# Particle Swarm Optimization for Control Strategy of Hybrid Electric Vehicles

**Article** · September 2020

DOI: 10.31663/tqujes.11.1.386(2020)



Basil Sh. Munahi
University of Basrah


Abdulbaqi K. Ali
University of Basrah

University of Thi_Qar Journal for Engineering Sciences
http://www.doi.org/10.31663/tqujes.11.1.386(2020)
Vol 11.1 (September 2020)
ISSN :2664- 5572 ( online)
ISSN:2664-5564 (print)
Available at http://jeng.utq.edu.iq
utjeng@ utq.edu.iq

# Particle Swarm Optimization for Control Strategy of Hybrid Electric Vehicles

**Zahraa N.Abdul hussain [†], Dr.Basil Sh.Munahi [‡] and Assist Prof Dr.Abdul baki K.Ali [ƚ]**

[†] Department of mechanical engineering, University of Basrah, Iraq, zahramecha486@gmail.com
[‡] Department of mechanical engineering, University of Basrah, Iraq, eng.dr.basil@gmail.com
[ƚ] Department of mechanical engineering, University of Basrah, Iraq, abdulbaki uof@gmail.com

## Abstract

This paper presents a particle swarm optimization algorithm (PSO) as a control strategy for the offline driving cycle to obtain the best torque distribution between the two sources: internal combustion engine (ICE) and the electric motor (EM). The purpose to minimize the fuel consumption, emissions, and maximize the state of charge of the battery for the model of power-split hybrid electric vehicles (PSHEV), while the requirements of the driving performance considered as constraints. The control strategy has been applied for the UDDS driving cycle under the Matlab Simulink software environment. The results of the value of fuel consumption compared with fuzzy logic control (FLC), the global optimization genetic algorithm (GA), and ADVISOR. After comparing, the results demonstrate the effectiveness of the (PSO) algorithm over the mentioned methods in lowering fuel consumption by 8.87% for the (FLC), 22.6% for the GA. Maximizing the state of charge of the battery by 5.6% for the ADVISOR program and closest to optimal results for FLC.

***Keywords:*** *Hybrid electric vehicle, Particle swarm optimization, Torque split strategy, Fuel consumption, SOC of battery, Emissions*

### Nomenclatures

| | | | |
|---|---|---|---|
| ADVISOR | Advanced Vehicle Simulator | MOGA | Multi Objective Genetic Algorithm |
| BCCDC | Basra City Center Driving Cycle | NiMh | Nickel Metal Hydride |
| DP | Dynamic Programming | PSHEV | Power Split Hybrid Electric Vehicle |
| CD | Charge-depleting | PSO | Particle swarm optimization |
| EM | Electric Motor | Pbest | Personal Best |
| EMS | Energy Management Strategy | QPSO | Quantum Particle Swarm Optimization |
| EPA | Environmental Protection Agency of the USA | SMPC | Stochastic Model Predictive Control |
| | | SOGA | Single Objective Genetic Algorithm |
| FC | Fuel Consumption | SA | Simulated Annealing |
| GA | Genetic Algorithm | SOC | State Of Charge |
| GPS | Global Positioning System | UDDS | Urban Dynamometer Driving Cycle |

### English symbol

| | |
|---|---|
| $t_{dcy}$ | Entire time for driving cycle |
| λ | normalized air-fuel-ratio |

## 1. Introduction

In the last years, the world is facing a dangerous problem that relates to the energy request and supply. There are only 1300 bilion barrels of certain stock of petroleum but the world expends about 85 million barrels of petroleum every day. Based on that the world will give out the oil in 40 years. Another challenge that the world faces global warming(Husain, 2011). The solution for these challenges was the hybrid electric vehicles (HEV) that use electric motor and ICE machine to transfer the driving power. The ICE in amalgamation with the electric motor and charging unit that supplies an extensive range for vehicles and reduce the pollution. The ICE and electric motor need the controls and support systems, besides the other parts of the vehicles that control the combination of the power that comes from the electric motor and ICE so the complexity is clear in the design of the hybrid vehicles (Mi & Masrur, 2017). There are three topologies for HEV powertrains that have been proposed: series hybrid vehicle, parallel hybrid vehicle, and series-parallel hybrid vehicle. The energy management strategy can identify the component responsible for operating. EMS also find the best power distribution to reduce the wastage energy of the vehicle after defining the relationship of the vehicle and identifying it by rule-based strategy(Chen et al., 2015). In hybrid electric vehicles (HEVs), the method of reducing the cost through improve the utilization rate of energy and improve the driving performance (Thompson et al., 2018). Thus, the optimization control strategy in energy management is an important factor in minimizing the fuel consumption, emission, and improvement the driving performance. The optimization process in energy management has become at the top of the research in the field of transportation. The authors (Lee et al., 2016) Study different types of power management strategies. The algorithm used was (DDP) and (SDP). PSR and ANNs optimized the results gained from (DDP). The results show that the performance of SDP is validated more than DDP in minimization the fuel consumption but the same results of the operation points for the engine and motor. ANNs have the ability to minimization fuel consumption more than PSR. The literature (Lihao et al., 2016) used fuzzy logic control depending on the vehicle torque and state of charge of battery while the optimization process utilized was QPSO. (Ming et al., 2017) presented fuzzy logic control (FLC) for energy management strategy to upgrade the rule-based algorithm for the plug-in hybrid electric vehicle depending on the required torque to drive the vehicle and battery charge. The researchers proved (FLC) can realize an elongation of charge-depleting (CD) stage above 4.5% and lower in energy loss can be above 5.99%. The algorithm SA-PSO proposed in energy management strategy depending on driving pattern recognition by optimizing the control parameters under three driving cycles (Lei et al., 2017). The authors (Wu et al., 2019) used dynamic programming to optimize the torque distribution for the electric motor to solve the problem that relates to the difference between the axial of the motor. Recent research presented the novel speed optimization depending on the PSO algorithm for the (HEV) queue to improve the ability of the vehicle to avoid the red traffic light and effectiveness of the battery charging (Wang et al., 2018).(Y. Zhou et al., 2020) used multi-mode energy management strategy for (FCHEV) by using Markov pattern recognizer. Ref. (Xie et al., 2019) utilized (MPC) depending on (DOD) to reduce the total cost for the fuel consumption and life loss of the battery. The result found that the control method minimizing the cost by 1.65%, 1.29%, and 1.38%. The genetic algorithm is used to control the torque distribution between the internal combustion engine (ICE) and electric motor (EM) straightway. The results proved that the fuel consumption proceeds about 1.8% better than the best-considered reference strategy on NEDC (Nellen et al., 2015). The literature (Lei et al., 2020) presented (DP) in the optimization of energy management strategy for four standard driving patterns. The driving status is specified online by the k-means clustering algorithm with the help of GPS and GIS. The result proved the effectiveness of the control strategy for most driving status besides the improvement in fuel economy.

