

Powersplit or Parallel - Selecting the Right Hybrid Architecture

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ABSTRACT

The automotive industry is rapidly expanding its Hybrid, Plug-in Hybrid and Battery Electric Vehicle product offerings in response to meet customer wants and regulatory requirements. One way for electrified vehicles to have an increasing impact on fleet-level CO₂ emissions is for their sales volumes to go up. This means that electrified vehicles need to deliver a complete set of vehicle level attributes like performance, Fuel Economy and range that is attractive to a wide customer base at an affordable cost of ownership.

As part of “democratizing” the Hybrid and plug-In Hybrid technology, automotive manufacturers aim to deliver these vehicle level attributes with a powertrain architecture at lowest cost and complexity, recognizing that customer wants may vary considerably between different classes of vehicles. For example, a medium duty truck application may have to support good trailer tow whereas a C-sized sedan customer may prefer superior city Fuel Economy. This difference in attribute wants can drive the need for different electrified architectures. Here, two commonly used Hybrid and Plug-in Hybrid Electric Vehicle architectures can be distinguished: Powersplit and Parallel configurations.

This paper studies the design differences between these Hybrid architectures and the intrinsic attribute advantages that one can provide over the other. Subsystem design criteria, including sizing of key components is considered. The two approaches are compared for a specific vehicle assumption for attributes and normalized cost.

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INTRODUCTION

Drivers for Electrification

Global vehicle emission and fuel economy regulations are becoming more stringent than ever before. In the US, under the One National Plan, CO₂ emissions are forecasted to reduce by 5% annually. EU and China regulations require similar rates of reduction going forward. While conventional engine technology has made significant headway in improving emissions and fuel economy without compromising performance, going forward the need for electrification is becoming exceedingly apparent in order to meet future emission and fuel economy standards. Having an onboard secondary electrical power source enables engine downsizing, start/stop functionality, efficient engine operation, and regenerative braking that helps improve fuel economy and emissions.

While the emission and fuel economy standards are tightening, customers want a no-compromise solution. Increasing fuel economy at the expense of some other attribute, like performance or towing/payload, may not be an option. Furthermore, electrification can no more be confined to a certain class of vehicles. Traditionally, small and medium sized vehicles have been the beneficiaries of electrification. Going forward, other vehicle segments will need to be electrified.

Customer expectation varies considerably with the class of vehicles. [Figure 1](#) shows the top purchase reasons for the CD car segment of vehicles while [figure 2](#) shows the same information for full size pickup trucks. While Value for the Money and Gas Mileage are the top reasons for the CD car segment, Trailering/Towing is the top reason for the full size pick-up truck segment. Gas Mileage does not even figure in top 10 purchase reason. This vastly different customer want is driving the need for different electrification strategy and architecture.

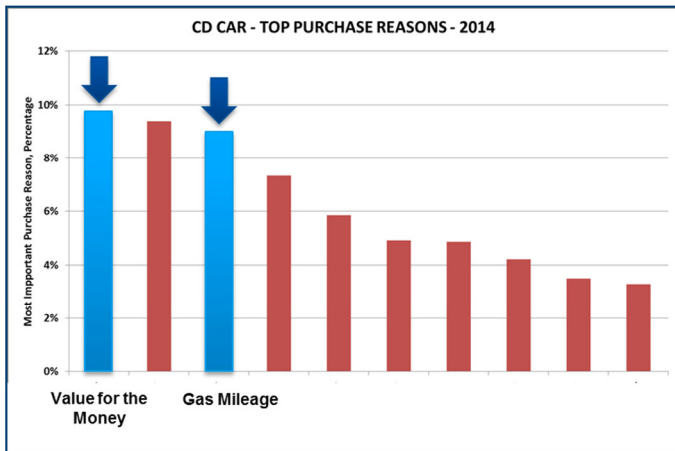


Figure 1. Top 10 purchase reasons for CD car. Top reasons being Value for the Money and Gas Mileage. Source: 2014 New Vehicle Customer Survey.

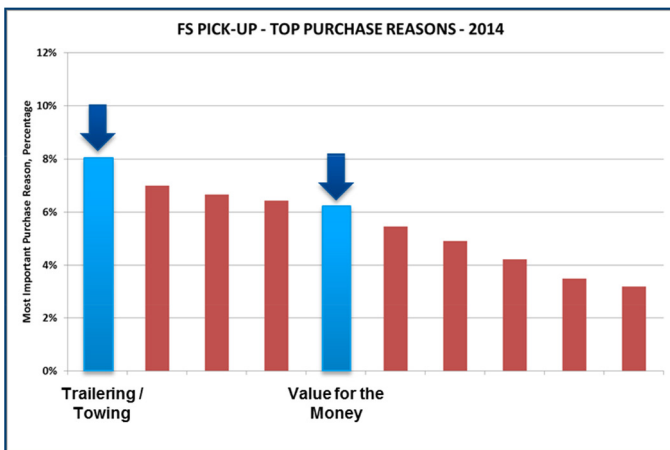


Figure 2. Top 10 purchase reasons for Full Size Pick-up Truck. Top reasons being Trailing/Towing and Value for Money. Source: 2014 New Vehicle Customer Survey.

