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Implementation of multi input DC-DC converter based fuel minimisation in hybrid vehicle using HBO optimisation method

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Abstract: This manuscript proposes a multi input DC to DC converter based on fuel minimisation in hybrid vehicle using heap based optimisation (HBO) method. The proposed system inputs include fuel cell (FC), energy storage system (ESS), and photovoltaic (PV) group. Fuel cell is regarded as important MN power source and the roof-top photovoltaic is utilised for charging batteries, improving performance and reducing fuel economy. The converter has the ability to provide power demand from one or two resources that are not present through a load. Moreover, a power management method is defined and given in the heap-based optimiser (HBO) technique. The main objective of the proposed method is to “meet tight direct current (DC) bus voltage regulation, better monitor the PV current to their reference and minimise fuel consumption”. The proposed HBO technique based hybrid electric vehicle (HEV) system is implemented in MATLAB/Simulink software.

Keywords: ESS; energy storage system; fuel cell; HBO; heap based optimisation; HEVs; hybrid electric vehicles; photovoltaic.

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1 Introduction

Transport is considered as the most significant contribution in carbon emission and the majorities of emission are coming from the road transport and are continuously increasing (Joseph and Devaraj, 2019; Sun et al., 2022; Luo et al., 2020). It is difficult for the hybrid electric vehicle (HEV) to achieve sustainable transportation by lessening the consumption of fossil fuels (Shajin et al., 2022). The polymer electrolyte membranes FC (PEMFCs) are considered as important significant innovation for the worldwide computerisation of automotive equipment (Rajesh et al., 2022a). The PEMFCs include different features, like perfect, effective, little size, lightweight and simple creation (Mohan et al., 2022; Chen et al., 2019; Chaudhari et al., 2019; Ravada and Tummuru, 2020; Kong et al., 2019; Mayer et al., 2019; Zhou et al., 2020a) and they are utilised in contrast to internal combustion motors. Additionally, some limitations, like high cost, credit, and sturdiness are present in the fuel cell (FCs) (Rajesh et al., 2022b). The moderate elements are ruled by the air supply framework and the fuel supply framework is considered as the major disadvantage of FCs (Shajin et al., 2023). A high voltage drop in an endorsed brief period is occurred because FCs are not able to react quick load changes that is required for any vehicle power, which is also known as fuel-starvation occasion (Bhattacharyya and Mandal, 2011; Lin and Zhang, 2016; Monteiro et al., 2020). Therefore, for extra energy storage, framework lithium-ion (Li-ion) batteries are utilised with PEMFC in order to enhance the moderate reaction energy. Li-ion battery storage PEMFC-HEV includes the benefits of PEMFCs and Li-ion battery stack (high power and power generation). In this research work, design and execution of fuel minimisation of dc to dc converter based hybrid vehicle using HBO optimisation method is proposed (Ardi et al., 2019; Bi and Jia, 2019). The proposed framework's output gain is improved when compared with existing hybrid renewable energy resource based electrical vehicle control system (Sakthimani and Pandarinathan, 2023). The proposed converter inputs include FC, PV group and ESS. FC is regarded as important power source and roof-top photovoltaic is used for charging batteries, improving performance and reducing fuel economy.

Previous research on fuel minimisation in hybrid vehicles using multi-input DC-DC converters (MIDC) has focused on developing and evaluating different control strategies. However, there is a lack of research on using optimisation methods to improve the performance of these control strategies. This paper addresses this research gap by proposing a novel HBO-based optimisation method for fuel minimisation in hybrid vehicles. The HBO algorithm is a powerful optimisation method that is well-suited for complex problems such as fuel minimisation in hybrid vehicles. The proposed method is evaluated using a realistic simulation model of a hybrid vehicle, and the results show that it can significantly improve the fuel economy of the vehicle compared to existing control strategies.

Contribution of the work:

- This paper presents the use of a heap-based optimiser (HBO) to improve the performance of a MIDC for fuel minimisation in hybrid vehicles.
- HBO is a relatively new optimisation algorithm that is well-suited for complex problems such as fuel minimisation.

- Fuel cell is regarded an important power source and rooftop photovoltaic is utilised to charge batteries, improve performance and reduce fuel consumption.
- The proposed method is evaluated using a realistic simulation model of a hybrid vehicle, and the results show that it can significantly improve the fuel economy of the vehicle compared to existing methods.
- The proposed work could be used to improve the design and operation of hybrid vehicles in the real world, leading to reduced fuel consumption and emissions.

2 Recent research work: a brief review

Various research works were available based on design and implementation of fuel minimisation of dc-dc converter based hybrid vehicle using numerous methods and aspects. Some of them are revised here.

Sarvaiya et al. (2021) have explained comparative analysis of battery life optimisation using various control methods on parallel HEV. Here, the effect of multiple parameters, like current and temperature on battery getting older and provides exact prediction of battery life were discussed. Song et al. (2021) have discussed the degradation adaptive power management method for fuel cell HEV (FCHEV) energy management. Turkdogan (2021) developed an alternative solution and method of HES to satisfy energy requirements of single family house including utilities and transportations. Lin and Wang (2021) have investigated the advantages of distributed hybrid power systems using various FC vehicles.

Gharibeh et al. (2021) have discussed a new energy management strategy (EMS) for FCHEV to consider the accurate detection of movement conditions, less battery power fluctuation, optimum power sharing, less fuel consumption. Sarma and Ganguly (2022) developed an energy management optimisation (EMO) method for determining the optimal power split on proton exchange membrane FC-battery-HES (PEMFC-B-HES) to provide a locomotive load. Şefkat and Özel (2022) have introduced the FLC method to recover the general energy efficiency of FCHEV, the balanced power consumption of the battery cell, and FC because the gradient descent optimisation technique used waste heat from hydrogen canisters through fuel control flow. Kumar and Krishnasamy (2022) have introduced the creation of large gain boost converter as power electronics interface for an FCEV.

2.1 Background of the research work

The review of recent studies explains the fuel consumption minimisation in HEV system was the important contributing factor. In such type of electric vehicle system, different types of DC-DC converters were utilised, such as standard boost, 3-level, isolated dual half- and full-bridge (DAB) and other converters. Among those converters, the DAB converter included different features, such as controllability of power; operate in two directions bi-directional, ability of soft-switching and high effectiveness. The reduction losses was done through zero voltage switching (ZVS) or zero current switching (ZCS) in every converter switch and occur high cost due to the additional components and complex control. The power flow was generated by the converters utilising phase shift

input. However, the operation of generating currents and reactive power under SPS control causes high energy loss. In such cases, different control algorithms, such as phase-shift and modulation strategies are developed to enhance the converter performance. In order to tackle these challenges, fuel consumption minimisation using advanced technology is needed. The above-mentioned limitations are inspired to do this investigation work.

