Fuel Economy and Emission Minimization of Hybrid Electric Vehicle using Improved COOT Bird Optimization Algorithm

N. Sangeetha [1*], K. Gayathri [2]

[1]Research Scholar, Department of Electrical Engineering,
Annamalai University, Annamalai nagar, Tamil nadu, India.

[2]Associate Professor, Department of Electrical Engineering,
Annamalai University, Annamalai nagar, Tamil nadu, India

Email: [1]sangaueee@gmail.com, [2]g.gayathri3@gmail.com

Abstract

The issue of pollution stemming from transportation systems, notably passenger vehicles, poses a substantial threat to both society and the environment. Therefore, it is essential to investigate methods to reduce vehicle pollution and enhance fuel efficiency. Well-engineered Hybrid Electric Vehicles (HEVs) may outperform traditional automobiles in terms of reliability and performance, presenting a more environmentally advantageous solution for mitigating harmful emissions. This article presents the optimization of HEV, considering Fuel economy and reduction of emission. The works aims studies the emission and economical aspects of a Hybrid Medium Commercial Vehicle (MCV), specifically for India vehicles. Herein, experiments are conducted on a three different IC engine to record the emission factors. The optimization is based on Improved COOT bird algorithm (ICBO), and this happens to be a combination of COOT bird Optimization (CBO) and Particle Swarm Optimization (PSO). The problem is treated as multi-objective optimization problem. The proposed ICBO is applied to minimize emission and fuel consumption cost of HEV. The final outcomes of the proposed approach are analyzed with other conventional and intelligent techniques for validating the superiority of devised algorithm.

Keywords: Hybrid Electric Vehicles, Multi-objective optimization, Fuel consumption cost, Emission of Diesel engines; Improved CBO algorithm.

1. INTRODUCTION

Presently fuel demand, rules and restrictions of environmental emissions are increased. So, the transportation sectors struggles to find new solutions. Vehicle exhaust emissions are one of the essential causes of air pollution. Carbon monoxide (CO), Nitrogen Oxides (NOx), Hydrocarbons (HC) and Sulfur Dioxide (SO2) are the main component of vehicle exhaust emissions [1]. Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs) are currently regarded as promising emerging technologies for propulsion of vehicles with potential to reduce greenhouse and other exhaust gas emissions from road transport. The wheels of a parallel HEV can be powered directly by an engine or an electrical source. We may even utilize both of them at the same time in certain driving modes. This hybrid electric vehicle type is the most widely used on the market owing to its distinct benefits, which include increased switching flexibility and longer driving economy. This research addresses the optimization process of a parallel hybrid electric car. The main objective of the problem is to minimize the fuel consumption and environmental emissions of HEVs [2].

Prior researchers, proposed various mathematical approaches, artificial intelligent techniques and experimental models for improving fuel economy and minimizing environmental emissions in series-parallel hybrid electric vehicles. Anatole Desreveaux *et. al* [3] developed a techno-economic model to improve the Electric vehicle total cost of ownership. This was model evaluated by experimental measurements on real cars using real driving cycles.

The authors minimize the fuel economy of the real diesel car. Pg Abas *et. al* [4] worked on the Techno-Economic and Environmental impact of hybrid Electric Vehicle using life cycle cost analysis. The authors Investigate the feasibility of introducing EVs into the Brunei market

A multi-objective optimization methodology [5] has been applied in HEVs to determine the optimal configurations, cost of power train equipment and minimize environmental impacts OSMOSE optimization tool has been implemented in the simulation model to obtain optimal solutions. Ridoy Das *et. al* [6] analyzed the same multi-objective problem and optimize the scheduling electric vehicle charging/discharging, fuel energy cost, battery life and CO2 emissions. A mathematical approach of augmented non-dominated ε-constraint method has been applied to solve the problem.

