A New Assessment Parameter to Determine the Efficiency of a Hybrid Vehicle

Khaled R. M. Mahmoud
University of Jeddah
Jeddah, Saudi Arabia
mrmahmoud@uj.edu.sa

Samy M. Ghania
University of Jeddah
Jeddah, Saudi Arabia
sghania@uj.edu.sa

Received: 25 July 2022 | Revised: 4 August 2022 | Accepted: 7 August 2022

Abstract-This paper presents a new evaluation technique for the determination of the efficiency of a hybrid vehicle. First, the savings in fuel consumption is estimated in the ideal case considering the vehicle runs through a standard driving cycle and the engine runs at the lowest specific fuel consumption all the time. The hybridization efficiency can be defined as the ratio between the fuel savings in hybrid mode to the ideal savings according to the standard driving cycle. A case study was conducted with a medium-size passenger car according to the new European standard driving cycle. The results showed that the new proposed evaluation criterion is very effective for evaluating hybrid vehicles.

Keywords-fuel consumption; hybridization efficiency; standard driving cycle

I. INTRODUCTION

The growing use of transportation based on fossil fuels has forced scientists and policymakers to take measures that would reduce the negative environmental and climate impacts, the demand for oil production, and increased fuel prices [1-3]. At present, the consumption of the transport sector represents two-thirds of the global consumption of petroleum, and passenger cars and light commercial transport represent half of that consumption. Therefore, the seek for alternative solutions that are highly efficient, smart, safe and clean has been among the challenges that draw the attention of researchers in both environmental and transportation fields [4-6]. Hence, the development of innovative technologies of hybrid electric vehicles is a potential environmentally friendly and cost-effective solution along with their applicability. Logically, there is an urgent need to switch from conventional Internal Combustion Engine (ICE) vehicles to hybrid vehicles. Nowadays, hybrid vehicles contribute significantly to the reduction of emissions, especially in urban areas. The use of hybrid vehicle technologies has recently accelerated not only for passenger cars but also for heavy vehicles [7-9].

Many factors affect the fuel economy of passenger cars include traffic conditions, road geometry, and vehicle running modes such as idling, cruise, load, acceleration, and so on. The combination of these conditions can be summarized in two cases: city and highway driving. Driving a vehicle on the highways means with semi constant engine speed and load is often associated with an economic performance featured by moderate fuel consumption with lower exhaust emissions per kilometer. City driving is usually recalling different engine modes especially idling, acceleration, and deceleration modes where low speeds and light or no loads which means low efficiency and excessive emission levels. So, the electric motor is the suitable alternative solution to reduce emissions and fuel consumption. Also, the possibility of using brake regeneration energy as a further energy source helps reduce fuel consumption by up to 15% [10-12].

Increase in intelligent technology used in hybrid vehicles such as the reduction of battery mass and the increased performance leads to increased number of hybrid vehicles in the auto market [13-16]. Many studies indicated a significant rise in the number of hybrid vehicles due to the expected improvement in fuel consumption and reducing harmful emissions. Some studies considered fuel consumption is little affected when running over vehicles for standard driving highway cycles and the effect is considerable within city roads [17-19]. The hybrid vehicle system operates the ICE mostly in the high efficiency and low consumption range. In addition, the batteries of the hybrid system are charged to reach the area of minimum fuel consumption whenever possible [20-22]. However, the main source of energy in hybrid vehicle systems is the ICE, and hybrid system deployment is one of the methods proven effective in achieving operating points close to the optimal operating point inherent to minimum specific fuel consumption for ICE operation most of the time [23, 24]. In other words, the main goal of the hybridization of vehicles is to operate the vehicle under the most economical operating conditions or as close to the highest efficiency range as possible [25, 26].

Usually, hybrid vehicles work on the basis that the efficiency of ICEs is relatively low and varies depending on the engine load and speed. On the other hand, the electric motor has high engine power and efficiency [27]. The operation of hybrid vehicles is an attempt to operate the vehicle engine in a high efficiency state as much as possible. The low energy demand at low vehicle speeds, especially in urban areas, requires low engine power. So, the battery motor is sufficient and efficient to power the vehicle, in what is called tailpipe zero emission mode. When the vehicle is running at a high

---

Corresponding author: Khaled R. M. Mahmoud speed (70-120km/h), and the engine is running in a high efficiency range, then the ICE can be relied upon to power the vehicle, which is known as the gasoline mode [28]. For high loads, it is possible to rely on both the ICE and the electric motor. The battery charging strategy is based on the use of the difference between the torque at maximum efficiency and the actual torque of the vehicle to charge the batteries. Hybrid vehicles are characterized by the fact that they use the energy resulting from regenerative braking energy recovery to charge the batteries and use it later when needed in the vehicle's motion, resulting in additional savings in fuel consumption [5, 29].