3 Mathematical modelling and operating principle of hybrid vehicle system

Figure 1 shows that the proposed HEV control system. The proposed system consist of proton exchange membrane FC (PEMFC) as key source is controlled through boost converter and the photovoltaic system is used for an auxiliary source to charge vehicle's battery and the function of charging is controlled through the converter of buck boost. Then, load is driven by an inverter with electric motor. A fuel cell is utilised to provide average power to load, while PV is used as the power source that provides transient power requirements required during acceleration, deceleration and peak loads.

3.1 Modelling of electric vehicle

The algebraic sum of the total attempt to move the vehicle resulting from each force exerted on the vehicle is represented as,

$$F_{te} = F_{rr} + F_{ad} + F_{hc} + F_{la} + F_{Wa} \quad (1)$$

Hence rolling tries is mentioned as F_{rr} , F_{la} denotes force needed to deliver a linear acceleration and F_{Wa} specifies force needed to deliver angular acceleration of engine rotation.

$$\text{Energy demand per second} = P_e = F_t \bullet V \quad (2)$$

The EV torque based upon the connection amid the transmission ratios (G) and radius (r) is find out by the electrical engine angular speed is expressed as,

$$W = G \frac{v}{r} \quad (3)$$

$$T = IG \frac{a}{r} \quad (4)$$

The constant is the critical point prior the engine reaching the critical angular speed is called as W_c and it is shown below,

$$\text{For } W < W_c \text{ or } V < \frac{r}{G} W_c \text{ then, } T = T_{\max} \quad (5)$$

$$\text{For } W < W_c \text{ or } V \geq \frac{r}{G} W_c \text{ then, } T = \frac{T_{\max} W_c}{W} \quad (6)$$

The energy efficiency is expressed by;

$$\eta_m = \frac{TW}{TW + K_c T^2 + K_i W + K_w W^3 + c} \quad (7)$$

The requirement of electric power through engine is higher than the mechanical output power,

$$P_{mot_{in}} = \frac{P_{mot_{out}}}{\eta_m} \quad P_{mot_{out}} = \frac{P_{te}}{\eta_g} \quad (8)$$

The electric vehicle is driven and the engine demand is represented as,

$$P_{mot_{in}} = P_{mot_{out}} \bullet \eta_m \quad P_{mot_{out}} = P_{te} \bullet \eta_g \quad (9)$$

The overall power requirement of the battery is derived as,

$$P_{bat} = P_{mot_{in}} \quad (10)$$

3.2 PV array model

A photovoltaic cell converts photon energy from sunshine into electricity, and cell material generates a constant open-circuit voltage (Sabarimuthu and Senthilnathan, 2021; Nahavandi et al., 2021).

Current ($I_{PV(\text{cell})}$) flow through load based on light energy (photons) shown below,

$$I_{PV(\text{cell})} = I_{ph} - I_o \left[\exp \left\{ \frac{\chi(v_{PV} + I_{PV} R_s)}{\eta_k T} \right\} - 1 \right] - \frac{v_{PV} + I_{PV} r_s}{r_p} \quad (11)$$

3.3 Mathematical modelling of fuel cell (FC)

Chemical energy is transformed into electric energy by FC. The fuel cell process is same as battery. Even though, until it supplied with hydrogen and oxygen(O) fuel cell generate DC power constantly.(Evangelou and Rehman-Shaikh, 2017; Zhang et al., 2020; Ahmadi et al., 2019; Zhou et al., 2020b; Askari et al., 2020) Because of increasing flexibility, effectiveness, and simple operation, fuel cell is used in distributed generation system (DGS). The FC unit voltage is stated below,

$$V_{FC} = N_o \left[E_o + \frac{rt}{2F} \ln \left(\frac{Ph_2 P_{O_2}^{0.5}}{Ph_2 O} \right) \right] - Ri_{FC} \quad (12)$$

From the above equation, r denotes the universal gas constant, t refers stack temperature, F denotes faraday's constant, based on the reaction free energy voltage denotes E_o , R portrays stack internal resistance, N_o refers number of cells in stack, P_{FC} is expressed as the current of FC system, partial pressures of water denotes $Ph_2 O$, partial pressures of hydrogen, and oxygen refers Ph_2 , PO_2 .

$$V_o = \frac{1}{1-d_s} V_i \quad (13)$$

where DC input and output voltage refers V_i and V_o , switching period of semi-conductor switch refers t_s . Hence, the duty ratio is represented below,

$$d_s = \frac{t_{on}}{t_s} \quad (14)$$

where t_{on} denotes on time period of semiconductor switch. Then, the equation for inductor on boost converter is given below,

$$L_{boost} = \frac{V_i d_s t_s}{\Delta i_L} \quad (15)$$

where inductor ripple is represented as Δi_L .

3.5 Mathematical modelling of battery

The approximation of battery capacity is expressed using the following equation,

$$c(i, \theta) = \frac{k_c c_0 \left(1 - \frac{\theta}{\theta_f}\right)^\varepsilon}{1 + (k_c - 1) \times \left(\left|\frac{i}{i_n}\right|\right)^\delta} \quad (16)$$