The environmental carbon emission and control strategy has been analyzed using Plug-in HEVs. Artificial intelligence model [7] has been implemented to control the environmental pollutions in cities. Modified ABC algorithm with the SQP methodology [8] has been applied to reduce various environmental emissions such as CO, NOX, HC and fuel consumption/ The hybrid approach also been applied to determine SOC of the battery unit. Slope-weighted energy-based rapid control analysis [9] has been implemented to solve the off-line control problem for parallel and series-parallel HEV. The simulation results were compared with Dynamic Programming (DP) method. A unified quantitative exploration approach [10] has been applied to investigate the energy conversion and losses by energy flows.

Shengxi Bai and Chunhua Liu [11] has documented a start of art for energy harvesting and emission reduction technologies in hybrid electric vehicles. Modified Salp Swarm Algorithm [12] was applied to determine the Techno-Economic and Environmental Analysis of Grid-Connected Electric Vehicle Charging Station in the northwest region of Delhi, India. The four different algorithms such as MOPSO, NSGAII, NSAGIII, and MOEA/D [13] have been projected for multi-objective optimization model of HEVs.

Shradhdha Sarvaiya *et. al* analyses the energy management strategies of HEVs and improves fuel economy and battery life [14]. Here, four different control strategies such as Thermostat, Fuzzy logic, Adaptive Equivalent Consumption Minimization Strategy and Q-learning considering battery aging obtain the optimal solutions. Chun Chung, *et. al* has developed a simulation model to [15] simulate the fuel economy of a power split HEV and an ICEV were tested by using a chassis dynamometer. A case study model has been developed by A. Desreveaux *et. al* [16] worked on the Techno-Economic benefits of HEVs. The proposed model improves the cost of ownership that varies by up to 4 %.

A genetic intelligence approach [17] has been applied on the HEVs power train. This technique has been applied on D class HEVs. It is also determines the techno-economical benefits of HEVs. Eduardo Aparecido Moreira Falcão *et. al* [18] developed a simulation model on CO2 emissions and techno-economic feasibility of an electric commercial vehicle Apurba Sakti *et. al* [19] has proposed practical models to evaluate the Techno-economic analysis and optimization of Li-ion batteries in a passenger electric vehicle. Most of the researchers are developed various only simulation models and soft computing techniques for minimization of emissions in HEVs. The determination of emission values from these simulation models necessitates the incorporation of an emission factor. This paper contributes to addressing this research gap by presenting a practical hardware approach in deriving the emission factor. Further most of the research in Emission reduction in EV were oriented towards passenger cars and the commercial vehicle segment needs focus.

In this article, a novel optimization approach is developed to analyze the fuel conception and environmental emissions in HEVs. An Improved COOT bird optimization (ICBO) tool is proposed to archive the optimal solutions. The control parameters of projected ICBO algorithm effectively optimize the HEV variables and highly reduce the fuel economy and environmental emissions of the developed model. Finally, the simulation results are compared with existing approaches available in literature.

2. SOLUTION METHODOLOGY

An effective and successful approach, the Improved Coot Bird Optimization (ICBO) algorithm is applied to minimize fuel cost and environmental emissions of Hybrid Electric Vehicles. The ICBO is the combination of CBO and PSO wherein the PSO is used to limit the search space. This reduces the computational time and ensures a global optimal point is reached. Numerical example with three different case studies is considered. Further, for each test case comparative study is also done for checking the progress of ICBO approach. The mathematical operation of this ICBO approach is described in the following section.

2.1 Coot Bird Optimization (CBO) algorithm

The Coot Bird Optimization (CBO) algorithm is inspired by natural behavior of different movements of coot birds on the water surface. It is a new and efficient meta-heuristic optimization algorithm and developed by Iraj Naruei *et .al.* in 2021 [20].The coot birds having two differ modes of movement on the water surface which is irregular and regular movement. It moves in the direction of a group of leading leaders to reach a food supply.

The characteristics of the Coot birds on the water surface, which are represented as follows [20].

