Algorithm and Control Strategies for Hybrid Electric Vehicle

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Abstract: ***In this paper, an approach to the problems regarding control of the electricity generation of hybrid electric vehicles (HEVs) is presented and an algorithm with the goal of minimization of fuel consumption is proposed. As increasing number of cars environmental pollution due to emissions from internal combustion engines (ICE), fuel consumption is increased. Currently, a number of researches are focused on the possibility of using fuel cells for producing energy from hydrogen. Electric Vehicles with fuel cells becomes a competitive alternative to the standard ICE which is used in today's cars. Electric vehicles are zero emission vehicles, called ZEV type vehicles (Zero-Emissions Vehicles. The hybrid electric vehicles are very complex dynamic systems and have an important number of interconnected electrical systems to achieve the required operating performances. As the time control of a hybrid electric vehicle is complex, it is necessary to integrate all the elements in a high speed communication network to assure the distributed control of all the resources. In this study, overview of HEVs with a focus on hybrid configurations, energy management strategies and electronic control units are presented. The latest trends and technological challenges in the near future for HEVs are discussed.***

Keywords: ICE, Hybrid Electric Vehicle, Control strategies, Fuel Consumption, Energy Management.

1. Introduction

The environmental scientists has given the solution for avoiding the catastrophic climate changes that, the emission of greenhouse gases should be reduced to 60% below the present level of greenhouse gases. The petroleum products are low in price hence it occupies 85 % of the world's basic energy. Petroleum products are the basic energy source for any vehicle and 40% of total emission of greenhouse gases is due to these automobiles [2]. Many of the laboratories from world and vehicle manufacturer have been started the projects on electric vehicle to reduce carbon emissions and dependency on petroleum energy. For accomplishing these objectives many configurations of electric vehicles are designed and Hybrid Electric Vehicle is one of those configurations. The traction power in HEV drive train is provided by the internal combustion engine and a secondary energy storage device [3].

1.1 Hybrid Electric Vehicle

Figure 1 shows, the probable subsystems of hybrid vehicle configurations. Hybrid Electric Vehicles are consists of the arrangement of internal combustion engine along with secondary energy storage device. HEV's are more fuel efficient than conventional vehicles and reduces air pollution. A Hybrid Electric Vehicle is different from a standard internal combustion engine driven vehicle by following parts:

- An electrical machine to convert electrical power into mechanical torque on wheels [1],
- A device to store large amount of electric energy,
- A transmission system between two different propulsion technique,
- A customized ICE adapted to hybrid electric use [2].

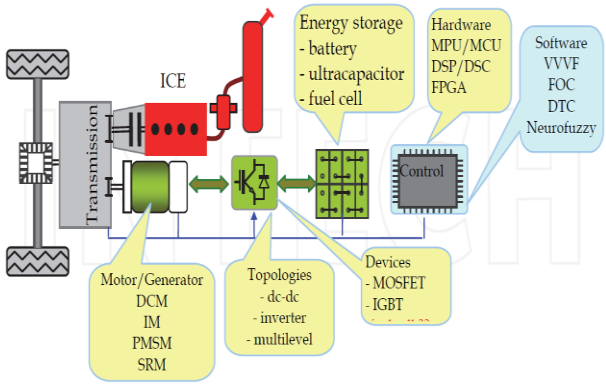

Figure 1: Components of HEV [1]

The planetary gear system of HEV divides the power generated by ICE and supplies amount of it to the wheels and remaining to the generator to either supply electric power to motor or to recharge the battery. A regenerative breaking system is also used to charge the system during deceleration of vehicle [7]. In terms of construction, operation and electronic control system, HEV's power train is complex than similar vehicle outfitted with conventional internal combustion engine. HEV's are classified according to power train configuration in three types:

- Series Hybrid Electric Vehicles
- Parallel Hybrid Electric Vehicles
- Combination Hybrid Electric Vehicles.

1.1.1 Series Hybrid Electric Vehicle:

Figure 2 shows the power flow of SHEV power train. In this type of configuration there are no mechanical connections between internal combustion engine and wheels. Internal combustion engine is off when the power is supplied from battery packs and it is turned on when the battery energy is low.

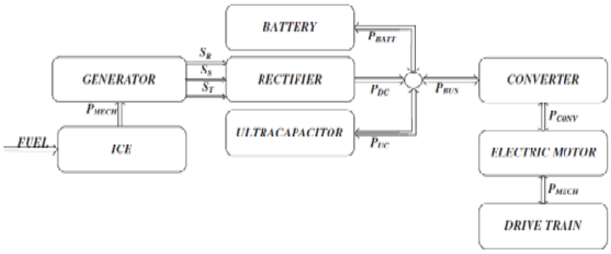

Figure 2: Power flow of SHEV power train [1]

Once the power requirement of electric motor is less than power output of generator then the remaining power is used to charge ultra capacitor banks and battery pack. If it is higher than power output of generator then required power is supplied from ultra capacitor banks and battery pack. With this arrangement, the fuel efficiency is better and pollution is also less compared to other vehicle configurations.

