

Control & Communication Networks in Hybrid Fuel Cell Vehicles using CAN Protocol

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Abstract— With the more stringent regulations on emissions and fuel economy, global warming, and constraints on energy resources, the electric, hybrid, and fuel cell vehicles have attracted more and more attention by automakers, governments, and customers. This subject describes the control and communication network in fuel cell vehicles, including both the protocol and the hardware. Based on the CAN (Controller Area Network) a new practical protocol is proposed and implemented for the control and communication network in fuel cell vehicles. To improve the reliability of data communication and to unify the network management. With the more stringent regulations on emissions and fuel economy, global warming, and constraints on energy resources, the electric, hybrid, and fuel cell vehicles have attracted more and more attention by automakers, governments, and customers. Research and development efforts have been focused on developing novel concepts, low-cost systems, and reliable hybrid electric power train. This paper reviews the state of the art of electric, hybrid, and fuel cell vehicles. The topologies for each category and the enabling technologies are discussed.

Key words: Hybrid Fuel Cell Vehicles, CAN Protocol

I. INTRODUCTION

The power train system of hybrid fuel cell vehicles consists of three kinds of power sources: the fuel cell engine, the battery, and the ultra-capacitor. This combination of power sources results in a drastic increase in the automotive power train complexity though better drivability, fuel consumption and reduction in pollutants may be achieved in such vehicles. A typical conventional harness weighs 35 kg, and contains 1.6 km of wiring and 300 connectors, costing over USD 1000.

Therefore, it is very necessary and urgent to adopt a series and multiplexing way to reduce the amount of wiring, connectors and sensors. Replacing a classical harness with a multiplexing (mux) network makes vehicles more competitive as it increases their flexibility and simplifies the wiring. A controller area network is the leading protocol for in-vehicle mux systems on account of its large speed spectrum and immunity to noise.[1]. \

Application of this protocol can especially save the amount of wiring, connectors, and sensors, especially for more complex hybrid fuel cell vehicles. In addition, when systems require distributed intelligence involving many communications, controller area network (CAN) can lead to a more convenient and flexible system.

Developing cars is a major factor that has determined the increasing of the civilization degree and the continuous stimulation of the society progress. Currently, in Europe, one in five active people and in the US, one in four, directly work in the automotive industry (research, design, manufacture, maintenance) or in related domains (fuel,

trade, traffic safety, roads, and environmental protection). Compared to conventional vehicles, hybrid electric vehicles (HEVs) are more fuel efficient due to the optimization of the engine operation and recovery of kinetic energy during braking. With the plug-in option (PHEV), the vehicle can be operated on electric-only modes for a driving range of up to 30–60 km.

The PHEVs are charged overnight from the electric power grid where energy can be generated from renewable sources such as wind and solar energy and from nuclear energy.[2]. Fuel cell vehicles (FCV) use hydrogen as fuel to produce electricity; therefore they are basically emission free. When connected to electric power grid (V2G), the FCV can provide electricity for emergency power backup during a power outage.

Due to hydrogen production, storage, and the technical limitations of fuel cells at the present time, FCVs are not available to the general public yet. HEVs are likely to dominate the advanced propulsion in coming years. Hybrid technologies can be used for almost all kinds of fuels and engines. Therefore, it is not a transition technology. In HEVs and FCVs, there are more electrical components used, such as electric machines, power electronic converters, batteries, ultra capacitors, sensors, and microcontrollers. In addition to these electrification components or subsystems, conventional internal combustion engines (ICE), and mechanical and hydraulic systems may still be present.

The challenge presented by these advanced propulsion systems include advanced power train components design, such as power electronic converters, electric machines and energy storage; power management; modeling and simulation of the power train system; hybrid control theory and optimization of vehicle control.

II. HISTORY OF ELECTRIC VEHICLE

The EV was invented in 1834. During the last decade of the 19th century, a number of companies produced EVs in America, Britain, and France. In London, there were Electric Cab Company's taxis. However, due to the limitations associated with the batteries and the rapid advancement in ICE vehicles, EVs have almost vanished from the scene since 1930. Nevertheless, in the early 1970s, some countries, compelled by the energy crisis, started the rekindling of interests in EVs.

