COMPREHENSIVE OVERVIEW OF HYBRID VEHICLE DRIVETRAINS

Zelieus Namirian[1]

[1]Student, Mechanical Engineering, Mumbai University, India

Abstract: *The goal of this study is to promote a deeper understanding of the EMS, basics, along with hybrid drive trains by reviewing the current literature and defining the key research needs. The facets of optimization for powertrain and EMS operation within the research sector are extensive. This article outlines the vital keys for achieving optimal control strategies, highlighting gaps in expertise, and providing suggestions for future study. This study's contributions are as follows: First, an outline of EMS, power / drive train concepts, various sequences, Series, Parallel and Power split (series / parallel) topologies, and their system configuration is given alongside various vehicle modelling approaches. The remainder of this report is structured as a section that classifies hybridization types-mild/moderate, Descriptions of Full HEVs (FHEVs), Plug-in HEVs (PHEVs), and identifies the prospective prospects for potential research developments. Finally, a few closing thoughts.*

***Key Words*: EMS-Energy Management Systems, HEVs-Hybrid Vehicles, Drive Trains, Series Hybrids/Drivetrains, Parallel Hybrids/Drivetrains, Power Split Hybrids, Full Hybrids, Plug-in Hybrids.**

1. INTRODUCTION

Hybrid cars achieve decreased fuel consumption by adding both an energy storage system and a means of transforming the stored energy into mechanical motion in the drive train, in addition to an internal combustion (IC) motor. Such hybrids can also transform mechanical motion into renewable energy. The holding unit may be a pump, a flywheel, compressible fluid, elastomer, or ultra-capacitor in a more general sense. The way to transfer energy between storage and mechanical motion is by using one or more engines / generators (e.g., electrical, pneumatic, hydraulic). In motor mode, these devices convert stored energy into mechanical movement to drive the vehicle and in generator mode, these devices convert vehicle movement into stored energy by supplying part of the vehicle braking mechanism (regeneration). Likewise, a fuel cell car is also a hybrid in which the fuel cell replaces the internal combustion engine, but this design would also need extra energy storage to satisfy peak power demands and enable the fuel cell to be scaled to the typical power need.

In addition to adding an electric motor, hybrid designs that have idle-stop and regenerative braking features, and in their traditional counterpart model, the IC engine is also downsized from this. Hybrid vehicle architectures using an internal combustion engine are included in this review, and battery-energy storage. It also briefly addresses hybrid battery and fuel cell vehicles (BEVs and FCVs) as other alternative power trains.

1.1 POWER TRAIN, DRIVE TRAIN DEMARCATION

The powertrain or power plant in a motor vehicle contains the main components producing power and reallocating the electricity to the ground surface, water, or air. That in itself includes the engine, transmission, drive shafts, differentials, and final drive (driving wheels, seamless track as in defense tanks or caterpillar tractors, rudder, etc.). In a wider context, the powertrain comprises all the elements that are used to turn storage energy (chemical, electrical, nuclear, kinetic, future, etc.) into kinetic power for propulsion. This covers multi-power and non-wheel-based vehicle use.

Hybrid powertrains also include one or more electric traction engines which work to drive the wheels of the vehicle. All-powered vehicles ("electric cars"), depending entirely on electric motors for propulsion, remove the engine altogether.

The driveline or drivetrain of a motor vehicle is composed of the powertrain components except the engine.In fact it is the collection of components that supply power from the engine or motor of a vehicle to the wheels of the vehicle. The configuration of the drivetrain in hybrid-electric cars defines how the electric motor operates in tandem with the traditional engine. The drivetrain has an impact on the mechanical performance, fuel consumption, and purchase price of the vehicle. This is the part of a car that varies according to whether a car is front-wheel, rear-wheel, or four-wheel drive, or less-common six-wheel or eight-wheel drive, after the prime mover.

1.2 *POWER TRAIN DESIGN AND EMS (ENERGY MANAGEMENT SYSTEMS)*

The hybrid and electric vehicle powertrain configuration protocol covers various stages, while the present analysis focuses on the topology of the powertrain and the construction of an EMS (Energy Management System). With that in view, Fig. 1 is an example of a system-level design process for an energy-efficient powertrain.

First, a topology for the powertrain will be selected depending on a vehicle's expected transport allocation considering the trade-off between cost and performance. The second step, based on the chosen topology, is to decide the technology and measurements needed for the respective hybrid elements, including the energy storage system (e.g., battery, supercapacitor and/or fuel cell), electric motors, and DC-DC/DC-AC converters.

The objective function of the EMS optimization problem is usually combined with the selection of topology for the powertrain, while the equipment and size of components are viewed as constraints of optimization. EMSs should play a key role in designing sustainable cars for young generations. An EMS's key aim is to divide the input capacity by choosing optimum multi-motif outlets to meet moving demands. Therefore, an effective EMS can help to minimize fuel consumption by taking into account battery efficiency (i.e. current rate and lifetime) and tailpipe emissions.

