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The Effectiveness of Merge the (A-ECMS) with Heuristics Rule-Based Control Strategy for Energy Management in a Parallel HEVs

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Abstract

The hybrid electric vehicle (HEV) is considered an effective technique to reduce fuel consumption and exhaust emissions. The effectiveness of the HEVs in reducing fuel consumption and exhaust emissions is required an accurate division of the total power demand between energy sources. This aim is reached by an accurate design of energy management strategy (EMS) in the HEVs. Dynamic programming is an effective strategy to found the optimal solution for energy management. This technique requires the driving cycle to be known previously, wherefore it's not suitable to implement in real-time. The Equivalent Consumption Minimization Strategy (ECMS) is an effective technique that can be implemented in real-time. This strategy is used to estimate and adapt the equivalent factor (EF) in real-time, which is used to convert the electric energy from the battery to equivalent fuel cost. The value of the (EF) varies with the driving cycle, therefore, the (EF) is suitable for a certain driving cycle and may lead to weak performance to another. This work proposed a technique based on the battery state of charge feedback called adaptive prediction (AP) to estimate and adapt the equivalent factor in real-time. The best-obtained results are ranged between (11.1 to 32.889) % for several different driving cycles.

Keywords: Adaptive equivalent consumption minimization strategy, Parallel hybrid electric vehicles, Online control strategy, Reducing fuel consumption and emission, AP based on SOC feedback technique.

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1. Introduction

Increasing worry about the fuels available in the future and environmental pollution and taking into consideration the enormous contribution of road transport in these problems [1]. Researchers in the world try to invent a variety of techniques to face these challenges. The hybrid electric vehicle is considered one of the most important techniques to face these challenges by adding a new propulsion system to the conventional system [2]. This new propulsion system consists of an energy storage system (battery), electric actuator (motor), and a device used to couple the above two systems. The term hybrid electric vehicle refers to a type of vehicle that has the ability to a regenerative braking power which is a technology used to convert the kinetic energy (vehicle momentum) to electric energy stored in the energy storage system for later use [3]. The most important feature of the HEVs is the reduction in the size of the ICE with the ability to meet the power demand. This advantage comes from the ability of the hybrid vehicle to meet the power demand by either the ICE, electric motor, or both at the same time [4], [5]. The efficiency of the hybrid electric vehicle depends mainly on the ideal division of power demand between energy sources, and that required an accurate design of the EMS [6]. HEVs control strategies can be classified as offline control strategies and online control strategies, where the offline control strategies rely on knowing a prior of the entire driving condition. These control strategies which are also known as a global control strategy give the best solution to the control problem for the entire driving cycle, which leads to some advantage and disadvantage features. The advantage of these types of EMS estimates the optimal solution of the control problem [7]. Whilst the disadvantage of this strategy is cannot be implemented in real-time, but it's used as a benchmark strategy. Dynamic programming is considered the best EMS where the performance of all other online control strategies is compared with it [2]. The online control strategies try to reduce global optimization problems to a succession of local optimization problems which computed the cost for the present moment, which leads to reducing the associated computational effort and eliminated the needing for the future driving cycle, which makes it applicable in real-time [8]. Despite the sub-optimal results obtained by using online control strategies when compared with the offline control strategies, online control strategies had received large attention from researchers in the field of hybrid vehicle controllers [3].

The researchers presented a set of techniques based on the battery SOC feedback technique for estimating and adapting the equivalent factor in real-time which will be briefly presented in this paper with its main equations.

Kessels et al. [9]. They adopt a mathematical equation based on battery SOC feedback for adapting the equivalent factor, this equation is:

$$s\,(x,\,t) = s_0 + k_P(x_{ref} - x(t)) + k_P\int_0^t (x_{ref} - x(t)) \qquad (1)$$

The above equation has two tuning parameters which are the initial equivalent factor (s_0), and the proportional controller gain (k_P). Where the accuracy of the above equation depends on the accurate estimation of the tuning parameters.

