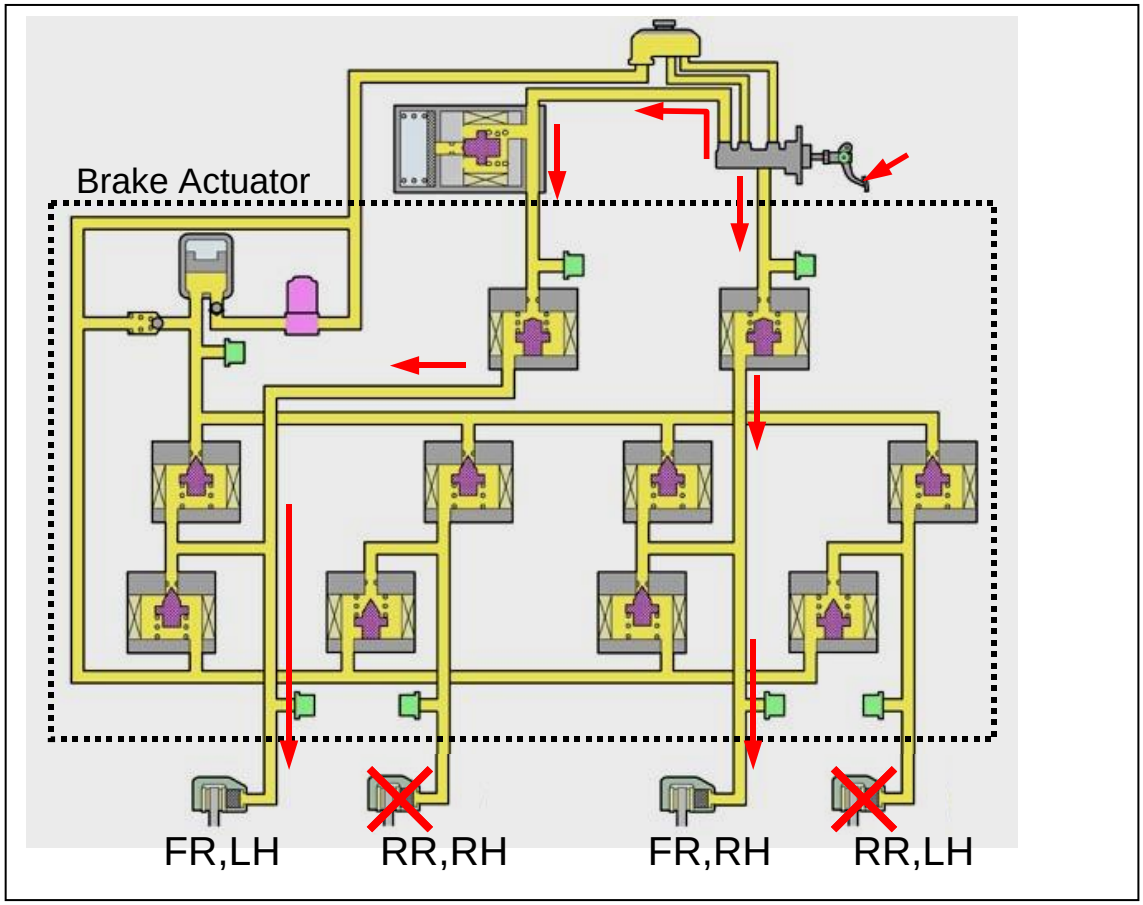


Braking

Shown in figure 2 is the state in which the solenoids are in when the vehicle is being driven. You will notice the master cylinder cut solenoids, (the top two in the diagrams) are in an electrically operated closed state (no flow through). You will also see the component to the left of the master cylinder – the brake pedal stroke simulator, with its internal solenoid in the open position. Bearing in mind the description of the previous two components, when the driver presses the brake pedal, the only place that the fluid is going to be able to travel is into the reservoir to the right of the solenoid inside the stroke simulator. This means in real terms when the driver presses on the brake pedal the fluid that he manually forces out of the master cylinder does not push fluid into the brake calipers, he is simply generating a hydraulic pressure signal. To ensure the pedal still feels like a conventional brake pedal the stroke simulator provides the spare volume for the fluid from the master cylinder to travel to. While the pedal is being pressed the pedal moves down, generating a pedal stoke signal, simultaneously the pressures increase just after the master cylinder and this pressure increase is detected by the master cylinder pressure sensors labelled in figure 1. The three sensors in total generate the driver braking demand signal and the ECB ECU is able to work out the rate of deceleration desired by the driver. At this point the two methods of deceleration come into effect. Regenerative braking does what it can and the hydraulics do the rest. The hydraulic pressure is then applied to the calipers via the pressure appliance solenoid valves controlled by the ECB ECU. These are duty cycle controlled linear solenoid valves which are as good as infinitely variable in their movement. Through them varying their position, the amount of pressure can be controlled which is applied to the calipers and the vehicle decelerates. When the braking manoeuvre is over and the driver releases the pedal, the pressure appliance solenoids shut and the linear pressure reduction solenoid valves will open. The exhaust fluid can then travel back around the circuit and back to the master cylinder.

Fail-safe

Fig 3



In the unlikely event of a complete electrical system failure, figure 3 shows what would happen. You will see that as all of the solenoids lose their electrical supply they all move back into the position that their own mechanical springs force them into. The stoke simulator solenoid is closed and the master cylinder cut solenoids open. This will allow the fluid forced out of the master cylinder (as the driver brakes) to travel directly though the master cylinder cut solenoids and into the two front calipers. It is a limited fail safe as it's not assisted in any way but with the hydraulic fail safe and the mechanical parking brake the rate of deceleration is deemed sufficient.

The fail safe situation just described is very much a worst case scenario as the system is highly intelligent. If the system detects a failure specific to one the brakes on any corner of the vehicle that part of the circuit will be shut down and the remaining parts of the circuit will operate as normal. The driver in this case would be under no illusions as to there being a problem with the braking circuit as the various warning lights and indicators on the dash board would light up clearly indicating when a failure or partial failure was detected by the system.

Power source backup unit

This is a unit containing 21 large capacitors and an integrated ECU. It is an additional failsafe system integrated into the ECB and is wired in parallel with the auxiliary battery supply to the ECB actuator. It acts as a voltage regulator during normal vehicle operation to compensate for auxiliary battery voltage fluctuations and in the event of electrical supply failure from the battery, the charge held in the power source backup unit is supplied to the ECB system to enable the brakes to still operate successfully for the required period of time.

Hybrid Air-conditioning systems. **A WARNING!**

The engine on a hybrid will stop and start as controlled by the management system. This has meant that in many cases the AC compressor is driven electrically. This gives the advantage of combing the compressor motor and pump, doing away with the glands and seals which are the cause of most “natural” refrigerant loss. It does mean however that the lubricant used has to have very high electrical insulation properties. For this reason it is essential that the correct AC lubricant is used and that recycling machines which automatically inject recovered oil quantities are disabled from doing so. Any recovered oil must be injected manually or that the reservoir in the recycling machine be replenished and bled through with the correct lubricant