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An Intelligent Coot Bird Optimization-based Energy Management Strategy in Hybrid Electric Vehicle

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Abstract

Energy Management in Hybrid Electric Vehicles (HEV) is a cost-effective tool for improving the equipment's energy efficiency and lowering energy costs to the consumer. Accordingly, it is important to quantify the fuel savings considering the vehicle constraints. The Vehicle power split has to be in such a way that every moment, the net power demand on a final drive is fulfilled by either the internal combustion engine alone or the electric motor alone or in combination. This dual momentum nature, the complex composition, and the operation modes in a series-parallel HEV create barriers in traditional methods. Therefore, meta-heuristic algorithm-based simulations are required to check the feasibility of the proposed design. Coot Bird Optimization (CBO) is one of the recent meta-heuristic methods acquired from the bird swarm named Coot. The coot leaders are represented by high-quality solutions and the coot members correspond to low-quality solutions. In order to get to a food source, the swarm advances towards a group of prominent leaders. This chosen technique CBO has proven to optimize the fuel depletion in each drive cycle. Henceforth, the proper energy diversification in the vehicle is substantiated by the proposed method.

1. Introduction

There is a growing need for clean and sustainable transport solutions namely Electric Vehicles due to the detrimental effects that conventional fossil fuel-powered vehicles have on the environment. Subsequentially, E-Mobility is the leading-edge revolution in the transport sector. HEV strives to minimize overall dependence on the oil industry and promotes widespread electrification (Husain). Light and heavy-duty cars, in particular, are a major contributor to global greenhouse gas emissions and have become a source of economic strain as a result of rising oil costs (Santini, Patterson, and Vyas). The researchers developed several mathematical and intelligent computational techniques (Debata, Samanta, and Panigrahi Marzougui et al. Hao et al. Shi et al. Wang et al. Phan et al. Liang et al. I Dokuyucu and Cakmakci Hmidi, Salem, and Amraoui Borhan et al. Mangun et al. Xue and Lin Naruei and Keniya) for achieving energy management in hybrid electric vehicles. Seshadev Debata et.al (Debata, Samanta, and Panigrahi) developed a hybrid approach of Suffered Frog Leaping Algorithm (SFLA) with ANN for the solution of the Energy Management (EM) problem in Hybrid Electric Vehicle (HEV). The SFLA optimizes the HEV variables and tuned results are trained by the ANN approach.

Hajer Marzougui (Marzougui et al.) applied fuzzy logic control, fitness control, and rule-based algorithm to split the energy flow between the three sources fuel cell, ultra-capacitor, and battery, and minimized the fuel economy.

Breath First Search (BFS) with the Dynamic Programming (DP) algorithm (Hao et al.) has been applied to reduce the fuel consumption of HEV. The BFS provides better results than the rule-based systems. An adaptive equivalent minimal fuel consumption strategy has been developed for improving the capabilities of energy storage and emission minimization in a PHEV (Shi et al. Wang et al.). Fuzzy logic controller (Phan et al. Liang et al. I Dokuyucu and Cakmakci) has been applied in hybrid electric autonomous vehicles for energy management. They determined the uncertainties of driving conditions and optimized the HEV variables for fuel consumption management of autonomous HEVs.

2. Proposed Methodology

The technological change in the transportation sector enforces new methodologies for the control of energy handling in hybrid electric vehicles. This paper contributes to the problem of fuel economy of series-parallel HEV. It is technically achieved by controlling the power flow between ICE and the electric motor subject to vehicle constraints. The intelligent COOT bird algorithm is used to estimate the PI controller gains with the objective of efficient energy management. Initially, we made simulations for conventional series parallel vehicle in MATLAB and then we used a trial method to adjust the controller gains followed by the COOT bird algorithm. This sequential operation enhances the profitability of the proposed model.

