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Artículos científicos

Tecnologías en los sistemas de propulsión híbridos: revisión de literatura

Technologies in hybrid powertrains: literature review

Tecnologias em motorizações híbridas: revisão da literatura

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Resumen

En este trabajo se presenta un resumen de una diversidad de desarrollos tecnológicos en los sistemas híbridos para la propulsión automotriz. Para ello, se buscaron en Google Scholar palabras clave como *propulsión híbrida*, *autos eléctricos* y *conversión a híbrido*. En total, se consiguieron cerca de 100 documentos publicados entre 1978 y 2018. En los datos recabados, se encontró que los sistemas de propulsión híbridos (gasolina y electricidad) presentan cinco áreas que describen el desarrollo tecnológico: unidad de potencia; sistema de control de potencia; sistema de almacenamiento de energía; estructura o arquitectura del tren motriz, y sistema para regenerar energía. Sin embargo, el desarrollo de vehículos eléctricos e híbridos aún requiere de mayor desarrollo para igualar o superar el desempeño y las características de los vehículos de MCI. Para lograrlo, se debe hacer énfasis en mejorar el sistema de almacenamiento de energía para alcanzar mayores recorridos por carga, así como incrementar la densidad de energía (kW/peso), reducir los costos, prolongar los ciclos de cargas y disminuir el tiempo de recarga.

Palabras clave: automóviles eléctricos, energía de origen renovable, movilidad urbana, sistema híbrido.

Abstract

This paper presents a summary of a diversity of technological developments in hybrid systems for automotive propulsion. To do this, keywords such as hybrid propulsion, electric cars and conversion to hybrid were searched in Google Scholar. In total, nearly 100 documents were obtained published between 1978 and 2018. In the data collected, it was found that hybrid propulsion systems (gasoline and electricity) present five areas that describe technological development: power unit; power control system; energy storage system; structure or architecture of the powertrain, and system to regenerate energy. However, the development of electric and hybrid vehicles still requires further development to match and go beyond the performance and characteristics of MCI vehicles. To achieve this, emphasis should be placed on improving the energy storage system to get greater travel per load, as well as increasing energy density (kW / weight), reducing costs, extending load cycles and charging time reduction.

Keywords: electric cars, renewable energy, urban mobility, hybrid system.

Resumo

Este artigo apresenta um resumo de uma diversidade de desenvolvimentos tecnológicos em sistemas híbridos de propulsão automotiva. Para fazer isso, eles pesquisaram no Google Scholar por palavras-chave como propulsão híbrida, carros elétricos e conversão para híbrido. No total, foram obtidos cerca de 100 documentos publicados entre 1978 e 2018. Nos dados coletados, constatou-se que os sistemas de propulsão híbridos (gasolina e eletricidade) apresentam cinco áreas que descrevem o desenvolvimento tecnológico: unidade de energia; sistema de controle de potência; sistema de armazenamento de energia; estrutura ou arquitetura do trem de força e sistema para regenerar energia. No entanto, o desenvolvimento de veículos elétricos e híbridos ainda requer mais desenvolvimento para corresponder ou exceder o desempenho e as características dos veículos MCI. Para tanto, deve-se dar ênfase à melhoria do sistema de armazenamento de energia para maiores viagens por carga, bem como ao aumento da densidade energética (kW / peso), redução de custos, prolongamento dos ciclos de carga e redução do tempo de recarga.

Palavras-chave: carros elétricos, energia renovável, mobilidade urbana, sistema híbrido.

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Introduction

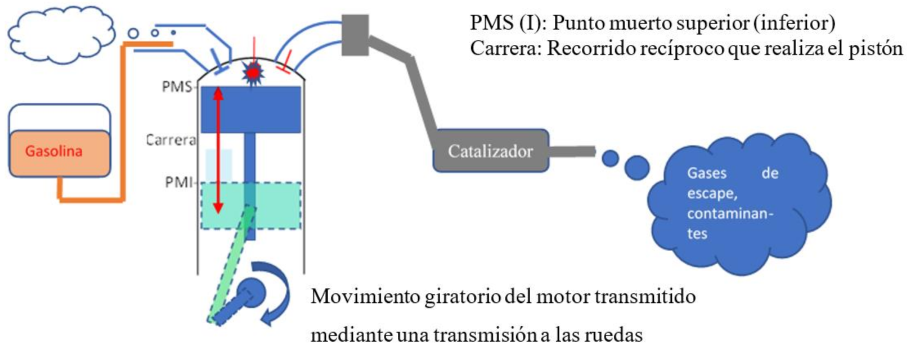
Globally, technology for urban mobility is beginning to use renewable energy sources as a strategy to respond to the growing demand from governments for internal combustion engines (ICMs) - which work using the chemical energy it provides. gasoline and diesel - reduce their consumption and generate fewer pollutants, such as CO2, CO, NO3, hydrocarbons and particulate matter (PM) that form the blue-gray fog layer that covers large cities (Yan and Emadi, 2014) and they change the environment (Fernando, 2017) (figure 1). Due to this, increasingly strict legislation has been established around noise reduction, production of polluting gases and increase in the travel capacity per unit of fuel of non-renewable origin.