In this paper, a torque split strategy based on offline particle swarm optimization is presented to optimize the operation of the engine to operate at most efficient points and minimize the fuel consumption, emissions and maximize the SOC of the battery. The optimization process was tested on the UDDS driving cycle to verify the effectiveness of the process of the PSO algorithm.

## 2.Vehicle model

The design of the (PSHEV) combining the character of the series and parallel hybrids. There is an extra mechanical link in comparison with the series hybrid and supplemental generator in comparison with the parallel hybrid (Chau, 2015). Figure (1) shows the system configuration of a power-split hybrid electric vehicle.

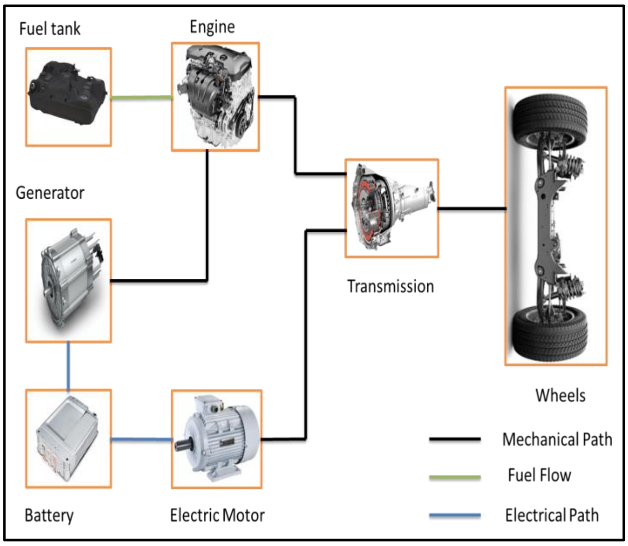



**Figure (1)power split hybrid vehicle**

The complication mechanical of the building power split is clear because it takes the feature both of the series and parallel hybrids. This vehicle is considered a sturdy hybrid because it achieves all the desired functions(Husain, 2011). In this study, the vehicle used was Toyota Prius _JPN 15 KW, petroleum engine, the parameters of a vehicle structure and its specification are listed in Table 1.

| Table (1):The characteristics Of Vehicle[Najim 2018] | | |
|---|---|---|
| Name | Value | Units |
| vehicle Mass | 1350 | Kg |
| Aerodynamic Drag Coefficient | 0.417 | ---- |
| Front area | 2.686 | ---- |
| The radius of rolling | 0.32 | M |
| Transmission Efficiency | 0.95 | --- |
| Battery Type | NiMH Spiral Wound | --- |
| Capacity of battery | 6.5 | AH |
| Nominal Battery Voltage | 288 | V |

The model of Ref. (Najim 2018) that shown in figure(2) has been used. The component of the vehicle are as follow, the nickel- metal hydride (NiMH) battery with two way DC-DC converter joined with DC-Generator and DC Motor. Moreover, the power split unit which can divide the power among the parts of the hybrid vehicle. The ICE is the most common power source in the hybrid vehicle. The vehicle body assembly to other parts like tires, brake, and rear differential.

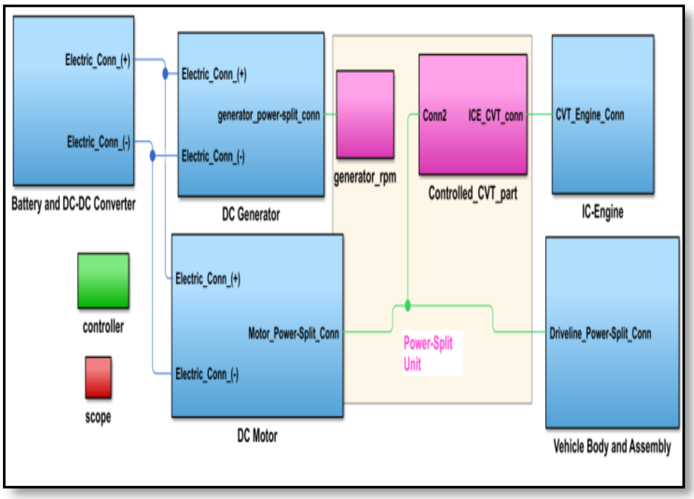



**Figure (2) model of power split hybrid vehicle**

## 3.Torque split technique

The main problem associated with energy management for HEVs is the torque distribution. Under the driver torque requirement, the ICE, the EM, or both the energy sources can be supplied the power to drive the vehicle. The work of optimization in this study is to produce the best distribution for the torque between two sources: ICE and EM, and make the engine operate at most efficient points according to the efficiency map of the ICE which is shown in figure (3)(Munahi 2013). This curve represented the optimal torque curve for the same ICE that used in this study by (Munahi 2013) who used Genetic algorithm to obtained it.

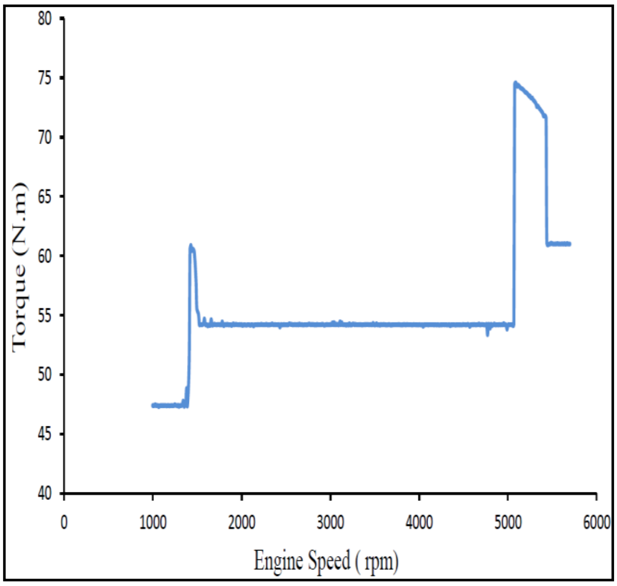



**Figure (3) efficiency map of ICE(Munahi 2013)**

The operation of distribution of the torque between the ICE and EM is done by considering the driving cycle as a sampled point. Then dividing the driving cycle to 100 parts. For every part, there is a ratio for the ICE torque generating by (PSO) algorithm. In this study, the particles of the swarm represent the probability of the torque distribution. Every particle from them represents the probability of the ICE torque for the driving cycle at every specific time from the total time of the driving cycle. The time between the parts of the UDDS driving cycle is 14 by dividing the entire time of the UDDS driving cycle over 100 parts.

The torque technique is the total combination of the particles along the driving cycle. One of the particles during the driving cycle represents the best probability for the torque of ICE that proposed by (PSO) algorithm. The remaining ratio from one percent represents the torque of the electric motor, however, during every part because the ICE and EM activate with a constant torque ratio and the total of the ICE and EM torque ratio must be equal to 100% or 1. The torque split technique is shown in the figure (4), where:$t_{DCY}$ entire time for driving cycle (sec), P: The period between every part in the driving cycle (sec).