The common evaluation parameter of hybrid vehicles is the degree of hybridization, defined as the ratio between the power of the battery pack and the sum of battery reverse power and ICE power [30]. In the same context, the degree of hybridization is defined as the ratio of the power developed by an electric motor in a hybrid vehicle to the total power consumed [31]. Similarly, authors in [5, 32] have defined Hybridization Factor (HF) as the ratio of electric motor power to the sum of electric motor power and ICE power.

The degree of hybridization indicates the degree of improvement over the traditional situation but does not provide sufficient information on whether this improvement has reached or is close to the ideal degree. Researchers have evaluated hybrid vehicles using the terms "hybridization degree" or "hybridization factor". This definition is limited to indicating the rate of reduction in fuel consumption compared to conventional vehicles. However, can the rate of the improvement increase and to what extent has this improvement reached its maximum value? The performance of any thermal or mechanical system is evaluated by calculating the efficiency, using the ratio between the actual case and the ideal condition, and for hybrid vehicles, the parameters for the ideal condition are not available until the efficiency is calculated. Therefore, a new evaluation is needed to calculate the efficiency of hybridization because of the special working of that type of car. The current evaluation of the hybrid vehicles has some shortages. It adds a considerable amount of electric power to the main driving power of the internal combustion engine to save fuel consumption, but it does not provide how close this saving is to the deal saving of the fuel consumption.

In this paper, hybrid vehicles are evaluated by calculating the efficiency of the vehicles when it runs over a complete standard driving cycle, as the term efficiency gives a more realistic impression of how close the system is to the ideal state. Therefore, a new evaluation was needed to estimate the efficiency of hybridization. Therefore, a new evaluation parameter will be introduced to evaluate the hybrid vehicles in terms of hybridization efficiency. This parameter is applied through a case study of a medium passenger car that undergoes the New European Driving Cycle (NEDC).

II. METHODOLOGY

The new method for evaluating hybrid vehicles is based on the determination of hybridization efficiency. The new method can be applied according to the following steps:

- Calculating the total energy E required to run through the whole driving cycle:

$$E = \int_0^t P(t)dt \quad (1)$$

where E is the required energy to complete the driving cycle, $P(t)$ is the required power, and t is the total time of the driving cycle.

- Calculating the required fuel consumption when the vehicle runs whole driving cycle in conventional mode, β_c in liters.
- Calculating the required fuel consumption when the vehicle runs the same driving cycle with hybrid mode, β_h in liters.
- Minimum track fuel consumption β_{min} can be achieved considering the ideal case that the engine is running at minimum specific fuel consumption $bsfc_{min}$.
- The minimum fuel consumption can be expressed as

$$\beta_{min} = \frac{E \ bsfc_{min}}{\rho_f} \quad (2)$$

where ρ_f is the fuel density.

As shown in Figure 1, it is considered that the fuel consumption with the conventional case is at 0% hybridization efficiency, while the 100% hybridization efficiency is at minimum fuel consumption. Normally, the fuel consumption in the hybrid condition lies between the conventional and the ideal cases. From Figure 1, the similarity of the triangles led to the following equation to calculate the hybridization efficiency.

$$\eta_h = \frac{\beta_c - \beta_h}{\beta_c - \beta_{min}} \quad (3)$$

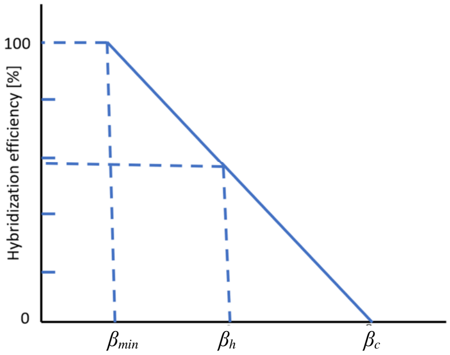

Fig. 1. Variation of the hybridization efficiency with fuel consumption.

The engine fuel consumption map can provide the brake specific fuel consumption *bsfc* at any point coordinated by engine speed and brake mean effective pressure (sometimes engine torque). Driving cycles are defined as a set of vehicle speed data points as a function of driving cycle time. In this study, the NEDC [35] is used as the standard driving cycle. The evaluation of vehicle performance while moving along a driving cycle depends on how many liters of fuel are consumed to drive a complete cycle. Brake specific fuel consumption varies according to the equivalent torque of a revolution. The vehicle specifications are shown in Table I. The engine fuel map of the vehicle used in this study is shown in Figure 2.

