Case study: Toyota Hybrid Synergy Drive

Introduction

Hybrid Synergy Drive, (HSD) is a set of hybrid car technologies developed by Toyota. HSD technology is used in the Prius, Highlander Hybrid sport-utility vehicle (SUV), Camry Hybrid, Lexus RX 400h, Lexus GS 450h, and Lexus LS 600h/LS 600hL automobiles. It combines an electric drive and a continuously variable transmission.

Toyota describes HSD-equipped vehicles as having E-CVT (Electronically-controlled Continuously Variable Transmission). We can classify the HSD-equipped vehicles as “combined HEV”.

The Synergy Drive is a drive-by-wire system with no direct mechanical connection between the engine and the engine controls: both the gas pedal and the gearshift lever in an HSD car merely send electrical signals to a control computer.

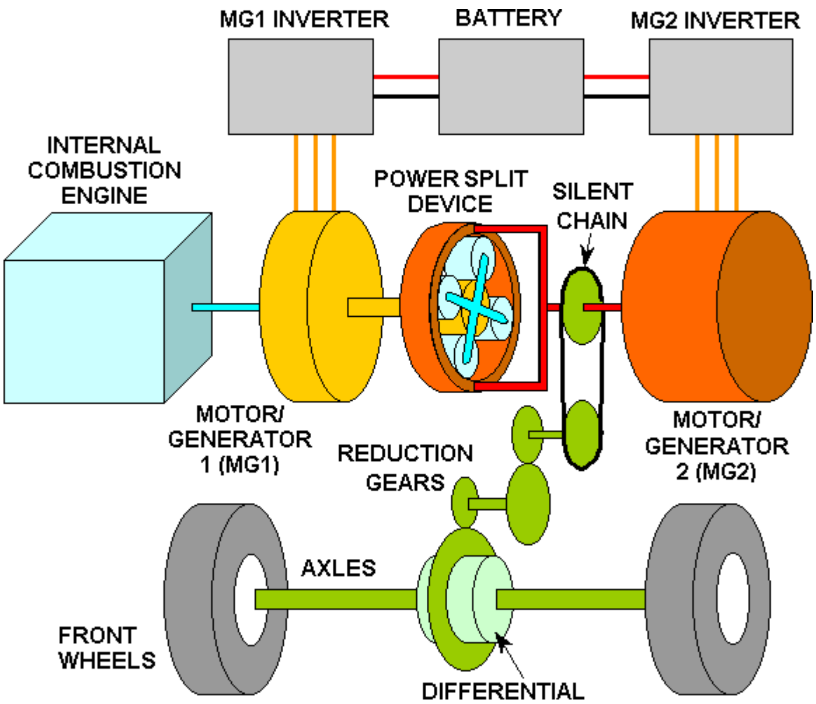
HSD is a refinement of the original Toyota Hybrid System (THS) used in the 1997–2003 Toyota Prius. As such it is occasionally referred to as THS II.

The name was changed in anticipation of its use in vehicles outside the Toyota brand (e.g. Lexus; the HSD-derived systems used in Lexus vehicles were termed Lexus Hybrid Drive since 2006). The Lexus Hybrid Drive system has since been touted for its increase in vehicle power as well as environmental and efficiency benefits.

1. Theory of operation

HSD replaces a normal geared transmission with an electromechanical system. All car powertrains drive a driveshaft that turns the drive wheels of the car. Because an internal combustion engine delivers energy best only over a small range of torque and speed, the crankshaft of the engine is usually attached to a switchable gear train that matches the needed torque at the wheels to the torque that can be delivered by the engine.

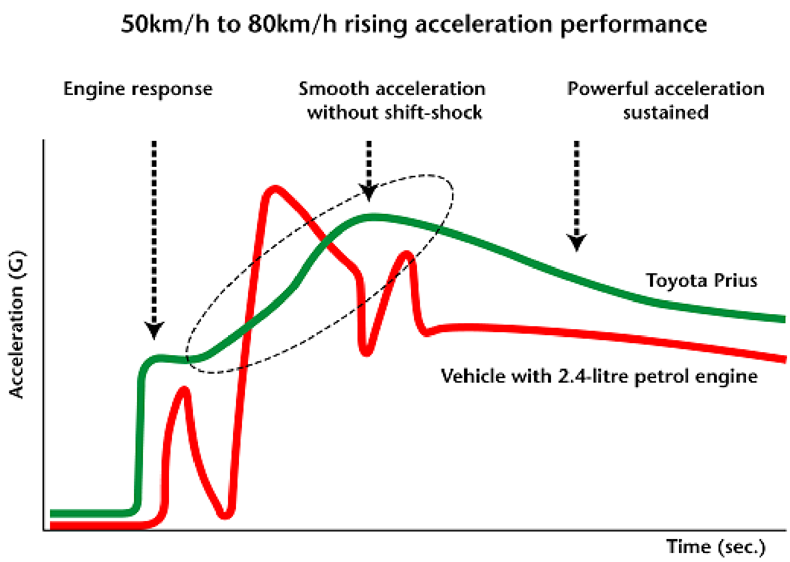
HSD replaces the gear box, alternator and starter motor with a *pair of electrical motor-generators (MG)*, a computerized shunt system to control them, *a mechanical power splitter* that acts as a second differential, and *a battery pack* that serves as an energy reservoir. Each Motor-Generator (MG) can convert electricity to motion (mechanical power) or vice-versa.



The mechanical connections of the system allow the computer to convert mechanical power from the engine between three forms: *extra torque at the w*heels (under constant rotation speed), *extra rotation speed at the wheels* (under constant torque), and *electricity*. This achieves the benefits of a continuously variable transmission, except that the torque/speed conversion uses electricity rather than direct mechanical connection.

The HSD works by shunting electrical power between the two motor generators and the battery pack to even out the load on the gasoline engine. Since a power boost is available for periods of acceleration, the gasoline engine can be sized to match only the average load on the car, rather than its peak load: this saves fuel because smaller engines are more power efficient. Furthermore, during normal operation the gasoline engine can be operated at its ideal speed and torque level for power, economy, or emissions, with the battery pack absorbing or supplying power as appropriate to balance the demand placed by the driver.

The following graph shows the difference between a shift-gear ICE vehicle and a vehicle with HSD.



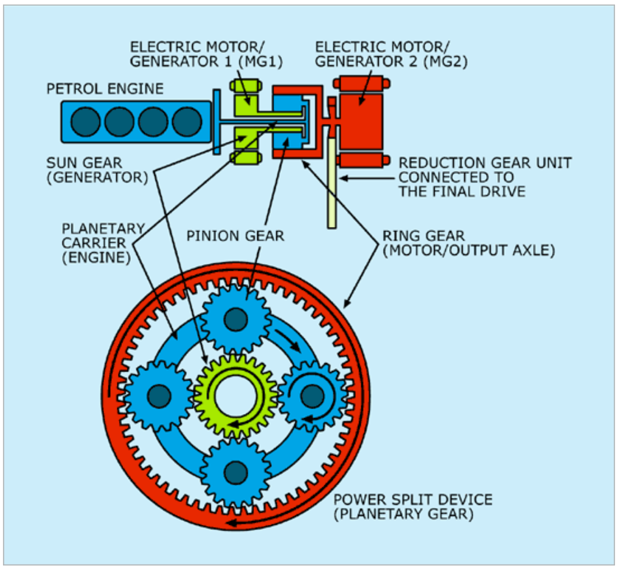
***Red line* = acceleration of a vehicle with IC petrol engine**
***Green line* = acceleration of a combined HEV**

An HSD car cannot operate without the computer, power electronics, and MG2, though in principle it could operate while missing the gasoline engine. In practice, HSD cars can be driven several kilometers without gasoline, as an emergency measure to reach a gas station.