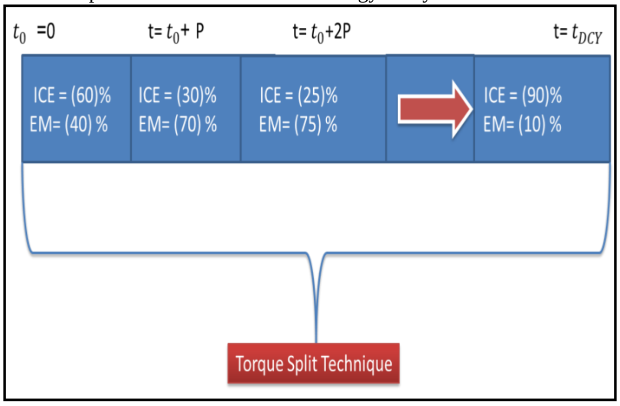



**Figure (4) Torque Split Technique**

## 4.Fuel Consumption

The fuel consumption estimation depending on many of factors such as the speed of the ICE and torque required in addition to the design of the engine, driving cycle and fuel energy components etc. (Jonasson, 2005). In this study the focusing was on torque and speed of the ICE so the estimation of the fuel consumption relying on the look-up tables which extracted from the data of the ICE map( Engine speed and engine torque ). The desired speed represents the driving cycle which is loaded in MatLab and used it in this block to calculate the value of fuel consumption for every kilo meter. The figure (5) shows the sub model for calculating the fuel consumption.

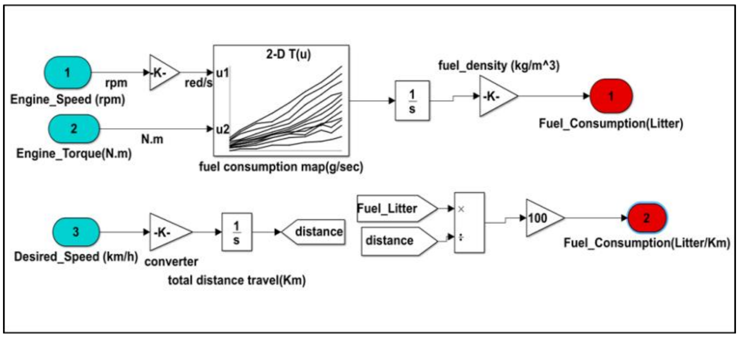



Figure (5) Fuel Consumption Calculation [Najim 2018]

## 5.Emissions

The emissions regulations are Hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NOX)(Jonasson, 2005). The (ICE) extract the fuel and air to provide power per contra causes the emission, the fuel is dependent on the hydrocarbons ($C_\alpha H_\beta$) and when the operation of combustion is done at λ = (A/F) =1 when the air and fuel are in complete proportion to each one of them. In this case the complete combustion or stoichiometric combustion is occurred and the contests of emission in this state are water ($H_2O$) and carbon dioxide ($CO_2$) and nitrogen ($N_2$) as in equation below.

$$\frac{1}{(\alpha+\frac{\beta}{4})\lambda} C_\alpha H_\beta + O_2 + \frac{79}{21} N_2 \xrightarrow{=1\lambda} \frac{\alpha}{(\alpha+\frac{\beta}{4})} CO_2 + \frac{\beta/2}{\alpha+\frac{\beta}{4}} H_2O + \frac{79}{21} N_2$$

The most general method to reduce the emissions is to utilize the λ-sensor value previous the catalytic converter to supervise and restrain time injection of the fuel and angle of throttle to obtain the value of λ = 1 and thus minimize the emissions(Johansson & Waller, 2005). In this study, the combustion assumed complete and find the efficiency of the catalytic converter at λ=1 for every parameters of emissions from the Fig. (6)

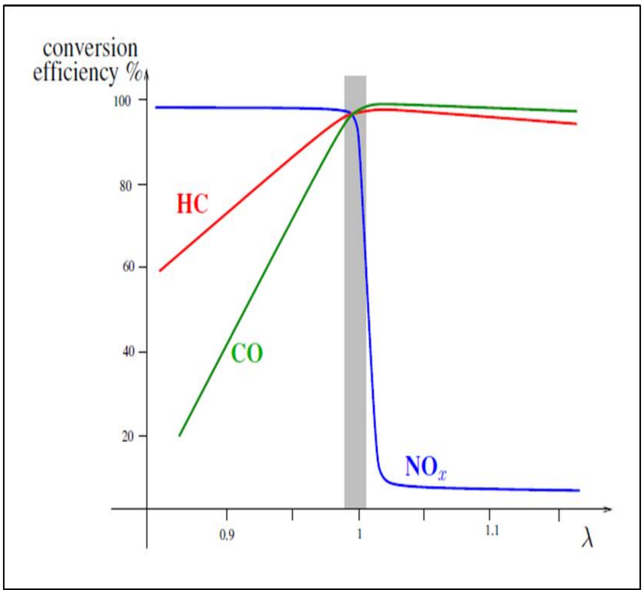



Figure (6) Catalytic Converter Efficiency (Leroy et al., 2007)

The parameters of emissions calculated based on the look-up tables which extracted from the data of the ICE map and as shown in figures below. The final result for each one of them is (X-ȠX) when (X) represents the emissions (CO or NOx or HC) and (Ƞ) represents the conversion efficiency for each parameter at steady state. The figure (7) show the block of calculation for HC which is similar to another parameters of emission except the difference in conversion efficiency.

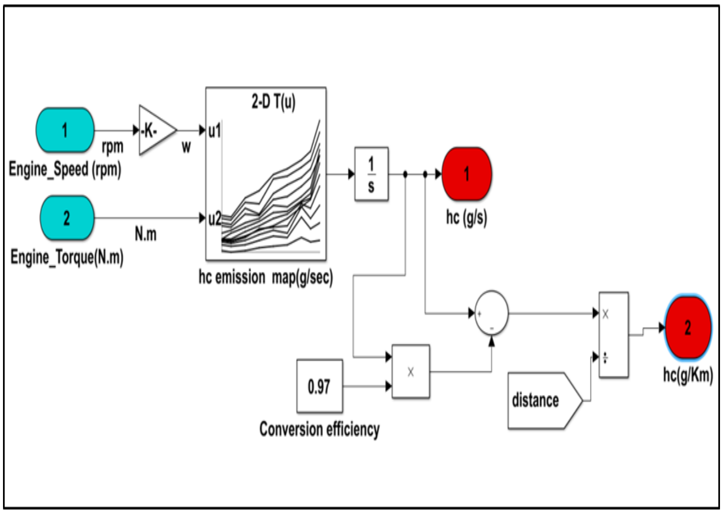



Figure (7) Calculation Of HC Emission

**6.Basic Particle Swarm Optimization**

Particle Swarm Optimization (PSO) is an algorithm which is introduced by Dr. Russell C. Eberhart and Dr. James Kennedy in 1995 (Kennedy & Eberhart, 1995). PSO is an evolutional calculation influenced by the gregarious demeanour of the schools of fish and bird flocking. PSO start by initializing a population of particles which represented the candidate solution to search the global solution through update the results**,** the continuous PSO Applying according to the equations below:

$$v_m^{t+1} = w.v_m^t + c_1 \cdot r_1 \cdot (pbest_m - x_m^t) + c_2 \cdot r_2 \cdot (Gbest_m - x_m^t)$$

$$x_m^{k+1} = x_m^k + v_m^{t+1}$$

Where the factor $w$ called the inertia weight while the constants $C_1$ , $C_2$ are defined as the learning rates for the particle, $r_1$ and $r_2$ are random numbers {0,1} . $x_m^t$ and $v_m^t$ represents the position and velocity of the particle in iteration t. $Gbest_m$ is the global best position (the best value for the particle in the whole swarm ). $pbest_m$ defined as the best position for a particle (Shaari et al., 2019). The calculation of $G$ include an exploration of the values for all particles in swarm , this means that each particle has admission to the facts or data of every particle in the swarm . The best position of the group (Gbest) describes the connection between the particles and sharing the information between them (Lim & Dehuri, 2009) . Figure (8) show a pictorial explanation for the (Gbest).

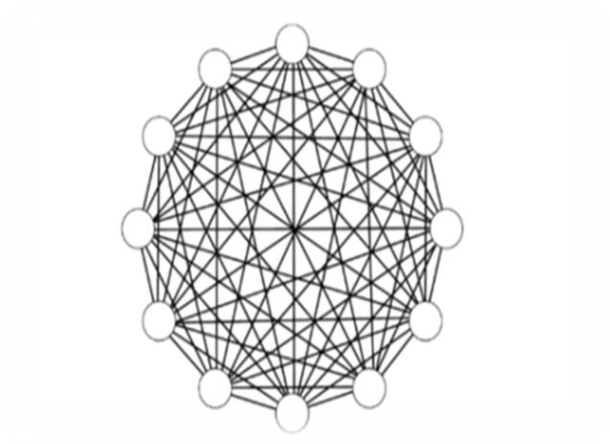


Figure (8) Schematic Representation For Gbest

The inertia weight chose closed to 1 because its suitable according to (Shehata et al., 2014) so chosen to be (0.9). The most suitable value for the optimization problem for the constants $C_1$ and $C_2$ is (2). the swarm size as a standard number which equates to 100(Vasant et al., 2016). Setting Vmax =Xmax as suggested by (Vasant et al., 2016) to improve the performance of the process. The first step for operating the Particle Swarm Optimization is initializing the main parameters for the (PSO) which cleared previously. Define the maximum and minimum value for the particles that represent the probability random for the torque ratio of the ICE. Then another step is finding the solution to the population by estimate the objective function. After evaluating the objective function for all the particles, the operation of optimization is repeated automatically up to the time which produces the goal or best - attained solution that mean the minimum cost function which gives the minimum fuel consumption and maximum state of charge . Figure (9) shows the flowchart for PSO.

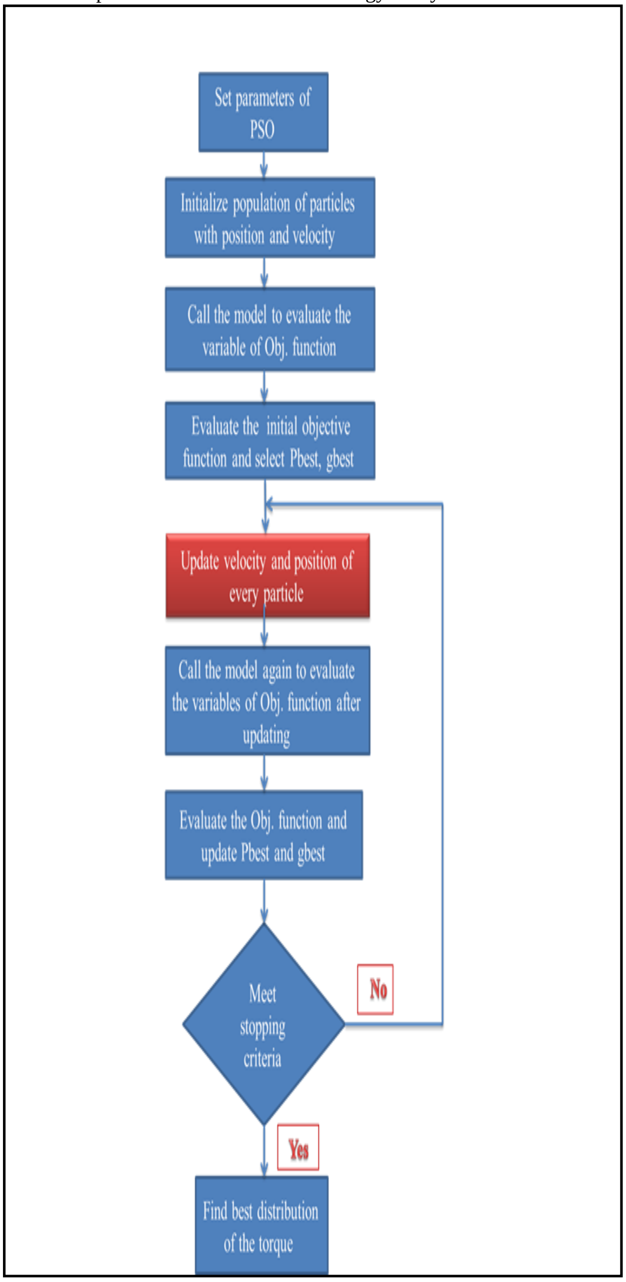



Figure (9) flow chart of particle swarm optimization

**7.Objective Function**

The fitness function is defined to estimate the performance of every particle. The objective function written in the following order (Dorri & Shamekhi, 2011).

$$J=\frac{1}{W1+W2+W3+W4+W5}\left(W1\times\frac{FC}{\overline{FC}}+W2\times\frac{CO}{\overline{CO}}+W3\times\frac{HC}{\overline{HC}}+W4\times\frac{NOx}{\overline{NOx}}-W5\times\frac{SOC}{\overline{SOC}}\right)$$

The weights of parameters of the fitness function are mostly chosen according to the degree of importance of the parameters in the problem, for example in an HEV in this study, the fuel consumption is more important than the state of charge of the battery and emission, so we will set higher weight for fuel consumption than the state of charge of the battery

In this study set weight of fuel consumption (W1)equal to (2) while the value of weight of (CO, HC, NOx, SOC) equal to (1). The ($\overline{FC}$,$\overline{CO}$,$\overline{HC}$, $\overline{NOx}$, $\overline{SOC}$ ) represents the target value that used to normalize the variable of fitness function

**8.Driving cycle**

To estimate the objective function for each particle in the optimization study, The Urban Dynamometer Driving Schedule (UDDS) driving cycle has been used which is utilized by the environmental protection agency, US (EPA) as a reference driving cycle for checking fuel economy for light-duty vehicles (BARLOW et al., 2009). The parameters of UDDS are displayed in a table (2). The driving cycle is shown in figure (10)