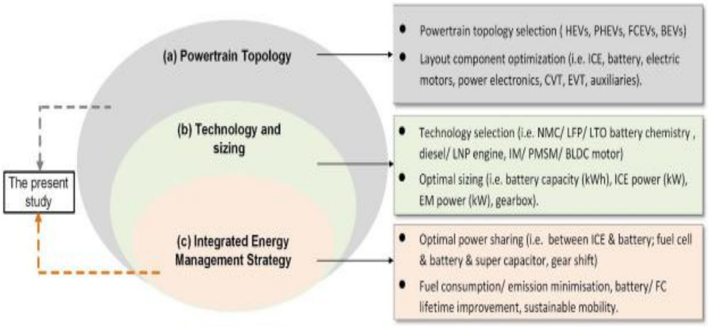

Fig. 1. System-level strategy used to accomplish an energy-efficient powertrain
Source- [1]

Due to the dynamic configuration of powertrain systems and unpredictable driving situations, designing a highly effective and flexible EMS is a daunting activity though. In fact, the EMS would provide a fairly simple and efficient real-time controller with a reasonable processing speed for a global optimisation algorithm to be applied.

There are abundant hybrid vehicles in fabrication, however, diesel hybridization (compression ignition; CI) vehicles are projected to offer much lower performance advantages than gasoline vehicle hybridization, in part because traditional CI vehicles also have lower fuel consumption than equivalent gasoline vehicles. Additionally, CI vehicles do have very low fuel consumption at idle, rendering idle-stop's advantages less desirable. Conventional CI power trains are more costly than their gasoline equivalent, which, when applied to the hybridization prices, makes a CI hybrid power train very costly with the extra savings in fuel consumption offered over and above either switching to a hybrid or CI power train alone. As a result, original equipment manufacturers (OEMs) will not be selling a wide variety of CI combinations. The most likely CI hybridization rates would be idle-stop, and maybe some moderate hybrids. Idle-stop does not include a substantial reduction in fuel consumption on the urban driving section of the FTP evaluation period, on which the conclusions in this study are based.[5]

2. HYBRID VEHICLE POWER TRAIN SYSTEM TOPOLOGIES

As already mentioned, Hybrid vehicle drive trains relay power for hybrid vehicles to the driving wheels. A hybrid vehicle has multiple motive forms:[4]

- By burning oil, a hybrid may receive its energy, but switch between an electric motor and a combustion engine.
- An internal combustion engine and batteries in diesel hybrid vehicles or ultra-capacitors.
- A power tank and fuel cell electric engine battery. Hybrid electric cars incorporate an ICE combined with a battery or supercapacitor that can recharge the batteries or fuel the engine.
- Other electric powertrains use energy-saving flywheels.
- Overhead electric lines and batteries in Trolley hybrid buses.(One of the first examples of hybrid land transportation is New Jersey's 'trackless' trolleybus trial, which lasted from 1935 to 1948 and normally used wired traction then. The trolleybus was built with an internal combustion engine (ICE) to control the mechanical drivetrain directly, and not to produce energy for the traction engine. This allowed the vehicle to be used for income service where touch wire was not available.

HEVs are therefore classified as providing an internal combustion engine and one or more electrical machines which can provide tractive force to propel the vehicle in any combination. An exception to this concept is the basic idle-stop configuration which does not have tractive force extracted from electricity. This section focuses on the core characteristics of the major powertrain topologies for PHEVs (Plug-in HEVs) / FEVs (Full Electric vehicles). First of all, it is important to understand the operating modes of a powertrain topology to devise an EMS optimization problem. Different powertrain topologies with different capacities may be configured by changing the drive source relation

A coupling may be either mechanical or electrical. **Based on the geometric arrangement of the drives, turbines, and engines, hybrid designs fall into three classes — parallel, linear, and mixed series / parallel (power-split), whereas the FEV powertrain encompasses of two types rendering/according to the main on-board energy source, either battery- or fuel-cell-based.**[3]

Broadly specified, the hybrid series uses the internal combustion engine primarily to drive a generator to charge the batteries and/or to power an electric drive motor. All tractive power is given by the electric motor. Energy flows to the motor from the IC engine through the generator and battery. For the parallel and mixed, series / parallel versions, the IC engine not only charges the battery but is also physically attached to the wheels, supplying tractive control together with the electric motor. Hybrid vehicles are further characterized by relative IC engine, tank, and motor sizes. Many of the more specific versions of these large groups are listed in the sections below. In both situations the power electronic circuitry used to regulate the electrical portion of the drive train is an economically and technically significant component of the device. [6]

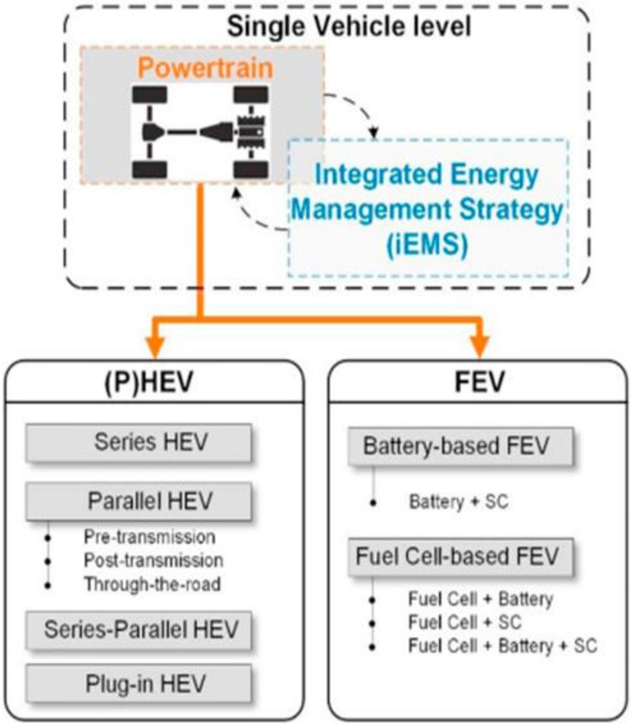

Fig. 2*-Classification of powertrain topologies for PHEVs and FEVs.*

2.1 TYPES BY DESIGN-

2.1.1. PARELLEL HYBRID

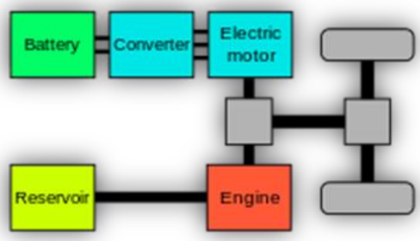

Fig. 3, Structure of a parallel electric hybrid vehicle orientation, the grey squares stand for differential gears