2. The planetary gear unit of Toyota Prius II

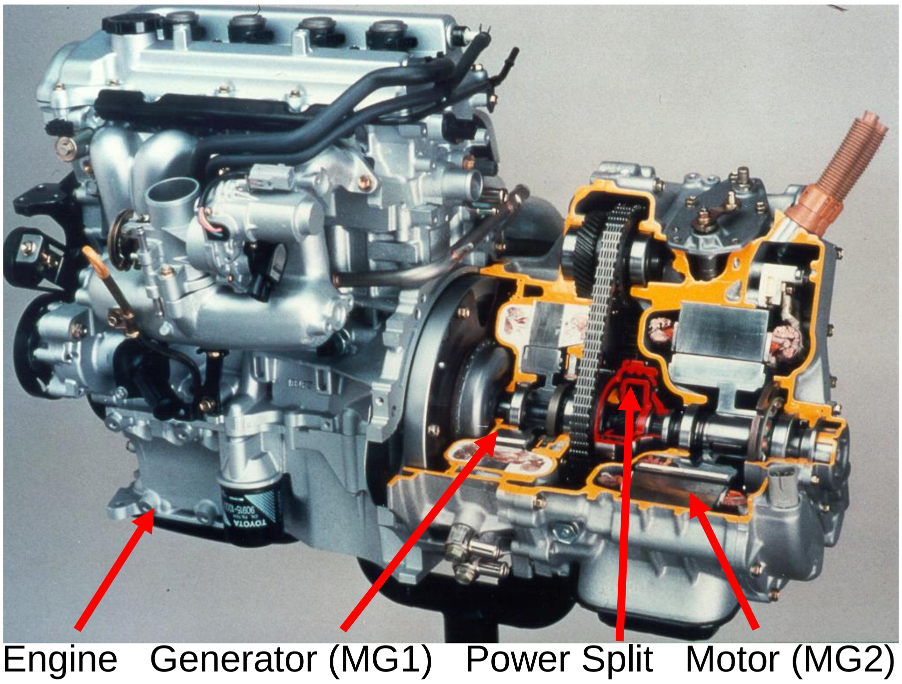
The motor (motor-generator MG2 in Toyota manuals; sometimes called "MG-T" for "Torque") is mounted on the driveshaft, and thus couples torque into or out of the driveshaft: feeding electricity into MG2 adds torque at the wheels.

Between the engine and the driveshaft, a "power split device" is mounted. This is an epicyclic gearset, also called planetary differential. One leg of this planetary unit is attached to the gasoline engine and the other leg is attached to the generator (a second motor-generator MG1 in Toyota manuals; sometimes "MG-S" for "Speed").

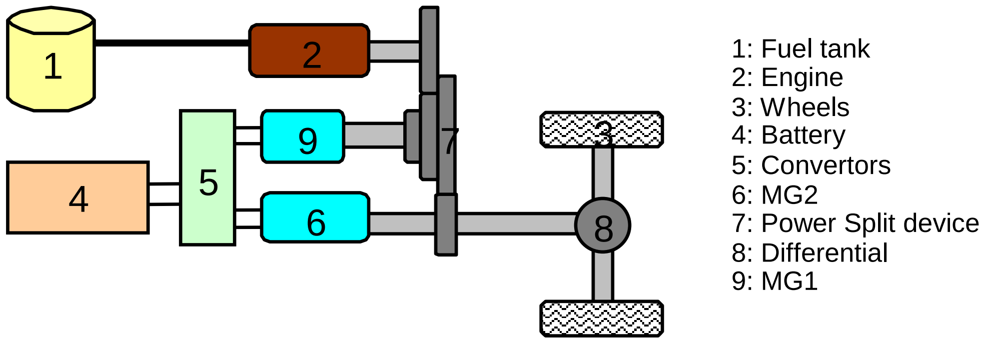


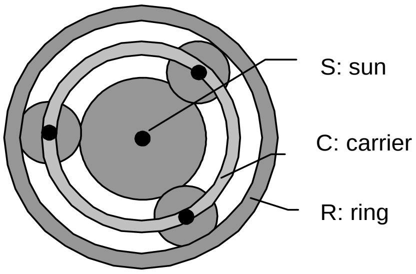
The planetary unit and the two motor-generators are all contained in a single housing that is bolted to the engine. Special couplings and sensors monitor rotation speed of each shaft and the total torque on the driveshaft, for feedback to the control computer.

Toyota Prius II power train



Toyota Prius II power train (other side)





$$(1+\rho)\cdot\omega_C = \omega_S + \rho\cdot\omega_R$$

$$\rho = z_R / z_S$$

Planetary unit used in the Prius II

The engine is connected to the planetary carrier, the generator MG1 is connected to the sun wheel and the output shaft and motor MG2 are both connected to the ring wheel.

These are basic equations for planetary gearsets:

$$(1+z_R/z_S).n_C = n_S+(z_R/z_S).n_R \quad \text{or} \quad (1+\rho).n_C = n_S + \rho.n_R$$

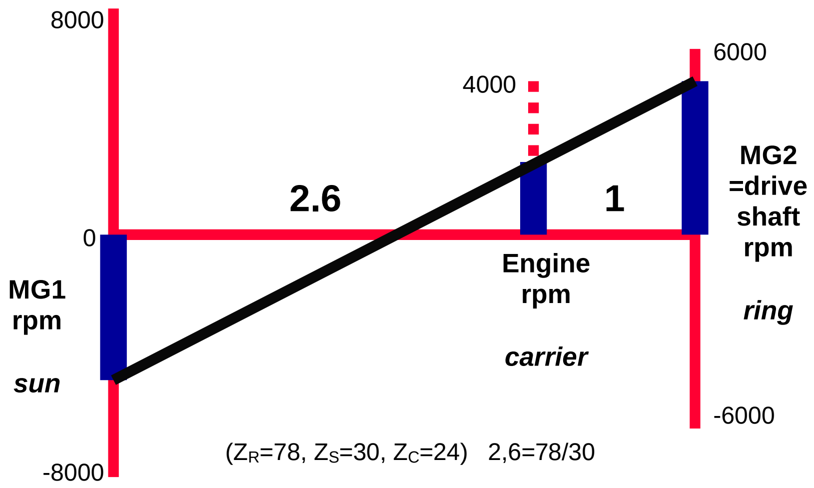
$T_C = T_R\ .(1+\rho)/\rho = T_S\ .(1+\rho)$

$P_C = P_R + P_S$

where

$\rho = z_R/z_S$
P = power
T = torque
n_S= speed of the sun wheel = MG1
n_R = speed of the ring wheel = MG2 = driveshaft
n_C = speed of the carrier wheel = engine
z_R= number of teeth of the ring wheel
z_C= number of teeth of the carrier wheel

A nomographic chart makes the speed equation more clear:



Vertical lines show rpm and the rotation direction for Sun Gear, Planetary Carrier, Ring Gear. Spaces between vertical lines show gear ratios

The generator (MG1) recharges the HV battery or supplies electrical power to drive the electrical motor (MG2). It also serves as a starter motor to start the engine.

The fraction of the engine *torque* which is transmitted to the sunwheel (MG1) and ringwheel (MG2) is fixed, (depends on the ration n_S/n_R only). The fraction of the engine *power* which is transmitted to the sunwheel (MG1) and ringwheel (MG2) depends on the speeds of these wheels as well.

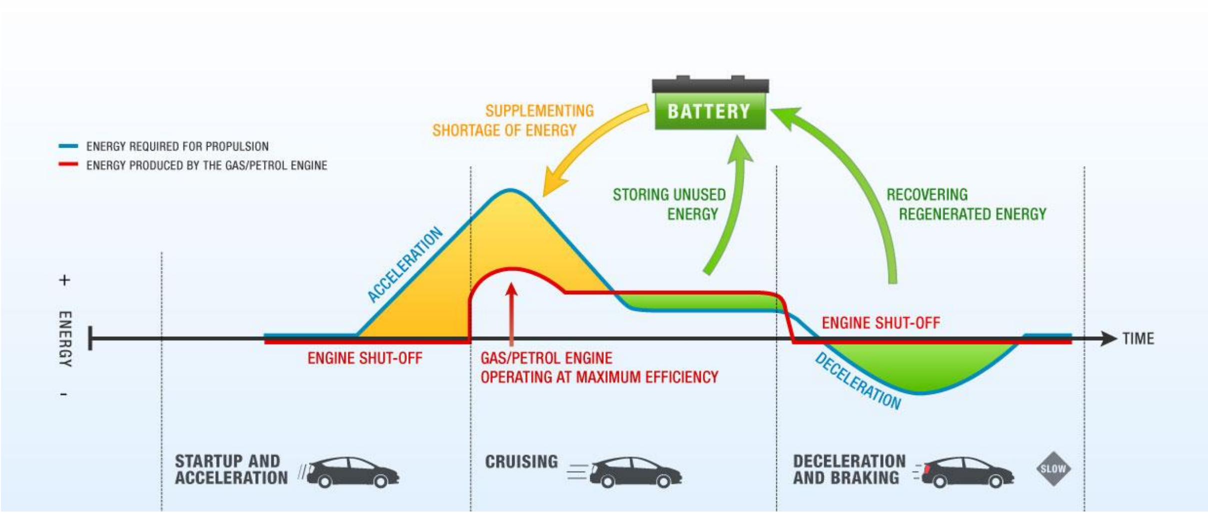
The planetary unit relates the rotation speed of the wheels (MG2) to the rotation speeds of the engine and MG1. By varying the speed of the generator MG1, the engine RPM can be held constant over a broad vehicle speed range. MG1 absorbs the difference between wheel and engine speed! With MG2, we can control the torque. With generator MG1, we can control the speed [Van Mierlo].