Table (2) Characteristic of the parameters of driving cycle[17]

| Driving cycle | UDDS |
|---|---|
| Time (s) | 1369 |
| Distance (km) | 11.99 |
| Max speed (km/h) | 91.15 |
| Avg. speed (km/h) | 31.6 |
| Number of stops | 14 |
| Average deceleration (m/$s^2$) | -0.464 |
| Average acceleration m/$s^2$) | 0.429 |

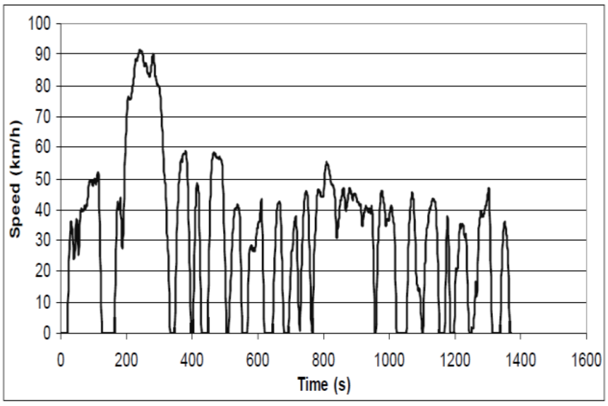



Figure (10)UDDS Driving Cycle

**9.Vehicle Performance Constraints:**

1- When the vehicle velocity less than (40 km/h), SOC of battery more than (0.5) the EM only providing the total propel torque to drive the vehicles.

2. When the state of charge battery lower than (50%), the engine is responsible to provide the torque to drive the vehicles without consideration for the velocity of the vehicle.

3. The control strategy for the distribution of the torque by the PSO algorithm will operate only when the vehicle velocity more than (40km/h) and SOC battery above (50%).

To force the ICE for working in the optimal points according to the performance map, set the continuously variable transmission has an important function to complete the work of ICE inefficient point and according to the constraints below:

1-If the Engine torque that coming from (PSO) above (54 N.m), the engine provides torque with an amount of (54) N.m and the extra torque provided by changing the gear ratio of the ( CVT ). The gear ratio changed by dividing the torque of ICE produced from the PSO by 54.

2-If the engine torque that coming from (PSO) below (54 N.m), the ICE Provides the torque desired. The gear ratio of the ( CVT) gear ratio equal to (1).

**10.Results and discussions**

Figure (11) shows that the vehicle velocity can follow the driving cycle pattern in a manner that signifies that the driving performance is satisfied**.**

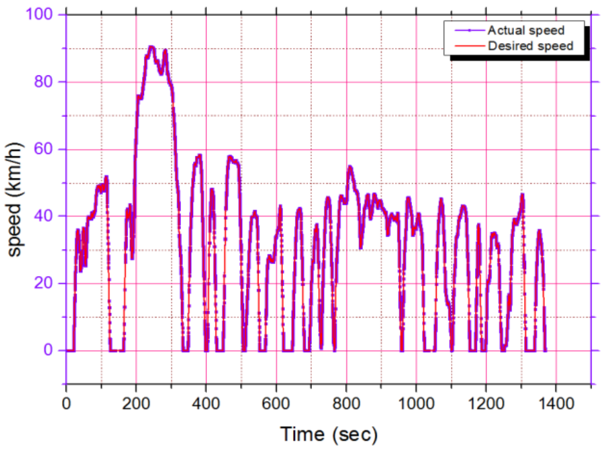



Figure (11) Driving Cycle Speed Path

Figure (12) shows the best probability for the ratio of the engine torque which gained through the (PSO) algorithm by dividing the driving cycle into many of parts, for every part, there is a specific ratio generated by (PSO) algorithm to maintain the best distribution between ICE and EM

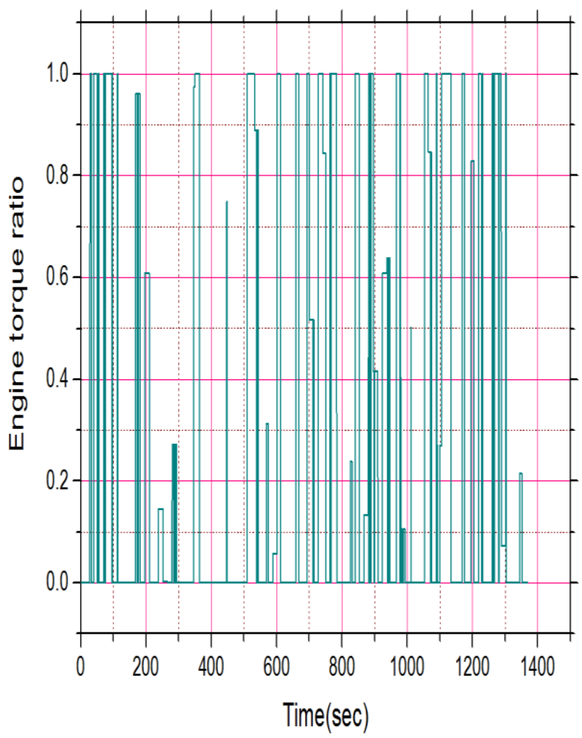



Figure (12) engine torque ratio

Figure (13) shows the engine torque along the time of the driving cycle. The values depend on the torque that gained from the PSO algorithm and after passing through CVT to force the engine for operating in an efficient point and according to the engine map that is shown in figure (3). the ICE worked according to the constraints set in this study, these constraints depending on the electric launch speed which considered the separator speed between the operation of ICE and EM, the other parameter for the constraints is (SOC) of the battery.

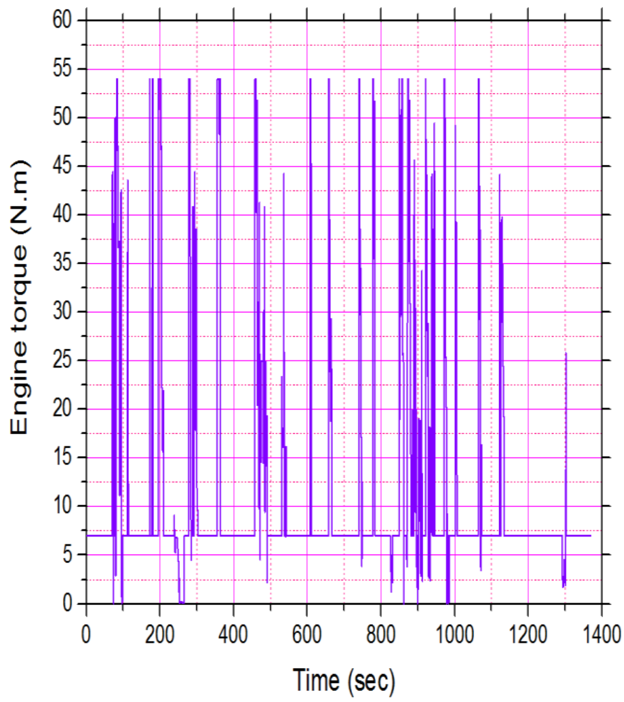



Figure (13) Torque of ICE

Figure (14) shows the gear ratio for the continuous variable transmission with time. whereas the value of gear ratio for (CVT) equal to (1) when there is no needed to provide additional torque because the engine torque less than(54) N.m while occurred the inversion when the engine torque above (54 )N.m, the gear ratio for ( CVT) changed from (1-8) to force the engine for operating in an efficient area.

