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Fundamentals and Classification of Hybrid Electric Vehicles

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Abstract:

Depleting fossil fuels at a drastic rate has encouraged many research enthusiasts to find an alternative source of energy to run the vehicles. To achieve substantial increase in fuel economy and reduced emissions, a concept of hybridization has set its way in 21st century. A HEV (hybrid electric vehicle) combines energy generated from multiple sources like diesel-electric, fuel cell-battery, gasoline-fly wheel. The aim of this paper is to give an overview of hybridization concept, classification of HEV and degree of hybridization.

Keywords — **Degree of Hybridization, Hybrid Vehicles, Parallel Hybrid, Series Hybrid.**

I. INTRODUCTION

A hybrid vehicle combines any two power generating sources. Many combinations such as diesel/electric, gasoline/fly wheel, and fuel cell (FC)/battery are usually used. Typically, one energy source is storage, and the other converts a fuel to energy. The combination of two power sources can support two separate propulsion systems or combine into a single propulsion system.

For example, a truck that uses a diesel to drive a generator, which in turn drives several electrical motors for all-wheel drive, is *not considered under hybrid*. However, if the truck has electrical energy storage to provide a second mode, which assists the primary driving source, then it is a HEV. The two power sources can be coupled either in series or in parallel. For series, the engine charges batteries and in turn, batteries charge electric motor that powers the vehicle. For parallel, both engine as well as electric motor constitute for driving power [9]. Regenerative braking is one of the new technologies applied in modern HEVs used to improve fuel efficiency. Unlike frictional loss in conventional braking, regenerative braking converts kinetic energy of vehicle into electrical energy. In some HEVs, electrical energy is generated by spinning electrical generator by the means of internal combustion engine. This is known as motor-generator combination, used either recharge batteries or power electric drive motors directly. In case of start-stop system, the ICE is shut down at idle and restarted when needed increasing fuel economy and reducing idle emissions. HEV has a smaller IC engine thus producing lesser emissions compared to a similar sized gasoline car. A HEV is formed by merging components from a pure electrical vehicle and a pure gasoline vehicle. The Electric Vehicle (EV) has an M/G (motor/generator) which allows regenerative braking for an EV. The M/G installed in the HEV enables regenerative braking. For the HEV, the M/G is tucked directly behind the engine. In Honda hybrids, the M/G is connected directly to the engine. The transmission appears next in line. This arrangement has two torque producers; the M/G in motor mode, M-mode, and the gasoline engine. The battery and M/G are connected electrically [8].

II. CONCEPTUAL ARCHITECTURE OF DRIVETRAIN

Concept of Hybrid Drivetrain: Fig. 1 shows the concept of a hybrid drivetrain and possible energy flow route. There are multiple patterns available patterns of combining the power flows to meet load requirement as described in the following: [5], [6]

1) powertrain 1 individually delivers power to the load.
2) powertrain 2 individually delivers power to the load;

3) both powertrain 1 and 2 deliver power to the load simultaneously
4) powertrain 2 obtains power from load (regenerative braking);
5) powertrain 2 obtains power from powertrain 1;
6) powertrain 2 obtains power from powertrain 1 and load at the same time;
7) powertrain 1 delivers power to load and to powertrain 2 at the same time;
8) powertrain 1 delivers power to powertrain 2, and powertrain 2 delivers power to load;
9) powertrain 1 delivers power to load, and load delivers power to powertrain 2.

Load power of a vehicle varies randomly in real operation due to frequently accelerating, decelerating, and climbing up and down grades.