Animation on the web: http://www.eahart.com/prius/psd/

3. Prius drive phases of operation

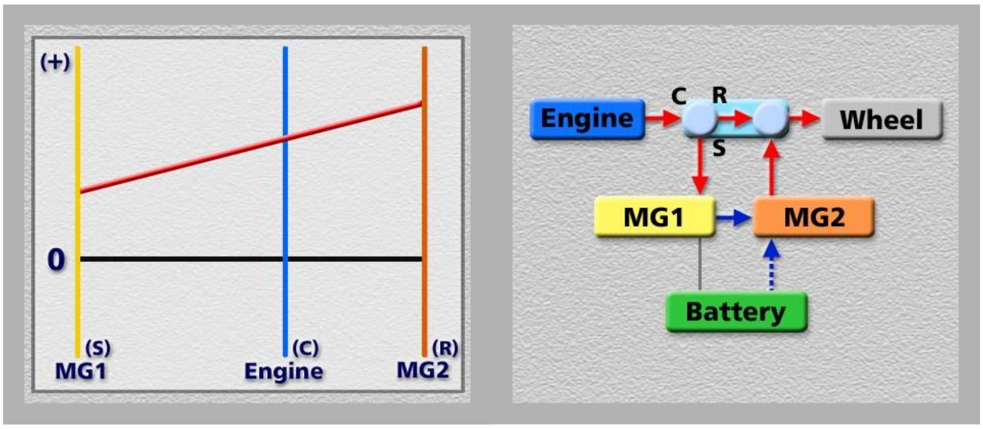
[See also slide show *HYBRID_SYNERGY_DRIVE.pdf* and movie *hybrid.wmv* by Toyota]

The HYBRID SYNERGY DRIVE computer oversees operation of the entire system, determining which engine/MG should be running, or if both should be in use, or shutting off the internal combustion engine when the electric motor is sufficient to provide the power.



1. At *start-off/low-speeds*, HSD runs the car on the electric motor(s) only, since the ICE does not perform efficiently.

2. The ICE is quite energy efficient for *cruising and acceleration*. Power produced by the gas/petrol engine is used to drive the wheels and also to drive the generator MG1. MG1 then provides power to the electric motor MG2 (acceleration, electric power assist drive) or to charge the battery (cruising at moderate power).



With ICE running, we can distinguish the following regimes:

CRUISING: ICE power

HSD uses the gas/petrol engine in the speed range in which it operates with good energy efficiency. The power produced by the ICE is used to drive the wheels directly, and part of the power is distributed to the generator MG1. MG1 is providing electricity to MG2. MG2 is adding torque at the driveshaft to supplement the ICE. MG1 runs backwards.

FULL ACCELERATION: ICE power + battery power

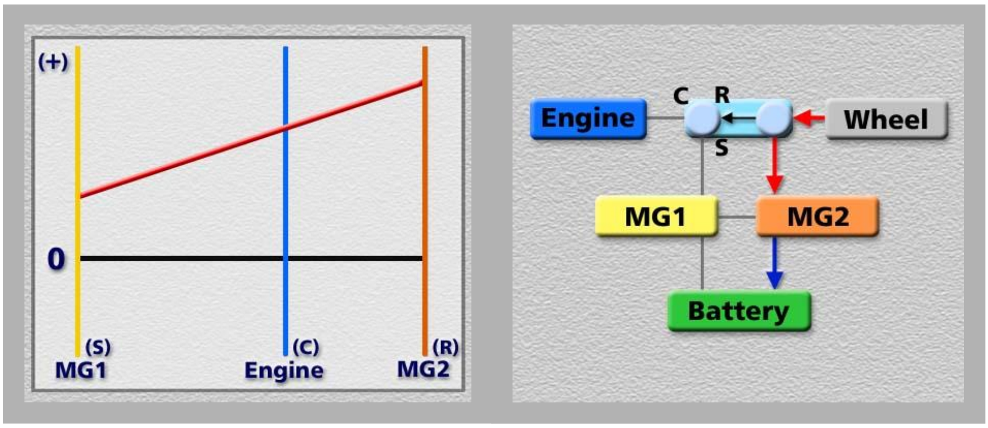
When strong acceleration is called for (e.g, for climbing a steep slope or overtaking) the power from the battery is supplied to the electric motor MG2, to supplement driving power.

By combining the power from the gas/petrol engine and the electric motors, HSD delivers power comparable to cars having one class larger engine. Most HSD systems have batteries that are sized for maximal boost during a single acceleration from zero to the top speed of the vehicle; if there is more demand, the battery can be completely exhausted, so that this extra torque boost is not available. Then the system reverts to just the power available from the engine.

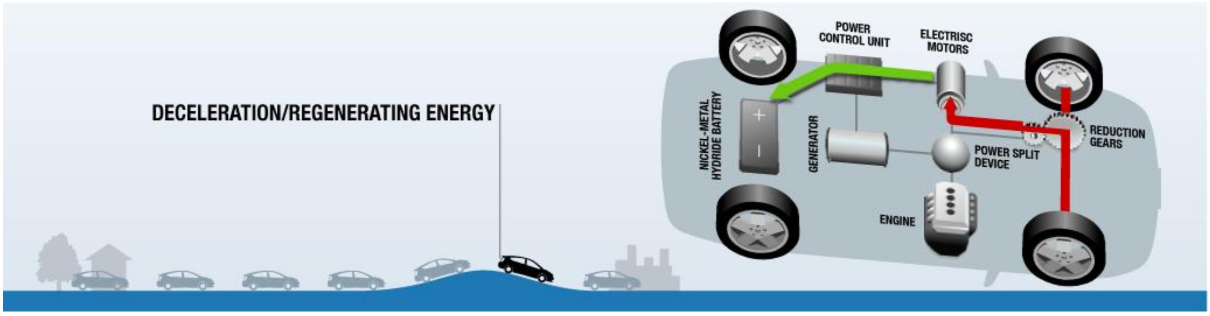
CRUISING: ICE power + battery charging

The battery SOC is low. The vehicle is cruising and the engine can meet the road load demand. The power from the engine is split between the mechanical path and the generator. The generator MG1 provides electrical energy to charge the battery.

3. Under *deceleration or braking*, HSD uses the car's kinetic energy to let the wheels turn the electric motors and recover regenerative energy to recharge the battery.



DECELERATION, BRAKING: kinetic energy recuperation for battery charging



Under braking, kinetic energy that is normally lost as friction heat is now converted into electrical energy. Electrical power is no longer supplied to MG1/MG2, but MG2 is powered by the wheels and acts as generator to recharge the HV battery. Even when the accelerator pedal is lifted, deceleration energy is recovered in the battery to be reused later.

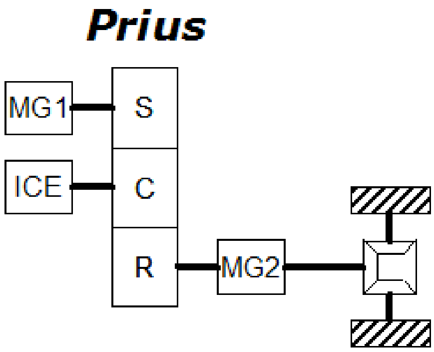
The HSD system has a special transmission setting labelled 'B' (for Brake) for engine braking on hills.

The regenerative brakes in an HSD system absorb a significant amount of the normal braking load, so the conventional brakes on HSD vehicles are undersized compared to brakes on a conventional car of similar mass. If the battery is full, the system switches to conventional compression braking, drawing power from MG2 and shunting it to MG1, speeding the engine with throttle closed and so slowing the vehicle.