- Random movement
- Chain movement
- Adjusting the position based on the group leaders
- Leader Movement

The population of the coot is randomly generated and mathematically represented using the equation (1).

$$CootPos(i) = rand(1, d).* (ub - lb) + lb \quad (1)$$

(i) Random movement

The random movements of the coot birds at position Q are mathematically defend using equation (2).

$$Q = rand(1, d).* (ub - lb) + lb \quad (2)$$

In order to keep away from a local optimum solution, updates the position of the coot using equation (3)

$$CootPos(i) = CootPos(i) + A \times R2 \times \left(Q - CootPos(i)\right) \quad (3)$$

Where R2 is a random number in the interval [0, 1], A is determined using equation (4).

$$A = 1 - L \times \left(\frac{1}{iter}\right) \quad (4)$$

(ii) Chain movement

The chain movement may be represented by average position of two coot birds which is represented as

$$CootPos(i) = 0.5 \times \left(CootPos(i-1) + CootPos(i)\right) \quad (5)$$

(iii) Adjusting the position based on the group leaders

The coot bird updates its own position according to the position of the leader in the group. The leader is selected using equation (6).

$$K = 1 + (iMOD\ NL) \quad (6)$$

The next position of the coot based on the selected leader is premeditated using the equation (7)

$$CootPos(i) = LeaderPos(k) + 2 \times R1 \times \cos(2R\pi) \times \left(LeaderPos(k) - CootPos(i)\right) \quad (7)$$

(iv) Leader Movement

The leader must jump from the existing local optimal position to the global optimal position for abstaining the best solution and mathematically described as

$$LeaderPos(i) = \begin{Bmatrix} B \times R3 \times \cos\left(2R\pi \times \left(gBest - LeaderPos(i)\right) + gBest & R4 < 0.5 \\ B \times R3 \times \cos\left(2R\pi \times \left(gBest - LeaderPos(i)\right) - gBest & R4 \geq 0.5 \end{Bmatrix} \quad (8)$$

B is calculated using the equation (9)

$$B = 2 - L \times \left(\frac{1}{Iter}\right) \quad (9)$$

2.2 Improved Coot Bird Optimization (ICBO) Algorithm

Improved CBO (ICBO) algorithm is the combination of PSO and CBO algorithm. Initially, PSO algorithm is applied to reduce the search space; thereafter this output of PSO is optimized by COOT algorithm for achieving the optimal global solution. These combinations improve program computation speed, high efficiency and good convergence [21].

PSO is a stochastic algorithm that is based on group collaboration by simulating the behavior of birds foraging. Through this mechanism, the proposed algorithm has got characteristics of both PSO and CBO. In the search strategy of the newly algorithm, the search characteristics of PSO is kept and the communication characteristics of CBO is embedded. This can enhance the search capabilities and improve the searching efficiency during search period.

The searching strategies of PSO are expressed as

$$v_i^{kg+1} = \omega v_i^{kg} + c_1 r_1 \left(p_i^{kg} - x_i^{kg}\right) + c_2 r_2 \left(BestS_i^{kg} - x_i^{kg}\right) \quad (10)$$

$$x_i^{kg+1} = x_i^{kg} = v_i^{kg+1} \quad (11)$$

3. PROBLEM FORMULATION

The primary goal of this research is to minimize Fuel Consumption (FC), Carbon Monoxide (CO), Nitrous Oxide (NOX), and Hydrocarbons (HC) to achieve optimal vehicle performance. The objective function, represented in Equation (1), is defined as follows:

$$\text{Min } F(y)=d1\cdot \text{FC}+d2\cdot \text{CO}+d3\cdot \text{NOX}+d4\cdot \text{HC} \qquad (12)$$

