Hybrid Electrical Vehicle, Control System for Parallel Design

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***Abstract*—A hybrid car is an automobile that has two or more major sources of propulsion power. Most hybrid cars currently marketed to consumers have both conventional gasoline and electric motors, with the ability to power the vehicle by either one independently or in tandem. This paper presents different architectures for hybrid electrical vehicle and the advantages of its use.**

***Index Terms* — HEVs components functions, hybrid electrical vehicle, mixed system, parallel system, series system**

I. INTRODUCTION

Hybrids are the wave of the future, with capabilities of running more efficiently, decreasing emissions what makes the planet a safer place, and conserves the planet's natural resources. There are three possible approaches to the problem of being dependent on petroleum fuels. First possibility is to make fuel consumption more efficient. The second possibility is to use alternative sources of power for vehicles. The third option is research and investment into new technologies.

Hybrid electric vehicles typically combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric vehicle. The combination offers lower emissions in the same power range keeping the same convenient fuelling (gasoline and diesel) — HEVs never need to be plugged in.

HEVs are powered by two energy sources — an energy conversion unit (such as an internal combustion engine or fuel cell) and an energy storage device (such as batteries or ultracapacitors). The energy conversion unit can be powered by gasoline, diesel, compressed natural gas, hydrogen, or other fuels.

II. HEVs COMPONENTS

An HEV combines an energy storage system, a power unit, and a vehicle propulsion system.

The primary options for energy storage include batteries, ultracapacitors, and flywheels. Batteries are the principal energy storage devices for hybrid electric vehicles. Desirable attributes of high-power batteries for HEV applications are high-peak and pulse-specific power, high specific energy at pulse power, a high charge acceptance to maximize regenerative braking utilization, long calendar and cycle life. Ultracapacitors are higher specific energy and power versions of electrolytic capacitors—devices that store energy as an electrostatic charge. They are electrochemical systems that store energy in a polarized liquid layer at the interface between an ionically conducting electrolyte and a conducting electrode. Energy storage capacity increases by enhancing the surface area of the interface. A flywheel is a mechanical battery that stores kinetic energy. Flywheels can be more responsive than chemical batteries, and they are less susceptible to the effects of weather.

TABLE I. BATTERY TYPES

Battery Type	Energy Density (Wh/kg)	Power Density (W/kg)	Cycle life	Vehicle Application
Lead-Acid	25 to 35	75 to 130	200 to 400	CARTA Bus, Solectria E10
Advanced Lead-Acid	35 to 42	240 to 412	500 to 800	Audi Duo, GM EV1, Solectrica Force
Nickel-Metal Hydrid	50 to 80	150 to 250	600 to 1500	Toyota RAV4-EV, Toyota Prius, Chrysler Epic minivan, Honda EV, Chevy S-10
Nickel-Cadmium	35 to 75	50 to 200	1000 to 2000	WWU Viking 23
Lithium-Ion	100 to 150	300	400 to 1200	Nissan Altra EV
Zinc-Bromide	56 to 70	100	500	
Lithium Polimer	100 to 155	100 to 315	400 to 600	
NaNiCl	90	100		
Zinc-Air	110 to 200	100	240 to 450	
Vanadium Redox	50	110	400	

Table I presents the characteristics of the most common types of batteries.

Hybrid's power unit options are spark ignition engines, compression ignition engines, gas turbines and fuel cells. Spark-ignition engine is an internal combustion engine in which the fuel mixture is ignited electrically. Compression ignition is the type of ignition that typically initiates combustion in a diesel engine. Rapid compressing of the air within the cylinders generates enough heat to ignite the fuel as it is injected. This is why diesel engines do not need spark plugs for ignition. Gas turbine represents a rotary engine that draws energy from a fuel-air mixture. A compressor raises the pressure and temperature of the inlet air. The air is then moved into a burner, where fuel is injected and combusted for increasing the temperature of the air. Power is produced when the heated high-pressure mixture is expanded and cooled through the turbine. Fuel cell is an electromechanical "engine" (no moving parts) that converts the chemical energy of hydrogen and oxygen into electricity without combustion; the only by-product is water. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode), the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes.