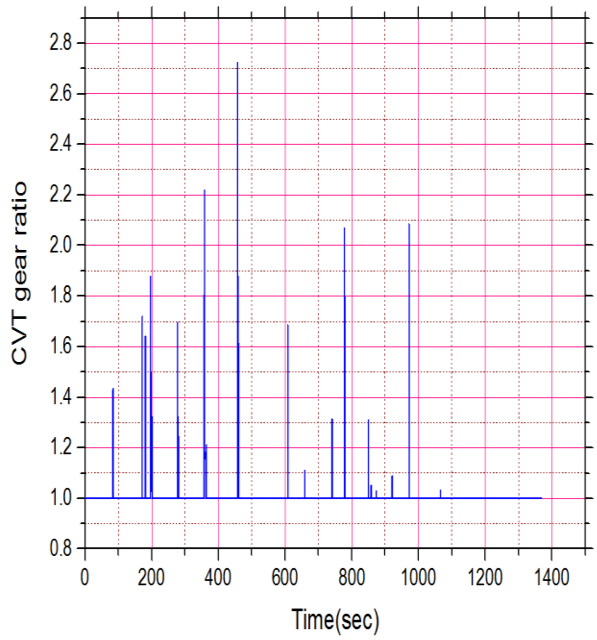



Figure (14) CVT Gear Ratio

Figure (15) shows the ratio of motor torque which obtained through the relation (1- engine torque ratio), whereas the total torque for the ICE and EM must be (1) or (100%).

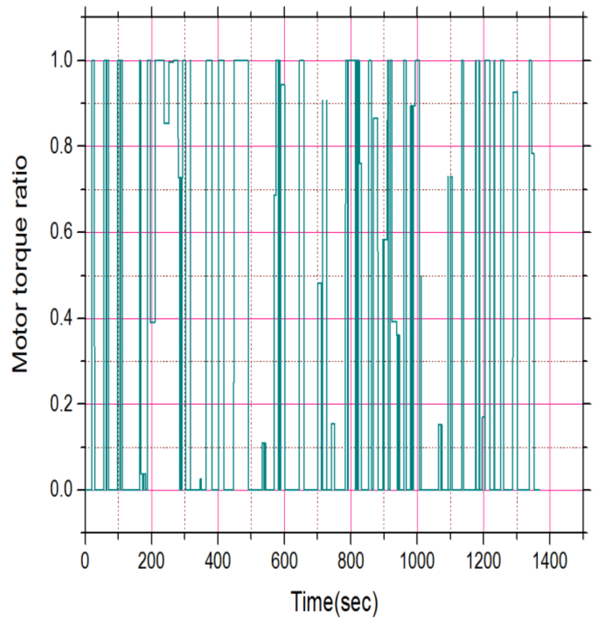



Figure (15)Motor Torque Ratio

Figure(16) shows the motor torque along the time of driving cycle. This values for the motor torque produced by multiplied the ratio of motor torque by the propel torque required. It can be seen that the torque of motor in the low or moderate range according to the performance map of the motor. The time of operation the electric motor relies on the constraints that set previously.

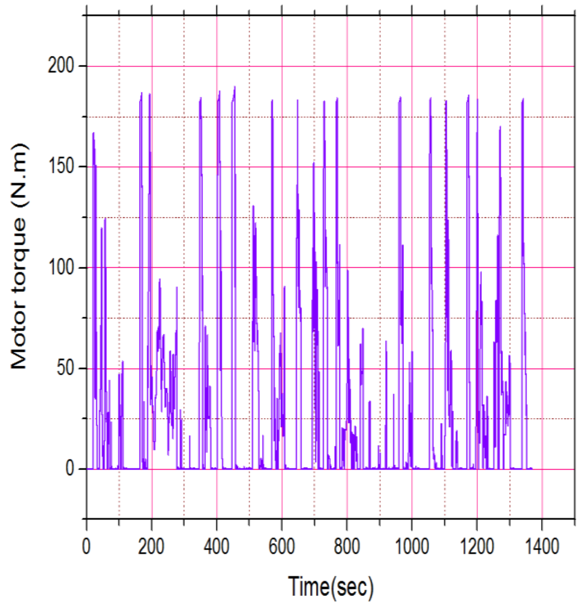



Figure (16) Motor Torque

Figure (17) demonstrates the (SOC) of the battery. Initially the SOC is set as 70%, because of the need for the high speed in the period (200-300), the (SOC) depleted quickly. The SOC continued within acceptable limits because of engine providing besides the process of regenerative braking. In the end of the process the SOC became 53% which is also acceptable value.

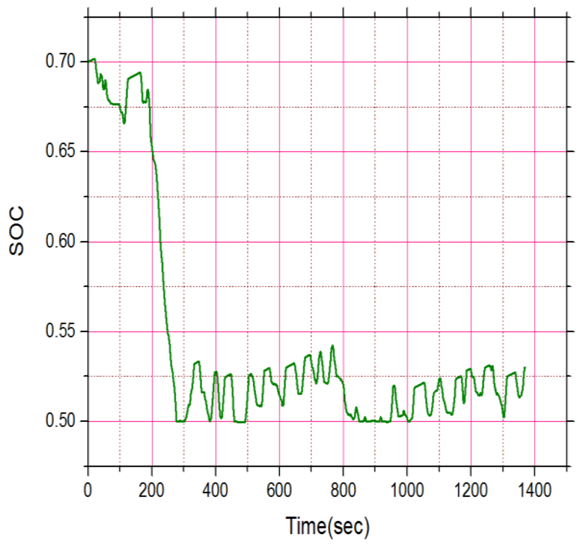



Figure (17) SOC Of Battery

Figure (18) displays the generator torque along the time of driving profile. The negative power represents the process of regenerative braking which is responsible on the storing the energy in the battery in the case of braking.. When the torque of the generator is constant at the value of (-7) N.m, then at this moment it means only the machine that charges the battery, not the generator.

