Hybrid Electric Vehicles (HEV): classification, configuration, and vehicle control

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Abstract : Public and private transport play a significant role in the economy, development and progress of a country. A well-functioning transportation system allows for expansion of markets and strengthening existing markets. It enables and promotes the strong economic growth that leads to global competitiveness. An inefficient system causes an increase in commute congestion, a decrease in productivity, and loss of social relations. The objective of this study is to present the classification such as Series HEV, Parallel HEV, combination HEV. This research also discusses the configuration, and vehicle control. To achieve the research objective we review the relevant literature on the Hybrid Electric Vehicles (HEV).

Keywords: HEV, HEV classification, HEV configuration, HEV vehicle control, Series HEV, Parallel HEV, combination HEV.

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Electric Vehicles (EVs) & Hybrid Vehicles (HVs) Definition

First of all, a distinction between 'traction' and 'propulsion' is required. Traction is provided by the motor while propulsion is provided by the combination of engine systems. When a car with an electric motor receives the energy it needs from a battery pack, it is considered an all-electric vehicle. This vehicle requires recharging stations that correspond with how far it can travel on a charge. If the electric motor is fed by the battery and a thermal engine, it is considered to be a hybrid vehicle. In reality, this vehicle is a water-fuel cell hybrid. Despite the fact that electric vehicles (EVs), either all-electric or hybrid, reduce emissions in local areas, they do not do the same for the rest of the world.

HYBRID ELECTRIC VEHICLES.

At least two energy converters, such as internal combustion engines (ICE), electric motors, hydraulic drives, etc., are combined in a hybrid electric vehicle (HEV). The ultimate aim of the HEV is to have the same power, range and protection as a traditional vehicle while reducing fuel consumption and harmful emissions that are harmful for health (Sanghvi and Gordon, 2021). Hybrid vehicles have the ability, including the following, to realize many benefits:

1. Higher efficiency of the electric machine: The electric machine is a simpler and more powerful machine compared with the ICE. For example, an electrical machine's moving parts consist primarily of the armature (DC motor) or rotor (AC motor) and bearings.
2. Regenerative braking: A regenerative brake is an energy system that decreases the speed of a vehicle by transforming some of its kinetic energy into a future storable type of energy, rather than dissipating it as heat as with a conventional brake.
3. Improved torque characteristics: Electric machines are more suitable for automotive applications, with low-speed high torque and lower cruising speed torque.
4. Reduced emissions - through smoothing and idle removal of transients.
5. For selected setups, optimum engine operation - run the engine in its 'sweet spot', staying close to its best output hand.
6. Engine downsizing could be necessary in order to cope with average load (not peak load) and thereby reduce the weight of the engine and powertrain.
7. It is possible to shut the engine off, thus reducing fuel consumption, pollution and NVH.
8. Accessory electrification enables the operation of parasitic loads on the necessary basis.

HEV drawbacks, however, include:

1. Powertrain and electronic complexity increased
2. Increased mass of the vehicle due to additional components
3. Increased cost due to extra components and power management difficulty
4. Overall system reliability can be lower due to increased complexity
5. If not optimized for the appropriate drive cycle, benefits may not be fully realized.

In order to comply with various applications, a variety of different device architectures are considered. They are generally categorized as split sequence, parallel, and strength. Device design selection depends primarily on the program. The car manufacturing organization is obliged to reduce the intensity of adverse effects on nature, as well as to increase the level of safety of its products, such as cars (Tengiz, 2020b) (Tengiz, 2020a). Besides, due to the complexity of many car manufacturing companies structures, a mathematical modeling becomes necessary in order to simplify reality using models, thereby increasing the ability of car producers to make the right decisions.(Magradze, 2020a) (Magradze, 2020b).

How Hybrids Work

Hybrid electric vehicles (HEVs) combine the benefits of gasoline engines and electric motors. They can be designed to meet different goals, such as better fuel economy or more power.

Most hybrids use several advanced technologies:

- **Braking Regenerative.** During coasting or braking, regenerative braking restores energy normally lost. It uses the wheels' forward motion to spin the engine. This provides energy which makes the car slow down.
- **Drive/Assist Electric Motor.** In order to help the engine accelerate, move, or hill climb, the electric motor provides power. This enables the use of a smaller, more-efficient engine. The electric motor alone propels the vehicle in some hybrids at low speeds, where gasoline engines are the least powerful.
- **Stop/Start Automatic.** When the car comes to a halt, the engine automatically shuts off and restarts when the accelerator is pressed. It minimizes wasted energy from idling.