In 1976, the U.S. launched the Electric and Hybrid Vehicle Research, Development and Demonstration Act, Public Law 94-413. In the beginning of the 21st century, California had a mandate on the use of zero emission vehicles. Today, EVs are mainly used for small vehicles and short distance applications due to the limitation of batteries. In London, due to a new mandate of using zero emission vehicles in the down town, around 900 small EVs recently have been used. With the aid of intelligent transportation

systems, EVs can be used as a car sharing system, when the user will travel for longer

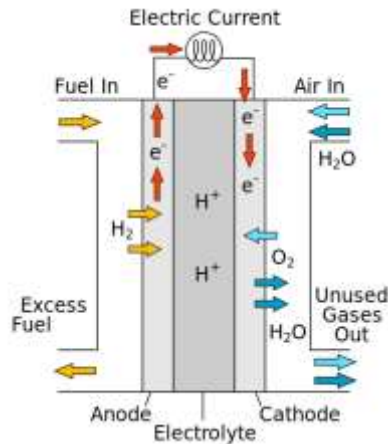


Fig. 1: Pure electric cell.

Working of pure electric cell- With a hydrogen fuel cell, the endgame is to make electricity, and to get that electric current from inside the cell to the outside where it can do useful work. The nature of electricity requires that the current flow from inside the cell through a load (the electric motor that powers a vehicle) and return to the cell in order to complete the circuit. Fuel cells require both hydrogen as the fuel and oxygen (to complete the chemical conversion) from the atmosphere to operate.[3]

- 1) Hydrogen atoms enter the cell at the anode (negative electrode), where a catalyst (at the electrolyte) causes a chemical reaction.
- 2) That strips off their electrons (e^-). These newly ionized hydrogen atoms (h^+) now have a positive electrical charge.
- 3) The negative electrons (e^-) become the DC (direct current) electricity that flows through wires and cables to provide power to the load (motor)

III. HISTORY OF HYBRID FUEL CELL

In 1898, the German Dr. Ferdinand Porsche built his first car, the Lohner Electric Chaise. It was the world's first front-wheel-drive car. Porsche's second car was a hybrid, using an ICE to spin a generator that provided power to electric motors located in the wheel hubs. On battery alone, the car could travel nearly 40 miles.

By 1900, American car companies had made 1681 steam, 1575 electric and 936 gasoline cars. In a poll conducted at the first National Automobile Show in New York City, patrons favored electric as their first choice, followed closely by steam. In the first few years of the 20th century, thousands of electric and hybrid cars were produced. This car, made in 1903 by the Krieger company, used a gasoline engine to supplement a battery pack. Also in 1900, a Belgian carmaker, Pieper, introduced a 3-1/2 horsepower Bvoiturette [in which the small gasoline engine was mated to an electric motor under the seat. When the car was Bruising, [its electric motor was in effect a generator, recharging the batteries. But when the car was climbing a grade, the electric motor, mounted coaxially with the gas engine, gave it a boost.

IV. HYBRID FUEL CELL

A hybrid electric vehicle (HEV) augments an electric vehicle (EV) with a second source of power referred to as the alter-native power unit (APU).

Pure electric vehicles currently do not have adequate range when powered by batteries alone, and since recharging re-quires several hours, the vehicles are viewed as impractical for driving extended distances. If air conditioning or heating is used, the vehicle's range is further reduced. Accordingly, the hybrid concept, where the alternative power unit is used as a second source of energy, is gaining acceptance and is overcoming some of the problems of pure electric vehicles.

HEVs are propelled by an ICE and an electric motor/ generator (EM) in series or parallel configurations. The ICE provides the vehicle an extended driving range, while the EM increases efficiency and fuel economy by regenerating energy during braking and storing excess energy from the ICE during coasting. Design and control of such power trains involve modeling and simulation of intelligent control algorithms and power management strategies, which aim to optimize the operating parameters to any given driving condition. Traditionally, there are two basic categories of HEV, namely series hybrids and parallel hybrids. [4]

In series HEV, the ICE mechanical output is first converted to electricity using a generator. The converted electricity either charges the battery or bypasses the battery to propel the wheels via an electric motor. This electric motor is also used to capture the energy during braking. A parallel HEV, on the other hand, has both the ICE and an electric motor coupled to the final drive shaft of the wheels via clutches. This configuration allows the ICE and the electric motor to deliver power to drive the wheels in combined mode, or ICE alone, or motor alone modes. The electric motor is also used for regenerative braking and for capturing the excess energy of the ICE during coasting. Recently, series-parallel and complex HEVs have been developed to improve the power performance and fuel economy.