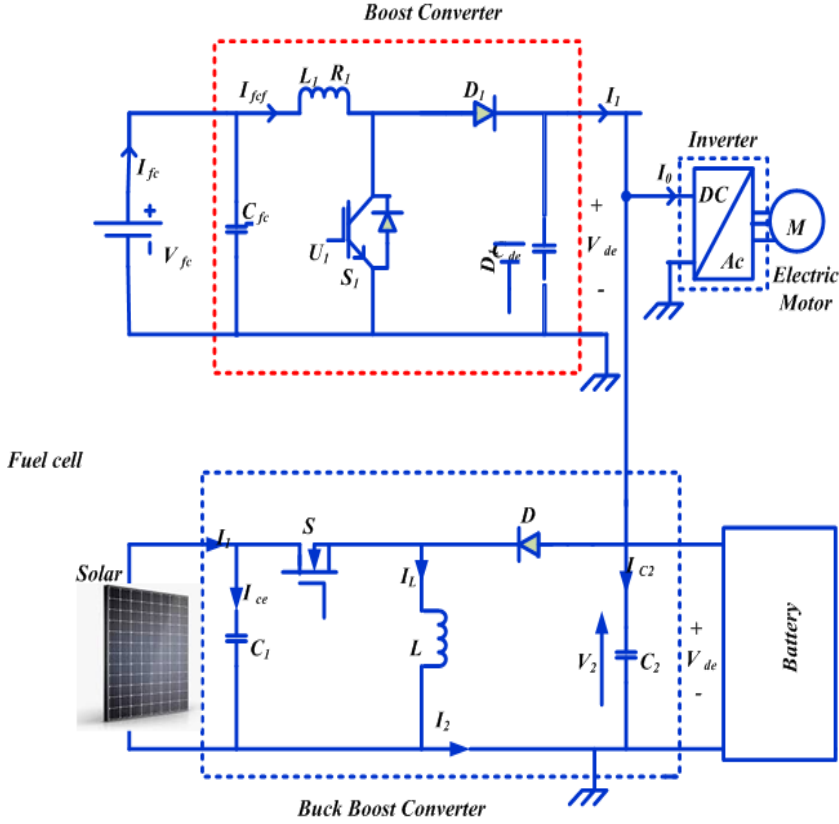
where an electrolyte temperature is represented as θ , rated current of battery is specified as i_n , constant parameters are $\theta_f, c_0, \varepsilon, \delta, k_c$. The SOC contains information's on battery energy is stored that ensures the battery at θ temperature.

3.6 Modes of operation of buck boost converter

DC to DC buck boost converter is utilised to maximise or minimise output voltage obtained as FC or battery and also used to control power as per power management system. The proposed technique is applied to boost and buck boost converters to make the output of the converter more reliable and efficient. The block diagram of proposed fuel minimisation is shown on Figure 2.

3.7 MPPT and battery charging

MPPT charge controller is used to enhance the effectiveness of the system. It extracts maximum power from the photovoltaic and delivers it to battery. The switch S of buck converter has a MOSFET with an inward opposition R_{on} . The ensuing output voltage and PV are used with the control circuit to fabricate the present and a while later decline the obligation pattern of buck-boost converter grow the working motivation behind the PV array.

Figure 2 Block diagram of proposed fuel minimisation system (see online version for colours)

3.8 Cost analysis

Fuel cell hydrogen consumption and the corresponding hydrogen produced by battery output power are combined to create hydrogen consumption that may be explained as follows:

$$\Delta m_{H_2-FC} = P_{fc} \quad (17)$$

$$m_{H_2-bat} = \Delta E_{bat} / \eta_{trans} LHV \quad (18)$$

where ΔE_{bats} (J) refers change in battery stored energy, η_{trans} refers efficiency factor, and (J/kg) denotes minimum hydrogen heat value. The amount of hydrogen spent by a fuel cell is proportional to its output power. The corresponding fuel cost may therefore be calculated as follows:

$$Cost_{H_2} = (\Delta m_{H_2-FC} + \Delta m_{H_2-bat}) price_{fuel} \quad (19)$$

Quantified degradation costs and typical DC-DC converter expense are included in the cost of operating the fuel cells. For FC, DC-DC converter cost implies \$300/kW. In this investigation, the primary investment in fuel cells, which includes the DC-DC converter

cost, is calculating the degradation cost. The operating cost of the FC may be determined using the FC degradation quantification model.

$$Cost_{FC} = \frac{\Delta\phi_{FC}}{10\%} * price_{FC} + price_{DC/DC} \quad (20)$$

where $price_{FC}$ (¥) refers fuel cell investment cost, and 10% of fuel cell contemplates at their end and 10% of voltage drop, $price_{DC/DC}$ refers DC-DC converter investment. The battery deprivation cost is described by,

$$price_{Bat} + price_{bBat.uni} \cdot q_{Bat} \quad (21)$$

where the battery pack initial investment cost is denoted $price_{Bat}$.

Constraints

Power balance constraints is described as,

$$P_{prim.s} + P_{sec.s} = P_{pl} \quad (22)$$

where power of primary source (driven in diesel engine)) is denoted as $P_{prim.s}$, power of secondary source is denoted as $P_{sec.s}$ and load power is denoted as P_{pl} .

The constraint based on the SOC is described by,

$$SOC_L \leq SOC \leq SOC_U \quad (23)$$

where SOC lower level is denoted as SOC_L , SOC upper level is denoted as is denoted as SOC_U .

4 Proposed heap-based optimiser (HBO) technique

The corporate position is nominated for executives in company or organisation. The job is to describe the job descriptions and responsibilities of employees. The position will alter depending on the firm and business, but they are determined at hierarchical order that is mentioned at dissimilar name, like Organisation Chart Tree or Corporate Hierarchy, corporate ranking hierarchy (CRH). This algorithm plays a vital role to obtain a systematised design for systematic operations and achieves the last optimal goal. The method increased the search agents logic based on the fitness contained in the hierarchy. The communication within managers and their instant employer are takes place. Figure 3 depicts flowchart of HBO algorithm, and step-by-step procedure of the HBO method is discussed below.

Step 1: Initialisation

Here, reactive power, apparent power of grid, optimum cost, electric vehicle, energy storage system (ESS), iteration, balanced value and constraints of system are initialised.

Step 2: Random generation

Generate the search population in random manner and it is expressed as,

$$Ra = \begin{bmatrix} (P_f)_1^1 & (P_f)_1^2 & \cdots & (P_f)_1^D \\ (P_f)_2^1 & (P_f)_2^2 & \cdots & (P_f)_2^D \\ \vdots & \vdots & \ddots & \vdots \\ (P_f)_n^1 & (P_f)_n^2 & \cdots & (P_f)_n^D \end{bmatrix} \quad (24)$$

Step 3: Fitness function

Fitness is utilised to define best optimal value. Then, it is examined based on objective function

$$F = \text{Max}[P_f] \quad (25)$$

Step 4: Choose the search agent

Assume the probability p_1, p_2, p_3 and it is expressed below,

$$\begin{aligned} P_1 &= 1 - \frac{i}{I} \\ P_2 &= P_1 + \frac{1 - P_1}{2} \\ P_3 &= 1 \end{aligned} \quad (26)$$

Step 5: Build heap

This structure is executed effectively using an array, since it contains the properties of fullness. Thus, the construction of heap is expressed below,

$$\text{Par}(K) = \left\lfloor \frac{K+1}{d} \right\rfloor \quad (27)$$

$$\text{Chi}(K, l) = d \times K - d + l + 1 \quad (28)$$

$$\text{Dep}(K) = \lceil \log_d (d \times K - K + 1) \rceil - 1 \quad (29)$$

$$\text{Colleague}(K) = \left\lceil \frac{d d^{\text{Dep}(K)-1} - 1}{d - 1} + 1, \frac{d d^{\text{Dep}(K)} - 1}{d - 1} \right\rceil \quad (30)$$

The structure goes up the heap as well as inserts node k in the correct place to keep up heap properties. This process repeats until correct parameter is updated.

