Management of Energy in Hybrid Electric Vehicle with Distinct Power Sources

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Abstract— **This paper proposes an energy management method for an electric hybrid vehicle (EHV) with several power sources, including a fuel cell (FC) as the major energy source and a battery and supercapacitor (SC) as secondary energy sources. The electric car gets its energy from a fuel cell, but auxiliary sources of energy come to the rescue when it comes to correcting for low power during acceleration or absorbing excess power during braking. The synergetic usage of secondary sources demonstrates its efficacy in enhancing vehicle economy, cutting hydrogen use significantly, and ensuring the system's overall robustness and durability. The proposed technique balances the power between several energy sources in order to meet the vehicle's power requirements as efficiently as possible. For simulation runs, MATLAB/Simulink is used as the platform.**

.Keywords— Electric hybrid vehicle, fuel cell, supercapacitor, battery, energy management

I. INTRODUCTION

On the one hand, global population growth is driving up energy consumption, while fossil fuels, which have been the primary source of energy until now, are depleting and have a finite lifespan. As a result of these factors, the focus has turned to renewable energy sources to cover a variety of energy needs. One such example is the paradigm shift away from conventional fossil fuel-based vehicles toward EHVs. Because EHVs do not contaminate the environment, they will be the centre of the future transportation system [1].

Due to the utilisation of a clean energy source such as hydrogen, these cars provide a fantastic option in terms of environmental protection. Because the energy conversion takes happen directly without involving any combustion, FC-based electric vehicles have an advantage over internal combustion engine-based vehicles in terms of efficiency and environmental friendliness [2].

The fuel efficiency remains high when the vehicle is partially loaded, as well as when the vehicle is in transition in urban or suburban regions, and the power requested by the vehicle from FC is minimal, requiring only a portion of the nominal FC power. As a result, FC-based vehicles have the potential to become the standard car in the future. In most EHVs, the clean energy sources include the FC, battery bank (BAT), and storage capacitor (SC). Chemical energy is directly transformed into electrical energy in FCs and BATs.

FC appears to be a key technology that has the potential to address future energy needs. Generation's requirements The gasoline supply is never interrupted. The FCs continue to generate power, while the BATs store it.When needed, it injects electrical energy into the system.

FCs, on the other hand, have several drawbacks, such as being less efficient when demand is low and the rate is high. During transitory periods, power transfer is slowed. conditions, as well as a high cost per watt [3]. Due to these factors, FCs are employed in EHVs in a synergetic manner, not alone, but in conjunction with other energy storage systems such as battery and SC to meet variable load demand, particularly during ramping up or transient conditions [4]. Furthermore, combining an FC with another energy source helps to reduce hydrogen consumption, which is the fuel utilised in the FC. The energy sources must be interfaced with the DC link via a unidirectional or bidirectional DC/DC converter, depending on the necessity.

Different synergy of energy sources have recently been explored for vehicle applications. Diverse control systems for power sharing among various energy sources have been revealed in the research. [5]-[11]. Some writers have presented a number of energy management strategies based on optimization approaches in [6], [7], and [9.]

The authors have utilised FC and BAT as the only storage system in these, which may not be the best option because the battery suffers from low power density and a sluggish charge and discharge cycle. The author has also used battery in connection with FC in [10]. A hybridization of BAT and SC is a superior option because it provides more power density.

The control technique proposed in this study is effective in maintaining active power balancing among varied energy sources, controlling the DC-link voltage (VDC) at 100 volts, and keeping the battery and SC state of charge (SoC) within limits. Following the introduction in section I, section II of the study describes the modelling of several EHV subsystems as employed in the article. The control approach of various subsystems is described in Section III, while the simulation results are presented and analysed in Section IV. Finally, section V brings the investigation and findings of the research to a close.