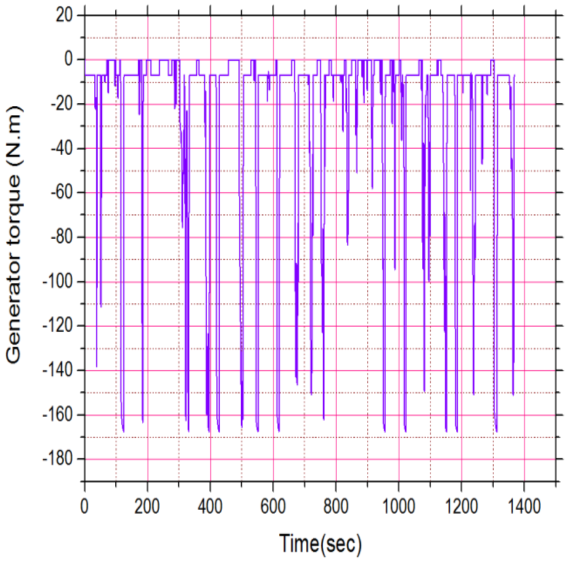



Figure (18) Generator Torque

The Figure (19) compare the fuel consumption over UDDS driving cycle when applied randomly probability for the value of the ICE torque which mean the operation of the model without optimization with another case in the state of optimization process. The results prove the validation of (PSO) algorithm in minimizing the fuel consumption.

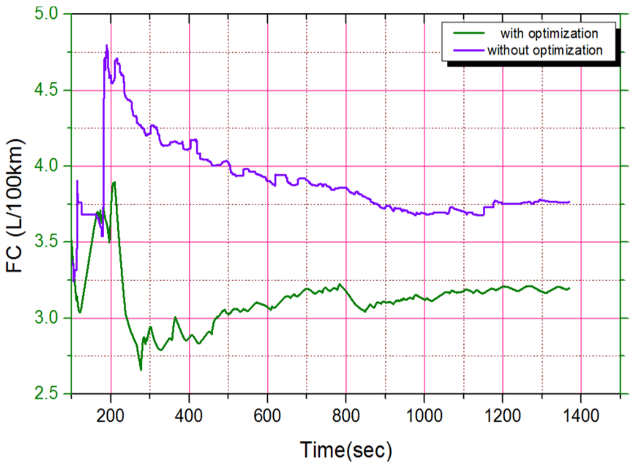
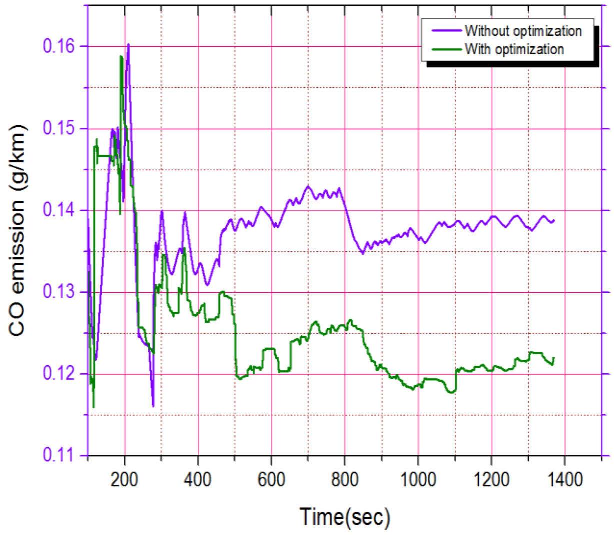
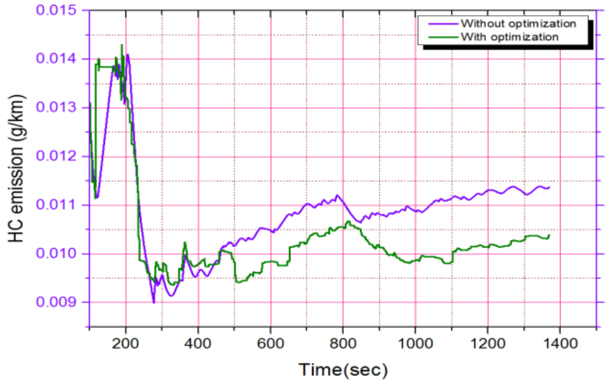



Figure (19)Fuel consumption over UDDC

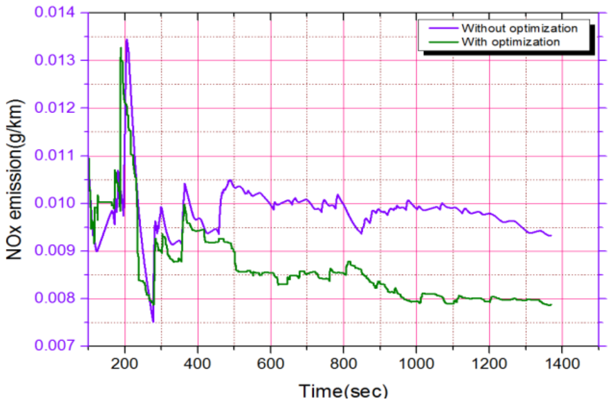
The emissions of vehicles calculated at steady state. Figures (20),(21),(22) compare the parameters of emissions over UDDS with random probability for the value of the engine torque and optimal numbers when applied the optimization process. The figures show the effectiveness of PSO in minimizing the emissions.




Figure(20)Variation of CO with time




Figure(21) Variation HC with time




Figure(22)Variation NOx with time

| Table (3) results of UDDS Driving Cycle | | | | | |
|---|---|---|---|---|---|
| Strategy | FC | SO | CO(g/k | HC(g/k | NOx(g/k |

| | (L/km) | C | m) | m) | m) |
|---|---|---|---|---|---|
| PSO | 3.195 | 0.52 | 0.1388 | 0.01137 | 0.00932 |
| FLC (Najim et al.,2018 | 3.506 | 0.52 | ----- | ----- | ----- |
| GA (Madanipour et al., 2016) | 4.1307 | ---- | ---- | ---- | ---- |
| FLC-GA (M. L. Zhou et al., 2013) | 4.9 | --- | ----- | ---- | ---- |
| ADVISOR | 4.9 | 0.50 | 0.135 | 0.19 | 0.071 |

The simulation results of UDDS cycle are shown in the table (3) and may be summered as below:

- The SOC of the battery has the same value as nearly in PSO and FLC and concerning the ADVISOR program.
- The PSO algorithm can minimize the fuel consumption over GA done at parallel plug-in HEV with 22.6% improvement and over FLC done at PSHEV with an 8.87% improvement.
- The PSO algorithm the fuel economy comparing with optimized FLC for parallel HEV based global optimization GA done by 21.8% .
- The results of emissions compared with ADVISOR which operated at steady state, as clear, All the parameters of emissions improved with a high range except CO which improved slightly comparing with NOx and HC.
- It can be seen that the control strategy may not improve all objectives in the same time, but improve one of the parameter with a high range while another range of improvement is little.