V. WORKING OF HYBRID FUEL CELL

- 1) First time battery provides the electricity but when battery reached to its predetermined discharged level then battery turns off and at the same time APU turns on.
- 2) Now onwards APU provides electricity and also charges the battery. When battery charged then again battery turns on and APU turns off.
- 3) Electricity is produced in the fuel cell which provides the power to the load.

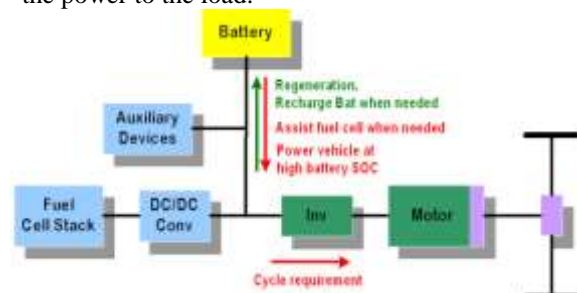


Fig. 2: Working of Hybrid Fuel Cell.

VI. MAJOR COMPONENTS OF HYBRID VEHICLES

A. Electric Drive Motors

Hybrid electric vehicles use an electric driveline and motor to provide the power for propulsion. The electric motor is a simple, efficient and durable device that is used every day in all sorts of applications. Electric motors range from those with fractional horsepower that run small appliances, to 5000-horsepower giants used in paper mills and other industries. An electric motor converts electric energy to mechanical energy (motion) to drive the hybrid vehicle. Every motor can be used as a generator by rewiring it to transform mechanical energy into electrical current, but not all motors make efficient generators. For this dual use, the hybrid may use the electric motor to start the engine and then switch to generating electricity to keep the batteries charged. This reduces both the weight and cost of having two separate devices for engine starting and battery recharging.

In conventional vehicles, engine size determines the total power available to a moving vehicle. Hybrids, on the other hand, have electric motors that provide additional power when needed by the vehicle. Both electric motors and engines can be rated in kilowatts (kW) — the preferred international standard — or in horse-power (hp). One hp equals 0.746 kW. When comparing horsepower ratings of a motor to an engine, it appears that electric vehicles are drastically under-powered. However, internal combustion engines are rated at the *maximum* power output, while electric motors are rated at their continuous power capabilities. A motor that can produce 10 hp continuously can easily produce three or four times that much power for a few minutes. Unlike internal combustion engines, electric motors emit zero harmful emissions.

B. Auxiliary Power Units

The auxiliary power unit (APU) of a hybrid vehicle supplies the baseline power required to the vehicle, recharges the batteries and powers accessories such as the air conditioner and heater.[5] The APU can consist of a mechanical type engine or a fuel cell. A mechanical type engine can be a spark ignition, compression ignition, rotary, and turbine or Stirling engine.

C. Generators

All the power systems described above, except for the fuel cell, require a generator to convert the mechanical power into electrical power when used in a series hybrid. Generators, like electrical motors, are either AC or DC.

AC Generators -An AC generator (or alternator) produces an electric current that reverses direction many times per second. It is also called a synchronous generator because it generates a voltage containing a high frequency proportional to, or synchronous with, the speed of the rotor. A simple AC generator has each end of its wire loop, or armature, attached to a slip ring. A carbon brush connected to the outside circuit rests against each of the slip rings.

As the armature rotates the current moves in the direction of the arrows. The brush at the first slip ring conducts the current out of the armature. When the armature rotates parallel to the magnetic field, no current is generated for a moment. When the armature rotates into the magnetic field again, the current reverses direction. It then flows out

of the armature through the second slip ring and back into the armature at the first slip ring.