In response to these strict requirements, automobile manufacturing companies are working on the research and development of propulsion systems whose conversion process is based on the use of energies that come from renewable sources (Mangusson and Berggren, 2001). These systems can be of two types: those that only use electric motors (EM), which convert electrical energy into mechanical energy with a conversion efficiency of around 92% (Fathabadi, 2018b) and hybrids, which use the energy from of the combination of the MCI with an ME (Passalacqua, Lanzarote, Repetto and Marchesoni, 2018), they achieve as a final result an efficiency superior to that obtained from only operating the MCI, data that depends on several design factors, that is to say, on how the ME interacts with the MCI, in series, parallel or series-parallel arrangement, the type of cycle of the MCI, the energy management or control algorithm, the durability of the battery charge, the size and technology of the ME and the MCI technology.

The technology of cars powered by alternative energy (electric and hybrid) of renewable origin has existed since around 1870. However, it was displaced by the MCI, which uses energy from non-renewable fuel because the latter was cheaper, offered great autonomy and quick recharging. Even so, at present, electric propulsion systems have regained interest because they use alternative energies of renewable origin (Mahmoudzadeh Andwari, Pesiridis, Rajoo, Martinez-

Botas and Esfahanian, 2017), although their points are still lacking for improvement. weak, so that their competitiveness is optimized (Guanetti *et al*., 2014; Palmer, Tate, Wadud y Nellthorp, 2018).

Figura 1. Motor de gasolina de cuatro tiempos ciclo otto



Fuente: Elaboración propia

The diversity of electric and hybrid models continues to grow. This is synonymous with the improvement in its technical concept, which allows it to increase its share in a market mostly covered by internal combustion vehicles. (Inegi, 2020; Palmer *et al*., 2018; Rodríguez y Lukie Srdjan, 2011).

Method

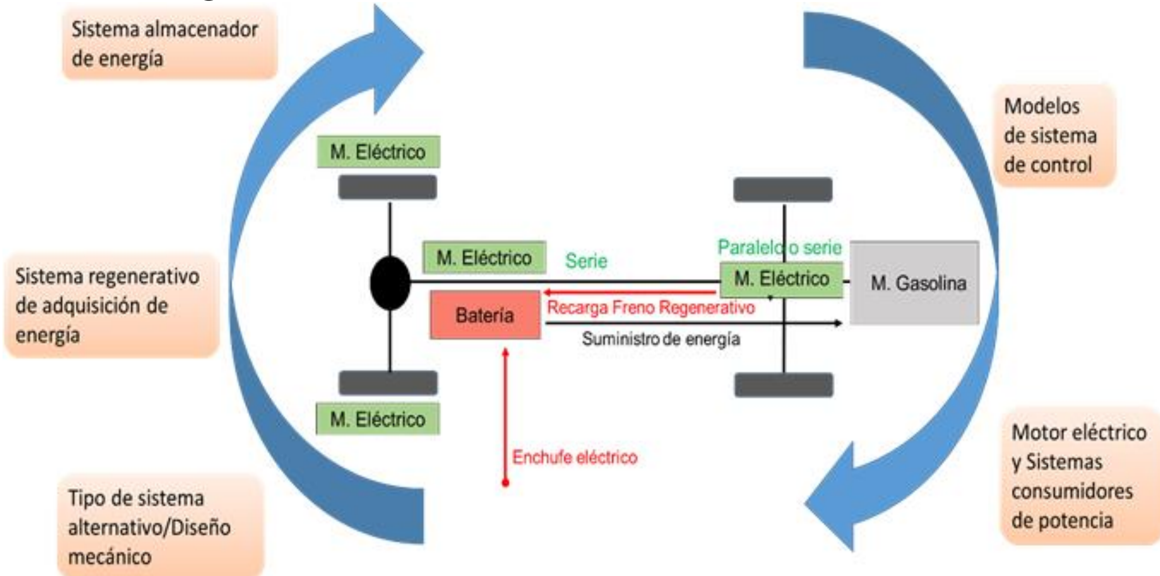
This paper presents a summary of a diversity of technological developments in hybrid systems for automotive propulsion. To do this, they searched Google Scholar for keywords such as hybrid propulsion, electric cars and converting to hybrid. In total, about 100 documents published in 1978 and 2018 were obtained.