Here, y belongs to *Y*, the total search space. 'y' is a variable vector containing the size of vehicle components and parameters of the control strategy. The weighting factors, denoted as *d*1 to *d*4, represent the importance of different parameters in the objective function and can vary between 0 and 1. The constraint limits of HEVs are articulated in equations (13)-(23)

$$\text{Acceleration time is } \leq 12 \text{ s for } 0\text{–}60 \text{ mph} \qquad (13)$$

$$\text{Acceleration time is } \leq 5.3 \text{ s for } 40\text{–}60 \text{ mph} \qquad (14)$$

$$\text{Acceleration time is } \leq 23.4 \text{ s for } 0\text{–}85 \text{ mph} \qquad (15)$$

$$\text{Gradeability is } \geq 6.5\% \text{ at 55 mph for 1200 s} \qquad (16)$$

$$\text{Maximum speed is } \geq 85.1 \text{ mph} \qquad (17)$$

$$\text{Maximum acceleration is } > 16.4 \text{ ft/s}^2 \qquad (18)$$

$$\text{Distance is } > 140 \text{ ft in 5 s} \qquad (19)$$

$$\text{Change in State of Charge } (\Delta SOC) \text{ is } \leq 0.5\% \qquad (20)$$

Also, subjected to the following operating conditions:

Engine power is as in equation,

$$P_{eng} > 0 \qquad (21)$$

The power output of the engine is restricted to the max power rating P_{eng_max}, of the engine

$$P_{eng} < P_{eng\_max} \qquad (22)$$

For the charge-sustaining control system response, the State of Charge (SOC) of the battery should be always within:

$$SOC_{low} < SOC_{battery} < SOC_{high}, \qquad (23)$$

3.1 Implementation of ICBO Algorithm for Fuel Consumption and Emission Optimization

The step by step procedure for Implementation of ICBO algorithm for minimization of fuel consumption and emission of HEVs are defined as.

- A HEV simulation model is developed in MATLAB. In this model various drive cycles are provided as input. The PSO algorithm is applied to narrow the search space. The output of the PSO sets the upper and lower limits for the COOT bird algorithm.
- The control variables are optimized to improve the MPG and reduce emission. Herein the improved COOT optimization Algorithm was to search the optimal solutions.

4. RESULTS AND DISCUSSION

Internal Combustion Engines (ICEs) in conventional cars emit direct emissions out of the exhaust, as well as through fuel system evaporation and fuelling operations. All-electric cars, on the other hand, emit no direct emissions. When in all-electric mode, plug-in hybrid electric vehicles (PHEVs) emit no direct emissions; nevertheless, they may release evaporative pollutants. PHEVs emit tailpipe emissions when operating with an ICE. They usually have lower direct emissions than equivalent conventional vehicles.

Distinct simulation studies are done on two different drive cycles such as FEUTP and ECE-EUDC and graphically displayed in fig. 1 and fig. 2. The results for Improved COOT Optimization (ICBO) algorithm with the FTP driving cycle are shown in Table 1 and the results for FTP driving cycle with multi-objective optimization is given in Table 2. On the other hand, Table 3 and Table 4 provide the simulation results with single and Multi - objective optimization with ECE-EUDC. In Multi Objective optimization, the reduction of fuel consumption is given more weight (50%) and the remaining 50 percent is allocated among the other three emission vehicle metrics.