The main types of electrified architectures currently in the market place are parallel and powersplits. Table 1 shows the major players for each type of architecture currently in the US market.

Table 1. Hybrid architecture and their usage by OEM in the US market. Data is

Architecture	Major Players
Parallel	BMW Hyundai/Kia Renault/Nissan Mercedes Benz Porsche VW/Audi Volvo
Powersplit	Ford/Lincoln Chevy/Cadillac Toyota/Lexus
Series	BMW (i3 range extender)

Parallel Architecture

Depending on the placement of the motor, there are many different implementation of parallel architecture. By industry convention, they are identified using the Pn nomenclature where n is a number corresponding to the placement of the motor in the system. The numbering convention is as follows -

- P0 - motor located at the input to the engine
- P1 - motor located at the output of the engine
- P2 - motor located between the engine and transmission
- P3 - motor located at the transmission output
- P4 - motor mounted on axle (eRAD, eFAD)

In this paper, references to a parallel hybrid refer to the P2 parallel hybrid system. This implementation is the most prevalent in the industry today.

A single motor, parallel P2 hybrid architecture layout is shown in figure 3. It consists of conventional vehicle architecture - comprising of an engine connected to a step-ratio or dual clutch (DCT) - with an electrical motor and battery added in parallel. A disconnect clutch is used to disengage the engine.

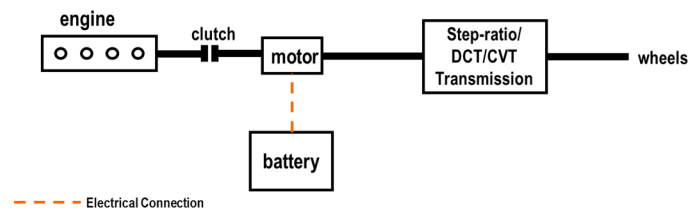


Figure 3. Typical parallel hybrid powertrain layout.

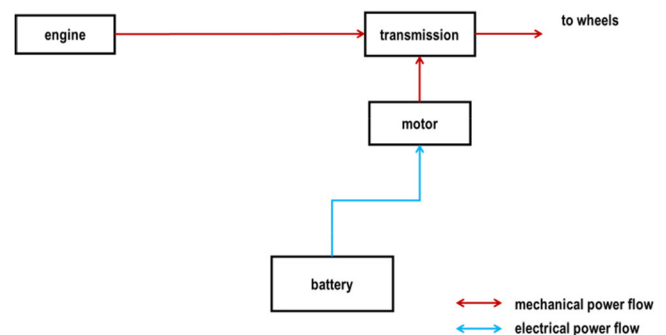


Figure 4. Parallel hybrid power flow diagram.

The power flow shown in figure 4. The mechanical power from the engine along with the electrical power from the battery (via the motor) is delivered to the wheels. During EV operation, with the engine off, electrical power is delivered to the wheels via the motor. In this mode, the clutch is open. In blended mode, the clutch is closed with the engine and the battery, via the motor, providing power to the wheels. In this mode, the engine speed is governed by the wheel speed and transmission gear ratio. Since part of the power to the wheels is provided by the motor, the engine may be operated at a torque point for best efficiency. Parallel hybrids therefore operate with two degrees of freedom - one continuous (torque) and one discrete (speed). During regenerative braking, the motor operating as a generator, recovers energy and stores it in the battery.

Detailed power flows for each of the modes of operation are shown in the [appendix](#).

Powersplit Architecture

While there are different implementations of the powersplit hybrid architecture, a simple, cost-effective layout using a planetary gear set is shown in [figure 5](#). This is a single mode configuration that uses a single planetary gear set without any clutches or brakes. This paper only assesses this powersplit particular configuration. In this configuration, the sun gear of the planetary gear is connected to the generator, the carrier is connected to the engine with the ring gear is connected to the wheels. The power from the engine is transmitted partly to the wheels (mechanical path) and partly to the battery via the generator (electrical path).