TABLE I. VEHICLE SPECIFICATIONS

Displacement	cm^3	1498
Bore/ Stroke	mm	73.0/89.4
Tire radius	mm	320
Projected area	m^2	2.1
Coefficient of air resistance	--	0.32
Gear ratios		3.643, 2.08, 1.361, 1.024, 0.83, and 0.686
Final drive ratio		4.105
Coefficient of rotating parts □		1.05
Gross vehicle mass (conventional)	kg	1285
Gross vehicle mass (hybrid)	kg	1515

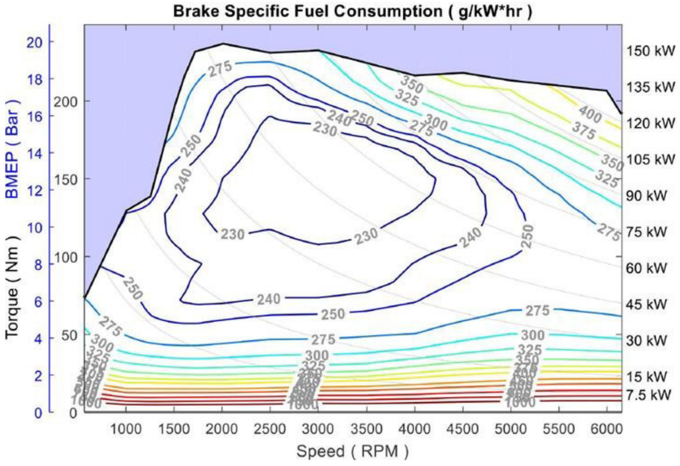

Fig. 2. Engine fuel consumption map.

The batteries specifications used in this study are:

- No of batteries: 38
- Battery voltage: 8.4V
- Battery ampere-hours: 8.4Ah

Figure 3 illustrates the power flow of the model. A Matlab/ Simulink model is built with the vehicle speed of the input driving cycle, and the model running time is the driving cycle time. The vehicle resistances are evaluated and the corresponding engine torque and power are calculated. The engine torque, the corresponding engine revolutions, and engine fuel map data are the inputs of the fuzzy controller to calculate the brake specific fuel consumption. Using (6) from [34], the track's fuel consumption can be calculated.

III. RESULTS

The total energy required to complete the entire drive cycle is a key parameter for evaluating hybridization efficiency. The total energy can be calculated by integrating the engine power. The nominal power required to operate the vehicle throughout the NEDC is shown in Figure 4. The energy required to achieve the cycle is shown in Figure 5 with and without brake energy recovery. In these Figures, there are four similar urban zones between 0s and about 800s, and the vehicle travels in the highway zone after this period. The maximum power in the highway zone can be about twice that in the urban zone. In the same context, the maximum negative power of the highway zone is higher than twice the value in the urban zone. However, the total energy required by the vehicle to achieve the NEDC without brake energy recovery is about 6000kJ, while, the total energy required to achieve the NEDC with brake energy regeneration is reduced by about 15% without brake energy regeneration. These results agree with [7, 32].

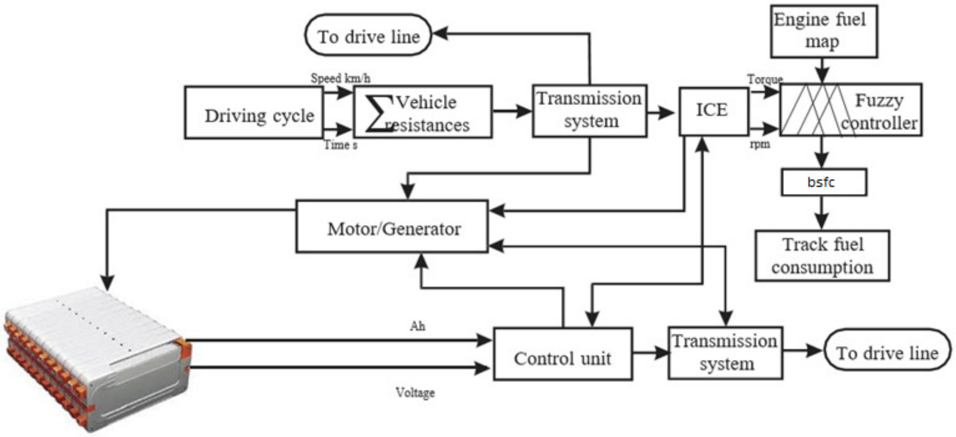

Fig. 3. Schematic diagram of the power flow chart of the hybrid vehicle.