Step 6: Interact using immediate boss

The parent node is depicted below an instant boss for their children.

$$\alpha = \left\lfloor 2 - \left(\frac{i \bmod \frac{I}{s}}{\frac{I}{4s}} \right) \right\rfloor \quad (31)$$

In this case, I refers total number of iterations, current iteration refers i , and s refers user-defined parameter.

Step 7: Updation

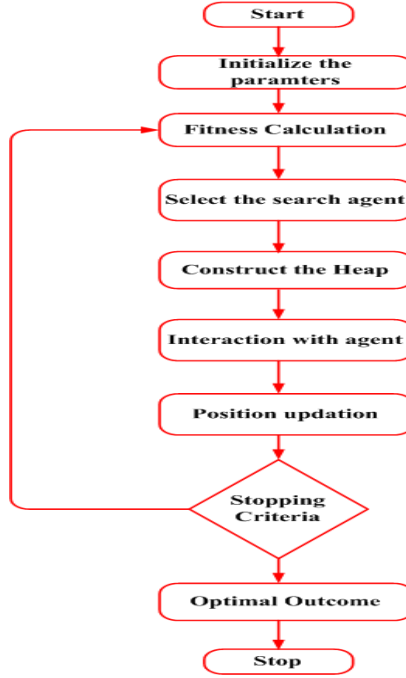
It is updated with the below equation,

$$X_k^l(i+1) = X_k^l(i) \quad (32)$$

Step 8: Stop criteria

Once the optimum result is received, the process ends, if not, go to step 3.

Figure 3 Flowchart of HBO algorithm (see online version for colours)



5 Result and discussion

Here, the simulation outcome and performance analyses of the proposed fuel minimisation system for a hybrid vehicle. The proposed system's Output gain is improved compared to regular works. The proposed converter inputs include ESS, fuel cell (FC), and photovoltaic (PV) group. Fuel cell is regarded as an important power source and roof-top photovoltaic is used for charging batteries, improving efficiency and reducing fuel economy. The simulation model is developed in MATLAB or Simulink software. Table 1 tabulated the simulation parameters. Figure 4 depicts the Simulink model of the proposed HBI based EVs fuel minimisation system.

Table 1 Simulation parameters

Solar photovoltaic system		
Parameter	Value	Unit
Increasing current at maximum power point	5.84	Amps
Increasing voltage at maximum power point	42.8	Volt
Less circuit current	6.2	Amps
Open circuit voltage	50.93	Volt
Increasing power per module	250	Watts

The specification of fuel cell		
Nominal power	4.2	Kw
Nominal voltage	45	Volt
Operating temperature	65	°C
Fuel supply pressure	1.5	Bar
Peak power	6	Kw
Nominal stack effectiveness	55	%

Figure 4 Simulink model (see online version for colours)

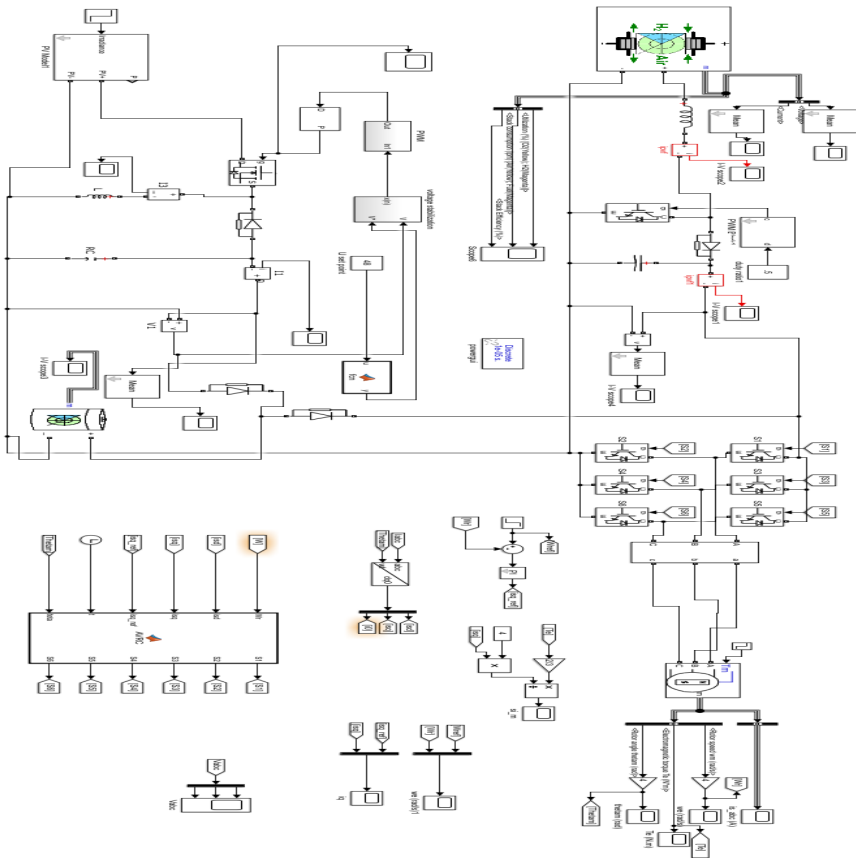
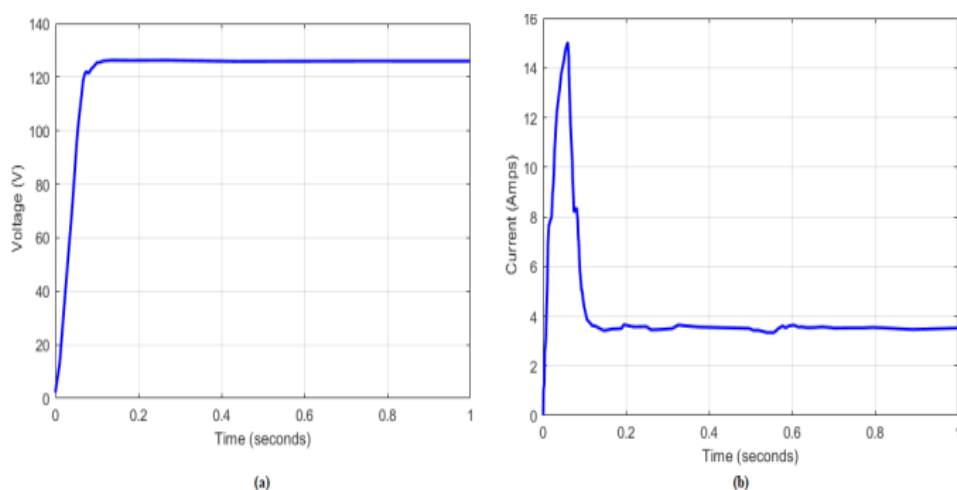