Figure 1. Functionality of Hybrid cars

Classification:

HEV can historically be categorized into three types: HEV sequence, HEV parallel, and HEV combination.

2.1.1. Configuration of Series HEV.

We can see from Figure 1 that the HEV series consists of the ICE, generator, power converter, motor, and battery. There is no mechanical connection between the ICE and the transmission, so the ICE will work at the maximum efficient point by controlling the output power of the battery to fulfill the vehicle's required power. However, the power from the ICE is transferred via the generator and the engine, so much more energy is lost. Because the engine is the final and sole drive unit, the engine must be sufficiently large to meet the vehicle's output, so the regenerative braking power can almost be stored by the engine in the battery. (Butler, Ehsani and Kamath, 1999)

Figure 2. Configuration of Series HEV.

In the HEV series, when it has to be recharged, an electric motor, coupled to an ICE, supplies electricity to the electric machine to drive the vehicle and to the energy storage system. One of the main benefits of the series is that the speeds of the engine and car are decoupled. As a result, the engine will run at its peak, substantially reducing the consumption of fuel. However, because the electrical machine is the only one connected to the wheels and the engine/generator set is sized for sustained grade power, this design includes a large pack of energy storage device, electrical machine and engine, adding inefficiencies and weight.

Configuration of Parallel HEV.

We can see from Figure 2 that the parallel HEV allows both the electric motor and ICE to deliver power to drive the vehicle in parallel, i.e. the ICE and motor can drive, respectively, or together. There is a mechanical relation between the ICE and the transmission, unlike the HEV series, and therefore the rotational speed of the ICE depends on the driving cycle, so that the ICE can run on the optimum running line by controlling the battery output power. (Tei *et al.*, 2003)

Figure 3. Configuration of parallel HEV.

Both the electric vehicle and the engine have mechanical connections to the wheels of parallel hybrids. Since both the electric machine and the engine are directly connected to the wheels, the power can be shared during accelerations. Compared to series hybrids, it is also possible to downsize both the engine and the electric motor. Since the ICE speed is linked to the vehicle speed, the ICE can operate close to its best efficiency curve only under certain conditions. However, since both mechanical and electrical energies can be used to directly propel the vehicle, the powertrain efficiency is increased compared to series configuration during most operating conditions.

2.1.3. Configuration of Combination HEV.

From Figure 3, we can see that the HEV combination combines the features of both series and parallel HEV, adding an additional mechanical link between ICE and transmission compared to the hybrid series, and also adding an additional generator compared to the parallel hybrid between ICE and power converter. Although structural complexity contributes to more costly production.

Figure 3. Configuration of Combination HEV.

To build an incredibly successful method, the HEV mix blends the best elements of both series and parallel hybrids. This system splits the power of the engine into two routes: one goes to the generator to generate electricity and one goes to drive the wheels via a mechanical gear system. In general, the series path is avoided as it is less efficient. The key additional characteristic is that the speeds of the engine, generator and motor are decoupled, allowing additional power independence. A HEV combination system (transmission), two electrical machines and an engine make up the most common configuration, called an input split. Several variants of the HEV combination have been added, each offering various benefits:

- The first electric machine is used to regulate the engine speed in a single HEV combination hybrid mode, while the second one provides the remaining power needed to track the vehicle track.
- A two mode power system is composed of a compound mode, in addition to the input mode. In this case, the size of the electric machine can be reduced as each motor is used to control the engine speed in various conditions. In

addition to minimizing the electric machine power requirements, the system performance can be further increased by reducing the energy recirculation by the use of the fixed gears.

2.2. Main Issues of HEV.

For the following purposes, the HEV can save fuel compared to traditional vehicles.

1. The HEV may store part of the kinetic energy of the vehicle in the battery during braking or downslope, where the heat of the conventional vehicle is otherwise incinerated in the brake drums.
2. Without compromising the efficiency of the vehicle, the ICE in the HEV can be configured to have a smaller displacement.
3. By controlling the output power of the battery to satisfy the necessary power of the vehicle, the HEV may make ICE work at the maximum efficiency point or optimum operating line.
4. HEV is a multi-energy system; the key challenge for HEV is how to maximize the flow of energy to achieve the best fuel economy or low emissions at lower costs, also referred to as the problem of energy management (EM). The problem will be addressed in depth in the next segment.

