بسم الله الرحمن الرحيم

الجامعة الإسلامية للتكنولوجيا

UNIVERSITÉ ISLAMIQUE DE TECHNOLOGIE

ISLAMIC UNIVERSITY OF TECHNOLOGY

DHAKA, BANGLADESH

ORGANIZATION OF ISLAMIC COOPERATION

AUTOMOTIVE HYBRID VEHICLE SYSTEM OR HYBRID AUTOMOBILE

BY

Hemyar Ahmed Saleh Merfaq (091305)

Abdulmalik Muhammad Yusuf (091307)

Supervised by:

Dr. Mir Md. Mafuf Morshed

Department of Mechanical and Chemical Engineering (MCE)

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A thesis presented to the Academic Faculty

By

Hemyar Ahmed Saleh Merfaq (091305)

Abdulmalik Muhammad Yusuf (091307)

In partial fulfillment of the Requirement for the Degree of Higher Diploma in Mechanical Engineering.

Approved by

Dr. Mir Md. Mafuf Morshed

ISLAMIC UNIVERSITY OF TECHNOLOGY (IUT)

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ABSTRACT

Abstract. *An increasingly diverse set of hybrid-electric vehicles (HEVs) is now available in North America. The recent generation of HEVs have higher fuel consumption, are heavier, and are significantly more powerful than the first generation of HEVs. We compare HEVs for sale in the United States in 2007 to equivalent conventional vehicles and determine how vehicle weight and system power affects fuel consumption within each vehicle set. We find that heavier and more powerful hybrid-electric vehicles are eroding the fuel consumption benefit of this technology. Nonetheless, the weight penalty for fuel consumption in HEVs is significantly lower than in equivalent conventional internal combustion engine vehicles (ICEVs). A 100 kg change in vehicle weight increases fuel consumption by 0.7 l/100 km in ICEVs compared with 0.4 l/100 km in HEVs. When the HEVs are compared with their ICEV counterparts in an equivalence model that differentiates between cars and sports-utility vehicles, the average fuel consumption benefit was 2.7 l/100 km. This analysis further reveals that a HEV which is 100 kg heavier than an identical ICEV would have a fuel consumption penalty of 0.15 l/100 km. Likewise, an increase in the HEV's power by 10 kW results in a fuel consumption penalty of 0.27 l/100 km.*

Keywords: *hybrid-electric vehicles, fuel consumption, performance, vehicle weight, system power*

CHAPTER 1-INTRODUCTION

The automotive industry is the main driver for pushing the fuel cell technology to its present status. However, the role of the supplier industry, which has to develop innovative components and parts for the fuel cell system and the electrical drive train is also of crucial importance for the final success of fuel cell powered vehicles. The HyLite Project is a joint project of 10 supplier companies and the German Aerospace Centre (DLR) to develop a fuel cell powered vehicle, which shall serve as a "technology carrier". The technology carrier helps the supplier industry in the development of advanced components for fuel cell systems. The basic vehicle, to be converted to a fuel cell "technology carrier", is a battery car, which was produced by a German manufacturer in a small scale production of nearly 150 vehicles. It is a two-seat concept, designed for urban usage, mainly. Its total weight is about 830 kg, whereby the battery pack of 14 lead acid batteries takes 340 kg. The maximum speed comes to 100 km/h. In the following it is described in which way this vehicle has been converted to a fuel cell power train "technology carrier".

Hybrid vehicles are vehicles with two or more power sources in the drivetrain. There are many different types of hybrid vehicles, although only the gasoline-electric hybrid is currently commercially available.

Hybrids are classified by the division of power between sources; both sources may operate in parallel to simultaneously provide acceleration, or they may operate in series with one source exclusively providing the acceleration and the second being used to augment the first's power reserve. The sources can also be used in both series and parallel as needed, the vehicle being primarily driven by one source but the second capable of providing direct additional acceleration if required. Current hybrids use both an internal combustion (IC) engine and a battery/electric drive system (using ultracapacitors) to improve fuel consumption, emission, and performance. Electrically assisted pedal bicycles are a form of hybrid drive. Other combinations of energy storage and conversion are possible, although not yet in commercial production.

Combustion-electric hybrids have larger battery sets than what a normal combustion engine only vehicle would have. Battery and supercapacitor technology is advancing. A potential advantage is that when these battery sets require renewing in the future, the newer battery sets will be potentially superior having higher energy storage giving greater range enhancing a vehicle.

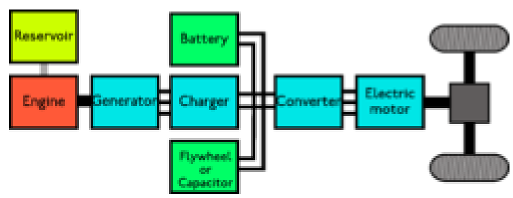
Automotive hybrid systems combine two power sources such as Internal Combustion engine (IC) and an electric motor. The most popular hybrid engine is where a gasoline engines teams up with an electric motor. Thus, a hybrid vehicle is a vehicle that uses two or more power sources to move the vehicle.

CHAPTER -2 TYPES OF HYBRID ENGINES

A. Series
B. Parallel

SERIES

***Series hybrids** have also been referred to as range-extended electric vehicles (REEV) where they are designed to be run mostly by the battery, but have a petrol or diesel generator to recharge the battery when going on a long drive. However, range extension can be accomplished with either series or parallel hybrid layouts. Alternatively, it can be viewed as an electric transmission, with the battery storing reserve power until it is needed.*



Structure of a series-hybrid vehicle. The grey square represents a differential gear. An alternative arrangement (not shown) is to have electric motors at two or four wheels.

Series-hybrid vehicles are driven only by electric traction. Unlike piston internal combustion engines, electric motors are efficient with exceptionally high power-to-weight ratios providing adequate torque over a wide speed range. Unlike combustion engines electric motors matched to the vehicle do not require a transmission between the engine and wheels shifting torque ratios. Transmissions add weight, bulk and sap power from the engine. Mechanical automatic shifting transmissions can be very complex. In a series-hybrid system, the combustion engine drives an electric generator instead of directly driving the wheels. The generator provides power for the driving electric motors. In short, a series-hybrid is simple, the vehicle is driven by electric motors with a generator set providing the electric power.

This arrangement is common in diesel-electric locomotives and ships. Ferdinand Porsche used this setup in the early 20th century in racing cars, effectively inventing the series-hybrid arrangement. Porsche named the system, System Mixt. A wheel hub motor arrangement, with a motor in each of the two front wheels was used, setting speed records. This arrangement was sometimes referred to as an electric transmission, as the electric *generator and driving motor replaced a mechanical transmission. The vehicle could not move unless the internal combustion engine was running. The setup was difficult for production cars being unable to synchronize the electric driving motors with the generator set power, resulting in higher fuel consumption. No longer an issue with modern computer engine management systems optimizing when the generator runs to match the power needed. Electric motors have become substantially smaller, lighter and efficient over the years. These advances have given the advantage to the electric transmission in normal operating conditions, over a conventional internal combustion engine and mechanical automatic transmission. One of the advantages is the smoother progressive ride with no stepped gear ratio changes.*

The electric transmission is currently viable in replacing the mechanical transmission. However, the modern series-hybrid vehicles takes the electric transmission to a higher plane adding greater value. There is a difference to an electric transmission. Modern series-hybrids contain:

- ***Electric traction only -*** *using only one or more electric motors to turn the wheels.*
- ***Combustion engine -*** *that turns only a generator.*
- ***A generator -*** *turned by the combustion engine to make up a generator set that also acts as an engine starter.*
- ***A battery bank -*** *which acts as an energy buffer.*
- ***Regenerative braking -*** *Driving motor becomes a generator and recovers potential and kinetic (inertial) energies through its conversion to electrical energy, a process which in turn is able to slow the vehicle and thus preventing wasteful transfer of this energy as thermal losses within the friction brakes.*
- *May be plugged into the electric mains system to recharge the battery bank.*
- *May have supercapacitors to assist the battery bank and claw back most energy from braking - only fitted in proven prototypes currently.*

The electric driving motor may run entirely fed by electricity from a large battery bank or via the generator turned by the internal combustion engine, or both. The battery bank may be charged by mains electricity reducing running costs as the range running under the electric motors only is extended. The vehicle conceptually resembles a Diesel-electric locomotive with the addition of large battery bank that may power the vehicle without the internal combustion engine running. The generator may simultaneously charge the battery bank and power the driving electric motor that moves the vehicle. The battery bank acts as an energy buffer. An advantage is that when the vehicle is stopped the combustion engine is switched off. When the *vehicle moves it does so using the energy in the batteries. This reduces kerbside emissions greatly in cities and towns. Vehicles at traffic lights, or in slow moving stop start traffic need not be polluting when stationary.*

In some arrangements when high levels of power are required, such as in vehicle acceleration, the electric driving motor draws electricity from both the batteries and the generator. With the Chevrolet Volt if the battery bank is depleted the vehicle may run entirely with electricity provided only from the generator. Some prototype vehicle designs such as the Volvo ReCharge and Ford F-Series pickup have electric motors in wheel hubs reducing the need for a differential saving weight, space and power being sapped by the differential. Series-hybrids can be also fitted with a supercapacitor or a flywheel to store regenerative braking energy, which can improve efficiency by clawing back energy that otherwise would be lost being dissipated via heat through the braking system.

Because a series-hybrid omits a mechanical link between the combustion engine and the wheels, the engine can be run at a constant and efficient rate even as the vehicle changes speed. The vehicle speed and engine speed are not necessarily in synchronization. The engine can thus maintain an efficiency closer to the theoretical limit of 37%, rather than the current average of 20%. At low or mixed speeds this could result in ~50% increase in overall efficiency (19% vs 29%). The Lotus company has introduced an engine/generator set design that runs at two speeds, giving 15 kW of electrical power at 1,500 rpm and 35 kW at 3,500 rpm via the integrated electrical generator.

As the requirements for the engine are not directly linked to vehicle speed, this gives greater scope for more efficient or alternative engine designs, such as a microturbine, rotary Atkinson cycle engine or a linear combustion engine.

General Motors in 1999 made the experimental EV1 series hybrid using a turbine generator set. The turbine weighed 220 lb (99.8 kg), measured 20 inches (50.8 cm) in diameter by 22 inches (55.9 cm) long and ran between 100,000 and 140,000 rpm. Fuel consumption was 60 mpg$_{\text{-US}}$ *(3.9 L/100 km; 72 mpg*$_{\text{-imp}}$*) to 100 mpg*$_{\text{-US}}$ *(2.4 L/100 km; 120 mpg*$_{\text{-imp}}$*) in hybrid mode. Depending on the driving conditions, a highway range of more than 390 miles (627.6 km) was achieved. The results were highly successful, and would have promised to be more successful if a smaller microturbine was used, yet the EV1 project was dropped.*

There are stages of operation: power from the combustion engine to the generator and then to the electric motor and, depending on the design, may *also run through the generator and into the battery pack then to the electric motor further reducing efficiency (see illustration). Each transformation through each stage results in a loss of energy. However in normal vehicle operating conditions the energy buffer of the battery bank, which stores clawed back energy from braking and the optimum running of the combustion engine may raise overall operating efficiency, despite each stage being an energy loss. The engine to mechanical automatic shifting transmission efficiency is approximately 70%-80%. A conventional mechanical clutch transmission has an engine to transmission efficiency of 98%. In a series-hybrid vehicle, during long-distance high speed highway driving, the combustion engine will need to supply the majority of the energy, in which case a series-hybrid may be 20%-30% less efficient than a parallel hybrid.*

The use of a motor driving a wheel directly eliminates the conventional mechanical transmission elements: gearbox, transmission shafts and differential, and can sometimes eliminate flexible couplings. This offers great simplicity. If the motors are integrated into the wheels a disadvantage is that the unsprang mass increases and suspension responsiveness decreases which impacts ride performance and potentially safety. However the impact should be minimal if at all as electric motors in wheel hubs such as Hi-Pa Drive, may be very small and light having exceptionally high power-to-weight ratios. The braking mechanisms can be lighter as the wheel motors brake the vehicle. Light aluminum wheels may be used reducing the unsprung mass of the wheel assembly. Vehicle designs may be optimized to lower the center of gravity having the heavy mechanics and battery banks at floor level. If the motors are attached to the vehicle body, flexible couplings are still required. Advantages of individual wheel motors include simplified traction control and all-wheel drive if required, allowing lower floors, which is useful for buses. Some 8x8 all-wheel drive military vehicles use individual wheel motors. Diesel-electric locomotives have used this concept (albeit with the individual motors driving axles connecting pairs of wheels) for 70 years.

In a typical road vehicle the whole series-hybrid power-transmission setup may be smaller and lighter than the equivalent conventional mechanical power-transmission setup which liberates space. As the combustion generator set only requires cables to the driving electric motors, there is greater flexibility in major component layout spread across the vehicle giving superior weight distribution and maximizing vehicle cabin space. This flexibility may lead to superior vehicle designs.

In 1997 Toyota released the first series-hybrid bus sold in Japan. Designline International of Ashburton, New Zealand produces city buses with a microturbine powered series-hybrid system. Supercapacitors combined with *a lithium ion battery bank have been used by AFS Trinity in a converted Saturn Vue SUV vehicle. Using supercapacitors they claim up to 150 mpg in a series-hybrid arrangement.*

Advantages of Series Hybrid

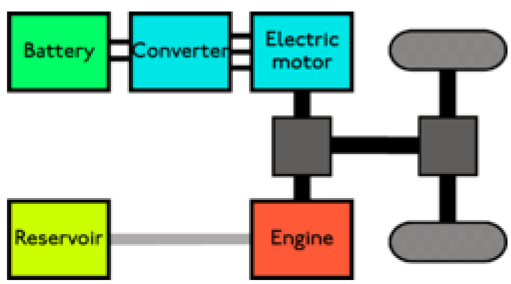
- *The engine never idles which reduces vehicle emissions.*
- *The engine can continuously operate in its most efficient region.*
- *It offers regenerative braking to capture the braking energy and store it in a battery.*
- *Lack of mechanical link between Internal Combustion Engine (ICE) and the wheels which reduces friction.*

Disadvantages of Series Hybrid

- *Requires large and heavier battery pack*
- *Requires separate motor and generator portions.*

PARALLEL

Parallel hybrid *systems, which are most commonly produced at present, have both an internal combustion engine (ICE) and an electric motor coupled. If they are joined at an axis in parallel, the speeds at this axis must be identical and the supplied torques adds together. Most electric bicycles are of this type. When only one of the two sources is being used, the other must either also rotate in an idling manner, be connected by a one-way clutch, or freewheel. With cars, the two sources are usually connected through a differential gear. Thus the torques supplied must be the same and the speeds add up, the exact ratio depending on the differential characteristics. When only one of the two sources is being used, the other must still supply a large part of the torque or be fitted with a reverse one-way clutch or automatic clamp.*



Structure of a parallel hybrid electric vehicle. The gray squares represent differential gears.

