Basic Elements of the Series Hybrid Vehicle

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Introduction

Significant reductions in emissions and improved fuel economy have led to a rapid increase in the popularity of hybrid technology in both vehicles and equipment. Advances in power conversion technology as well as battery design and efficiency have enabled the expansion of the technology into consumer markets with hybrid vehicles now available at a price point comparable to conventional vehicles. Hybrid vehicles or equipment are those which use more than one source of power. Hybrid technology is rapidly gaining popularity due to its advantages of reduced emissions and improved fuel economy over that seen in conventional vehicles. A popular form of hybrid technology today is the ICE/Electric hybrid. The ICE (Internal Combustion Engine) is generally a gas or diesel powered engine, typically smaller than that used in a conventional vehicle, and the electric motor would most commonly be an induction type or a permanent magnet AC. Hybrid vehicles can be further categorized by their architecture: parallel or series. There are also other terms used, including mild hybrid, full hybrid, power hybrid, and micro hybrid, but these generally do not describe the system architecture, but rather the amount of power produced by the electric motor versus the ICE.

In a parallel hybrid design for traction, there are two prime movers (the ICE and the electric motor or motors) which are physically connected to the vehicle’s driving wheels, as if they were “parallel supplies”. In this configuration, either the electric motor or the ICE (or a combination of both) can power the vehicle’s wheels. Parallel hybrids are sometimes referred to as “full hybrids”. This type of architecture tends to be mechanically complex, requiring a larger combustion engine, a transmission, and a mechanism to couple both motors to the drive wheels.

A series hybrid vehicle also contains a gasoline or diesel engine, but it is used to power a generator. The generator provides electric power to the vehicle’s traction motor(s) and auxiliary devices, and to a storage element, typically consisting of batteries and/or capacitors. By using a relatively small internal combustion engine, which is run at an optimum speed, and using stored battery power to provide for acceleration demands, energy savings and reduced emissions are achieved. Unlike a parallel hybrid design, there is no mechanical connection between the internal combustion engine and the vehicle drive train.

Since electric motors drive the wheels, another mechanism for energy savings is easily exploited: regenerative braking. During acceleration and cruising, electric power from the batteries powers the traction motor or motors, thus propelling the vehicle. When decelerating though, or when maintaining speed on a downhill stretch of road, the traction motor begins to act as a generator, providing braking torque to the wheels, and sending electric power back to the batteries.

Series hybrid design has the advantages of reliability, fuel efficiency, and redundancy in the design that will allow vehicle operation even after failure of the engine, albeit not at full power. In this paper, the series type will be considered.
SERIES HYBRID DIAGRAM

PARALLEL HYBRID DIAGRAM
Implementation

The critical components required include several that are manufactured by Parker Hannifin’s various divisions. The electrical system of most hybrid vehicles consists of the following subsystems: Traction Drive, Auxiliary Power Unit (APU), Energy Storage System, Onboard Diagnostics and Vehicle Control, and Auxiliary equipment. Every series hybrid vehicle employs a generator, usually an induction or permanent magnet AC (PMAC) motor coupled to the engine. (A motor will function as a generator when it is rotated by an outside force.) The output from the generator is converted to a form that can charge the batteries. Generally, the conversion is from three phase alternating current (AC) at a variable frequency proportional to its running speed, to smooth direct current (DC) to feed the DC Bus. The main traction drive motor (or motors) is typically an induction or PMAC type. A bi-directional motor controller sources its power from the DC bus (the energy storage system) and provides a variable frequency output to control the speed and torque of the main traction motor based on the driver’s command. Auxiliary equipment includes fans, pumps, and compressors, for functions like power steering, ventilation, and air conditioning. Generally an additional inverter (DC to AC conversion) is used on each of these motors, though not necessarily with adjustable frequency.

Now we will examine each part of the electrical system in detail:

Traction Drive Subsystem – This consists of the components that actually drive the wheels: electric motor or motors, bi-directional inverter(s), gear reduction system in some examples, driveline, and related components.

Auxiliary Power Unit (APU) – The charging system consists of an internal combustion engine (generally gasoline or diesel, in conventional or turbine configuration), an electric generator, and related components.

Energy Storage System – This can consist of batteries, capacitors, fuel cells, or any storage or generating technology, along with the applicable monitoring, charging, equalization, and thermal control devices.

Onboard Diagnostics and Vehicle Control – These include battery management controls to ensure that charging is accomplished, dashboard displays, diagnostic tools, and related components. The accelerator and brake pedals are interfaced to the power conversion components.

Auxiliary equipment – In a typical hybrid vehicle, this includes electrical power steering and braking systems, ventilation and air conditioning systems, and related components.

Of the above items in a typical hybrid vehicle, Parker can provide a good number of components and sub-systems. The first of the electrical components in every series hybrid vehicle is the generator. The function of the generator is to turn the mechanical energy from the crankshaft of the APU engine into electrical power. The generator can be an induction or PMAC motor.

Next, the raw output from the generator must be managed and converted to a form that can charge the batteries and run the electric motors in the vehicle. The battery is inherently a direct current (DC) device, while the generator and motors are nearly always AC (alternating current) machines. This is where the motor controllers or inverter drives from Parker come into play. In the case of an AC generator, the conversion is from three phase AC at a variable frequency, to smooth DC to feed the DC Bus, the “backbone” of the electrical system.