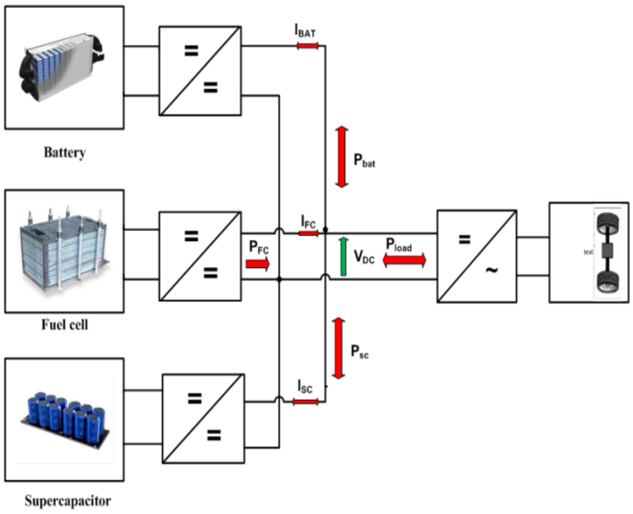


Fig.1 Electric vehicle system

II. SYSTEM DESCRIPTION AND MODELLING

A. System Structure

The system structure, as shown in Fig. 1, includes the FC as the primary energy source, as well as the battery and SC as secondary support energy sources. The DC link is connected to the FC via a DC/DC boost converter, and the secondary support energy sources are connected to the DC link by bidirectional power converters. The proposed control technique aims to ensure efficient and effective energy management amongst these three sources.

B. Energy sources

(i) Fuel cell

The FC is a system that generates electric energy using an electrochemical energy conversion process described by equation (1) [12]. Between hydrogen and oxygen, a chemical reaction occurs, leading in the formation of electric power as well as heat and water as byproducts.

$$2H_2 + O_2 \rightarrow H_2O + \text{electricity} + \text{heat} \tag{1}$$

The kind of electrolyte divides FCs into different groups, and the proton exchange membrane FC (PEMFC), whose characteristics are listed in table 1 [13], is the most widely utilised in electric vehicle applications.

Mathematical modeling of FC

Equations (2) and (3), which relate the terminal voltage of the FC (VFC) and the hydrogen consumption (NH2) with the other system variables [14], can be used to describe an FC mathematically.

$$V_{FC} = E_{FC} - V_C - V_{ohm} \tag{2}$$

$$NH_2 = I_{FC}/2F \tag{3}$$

The internal Nernst voltage, the voltage due to internal capacitance (F) of the FC, the ohmic losses in the FC, and the output current of the FC stack, respectively, are represented by E_{FC}, V_C, V_{ohm}, and I_{FC}.

Equation [15] can be used to describe Nernst voltage in more detail.

$$E_{FC} = N_0[E_0 + \frac{RT}{2F}\log[\frac{\rho h2 \rho_{0.2}^{0.5}}{\rho h_2 o}] \tag{4}$$

(ii) Battery

The battery energy storage system comes to the rescue in maintaining the system's power balance by injecting extra power into the system when the FC is unable to meet the load demand and absorbing electricity from the FC when the load exceeds the load [16]. However, the battery system's response time to transients is a little slow. Table 2 [1] lists the battery specs that were employed in this study.

Mathematical modeling of Battery

In this study, the Nickel-Metal-Hydride model, which is accessible in Matlab®, is used. Because sudden charging and discharging reduces battery life, charging and discharging have been kept gradual and within SoC limits: 20% SoC Bat 80%. Equations (5) and (6) [17] define the mathematics of the battery model, which is schematically represented in Figure 2.

$$E = Eo - K\frac{Q}{Q-\int i\, dt} + Ae^{(-B\int i\, dt)} \tag{5}$$

$$V_{batt} = E - I_{batt} \tag{6}$$

Where E and E0 stand for the no load and constant voltages, respectively, and K stands for the polarisation constant. (V/Ah), where Q is the battery's maximum ampere-hour capacity.(Ah), ∫idt is the charge taken/delivered by battery (Ah), A is the voltage that grows exponentially,

Vbatt and Rbatt are the battery terminal voltage and internal resistance, respectively, and Ibatt is the battery current. B is the exponential capacity (Ah1), Vbatt and Rbatt are the battery terminal voltage and internal resistance, respectively, and Ibatt is the battery current.