Parallel hybrid vehicles, or hybrids with parallel drive trains (Parallel HEVs), are fitted with both an internal combustion engine and an electric motor that can drive the car independently or both together (simultaneously) give power.

As of 2016 this is the most common hybrid system. For a parallel hybrid, the combustion engine and the electric motor are attached separately to the transmission, thus, the two inputs are usually applied to the same shaft, where they are attached at an axis (in parallel), the speeds (turning speeds) on that axis must be similar and the torques supplied must be transferred to the electric motor, adding or subtracting torque to the mechanism if required i.e. in parallel-HEV topology, the combined power is mechanical rather than electrical, in which the IC Engine (ICE) and the Electric motor (EM) are attached to a torque coupling such that their torque is coupled and then transferred to the wheels via a traditional driveshaft and probably a differential gear (see Figure 4).

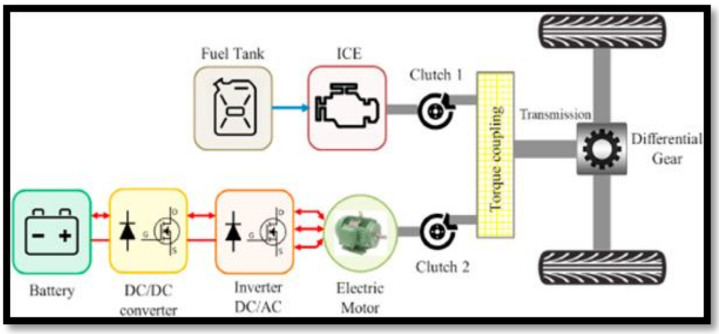

Fig. 4, ICE-based parallel-HEV configuration.

If either one of the two engines is in operation, the other will either spin (idle), and be connected by a one-way clutch or freewheel. The electric motor is designed to provide power during stop-and-go traffic when at highway speeds the car is driven entirely by the internal combustion engine. At acceleration the transmission is powered by both the electric motor and the combustion engine.

Since the motor in parallel drivetrains is attached directly to the wheels, the inefficiency of transferring mechanical power to electricity and back is avoided, thereby increasing the efficiency of such hybrids on the highway.To hold it recharged, parallel hybrids rely more on regenerative braking and the ICE can also serve as a secondary recharging engine.

In urban 'stop-and-go' conditions, that makes them more effective. They also prefer to use a smaller battery pack than other drivetrains and hybrids.

Owing mechanical relation the energy losses of the Parallel HEV are lower than those of the Series-HEV. The ICE used in a Parallel HEV is usually bigger, however, whereas the

Electric Motor is comparatively smaller and less powerful than the equivalent EM used in a Series-HEV.

Honda's early IMA-based Vision, Civic and Accord hybrids are examples of parallel hybrid production. General Motors Parallel Hybrid Truck (PHT) and BAS Hybrids such as the Saturn VUE and Aura Greenline and Chevrolet Malibu hybrids also engage parallel hybrid design. (Most bicycles of this type are electric).Parallel HEV powertrain systems can be loosely classified as post and pre-transmission systems as well.

THROUGH THE ROAD (TTR) HYBRID:

Another alternative configuration of a P-HEV is a through-road (TTR) HEV that incorporates two types of traction forces 'through the road' by adding ICE to the front wheels and EMs (typically in-wheel motors) to the rear wheels i.e. In this system, a traditional drivetrain powers one axle and an electric motor(s) driving another.

The first 'off road' trolleybuses used this arrangement. It provides an all-round backup power train in turn. Batteries can be recharged in new engines by regenerative braking or through cruising by charging the electrically driven wheels.

It makes a simplified Power Control approach. This configuration also has the bonus of having four-wheel-drive in some circumstances. (An example of this concept is a bike equipped with a front hub motor supporting the pedaling force of the rider at the rear wheel.)

Wagons of this kind include the concept cars Audi 100 Duo II and Subaru VIZIV, the vans Peugeot 3008 of PSA Group, Peugeot 508, 508 RXH, Citroen DS5 all use HYbrid4.

Parallel hybrids may be further classified by the equilibrium between the different motors: the ICE may be dominant (engaging the electric motor only under limited circumstances) or vice versa; while some can operate on the electrical grid alone, but since modern parallel hybrids are not capable of having electrical or internal combustion-only configurations, they are mostly categorized as mild hybrids (see sections ahead).

PARALLEL HEV OPERATION MODE:

Hybrid vehicles can be used in multiple ways. The figure indicates some common modes for a hybrid system on parallel.