Propulsion can come entirely from an electric motor, such as in a series configuration, or the engine might provide direct mechanical input to the vehicle propulsion system in a parallel configuration.

A typical example of HEVs components is presented in Fig. 1.

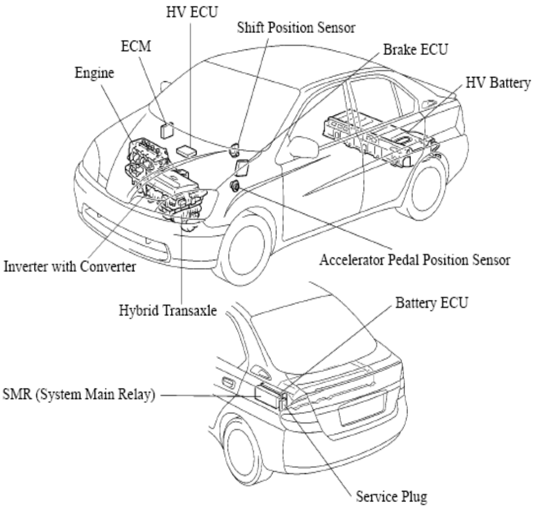

Fig. 1 HEVs Components

Main functions of HEVs components are presented in table II:

TABLE II. HEVS COMPONENTS FUNCTIONS

Hybrid Transaxle	A hybrid car's transaxle is a gear assembly that couples together its engine, motors, and wheels; conveys mechanical power between those devices; replaces the transmission of a normal car.
HV Battery	Supplies electric power during start-off, acceleration, and uphill driving; recharged during braking or when the accelerator pedal is not depressed.
Inverter	A device that converts the high-voltage DC into AC and vice versa.
Converter	Drops the high-voltage direct current into DC 12 V in order to supply electricity to body electrical components, as well as to recharge the auxiliary battery.
HV (Hybrid Vehicle Control) ECU	Information from each sensor as well as from the ECU (ECM, Battery ECU, ABS ECU) is received, and based on this, the required torque and output power is calculated. The HV ECU sends the calculated result to the actuators and controllers.
ECM	Sends a throttle open command to the electronically-controlled throttle in accordance with the engine output request factor received from the HV ECU.
Battery ECU	Monitors the charging condition of the HV battery.
Brake ECU	Controls the regenerative brake and conventionally performs the ABS control.
Accelerator Pedal Position Sensor	Converts the accelerator angle into an electrical signal and outputs it to the HV ECU.
Shift Position Sensor	Converts the shift lever position into an electrical signal and outputs it to the HV ECU.
SMR (System Main Relay)	Connects and disconnects the high-voltage power circuit using a signal from the HV ECU.
Service plug	Shuts off the high-voltage circuit of the HV battery when this plug is removed for vehicle inspection or maintenance.

III. HEVS DESIGN SYSTEM

Hybrid electric vehicles have the potential to be two or three times more fuel-efficient than conventional vehicles. HEVs can have a parallel design, a series design, or a combination of this two.

III.1. SERIES SYSTEM

The typical setup of a series-hybrid consists of an internal combustion engine, a generator, electric battery pack, and an electric motor.

Usually, an electric motor is used to do all the driving motion. The one major drawback to the series-hybrid is the weight problems that come with this system, which has been the reason for limiting the technology to only large propulsion systems.