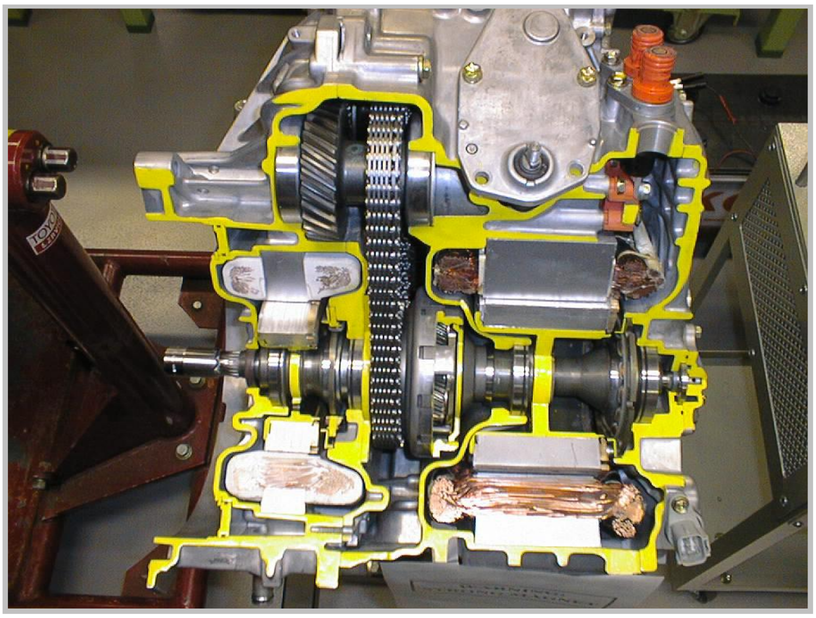
4. The power electronics of the Toyota Prius II

The power train of the Prius II consists of:

- A 1.5 liter 4 cylinder gasoline engine
- A special generator MG1 mounted to the back of the engine which doubles as a starter motor
- A planetary gear set that connects the generator and the gasoline engine to the drive wheels
- An electric motor MG2 also connected to the drive wheels
- A HV Ni-MH battery pack with a rated voltage of 273,6 V.



Hybrid Synergy Drive in Prius
S = Sun wheel, C = Carrier wheel, R = Ring wheel



Internal Combustion Engine

The Prius has an internal combustion engine (ICE) which is unusually small for a car of this size (1300 kg). A conventional car, with an engine sized for hard acceleration and climbing steep hills, almost always operates that engine with low efficiency. Maximum efficiency generally occurs at around half of the engine's peak power output. A small engine can operate closer to this maximum efficiency because power demands encountered in normal driving are a larger fraction of its peak power. The possibility of using a small engine in a hybrid vehicle is called "engine downsizing".
In addition to being downsized, the Prius engine uses many techniques to improve efficiency and broaden the range of conditions under which high efficiency is achieved. The engine uses the Atkinson cycle, rather than the usual Otto cycle, which improves efficiency particularly at lower power by reducing "pumping loss". Limiting the maximum spin rate (to 4500 r.p.m. in the Generation II Prius (2000 - 2003) and 5000 r.p.m. in the Generation III Prius (2003 onwards)) allows lightweight parts to be used, reducing inertia and friction losses. The crankshaft is offset from the cylinder axes so that during the combustion stroke the force from the piston is transmitted to the crankshaft through a straight rather than tilted connecting rod. The valves have narrow stems and low force springs to reduce energy lost in operating the valves. The engine power is 70 hp at 4500 rpm.

Toyota Prius II Battery Pack

Toyota uses prismatic NiMH modules from Panasonic. Each module consists of six 1,2 V cells connected in series. The module has a nominal voltage of 7,2 V, capacity of 6,5 Ah, weighs 1,04 kg, and has dimensions of 19,6mm(W) x 106mm(H) x 275mm(L).

The Toyota Prius II battery stack consists of 38 prismatic NiMH modules connected in series. It delivers a nominal 273,6 Volts and has a 6,5 Ah capacity. The complete battery pack consists of the battery stack, enclosure for structural support and airflow, battery electronic control unit/monitor, relays and safety switch. The weight of the complete battery pack is 53,3 kg. The pack is horizontally positioned in the boot of the vehicle partially under the back seat. A blower for moving air and associated air ducts are in the boot.

The maximum current of the battery is 80 amps discharge and 50 amps charge. This is remarkable, since each cell is similar in size to an ordinary D-cell such as you would use in a large flashlight. In fact, the Generation 1 Prius used an earlier version of battery cells that really were D-cells. The Generation III Prius actually has a less powerful battery pack than the Generation II. The Generation III Prius battery pack is still made up of the same type of 1,2 volt cells but instead of 38 modules of 6 cells it only has 28 modules for a total nominal voltage of only 201,6 volts. A boost convertor is used to produce 500 Volt DC supply voltage for the inverters for MG1 and MG2.

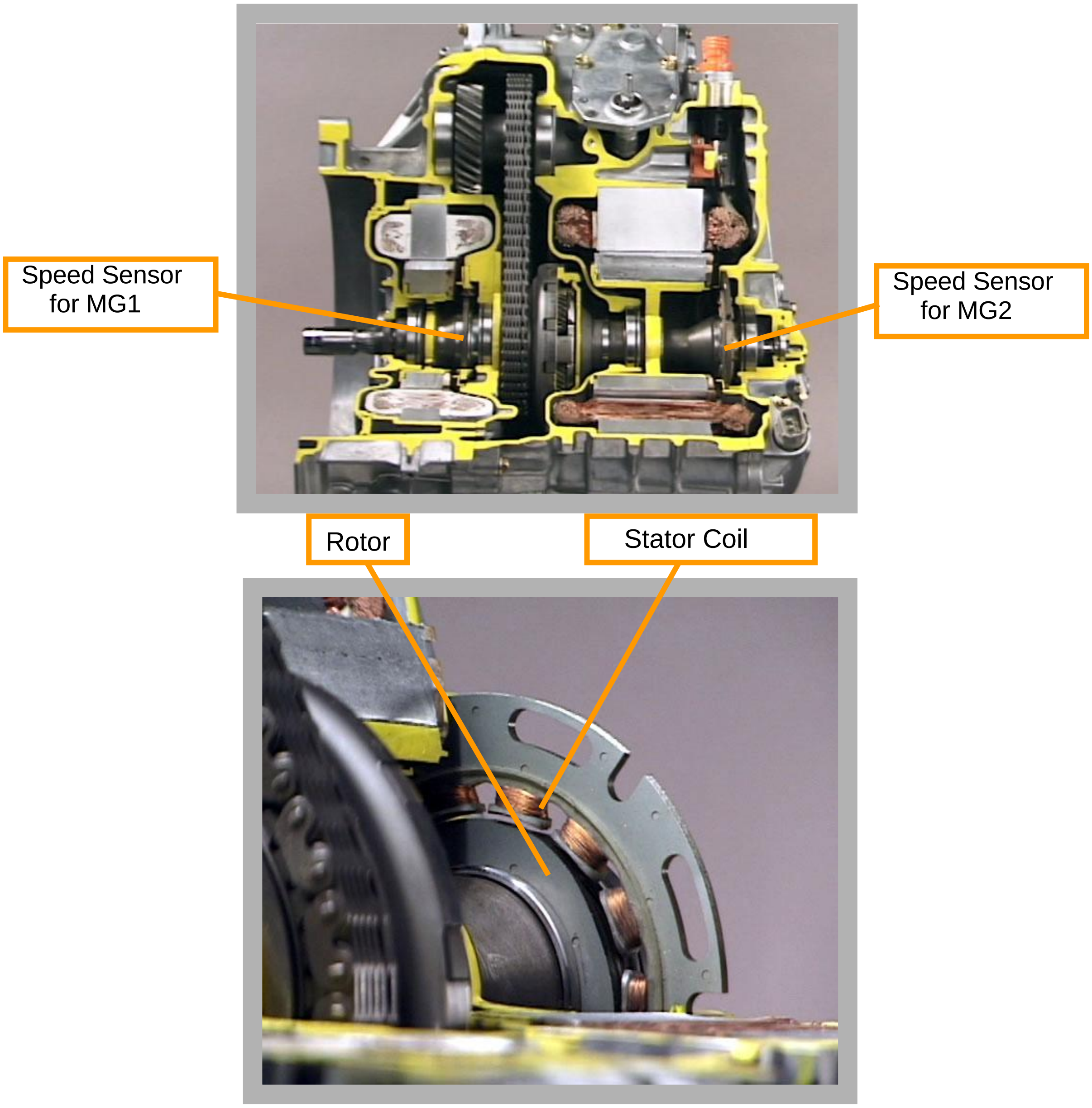
The rated capacity of both battery packs is 6,5 Ah, however, the car's electronics only allow 40% of this capacity to be used so as to prolong battery life. The state of charge is allowed to vary only between 40% and 80% of the rated full charge. Multiplying up the battery voltage and current capacity, its rated energy storage capacity is 6,4 MJ (megajoules) and its usable capacity is 2,56 MJ. This is enough energy to accelerate the car, driver and a passenger up to 105 km/h (without help from the ICE) four times. Alternatively, it is enough to raise the car through 200 vertical meters.