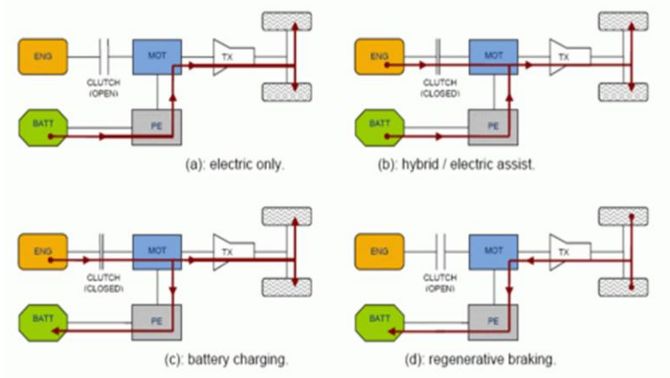

Fig. 5, Operation Modes of HEVs

2.1.2. SERIES HYBRID OR EXTENDED RANGE VEHICLES

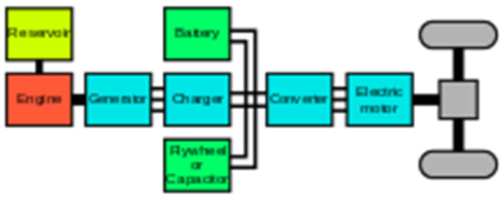

Fig. 6, Structure of a series-hybrid vehicle. The grey square represents a differential gear, orientation.

Since 1903 electric transmission is available as an alternative to traditional mechanical transmissions. Mechanical transmissions usually enforce multiple penalties, including weight, size, noise, expense, complexity and drain on engine power for each gear shift, whether manually or automatically. Unlike ICEs, electric motors do not require a transmission. Effectively, the entire mechanical connection between the ICE and the wheels is eliminated and replaced with an electrical engine, some cable and controls, and electronic traction motors, with the benefit that the ICE is no longer directly connected to the application. These Hybrids are series hybrids.

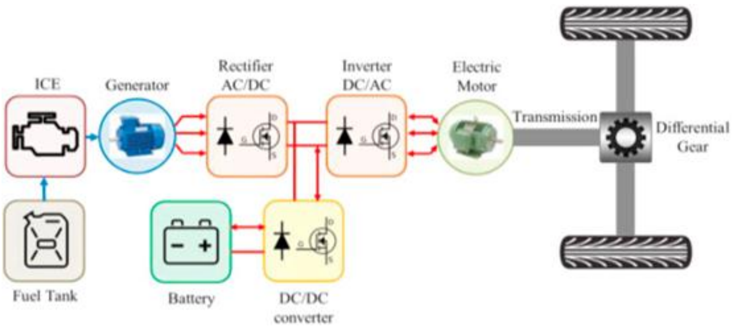

Fig. 7, ICE based Series-HEV Configuration

Therefore, the Hybrids with **series drivetrain or series hybrid (series HEVs) derive solely, mechanical power from the electric motor for further propulsion, run by either a battery or a gasoline-powered generator; the electric motor is the only way to power the wheels.**

The IC engine's primary purpose is to charge the battery when driving.

Thus, Series drivetrains are the simplest hybrid system. The motor generates electrical power either from the battery pack or from a generator powered by a gasoline engine, i.e. the ICE powers a generator whose electrical power output is coupled with the electrical storage power which is transferred to an electric motor (EM) by an electric dc-bus. (Fig.12)

A computer calculates how much of the battery or engine / generator input comes from it. The battery pack is recharged both by the engine / generator and by regenerative braking.

Series hybrids are also known as extended range electric vehicles (EREVs) or extended range electric vehicles (REEVs). (The California Air Management Board classifies series hybrids with different features as range-extended battery-electric vehicles (BEVx))

Since there is no mechanical interface between the IC and the wheels

- The engine and battery must be balanced to satisfy the maximum torque and power requirements of the car.
- The engine can work at a steady and effective rate regardless of the speed of the car, achieving higher performance (37%, rather than the ICE average of 20%) even at low or mixed speeds, resulting in an overall output gain of ~50% (19% vs 29%).
- ICE can be turned off for brief stretches of time for a temporary all-electric vehicle service, hence, Series hybrids work at their peak during stop-and-go traffic, where gasoline and diesel engines are unreliable. The vehicle's machine will opt to only drive the motor with the battery pack, saving the engine for more effective scenarios.

Within a series drivetrain, the engine is usually smaller because it only has to satisfy those power demands; within addition, the battery pack is more efficient than the one in parallel hybrids to supply the additional power requirements. In addition to the engine, a bigger battery and motor contribute to the expense of the car, making series hybrids more costly than parallel hybrids.

The use of an electric motor driving a wheel removes the traditional mechanical control components directly: gearbox, drive shafts and differential, which may also replace adjustable couplings.S-HEV topologies are mainly considered for buses and commercial cars, achieving high efficiency in stop-and-go traffic, but are not ideal for highway or inter-urban travel due to higher conversion losses and the need for a large EM at high speeds.

For a series-hybrid system for road vehicles, when an intermediate electric battery, serving as an energy reserve, lies between the electric generator and the electric traction motors, the claims of greater durability, higher performance and reduced emissions at the point of use are accomplished. Traction motors are also only driven by the electric batteries, which can be charged from other outlets such as the power grid. It makes a vehicle with an engine / generator that works only as required, such as when the battery is exhausted, or battery charging. Thus, Series-hybrid systems offer slicker acceleration by avoiding gear changes. Series-hybrids unite:

- Only electric traction-to spin the wheels use only electric motors.
- ICE-just powers the engine.
- Generator – switched by ICE for energy generation and engine ignition.
- Battery-capacitor for electricity.
- Regenerative braking – The drive engine becomes a turbine and absorbs energy by transforming kinetics to power, slowing down cars as well as reducing thermal losses. Supercapacitors help the battery and extract much energy from braking. Series hybrids can be fitted with a supercapacitor or flywheel to store regenerative braking energy, and can increase performance by storing energy that is actually wasted as heat in the braking system.