Onori et al. [10] adopted a technique based on battery SOC feedback for adapting the equivalent factor (EF) online. The adaptation of the (EF) is not done continuously at each instant of time but at a regular period of duration (t), the main equation of this method is:

$$s_{k+1} = s_k + k_P(x_{ref} - x(t)) \qquad (2)$$

Where (s_{k+1}) represents the new value of the (EF), (s_k) is the previous value of the (EF). The tuning parameter of this method is the proportional controller gain (k_P) and the duration time (t). The performance of this technique is based on an appropriate estimation of the tuning parameters.

Onori et al. [10] adopted a mathematical equation based on SOC feedback for adapting the equivalent factor, this equation is:

$$s_k\,(x,\,T) = \frac{s_{k-1} + s_{k-2}}{2} + k_P^d(x_{ref} - x(T)) \qquad (3)$$

The above equation has one tuning parameter which is (k_P^d).

Chasse et al. [11] adopted a method based on SOC feedback for adapting the equivalent online. The mathematical equation for the proposed method is:

$$s\,(x,\,t) = s^{o} + k_P(x^{sp} - x(t)) \qquad (4)$$

The above equation has two tuning parameters which are (s^o) that can be estimated during the offline part and are valued depending on the driving pattern, and (k_P) is the proportional controller gain that must be adapted to avoid the SOC variations from the acceptable range.

Jiang et al. [12] used another mathematical equation based on SOC feedback to adapt the equivalent factor online. The value of the equivalent factor is adjusted at regular intervals of time (T). The main equation of it is:

$$s_{k+1} = \frac{1}{2}(s_{k-1} + s_k) + K_p(SOC_{ref} - SOC\,(kT)) \qquad (5)$$

The above equation has two tuning parameters which are the period and the proportional controller gain.

Montazeri-Gh et al. [13] adopted a methodology based on the battery SOC feedback for adapting the equivalent factor online. The value of the (EF) is adjusted at a regular period (t). The main equation of it is:

$$s\,(t) = c_1 + c_2\,tan\left(c_3\pi\,(SOC_{ref} - SOC\,(t))\right) \qquad (6)$$

The above equation has three tuning parameters required to estimate and find the appropriate equivalent factor.

Wang et al. [14] combined the basic (ECMS) with fuzzy logic control strategy to introduce a new real-time energy management strategy, referred to as a fuzzy adaptive equivalent consumption minimization strategy (Fuzzy A-ECMS). The main equation in this method is:

$$S(k+1) = S(k) + k_p(SOC_r - SOC\,(t)) \qquad (7)$$

This method has one tuning parameter which is proportional controller gain (k_p) and the researchers used the fuzzy logic control strategy to adjust (k_p) based on current speed and SOC deviation.

Enang et al. [3] adopted a method based on SOC feedback for adapting the equivalent online. The mathematical equation for the proposed method is:

$$\varepsilon_t = \varepsilon_0 + K_{ps}(SOC_{ref} - SOC\,(t)) \qquad (8)$$

Where (ε_o) is the initial equivalent factor value and (K_{ps}) is the proportional controller gain which represents the tuning parameter. These parameters consider as a constant which values are: $\varepsilon_0 = 3.47$ and $K_{ps} = 1.7$.

Deng et al. [15] adopted a method based on SOC feedback for adapting the equivalent online. The mathematical equation for the proposed method is:

$$s\,(k+1) = \frac{(s_{k-1} + s_k)}{2} + K_p(SOC_{ref} - SOC\,(t)) \qquad (9)$$

$$t = kT,\ k = 1, 2, 3, \ldots.$$

The above mathematical equation has one tuning parameter which is proportional controller gain (K_p).

The objective of the present work is to increase the efficiency of the (A-ECMS) by merging this strategy with a simple rule-based control strategy.

2. Equivalent consumption minimization strategy

The equivalent consumption minimization strategy is considered the most promising energy management control strategy in HEVs which can be implemented in real-time. This energy management strategy is computationally cheap with good robustness in reducing cost function. Furthermore, its result is very close to the dynamic programming results as shown in Table 1 [2].

Table 1. Fuel economy for different driving cycles: DP versus ECMS [2].