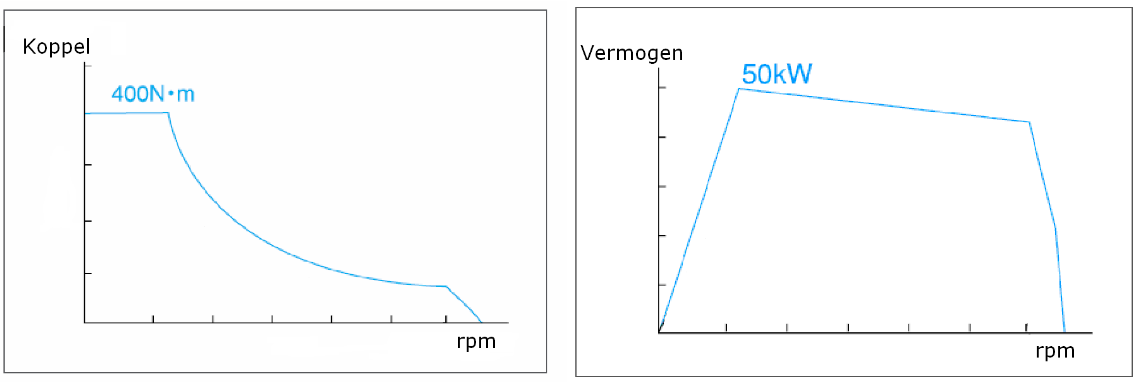
Discharge power capability of the Prius II pack is around 20 kW at 50% SOC with regenerative capability of 14,5 kW at 2C. The power capability increases with higher temperatures and decreases at lower temperatures.

Active thermal management to keep the batteries operating within a desirable temperature range can improve power capability at lower outside temperatures. The Prius supplies conditioned air from the cabin as thermal management for cooling the batteries. The Prius has a computer that's solely dedicated to keeping the Prius battery at the optimum temperature and optimum charge level.

The MG1 and MG2 motor/generators

Item	**MG1**	**MG2**
Type	**three-phase PMSM**	**three-phase PMSM**
Function	**Generator, Engine Starter**	**Generator, Wheel Drive**
Rated Voltage [V]	**AC 500**	**AC 500**
Maximum Output [kW / rpm]	**37.8 / 9500**	**50 / 1200 – 1540**
Maximum Torque [N·m / rpm]	**45 / 0 – 6000**	**400 / 0 – 1200**
Current at maximum torque [A]	**75**	**230**
Maximum rpm	**10,000 rpm**	
Cooling System	**Water-cooled**	



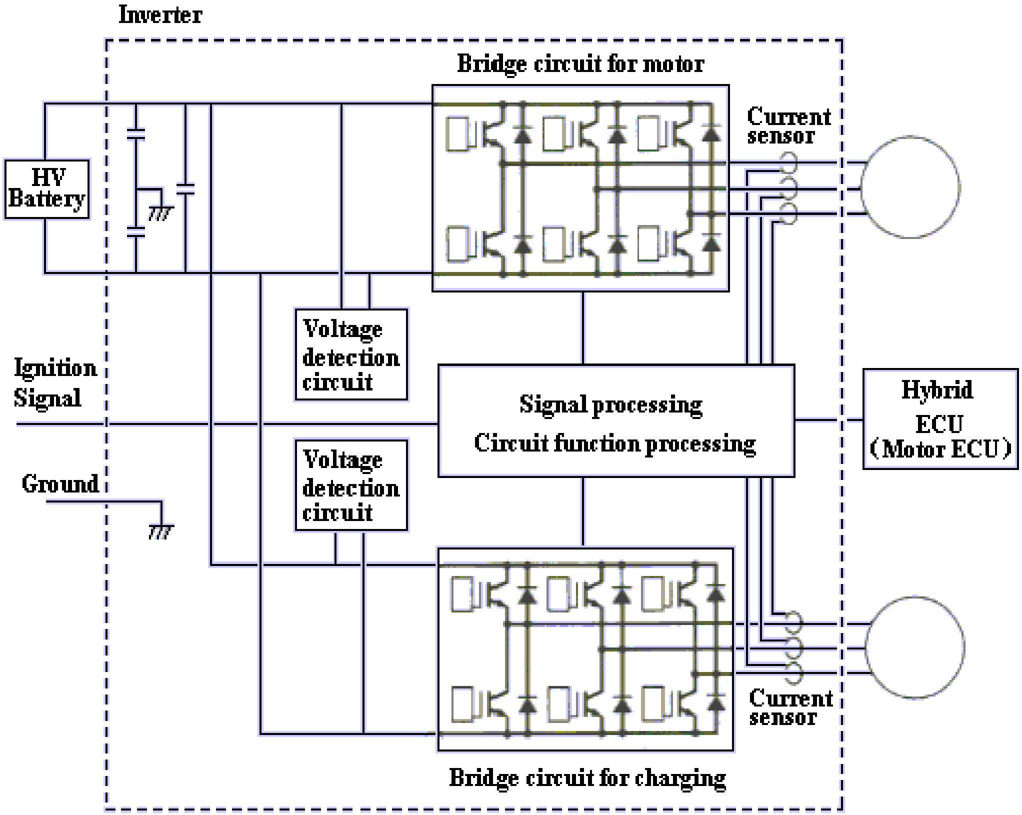


Prius MG2 characteristics

Toyota Prius Converters

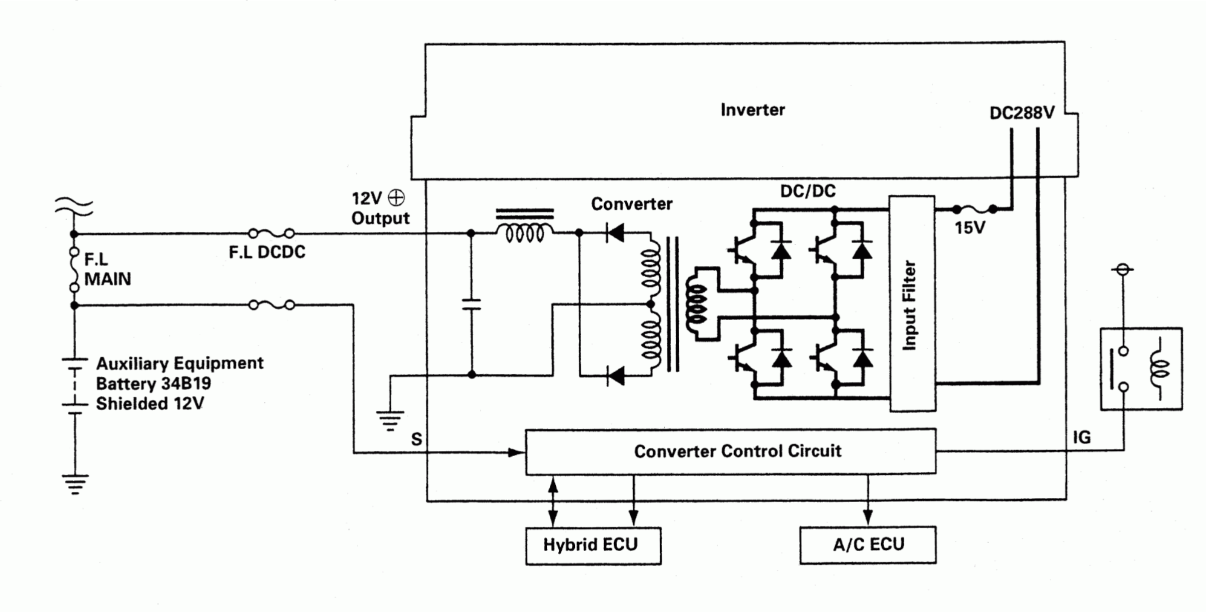
In the Prius III, a combined *stepdown/boost converter* links the battery with the 500 V inverter DC High Voltage.

The *inverter* converts the DC High Voltage to AC currents for the MG1 and MG2 motor/generators. Speed Sensors (Resolvers) detect the position of MG1/MG2 rotors. The inverter knows the position of its MG's rotor and switches current through the windings as required to keep it spinning at the desired speed and with the desired torque.