The power train of Series-parallel HEV is shown in Fig.1**.** This section presents the formulas used to calculate individual force terms and the net traction effort. Perhaps, a simple MATLAB script was used to implement this task and it’s described below. The Rolling resistance F_r is created mainly due to the vehicle tires and mildly from the bearing parts. The equation for this is,

$$F_r = mgC_r \tag{1}$$

Whereas

M is the mass of the vehicle,
g is the acceleration due to gravity,
Cr is the coefficient of rolling resistance

The next term the aerodynamic component is given by,

$$F_d = \frac{1}{2}\,\rho\, C_d A U^2 \tag{2}$$

Where,

ρ is the air density,
C_d is the drag coefficient,
A is the frontal area,
U is the velocity of the vehicle

Then, the Hill climbing force needed when a vehicle moves up a slope needs to the calculated.

$$F_h = m\, g\sin\beta \tag{3}$$

$$F_{al} + F_{a\omega} = 1.05\, Ma \tag{4}$$

Then the overall tractive effort,

$$F_t = F_r + F_d + F_h + F_{al} + F_{a\omega} \tag{5}$$

The battery power in motoring mode (P_{sm}) and charging (Ps_{reg}) in regeneration mode are obtained as given in (6) and (7) respectively.

$$P_{sm} = \frac{F_T U}{\eta} \tag{6}$$

$$P_{sreg} = F_t U \eta \tag{7}$$

$$\eta = \eta_t \eta_m \eta_i \eta_c \tag{8}$$

Whereas η_t, η_m, η_i and $\eta_c$are efficiency of the mechanical transmission, motor, inverter, and converter respectively. Using an efficiency of 90% for the motor, 90% for the transmission system, and 95% for the inverter and converter, the overall efficiency of the EV system is considered to be 78% at full load for the simulation studies. By integrating the source power in equations (6) and (7) to time, the energy needed from the source is determined. It is expected that supplementary appliances run on a separate 12 V battery. Power Train of Series Parallel HEV is shown in Figure 1.

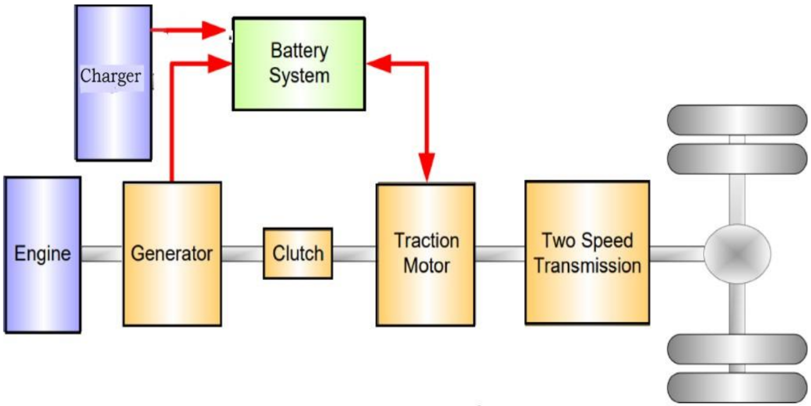

Figure 1. Power Train of Series Parallel HEV

3. Coot Bird Optimization Algorithm

The Coot Bird Optimization (CBO) algorithm takes its cues from the varied motions of coot birds on the water's surface in nature. Iraj Naruei et al. created a brand-new and an effective meta-heuristic optimization technique in 2021 (Naruei and Keniya). To get to a food supply, it travels in the direction of a group of powerful leaders. Furthermore, three movements are involved in the behavior of a swarm of coots on water: a synchronized movement, a chaotic movement of activity, and a chain movement on the water's surface, where each coot follows its lead coot. The population of the coot is randomly generated and mathematically represented using the equation (9).

$$CootPos(i) = rand(1,d) * (ub - lb) + lb \qquad (9)$$

Whereas, d is the number of parameters varied lb and ub are the lower and upper limits of parameter space. The chaotic movement of the coot birds in position

$$Q = rand(1,d) * (ub - lb) + lb \qquad (10)$$

Followed by synchronized movement

gBest is the global optima, R3 and R4 ranges

$$CootPos(i) = 0.5 \times (CootPos(i-1) + CootPos(i)) \qquad (11)$$

The selected leader position after the swarm movement

$$CootPos(i) = LeaderPos(k) + 2 \times R1 \times \cos(2R\pi) \times (LeaderPos(k) - CootPos(i)) \qquad (12)$$

The global optima for obtaining the best solution given by

$$CootPos(i) = LeaderPos(k) + 2 \times R1 \times \cos(2R\pi) \times (LeaderPos(k) - CootPos(i)) \qquad (13)$$

Where $\left(B = 2 - L \times \left(\frac{1}{Iter}\right)\right)$ between [0, 1], R range between (Husain)

4. Results And Discussion

The PMSM offers a high density, and efficiency, and provides a sinusoidal EMF. The electrical motor is a 500 V_{dc}, 40 kW interior PMSM with the associated drive. This motor has 8 poles and the magnets are buried, i.e., the salient rotor's type. Motor parameters are shown in Table 1.