Likewise, a correspondence was established with the systems moved by MCI, that is, the power source, the structure of the propulsion system, the energy storage system and the power control system.

Results

Hybrid propulsion systems (gasoline and electricity) were found to have five areas that describe technological development: power unit; power control system; energy storage system; structure or architecture of the powertrain, and system to regenerate energy (figure 2).

Figura 2. Áreas de desarrollo de los vehículos eléctricos e híbridos



Fuente: Elaboración propia

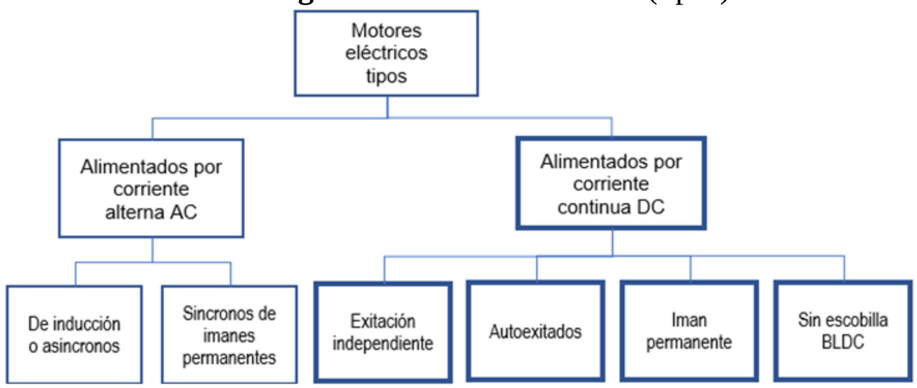
Power unit in electric and hybrid vehicles

In vehicles powered by electric or hybrid motors, their system is made up of an electric motor or a combination of an electric motor and an internal combustion engine. The hybrid transmission is similar to that of the MCI, while in the electric it is only a speed reducer of the ME, which increases its torque delivered to the wheel. Regarding the differential, this depends on the design and arrangement of the EMs (Farina et al., 2018; Guan, Zhu, Afinowi, Mipo and Farah, 2016).

The electric motor provides the power that the vehicle demands and can have different locations, depending on the specific design of the car, both in pure electric vehicles or hybrids (MCI-ME). The source of energy through batteries (due to its large size) is generally located between the wheels, below the occupants of the car (Mehrdad, Yimin and John, 2007; Shen, Shan and Gao, 2011).

EVs, like HEVs, use electric motors of the induction or permanent magnet type, direct or alternating current, three-phase or single-phase, to transform electrical energy into mechanical energy; while for hybrids there is an MCI that interacts with the electric motor supporting the power and / or moving an electric current generator (figure 3).

Figura 3. Motores eléctricos (tipos)



Fuente: Elaboración propia

In the latter, the interaction between the electric motor and the internal combustion motor occurs in different ways, and is classified as series, parallel or series parallel. The selection of engines is based on comparative studies that allow choosing the ME and the technology that best meets the characteristics defined for the vehicle and driving conditions to which it will be subjected. For example, in a simulation study for a luxury midsize vehicle, the IPM type is more efficient (between 2% and 3%) than the IM due to the better low-speed torque (Guan et al., 2016).

The VE, being driven by ME, does not require a gearbox to convert speed to torque because it provides high torque from the start of its speed; However, using a gearbox with two gears can reduce the size of the battery or have lower energy consumption (between 14.01% and 17.83%) (Ruan, Walker, Zhang and Wu, 2017).

On the other hand, EVs may require more power to move more weight without sacrificing speed, so the investigation of a double stator electric motor shows a feasibility according to the results given when applied to a bicycle. This provides a torque of 16.2 N-m, which equivalent to a simple ME would require a larger and heavier engine (Farina et al., 2018).

The technology where the ME and the MCI jointly provide driving torque to the wheels has a clutch to perform at the required moment the engagement or disengagement of the MCI stem, so that at a given moment only the propulsion by the ME remains. , which depends on the needs that driving demands, thus shown in the patent (Trent J. US 2018/0022200 A1, 2018).