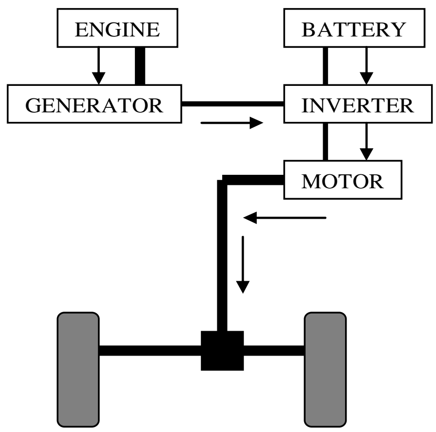

Fig. 2 Series System

Fig. 2 shows the energy flows in a series path. This is a proven technology which has been used in commercial buses and in freight trains for years. Weight became an issue because at the moment the series-hybrid was first considered, battery technologies were not where they are today. Batteries were heavy and bulky, being unsuitable for automotive applications.

III.2. PARALLEL SYSTEM

The parallel-hybrid strongly resembles with series-hybrid because of an internal combustion engine, electric motor and battery pack, but the series-hybrid also has the mechanical transmission that is connected to the mechanical final drive. It is called a parallel-hybrid because the energy takes one of two paths or it takes both paths.

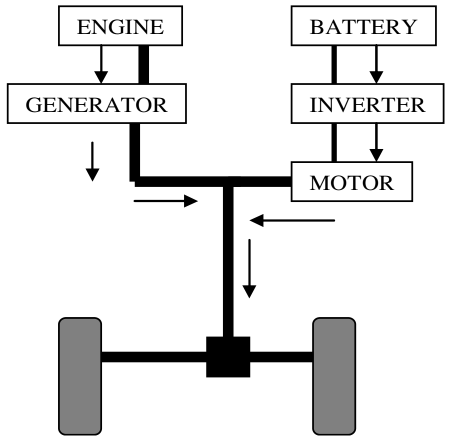

Fig. 3 Parallel System

Fig. 3 shows how the energy takes a parallel path where the transmission and the electric motor contribute to the final drive of the vehicle. This connection is normally made either with a mechanical connection to the drive train, or it occurs through other median, such as the road.

III.3. MIXED SYSTEM

The mixed system design integrates both the series and the parallel hybrid systems to form a power-split hybrid. In this configuration the vehicle can be powered by the internal combustion engine with the mechanical drive train or with the electronic drive train, or both, Fig. 4.

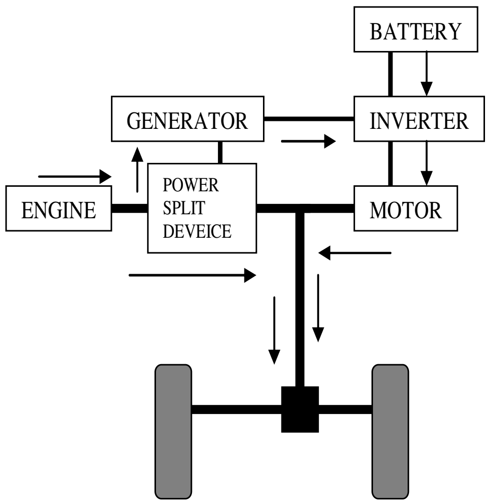

Fig. 4 Mixed System

The internal combustion engine is connected to the power split device, which is normally a unique transmission that has a planetary gear set and an electric motor that is incorporated into the transmission design. This design is found in many nowadays vehicles such as the Toyota Prius and the General Motors 2 ModeTahoe.

IV. CONTROL SYSTEM FOR PARALLEL DESIGN

The presented system is that one used to control the parallel configuration. Most hybrid dynamical systems have been designed using the concept of centralized and distributed control as in Fig. 5.