An alternative parallel hybrid layout is the 'through the road' type. Here a conventional drivetrain powers one axle, with an electric motor or motors driving the other. The batteries can be recharged through regenerative braking, or by loading the electrically driven wheels during cruise. Power is thus transferred from the engine to the batteries through the road surface. This layout also has the advantage of providing four-wheel-drive in some conditions.

Parallel hybrids can be further categorized depending upon how balanced the different portions are at providing motive power. In some cases, the combustion engine is dominant (the electric motor turns on only when a boost is needed) and vice versa. Others can run with just the electric system operating. But because current parallel hybrids are unable to provide all-electric (ICE=OFF) propulsion, they are often categorized as ***mild hybrids*** *(see below).*

Because parallel hybrids can use a smaller battery pack as they rely more on regenerative braking and the internal combustion engine can also act as a generator for supplemental recharging, they are more efficient on highway driving compared to urban stop-and-go conditions or city driving. Honda's Insight, Civic, and Accord hybrids are examples of production parallel hybrids.[2] General Motors Parallel Hybrid Truck (PHT) and BAS Hybrids such as the Saturn VUE and Aura Green line and Chevrolet Malibu hybrids are also considered as utilizing a parallel architecture.

Advantages of Parallel Hybrid

- *It has a smaller engine which provide more efficient operation*
- *The vehicle has more power because both motor and Internal Combustion Engine are involved.*

SERIES/PARALLEL SYTEMS

In order to achieve the highest efficiency level, this system is employed. This system only uses an electric motor or driving power from both the electric motor and the engine.

CHAPTER-3 HYBRIDIZATION

TYPES OF HYBRIDIZATION

- A. *Full hybrid*
- B. *Mild hybrid*
- C. *Plug-in hybrid.*

FULL HYBRID

*A **full hybrid**, sometimes also called a **strong hybrid**, is a vehicle that can run on just the engine, just the batteries, or a combination of both. The Toyota Prius, Toyota Camry Hybrid, Ford Escape Hybrid/Mercury Mariner Hybrid, Ford Fusion Hybrid/Mercury Milan Hybrid, Kia Optima Hybrid, as well as the General Motors 2-mode hybrid trucks and SUVs, are examples of this type of hybridization as they are able to be propelled on battery power alone. A large, high-capacity battery pack is needed for battery-only operation. These vehicles have a split power path that allows more flexibility in the drivetrain by inter-converting mechanical and electrical power, at some cost in complexity. To balance the forces from each portion, the vehicles use a differential-style linkage between the engine and motor connected to the head end of the transmission.*

Mercury Mariner Hybrid Engine compartment of a 2006

The Toyota brand name for this technology is Hybrid Synergy Drive, which is being used in the Prius, the Highlander Hybrid SUV, and the Camry Hybrid. A computer oversees operation of the entire system, determining which half should be running, or if both should be in use. The operation of the Prius can be divided into six distinct regimes.

***Electric vehicle mode**: The engine is off, and the battery provides electrical energy to power the motor (or the reverse when*

regenerative braking is engaged). Used for idling as well when the battery State Of Charge (SOC) is high.
Cruise mode*: The vehicle is cruising (i.e. not accelerating), and the engine can meet the road load demand. The power from the engine is split between the mechanical path and the generator. The battery provides electrical energy to power the motor, whose power is summed mechanically with the engine. If the battery state-of-charge is low, part of the power from the generator is directed towards charging the battery.*
Overdrive mode*: A portion of the rotational energy is siphoned off by the main electric motor, operating as a generator, to produce electricity. This electrical energy is used to drive the sun gear in the direction opposite its usual rotation. The end result has the ring gear rotating faster than the engine, albeit at lower torque.*
Battery charge mode*: Also used for idling, except that in this case the battery state-of-charge is low and requires charging, which is provided by the engine and generator.*
Power boost mode*: Employed in situations where the engine cannot meet the road load demand. The battery is then used to power the motor to provide a boost to the engine power.*
Negative split mode*: The vehicle is cruising and the battery state-of-charge is high. The battery provides power to both the motor (to provide mechanical power) and to the generator. The generator converts this to mechanical energy that it directs towards the engine shaft, slowing it down (although not altering its torque output). The purpose of this engine "lugging" is to increase the fuel economy of the vehicle.*

The hybrid drivetrain of the Prius, in combination with aerodynamics and optimizations in the engine itself to reduce drag, results in 80%–100% gains in fuel economy compared to four-door conventional cars of similar weight and size.

MILD HYBRID

***Mild hybrids** are essentially conventional vehicles with some degree of hybrid hardware, but with limited hybrid feature utilization. Typically they are a parallel system with start-stop only or possibly in combination with modest levels of engine assist or regenerative braking features. Unlike full hybrids, **Mild hybrids** generally cannot provide ICE-OFF all-electric (EV) propulsion.*

Engine compartment of a 2006 GMC Sierra Hybrid.

Mild hybrids *like the General Motors 2004-07 Parallel Hybrid Truck (PHT) and the Honda Eco-Assist hybrids are equipped with a 3-phase electric motor motor mounted within the bell-housing between the engine and transmission, allowing the engine to be turned off whenever the truck is coasting, braking, or stopped, yet restart quickly when required. Accessories can continue to run on electrical power while the engine is off, and as in other hybrid designs, the motor is used for regenerative braking to recapture energy. The large electric motor is used to spin up the engine to operating rpm speeds before injecting any fuel.*

The 2004-07 Chevrolet Silverado PHT was a full-size pickup truck. Chevrolet was able to get a 10% improvement on the Silverado's fuel efficiency by shutting down and restarting the engine on demand and using regenerative braking. However the electrical motor was not used to provide propulsion or assist, rather the electrical energy was used to drive accessories like the A/C and power steering. The GM PHT used a 42 volt systems via a pack comprised three 12V vented lead acid batteries connected in series (36V total) to supply the power needed for the startup motor, as well as to compensate for the increasing number of electronic accessories on modern vehicles.

General Motors followed the parallel hybrid truck with their BAS Hybrid system, another mild hybrid implementation officially released on the 2007 Saturn Vue Green Line. For its "start-stop" functionality, it operates similarly to the system in the Silverado, although via a belted connection to the motor/generator unit. However the GM BAS Hybrid systems has broader hybrid functionality as the electric motor can also provide modest assist under acceleration and during steady driving, and captures energy during regenerative (blended) braking. The BAS Hybrid can result in as much as a 27% improvement in combined fuel efficiency as noted by the EPA in testing *of the 2009 Saturn VUE. The BAS Hybrid system can also be found on the 2008-09 Saturn Aura and the 2008-2010 Chevrolet Malibu hybrids.*

Another way to provide for shutting off a car's engine when it is stopped, then immediately restarting it when it's time to go, is by employing a static start engine. Such an engine requires no starter motor, but employs sensors to determine the exact position of each piston, then precisely timing the injection and ignition of fuel to turn over the engine.

Mild hybrids are sometimes called Power assist hybrids' as they use the engine for primary power, with a torque-boosting electric motor also connected to a largely conventional power train. The electric motor, mounted between the engine and transmission, is essentially a very large starter motor, which operates not only when the engine needs to be turned over, but also when the driver "steps on the gas" and requires extra power. The electric motor may also be used to re-start the combustion engine, deriving the same benefits from shutting down the main engine at idle, while the enhanced battery system is used to power accessories. GM is going to produce Buick LaCrosse and [Buick Regal] mild hybrids dubbed Eassist.

Honda's hybrids including the Insight use this design, leveraging their reputation for design of small, efficient gasoline engines; their system is dubbed Integrated Motor Assist (IMA). Assist hybrids differ fundamentally from full hybrids in that propulsion cannot be accomplished on electric power alone. However, since the amount of electrical power needed is much smaller, the size of the system is reduced.

