International Journal of Innovative Research in Computer Science & Technology (IJIRCST)
ISSN: 2347-5552, Volume-9, Issue-4, July 2021
https://doi.org/10.55524/ijircst.2021.9.4.28
Article ID IRPD219428, Pages 123- 127
www.ijircst.org

Dynamic Modelling and Control Analysis of a Fuel Cell Connected to Electric Vehicle

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ABSTRACT- A fuel cell electric vehicle (FCEV) is an electric vehicle that uses a fuel cell to power an electric motor. FCEV aims to provide customers with the benefits of battery electric vehicles such as low-to-zero emissions, high efficiency and low maintenance, without compromising on range and recharge times. A novel power management control strategy is proposed to improve the fuel cell system simulation model that is easy to use and has acceptable accuracy at the same time. The simulation model is developed through MATLAB / Simulink software using the energy macroscopic representation method, the accuracy of this method is compared with an established model. Fuel cell integration simulation analysis is performed using experimental data from a real battery car.

KEYWORDS- Control Analysis, Fuel Cell, Non-Hybrid Fuel Cell Vehicle, Electric Vehicle

I. INTRODUCTION

Recent advancements in fuel cell technology have made them suitable candidates for portable applications and specifically in vehicles. Electric vehicles take the most advantage of fuel cells in different configurations. They bring the advantage of longer driving range compare to battery-powered vehicles and increase the performance of the system by providing fuel-economy configurations. Electric vehicles use fuel cells either as the only source of energy or they are connected to a backup source of power such as battery or ultra-capacitors to configure non-hybrid or hybrid electric vehicles respectively

Energy in general means capacity or ability to produce work. Energy is essential part of our life and it's impossible to survive without it. As time passed by and with technological advancement humans were able to use this energy in various forms. Considering the utilization of energy in daily life it was possible to categorize it as renewable and non-renewable sources. Microgrids are possibly implemented in two ways; it can be similar to small electrical generator to provide backup power or a complex system integrated with the Grid consisting of generation, storage and power management systems. These systems consist of a bunch of technologies on the supply side as well as on demand side and located at or near the location of loads.

A. Non-Hybrid Fuel Cell Vehicle

Electric vehicles that use fuel cells in their power train are often called fuel cell vehicles. As mentioned earlier, if fuel cells are the only source of power in the vehicle the configuration is a non-hybrid fuel cell vehicle. This vehicle has a fuel cell to provide electric power, a DC/DC convertor to boost up the low output voltage of the fuel cell and an inverter to feed the required waveforms to the electric motor.

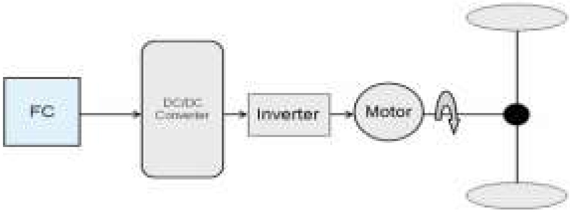

Figure 1: Non-hybrid Fuel cell vehicle

Figure 1 shows schematic of a non-hybrid fuel cell vehicle. The fuel cell can provide a range of power in minimum Pfcmin and maximum PfcMax. This range of power can also be controlled by the power electronic converters in the vehicle to obtain a faster response to the command. In different driving cycles the fuel cell is also controlled to lower the fuel consumption. Like other power sources, fuel cells have an optimum operating point that generates maximum efficient power and increases the fuel-economy. The best design is the one that powers up the system while maintaining the optimal operating point of the fuel cell. The power demand has a huge impact on operation of the fuel cells. To meet the demand in non-hybrid fuel cell vehicles, the nominal power of the fuel cell is chosen at the maximum possible power of the vehicle. Therefore, depend upon the driving conditions, the fuel cell may not necessarily operate in optimal conditions, specifically when it is operating in urban driving cycle while lower loads are required from a huge fuel cell.