Driving cycle	ECMS	DP
FUDS	25.7 km/L	25.7 km/L
FHDS	25.9 km/L	26 km/L
ECE	24.5 km/L	24.5 km/L
EUDC	24.7 km/L	24.8 km/L
NEDC	24.5 km/L	24.5 km/L
JP1015	25.1 km/L	25.2 km/L

The main problem in this energy management strategy is the accurate estimation and adaptation of the equivalent factor which considers the essence of this strategy and is used to convert the electric energy of the battery to the equivalent fuel cost based on the present vehicle information, this factor has a direct effect on reducing the fuel consumption rate and ensures charge sustaining for the HEVs. This equivalent factor varies with the driving cycle so that the equivalent factor that's suitable for one driving cycle will lead to poor performance or even not support the charge sustaining conditions [3]. The driving cycle is required to be known in a priori for appropriate estimating of the equivalent factor, which makes this strategy in its current form is inflexible and cannot implement in real-time.

For appropriate estimating and adapting the equivalence factor online, several techniques have been suggested which leads to guarantee the goal of reducing fuel consumption as well as ensuring the battery's charge sustenance over any driving cycle, and then this energy management strategy will be indicated as adaptive equivalent consumption minimization strategy and in short as (A-ECMS). The simplest way is by tuning the equivalent factor (EF) equal to one at each instant and for any driving cycle [16]. This way will lead to the poor performance of the controller which causes either charge depleting or charge hoarding depending on the driving pattern.

As a result, many strategies have been suggested for adapting the (EF) in real-time. Among the most important techniques for adapting the equivalent factor, the first way is based on driving cycle prediction by using the global position system (GPS) [17]. The second way is based on driving cycle recognition [18]. The third way is based on the battery state of charge (SOC) feedback technique [19]. Adapting the (EF) based on the state of charge feedback seems to be the most promising technique and the applicable and cost-effective style which meets the aims of the charge-sustaining and reducing fuel consumption and emission in real-time [8], as shown in Table 2.

Table 2. Comparison between the techniques used for adapting the (EF) [8].

Comparison factor	**Adaptive the (EF) based on driving cycle prediction**	**Adaptive the (EF) based on driving cycle recognition**	**Adaptive the (EF) based on battery SOC feedback**
Computational load and cost	**High**	**High**	**Low**
Susceptibility to errors	**High**	**High**	**Low**
Need for external prediction equipment	**High**	**None**	**None**
Real-time implementation cost	**High**	**Average**	**low**
Adaptability to varying driving conditions	**High**	**High**	**Low**

Desired factors ⬛ Undesired factors 🟥

3. Parallel hybrid electric vehicle architecture

This study will adopt a parallel HEVs powertrain architecture as shown in Fig. 1. In this configuration, there are two propulsion systems. The first propulsion system is a conventional thermal driveline, consisting of a gasoline engine with a maximum power of (43 kW) and a maximum speed of (4000 rpm), gearbox, clutch, and final differential. The second drivetrain is an electrical system that consists of an electric motor with a maximum power of (25 kW), (57.6 kW), a lithium-ion electric battery with a nominal voltage of (615 V), a fixed coupling gearing, and a final differential. The coupling between the conventional and electric systems occurs after the gearbox, this architecture is specifically identified as a post-transmission parallel HEVs [20].

In the conventional thermal powertrain, there are five transmission gears, where the gearbox was modeled by using State Flow. This vehicle is charge-sustaining (not rechargeable through an external electric plug), where the electric battery is recharging by the captured energy during regenerative braking mode or by the energy produced from the IC engine during trickle charging mode. In this work, the hybrid vehicle is operating in five-mode which is (Engine only mode, motor only mode, power assist mode, regenerative braking mode, and trickle charging mode), and in this study, the hybrid vehicle is modeled as several subsystems which are:

3.1. *Modelling of the driver subsystem*

The driver subsystem was designed and created as simple equations as in all model parts. This subsystem calculates the hybrid vehicle required wheel torque in the case of acceleration or deceleration. During acceleration which represents the total wheel torque required for propelling the hybrid vehicle at the driver required speed, and during deceleration, the controller calculated the total torque required for braking the vehicle. The propelling wheel torque is divided into two parts, the first part represents the wheel torque that is required to overcome the resistance four force which is:

- An aerodynamic drag resistance force.
- Grade resistance force.
- Rolling resistance force.
- Inertial resistance force.