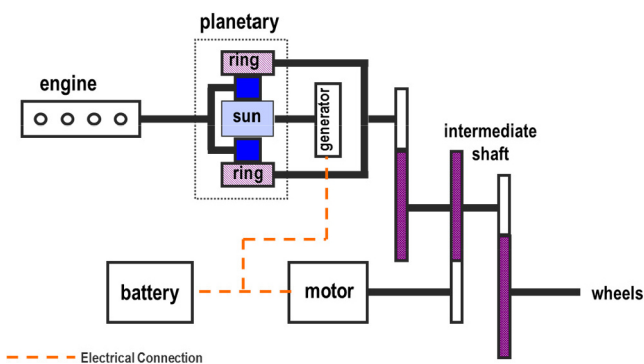


Figure 5. Typical powersplit powertrain layout.

The power flow diagram for a powersplit is shown in [figure 6](#). During EV operation, the electrical power from the battery is delivered to the wheels via the motor. In blended mode, the engine power is “split” in the planetary into the mechanical and electrical paths. The amount of the “split” is optimized for maximum efficiency. Due to the nature of the planetary, the engine operating point can be varied in the speed and torque domains allowing powersplits to also have two degrees of freedom but with both being continuous. During regenerative braking, the motor operates like a generator to store power in the battery.

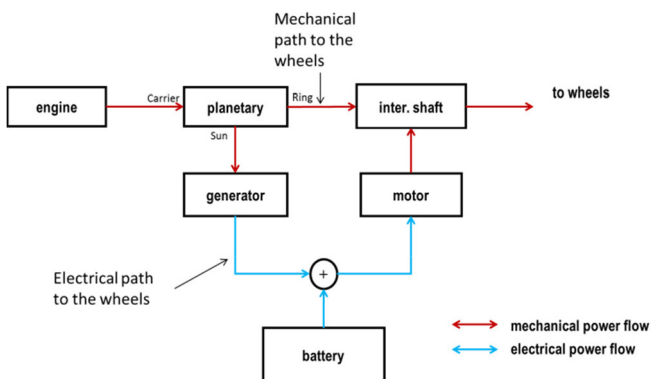


Figure 6. Powersplit powertrain power flow diagram.

Detailed power flows for each of the modes of operation of a powersplit are shown in the [appendix](#).

Powersplits have generally better efficiency than the parallel hybrids. [Figure 7](#) shows the relative efficiency of a powersplit and parallel architecture for EV launch operation. For the powersplit, the electrical power passes through the Variable Voltage Controller (VVC) and the Inverter System Controller (ISC) and Motor where the electrical power is converted to mechanical power at 87% efficiency. The mechanical power then goes through the counter gears before it is delivered to the wheels with an overall efficiency of 82%. For the parallel hybrid, the ISC/Motor power output is sent to a conventional transmission which typically operates at an average efficiency of 89%. The path then goes through a Final Drive Ratio (FDR) before being delivered to the wheels.

A similar efficiency compare is shown for regenerative braking operation in [figure 8](#). The path for regenerative braking is similar to the EV launch operation except in the opposite direction with friction brake losses added. The decreased efficiency in both directions of the power flow is multiplicative which results in even lower overall efficiency for the parallel system.

Note that this comparison is for a typical, generic vehicle to illustrate the relative efficiencies of powersplit and parallel hybrids. Specific applications of these architectures may have different relative efficiencies.

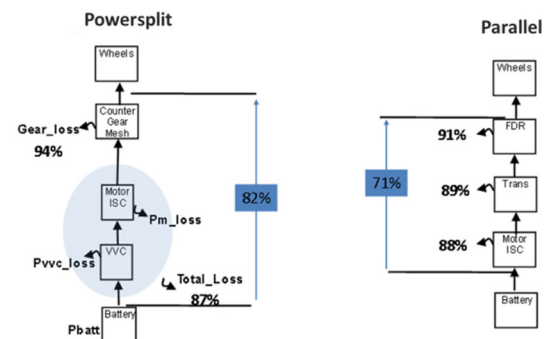


Figure 7. Efficiency comparison between Powersplit and Parallel Architectures during EV operation.

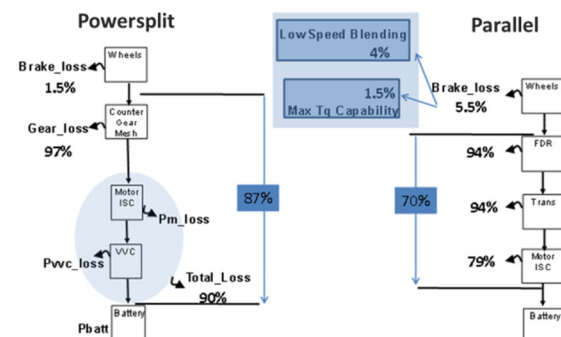


Figure 8. Efficiency comparison between Powersplit and Parallel Architectures during regenerative braking operation.