B. Objective

Conventional designs of hybrid fuel cell vehicles make use of a single fuel cell power source and a storage device to provide the base load and transients in various driving cycles. This research proposed a new configuration of multiple fuel cell power sources in hybrid fuel cell vehicles. Multiple fuel cells were downsized to provide the same amount of power, which brought the advantage of a highly fuel economic design. Highly efficient driving conditions in urban applications were obtained which also resulted in more reliable system configurations. The proposed power management for this new configuration was presented and the simulation results for a double fuel cell configuration showed the predicted response of power sources. Fuel cells were efficient while they operated in their higher loading percentage. Efficiency curves were introduced and used for efficiency analysis. To gain higher efficiencies in hybrid fuel cell vehicles, fuel cells should be loaded in their efficient region of operation. The main objective of this paper was to achieve a higher efficiency in urban driving cycle. In conventional configurations, the fuel cell was not efficiently loaded in urban driving cycles, where small powers were required from the single fuel cell power source. In that case, the fuel cell was usually loaded in its low efficient region which made the whole system inefficient. By utilizing the new configuration, fuel cells could be loaded in their efficient region in urban driving cycles and provided a fuel economic vehicle.

II. CIRCUIT MODELLING AND CONTROL STRATEGY

A. Circuit Modelling

In equivalent circuit modelling, shown in Figure 2 voltage represents the pressure and current represents the mole flow. The capacitor C1 shows the effect of the constant V/RT.

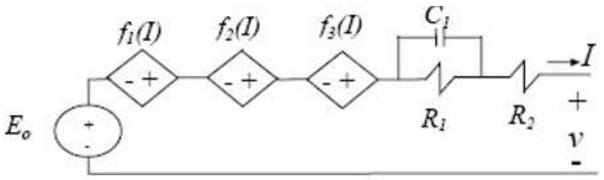

Figure 2: The main circuit model for fuel cell

PEM Fuel Cell Simulation in MATLAB/Simulink
The circuit model obtained in previous section is completely modeled in this part using MATLAB/Simulink. The input hydrogen and oxygen mole flow rate are presented by a 0-5volts input in the model. Number of cells in the model is N= 60 and the channel flow area is19.4 cm 2. The output is the fuel cell stack voltage which is connected to a load where in the simulation the load is considered purely resistive. The V-I characteristic curve of this fuel cell is shown in Figure 3. As it can be seen in this figure 3, the V-I characteristic of the fuel cell model is as expected and similar to that of a real fuel cell. The activation, ohmic and concentration losses can be seen in the V-I characteristic of the fuel cell model.

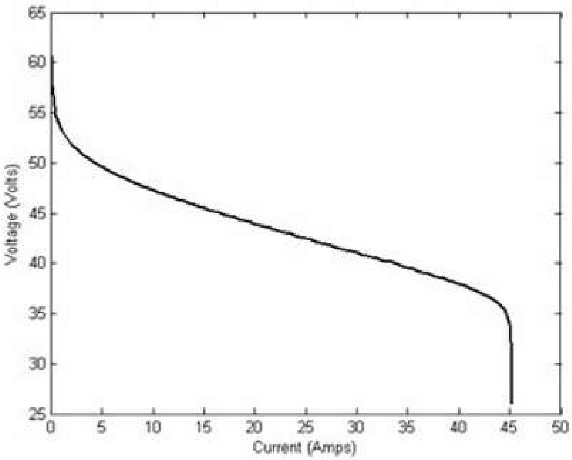

Figure 3: V-I characteristic curve of the fuel cell model in MATLAB

B. Control Strategy

The power management algorithm for this type of vehicle is shown in Figure 4. In this algorithm Pcomm stands for the command power (also known as the maximum required power Pmax as (3.2.2)), PfcMax is the rated (maximum) power of the fuel cell, Pfcmin is the minimum power of the fuel cell. This algorithm explains a comparison-based technique to determine the command power according to the fuel cell capabilities. If the power is out of the range, it is limited to the fuel cell power capabilities, and if it is in range the command power is the power required from the fuel cell.
To simulate the control algorithm for different driving cycles, a Sport Utility Vehicle (SUV) with parameters is chosen and equipped with fuel cell and electric traction system as shown in Figure 4.