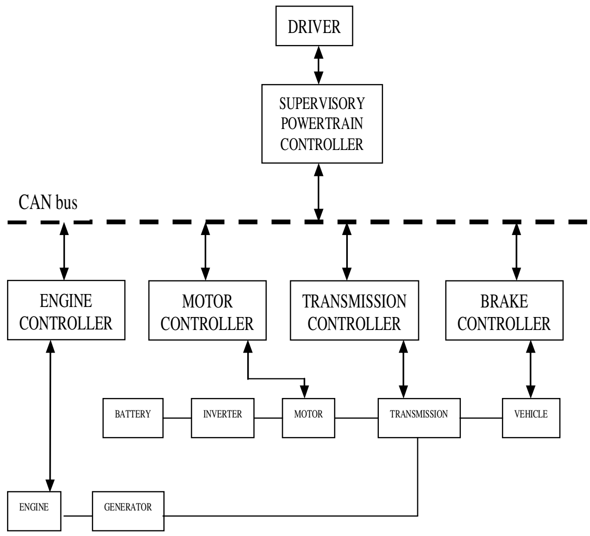

Fig. 5 Control System for Parallel Design

The supervisory powertrain controller (SPC) represents a high-level vehicle control system that can coordinate the overall powertrain to satisfy certain performance indices. Based on the driver's demand and operating parameter feedback signals of the vehicle and its components, the SPC must determine the desired propelling torque distribution between the internal combustion engine (IC engine) and the electric machine (EM), or the desired brake torque distribution between the EM and friction brake system, and the gear position. Therefore, the main function of the SPC is to determine the desired output of various sub-systems according to driver's commands, system parameter feedback signals and a pre-programmed control strategy. Different control strategies results in different fuel economy and emission characteristics.

The modelling of the vehicle dynamics derives from the basic equation for solid-body motions (Newton's Second Law):

$$F=M\cdot g\cdot C_r+\frac{1}{2}D_{air}\cdot C_d\cdot A_f\cdot V^2+M_i\cdot\frac{dV}{dt}+M\cdot g\cdot\sin(\theta) \quad (1)$$

where **F** is the force required at the vehicle wheels to reach a certain acceleration at speed **V**; **M** is the mass of the vehicle; **g** represents the acceleration of gravity; $\mathbf{C_r}$ is the coefficient of the rolling resistance between the tires and the road surface; $\mathbf{D_{air}}$ represents the air density; $\mathbf{C_d}$ is the coefficient of the aerodynamic drag for the vehicle in the travelling direction; $\mathbf{A_f}$ is the frontal area of the vehicle; $\mathbf{M_i}$ is the inertial mass of the vehicle including the rotational inertia contribution; and **θ** represents the gradient of the road.

The vehicle acceleration (**a**) is given by next:

$$a=\frac{\eta_{gb}\cdot\frac{R(k)\cdot T}{r}-M\cdot g\cdot C_r-\frac{1}{2}D_{air}\cdot C_d\cdot A_f\cdot V^2-M\cdot g\cdot\sin(\theta)}{M_i} \quad (2)$$

where $\boldsymbol{\eta_{gb}}$ denotes the efficiency of the gear box; **R(k)** is the gear ratio; **T** represents the effective torque; **r** is the radius of the wheels.

Speed is given by equation (3):

$$V = \int a \cdot dt \quad (3)$$

V. HEVs ADVANTAGES

Hybrid electric vehicles have several advantages over conventional vehicles:

- Greater operating efficiency – HEVs use regenerative braking, which helps to minimize energy loss and recover the energy used to slow down or stop a vehicle;
- Lighter engines – engines can be sized to accommodate average load, not peak load, which reduces the engine's weight;
- Greater fuel efficiency – hybrids consume significantly less fuel than vehicles powered by gasoline alone;
- Cleaner operation – HEVs can run on alternative fuels (which have lower emissions), thereby decreasing our dependency on fossil fuels (which helps ensuring our national security); and
- Less vehicle weight – special lightweight materials are used in their manufacture.

VI. CONCLUSION

This paper presents main components of a hybrid electrical vehicle, their functions. We insist on the using concept of centralized and distributed control system for a parallel design.

Hybrid electric vehicles are becoming cost-competitive with similar conventional vehicles. Some states even offer incentives to consumers for buying HEVs.

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