Figure 5 portrays the fuel cell response of voltage and current. In Figure 5(a) the FC response of voltage is presented. It is observed that for load changes instantaneously and the fuel cell voltage takes about 0–0.1 s to meet the steady state response. This steady state voltage is 126 V. Figure 5(b) portrays the current response of FC. It is observed that for load changes instantaneously and the fuel cell current takes about 0–0.1 s to meet the steady state response. This steady-state current is 3.5 Amps. The graph of the voltage response of a fuel cell to a change in load shows that the voltage drops rapidly when the load is increased, but then recovers gradually over time. The voltage eventually reaches a steady state value that is lower than the original voltage. The graph shows that the current starts at zero and then increases linearly until it reaches a maximum value. The current then remains at this maximum value for a period of time before it starts to decrease linearly until it reaches zero again.

Figure 5 Fuel cell response of: (a) voltage and (b) current (see online version for colours)



The fuel flow rate (lpm) response of fuel cell is shown in Figure 6. In Figure 6(a) the graph shows the voltage (V) and current (A) of a device over time (s). The voltage curve starts at 55 V and decreases linearly until it reaches 35 V. The current curve starts at zero and increases linearly until it reaches a maximum value of 90 A. In Figure 6(b) the current then remains at this maximum value for a period of time before it starts to decrease linearly until it reaches zero again. The graph shows the voltage and current of a device over time. The voltage starts high and decreases, while the current starts low and increases to a maximum value before decreasing again.

Fuel flow consumption of (a) voltage and (b) current is shown in Figure 7. The graph shows the voltage and current of a device over time. In Figure 7(a) the graph shows the voltage (V) and current (A) of a device over time (s). The voltage curve starts at 55 V and decreases linearly until it reaches 35 V. In Figure 7(b) the current curve starts at zero and increases linearly until it reaches a maximum value of 90 A. The voltage starts high and decreases linearly, while the current starts low and increases to a maximum value before decreasing again. This could represent the charging and discharging of a capacitor or inductor, or the operation of a power converter or other electronic device.

Figure 6 Fuel flow rate response of fuel cell: (a) voltage and (b) current (see online version for colours)

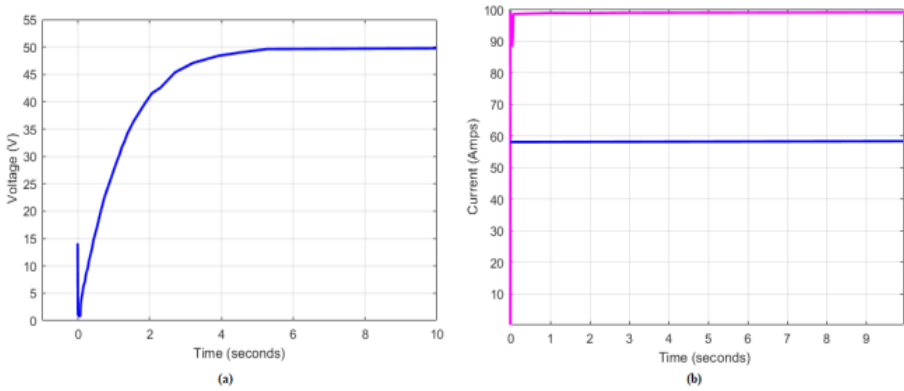


Figure 7 Fuel flow consumption of (a) voltage and (b) current (see online version for colours)

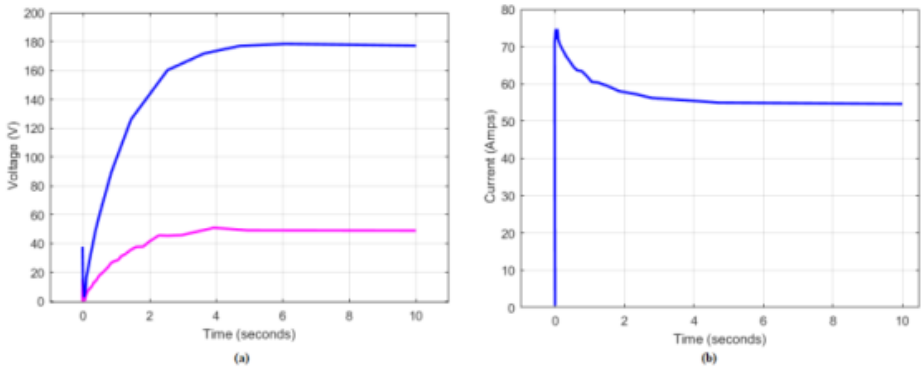


Figure 8 shows the Solar PV Voltage Response of a proposed HEV system. The y-axis shows the solar DC voltage = 44.9 V with respect to time 1 s. The graph shows the voltage of a device over time. The voltage starts at 45 V and decreases linearly until it reaches 40 V. This graph could be used to study the decay of a voltage over time, or to characterise the performance of a device that is generating or consuming voltage.

Figure 8 Solar PV voltage response (see online version for colours)

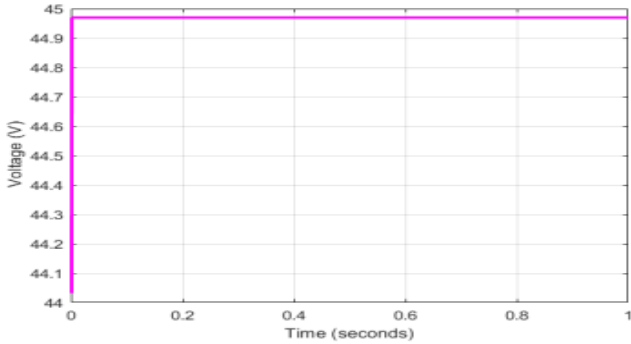
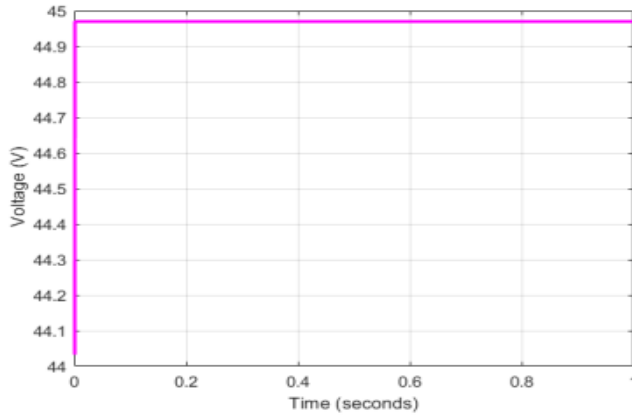