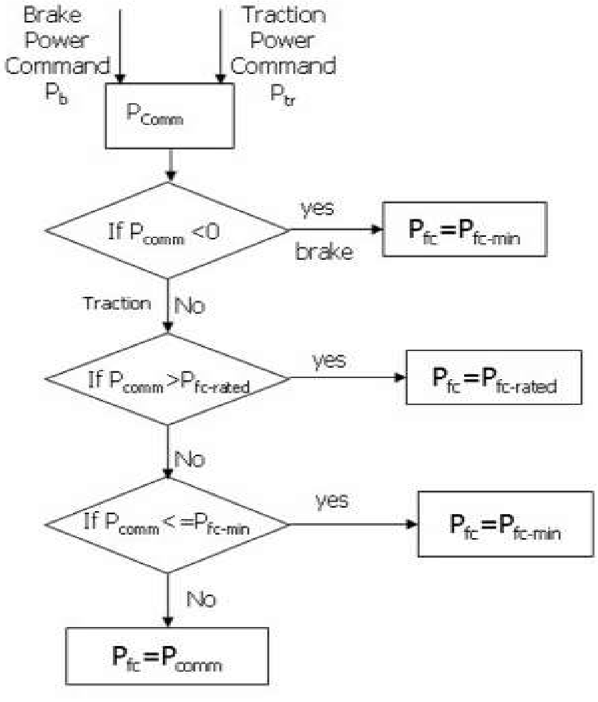

Figure 4: Power flow algorithm for the non-hybrid fuel cell vehicle

C. Schematic

Recent advances in fuel cell structures have introduced them to many applications such as hybrid electric vehicles and heat/power cogenerations. They bring the advantage of clean energy and decrease the dependency on imported oil by providing fuel efficient devices in many applications such as electric vehicles.

Efficiency of the electric vehicles depends on the size and efficiency of the fuel cell, power electronics and electric motor applied in them. Significant research has been conducted to improve the performance of electric vehicles by introducing more efficient fuel cell and battery configurations. Traditional designs of hybrid electric cars utilize a single fuel cell and battery backup. Figure 5 shows the schematic illustration of the fuel cell powered vehicle containing a fuel cell, battery unit, power electronics, electric motor and transmission systems as major components.

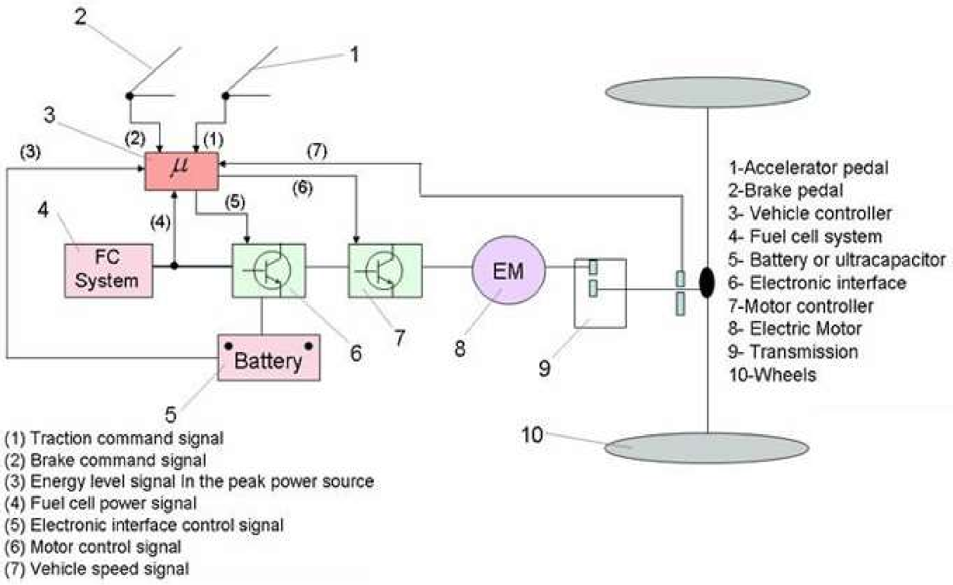

Figure 5: the schematic configuration of the fuel cell powered vehicle

The system provides the total power required for the vehicle at each time instant. The response time of fuel cells is considered negligible. The fact is that the response times of fuel cells vary by the size and operating conditions, i.e., smaller size fuel cells have short start-up time and they operate efficiently at higher percentage of their nominal power. Therefore, downsizing of a high-power fuel cell offers an efficient and fast unit.