The track fuel consumption of the conventional vehicle running the whole NEDC in ml/s is plotted in Figure 6. The fuel consumption ranges from 0.12ml/s (idle case) to 3.4ml/s. In the urban region, there are four similar ranges with maximum values of about 1.5ml/s, while in the highway region, the enroute fuel consumption in ml/s is relatively higher. The total fuel consumption in conventional condition, β_c in liters, can be calculated as the integration of fuel consumption with driving cycle time. In this case, it is 0.826lt. The track fuel consumption of the hybrid vehicle without regenerative braking energy recovery when running through the entire NEDC is plotted in Figure 7. The Stae Of Charge (SOC) is assumed to be 100% at the beginning of the driving cycle. In urban areas, the vehicle is driven by the electric motor (tailpipe zero emission mode). SOC reaches about 60% at urban areas within the period of 0-840s of the driving cycle time.

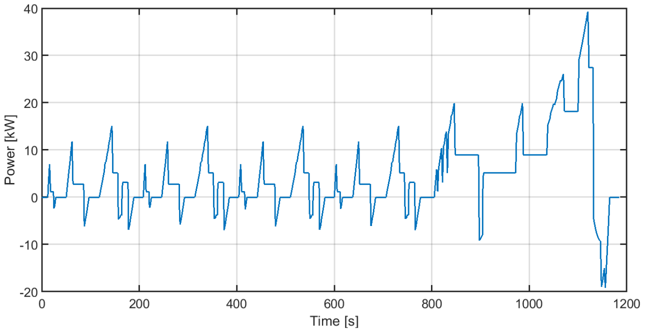

Fig. 4. Engine power variations within a cycle time of NEDC.

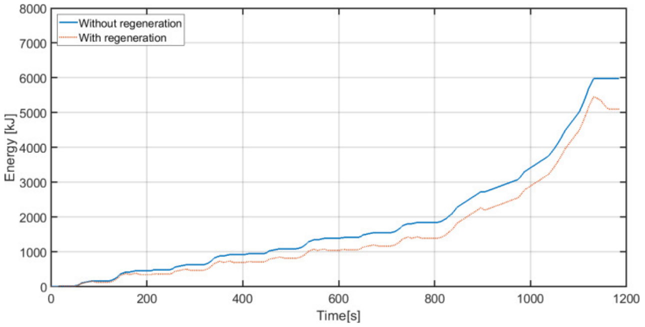

Fig. 5. Vehicle energy variations within the NEDC cycle time.

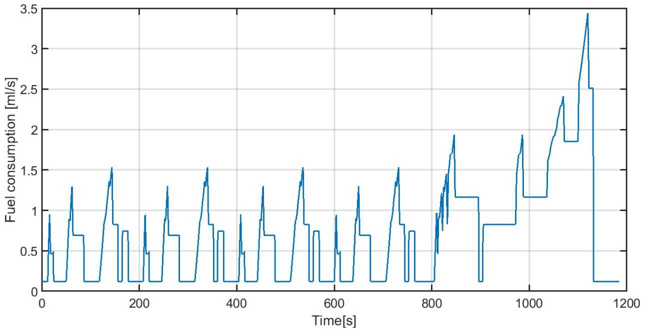

Fig. 6. Fuel consumption of the conventional vehicle according to NEDC.

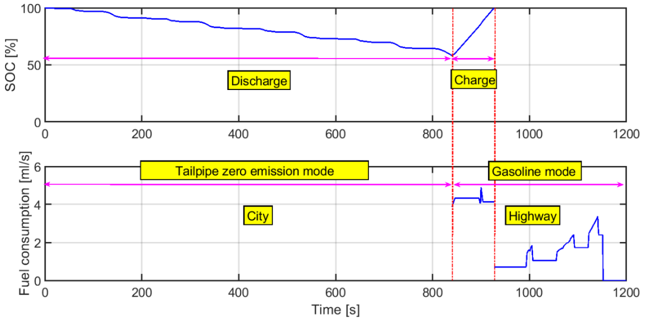

Fig. 7. Fuel consumption and SOC of the hybrid vehicle without regenerative brake energy recovery running over the NEDC.