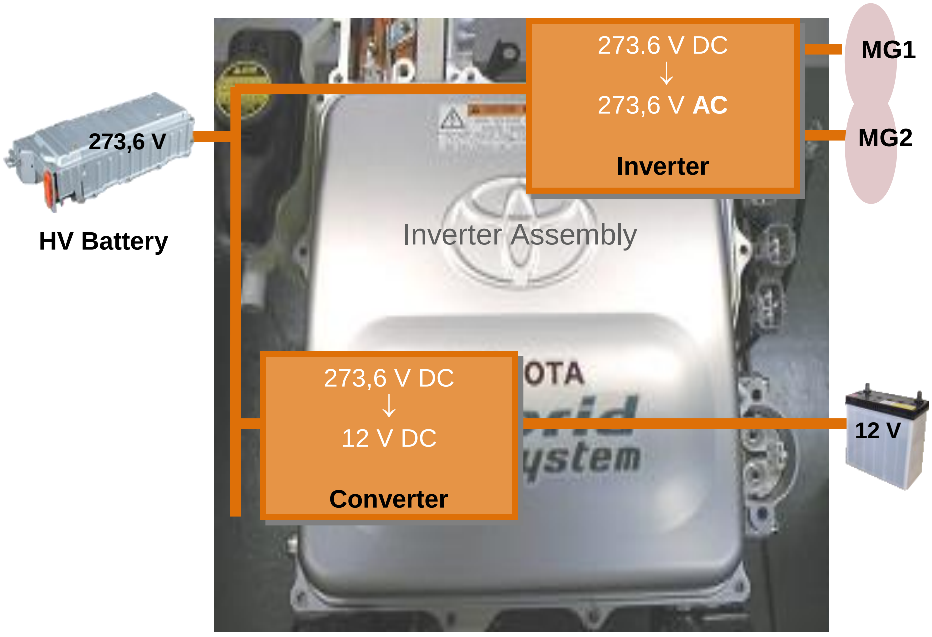


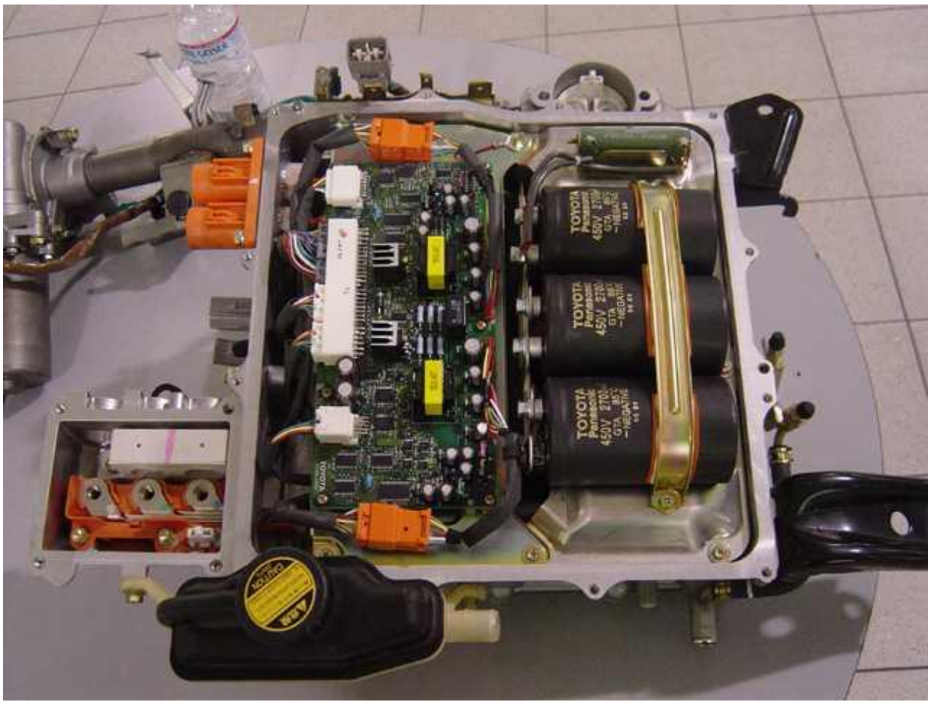
Inverter for MG2 (top) and MG1 (bottom) with control circuitry

The Prius also has an auxiliary battery. The power source for auxiliary equipment of the vehicle such as the lights, audio system, and air conditioner cooling fan, as well as the ECU’s, is based on a 12 V system. A 12 volt, 28 ampere hour lead-acid battery lives in the passenger’s side of the boot in the Generation II Prius and in the driver’s side of the boot in the Generation III Prius. It supplies power to the electronics and accessories when the hybrid system is turned off and the high-voltage battery main relay is off. A *stepdown converter* is used to transform the HV battery voltage to 12 V DC in order to recharge this auxiliary battery.



Pushpull stepdown converter 288 Volt – 12 Volt





High voltage unit of the HSD

[source: http://www.cleangreencar.co.nz/page/prius-battery-pack and http://www.cleangreencar.co.nz/page/prius-technical-info]

5. History and Future of Toyota hybrid vehicles

The basic design of the Toyota Hybrid System / Hybrid Synergy Drive has not changed since its introduction in the 1997 Japanese-market Toyota Prius, but there have been a number of refinements.

First generation: Toyota Hybrid System (THS)

The original Prius used shrink-wrapped 1.2 volt D cells. The original THS did not have the second torque-providing electric motor (MG2).

All subsequent THS/HSD vehicles have used custom 7.2 V battery modules mounted in a carrier. There has been a continuous, gradual improvement in specific capacity.

The Toyota Hybrid System relies on the voltage of the battery pack — between 276 and 288 V.
The Prius II with HSD has the following improvements compared to the Prius I:

- Superior power: ICE + 8% and electrical MGs +50%
- Torque electrical motor + 14 %
- Inferior electrical losses
- Improved charge capacity of the generator
- New HV battery with superior power density and charge/discharge capacity, and 14% weight reduction
- Mass reduction: Aluminum high voltage cabling

Second generation: Hybrid Synergy Drive (HSD)

The Hybrid Synergy Drive adds a DC to DC converter boosting the potential of the battery to 500 V or more. This allows smaller battery packs to be used, and more powerful motors.

Although not part of the HSD as such, all HSD vehicles from the 2004 Prius onwards have been fitted with an electric air-conditioning compressor, instead of the conventional engine-driven type. This removes the need to continuously run the engine when cabin cooling is required. Although as noted above, the heat source for the climate control heater is still the gasoline engine and will run as long as heat is needed for the cabin.

Vehicles such as the Lexus RX 400h and Toyota Highlander Hybrid added four-wheel drive operation by the addition of a *third electric motor* ("MGR") on the rear axle. In this system, the rear axle is purely electrically powered, and there is no mechanical link between the engine and the rear wheels. This also permits regenerative braking on the rear wheels. In addition, the Motor (MG2) is linked to the front wheel transaxle by means of a second planetary gearset, thereby making it possible to increase the power density of the motor.

Ford has developed a similar hybrid system, introduced in the Ford Escape Hybrid.

The latest addition to the family of Hybrid Synergy Drivetrains is used in the Lexus GS 450h / LS 600h. This system uses two clutches (or brakes) to switch the second motors gear ratio to the wheels between a ratio of 3.9 and 1.9, for low and high speed driving regimes respectively. This decreases the power flowing from MG1 to MG2 (or vice versa) during higher speeds. The electrical path is only about 70% efficient, thus decreasing the power flow there increases the overall performance of the transmission. The second planetary gearset is extended with a second carrier and sun gear to a ravigneaux-type gear with four shafts, two of which can be held still alternatively by a brake/clutch.

Third generation

The new Prius III (2009) has a re-engineered Hybrid Synergy Drive system. It brings significant reductions in weight and size, contributing to the overall improvements in fuel economy:

- The ICE is a new 1.8-litre VVT-i Atkinson cycle petrol engine with cooled Exhaust Gas Recirculation. It is more powerful (90 hp vs 70 hp).
- The electric motor MG2 is 20% more powerful (60kW vs 50 kW) and 33% smaller!
- The Ni-MH battery power has been increased to a maximum 27kW (+2kW), and has reduced size. Plans to replace NiMH batteries with lithium-ion batteries are delayed. Lithium-ion batteries have a higher energy capacity-to-weight ratio, but cost more, and operate at higher temperatures, raising safety concerns.
- The new inverter is 36% lighter and 37% more compact than before, has faster switching for improved efficiency and now converts the battery’s DC into a higher, 650V (+150V) voltage to drive the electric motor.

Further weight saving gains are achieved through more extensive use of lightweight aluminium and ultra high-tensile steel in new Prius’s construction.

The new Prius III has more interior space and comfort. Overall system power has been increased by 22%, fuel economy improved by 14% (4 liter/100 km), CO_2 emissions are reduced to 89g/km.

The same technology is used in the Lexus CT200h and the Toyota Auris hybrid.