III. SIMULATION RESULT

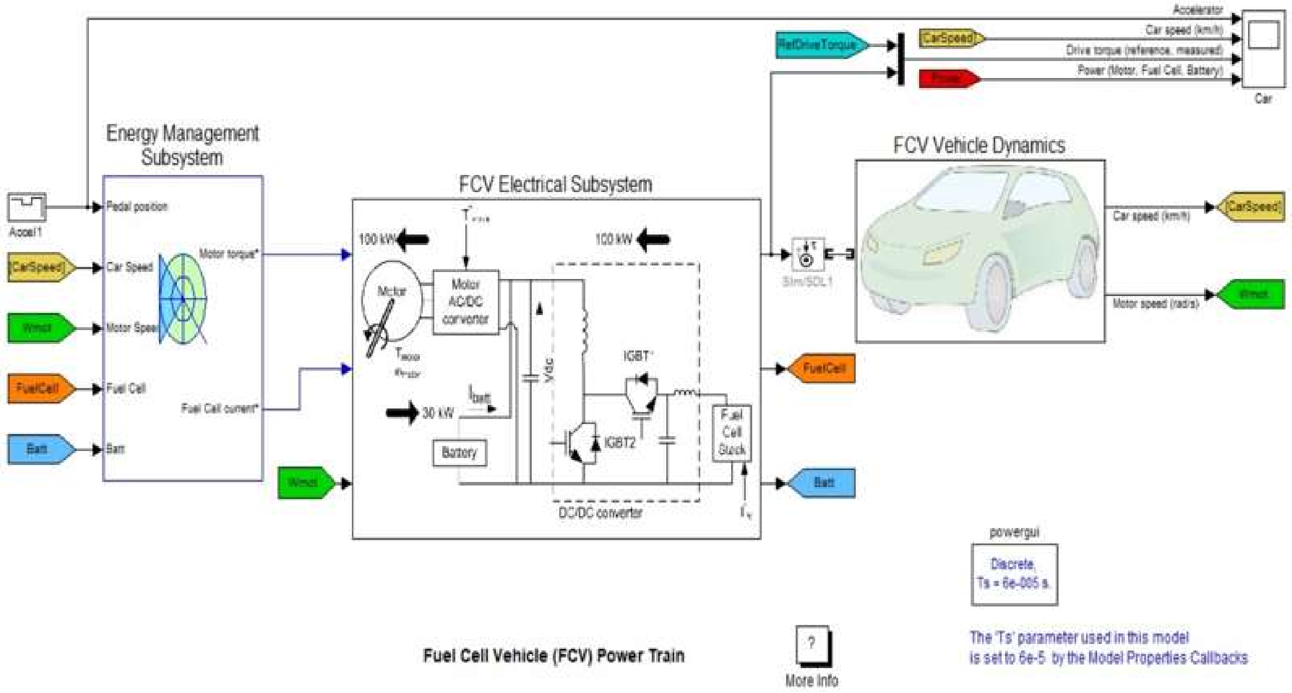

Figure 6: Simulation model of Proposed Fuel Cell Vehicle

A. *Case 1: Highway Roads*

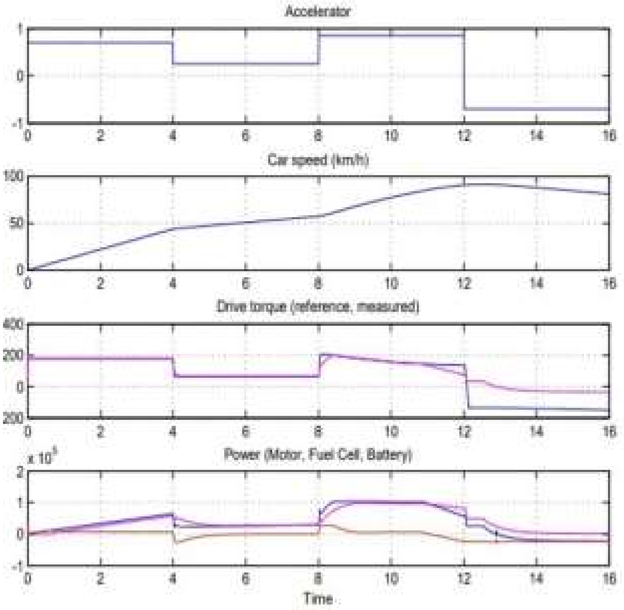

Figure 7: Simulation Result of Proposed FCV in case of Highway Roads

The control scheme is simulated with MATLAB/Simulink. At 4sec of the simulation time, the power drops from 60kW to 22kW, and at 8sec of the simulation time, the load should be varied. At 16sec of the simulation time, EV motor demand suddenly goes up from 22kW to 110kW; it can be seen in Figure 7.

B. *Case 2: Traffic Roads*

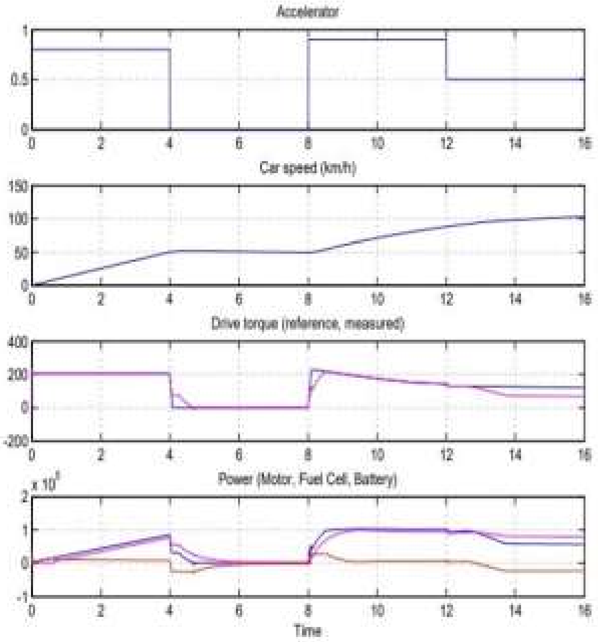

Figure 8: Simulation Result of Proposed FCV in case of Traffic Roads

In this case, between the simulation time of 4 to 8sec, the EV charging demand is low while the Fuel Cell generation is sufficient. Therefore, both Fuel Cell and Ultracapacitor modes are triggered, and the surplus Fuel Cell generation charges the Ultra capacitor. Between the simulation time of 8sec to 12sec, the Fuel Cell can provide 50kW which meets the EV charging amount. After the charging demand increase at 12sec, the Fuel Cell are not able to supply all the required 100kW charging power under the condition of 40kW supply. Therefore, the Ultracapacitor starts to discharge and supply Motor with 12kW and provides voltage support, as shown in Figure 8.

IV. CONCLUSION