Table 1. Motor parameters S.

No	Parameter	Value
1	Nominal Voltage	500 V
2	Rated capacity	40KW
3	Series Resistance	0.02
4	Internal Resistance	0.246

The torque demand was established using the difference between the reference and actual rotor speeds in the PMSM's vector controller for control. Vector control was used to translate the torque demand into predetermined values for the d and q currents. IC Engine parameters are shown in Table 2.

Table 2. **IC Engine parameters**

	Parameter	Value
1	Shaft Inertia	0.25
2	Power	112 Hp
3	Rated Engine RPM	5000
4	IC engine speed sensor constant	0.2079

For Kicking off and uphill acceleration, an EV requires a constant torque operating zone at low speed, followed by a constant power speed range at high speed. This idea is to reflect typical urban driving styles and be found in data sets like the ECE15. Further, the overload torque and power will be limited by the inverter ratings. The Urban drive cycle is shown in Figure 2.

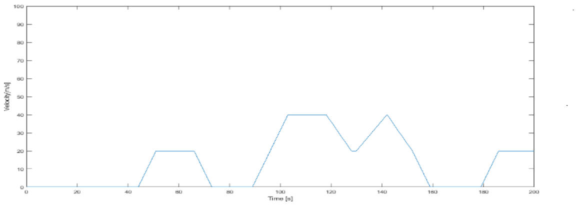

Figure 2. **Urban drive cycle**

Table 3. **Simulation results of Fuel Consumption for Urban Drive Cycle 1**

S.No	Test Case 1 urban drive cycle 1	Value
1	Fuel Consumption in Liters - Without Optimization	3.29
2	Fuel Consumption in Liters - With Optimization	2.77
3	D.C to D.C converter Kp	1.2
4	D.C to D.C converter KI	0.11
5	Vehicle Speed Controller Kp	1.68
6	Vehicle Speed Controller Ki	1.85

From Table 3 and Table 4. it's obvious, that the four parameters optimized by coot optimization provide reduced fuel consumption. Again, the algorithm also searches the gain values within the stability limits of the controller.

HEV engines are often smaller than traditional vehicles for the same configuration. The dimensions chosen correspond to the vehicle's overall power requirements. The throttle input signal in Figure 3. is between 0 and 1. This indicates that the engine torque demand is a small portion of the maximum torque. Also, the throttle range indirectly regulates the engine speed since air-fuel combustion dynamics which is kept constant in this model

Table 4. **Simulation results of Fuel Consumption for Urban Drive Cycle 2**

S.No	Test Case 2 urban drive cycle 2	Value
1	Fuel Consumption in Liters - Without Optimization	3.83
2	Fuel Consumption in Liters - With Optimization	3.19
3	D.C to D.C converter Kp	1.510
4	D.C to D.C converter KI	0.335
5	Vehicle Speed Controller Kp	1.217
6	Vehicle Speed Controller Ki	0.01

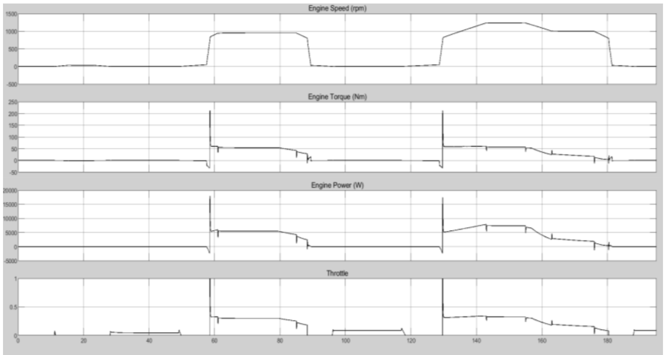

Figure 3. **IC Engine Plots for urban drive cycle**

5. Conclusion

Electric vehicles are currently proliferating

with their environmentally friendly characteristics in terms of quality, functional simplicity, and above all, energy efficiency. Power Management in HEV contributes to fleet electrification success and helps to minimize conventional fuel costs. This design devised a method for optimizing a series-parallel HEV controller for power management. The power demand from the pedal position is split between two propulsion systems to obtain better fuel economy. Exploiting the Optimized controller parameters, we realize that a HEV supports good fuel thrift compared to manual controller tuning. Further research on this topic will be to append the motor loss models and emission constraints.

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