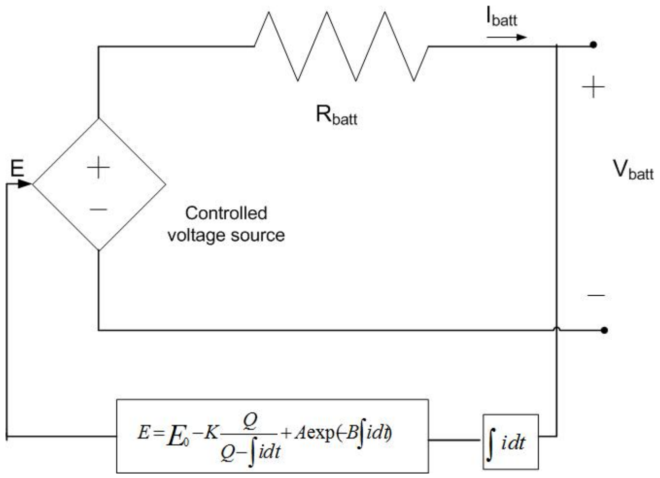


Figure 2 shows a battery-powered electrical model.

(iii) Supercapacitor

The SC is a very quick charging and discharging energy storage technology, with a very high power density and a very fast response time, supporting its use to compensate for the slow dynamics of the battery. Figure 3 shows the mathematical model of the SC, which consists of a capacitance in series with equivalent resistance. Table 3 [18] lists the SC's specifications as they apply to this application.

Equation (7) [1] relates the SC voltage and current.

$$Vsc = V1 - Rsc * Isc = \frac{Qsc}{Csc} - Rsc * Isc \tag{7}$$

The quantity of electricity stored in SC is denoted by Qsc. Equation (8) [1] can be used to calculate the SC power.

$$Psc = \frac{Qsc}{Csc} * Isc - Rsc * Isc^2 \tag{8}$$

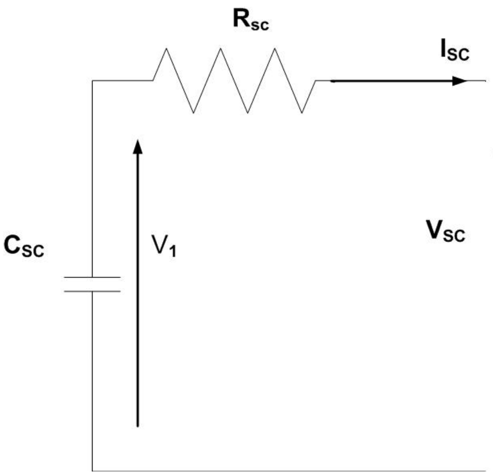


Fig.3- Electrical model of a supercapacitor

Table1 Specifications of FC

Model type PEMFC	PEMFC
Power rating	6kW
Voltage rating	45V
Utilization %	99.56%(H2) 59.3%(O2)
Stack efficiency	55%

Table2 Specifications of Battery

battery type	Nickel-Metal Hydride
Rated capacity (Ah)	6.5
Maximum capacity (Ah)	7
voltage rating	100V
Depth of discharge (DoD)	60%
Internal resistance (ohms)	0.0015

Table 3 Specifications of SC

Battery type	Nickel-Metal Hydride
Capacitance	500F
DoD	100%
Maximum peak current	150A
Voltage	100
No. of series supercapacitors	6
No. of parallel supercapacitors	1

III. CONTROL SCHEME FOR HYBRID EV

DC/DC unidirectional converter

The suggested hybrid system structure is presented in Figure 1, with the FC connected to the DC link through a unidirectional boost converter. A 6KW, 45V generator is used here.An average value of has been fed into a PEMFC stack.100 volts direct current. The output voltage of the converter must be carefully regulated for best performance, which is achieved in this work utilizing a proportional-integral (PI) controller.