A series-hybrid configuration and popular in diesel-electric locomotives and ships (the Russian river ship Vandal, built in 1903, was the world's first diesel-powered and diesel-powered vessel) and Ferdinand Porsche used this system successfully in race vehicles, including the Lohner-Porsche Mixte Hybrid, in the early 20th century.

Toyota launched the first series-hybrid bus which was sold in Japan in 1997. Ashburton, New Zealand's production line International manufactures city buses with a series-hybrid micro turbine driven system

Well recognized hybrid variants of the automobile series include the BMW i3 version, which is fitted with a range extender. The Fisker Karma is another example of a sequence of electric cars. The Chevrolet Volt is like a hybrid series which still has a mechanical connection between the engine and the wheels over 70 mph.

The airline industry has also taken on series-hybrids. The DA36 E-Star, an aircraft designed by Siemens, Diamond Aircraft and EADS, employs a system of hybrid powertrains with a 70 kW (94 hp) Siemens electric motor spinning the propeller.[8]

2.1.3. SERIES PARALLEL DRIVE-TRAINS OR POWER SPLIT HYBRIDS

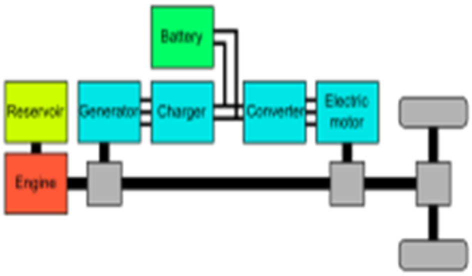

Fig. 8, Structure of a combined hybrid electric vehicle

Power-split hybrid or series-parallel hybrid (SP HEVs) are parallel hybrids which integrate power-split devices, providing power paths from the ICE to wheels that can be either mechanical or electrical. The principal theory is to decouple the electricity provided by the primary source from the driver's power demand.Series / parallel drivetrains require power to be supplied separately or in combination with each other by the engine and electric motor.

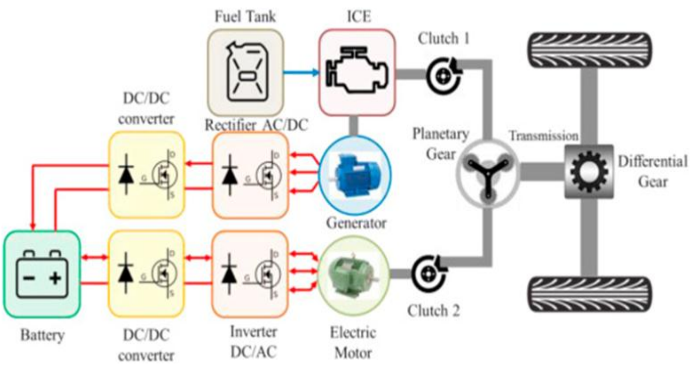

Fig. 9, ICE-based series-parallel HEV (complex type) configuration.

Series / parallel drivetrains combine the parallel and series drivetrain benefits and complexities. When merging the two types, the engine will both drive the wheels directly (as in the parallel drivetrain), and be essentially detached, supplying power only to the electric motor (as in the series drivetrain). The Toyota Prius helped create a famous concept of series / parallel drivetrains.

The engine works most frequently at near-optimal output with gas-only and electric-only solutions. It acts more like a series vehicle at lower speeds, while the engine takes over at high speeds, where the series drivetrain is less powerful, and the loss of energy is minimized. SP-HEVs thus get a pace advantage. This operating mode allows control of the operation of the IC engine for optimum fuel consumption reduction. The automobiles using this power split configuration demonstrate a spectrum of reduction in fuel consumption from 10 to 50 per cent.

A series-parallel HEV (SP-HEV) topology will reduce the size of the energy storage system (ESS) and the electric motor compared to a series-HEV and reduce the size of the ICE compared to that of a parallel-HEV system.

SP-HEV powertrains, however, are dynamic systems involving two Electric Motors acting as a generator and a drive motor attached to a radial gear system (differential gear system) replacing the conventional gearbox and operating as a continuously variable transmission (CVT).

Thus, a power-split system's power flow control is one of the main challenges for an SP-HEV as it requires the normal / standard operating modes of both series and parallel HEVs in addition to other modes such as engine-heavy and electric-heavy.

This design involves higher costs than a mere parallel configuration, as it includes a compressor, a bigger battery pack, and more processing capacity for dual device operation. Yet its efficiencies mean that the series / parallel drivetrain can do better than the series or parallel systems alone, and use less power.

At lower RPMs, ICE torque output is minimal, and conventional vehicles increase engine size to meet market demands for acceptable initial accelerations. The larger engine has more cruising power than it needs. At low RPMs, electric motors deliver maximum torque at standstill and are well-suited to replace the ICE torque deficiency. A lighter, less versatile, and more powerful engine can be used in a power-split hybrid. The standard Otto cycle (higher power density, lower RPM torque, lower fuel efficiency) is sometimes adjusted to an Atkinson or Miller cycle (lower power density, lower rpm torque, higher fuel efficiency; also called an Atkinson-Miller cycle).