Energy is stored in the vehicle’s battery, or a combination of battery and capacitors. Continued improvements in battery design, with higher power density, lower cost, and better charge cycles, will be crucial to the continued progress of hybrid vehicles. Over the past few years some major advances
have been made, and improvements in designs continue. A good electronic battery management system (BMS) is critical, and greatly influences battery life and performance.

The main traction drive motor can be either induction or PMAC type. (Switched Reluctance (SR) motors are sometimes used, but require a completely different control system, so will not be considered in the context of this paper.) This motor (or multiple motors) acts to power the wheels of the vehicle, as well as to absorb power when the vehicle is decelerating. For this application, a “regenerative” or bi-directional motor controller is used. Depending on the type of vehicle, more than one of these main drive units may be used. The inverter sources its power from the DC bus and provides a variable frequency output to control the speed of the main traction motor based on the driver’s input. In addition to the bi-directional inverter configuration, dynamic braking circuit is generally required. In the event that the drive cannot absorb or regenerate sufficient power to brake the vehicle, the dynamic braking resistor is switched in to dump power. On some larger vehicles, more than one motor and inverter are employed for system redundancy.

Auxiliary applications in a typical hybrid vehicle include fans, pumps, and compressors. In some cases, these are constant speed applications, but in others, variable speed is required. Depending on the situation, either a single phase or three phase output is provided. Generally for those motors that require variable speed, a controller must be used on each motor, while those motors running at a steady speed can be parallel-connected with individual overload protection.

Electric motor selection is generally determined by the type of vehicle and the design goals. Most mass-produced vehicles tend to use very specialized and custom designs, but many lower-production vehicles utilize standard or modified standard motors. Of the different types of motors used, the three most popular are presently the induction motor, the permanent magnet AC motor, and the switched reluctance motor. Each has its advantages and disadvantages. The simplest and most widely manufactured technology, AC induction, is not the most efficient, and represents a mature technology. PMAC motors display the highest power density, and better efficiency than induction, but can be costly and limited in speed range. Switched reluctance motors, while low in cost in high quantities, can display torque ripple, audible noise, and poor power factor. They also require a fairly complex drive system.

Example of applications and value-in-use

A variety of practical applications in series hybrid vehicles have already been realized, including the following. In all cases, power conversion units from Parker SSD Drives Division were used. In some, electric motors
and hydraulic components from Parker are used as well.

Transit Bus - Parker motor controllers have been successfully applied as a 250 HP main traction drive, a 60 HP generator (charging) inverter and a 2 HP blower drive on a 40 foot induction motor-powered hybrid electric bus. In this case, “off the shelf” standard drives with CAN-Open communication cards were applied. The major value-in-use here is the absence of engineering expenses, as the drive was not custom made for the application. In addition, the short lead time reduces the need for the customer to maintain inventory of hard-to-obtain or custom parts, and eliminates the need for us to document a special system.

Express Van - Standard production Class 1 though 3 commercial vans have been converted to hybrid drive trains, increasing their efficiency while generating a return on investment for the owners from the realized fuel savings. The rugged MA3 motor controller and GVM series motor from Parker proved to be a winning combination, combining efficiency and road-worthiness. The hybrid drivetrain allowed a smaller ICE to be specified, without sacrificing performance or drivability.

Wake Boat - In addition to land based opportunities, there are also others, like a high performance wake boat commonly used for recreational and competition water skiing. Replacing the traditional gasoline powered engine with an electric propulsion system resulted in a boat that not only uses half the fuel and produces less emissions, but runs much more quietly and efficiently. Running on batteries alone provides 3 hours of boating, while when supplemented with a small gas powered APU, 30 hours is achievable.

Utility Truck - Another application is on an aerial lift truck or “cherry picker”. To reduce emissions, fuel consumption, and audible noise, a battery system is used to operate the hydraulic lift mechanism for the boom, eliminating the need to leave the combustion engine idling while workers are on the lift. In this case, the electric motor is not driving the wheels of the vehicle, but rather a hydraulic pump. A Parker inverter charges the battery (a 650 volt lithium-ion array) when the combustion engine is running, and powers the hydraulic pump from the battery when called upon. A clutch arrangement allows a single motor to both power the pump and to double as a generator. In addition, the vehicle can be “plugged in” to charge the batteries during periods of non-use. Value in use includes fuel savings, reduced emissions, and reduction of audible noise required by some communities. Many other types of construction equipment also include hydraulic apparatus, generally driven by mechanical coupling or power take-off from the ICE.

Conclusion

Hybrid vehicles and equipment will be around for the long haul. In addition to a broad range of hydraulic, pneumatic, and other mechanical components, Parker offers mobile motor, generator, and power electronics solutions that are designed for use in the hybrid vehicle market. Parker's SSD Drives Division manufactures power conversion equipment for hybrid vehicle applications in the range from fractional to 1600 HP. DC bus voltages of up to 1000 volts can be accommodated. Power conversion equipment is essential in the design of hybrid vehicles. By adapting proven power electronic platforms to vehicular requirements using induction or PMAC motors and generators, Parker is able to provide
short turnaround time (concept to cash) and use proven technology. The value inherent in the hybrid vehicle design, of course, is to increase fuel efficiency and to reduce harmful emissions from the vehicle in question. A lightweight and efficient power conversion device enhances the savings. And further advantages offered include shortened development time by using standard and modified standard designs, and Parker's ability to offer a comprehensive range of products and technologies from multiple divisions.