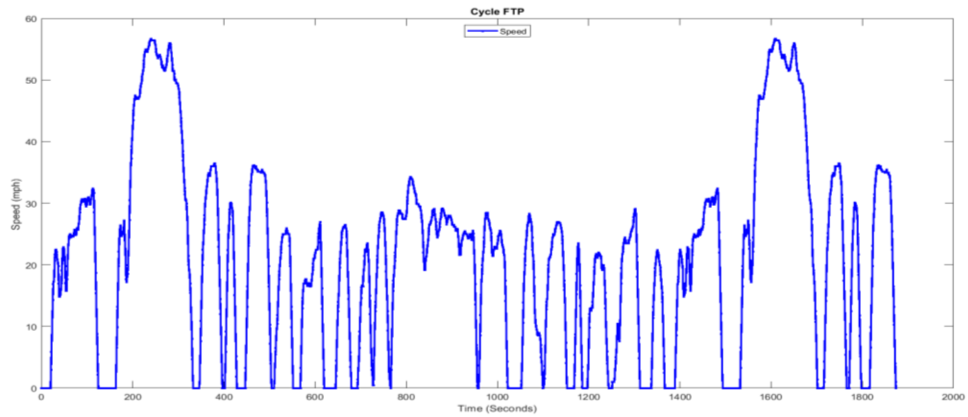

Fig 1 FTP – Drive Cycle

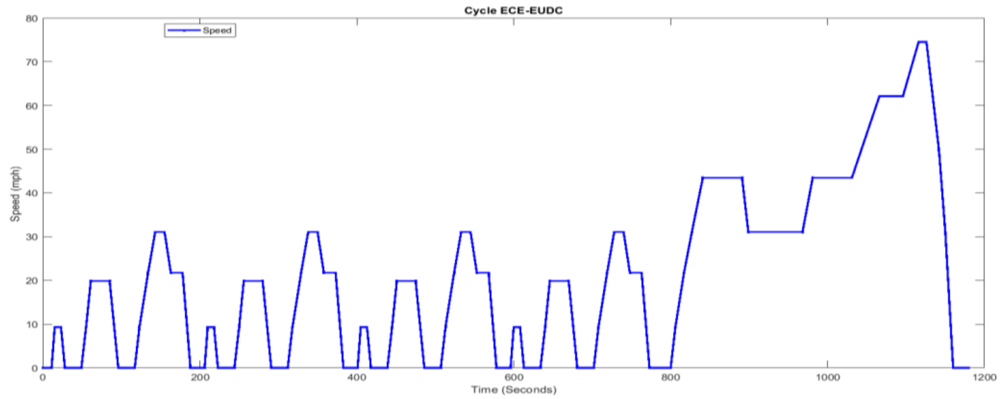

Fig. 2 EUDC Drive Cycle

Table 1 Optimization with MPG as objective

	Parameter	**ICBO (Proposed)**	CBO	LP
Variables	DC – DC converter Kp	**1.943**	1.7	1.5
	DC – DC converter Ki	**1.957**	1.8	1.9
	Speed Controller Kp	**0.29649**	0.3	0.4
	Speed Controller KI	**1.8882**	1.5	2
Constraints	Grade (%)	**7.200**	7.200	7.200
	0–60 mph time (s)	**8.400**	8.400	8.400
	40–60 mph time(s)	**4.000**	4.000	4.000
	0–85 mph (s)	**16.300**	16.300	16.300
	Max speed (mph)	**127.000**	127.000	127.000
	Max accel (ft/s2)	**16.400**	16.400	16.400
	Distance in 5 s (ft)	**183.700**	183.700	183.700
Optimized values	Objective - MPG	**33.5**	32.9317	32.195
	CO g/m	**0.5522**	0.5574	0.5746
	HC g/m	**1.9881**	2.0065	2.0686
	NOx g/m	**0.4970**	0.5016	0.5172

Table 2 Optimization with MPG + Emission as objective

	Parameter	**ICBO (Proposed)**	CBO	LP
Variables	DC – DC converter Kp	**1.1**	1.943	1.0
	DC – DC converter Ki	**2**	1.957	1.9
	Speed Controller Kp	**0.5**	0.29649	0.4
	Speed Controller KI	**1.7**	1.8882	1.9
Constraints	Grade (%)	**7.200**	7.200	7.200
	0–60 mph time (s)	**8.400**	8.400	8.400
	40–60 mph time(s)	**4.000**	4.000	4.000
	0–85 mph (s)	**16.300**	16.300	16.300
	Max speed (mph)	**127.000**	127.000	127.00
	Max accel (ft/s2)	**16.400**	16.400	16.400
	Distance in 5 s (ft)	**183.700**	183.700	183.70
Optimized results	Objective – MPG	**33.0**	30.1317	32.195
	CO g/m	**0.5606**	0.6140	0.5746
	HC g/m	**2.0182**	2.2104	2.0686
	NOx g/m	**0.5045**	0.5526	0.5172