The smaller engine, which uses a more powerful cycle and usually works in the desirable area of the brake related fuel consumption diagram, contributes significantly to the vehicle's higher overall performance. Interesting variations of the simple design found, for example, in the well-known Toyota Prius.

2.2. SUMMARY:

Table-1 summarises the main advantages and disadvantages of the three HEV powertrains in more detail:-

3. DEGREES OF HYBRIDIZATION :

Table-2: Summary of Hybridizations

Type	Start-stop system	Regenerative braking Electric boost	Charge-depleting mode	Rechargeable
Micro hybrid	Yes	No	No	No
Mild hybrid	Yes	Yes	No	No
Full hybrid	Yes	Yes	Yes	No
Plug-in hybrid	Yes	Yes	Yes	Yes

3.1. Micro hybrids

Micro hybrid is a general term given to vehicles that use a sort of start-stop mechanism to turn off the engine automatically while idling. Strictly speaking, micro hybrids are not real hybrid cars, since they do not depend on two different power sources.

3.2. Mild hybrids

In the most part, mild hybrids are traditional cars with some hybrid technology but with minimal hybrid features. They are usually a parallel hybrid of start-stop and limited engine level support or regenerative braking. Generally speaking, the mild hybrids cannot provide all-electric propulsion. Accessories will continue to operate on electrical power while the engine is off, and regenerative braking recaptures energy as in most hybrid systems. Upon pumping fuel the large electric motor spins the engine at operating rates.

Another option to give start / stop is with the use of a static start motor. Such an engine does not need a starting motor but uses sensors to calculate the exact location of each piston, instead timing the fuel injection and ignition precisely to turn the engine over.

Mild hybrids are also called Power Assist hybrids because they are using the ICE for primary control, with a torque-boosting electric motor attached to a (mostly) traditional drive engine. The electric motor is mounted between the transmission and the engine. Essentially, it is a big starter motor that works when the engine needs to be switched over and the driver "steps on the gas"

The electric motor will also restart the combustion engine and shut down the main engine in idle while using the improved battery capacity to drive accessories.

In all other operating conditions, the machine is disengaged, and it does not specifically boost efficiency or economy, but enables the use of a smaller, more efficient engine compared to total power.

Table-1: Advantages and Disadvantages of the 3 HEVs

Powertrain	Advantages	Disadvantages
Series	• Optimised efficient traction driveline (engine downsizing) • Modular power plant possibilities (space packaging advantages) • Long operational life • Excellent transient response • Zero emission operation possible	• Larger traction drive system • Multiple energy conversions
	Application: Larger vehicles such as heavy-duty buses, trucks and locomotives.	
Parallel	• Economic gain at high cost • Zero emission operation possible	• High voltages needed for efficiency • Complex space packaging
	Application: urban passenger cars.	
Series-parallel	• Zero emission operation possible	• Very expensive system • Control complexity • Complex space packaging
	Application: passenger cars, light duty vehicles.	

3.3. FULL HYBRIDS

A complete hybrid is a car that can run on either the battery, the batteries or a mix, also often called a solid hybrid. The Toyota Prius, Toyota Camry Hybrid, Ford Escape Hybrid / Mercury Mariner Hybrid, Ford Fusion Hybrid / Lincoln MKZ Hybrid / Mercury Milan Hybrid, Ford C-Max Hybrid, Kia Optima Hybrid and the General Motors 2-mode Hybrid Trucks and SUVs are examples of this type of hybridization as they can operate on battery power alone.

A huge, high-capacity battery allows power only by battery. Such cars have a divided control line that allows mechanical and electrical control to interconvert greater freedom in the drivetrain. The automobiles have a differential-style coupling between the engine and the motor attached to the transmission head end to offset the forces from each component.

3.3.1. FULL ELECTRIC VEHICLES-BATTERY-BASED FEVs

The battery is the primary component of a high-energy element in battery-based systems. Therefore, the battery can be combined with other high-power capacity systems such as a supercapacitor (SC) (also known as an ultra-capacitor (UC) or electronic double-layer condenser (EDLC)), high-power battery, or lithium-capacitor (LiC) to form a hybrid energy storage system (HESS).

For general, as opposed to a SC, the batteries have a high energy capacity and low power output. Thus, a HESS can store enough energy and fulfil the vehicle's sudden power demands to achieve the necessary acceleration efficiency.

Compared to a single battery-based FEV system, a HESS-based system has many benefits, such as higher energy / power capacity, longer battery life cycle, better acceleration dynamic response and the ability to consume more energy in regenerative braking mode. HESS-based systems can differ by a "powertrains" when considering the form of converter and its positions

3.3.2. FUEL CELL-BASED FEVs

The FC is the primary energy source used to produce electricity from hydrogen and air in fuel-cell (FC)-based FEVs. An FC's potential energy and its maximum capacity are similar to and slightly smaller than that of fuel, respectively. Owing to the slow dynamics of FC systems, strong power transients can lead to gas hunger, resulting in permanent damage to the FC.

Batteries, SCs, or battery-SCs may also be built into a network to boost dynamic efficiency and increase lifetime of the FC.

With this model, the Toyota brand name is Hybrid Synergy Drive, which is found in the Prius, the Highlander Hybrid Crossover and the Camry Hybrid. A program controls the operation of the network, deciding whether the power supplies are combined. The processes at Prius can be split into six different regimes.