The second part represents the extra torque required for propelling the hybrid vehicle at the driver's extra speed which is designed as a simple PID controller and calculated by using equation (10) [3].

$$T_{extra} = K_p(V_c - V_v) + K_i \int (V_c - V_v)\,dt + K_d \frac{d(V_c - V_v)}{dt} \qquad (10)$$

The gain values of the driver subsystem are tuned as parameters calculated by test many driven cycles by using Matlab Simulink to estimate the best values, which enable the hybrid vehicle to reach the driver speed required. The obtained values of the tuning parameter are [8]:

K_p = 0.272 Ki = 0.35 K_d = 2

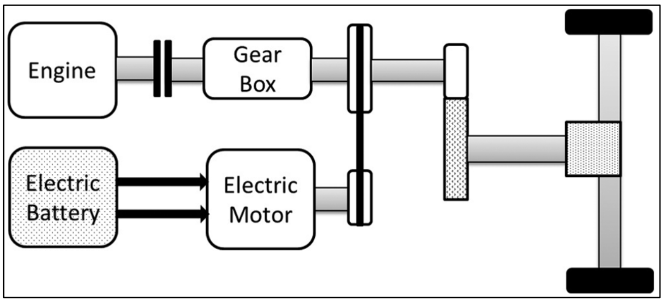

Fig. 1 Parallel hybrid electric vehicle [8].

3.2. Modelling of the internal combustion engine

Modelling the IC engine for contributing to the development of the HEVs control strategy, where the mathematical equations are used for creating this subsystem. The internal combustion engine is a part of the drivetrain for propulsion the hybrid electric vehicle in the following operating modes, engine only mode, power assist mode and trickles charging mode. This means the internal combustion engine is in an idling mode when it's not used for propulsion the hybrid vehicle. During the braking mode, the fuel is cut off from the engine by using shut off and start-up features. The rate of fuel consumption for the ICE is a function of the engine torque and engine speed which is calculated by using equations (11) and (12) respectively [21], so that these values with the fuel consumption Map which is obtained from the advisor package as shown in Fig. 2, this figure can be used to calculate the fuel consumption rate at every instant [22].

$$T_{ICE} = \frac{\left(m\frac{dV_v}{dt} + \sum\left(F_{aero} + F_{rolling} + F_{grade} + F_{extra}\right)\right) R_w}{FDR\ GBR\ \eta_{drivetrain}} - \frac{P_{motor}}{GBR\ FDR\ \eta_{drivetrain}\ \omega_{wheel}\ \frac{2\pi}{60}} \tag{11}$$

$$\omega_{ICE} = \omega_{wheel}\ FDR\ GBR \tag{12}$$

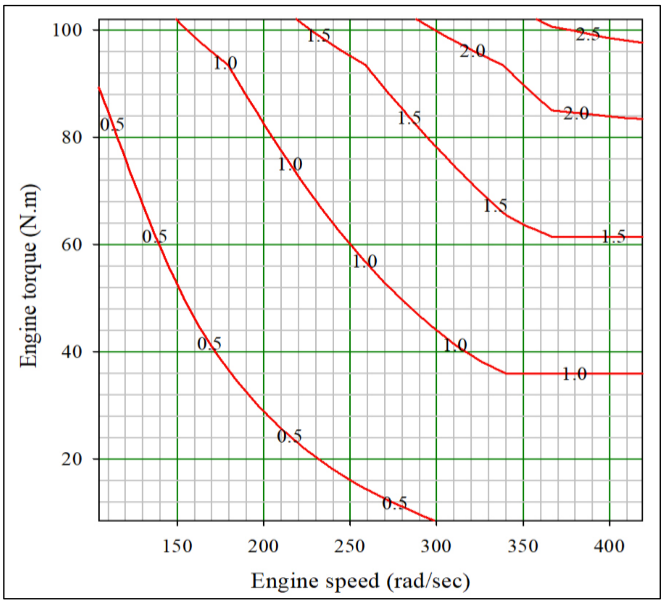

Fig. 2 Engine fuel consumption map [22].