DC/DC bidirectional converter

The energy storage systems, in this example the battery and SC, must be connected to the DC link via a reversible current converter in order to support both charging and discharging modes. As a result, two bidirectional DC/DC converters are utilised in this application to allow for power flow in both directions. As a result, the analysis is carried out in two working modes: as a buck converter, when power is extracted from the DC link by the SC, and as a boost converter, when power is fed into the DC link by the SC. Depending on the duty cycle, this converter may output a voltage that is higher or lower than the input voltage. For This study uses a PI controller for control purposes. Calculate the converter's duty cycle.

Energy management

The suggested energy management control scheme determines which energy source will be used to meet power demand at any given time. A block diagram depicting the management structure is depicted in Figure 4. When the FC generates more power than the P_{load}, the additional power is used to charge the energy storage device until it reaches its maximum SoC capacity. When the FC produces less power than the P_{load}, the storage system compensates until it reaches its lower SoC limit. In both cases, low frequency components of unbalanced power are separated from high frequency components and used for charging or discharging the battery and SC. This current is filtered to remove the low-frequency component, which is then processed with a rate limiter to provide battery reference current, which determines the battery's charge/discharge rate. Another PI controller calculates the difference between the actual and reference battery currents to determine the duty cycle to be sent to the PWM generator for generating switching signals for the battery's DC/DC converter. SC uses the reference current ISC* to compensate for any residual power. By comparing two values, the PI controller generates duty cycle. As a result, the actual SC current and its reference value are generated. Switching signals for the SC's DC/DC converter.

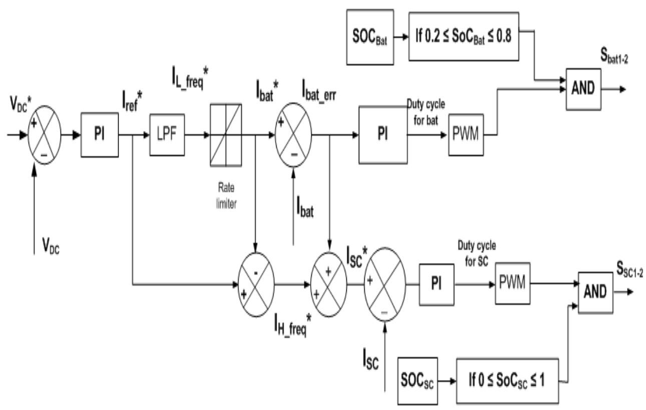


Fig. 4 Block diagram for energy management scheme

IV.SIMULATION RESULTS

The simulations are run in MATLAB/Simulink and are displayed separately in Figures 5(a-d), 6(a-c), and 7(a-c) for the various energy sources (FC, battery, and SC), respectively, with the variable load profile as shown in Fig. 9(b) whose corresponding power consumption is shown in Fig. 9(c) (a). In addition, Fig. 8 shows the DC link voltage.

A. Fuel cell simulation results:

Figure 5 (a), (b), (c), (d) shows the simulation results of an FC connected to a boost converter, displaying the voltage and current variables of the FC and the converter. The effect of altering load current on the voltage and current of FC is shown in Figures 5 (a) and (b). Due to the PI regulator, the converter output voltage, as shown in Fig. 5 (c), remains constant at all times, even when the load current is large.