Conventional designs of hybrid fuel cell vehicles make use of a single fuel cell power source and a storage device to provide the base load and transients in various driving cycles. This research proposed a new configuration of multiple fuel cell power sources in hybrid fuel cell vehicles. Multiple fuel cells were downsized to provide the same amount of power, which brought the advantage of a highly fuel economic design. Highly efficient driving conditions in urban applications were obtained which also resulted in more reliable system configurations. The proposed power management for this new configuration was presented and the simulation results for a double fuel cell configuration showed the predicted response of power sources. Fuel cells were efficient while they operated in their higher loading percentage. Efficiency curves were introduced and used for efficiency analysis. To gain higher efficiencies in hybrid fuel cell vehicles, fuel cells should be loaded in their efficient region of operation. The main objective of this paper was to achieve a higher efficiency in urban driving cycle. In conventional configurations, the fuel cell was not efficiently loaded in urban driving cycles, where small powers were required from the single fuel cell power source. In that case, the fuel cell was usually loaded in its low efficient region which made the whole system inefficient. By utilizing the new configuration, fuel cells could be loaded in their efficient region in urban driving cycles and provided a fuel economic vehicle.

Efficiency simulations showed that in standard urban driving cycle (FTP75), efficiency was enhanced for almost 27.3% in urban driving cycle which showed.

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