3.3. Modelling of the electric motor

Depending on the application area, a wide range of electric machines is available. In general, electric parts can be mainly classified into AC and DC machines. It is important to measure the electrical performance of the electric actuator which is estimated by the controller. The electric motor efficiency (η_{motor}) is adjusted dynamically according to motor speed (W_{motor}) and torque (T_{motor}) which is calculated by using equations (13) and (14) respectively [3], where the efficiency of the electric motor is estimated immediately from a lookup table.

$$\omega_{motor} = G_{motor}\ \ FDR\ \ \omega_{wheel} \tag{13}$$

$$T_{motor} = \frac{P_{motor}}{G_{motor}\ FDR\ \eta_{drivetrain}\ \omega_{wheel}\ \frac{2\pi}{60}} \tag{14}$$

The electric motor efficiency map can be shown in Fig. 3, for both traction and braking mode which is obtained from the advisor package [23].

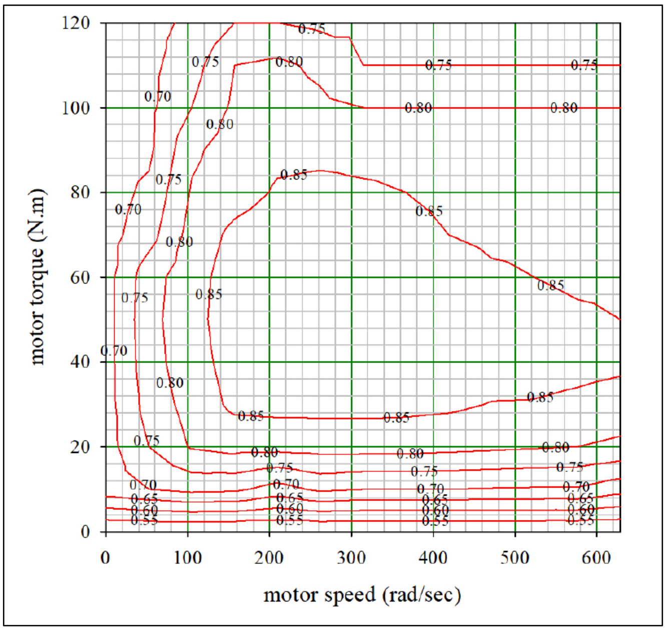

Fig. 3 Electric motor efficiency map [22].

3.4. Modelling of the energy storage system

For representing the actual behaviour of the electric battery. Many models have been developed for this purpose. The simplest form which is adopted is based on the battery's electrochemistry, modelling battery by this way lead to ignoring thermodynamic effects, and consequently are unable to model phenomena such as time rate of change voltage under load, battery's temperature, and ageing effects [23]. This form of battery model can be shown in Fig. 4.

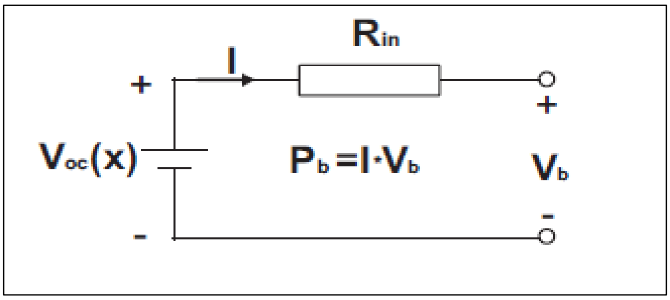

Fig. 4 Battery circuit model [24].

The integral battery current ($I_{battery}$) left in a battery is referred to as the battery state of charge (SOC) in the simulation process which represents the ratio of battery current to the battery capacity which can be estimated by equation (15) [25].

$$SOC_{t+1} = SOC_t \pm \int_t^{t+1} \frac{I_{battery}\ t}{Q_{battery}}\,dt \tag{15}$$

Charge: (+) Discharge: (-)

Where ($I_{battery}$) is the battery current, and ($Q_{battery}$) is the battery capacity. The performance efficiency data of the electric motor is obtained from the advisor package.

4. Proposed equivalent factor adaptation strategy

This literature will adopt the Adaptive Prediction based on SOC feed-back (AP) technique to estimate and adapt the equivalent factor online, and the control strategy is referred to as adaptive equivalent consumption minimization strategy (A-ECMS). The adaption equation is characterized by not containing any tuning parameter, considered as a positive point to be added to this equation, allowing it easy to implement in real-time. This equation is described as a charge sustaining technique with little fuel savings. The main equation of the adopted technique is expressed in equations (16) and (17) respectively [3].