On the highway, the vehicle's engine performs two tasks: it mainly drives the vehicle and the rest of the maximum engine torque is used to charge the batteries. A time period of about 70s is sufficient in this case to recharge the batteries and bring the SOC back to 100%. The average fuel consumption during this period is about 4.3ml/s. Finally, in the last period, the vehicle runs in gasoline mode, as this is economically feasible on the highway. The total fuel consumption on the highway when the vehicle is driven in gasoline mode and the batteries are recharged to 100% within SOC is about 0.67lt, which is about 19% lower than the conventional vehicle. These results are in accordance with [33, 34]. The fuel consumption for the hybrid vehicle for the case of brake regeneration energy recovery is shown in Figure 8. When the vehicle is driven in the urban area in the tailpipe zero -emission mode, the SOC decreases from 100% to about 72%. When the vehicle is on the highway, in addition to charging the batteries, it also takes 55s to recharge the SOC to 100%. The total fuel consumption required for highway driving, in addition to battery charging, is about 0.583lt, which is 35% less than the conventional vehicle and about 13% less than the hybrid vehicle without regenerative braking energy recovery.

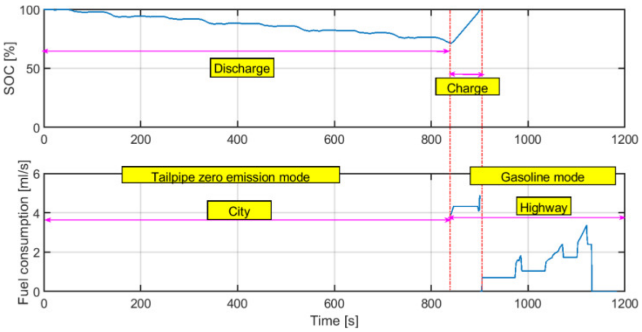

Fig. 8. Fuel consumption and SOC of the hybrid vehicle with regenerative brake energy recovery according to the NEDC.

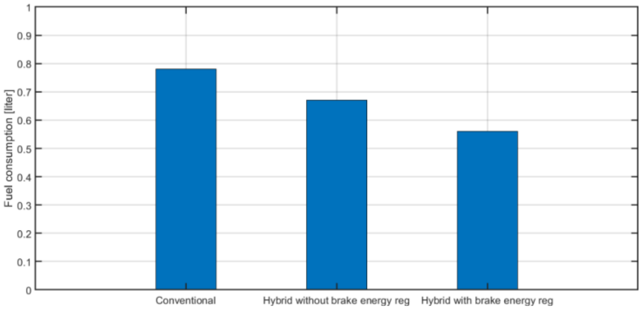

Fig. 9. Track fuel consumption of the vehicle according to the NEDC.

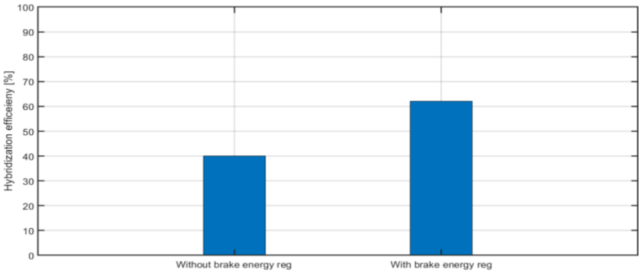

Fig. 10. Hybridization efficiency of the vehicle according to the NEDC.

It can be concluded that this comparison shows a significant improvement when using the hybrid system with and without brake energy regeneration. But have these improvements reached the maximum limits, or can the fuel savings be increased? This evaluation method does not give us an indication of the fuel economy in the ideal case. Equation (3) was applied to evaluate the proposed new evaluation parameter and the result is shown in Figure 10. It shows the relationship between hybridization efficiency in the two usage modes and the non-use of brake energy recovery for both driving cycles. Efficiency is a measurable and easily understood concept that provides a clear indication of the extent to which the hybridization efficiency reaches the ideal state.

Figure 11 shows the degree of hybridization of the vehicle crossing the whole NEDC with and without brake regeneration energy. Looking in depth at the current assessment, there are some shortcomings, which are the extent to which the optimum reduction in fuel consumption can be reached. The expression in terms of efficiency provides a clear picture of how close this is to the ideal case.

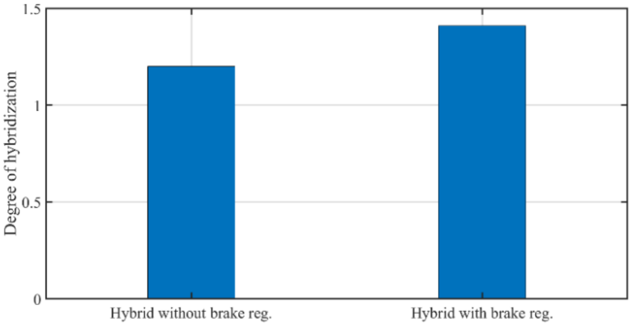

Fig. 11. Degree of hybridization according to the NEDC (current assessment).