A variation on this type of hybrid is the Saturn Vue Green Line BAS Hybrid system that uses a smaller electric motor (mounted to the side of the engine), and battery pack than the Honda IMA, but functions similarly.

Another variation on this type is Mazda's e-4WD system, offered on the Mazda Demio sold in Japan. This front-wheel drive vehicle has an electric motor which can drive the rear wheels when extra traction is needed. The system is entirely disengaged in all other driving conditions, so it does not directly enhance performance or economy but allows the use of a smaller and more economical engine relative to total performance.

Ford has dubbed Honda's hybrids "mild" in their advertising for the Escape Hybrid, arguing that the Escape's full hybrid design is more efficient.

PLUG-IN HYBRID

*A plug-in hybrid electric vehicle (**PHEV**) has two defining characteristics: 1) it can be plugged in to an electrical outlet to be charged and (2) has some range that can be traveled on the energy it stored while plugged in. They are full hybrid, able to run in electric-only mode, with larger batteries and the ability to recharge from the electric power grid. And can be parallel or series hybrid designs. They are also called **gas-optional**, or **griddable hybrids**. Their main benefit is that they can be gasoline-independent for daily commuting, but also have the extended range of a hybrid for long trips. They can also be multi-fuel, with the electric power supplemented by diesel, biodiesel, or hydrogen. The Electric Power Research Institute's research indicates a lower total cost of ownership for PHEVs due to reduced service costs and gradually improving batteries. The "well-to-wheel" efficiency and emissions of PHEVs compared to gasoline hybrids depends on the energy sources of the grid (the US grid is 50% coal; California's grid is primarily natural gas, hydroelectric power, and wind power). Particular interest in PHEVs is in California*

Engine compartment of a BYD F3DM plug-in hybrid.

where a "million solar homes" initiative is under way, and global warming legislation has been enacted.

Prototypes of PHEVs, with larger battery packs that can be recharged from the power grid, have been built in the U.S., notably at Prof. Andy Frank's Hybrid Center[19] at University of California, Davis and one production PHEV, the Renault Kangoo, went on sale in France in 2003. DaimlerChrysler is currently building PHEVs based on the Mercedes-Benz Sprinter van. Light Trucks are also offered by Micro-Vett SPA the so called Daily Bimodale.

The California Cars Initiative has converted the '04 and newer Toyota Prius to become a prototype of what it calls the PRIUS+. With the addition of

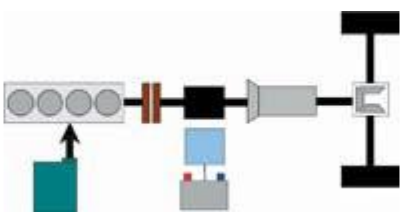
140 kg (300 lb) of lead-acid batteries, the PRIUS+ achieves roughly double the gasoline mileage of a standard Prius and can make trips of up to 16 km (10 mi) miles using only electric power.

Chinese battery manufacturer and automaker BYD Auto released the F3DM PHEV-62 (PHEV-100 km) compact sedan to the Chinese fleet market on December 15, 2008.[22][23] General Motors expects to launch the 2011 Chevrolet Volt series plug-in (PHEV-40) by November 2010.

CHAPTER-4 HYBRID TECHNOLOGY

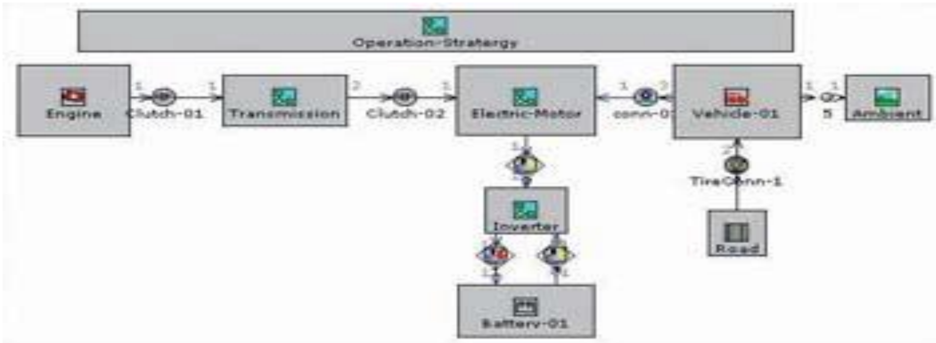
Optimization of Hybrid Concepts through Simulation

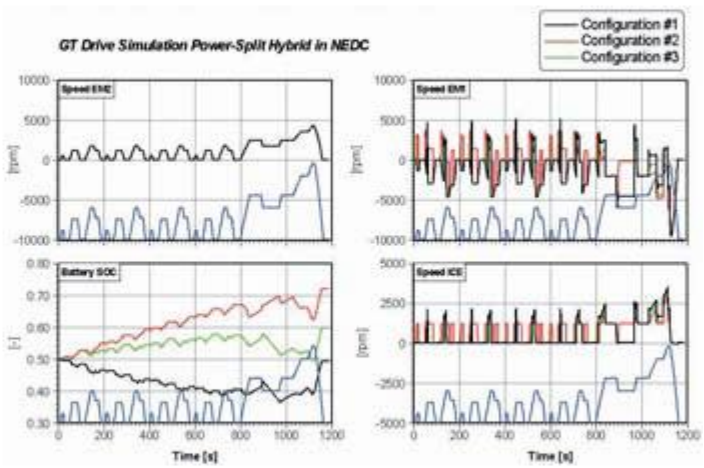
FEV's simulation models of various hybrid power train configurations provide a detailed analysis of the interaction between power train components and improve the understanding of engine and component characteristics.



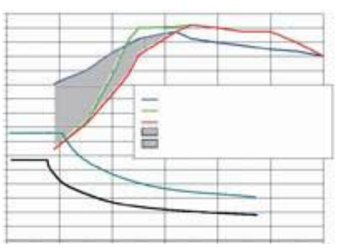
Simulation Work

- *All relevant software codes available (Matlab-Simulink, GT-Drive)*
- *Models available for*
    - *Parallel, series, and power-split*
    - *Hybrid-relevant components*
    - *Hybrid operation strategies*
- *Flexible boundary conditions (e.g. vehicle class, market segment, ICE type, hybrid concept and driving profile)*
- *Correlation with vehicle measurements*
- *Correlation with benchmark data (FEV database)*





Combustion Engines in Hybrid Drivetrains



The various hybrid powertrain structures use different strategies to optimize powertrain behavior. Therefore, the demands placed on the internal combustion engine differ, depending on the type of hybrid system that is selected. For example, in vehicles that use a parallel hybrid layout, the engine should be optimized for a large part of its operating area to exploit the full potential of the hybrid technology. Vehicles that utilize power-split hybrid designs should

Diesel Hybrid

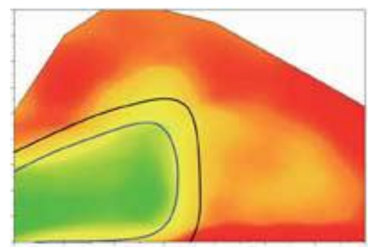
- *Diesel hybrid engines usually operate within map areas with low BSFC and low exhaust emissions.*
- *The overall optimization of diesel hybrid power trains is strongly dependent on the exhaust gas after treatment concept that is selected.*

- *A well-tuned compromise between fuel consumption and NOx emissions must be found.*

Gasoline Hybrid

- *Simplification of the combustion engine (e.g. Miller/Atkinson cycle)*
- *Hybrids offer opportunity for downsizing without the drawbacks of insufficient low-end torque because electric machines are capable of providing high peak torque at low speeds.*
- *Combining hybrid with lean-burn combustion technology can also be advantageous.*

FEV's experience enables the following hybrid concept development:



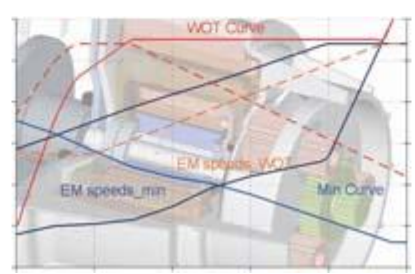
- *Evaluation of IC engine configurations such as naturally aspirated turbocharged and spark ignition diesel versus hybrid power train concepts such as parallel, series and power-split*
- *Monodirectional optimization for fuel economy or multidimensional optimization for areas such as FE, emissions and NVH*
- *Realization of prototype and production power trains*

Hybrid Transmission Concepts

Optimum hybrid transmission concepts can be determined during the concept phase, with state-of-the-art CAE technologies. Optimum total system layout can also be achieved applying these technologies.