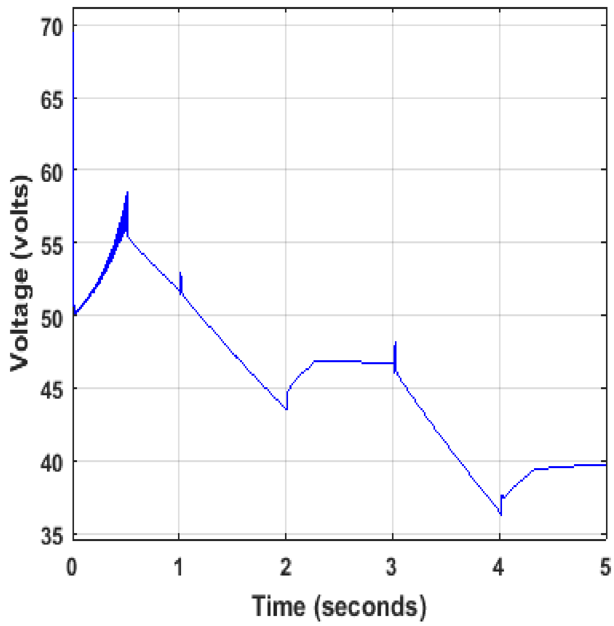


Fig 5(a) - FC voltage

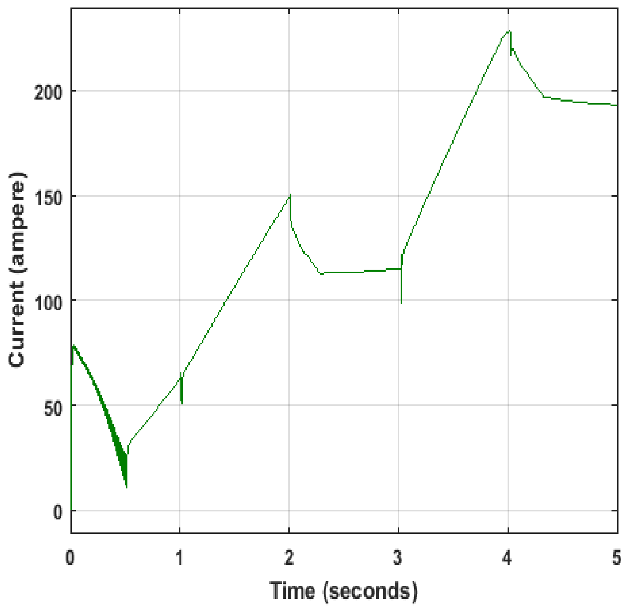


Fig 5(b) –FC current

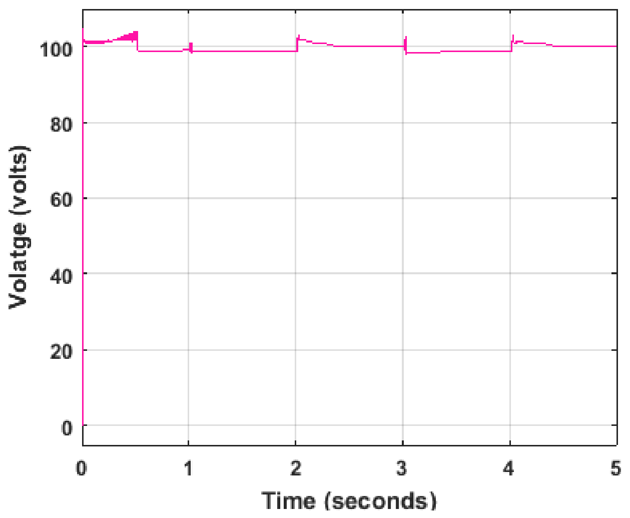


Fig 5(c) – Converter output voltage

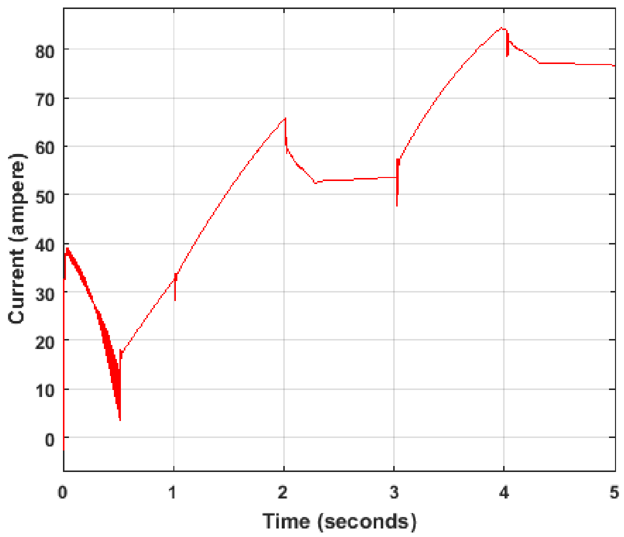
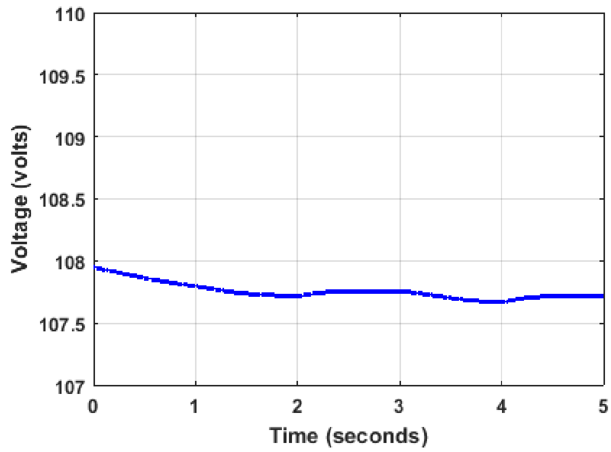