1.1.2 Parallel Hybrid Electric Vehicle

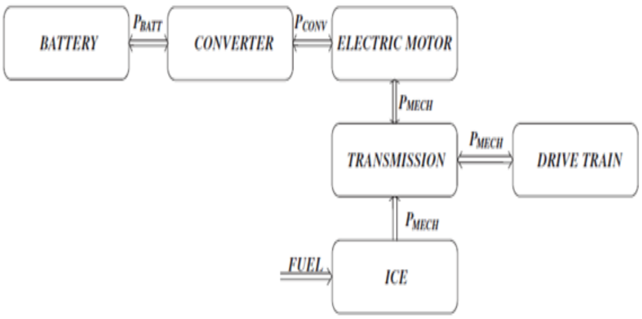

Figure 3: Power flow of PHEV power train [2]

Figure 3 shows, power flow of PHEV power train. Transmission is driven by both mechanical and electric power output which is connected in parallel in this type of configuration. In general, internal combustion engine is on. Once the power requirement from transmission is higher than output power of ICE then electric motor is turned on, so power is supplied by both ICE and electric motor and if it is less than output power of ICE then battery packs are charged using remaining power.

1.1.3Combination of Parallel and Series Hybrid Electric Vehicle:

The combination type of configuration is neither totally parallel nor series [1]. This configuration has features of both series and parallel hybrid configurations. Though this configuration is expensive, zero emission operation can be achieved in it [2][4].

2. Control Strategies for hybrid vehicle:

With different requirements, various control strategies can be used in drive train of vehicle. The main objectives of the hybrid electric vehicle are:

- To operate each component of vehicle with optimum efficiency
- To fulfill the power requirements of driver
- To recover breaking energy as much as possible,
- To maintain state of charge of battery in a preset window [2].

Energy management control strategies can be divided into two main parts:

- Rule based control strategy,
- Optimization control strategy.

2.1 Rule based Control Strategy

The effectiveness of rule based control strategy in real time supervisory control of power flow of hybrid power train is the main feature of this strategy. The fundamental idea behind this strategy is load leveling. By moving the actual ICE operating point as close as possible to predetermined value for every instant in time during operation of vehicle is the fundamental concept of load leveling of HEV. Two types of this strategy are deterministic based method and fuzzy rule based method.

2.2 Optimization Control Strategy

Finding optimal torques for power convertors and optimal gear ratio by minimizing the fuel consumption is major idea of this strategy. A global optimum function is found by performing this optimization over a fixed driving cycle. Though this approach cannot be used directly for real time energy management, it can be the basic concept for designing rules for online implementation or comparison for measuring the quality of further control strategies. This strategy can be classified into global optimization and real time optimization [3][6]. Along with these two coordinate subsystems a Vehicle System Controller (VSC) is used in hybrid electrical vehicle. Transmission control module (TCM) is used to transmit the controller's command to electric generator and electric motor.

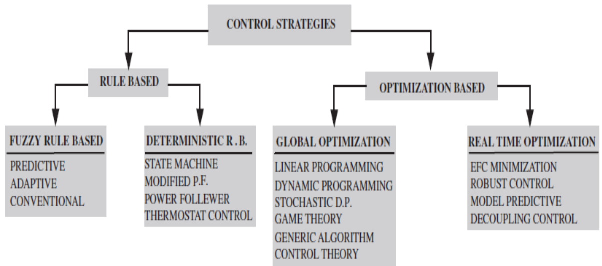

Figure 4: Energy management control strategies

Basically the function of VSC is to take inputs as environmental situations, driver's requirements and current state of vehicle and give output as commands for components as shown in fig.

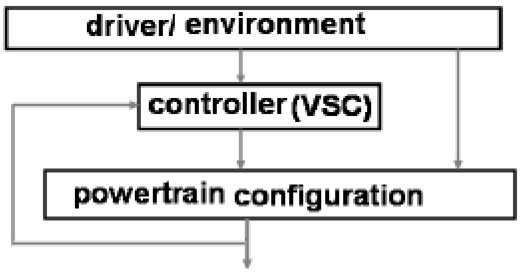

Figure 5: Vehicle System Controller

Vehicle system controller has some functionality. Using them we can predict and optimize the fuel consumption in hybrid electrical vehicle. The elements of that functionality are as follow:

- **Fuel consumption modeling:**

In this type, route of the vehicle is divided into number of segments which are linked to each other. Each of these segments has parameters like length of segment, road grade, and estimated vehicle speed for that segment. All of these parameters are the function of distance and time. Now using these parameters vehicle system controller controls the battery state of charge (SoC) at every segment. VSC and Monte Carlo simulation are used to average the fuel consumption in hybrid electric vehicle [4].