Case study: Lexus CT200h - Toyota Auris hybrid

The Lexus CT200 and Auris hybrids are being sold in Belgium since the end of 2010.

ICE:
1800 cc, 4 cylinder, petrol
73 kW @ 5200 rpm
142 Nm @ 4000 rpm.
Emission level EUR 5

PMSM motor 60 kW.
Max voltage 650 VDC
Max power 80 hp
Max torque 207 Nm

Max system voltage (DC voltage for M/G): 650 Volt.

NiMH battery 201.6 Volt (168 x 1.2V cells, 28 battery modules)
Capacity 6.5 Ah
Max power 27 kW

Four drive-modes: Normal, Eco, Sport and EV.

Case study: Lexus RX400h

Introduction

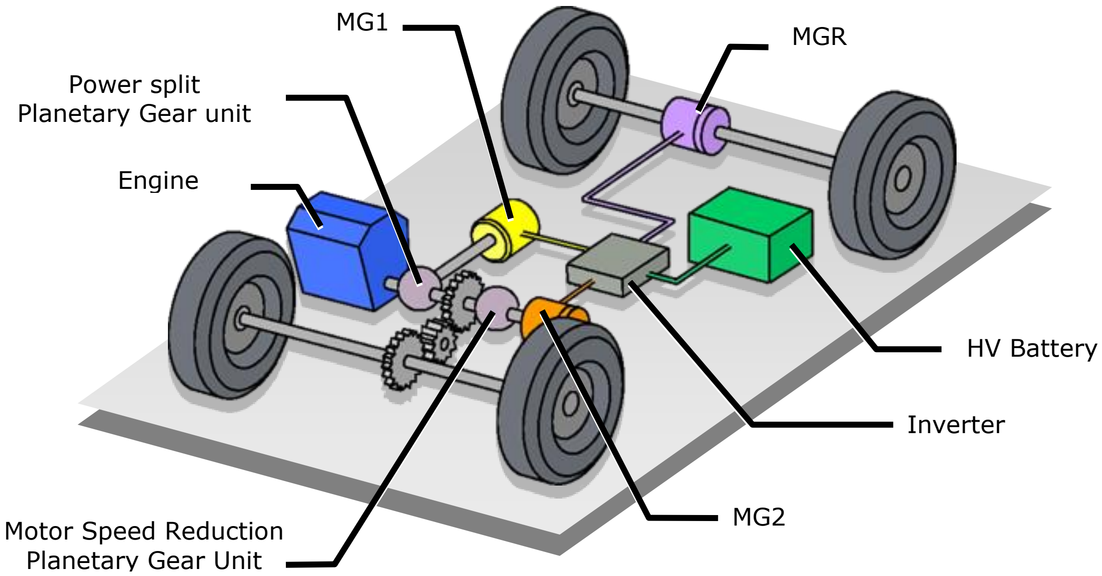
The Toyota Hybrid Synergy Drive, implemented in the Prius II, has only a single power split device, incorporated as a 3 shaft planetary gearset. This is a typical example of an *Input-Split Hybrid*, due to the fact that a fixed amount of torque is transferred via the electrical path from the engine to the wheels. This in turn makes this setup simple in mechanical terms, but does have some drawbacks of its own. For example the maximum speed is mainly limited by the speed of the smaller electric motor. Also, the efficiency of the transmission is heavily dependent on the amount of power being transmitted over the electrical path. The latter has multiple conversions, with a low efficiency (70%) compared with the efficiency of the purely mechanical path (98%). Especially in higher speed regimes (>120 km/h) the efficiency (of the transmission alone) therefore drops below that of a generic automatic transmission with hydrodynamic coupler.

The main difference to the Input-Split Hybrid is the addition of a second planetary gearset, and the addition of four clutches (which can actually operate as one). This enables the switching of the percentage of mechanically vs. electrically transmitted power (two modes). This way, it is possible to cope both with low-and high-speed regimes, enabling smaller motors to do the job of larger motors when compared to a single mode type system. The four fixed gears enable the Two-mode hybrid to function like a conventional parallel hybrid under high continuous power regions, like sustained high speed cruising or during towing. Full electric boost is available in fixed gear modes.

The powertrain of the Lexus

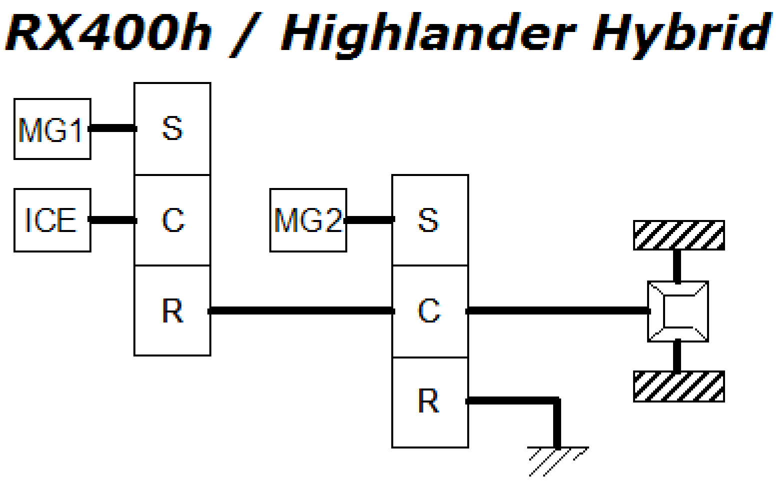
Vehicles such as the ***Lexus RX 400h and Toyota Highlander*** Hybrid added *four-wheel drive* operation by the addition of a *third electric motor* ("MGR") on the rear axle. In this system, the rear axle is purely electrically powered, and there is no mechanical link between the engine and the rear wheels. This also permits regenerative braking on the rear wheels.

In addition, a fixed gear second gearset is implemented: the drive motor (MG2) is linked to the front wheel transaxle by means of a *second planetary gearset*, thereby making it possible to increase the power density of the MG2. This allows for a motor with less torque but higher power (and higher maximum rotary speed).

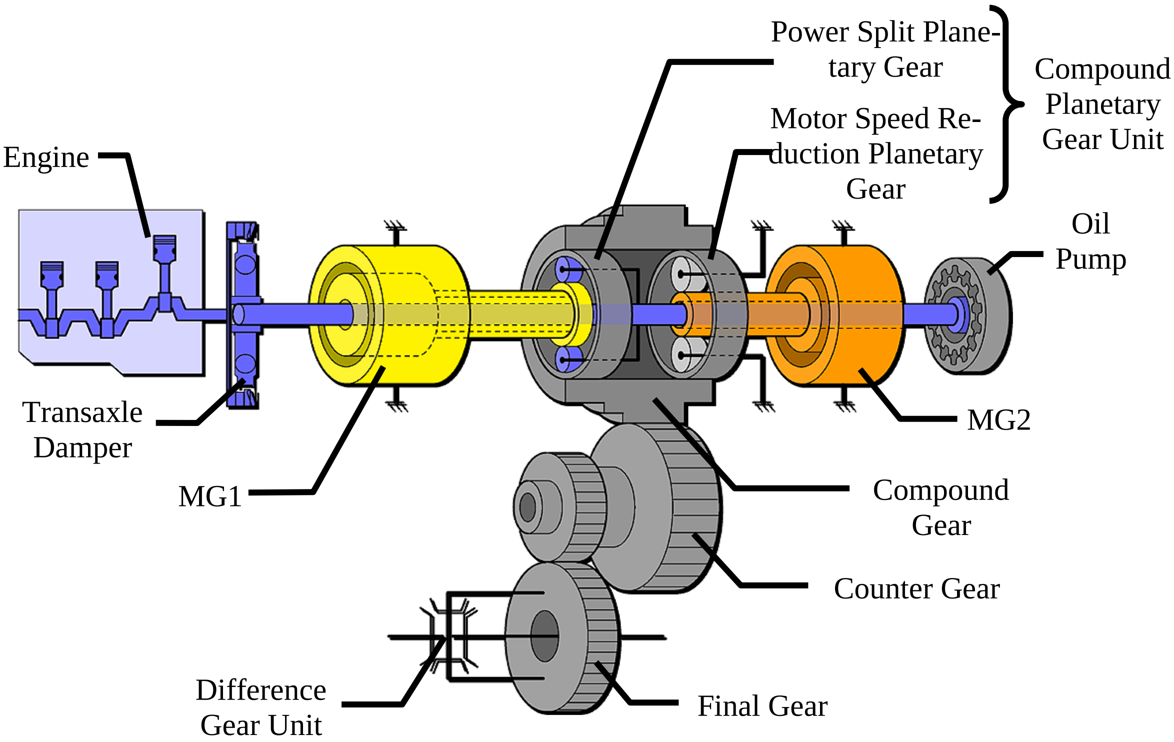


The power train of the Lexus consists of

- ICE: V6 3.3 liter 24-valve VVT-i gasoline engine. It produces, in the case of the Harrier Hybrid, **155 kW** @ 5,600 rpm 288 Nm @ 4,400 rpm.
- Generator MG1: PMSM, max 650V, max **109 kW** @ 13000 rpm, max 80 Nm @ 0-13000 rpm
- Motor Generator MG2: max 650V, max **123 kW** @ 4500 rpm, max 333 Nm @ 0-1500 rpm (front wheel drive)
- Motor Generator Rear MGR: PMSM max 650 V, max **50 kW** @ 4610-5120 rpm, max 130 Nm @ 0-610 rpm (rear wheel drive)
- HV Ni-MH battery pack with a rated voltage of 288 V.