Development of the concept, building of prototypes and production development continues up to Start Of Production (SOP).

3 Examples of Transmission Concepts can be described as follows:



Hybrid AT Concept (SUV)

- *Carry over 6-speed auto. transmission*
- *Replace conventional converter by electric converters*
- *Full hybrid functionality:*

- *Performance improved by 30%*
- *Fuel economy improved by 20%*
- *Premium NVH*
- *Same package as base transmission*
- *Modular low cost system*

Hybrid Belt-CVT/DCT

- *Carry over base transmission*
- *Additional gearset, E-Motor and clutches*
- *Simplify base transmissions, such as the DNR set*
- *Full hybrid functionality:*
  - *Excellent performance*
  - *Excellent shift quality*
  - *Increased packaging*
  - *Modular low cost system*

Multi-Shaft E-CVT Transmissions
(Midsize Vehicle)

- *Reducing transmission complexity at the cost of required electric motor power*
- *System strongly dependent on vehicle type*
- *Full hybrid functionality:*
  - *Performance improved up to 25%*
  - *Fuel economy improved up to 25%*
  - *Premium NVH*
  - *Tectonic functionality possible*
  - *High-volume applications*

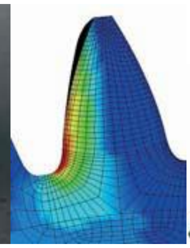
Transmission Support

- *Layout of transmission ratios*
- *NVH refinement of internal and external excitations as well as structural dynamics*
- *Hydraulic system layout of components such as clutches and the electric oil pump*
- *Mode changes and clutch shifts in combination with electric motors*
- *Software development for shift sequencing*
- *Parameter excitation of gears (whining)*

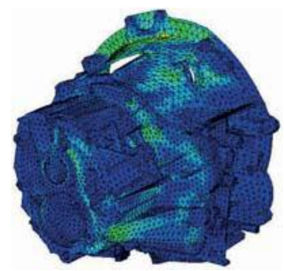
Hybrid Power train Mechanics

FEV offers a development solution which stretches from the design concept phase to SOP. During all development stages, FEV utilizes state-of-the-art CAE tools to calculate and optimize the durability and NVH of hybrid power train components. FEV, in partial cooperation with its partners, provides extensive testing of prototype power trains for function, durability, NVH and benchmarking.



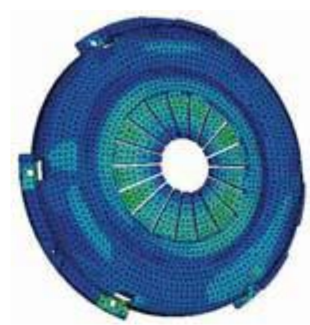



Mechanical Testing



- *Temperatures (thermocouples, infra-red)*
- *Deformation and transmitted forces / torques (strain gauges and telemetry)*
- *Movement and gear wobbling (Eddy-current)*
- *Rotation, rotation speed and rotational irregularities*
- *E-motor/-generator measurements (torque, efficiency and power consumption)*

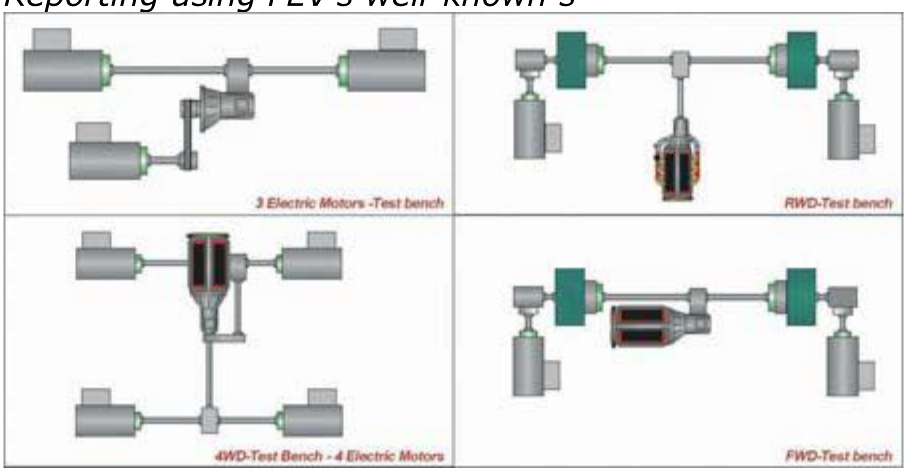
CAE Support



- *Planetary gear layout (profile and micro geometry)*
- *In-depth tolerance analysis*
- *Durability calculation of gears (planetary gear set)*
- *NVH calculation and optimization*
- *Durability calculation for shafts, housing and bearings*
- *Optimization loops, such as topology opt.*
- *Model validation using test results*
- *Parameter excitation of gears (whining)*

Benchmarking

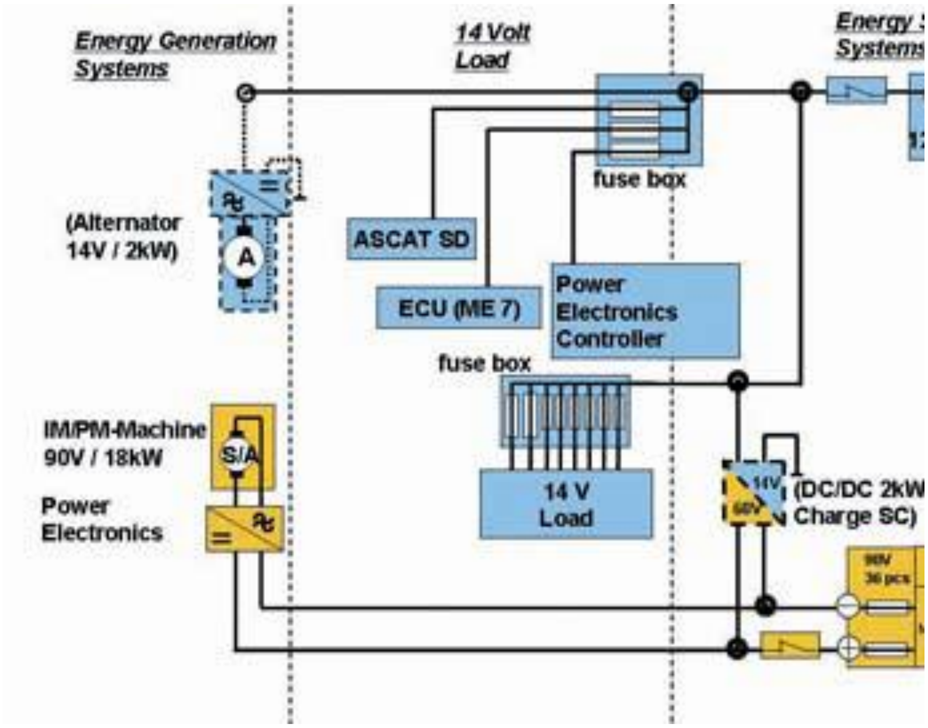
- *Benchmarking of hybrid power train systems including comparisons to conventional power trains, if requested*
- *Reporting using FEV's well-known s*



High-Voltage Systems, Wiring Harness and Safety

Increasing electrical power in vehicles introduced powerful high-voltage systems consisting of high-voltage components, related wiring harnesses and dedicated safety concepts.