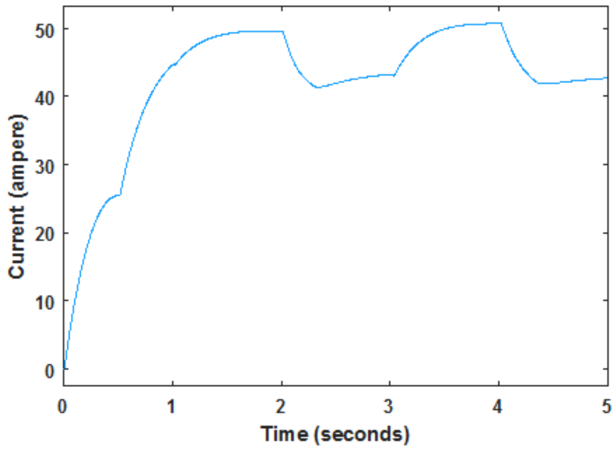
Fig.5 (d) - Converter output current

B. Battery simulation results:

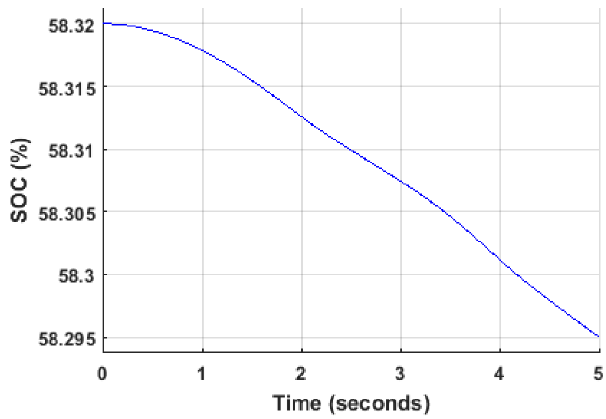
Figures 6(a), (b), and (c) show the battery's voltage, current, and state of charge, respectively. As seen in Fig. 9, the dramatic reduction in power demand may be seen between 2 and 3 seconds (a). Both the battery and the SC enter recovery mode at this time interval, as seen in Figs. 6 (b) and 7(b), respectively, when both are shown charging between 2 and 3 seconds. Charging takes occurs in the interval of 4 to 5 seconds, as well. The voltage waveforms in Figs. 6 (a) and 7(a) illustrate that, despite their current changes, the battery and SC voltages do not experience considerable changes because the SOC is limited by the PI controller.



(a)



(b)

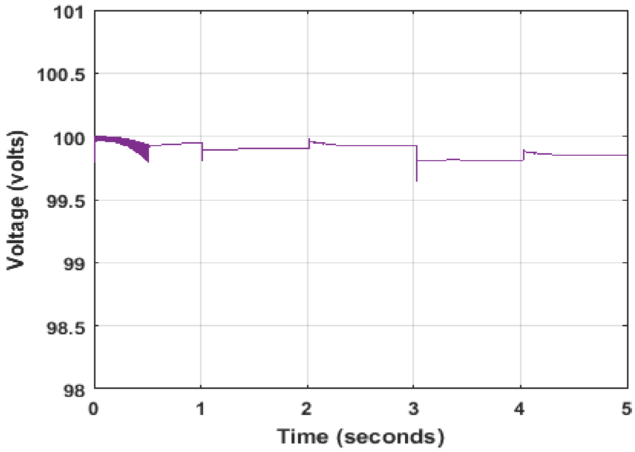


(c)