- Electric car mode — ICE is off and the engine (or charges during regenerative braking) is powered by the battery. Using when the battery charging condition (SOC) is high to idle.
- Cruise mode — the car cruises (i.e. does not accelerate), so the ICE will satisfy the demand. The power from the engine is divided between the generator and the mechanical direction. The batteries must drive the engine, whose output is mechanically summed up by the motor. When the battery charge level is small, the battery is powered by part of the electricity from the generator.
- Overdrive mode — a portion of the rotational energy generates electricity, as it does not require the maximum strength of the ICE to maintain pace. This electric power is used to move the sun gear in the reverse direction to its normal rotation. The end result is allowing the ring gear to spin faster than the piston, but at lower torque.
- Battery charge mode — often used for idling, except that the battery charging level is small in this case and involves charging, which is given by the engine and the generator. Power boost mode-Used in cases where the engine is unable to reach the desired rpm. The battery powers the engine to supplement the capacity of the engine.
- Negative split mode — the car is cruising and the state-of - charge battery is small. The battery supplies both engine power (to provide hydraulic power) and turbine electricity. The generator transforms this to mechanical energy, which it channels into the shaft of the engine, slowing it down (although its torque output is not changed). This "lugging" engine aims to improve fuel economy

3.4. DUAL HYBRIDS

An example of dual hybrids are Formula One cars.

3.5. PLUG-IN HYBRIDS[(P)HEVs]

As illustrated in the Figure. The plug-in hybrid electric vehicle (PHEV) has exactly the same configuration as the HEV but is fitted with an additional electric charging port, larger electrical parts (i.e. electric motor and battery) and a small engine. PHEVs can operate on full-electric mode for long periods of time, thanks to the high efficiency of the electrical components

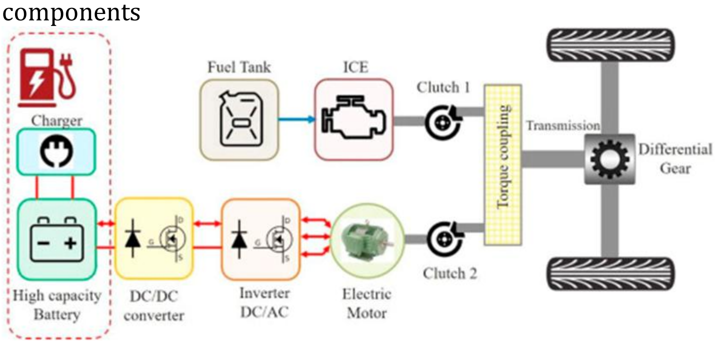

Fig. 10, Plug-in HEV

There are many operating modes in a (P)HEV, including battery-only mode (only the battery supplies fuel), engine-only mode (only the ICE propels the car), mixed mode (both the ICE and the battery provide the necessary electricity), and fuel-only mode (the ICE electricity is separated to drive the vehicle and charge the battery).

The potential modes of operation in (P)HEVs depend explicitly on the materials used, the configuration and the topology of the vehicles. Considering the (P)HEV topologies, the table below presents a description of different potential operating modes.

Table-3: Possible Operation Modes of (P)HEVs

No	Operation modes	Powertrain topologies			
		Series	Parallel	Series-Parallel	Plug-in
1	Battery alone mode	✓	✓	✓	✓
2	Engine alone mode	✓	✓	✓	✓
3	Combined mode	✓	✓	✓	✓
4	Power split mode	✓	✓	✓	✓
5	Stationary charging mode	✓	✓	✓	✓
6	Regenerative braking mode	✓	✓	✓	✓
7	Engine-heavy mode	–	–	✓	–
8	Electric-heavy mode	–	–	✓	–
9	Charging battery mode	–	–	–	✓
10	Extended driving mode	–	–	–	✓

Because of the low power of the battery, HEVs often use charging service (CS) mode to charge / discharge their battery with a minimal number of cycles. In comparison, the PHEVs will operate in charge-depleting (CD)–charge-sustaining (CS) mode, in which the vehicle operates in CD mode before the on-board rechargeable energy storage device depletes to a predefined lower charge (SoC) state, and then changes to CS mode.

Due to its flexibility and ease of execution the CD-CS mode is commonly used given its lack of optimality. Numerous researchers have suggested the use of blended mode to increase the energy efficiency of a PHEV, in which the battery is slowly drained over a previously established driving loop.

They are complete hybrids, capable of operating on battery power. We deliver greater battery capacity and grid recharging capabilities. They can be either constructed in parallel or in sequence. These are sometimes called hybrids and are gas-optional, or griddable. Their key advantage is that they can be clear of fuel for short distances, with an ICE's increased range for longer journeys.

4. POWERTRAIN MODELLING APPROACHES SUITABLE FOR EMS ASSESSMENT:

When the topology of a vehicle is chosen, modelling the powertrain is a crucial step in the development of an effective EMS. The powertrain models should be sufficiently accurate to describe the device and use other high-fidelity models to allow validation. Based on the intent of the study, the simulation of a powertrain device requires various degrees of complexity and precision

Table-4: EMS Model for powertrain

	Simplified model	Medium/High-fidelity model
Research purpose	Energy management, performance, and emission	Drivability, stability and handling Noise, vibration and harshness
Modelling approach	Forward/Backward	Forward
Vehicle dynamics	Lumped vehicle and powertrain inertia; Longitudinal model	Longitudinal-lateral model
Type of model	Static/Quasi-static model	Low-frequency/High-frequency dynamic model
Engine	Stationary fuel consumption map	First-order dynamics and fuel consumption map
Engine starter	Instantaneous power on	Electrical cranking
Clutch/Torque converter dynamics	Instantaneous engagement	Slip dynamic
Electric motor/Generator	Efficiency map	d-q model
Converter/Inverter	Constant efficiency or efficiency map	Average/small-signal model
Battery/SC	Electrical model with SoC and SoH model	First- or second-order model
Fuel Cell	Stationary hydrogen consumption map or efficiency map	First-order dynamics and hydrogen consumption map