IV. CONCLUSIONS

In this paper, the status of hybrid vehicle evaluation was reviewed. It was found that there are some shortcomings in the current evaluation parameters, regardless of the degree of hybridization or the hybridization factor. These inadequacies, since the fuel economy savings are given as a percentage of the conventional condition, do not refer to the ideal conditions (the concept of efficiency). Therefore, a new evaluation parameter can be used to evaluate the hybridization efficiency with reference to the ideal condition. Hybridization efficiency can be calculated by dividing the fuel economy in hybrid mode by the maximum economy in the ideal condition when the vehicle runs the entire standard driving cycle. Hybridization efficiency gives a tangible and accurate comparative formula for evaluating hybrid vehicles. In this study, two case studies are presented with a mid-size passenger car in the full NEDC driving cycle with and without brake energy regeneration. The results show that the new factor, hybridization efficiency, is very effective and provides tangible and logical results. The hybridization efficiency is about 40% and 61% without and with regenerative braking energy respectively, when the vehicle goes through the whole NEDC driving cycle.

ACKNOWLEDGEMENT

This work was funded by the University of Jeddah, Jeddah, Saudi Arabia, under grant No. (UJ-21-DR-39). The authors thank the University of Jeddah for the technical and financial support.

REFERENCES

[1] J. Cao, J. Peng, and H. He, "Modeling and Simulation Research on Power-split Hybrid Electric Vehicle," *Energy Procedia*, vol. 104, pp. 354–359, Dec. 2016, https://doi.org/10.1016/j.egypro.2016.12.060.

[2] A. Dubray and P. Beguery, "Energy Management Strategy of Hybrid Electric Vehicles and Driving Cycles," *IFAC Proceedings Volumes*, vol. 33, no. 17, pp. 1131–1136, Jul. 2000, https://doi.org/10.1016/S1474-6670(17)39564-2.

[3] H. Liu, J. Zhao, T. Qing, X. Li, and Z. Wang, "Energy consumption analysis of a parallel PHEV with different configurations based on a typical driving cycle," *Energy Reports*, vol. 7, pp. 254–265, Nov. 2021, https://doi.org/10.1016/j.egyr.2020.12.036.

[4] M. Mourad and K. Mahmoud, "Investigation into SI engine performance characteristics and emissions fuelled with ethanol/butanol-gasoline blends," *Renewable Energy*, vol. 143, pp. 762–771, Dec. 2019, https://doi.org/10.1016/j.renene.2019.05.064.

[5] M. E. Bendib and A. Mekias, "Solar Panel and Wireless Power Transmission System as a Smart Grid for Electric Vehicles," *Engineering, Technology & Applied Science Research*, vol. 10, no. 3, pp. 5683–5688, Jun. 2020, https://doi.org/10.48084/etasr.3473.

[6] A. Khadhraoui, T. Selmi, and A. Cherif, "Energy Management of a Hybrid Electric Vehicle," *Engineering, Technology & Applied Science Research*, vol. 12, no. 4, pp. 8916–8921, Aug. 2022, https://doi.org/10.48084/etasr.5058.

[7] S. Changizian, P. Ahmadi, M. Raeesi, and N. Javani, "Performance optimization of hybrid hydrogen fuel cell-electric vehicles in real driving cycles," *International Journal of Hydrogen Energy*, vol. 45, no. 60, pp. 35180–35197, Dec. 2020, https://doi.org/10.1016/j.ijhydene.2020.01.015.

[8] G. Fontaras, P. Pistikopoulos, and Z. Samaras, "Experimental evaluation of hybrid vehicle fuel economy and pollutant emissions over real-world simulation driving cycles," *Atmospheric Environment*, vol. 42, no. 18, pp. 4023–4035, Jun. 2008, https://doi.org/10.1016/j.atmosenv.2008.01.053.

[9] K. Mahmud, G. E. Town, S. Morsalin, and M. J. Hossain, "Integration of electric vehicles and management in the internet of energy," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 4179–4203, Feb. 2018, https://doi.org/10.1016/j.rser.2017.11.004.

[10] C. Lv, J. Zhang, Y. Li, and Y. Yuan, "Mechanism analysis and evaluation methodology of regenerative braking contribution to energy efficiency improvement of electrified vehicles," *Energy Conversion and Management*, vol. 92, pp. 469–482, Mar. 2015, https://doi.org/10.1016/j.enconman.2014.12.092.