- **Path dependent control:**

Vehicle route is also divided into number of segments connected with one another. The sequence of the State of Charge (SoC) set points is prescribed by this functionality to minimize the total fuel consumption. In the every segment, related to set point the VSC controls the battery state of charge and Control law is a function of state vector. This state vector has two components segment/node and state of charge at that node. Using all the expected combinations of state of charge at beginning of each element and set point for state of charge in that segment, fuel consumption is estimated [5].

The major difference between conventional vehicles and hybrid vehicles is conventional vehicles are solely dependent on internal combustion engine for motive power whereas hybrid vehicle can have many configurations along with their specific energy flow patterns. In conventional vehicles, overall efficiency is determined by combined efficiency of its components. On the other hand overall efficiency of hybrid vehicle is determined by its configuration and utilization of components. In hybrid vehicles energy management ensures that vehicle energy resources are effectively utilized. Energy management system minimizes fuel consumption, reduces component load and carbon emissions.

3. Control Strategy Algorithm:

It can be of two distinct modes:

- Charge Depleting mode:

Vehicle is operated by electric drive, engine subsystem or both. There is a net decrease in battery state of charge during this mode.

- Charge Sustaining mode:

In this mode also vehicle is operated by engine drive, engine subsystem or both but battery state of charge is constant.
The behavior of battery state of charge is as per following graph:

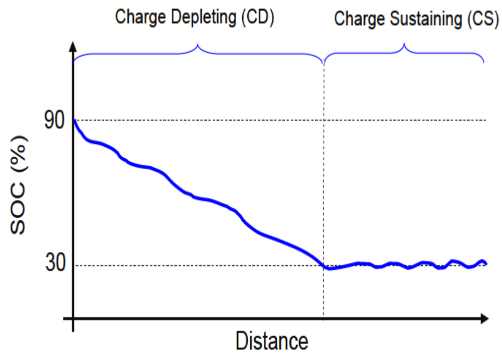

Figure 6: Control strategy SOC behavior

The important part of control strategy logic is logic of engine ON/OFF. Following conditions are the base of engine ON logic:

- Power requested is above the threshold
- Battery SOC is lower than a threshold
- Required wheel torque cannot be provided by the electric motor

Along with these parameters additional logic is included. By maintaining the engine ON or OFF during certain duration this logic ensures this logic ensures proper drive quality. In case of avoiding unintended engine ON events caused due to sudden rise in power demand, the required power has to be above the threshold for predefined duration. Engine ON and OFF logic condition are similar. Power demand used to determine the engine ON/OFF logic is the addition of requested power at the wheels and additional power that depends on battery state of charge. This enables to regulate battery SOC especially during charge depleting mode. The engine ON/OFF logic is as below:

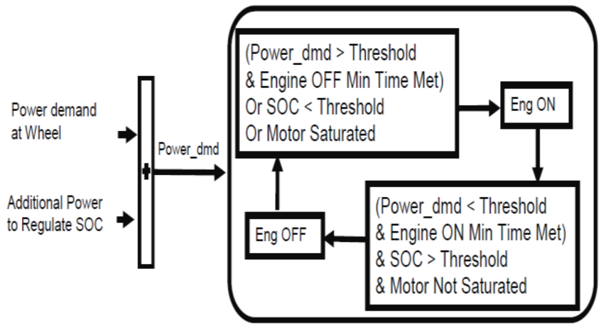

Figure 7: Simplified Engine ON/OFF Logic

Among all the algorithms used, DIRECT algorithm works especially well. It is a derivative free algorithm. At the start, the design box is scaled to an 'n' dimensional unit hypercube. The purpose function is evaluated at the center point of the hypercube; with this the algorithm starts its search [1]. Then by sampling the longest co-ordinate directions of the hyper-triangle it divides potentially optimal hyper-triangles. Sampling process gives each sampled point as the center of its own n dimensional rectangle. When convergence is achieved or termination is reached, the division process stops [6].

4. Conclusion

The technology developers has forced to use new energy sources as their design basics because of the Vanishing fossil fuel energy sources and the increase in emission of carbon .HEV's are the solutions having low emissions ,low fuel consumption and low operating cost. With development in technology and support of government to manufacturers, hybrid electrical vehicle is going to be a far better as well as popular option in future years [4]. Overview of hybrid electrical vehicle along with its basic configurations, energy management systems and electronic control strategies are highlighted in this paper. Further development in the parameters of HEV will increase its efficiency [6]. Control systems which are explained, allows the vehicle to operate in diverse set of modes along with the minimum fuel consumption. The additional development in technology will help in further reducing the emissions. Overview of positive points of HEV over the conventional vehicles will promote the further development in technology [3].

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