When $SOC_t < SOC_{ref}$

$$\varepsilon_t = \varepsilon_{t\text{-}1}\left(1 + \left(\frac{\tan\left(SOC_{ref} - SOC_t\right)\frac{\pi}{180}}{\tan\left(SOC_{ref} - SOC_{min}\right)\frac{\pi}{180}}\right)^n\right) \tag{16}$$

When $SOC_t > SOC_{ref}$

$$\varepsilon_t = \varepsilon_{t\text{-}1}\left(1 - \left(\frac{\tan\left(SOC_{ref} - SOC_t\right)\frac{\pi}{180}}{\tan\left(SOC_{ref} - SOC_{max}\right)\frac{\pi}{180}}\right)^n\right) \tag{17}$$

$n = 2,\quad SOC_{ref} = 60\ \%,\quad SOC_{min} = 40\ \%,\quad SOC_{max} = 80\ \%$

The aim of this work is to improve the efficiency of the (A-ECMS) by merging the EMS with a simple rule-based control strategy to increase the performance of the hybrid electric vehicle to reduce the fuel consumption rate and keeping the battery SOC within the recommended range (charge sustaining). The simple heuristic rule-based control strategy with (A-ECMS) will use to improve the operation mode and regeneration braking mode.

4.1. Simple rule-based control strategy implementation

This section is dedicated to implementing the simple rule-based control strategy in the parallel hybrid electric vehicle. In this section, the (A-ECMS) is merged with the simple heuristic rule-based control strategy to optimize the performance of the hybrid electric vehicle to reduce the fuel consumption rate by improving the operation mode and maximize the captured energy during regenerative braking mode.

4.1.1. Rule-based and regeneration braking mode

Employ of the brake pedal during the driving cycle is of great importance as the essence of using the HEVs is its ability to capture the braking energy and convert it to electrical energy stored in the battery for later use. This literature tries to maximize the captured braking energy by the simple rule-based control strategy to capture as much as possible of the kinetic energy of the hybrid vehicle (movement momentum). The simple heuristic rule-based control strategy (RB) has been modeled based on the (IF-THEN) relationship which will act as a hard constraint. The rotation speed of the electric motor is used with a lookup table to determine the maximum braking power of the electric motor when works as a generator which can be used for stopping or slowdown the hybrid vehicle (P_{max_regen}) at that instant. The estimated value of the braking motor power is then push through the rule-based controller, where the value of (P_{max_regen}) with the battery state of charge to decide the appropriate mode of braking as shown in Table 3 [26].

Table 3. braking mode constrain [26].

Rule	Activated mode	Resulting control action
IF $P_{demand} < P_{regen\text{-}max}$ @ $SOC_t < SOC_{max}$	Regenerative braking, where the electric motor is used for braking the HEV	$P_{motor} = P_{demand}$
IF $P_{demand} \geq P_{regen\text{-}max}$ @ $SOC_t < SOC_{max}$	Regenerative braking and mechanical breaking	$P_{motor} = P_{regen\text{-}max}$ $P_{mech\_brake} = P_{demand} - P_{max\_regen}$
IF $SOC_t \geq SOC_{max}$	Mechanical braking	$P_{mech\_brake} = P_{demand}$

4.1.2. Rule-based and driving mode

When the hybrid electric vehicle is in the traction mode, the total power demand is positive. The estimated value of the total power demand of the hybrid vehicle model with the battery state of charge and maximum motor tractive power which is considered the control variable of the energy management strategy (A-ECMS) will enter to the simple heuristic rule-based controller (RB) to estimate the proper operation mode that optimizes the vehicle performance and reduce the fuel consumption and protect the vehicle equipment from damage in each instant as shown in Table 4 [26].

Table 4. Operation mode constrain [26].