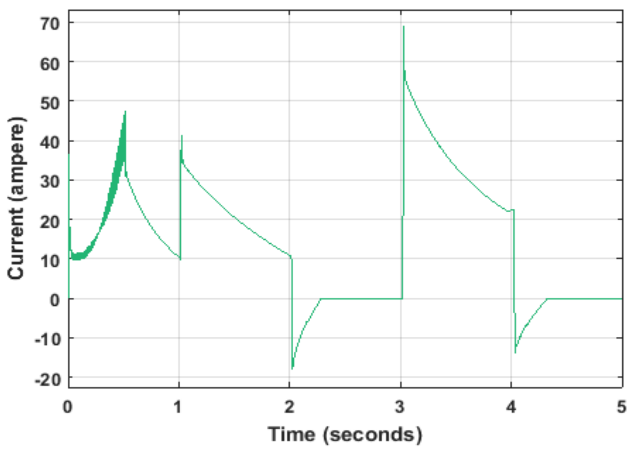
Fig.6 (a) Battery voltage (b) Battery current (c) Battery SOC

C. Supercapacitor simulation results:

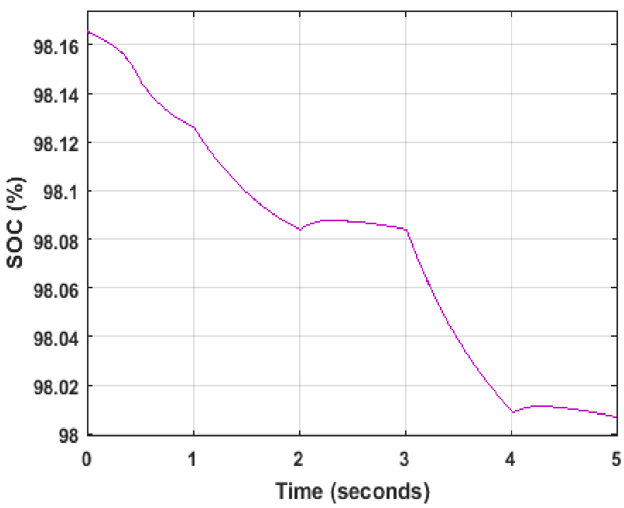
Figures 7 (a), (b), and (c) show the SC voltage, current, and SOC, respectively (c).



(a)



(b)



(c)

Fig. 7 (a) Supercapacitor voltage (b) Supercapacitor current (c) Supercapacitor SOC.

D. DC bus (link) voltage (V_{DC})

The DC bus (link) voltage, which is rated at 100 volts, is displayed in Fig. 8, and it can be seen that the PI controller is effective in maintaining a constant voltage even when there is a high load current need.

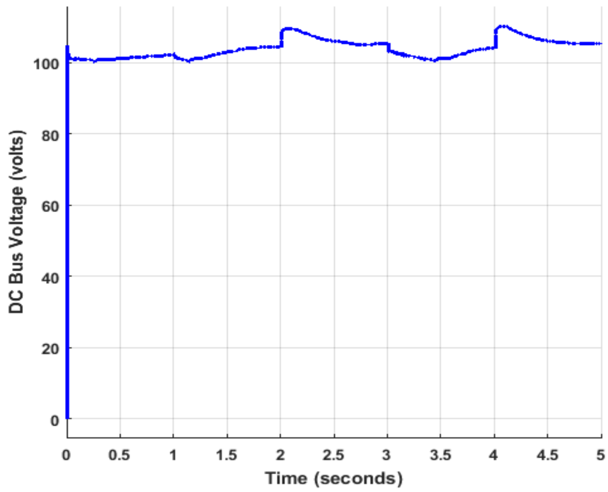


Fig. 8 DC bus voltage

E. Load profile

The load variation pattern depicted in Fig. 9 (a) is used to assess the performance of various energy sources. The load step fluctuations represent the electric vehicle's accelerations and decelerations, and the equivalent load current profile is shown in Fig. 9. (b). The results clearly illustrate that the various energy sources efficiently collaborate in giving current (power) to the vehicle load while functioning within their restrictions, as illustrated in Fig.10.