[11] S. Zhou, P. Walker, and N. Zhang, "Parametric design and regenerative braking control of a parallel hydraulic hybrid vehicle," *Mechanism and Machine Theory*, vol. 146, Apr. 2020, Art. no. 103714, https://doi.org/10.1016/j.mechmachtheory.2019.103714.

[12] L. Li, Y. Zhang, C. Yang, B. Yan, and C. Marina Martinez, "Model predictive control-based efficient energy recovery control strategy for regenerative braking system of hybrid electric bus," *Energy Conversion and Management*, vol. 111, pp. 299–314, Mar. 2016, https://doi.org/10.1016/j.enconman.2015.12.077.

[13] W. Gu, D. Zhao, and B. Mason, "A Review of Intelligent Road Preview Methods for Energy Management of Hybrid Vehicles," *IFAC-PapersOnLine*, vol. 52, no. 5, pp. 654–660, Jan. 2019, https://doi.org/10.1016/j.ifacol.2019.09.104.

[14] S. Sharma, A. K. Panwar, and M. M. Tripathi, "Storage technologies for electric vehicles," *Journal of Traffic and Transportation Engineering*, vol. 7, no. 3, pp. 340–361, Jun. 2020, https://doi.org/10.1016/j.jtte.2020.04.004.

[15] K. Uddin, M. Dubarry, and M. B. Glick, "The viability of vehicle-to-grid operations from a battery technology and policy perspective," *Energy Policy*, vol. 113, pp. 342–347, Feb. 2018, https://doi.org/10.1016/j.enpol.2017.11.015.

[16] A. Rabbani and M. Rokni, "Dynamic characteristics of an automotive fuel cell system for transitory load changes," *Sustainable Energy Technologies and Assessments*, vol. 1, pp. 34–43, Mar. 2013, https://doi.org/10.1016/j.seta.2012.12.003.

[17] A. Al-Samari, "Study of emissions and fuel economy for parallel hybrid versus conventional vehicles on real world and standard driving cycles," *Alexandria Engineering Journal*, vol. 56, no. 4, pp. 721–726, Dec. 2017, https://doi.org/10.1016/j.aej.2017.04.010.

[18] P. Plotz, S. A. Funke, and P. Jochem, "Empirical Fuel Consumption and CO2 Emissions of Plug-In Hybrid Electric Vehicles," *Journal of Industrial Ecology*, vol. 22, no. 4, pp. 773–784, 2018, https://doi.org/10.1111/jiec.12623.

[19] J. Rios-Torres, J. Liu, and A. Khattak, "Fuel consumption for various driving styles in conventional and hybrid electric vehicles: Integrating driving cycle predictions with fuel consumption optimization," *International Journal of Sustainable Transportation*, vol. 13, no. 2, pp. 123–137, Feb. 2019, https://doi.org/10.1080/15568318.2018.1445321.

[20] A. Tchetchik, L. I. Zvi, S. Kaplan, and V. Blass, "The joint effects of driving hedonism and trialability on the choice between internal combustion engine, hybrid, and electric vehicles," *Technological Forecasting and Social Change*, vol. 151, Feb. 2020, Art. no. 119815, https://doi.org/10.1016/j.techfore.2019.119815.

[21] F. Salek, M. Zamen, S. V. Hosseini, and M. Babaie, "Novel hybrid system of pulsed HHO generator/TEG waste heat recovery for CO reduction of a gasoline engine," *International Journal of Hydrogen Energy*, vol. 45, no. 43, pp. 23576–23586, Sep. 2020, https://doi.org/10.1016/j.ijhydene.2020.06.075.

[22] D. A. Howey, R. F. Martinez-Botas, B. Cussons, and L. Lytton, "Comparative measurements of the energy consumption of 51 electric, hybrid and internal combustion engine vehicles," *Transportation Research Part D: Transport and Environment*, vol. 16, no. 6, pp. 459–464, Aug. 2011, https://doi.org/10.1016/j.trd.2011.04.001.

[23] H. Choi and I. Oh, "Analysis of product efficiency of hybrid vehicles and promotion policies," *Energy Policy*, vol. 38, no. 5, pp. 2262–2271, May 2010, https://doi.org/10.1016/j.enpol.2009.12.014.

[24] P. Leiby and J. Rubin, "Understanding the Transition to New Fuels and Vehicles: Lessons Learned from Analysis and Experience of Alternative Fuel and Hybrid Vehicles," in *The Hydrogen Energy Transition*, D. Sperling and J. S. Cannon, Eds. Burlington, MA, USA: Academic Press, 2004, pp. 191–212.