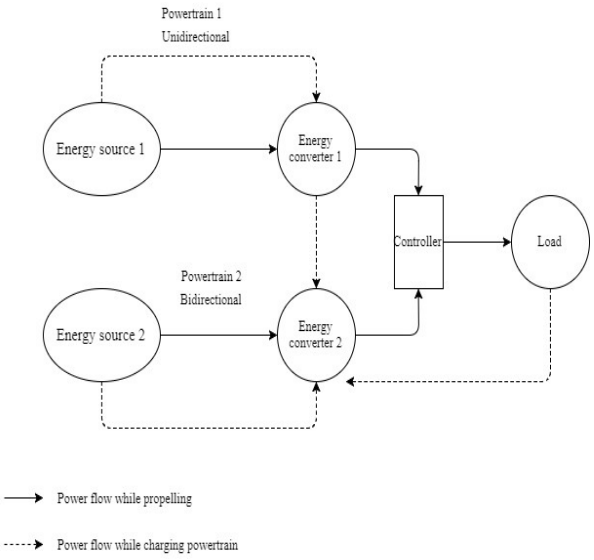

Figure 1: Architecture of Drivetrain

Basically, the load power is converted into two components: steady (average) power and dynamic power. Steady power has a constant value whereas dynamic power has a zero average.
In case of hybrid vehicles, one powertrain,
which supports steady-state operation, such as an IC engine
fuel cell, is used to supply the average power. On the other hand, other powertrains, such as an electric motor,
are usually used to supply the dynamic power. In the entire driving cycle, total output from dynamic powertrain is zero, implying that energy source of dynamic powertrain does not lose its capacity at the end of driving cycle. It functions just as a power damper.
For steady-state load, power is usually provided usually by an IC engine or a fuel cell. This steady-state load follows steady-state operating characteristics. Its operating point can be designed and controlled in optimal region to obtain maximum operating efficiency. Electric traction system provides dynamic load to get high power when required and recover brake power to make system extremely energy efficient.
Hybrid drivetrain have following architectures by which they are classified as series, parallel, series-parallel which will be discussed further.

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III. CLASSIFICATION OF HEVs

Hybrid Electric Vehicles can be classified based on propulsion system, energy storage system, energy source and various other parameters, some of which are discussed below [3].

A. Based on Architecture:

1) Series Configuration:

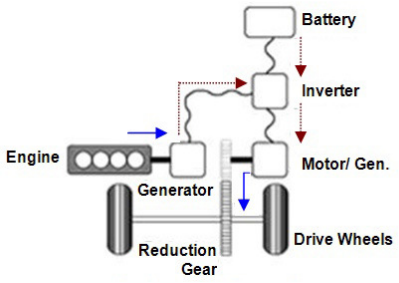

Figure 2: Series Hybrid

A series is one in which only one energy converter can provide propulsion power [2]. IC engine acts as a prime mover. It drives an electric generator that delivers power to the battery or energy storage link and the propulsion motor. A downsized IC engine

drives a generator, which supplements the batteries and can charge them when they fall below a certain SOC. The power required to propel the vehicle is provided solely by the electric motor. Electric motor power requirements are exactly the same as an electric vehicle.

*2) **Parallel Configuration:***

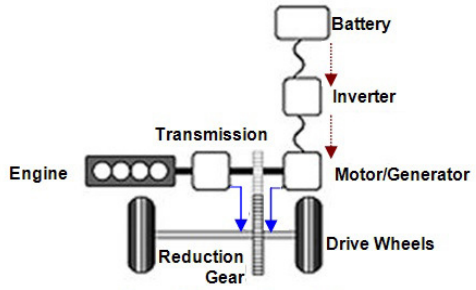

Figure 3: Parallel Hybrid

A parallel hybrid is one in which more than one conversion device can deliver propulsion power to the wheels [2]. The IC engine and electric motor are configured in parallel with a mechanical coupling that blends the torque coming from two sources. In parallel HEV, the power requirements of the electric motor are lower than electric vehicle or series hybrid; since IC engine complements to total power demand of the vehicle.

*3) **Series-Parallel Hybrid (Split Type):***

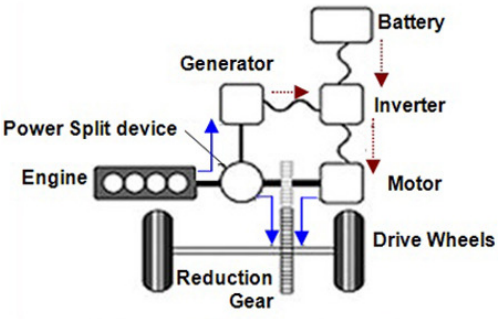

Figure 4: Series-Parallel Hybrid

In S-P hybrids, the IC engine is also used to charge the battery. The architecture is more complicated, involving additional mechanical links and controls compared to series hybrid and an additional generator compared to parallel hybrid. S-P HEV is basically series HEV but with a small series element added to the architecture. It ensures that the battery charge is sustained in prolonged wait periods in traffic jams. The power split device allocated power from IC engine to front wheels through driveshaft and electric generator depending on driving condition. For short bursts of acceleration, power can be delivered to the driveshaft from both IC engine and electric motor. A central control unit regulates power flow for the system using multiple feedback signals from various sensors.