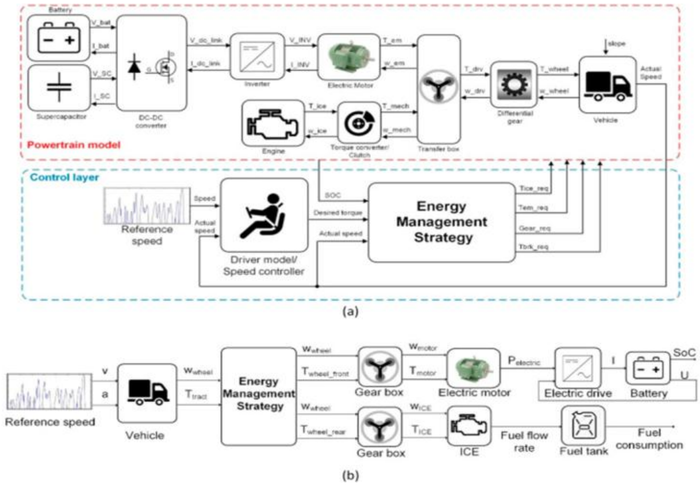

Fig. 11, EMS Strategy, source:[7]

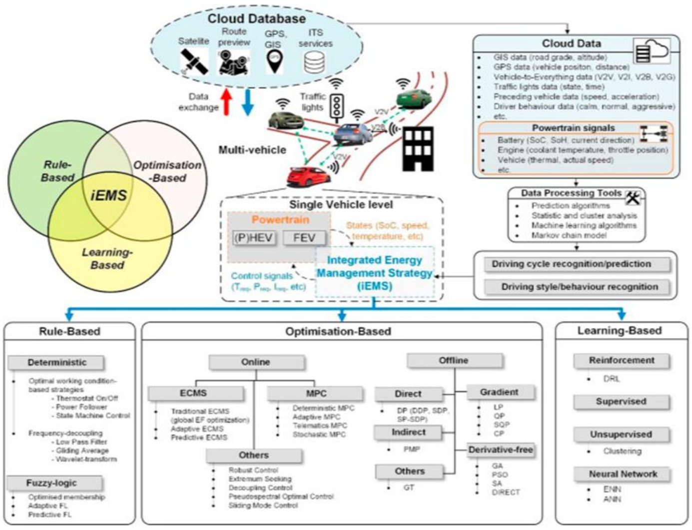

Fig. 12, Integrated-EMS Strategy (iEMS), Source:[7]

5. AFTERMARKET OPTIONS

A car can be fitted with an aftermarket powertrain. Once the customer ships the glider (rolling chassis) and the hybrid (two engines) or all-electric (only an electric motor) powertrain kit to the automaker, the aftermarket approach is used and the car is provided with the software fitted. An aftermarket manufacturer may attach one (electric or hybrid) powertrain to a glider.

In 2013, On the Eco, a research team from the University of Central Florida, was working to create a bolt-on hybrid conversion package to convert an older model car into a gas-electric hybrid. [2]

An engineer in California had demonstrated a conversion of a 1966 Mustang. The machine replaced the alternator with a brushless electric motor which was 12 kW (30 kW peak). Power and gas mileage boosted.

6. CONCLUSION

Hybrid Vehicles are thus, vehicles used with integration of Motor and Engine, these vehicles have different drivetrain configuration and these configurations have been discussed successfully above. Parallel hybrid vehicles, or hybrids with parallel drive trains (Parallel HEVs), are fitted with both an internal combustion engine and an electric motor that can drive the car independently or both together (simultaneously) give power. Whereas, the Hybrids with series drivetrain or series hybrid (series HEVs) derive solely, mechanical power from the electric motor for further propulsion, run by either a battery or a gasoline-powered generator; the electric motor is the only way to power the wheels. Series hybrids are also known as extended range electric vehicles (EREVs) or extended range electric vehicles (REEVs). Also,Power-split hybrid or series-parallel hybrid (SP HEVs) are parallel hybrids which integrate power-split devices, providing power paths from the ICE to wheels that can be either mechanical or electrical.

REFERENCES

[1] Dai-Duong Tran, March 2020, 109596

[2] On the Green. Retrieved April 18, 2013.

[3] A comprehensive overview of hybrid electric vehicle: Powertrain configurations, powertrain control techniques and electronic control units

[4] Hybrid Power Trains- Patent - US5495912A United States

[5] Renewable and Sustainanle Energy Service Reviews - Thorough state-of-the-art analysis of electric and hybrid vehicle powertrains: doi-10.1016/j.rser.2019.109596

[6] https://www.nap.edu/read/12924/chapter/8 (hybrid power train systems)

[7] Research article- Design and analysis of hybrid electric vehicle powertrain configurations considering energy transformation , doi-10.1002/er.4225

[8] S. Delprat, J. Lauber, T. M. Guerra and J. Rimaux, "Control of a parallel hybrid powertrain: optimal control," in IEEE Transactions on Vehicular Technology, vol. 53, no. 3, pp. 872-881, May 2004, doi: 10.1109/TVT.2004.827161.