[25] L. Youngjae, K. Gangchul, and P. Youngdug, "The Influence of Operating Conditions on Fuel Economy of the Hybrid Electric Vehicle," *Transactions of the Korean Society of Automotive Engineers*, vol. 13, no. 3, pp. 35–40, 2005.

[26] B. Y. Liaw and M. Dubarry, "From driving cycle analysis to understanding battery performance in real-life electric hybrid vehicle operation," *Journal of Power Sources*, vol. 174, no. 1, pp. 76–88, Nov. 2007, https://doi.org/10.1016/j.jpowsour.2007.06.010.

[27] F. Leach, G. Kalghatgi, R. Stone, and P. Miles, "The scope for improving the efficiency and environmental impact of internal combustion engines," *Transportation Engineering*, vol. 1, Jun. 2020, Art. no. 100005, https://doi.org/10.1016/j.treng.2020.100005.

[28] Y. Wang *et al.*, "Fuel consumption and emission performance from light-duty conventional/hybrid-electric vehicles over different cycles and real driving tests," *Fuel*, vol. 278, Oct. 2020, Art. no. 118340, https://doi.org/10.1016/j.fuel.2020.118340.

[29] Y.-T. Zhang, C. G. Claudel, M.-B. Hu, Y.-H. Yu, and C.-L. Shi, "Develop of a fuel consumption model for hybrid vehicles," *Energy Conversion and Management*, vol. 207, Mar. 2020, Art. no. 112546, https://doi.org/10.1016/j.enconman.2020.112546.

[30] R. Capata and A. Coccia, "Procedure for the Design of a Hybrid-Series Vehicle and the Hybridization Degree Choice," *Energies*, vol. 3, no. 3, pp. 450–461, Mar. 2010, https://doi.org/10.3390/en3030450.

[31] O. M. Govardhan, "Fundamentals and Classification of Hybrid Electric Vehicles," *International Journal of Engineering and Techniques*, vol. 3, no. 5, pp. 194–198, 2017.

[32] J. M. Tyrus, R. M. Long, M. Kramskaya, Y. Fertman, and A. Emadi, "Hybrid electric sport utility vehicles," *IEEE Transactions on Vehicular Technology*, vol. 53, no. 5, pp. 1607–1622, Sep. 2004, https://doi.org/10.1109/TVT.2004.832418.

[33] P. Lijewski, M. Kozak, P. Fuc, L. Rymaniak, and A. Ziolkowski, "Exhaust emissions generated under actual operating conditions from a hybrid vehicle and an electric one fitted with a range extender," *Transportation Research Part D: Transport and Environment*, vol. 78, Jan. 2020, Art. no. 102183, https://doi.org/10.1016/j.trd.2019.11.012.

[34] K. Ahn and H. A. Rakha, "A Simple Hybrid Electric Vehicle Fuel Consumption Model for Transportation Applications," in *Applied Electromechanical Devices and Machines for Electric Mobility Solutions*, London, UK: IntechOpen, 2019.

[35] A. S. Khameesa and M. R. Altaay, "Evaluating the Efficiency of Finance Methods in Residential Complex Projects in Iraq," *Engineering, Technology & Applied Science Research*, vol. 12, no. 1, pp. 8080–8084, Feb. 2022, https://doi.org/10.48084/etasr.4663.

AUTHORS PROFILE

Khaled R. M. Mahmoud, is a professor in the Mechanical and Materials Engineering Department, College of Engineering, University of Jeddah, Saudi Arabia. He received his Ph.D. degree from the Heinz Nixdorf Institute, University of Paderborn, Paderborn, Germany in 2005. He has pioneered research in vehicle dynamics and vehicle braking systems and has published more than 35 research articles. He has reviewed several research papers in ISI journals, in fields such as Energy Conversion and Management and Vehicle Dynamics. His current research interests lie on the dynamics of hybrid vehicle systems and internal combustion engines fueled by alternative fuels.

Samy M. Ghania was born in Egypt, in 1971. He received the B.Sc., M.Sc., and Ph.D. degrees in Electrical Engineering from the Faculty of Engineering, Benha University, Cairo, Egypt, in 1995, 2001, and 2005 respectively. In July 2006, he joined the University of Waterloo, Waterloo, ON, Canada, as a Postdoctoral Fellow. He is currently working as a Professor of Electrical Engineering at the University of Jeddah, Saudi Arabia. He has published several papers in international journals and conferences in electrical machines, drives, interference, and electromagnetic simulation, and effects on the human body. He has carried several projects on electrical machine control using micro-controllers, DSP, programmable logic control, and renewable energy resources. His areas of interest include modeling and simulation of electrical machines, drives for electrical vehicles, and its control systems.