Rule	Activated mode	Resulting control action
IF $P_{demand} < P_{motor\_max}$ $SOC_t > SOC_{min}$	Motor only mode	$P_{motor} = P_{demand}$
IF $P_{demand} \geq P_{motor\_max}$ $SOC_t > SOC_{min}$	Assist mode	$P_{motor} = P_{motor\_max}$ $P_{ICE} = P_{demand} - P_{motor\_max}$
$SOC_t \leq SOC_{min}$	Engine only mode	$P_{ICE} = P_{demand}$

5. Results and discussion

5.1. Verification of the performance of the parallel hybrid electric vehicle

After completion and construction of the parallel hybrid electric vehicle, the performance of the parallel hybrid vehicle is investigated over some global driving cycles such as UDDS, and HWEFT.

Instead of investigated every subsystem of the PHEV which considers a very hard mission, the focus is on checking the vehicle's ability to:

- Checking the accuracy of the PHEV to tracking the required speed of the driver (driving cycle) by comparing the vehicle velocity data with the same driving cycle data.
- Estimate the fuel consumption rate (FCR) of the hybrid vehicle in this work when the electric motor is shut off and compared it with the FCR of the conventional vehicle in the advisor package with the same characteristics and over the same driving cycle.

5.1.1. Vehicle ability to respond to the driver required speed

In this section, the ability of the PHEVs to respond to the driver's required speed (driving cycle) is verified. This subsystem has a good tracking ability to the UDDS and HWEFT driving cycles respectively, which represent different patterns of driving cycles, as shown in Figs. 5 and 6 respectively.

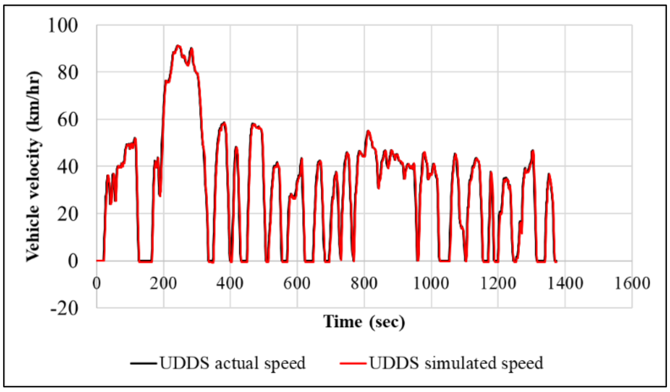

Fig. 5 UDDS driving cycle simulated and actual speed.

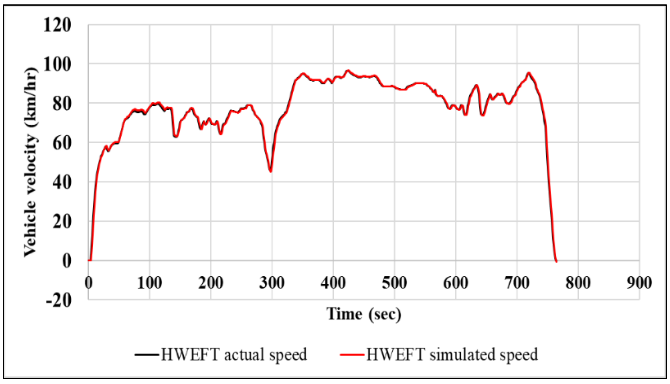

Fig. 6 HWEFT driving cycle simulated and actual speed.

5.1.2. Vehicle ability to estimate the fuel consumption rate

A comparison results of the cumulative fuel consumption rate of a conventional vehicle with the conventional vehicle in the advisor package showed a significant convergence between the results of the two vehicles when the electric motor is shut off over UDDS and HWEFT driving cycles as shown in Figs. 7 and 8 respectively.

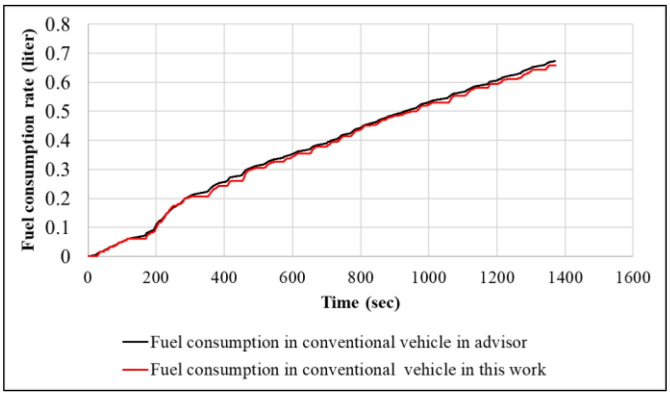

Fig. 7 Accumulative fuel consumption rate for UDDS and simulated driving cycle.