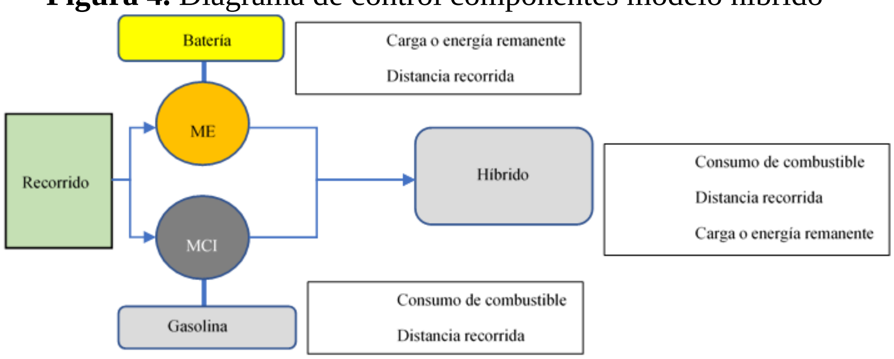
There are hybrid vehicles whose power is supplied by the ME, by the MCI or jointly. This selection is achieved through an automatic control system that determines the source according to the requirement of the driving conditions at the given time. Thus, the limit speeds where these changes will be made can be manipulated (Porras et al. US 9,884,619 B2, 2018).

Based on the above, the type of ME to choose is subject to the characteristics of the vehicle: weight, dimensions, downforce, wheel type, load capacity, kilometers to travel per load, acceleration response, weight / size of the vehicle. ME, average and top speed, area you will ride (type of drive cycle), battery pack size, vehicle purpose, and distance / charge range. All this plus the simulation tests will lead to the choice of a DC or AC motor (Emadi, 2014).

Energy control system

This system controls the battery energy against the power demand to achieve the maximum charging duration and, consequently, a greater distance to travel, that is, it manages the energy demanded according to the available, the recovered and the source (Capasso, Lauria y Veneri, 2017; Cao y Xiong, 2017; Passalacqua, Lanzarotto, Repetto y Marchesoni, 2017; Tremblay, Dessaint y Dekkiche, 2007).

Figura 4. Diagrama de control componentes modelo híbrido



Fuente: Elaboración propia

Electric vehicles, being powered by electric current, take it from the battery pack and supercapacitors, where the energy is stored. Then, depending on the expense or its consumption, it will provide the performance to the vehicle. In this way, energy control (management) is key to the durability of the charge and the life of the battery (figure 4). The control modeling (algorithm) supplies or receives power depending on the driving condition, converting the ME to GE or activating an additional GE at the appropriate time. Through operation simulation, it is possible to understand the energy management of a specific model and make the algorithm more efficient (Cao and Xiong, 2017; Gardner C. US 005,346,031, 1994; Tremblay et al., 2007).

As an example, we have the activation and deactivation of the MCI or the ME by means of a clutch (Trent J. US 2018/0022200 A1, 2018), the activation or deactivation of the ME or hybrid mode by means of an automatic control based on manually established speed limits (Porras et al., US 9,884,619 B2, 2018), and an automatic propulsion selection control that, depending on the energy level of the previously established battery pack, acts as electric or hybrid (Tribioli et al., 2014). For situations where the control value falls between two reference or limiting points, which demands an adjustment or intermediate value, fuzzy type controllers are used, which allows monitoring and adjusting according to topographic conditions. This, added to the use of supercapacitors, improves the battery's energy charge state (Michalczuk, Ufnalski & Grzesiak, 2018).

In hybrid vehicles, control modeling adjusts the inverter to establish optimal energy management with respect to driving demands, thereby reducing harsh accelerations. This, when evaluated in the US06 drive cycle, reduces electrical power consumption. (Anwar, Teimor, Savagian, Saito y Matsuo, 2016).

Energy storage systems are affected by the high temperatures they reach during their operation, which reduces the vehicle's ability to travel. Artificial intelligence based on genetic algorithms improves charge / discharge management and energy flow for temperatures above 60ºC; however, high temperatures affect battery life (Panday and Bansal, 2015).

For HEV parallel type vehicles, the relative RPM between the MCI and ME establishes the division of the load and the required power. Thus, it is feasible to predict the required MCI, thereby reducing consumption from 5.44 L / 100 km to 5.33 L / 100 km, for a pre-established driving pattern (Denis, Dubois, Trovao and Desrochers, 2017; Qi, Xiang, Wang, Wen and Ding, 2017), and using fuzzy logic reduces 7.7% in energy use (Salman, Schouten and Kheir, 2000). Predictive models that learn and take precedence over management manage to increase the SOC, reducing CO_2 emission from 7% to 1% (Fadul, Aris, Misron, Halin and Iqbal, 2018), or the simulation carried out by comparing results and adjusting values predictive following the US06 management cycle (Huang et al., 2017; Uthaichana, De Carlo, Bengea, Zefran and Pekarek 2011).