Table 3 UDDS with MPG as objective

	Parameter	**ICBO (Proposed)**	CBO	LP
Variables	DC – DC converter Kp	**0.349**	0.302	0. 49
	DC – DC converter Ki	**0.4070**	0.4001	0.3070
	Speed Controller Kp	**1.735**	1.575	1. 35
	Speed Controller KI	**0.1294**	0.1294	0.103
Constraints	Grade (%)	**7.200**	7.200	7.200
	0–60 mph time (s)	**8.400**	8.400	8.400
	40–60 mph time(s)	**4.000**	4.000	4.000
	0–85 mph (s)	**16.300**	16.300	16.300
	Max speed (mph)	**127.000**	127.000	127.000
	Max accel (ft/s2)	**16.400**	16.400	16.400
	Distance in 5 s (ft)	**183.700**	183.700	183.700
Optimized results	Objective - MPG	**15.722**	14.41	14.03
	CO g/m	**1.1767**	1.1767	1.318
	HC g/m	**4.2360**	4.2360	4.747
	NOx g/m	**1.0590**	1.0590	1.186

The HEV fuel consumption was verified using EPA test cycles, such as the FTP and the Urban Dynamometer Driving Schedule (UDDS). As in table 1 an optimal fuel economy of 33.5 mpg and 15.7 mpg was obtained for FTP, UDDS respectively.

Table 4 UDDS with MPG + Emission as objective

	Parameter	**ICBO (Proposed)**	CBO	LP
Variables	DC – DC converter Kp	**0.349**	1.502	0.4
	DC – DC converter Ki	**0.4070**	1.845	0.430
	Speed Controller Kp	**1.735**	0.249	1.523
	Speed Controller KI	**0.1294**	1. 22	0.145
Constraints	Grade (%)	**7.200**	7.200	7.200
	0–60 mph time (s)	**8.400**	8.400	8.400

	40–60 mph time(s)	**4.000**	4.000	4.000
	0–85 mph (s)	**16.300**	16.300	16.300
	Max speed (mph)	**127.000**	127.000	127.000
	Max accel (ft/s2)	**16.400**	16.400	16.400
	Distance in 5 s (ft)	**183.700**	183.700	183.700
Optimized results	Objective - MPG	**14.02**	13.41	13.03
	CO g/m	**1.3195**	1.3796	1.4798
	HC g/m	**4.7504**	4.664	5.113
	NOx g/m	**1.1876**	1.2416	1.2778

The measurement and evaluation of different pollutants released during combustion are part of the emission analysis process for IC engine. These pollutants will negatively impact air quality and exacerbate environmental problems like acid rain, smog, and climate change. Internal combustion engines release the following primary pollutants into the air, carbon monoxide (CO), Nitrogen Oxides (NOx), Particulate Matter (PM), Hydrocarbons(HC) and sulfur Dioxide (SO2). The emission values in table 1 to 4 are all presented in g/m. The emission factor used to evaluate the CO, NO and HO factor are found through experimentation on three different vehicles.

5. CONCLUSION

This paper minimizes the fuel economy and various emissions of HEVs using intelligent soft computing technique and practical approach. A novel and effective Improved COOT bird optimization (ICBO) approach is applied to obtain the optimal solutions. The simulation results of fuel consumption, various emissions, controller gains and optimal value of multi-objective functions are presented. From the tabulated results it's obviously that for the tested drive cycles, the ICBO was able to provide an improved MPG compared to Conventional CBO and LP method. Further, results revealed that the proposed approach significantly improves fuel economy by 0.5683 MPG for FTP and 1.3120 MPG for ECE-EUDC driving cycles. The novelty of the proposed work is the emission reduction is shown as a two stage process; first as a primer the diesel injection timing effect is demonstrated, then in the second stage reduction is achieved by ICBO algorithm

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