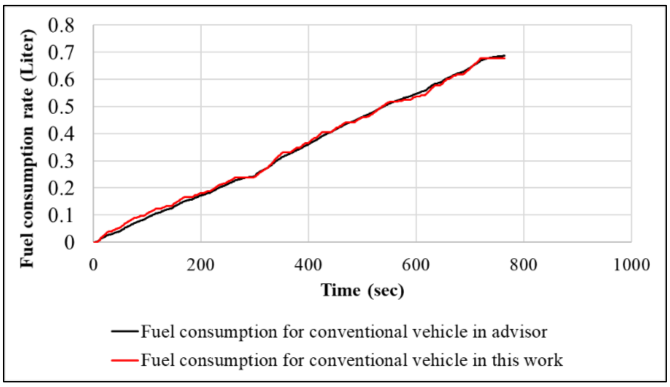

Fig. 8 Accumulative fuel consumption rate for HWEFT and simulated driving cycle.

The final results were obtained from merging the (A-ECMS) with a simple heuristic rule-based control strategy over UDDS, NEDC, US06, Japan1015, LA92, Artemis U130, HWEFT, and Basrah driving cycle [27], as shown in Table 5.

Table 5. Final Simulink result.

Driving cycle	**Fuel-saving (%)**	**Final battery SOC (%)**
UDDS	32.889	56.35
NEDC	13.014	72.85
US06	11.1	81.09
Japan1015	24.333	56.68
LA92	26.112	58.61
Artemis U130	15.37	71.06
HWEFT	18.756	61.83
Basrah	27.33	64.32

5.2. Comparing the results of the present work with offline control strategies

When comparing the results of this work with some offline control strategies in hybrid electric vehicles demonstrate the efficiency of the adopted method of energy management when comparing with these benchmark strategies.

5.2.1. Dynamic programming

The results of the comparison of the current work results with the dynamic programming technique over UDDS, NEDC, US06, Japan1015, LA92, Artemis U130, and HWEFT driving cycles are shown in Table 6.

Table 6. Dynamic programming comparison results.

Driving cycle	**Fuel-saving (A-ECMS) technique (%)**	**Fuel-saving dynamic programming technique (%)**	**Performance of the present work (W.R.T) DP (%)**
UDDS	32.889	38.1 → [28]	86.35
NEDC	13.014	15.58 → [3]	83.53
US06	11.1	15.625 → [29]	75.782
Japan1015	24.333	25.05 → [8]	97.137
LA92	26.112	38.069 → [30]	68.592
Artemis U130	15.37	21.6 → [7]	71.157
HWEFT	18.756	26.1 → [7]	73.266

5.2.2. Fuzzy logic control strategy

The results of comparison the current work results with the Fuzzy logic control strategy results [31], for UDDS, HWEFT, and Basrah driving cycle [27], as shown in Table 7.

Table 7. Fuzzy logic comparison results.

Driving cycle	Fuel consumption rate of the vehicle with (A-ECMS) (%)	Fuel consumption rate of the vehicle with Fuzzy logic (%)	Performance of present work (W.R.T) Fuzzy logic (%)
UDDS	32.889	39.24	83.84
HWEFT	18.7561	25.48	73.661
Basrah	27.3305	42.31	64.6

6. Conclusions

This control strategy (A-ECMS) proves useful as a near-suboptimal, charge-sustaining, and fuel reduction over different driving patterns.

1. This control strategy (AP-based SOC feedback) eliminates need for expensive telematics to accurate estimation and adaptation of the equivalent factor.
2. Although (AP-based SOC feedback) is a cheap technique, but proven its efficiency toward support charge sustenance and fuel reduction.
3. Although the (A-ECMS) is very active and a promising online optimization technique suitable for real-time application, but the equivalence factor for this control strategy is very sensitive to change the driving pattern.
4. The optimal equivalence factor for one driving cycle might lead to poor performance on another driving cycle.

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