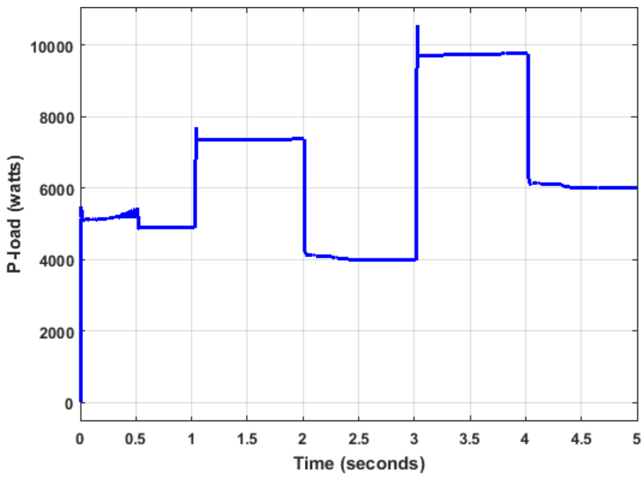


Fig.9 (a) Power demanded by vehicle at various time instances

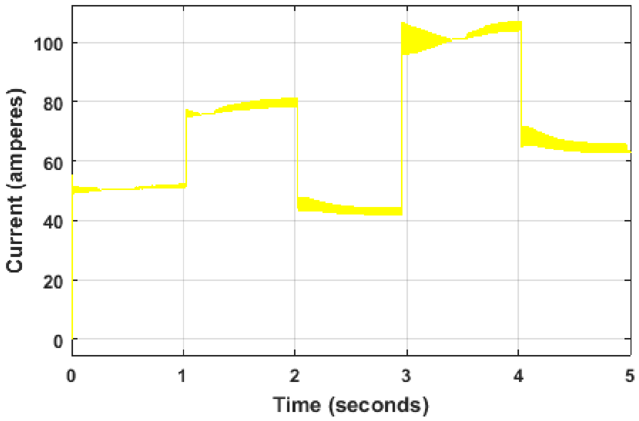


Fig. 9 (b) Load current

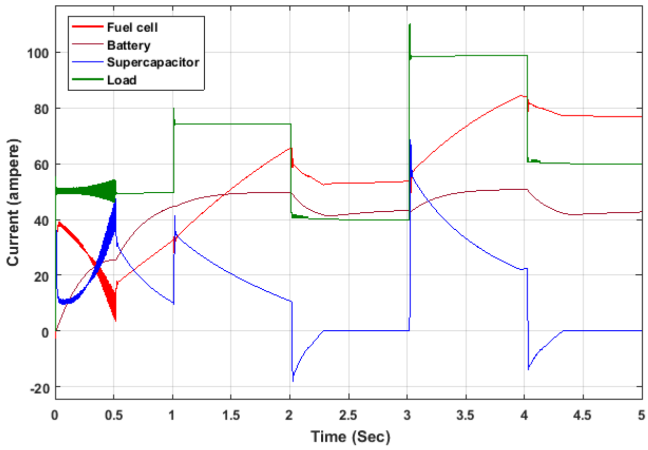


Fig. 10 - Current curves of FC, Bat, SC and load.

V. CONCLUSIONS

The control approach for appropriate energy management of the different energy sources used in synergy with each other, as used in the electric hybrid car, has been provided in this study. The efficient power share among the numerous sources at any given time has been established. When the power produced by FC is limited, as well as when there is surplus power produced by FC, the control technique has been successfully analyzed. In both cases, the VDC was maintained by the controller. Furthermore, by directing low frequency components to the battery and high frequency components to the SC, the charging and discharging of the battery is kept smooth, and the SoC is kept within limits. The simulation findings support the hypothesis presented in this research.

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