DC Generators- A DC generator produces an electric current that always flows in the same direction. It is different from the AC generator in both the way it is built and how it is used. The commutator rotates with a loop of wire just as the slip rings do with the rotor of an AC generator. Each half of the commutator ring is called the commutator segment and is insulated from the other half. Each end of the rotating loop of wire is connected to a commutator segment. Two carbon brushes connected to the outside circuit rest against the rotating commutator. One brush conducts the current out of the generator and the other brush feeds the current back in. The commutator is designed so that no matter how current in the loop alternates, the commutator segment containing outward-going current is always against the “out” brush at the proper time.

D. Batteries

Batteries are one of the most important parts of a hybrid vehicle. A battery produces electricity by means of chemical action. It consists of one or more electric cells. Each cell has all the chemicals and parts needed to produce an electric current.

There are two types of batteries: primary and secondary (or storage) batteries. Primary batteries discharge and must be discarded after one or more of the chemicals is used up. Secondary batteries, on the other hand, can be recharged after they have delivered their electrical energy. Consequently, secondary batteries are ideal for hybrid application. They are able to supply power to the vehicle and be re-used. The criteria used for battery selection are: temperature, energy density, power density, service life, shelf life, cost, reliability, cell configuration, charge/discharge cycle, safety, operating environment, recycling, minimal memory effect and efficiency.

VII. CAN HISTORY

Bosch originally developed the Controller Area Network (CAN) in 1985 for in-vehicle networks. In the past, automotive manufacturers connected electronic devices in vehicles using point-to-point wiring systems. Manufacturers began using more and more electronics in vehicles, which resulted in bulky wire harnesses that were heavy and expensive. They then replaced dedicated wiring with in-vehicle networks, which reduced wiring cost, complexity, and weight. CAN, a high-integrity serial bus system for networking intelligent devices, emerged as the standard in-vehicle network.[6]

CAN was first created for automotive use, so its most common application is in-vehicle electronic networking. However, as other industries have realized the dependability and advantages of CAN over the past 20 years, they have adopted the bus for a wide variety of applications. Railway applications such as streetcars, trams, undergrounds, light railways, and long-distance trains incorporate CAN.

VIII. NEED FOR CAN

A vehicle contains a network of electronic devices to share information/data with each other. For example A spark

ignition engine requires a spark to initiate the combustion chamber at the correct time so it communicates with engine control unit that adjusts the exact timing for ignition to provide better power and fuel efficiency. Every electronic device has an ECU/MCU (electronic/microcontroller control unit) with its own set of rules to share/transfer information.

For two or more devices to interact they should have the necessary hardware and software which allows them to communicate with each other. Before CAN was introduced in the automobiles, each electronic device was connected to other device using the wires (point to point wiring) which worked fine, when the functions in the system were limited. The figure below is the pictorial view of the point to point wiring connection

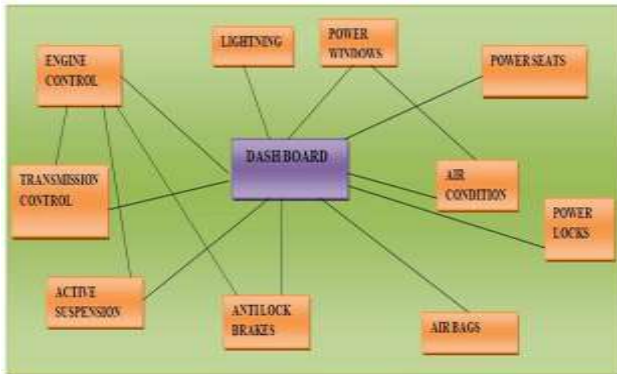


Fig. 3: Pictorial view of point to point wiring connection.

One of the major problems for automotive engineers was linking the ECUs of the different devices so that real time information can be exchanged. CAN protocol was designed to address this problem. It laid down the rules through which the various electronic devices can exchange information with each other over a common serial bus This in turn reduced the wiring connections to a great extent thereby reducing the bulkiness and complexity of the system.

IX. CAN BENEFITS

A. Low-Cost, Light weight Network

CAN provide an inexpensive, durable network that helps multiple CAN devices communicate with one another. An advantage to this is that electronic control units (ECUs) can have a single CAN interface rather than analog and digital inputs to every device in the system. This decreases overall cost and weight in automobiles.