Vehicle Control in HEV.

The control system of the HEV is very complex. For large-scale and complex systems, multilevel hierarchical control is an important control technique. Hierarchical regulation is thus commonly adapted to HEV control, as seen in Figure 4. (series HEV). The HEV controller consists of an interpreter for driver control, a vehicle system controller and an electronic controller. The Vehicle System Controller is the level of decision to assess the torque requirements of the engine, generator, ICE, and mechanical brake according to the torque demand of the driver, vehicle speed, and state of charge of the battery (SOC), where the SOC is estimated by the battery management system (BMS), the sensor feeds the vehicle speed (Serrao, Onori and Rizzoni, 2009) (Pisu and Rizzoni, 2007) The electronic controller is the execution stage at which the vehicle system controller carries out the order to make the corresponding parts operate.

(1) Command Interpreter for Drivers. The driver command interpreter's job is to measure the torque demand of the driver according to the desired vehicle speed and actual vehicle speed. Vehicle speed is controlled by the direction of the accelerator pedal and brake pedal. By changing the accelerator pedal and brake pedal position, this is a feed control device to make the vehicle obey the desired vehicle (Wenzhong and Porandla, 2005). (Yan, Wang and Huang, 2012)

(2) Vehicle System Controller. HEV is a multiple energy source compared to traditional vehicles, so how to divide the required power between energy sources is referred to as EM. By using EM strategies according to command signals obtained from the driver command interpreter and parameter information input from the electronic controller, the vehicle system controller performs powertrain control. As shown in Figure 5, the vehicle system controller can be categorized into three feature blocks. (Johnson, Wipke and Rausen, 2000) (Lee and Sul, 1998) (Enang and Bannister, 2017) I) Required vehicle interpreter capacity. (ii) Methods for handling electricity. (iii) Translator of torque. The vehicle interpreter's necessary power is a function block for translating the torque demand of the driver to power demand. HEV is a multiple energy device, distinct from traditional vehicles that can only produce power, not only can battery output power, but also consume energy. The hot topic among technology developers is how to divide the necessary power between two energy sources and mechanical brakes in order to reduce fuel consumption or emissions. (Plett, 2004).

Electronic Controller (3). The electronic controller is an embedded device that carries out commands from the controller of the vehicle system to operate the corresponding components. In Figure 4, the electronic controller comprises the engine control unit (ECU), the engine control unit (MCU), the generator control unit (GCU), the mechanical brake control unit and the battery management system (BMS). The engine control unit is an electronic control unit (ECU) for ICE control; by injecting fuel into the ICE combustion chambers, it generates the desired ICE output torque coming from the vehicle system controller control signal. The ICE operating point can be defined by torque and velocity. There is no mechanical link between ICE and the transmission in the HEV series, so how can ICE speed be controlled? There is a mechanical link between the ICE and the generator, so the speed of the ICE is regulated by the torque demand of the generator. Motor is the final drive system and is connected to the transmission by mechanical connection, and thus the speed of the motor depends on the driving cycle, similarly, the operating point of the motor can typically be represented by torque and speed; due to mechanical connection to transmission, the torque demand of the motor is determined by the torque demand of the driver. Using FOC technology, the MCU normally makes the engine run at the desired torque. During braking or down slope, engines, commonly used for traction, may also become a generator. Therefore, the kinetic energy of the engine, otherwise burned in the form of heat in the brake drums, can be transformed into electrical energy and sent back to the battery. If the battery is non-receptive, it will operate with the electronic braking system control unit.

Figure 4. Vehicle Control in HEV

Notation	Explanation
s_d	Desired speed of vehicle
s	Speed of vehicle
Δs	Difference of desired speed and speed of vehicle
T_{drv_dmd}	Driver demand
SOC	State of charge
T_{ice_dmd}	Torque demand of ICE
T_{gc_dmd}	Torque demand of generator
T_{mc_dmd}	Torque demand of motor
T_{bh_dmd}	Torque demand of braking

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