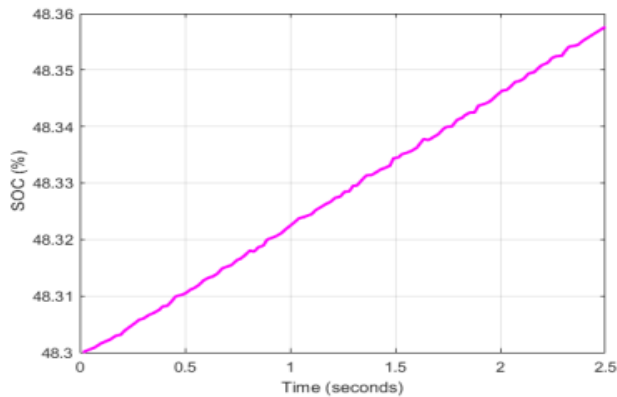
Figure 9 shows the response of DC to DC buck boost converter. The maximum output voltage of proposed converter implies 85 V with respect 0.2 s. The graph shows the voltage of a device over time. The voltage starts at 90 V and decreases linearly until it reaches 0 V. This could represent the discharging of a capacitor or inductor. It could also represent the operation of a power converter or other electronic device that is consuming power.

Figure 9 DC to DC buck boost converter response (see online version for colours)



The analysis of SoC is shown in Figure 10. Figure 10 shows a line graph with two axes: time (in seconds) on the x-axis and SOC percentage on the y-axis. The line on the graph shows the SOC percentage over time. The graph shows that the SOC percentage starts at 100% and decreases linearly until it reaches 0%. This means that the device is discharging at a constant rate. The time it takes for the SOC percentage to reach 0% is the battery life of the device. In this case, the battery life is 10 s.

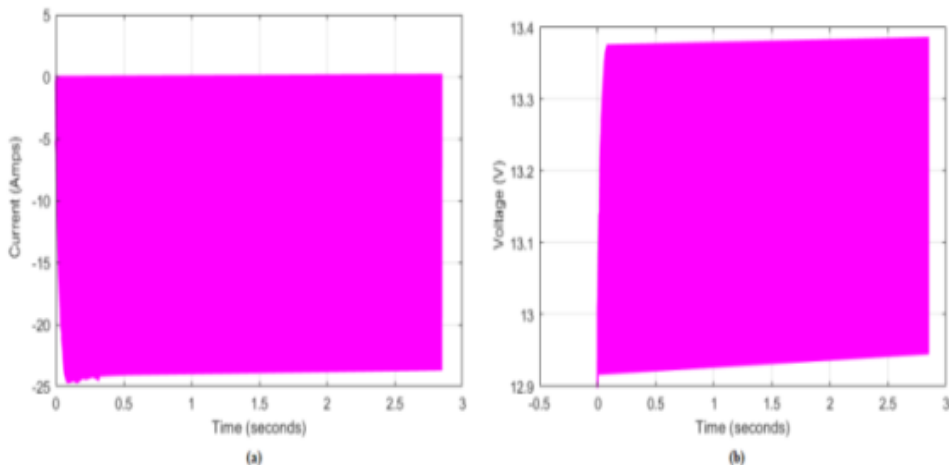
Figure 10 Analysis of SoC (see online version for colours)



In Figure 11 the battery VI characteristics response is presented. Figure 11 shows the voltage and current of a device over time. The voltage curve starts at 13.4 V and decreases linearly until it reaches -20 V. The current curve starts at 20 A and increases to

–25 A over 1.5 s. The current then remains at –25 A for 0.5 s before decreasing to zero over 0.5 s. This figure could represent the charging and discharging of a capacitor or inductor.

Figure 11 Battery VI characteristics: (a) current and (b) voltage (see online version for colours)



The simulation result against current response of PMSM for the proposed HBO technique is shown in Figure 12. Initially, the current oscillated at 0.05 time/s, the oscillation is controlled.

Figure 12 Current response of PMSM (see online version for colours)

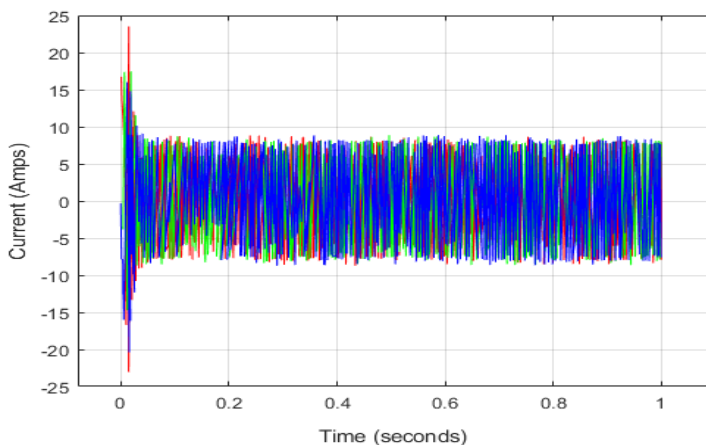


Figure 13 depicts the analyses of Figure 13(a) speed response and Figure 13(b) electro-magnetic torque response. The speed response of proposed hybrid electrical vehicle system is shown in Figure 13(a). Beside that the reference speed of 1300 rpm, the proposed HBO perfectly obtain the reference speed based on controlling the modulation index. The electromagnetic torque response of proposed electrical vehicle with PMSM motor drive is shown in Figure 13(b). By using HBO method, the angle and magnitude of the electromagnetic torque and flux were perfectly controlled.