**11.Conclusions**

This paper proposed an energy management strategy based on a particle swarm optimization algorithm method to minimize fuel consumption, emissions, and maximize the state of charge of battery for the power-split hybrid electric vehicle (PSHEV) besides to force the engine to operate in the efficient area. The PSO algorithm has been used to obtain the best or optimum torque distributed between the engine and motor depending on the behavior of the driving cycle. The path of the driving cycle was divided into samples, for every sample, there is a specific value of torque distributed between the main source was found by linking the model of the vehicle and PSO algorithm. The validation of the algorithm was tested on the UDDS driving cycle. The results of the proposed method was compared with FLC, GA, FLC-GA and ADVISOR program. The fuel consumption is less than the optimal results obtained by the control method that has been used for comparing besides the ADVISOR program while the SOC of battery is closest to the optimal results obtained by FLC and over than the value in the ADVISOR program. The finding proved the validation of PSO by minimizing the emissions in the case of a steady state while comparing with ADVISOR program . The energy management strategy made the engine run within its best performance limit in the efficient area that guarantees the lower fuel consumption and best performance for the vehicle. The best torque distributed produced from the PSO algorithm special in the specific driving cycle and cannot be applied to another driving cycle because the specific driving cycle doesn’t cover all the state of driving in the city.

**References**

[1] Barlow, T. J., Latham, S., McCrae, I. S., Boulter, P. G.2009. A reference book of driving cycles for use in the measurement of road vehicle emissions. *TRL Published Project Report*.

[2] Basil. S. Munahi "Development of an Intelligent Controller for a Hybrid Engine Vehicle", University of Basra at college of engineering, thesis for the degree of doctor of philosophy of science of Mechanical engineering, (2013).

[3] Chau, K. T. 2015. *Electric vehicle machines and drives: design, analysis and application*. John Wiley & Sons.

[4] Chen, Z., Xiong, R., Wang, K., Jiao, B " Optimal energy management strategy of a plug-in hybrid electric vehicle based on a particle swarm optimization algorithm." Energies,2015 8(5), 3661–3678.

[5] Dorri, M., & Shamekhi, A. H " Design and optimization of a new control strategy in a parallel hybrid electric vehicle in order to improve fuel economy." Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering,2011, 225(6), 747–759.

[6] Husain, I . 2011. Electric and hybrid vehicles: design fundamentals. CRC press.

[7] Haider. S. Najim, A. K. Ali , B. Sh. Munahi. 2018. A Study and Development of Modern Control Techniques for Hybrid Electric Vehicle (HEV): University Of Basra, MSc thesis.

[8] Johansson, J., Waller, M. " Control oriented modeling of the dynamics in a catalytic converter." Institutionen for systemteknik., 2005.

[9] Jonasson, Karin ." Control of hybrid electric vehicles with diesel engines." Citeseer.2005.

[10] Kennedy, J., Eberhart, R..1995 . Particle swarm optimization . Proceedings of ICNN'95-International Conference on Neural Networks, 4, 1942–1948.

[11] Lee, H., Kang, C., Park, Y., Cha, S. W. " Study on Power Management Strategy of HEV using Dynamic Programming.". World Electric Vehicle Journal,2016, 8(1), 274–280.

[12] Lei, Z., Cheng, D., Liu, Y., Qin, D., Zhang, Y., & Xie, Q. " A dynamic control strategy for hybrid electric vehicles based on parameter optimization for multiple driving cycles and driving pattern recognition." Energies,2017, 10(1), 54.

[13] Lei, Z., Qin, D., Zhao, P., Li, J., Liu, Y., Chen, Z. " A real-time blended energy management strategy of plug-in hybrid electric vehicles considering driving conditions." Journal of Cleaner Production,2020, 252, 119735.

[14] Leroy, T., Chauvin, J., Le Solliec, G., & Corde, G. 2007. Air path estimation for a turbocharged SI engine with variable valve timing. American Control Conference, 5088–5093.

[15] Lihao, Y., Youjun, W., Congmin, Z. " Study on fuzzy energy management strategy of parallel hybrid vehicle based on quantum PSO algorithm." International Journal of Multimedia and Ubiquitous Engineering, 2016,11(5), 147–158.

[16] Lim, C. P., & Dehuri, S. 2009. Innovations in swarm intelligence (Vol. 248). Springer Science & Business Media.

[17] Madanipour, V., Montazeri-Gh, M., & Mahmoodi-k, M. " Optimization of the component sizing for a plug-in hybrid electric vehicle using a genetic algorithm." Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 2016,230(5), 692–708.

[18] Mi, C., Masrur, M. A. 2017. Hybrid electric vehicles: principles and applications with practical perspectives. John Wiley & Sons.

[19] Ming, L., Ying, Y., Liang, L., Yao, L., Zhou, W. " Energy management strategy of a plug-in parallel hybrid electric vehicle using fuzzy control." Energy Procedia, 2017,105, 2660–2665.

[20] Nellen, J., Wolters, B., Netz, L., Geulen, S., Ábrahám, E." A Genetic Algorithm based Control Strategy for the Energy Management Problem in PHEVs." GCAI,2015, 196–214.

[21] Shaari, G., Tekbiyik-Ersoy, N., & Dagbasi, M. " The State of Art in Particle Swarm Optimization Based Unit Commitment: A Review." Processes,2019, 7(10), 733.

[22] Shehata, R. H., Mekhamer, S. F., El-Sherif, N., Badr, M. A. L. " Particle swarm optimization: Developments and application fields." International Journal of Energy and Power Engineering, 2014,5(1), 437–449.

[23] Thompson, S. T., James, B. D., Huya-Kouadio, J. M., Houchins, C., DeSantis, D. A., Ahluwalia, R., Wilson, A. R., Kleen, G., Papageorgopoulos, D. " Direct hydrogen fuel cell electric vehicle cost analysis: System and high-volume manufacturing description, validation, and outlook." Journal of Power Sources,2018, 399, 304–313.

[24] Vasant, P. M., Rahman, I., Singh, B. S. M., Abdullah-Al-Wadud, M. " Optimal power allocation scheme for plug-in hybrid electric vehicles using swarm intelligence techniques." Cogent Engineering,2016, 3(1), 1203083.

[25] Wang, S., Yu, C., Shi, D., Sun, X. " Research on speed optimization strategy of hybrid electric vehicle queue based on particle swarm optimization." Mathematical Problems in Engineering, 2018.

[26] Wu, X., Zheng, D., Wang, T., Du, J. " Torque allocation strategy of all-wheel drive electric vehicle based on difference of efficiency characteristics between axis motors. " Energies, 2019, 12(6), 1122.

[27] Xie, S., Hu, X., Qi, S., Tang, X., Lang, K., Xin, Z., Brighton, J. " Model predictive energy management for plug-in hybrid electric vehicles considering optimal battery depth of discharge." Energy,2019 173, 667–678.

[28] Zhou, M. L., Lu, D. K., Li, W. M., Xu, H. F. " Optimized fuzzy logic control strategy for parallel hybrid electric vehicle based on genetic algorithm." Applied Mechanics and Materials,2013, 274, 345–349.

[29] Zhou, Y., Ravey, A., Péra, M.-C. " Multi-mode predictive energy management for fuel cell hybrid electric vehicles using Markov driving pattern recognizer." Applied Energy, 2020, 258, 114057.