FEV turns your plans of successfully integrating high-voltage systems into reality.



Engineering Services

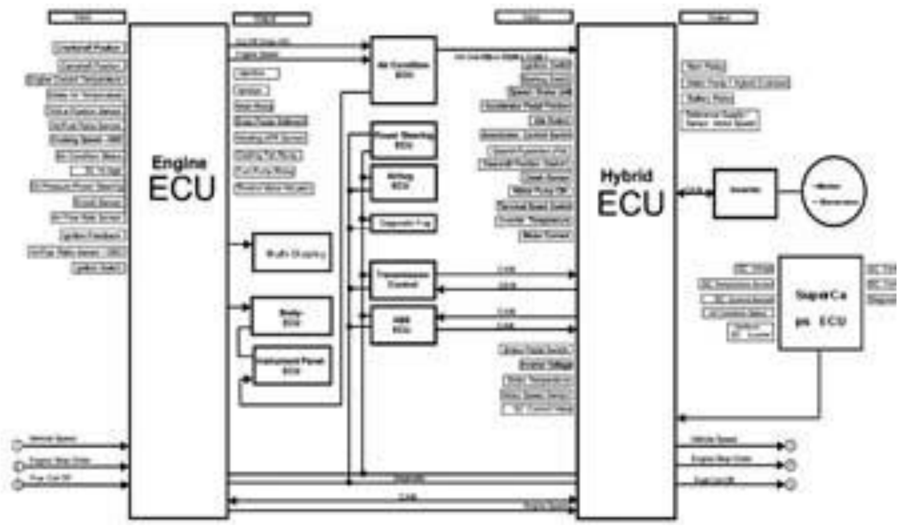
- *Design of high-voltage power supply systems*
- *Simulation of energy distribution in the vehicle*
- *Interfacing with inverter units*
- *Interfacing with battery management units*
- *Interfacing with DC/DC converters*
- *Layout of wiring harnesses*
- *Integration of relays and fuses*
- *Layout of safety system measures such as:*
    - *Pole switches*
    - *Mechanical master switch*
    - *Contacted connectors*
    - *Component housing contacts*
    - *Shielded/high-voltage cables*
    - *Grounding concept*
    - *Insulation specifications*

The introduction of high voltage systems must take into account:

- *Legislative requirements with respect to EMC/EMI and safety such as EN 61508*
- *Specifications (ISO, DIN, SAE and GB)*
- *Special technical problems like "arcing"*

Hybrid Control Unit and HiL Testing

Control of components must be optimized to achieve the full benefits of hybridization. The control structure is dependent on the existing topology. The Hybrid Control Unit (HCU) can be separate or can be integrated into existing control units like the Transmission Control Unit (TCU) or the Engine Control Unit (ECU).



Engineering Services

- *Controller topology specification (master/slave)*
- *Hybrid control unit hardware specification*
- *Hybrid control unit I/O*
- *Interface protocols*
- *System diagnosis*
- *Fail-safe concept*
- *EOL testing*

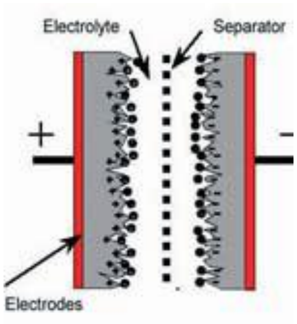
Hardware in the Loop (HiL) Testing

- *Controller topology specification (master/slave)*
- *Hybrid control unit hardware test*
- *Hybrid control unit interactions*
- *Hybrid function frame verification*
- *Automated testing for 24/7 operation*

HCU Software Development

- *Rapid prototyping*
- *Auto-code generation*
- *Torque arbitration*
- *Hybrid specific (start/stop, boost, brake energy recovery, SOC management and power split operating modes)*

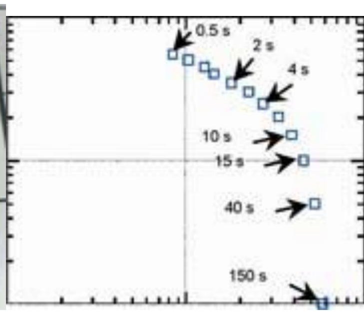
- *Transmission functions development driving strategy and gear selection)*
- *Safety functions*



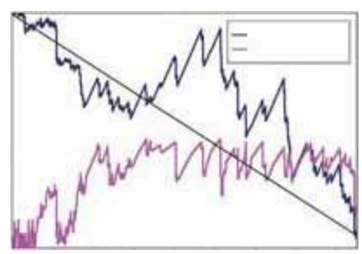
Batteries

One of the key components of the electric hybrid system is the battery. Besides the mature lead acid technology for low power applications, the de facto standard for passenger cars in today's production applications is the NiMH technology. Since the lifetime of these batteries is closely related to the State of Charge (SOC) strategy, overall optimization is mandatory.

New emerging technologies, like Li-Ion, are expected to improve system capabilities within the next few years.

Electrochemical Impedance Spectroscopy (EIS)



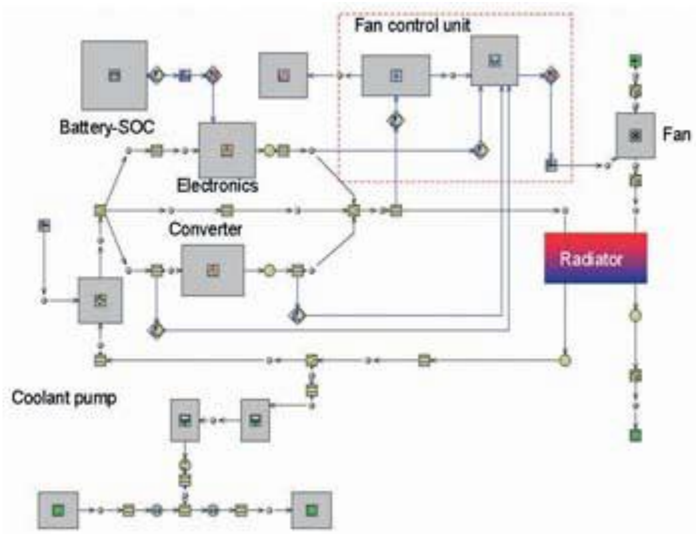
- *Measurement of the complex impedance*
- *Galvanostatic measurement*
- *Frequency range: 10 kHz - 1µHz*
- *High precision, even for the lowest frequencies and long time stability*

Cooling System Layout

FEV has developed a 1D calculation approach to determine a favorable layout of the cooling system and to define system component requirements. This tool allows vehicle simulation in any driving cycle. The tool also allows the calculation of coolant temperatures and flow rates within the cooling systems of the electronics and in the engine, which is dependent on the actual operating status of the vehicle.