Hybrid Synergy Drive in Lexus RX400h.
S = Sun wheel, C = Carrier wheel, R = Ring wheel



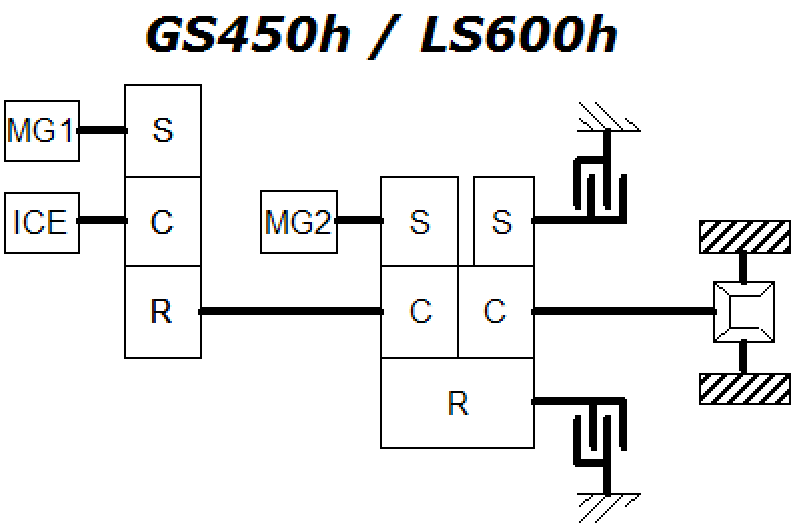
The whole system, called Lexus Hybrid Drive (also Hybrid Synergy Drive), produces a maximum of 200 kW. Under normal driving conditions only the front motor and gasoline engine will be used. The rear motor will only be used under full-throttle acceleration or when the front wheels lose traction. The Electronically Controlled Continuously Variable Transmission (ECVT) delivers smooth acceleration without conventional gear shifting, while enhancing efficiency. The advanced application of the electric motor/generators, power split device and reduction device helps optimize available performance and economy.

The power split planetary gear set splits engine power between the front wheels and MG1. It distributes 70% of engine torque to the output axle and 30% to MG1 to power MG2 or recharge the hybrid battery. Lexus hybrid vehicles never need to be “plugged in.” The LHD system automatically recharges its HV battery.

When either stationary, decelerating, or being driven at a slow speed, the gasoline engine will switch off automatically and the car will be electrically driven. Lexus hybrid vehicles are capable of being powered by the electric motors alone without assistance from the engine.

The electric motors operate at times when they’re most efficient (i.e. start-up and low-speed cruising), while the gasoline engine operates at times when it is most efficient (i.e. heavy acceleration and highway cruising).

The assistance of the electric motor increases the vehicle's performance; the 400h/Harrier Hybrid can reach 97 km/h in less than 8 s, quicker than the gasoline-only RX. Despite the increased performance, the RX 400h/Harrier Hybrid consumes roughly the same amount of gasoline as a compact four-cylinder saloon.



Hybrid Synergy Drive in new Lexus
S = Sun wheel, C = Carrier wheel, R = Ring wheel

The latest addition to the family of Hybrid Synergy Drivetrains is used in the Lexus ***GS 450h / LS 600h***. This system has a Dual-Range Motor Reduction. The device uses two clutches (or brakes) to switch the gear ratio from MG2 to the wheel shaft. Therefore, the second planetary gearset is extended with a second carrier and sun gear to a ravigneaux-type gear, with four shafts, two of which can be held still alternatively by a brake/clutch. The gear ratio to the wheel shaft can be switched between a ratio of 3.9 and 1.9, for low speed (higher torque) and high speed driving regimes - up to 250 km/h. This way, the power flowing from MG1 to MG2 (or vice versa) is decreased during higher speeds. The electrical path is only about 70% efficient, thus decreasing the power flow there increases the overall performance of the transmission, while contributing to improved fuel economy.

The power electronics of the Lexus

The RX400h utilizes the following DC voltage systems:

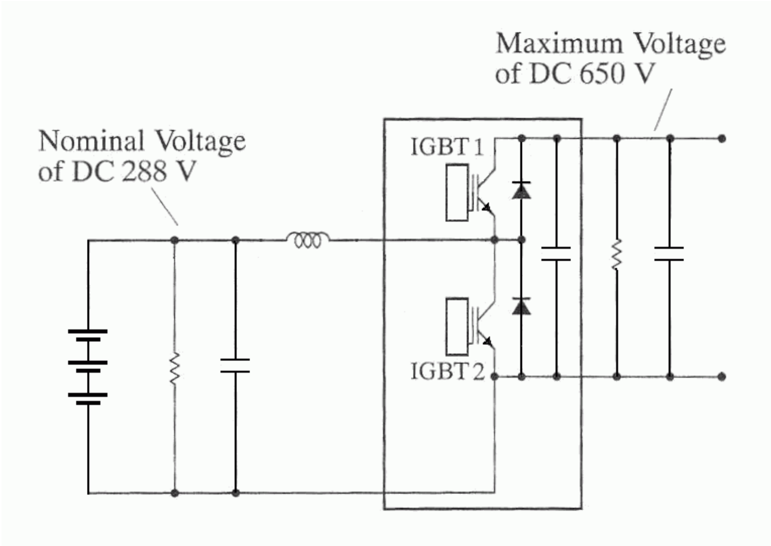
- Max 650 Volt DC
- Nominal 288 Volt DC
- Nominal 42 Volt DC
- Nominal 12 Volt DC

Electric Start Motor/Generator (***MG1***): Acts primarily as a generator by producing power to re-charge the hybrid battery and provide power to Electric Drive Motor/Generator (MG2) during acceleration. When acting as a motor, MG 1 starts the engine.

Electric Drive Motor/Generator (***MG2***): Provides power to the rear wheels and generates power during braking to re-charge the hybrid battery.

The 288 Volt ***Ni-MH batte*****ry** is composed of 30 low voltage (9,2 Volt) sealed nickel-metal hydride modules. The hybrid battery supplies power to the power inverter for use by the electric motors, air conditioning and power steering. During coasting and braking conditions, it stores regenerative energy captured by the electric motors.

A combined ***stepdown/boost converter*** links the battery with the inverter DC input voltage. This converter can also boost the hybrid battery's power from 288 volts up to 650 volts as needed for maximum power.



Bilateral DC-DC converter
During boost converter operation (288V → 650V) IGBT2 is switched
During buck converter operation (650V → 288 V) IGBT1 is switched
[Lexus RX400h]

The power ***inverter*** converts the DC voltage into AC current for the electric motors and vice versa, depending on driving demands and electrical system.

The Hybrid Electronic Control Unit (***ECU***) monitors and controls the power flow between all key components of the hybrid systems (engine, motors, battery, etc.) to ensure optimum performance and efficiency.

Sources:

http://encyclopedia.thefreedictionary.com/Hybrid+Synergy+Drive
http://encyclopedia.thefreedictionary.com/Lexus+RX+400h

Plug in Hybrid Vehicles

The Toyota Plug-in Hybrid Vehicles (PHV) (2012) will be equipped with a powerful lithium-ion battery, extending the vehicle's range in EV mode for a silent, zero emissions drive.
A PHV can be charged during driving like a regular hybrid (through driving, deceleration or braking) or by attaching its plug to a standard electrical outlet either at home or at work. Compared to Toyota's full hybrid Prius, a PHV is able to run more often in its petrol-free, electric-only mode, meaning lower running costs and less CO2, especially when renewable energy is used.


Hymotion
PHEV
PLUG-IN HYBRID VEHICLE


Prius
Plugs in
Detroit
Plug-in
HYBRID
TOYOTA