Figure 13 Analyses of: (a) speed response and (b) electromagnetic torque response (see online version for colours)

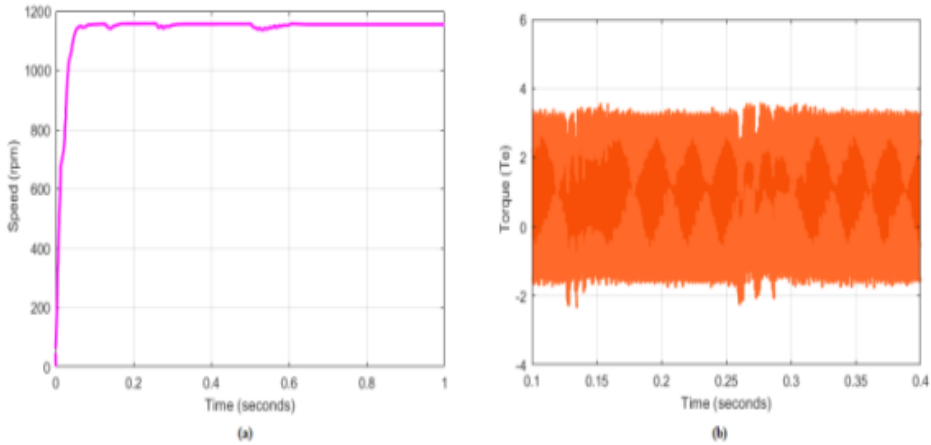


Figure 14 shows a line graph with two axes: SOC percentage on the y-axis and time (in s) on the x-axis. The line on figure shows the SOC percentage over time. Figure 14 depicts the SOC percentage starts at 100% and decreases linearly until it reaches 0%. This means that the device is discharging at a constant rate. The time it takes for the SOC percentage to reach 0% is the battery life of the device. In this case, the battery life is 10 s.

Figure 14 Comparative analysis of SOC (see online version for colours)

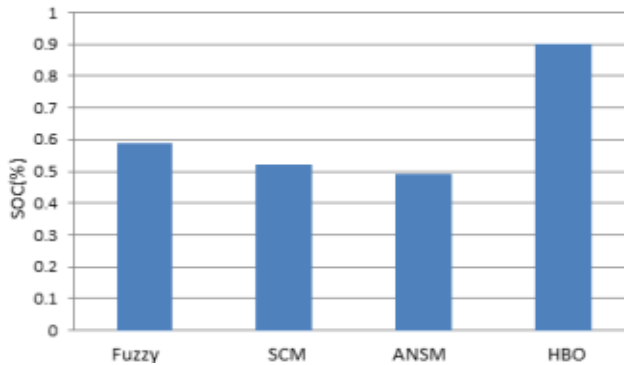


Figure 15 shows a bar graph with fuzzy, sliding mode control, average normalised similarity measure (ANSM), HBO, and compensated Fc (L/100km) methods. The bar graph shows the each control technique to improve fuel efficiency in vehicles. The graph shows that the most popular control technique is compensated Fc (L/100km), with 40%. The fuzzy is 30%. The sliding mode control is 20% o. The ANSM is 10%. The HBO is 5%.

Cost comparison of proposed and online dynamic programming (DP), soft actor-critic (SAC) networks is displayed in Figure 16. From figure the proposed method based cost is less than the existing one. The graph shows that the proposed model control technique achieves a higher SOC percentage over time than the SAC control technique. This suggests that the proposed model control technique is more effective at improving fuel

efficiency than the SAC control technique. This is likely due to the fact that the proposed model control technique takes into account more factors than the SAC control technique, such as the vehicle's speed, acceleration, and road conditions. The graph also shows that the proposed model control technique is more stable than the SAC control technique. This means that the SOC percentage of the vehicle is less likely to fluctuate with the proposed model control technique.

Figure 15 Analysis of compensated fuel consumption (see online version for colours)

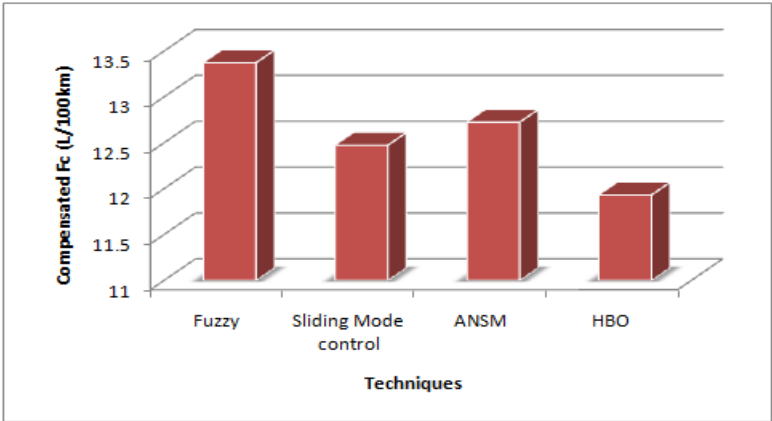


Figure 16 Cost comparison of proposed and online dynamic programming (DP), soft actor-critic (SAC) networks (see online version for colours)

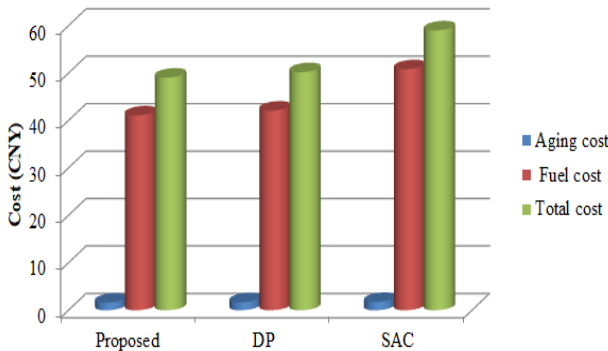
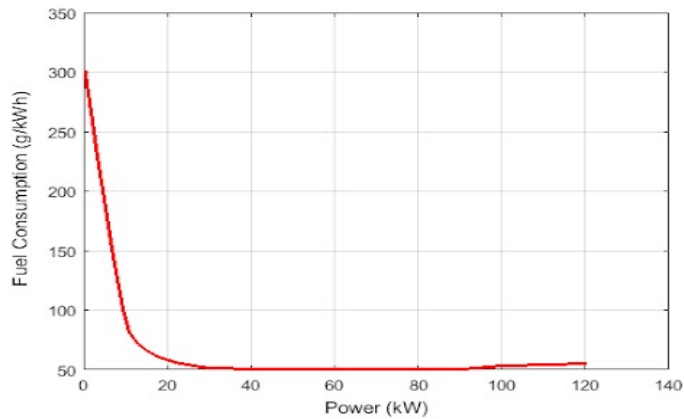


Figure 17 shows the fuel cell consumption. The marginal change in fuel consumption with respect to change in battery voltage is an important factor to consider when optimising the control strategy for the multi-input dc to dc converter in hybrid vehicles. The optimal control strategy will depend on the current battery voltage. If the battery voltage is low, the multi-input dc to dc converter should be operated in a way that increases the battery voltage as quickly as possible. However, if the battery voltage is high, the MIDC should be operated in a way that maintains the battery voltage at a constant level. Table 2 demonstrates the PMSM motor rating parameter.