Engineering Services

- *Pre-design: Definition of the system topography*
- *Detailing: Definition of required component characteristics*
- *Basic system calculation and assessment*
- *System control strategy optimization*
- *Optimized system:*
    - *Lowest electrical power demand*
- *Future development:*
    - *Fuel consumption reduction and vehicle climate testing*



The model includes:

- *Combustion engine cooling system*
- *Engine internal friction losses*
- *Combustion engine thermal behavior*
- *Transmission ratio and efficiencies*
- *Engine independent heater applications including power demand*
- *Parasitic losses (such as fan and generator)*
- *Electric drive system including battery SOC*
- *Heat rejection from the electronic components*
- *Vehicle driving cycle*
- *Ambient conditions*
- *Vehicle interior heating performance*

Hybrid Powertrain Design and Integration

FEV offers full design support in hybrid powertrain development from concept to start- of-production. A common design process has been established. The process is characterized by a clear structure that is derived from the well-known Design for Six Sigma methodology.

The motivated design team is highly experienced and fully integrated into the overall development process.

The primary design tasks for developing a hybrid powertrain are the packaging of the various subsystems and the layout and detail design of the hybrid transmission, which is the heart of hybrid powertrain system. FEV also provides the complete production design documentation and engineering support to the component and system suppliers.

Design Services

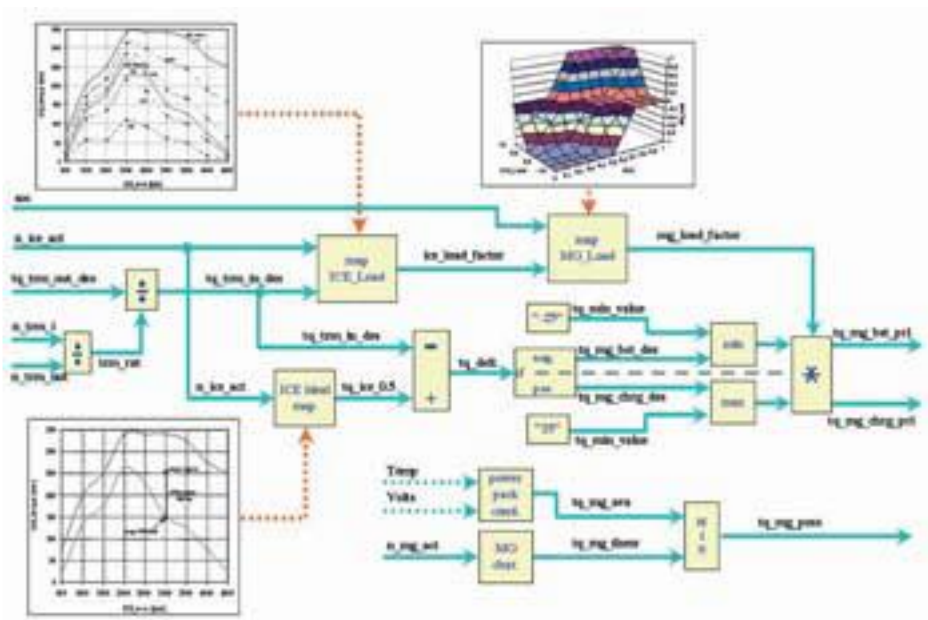
- *Design of power train components*
    - *Concept development and layout*
    - *Base engine and accessory adaptation*
    - *Transmission*
    - *Transfer case*
    - *Driveshaft*
- *Vehicle integration*
    - *Packaging of powertrain components*
    - *Packaging of electrical components*
    - *Packaging of control system*
    - *High-voltage cable routing*
    - *Body modification for prototypes*
    - *Prototype procurement and build*
    - *Production design documentation*

Hybrid Power train Calibration

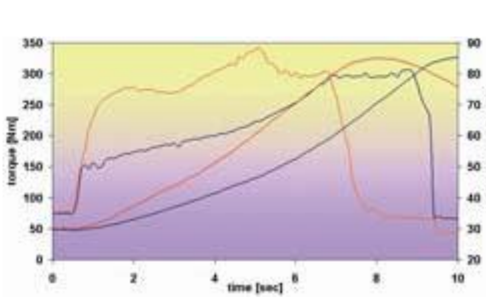
Control unit architecture and functions of a hybrid electric vehicle are highly complex and thus a challenge for calibration. Advanced tools and strategies are required for system optimization:

Engineering Services

- *Rapid prototyping, HiL and SiL for function development of hybrid controller*
- *Offline and online tools for automatic calibration vehicle functions*
- *Hybrid measurement techniques, including electric machine power, out-of-phase currents and transmission shaft torque with infrared telemetry systems*

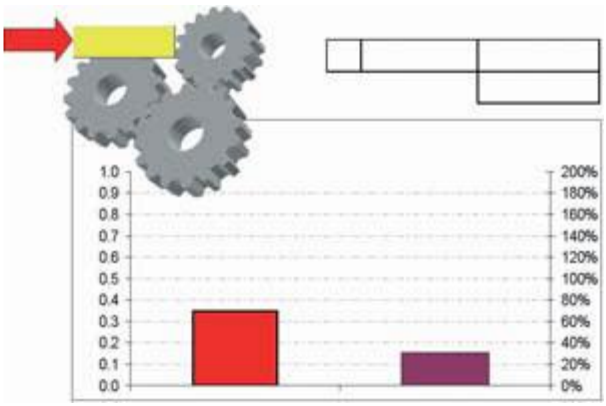


Calibration focuses on electric boost and generation with an optimum state-of-charge, start/stop and gear selection.



Objective determination of shift and overall transmission quality using tools such as:

- *FEVos processing vehicle compartment acceleration sensor data*
- *FEV Shift Analyser*



Cost/Benefit Considerations of Hybrid Systems

The chart compares different hybrid systems. In general, start/stop functions can be provided with today's vehicle net voltage level, significant electric power assist, however, will require future systems with 42 or even higher voltage levels. While lead / acid based batteries might still be used for 14 V ISG functions, Nickel/Metal-Hydrid (NiMH) batteries will be necessary in ISG's with power assist functions, due to their much higher cycle life expectations.

HYBRIDS	ISG	ISG Hybrid	Mild Hybrid	Full Hybrid
	Start / Stop	Start / Stop Regeneration AER < 1 mi	Start / Stop Regeneration Power Assist	Start / Stop Regeneration Power Assist AER > 1 mi
IC-Engine	Conventional	Conventional	Downsized	Downsized
Electric Motor	Beltdrive	Belt/Crankdrive	Crankdrive	Crankdrive/ Power Split
Electric Power	2 - 4 kW	4 - 10 kW	10 - 20 kW	15 - 50 kW
Voltage	14 V	42 V	> 42 V	> 100 V
Main Battery	Pb/A 25 kg	NiMH 25 kg	NiMH/ Supercap 25 kg	NiMH/Li-Ion 40 kg
Fuel Economy Improv. (NEDC)	3 - 7 %	6 - 10 %	15 - 25 %	20 - 30 %
Add. Costs	200 - 500 €	500 - 900 €	900 - 2.200 €	2.500 - 5.000 €

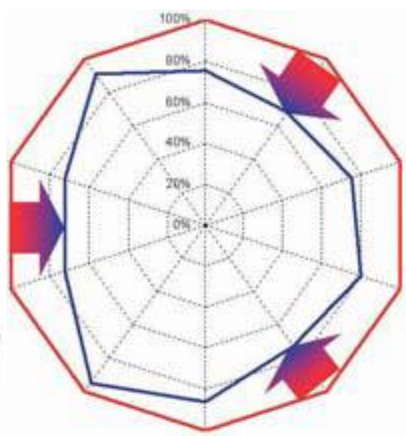
In general, the introduction of hybrid systems will depend on the one side to a large extend on the progress in the development of new batteries which can tolerate frequent and fast load changes. New electrolytic double layer capacitors or supercapacitors promise to deliver an extremely high power density with almost unlimited cycle life. A major drawback is their poor *energy density when compared to electrochemical batteries. For this reason, supercapacitors are expected to become key elements first of all for power assist concepts, where short term support is delivered by the electrical assist avoiding the burden of heavy batteries.*

On the other side, the additional production costs of the electrical components will strongly dictate the market introduction time schedule of hybrids together with the availability of 42 V net technology in cars.