*B. **Based on Degree of Hybridization:***

Parallel and combined hybrids can be categorized according to degree of hybridization. Degree of hybridization depends upon the power supplied by IC engine and electric motor. In some vehicles, IC engine is dominant; electric motor turns on only when boost is needed. In many vehicles, both IC engine and electric motor share equal loads. Others can run only with electric motor system operating.

The ratio of power developed by an electric motor in a hybrid vehicle to the total power consumed by the vehicle is known as degree of hybridization.

$$\text{Degree of hybridization} = \frac{\text{Motor Power}}{\text{Motor Power} + \text{Engine Power}} * 100$$

Type Of hybrid	Degree of hybridization
Micro	<5%
Mild	Up to 10%
Full Hybrid: Parallel Series	 10% to 50% 50% to 75%
Electric vehicle	100%

*1) **Micro Hybrid:***

- Electric motor functions to start or stop the system to automatically shut off the engine while idling.
- This motor does not provide additional torque to the vehicle [1].
- Electric Motor supplies power 2.5kW at 12 volts [7].
- Energy saving 5 to 10%.
- Example: BMW 1 series, Fortwo Mercedes, etc

*2) **Mild Hybrid:***

- Electric motor generator is integrated to provide 10% of maximum engine power.
- These hybrids improve drawbacks of fossil fuel vehicles. Here motor or generator is in parallel with IC engine [1].
- Electric Motor supplies power 10 to 20 kW at 100-200 volts [7].
- Energy saving 20 to 30%
- Examples: Chevrolet Malibu, Chevrolet Silveradois a full-size pickup truck, Honda Escape, etc.

*3) **Full Hybrid:***

- Electric motor provides at least 40% of engine power as additional torque.
- Bigger motor and battery reduces the required size of conventional engine [1].
- It has improved fuel consumptions and reduced emissions.
- Circa Electric Motor supplies power 50 kW at 200-300 volts [7].
- Energy saving 30 to 50%
- Example: -Toyota Prius, Camry Hybrid, Ford Escape Hybrid, Ford Fusion Hybrid/Lincoln MKZ Hybrid, Ford C-Max Hybrid, Kia Optima Hybrid, as well as the General Motors hybrid trucks with 2 –mode.

*4) **Plug-in Hybrid:***

- Plug-in hybrid electric vehicles–known as PHEVs–combine a gasoline or diesel engine with an electric motor and a large rechargeable battery.
- Unlike conventional hybrids, these hybrids can be plugged-in and recharged from an outlet, allowing the vehicle to drive extended distances using just electricity.
- When the battery is emptied, the conventional engine turns on and the vehicle operates as a conventional, non-plug-in hybrid.
- Example: Chevrolet Volt, Mitsubishi Outlander P-HEV, Toyota Prius P-HEV, etc.

C. Nature of power source

*1) **Electric-IC engine hybrid***

Electric-IC engine hybrid can be created in many ways. variety of designs differentiate upon how electric motor and combustion engine power train are connected (Series, parallel, series-parallel), what percent of power is produced by electric motor and IC engine, the time at which both portions operate [4].

*2) **Fuel Cells***

First successful fuel cells were designed by Francis Bacon in 1932 (designed alkaline fuel cell system with porous electrodes). Main source of energy is hydrogen. They need ultra-capacitor to increase power density required to start the vehicle. They have high energy efficiency. Use of hydrogen results in low use of crude oil as vehicular fuel and low carbon emissions as well [4].

IV. CONCLUSIONS

In this paper, overview on HEVs with emphasis on classification has been presented.

Storage devices like batteries take up a part of load in turn reducing the need for larger IC engines. Battery contributing leads to prudent use of fuels

increasing fuel efficiency. Thus, downsizing of IC engines is possible saving space.

Regenerative braking system installed in most of the hybrid vehicles captures some amount of energy normally lost due to friction. This energy is stored in the batteries and can be used for propulsion.

Hybrid also avoids energy losses associated with engine operation where normal IC engine is inefficient at different speed and load combinations.

Hence in this competitive world with latest technologies emerging, hybrid concept is extremely pragmatic.

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