Figure 17 Fuel cell consumption (see online version for colours)**Table 2** PMSM motor rating parameter

<i>S. No.</i>	<i>Parameter</i>	<i>Ratings</i>
1	Count of phases	3
2	Vicious damping	0.0011 N.m.s
3	Armature inductance	0.0008352
4	Stator phase resistance	0.70
5	Permanent magnet flux linkage	0.1052
6	Rotor inertia	0.000801 kg·m ²
7	Nominal torque	19 N·m
8	Back electromagnetic force waveform	Sinusoidal
9	Nominal speed	3000 rpm
10	Rotor type	Round

Source: Wang et al. (2019)

Table 3 lists out the response of various controls system parameters to various control methods. The HBO technique delivers the perfect results against all switching control parameters while compared with existing fuzzy, sliding mode controls, and ANSM. The comparison of robustness test result is illustrated in Table 4. Table 5 depicts the analyses of computation time of proposed and existing methods. The computation time for the proposed approach is 2.5 s and the existing ANN, BSNSGA, and RNN methods are 5.8 s, 3.7 s, and 4.1 s. Table 6 displays the confusion matrix. The true positive is assigned as correctly labelled positive signals, true negative as correctly labelled negative signal. The false positive is offered as imperfectly labelled negative signals. The false negative as imperfectly labelled positive signals.

Table 7 tabulates the comparison of quality of service (QoS) using proposed offline approach and existing online techniques like PA, SA. The proposed method QoS parameters are best, worst, mean, standard deviation, variation coefficient, and error attains 1110916.01, 1097312.12, 1107616.56, 1041.98, 0.045 and 0.81 respectively.

Table 3 Response of various controls system parameters to various control methods

<i>Parameters</i>	<i>Methods</i>			
	<i>Fuzzy</i>	<i>Sliding mode control</i>	<i>ANSM</i>	<i>HBO</i>
Peak overshoot time (sec)	1.522	1.145	0.15	0.13
Recovery time(sec)	0.66	0.56	0.42	0.2
Peak time (sec)	0.9417	0.6010	0.12	0.9
Steady state error (%)	10	8	6	4
THD (%)	13.5	8.2	3.3	2.1

Source: Liu et al. (2021)**Table 4** Comparison of robustness test result

<i>Parameters</i>	<i>Methods</i>			
	<i>Fuzzy</i>	<i>Sliding mode control</i>	<i>ANSM</i>	<i>HBO</i>
Fuel efficiency (km/L) mean value	211.25	197.31	173.09	165.23
Fuel efficiency (km/L) standard deviation	0.83	0.72	5.97	6.22
Fuel efficiency to baseline (%)variation	−3.28	−2.92	−9.43	−10.36
Final EES voltage (V) mean value	45.67	47.37	46.78	45.63
Final EES voltage (v) standard deviation	0.067	0.049	0.106	0.231
Final EES voltage to baseline variations (%)	−0.17	−0.92	0.95	1.23

Source: Liu et al. (2021)**Table 5** Computation time analyses of proposed offline and existing online approaches

<i>Controllers</i>	<i>Computation time (s)</i>
SAC	4.1
ANN	5.8
DP	3.7
Proposed	2.5

Source: Wang et al. (2019)**Table 6** Confusion matrix

<i>Techniques</i>	<i>Accuracy</i>	<i>Precision</i>	<i>Specificity</i>	<i>Sensitivity</i>
Proposed	95.45%	94.74%	75%	10%
DP	90.91%	90%	50.5%	10%
SAC	84%	81.82%	42.86%	10%

Source: Evangelou and Rehman-Shaikh (2017)

Table 7 Comparison of quality of service

<i>Techniques</i>	<i>Best fitness</i>	<i>Worst fitness</i>	<i>Mean fitness</i>	<i>Error of the best</i>
Proposed	1110916.01	1097312.12	1107616.56	0.81
DP	1105143.97	1093932.90	1105204.43	0.11
SAC	1104217.15	1092458.11	1104159.17	0.12

Source: Evangelou and Rehman-Shaikh (2017)

6 Conclusion

This manuscript presents a multi input DC-DC converter based on fuel minimisation in hybrid vehicle using heap based optimisation (HBO) method. The proposed system inputs include fuel cell (FC), energy storage system (ESS), and photovoltaic (PV) group. Fuel cell is regarded as important power source and the roof-top photovoltaic is utilised for charging batteries, improving performance and reducing fuel consumption. The subject of renewable energy source (RES) is turning out to be progressively apparent in the view of rising petroleum derivative costs, an Earth-wide temperature boost and expanding power demand. Among different RESs, usage of fuel cell (FC) is increasing because of its less noise, increasing power density, high unwavering quality and high proficiency. Here, presents a multi-input DC to DC converter depends on fuel minimisation in hybrid vehicle using HBO method. The reason behind the proposed method is to plan a reliable power source while extracting the most extreme power from the hybrid system parts. Subsequently, the HBO method is applied to hybrid system. Then, the exhibition of proposed controller is approved through simulation. The simulation outcome of the proposed method is more solid and proficient than the traditional source setup as likened with the existing system; and the proposed method achieves good results. The computation time of proposed method is 2.5 s compared to the existing methods. ANN, BSNSGA, and RNN methods times 5.8 s, 3.7 s, and 4.1 s. Finally, the simulation shows that the computation time of proposed method is low.

6.1 Future scope

- Multi-input DC-DC converters (MIDC) are becoming increasingly important in hybrid vehicles, as they allow for the efficient integration of multiple energy sources, like batteries, fuel cells, and solar panels.
- Developing and evaluating new optimisation algorithms for fuel minimisation in hybrid vehicles.
- The HBO method is a promising new algorithm, but there may be other algorithms that are even more effective.
- Future studies could develop and evaluate new optimisation algorithms for fuel minimisation in hybrid vehicles, and compare them to the HBO algorithm.

- The proposed method may be applied to different types of hybrid vehicles, such as plug-in hybrid electric vehicles (PHEVs) and extended-range electric vehicles (EREVs). This would help to assess the generality of the proposed method and its applicability to a wider range of hybrid vehicles.
- Future studies could investigate the impact of these parameters on the performance of the proposed method and develop guidelines for selecting the optimal parameter values.

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