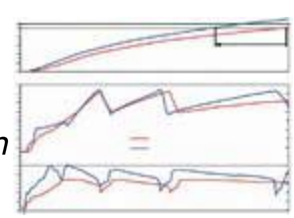
FEV Electric Hybrid Vehicles

Mature simulation methods and virtual system synthesis allow for the optimization of designs that are close to final production. Verification of project targets require a demonstration vehicle to provide a final proof of the results.

FEV has built several demonstration vehicles, such as a conversion of a base vehicle to a hybrid demonstrator vehicle. The logistics and organization of prototype / pre-pilot production vehicles is also a part of FEV's portfolio.



Engineering Services Offered for Hybrid Vehicles:



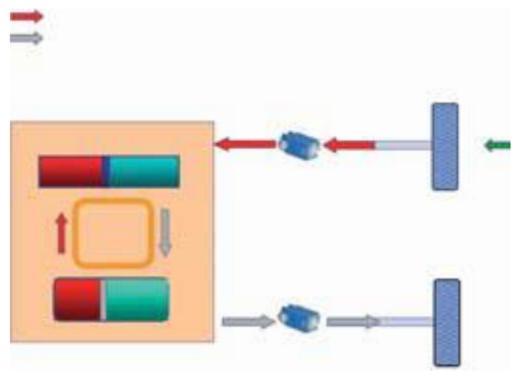
- *Hybrid system integration of all hybrid concepts, such as parallel, input and compound split*
- *Hybrid vehicle equipment adaptation for A/C, electrical steering and brake systems*
- *Safety concept implementation*
- *Start / Stop operation*
- *Drivetrain calibration for driveability, fuel economy, emissions*

- *NVH Optimization*
-

FEV Hydraulic Hybrid Vehicles

FEV possesses a broad range of experience in the design and development of hydraulic hybrid powertrains and vehicle integration. This experience includes clean sheet design and fabrication of hydraulic systems, pumps, motors, and integrated drive units for complete turnkey vehicles, utilizing either parallel or series technology.

Among the advantages of hydraulic hybrids, compared to other technologies, is the very high kinetic energy obtained from braking recovery. The high regenerative efficiency, more than doubles that of other hybrid technologies, translates into significant fuel economy improvements.



- *Advantages*
  - *High power density- improved acceleration*
  - *High kinetic energy braking recovery (regeneration)*
  - *Known technologies*
  - *Significant fuel economy improvement*
- *Challenges*
  - *Weight*
  - *Cost*
  - *Packaging/NVH of passenger vehicle applications*

Industrialization of HEV production development projects

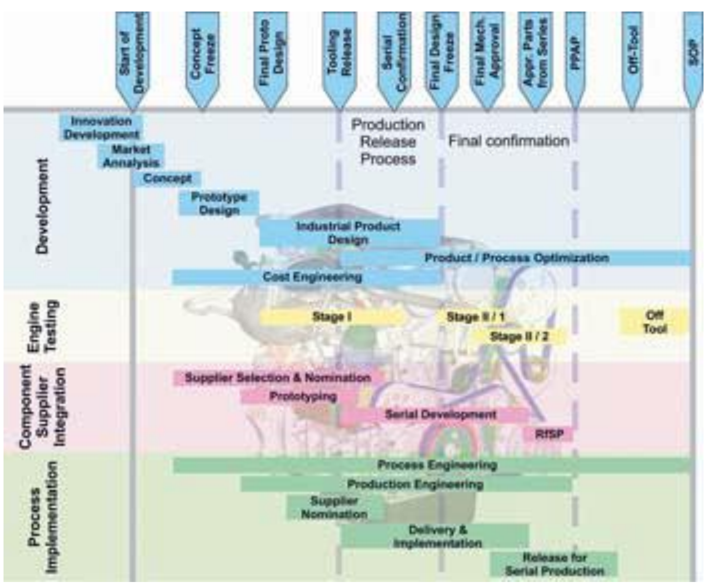
Project Management

In addition to a high level of technical skills, significant management skills are required to make the development of a production hybrid vehicle program a success. FEV has a broad range of experience in managing complex projects from concept phase up to the start of production and beyond. This includes *the key area of managing the "Launch-Phase", which includes pilot, pre-production, SOP and ramp-up.*

Key FEV Competences

- *Overall project management*
- *Detailed vehicle, subsystem and component technical specifications*
- *Support of supplier selection*
- *Handling and management of suppliers and engineering partners*
- *Prototype, tooling and production release of all components*
- *Launch management including handling of PPAP, quality assurance, logistics and manufacturing engineering*
- *Support after SOP*
- *Change management in production and model year programs*

Interdisciplinary Skills
The development of a hybrid vehicle encompasses almost all systems and subsystems of the vehicle. In addition to the vehicle's powertrain, areas such as crash testing, Body-in-White, exterior and interior are affected. In order to provide our customers with a turnkey project service, FEV has built up a network of experienced engineering partners and suppliers, which enable us to cover all development aspects on a hybrid vehicle.



Certification and Aftermarket Documentation

Certification

Prior to use on public roads, a vehicle has to undergo the certification process for the respective market. This is especially important for HEVs, *because of their additional weight and the potential usage of a high voltage electrical system. Special care must be taken, concerning their certification. Emission and fuel consumption legislation specific to hybrid vehicle applications is extremely important. In addition, changes to the vehicle such as additional battery weight or interior changes due to battery package might deteriorate certification-relevant criteria like the crash test performance and occupant safety. FEV offers certification support to the OEM that includes up to a full responsibility for vehicle certification, including coordination with government authorities for the relevant market requirements. Non-powertrain related subjects can be handled with the assistance of established engineering partners.*

CHAPTER-6 SYTEM OPERATIONS

- ***Start and low mid-range speed***

The engine stops in an efficient range, such as, at start-up and in low to mid-range speeds. The vehicle runs on the motor alone when the engine stops.

- ***Driving under normal conditions***

Engine power is divided by the power split device. Some of the power turns the generator, which in turn, drives the motor. The rest of the power drives the wheel directly. Power allocation is controlled to maximize efficiency.

- ***Sudden Acceleration***

Extra power is supplied from the battery, while the engine and high output motor provide smooth response for improved acceleration characteristics.

- ***Deceleration, Braking***

The high output motor acts as high-output generator, driven by the vehicle's wheel. The regenerative braking system recovers kinetic energy as electrical energy, which is stored in the high-performance battery.

- ***Battery charging***

Battery level is managed to maintain sufficient reserves. The engine drives the generator to recharge the battery when necessary.

- ***At rest***

The engine stops automatically.

Continuously Variable Transmission (CVT)

- *A new kind of automotive transmission.*
- *Recently begin appearing in most cars.*
- *No gear, friction plates, hydraulic fluids or torque.*
- *Uses a simple belt and pulley design.*

Regenerative Breaking

A regenerative breaking is an apparatus, a device or a system which allows a vehicle to recapture and store part of the kinetic energy during braking. The forward momentum and breaking of the vehicle are converted from mechanical energy to electrical energy and sent back to the battery for storage. Estimated Efficiency of a regenerative system is about 31.1%, Electric motor acts as a generator.

Hybrid Battery

Normal conventional vehicles use a lead acid battery to start the engine. Hybrid has Nickel metal-Hybrid batteries as well as lead acid batteries. Most of the recent hybrids have Lithium batteries which are more efficient and more durable.