B. Broadcast Communication

Each of the devices on the network has a CAN controller chip and is therefore intelligent. All devices on the network see all transmitted messages. Each device can decide if a message is relevant or if it should be filtered. This structure allows modifications to CAN networks with minimal impact. Additional non-transmitting nodes can be added without modification to the network.

C. Priority

Every message has a priority, so if two nodes try to send messages simultaneously, the one with the higher priority gets transmitted and the one with the lower priority gets postponed. This arbitration is non-destructive and results in non-interrupted transmission of the highest priority

message. This also allows networks to meet deterministic timing constraints.

D. Error Capabilities

The CAN specification includes a Cyclic Redundancy Code (CRC) to perform error checking on each frame's contents. Frames with errors are disregarded by all nodes, and an error frame can be transmitted to signal the error to the network. Global and local errors are differentiated by the controller, and if too many errors are detected, individual nodes can stop transmitting errors or disconnect itself from the network completely. A decentralized architecture provides autonomy to each specified control unit; for example, each electronic control unit can handle its local sensor signals. It is obvious that development of decentralized architecture requires one fundamentally necessary condition-reliable data exchange among all the separate electronic control units.[7]

Originally specified by Bosch, CAN is an advanced serial communication network, which efficiently supports distributed real-time control and multiplexing with a very high safety level. Consequently, CAN-based networks have been widely used in the automotive field and extended to other industrial environments. CAN seems to be the best candidate for providing a reliable and safe control and communication network for distributed control systems.

A hybrid fuel cell vehicle is not the same as a traditional vehicle. It has some heavy current components, which are distributed throughout the vehicle, such as the fuel cell engine, the battery, the motor, etc. If a centralized controller is used to control all of these parts, the vehicle may not be able to move because the heavy currents will always disturb the weaker currents, especially for analog signals. For these reasons, a CAN-based distributed control system is selected for our fuel cell vehicle.

The power train of fuel cell vehicle is made up of six parts: a battery, a main DC/DC controller, a fuel cell engine, an ultra capacitor, a 24-V DC/DC converter, and a motor. Each part has its own control unit. The control strategy is realized by the vehicle system controller(VSC), which accepts status signals from subcomponents and sends control signals to them through the CAN bus. In addition, we use a data acquisition unit to acquire the status of the vehicle, and a display and diagnosis unit to display and diagnose the data flow in the CAN bus. The CAN board is the bridge for data exchange between the electric unit and one CAN bus; one electric unit and a CAN board comprise one network node. Above Fig. shows all the nodes in the CAN-based network.

X. WORKING OF CONTROL & COMMUNICATION NETWORK

- 1) A hybrid vehicle is not the same as a traditional vehicle it has some heavy current components, which are distributed throughout the vehicle, such as the fuel cell engine, battery, motor etc as shown in the above fig.
- 2) Each part has its own control unit
- 3) The control strategy is realized by the vehicle system controller(VSC),which accepts status signals from subcomponents & sends control signal to them through the CAN bus.

- 4) The CAN board the bridge for data exchange between the electric unit & CAN bus.
- 5) In this way control network is implemented by using CAN protocol & CAN seems to be best candidate for providing a reliable & safe control & communication network for distributed control system. [8].

XI. CONCLUSION

The hybrid electric vehicles are very complex dynamic systems and have an important number of interconnected electrical systems to achieve the required operating performances. Because of the complexity of the real time control for a hybrid electric vehicle it is necessary to integrate all the elements in a high speed CAN communication network to assure the distributed control of all the resources. For the hybrid electric vehicle experimental model is used a CAN open network with one master node and four slave nodes. The distributed system control with the CAN open protocol on a CAN bus permits the control of the electrical drives systems in safe conditions and with improved dynamic performances.

With the ever more stringent constraints on energy resources and environmental concerns, HEVs will attract more interest from the automotive industry and the consumer. Although the market share is still insignificant today, it can be predicted that HEVs will gradually gain popularity in the market due to the superior fuel economy and vehicle performance. Modeling and simulation will play important roles in the success of HEV design and development.

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