The automatic control system of the energy management is complex, although it was simplified by making them selective manually so that its selector refers to the type of driving. The design under study of four options to choose from shows a reduction of fuel from non-renewable sources of 3% (Maamria, Gillet, Colin, Chamaillard y Nouillant, 2018).

Taking the development of a system with power in each wheel independently, a control system that manages the power between the wheels without one being saturated to cover the need, a system that manages the electric vector torque of the rear axle drive (TVeRAD), and the same applied to the front axle, allows modulating the power distribution between the wheels and controlling the turning of the vehicle to a minimum. This achieves stability and good torque at high speed (140 km / h), while others without this control are unstable (Alcantar and Assadian and Kuang, 2018).

When using fuel cell to generate electrical energy, this is of low magnitude, so it requires a battery pack and supercapacitors. Thus, the control system must manage the energy between these three sources and be effective in the various regulatory management cycles (Boukhnifer, Ouddah, Azib and Chaibet, 2016; Marzougui, Amari, Kadri, Bacha and Ghouili, 2017). Controls by genetic algorithms and a metaheuristic program for HEV with a fuel cell also give good results, reducing between 20% and 33% the consumption of gasoline (Melo, Ribau y Silva, 2014).

Energy storage system

Electric vehicles powered by renewable energy sources store energy in the battery pack, in supercapacitors and, in addition, in MCI's gasoline or diesel tank for hybrid vehicles (Burke, 2007).

To use and convert renewable energy into mechanical movement and achieve propulsion, it is stored and taken from batteries whose technology allows downloading and recharging electrical energy, and whose capacity depends on their chemistry (figure 5) (Hayes and Goodarzi, 2018).

The lithium-ion battery is the most widely used for its manufacturing process, the amount of energy and the force it supplies, which are arranged in series and parallel to achieve the necessary voltage and current values (they are called battery pack) . This is supported by carbon-carbon ultracapacitors to handle large loads required in accelerations, which protects batteries that are susceptible to reduced life and capacity due to high and repetitive loads, increasing efficiency by 28.6% compared to systems. traditional batteries (Song *et al*., 2018).

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Figura 5. Química de las baterías recargables

Química	Electrodo	Reacción	Ecuación	Voltaje
Plomo acido	Cátodo	Oxidación	$PbSO_4 + 2H_2O \rightarrow PbO_2 + H_2SO_4 + 2H^+ + 2e^-$	1.69
carga	Ánodo	Reducción	$PbSO_4 + 2H^+ + 2e^- \rightarrow Pb + H_2SO_4$	−0.36
	Cell		$2PbSO_4 + 2H_2O \rightarrow Pb + PbO_2 + 2H_2SO_4$	2.05
Plomo acido	Cátodo	Oxidación	$PbO_2 + H_2SO_4 + 2H^+ + 2e^- \rightarrow PbSO_4 + 2H_2O$	1.69
descarga	Ánodo	Reducción	$Pb + H_2SO_4 \rightarrow PbSO_4 + 2H^+ + 2e^-$	−0.36
	Cell		$Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$	2.05
NiMH	Cátodo	Oxidación	$Ni(OH)_2 + OH^- \rightarrow NiOOH + H_2O + e^-$	0.45
carga	Ánodo	Reducción	$MH + OH^- + e^- \rightarrow M + H_2O$	−0.83
	Cell		$Ni(OH)_2 + M \rightarrow NiOOH + MH$	1.28
NiMH	Cátodo	Oxidación	$NiOOH + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$	0.45
descarga	Ánodo	Reducción	$M + H_2O \rightarrow MH + OH^- + e^-$	−0.83
	Cell		$NiOOH + MH \rightarrow Ni(OH)_2 + M$	1.28
Li-ion	Cátodo	Oxidación	$LiMO_2 \rightarrow MO_2 + Li^+ + e^-$	1
carga	Ánodo	Reducción	$C_6 + Li^+ + e^- \rightarrow LiC_6$	−3
	Cell		$LiMO_2 + C_6 \rightarrow MO_2 + LiC_6$	4
Li-ion	Cátodo	Oxidación	$MO_2 + Li^+ + e^- \rightarrow LiMO_2$	1
descarga	Ánodo	Reducción	$LiC_6 \rightarrow C_6 + Li^+ + e^-$	−3
			$MO_2 + LiC_6 \rightarrow LiMO_2 + C_6$	4

Fuente: Hayes y Goodarzi (2018, p. 75)

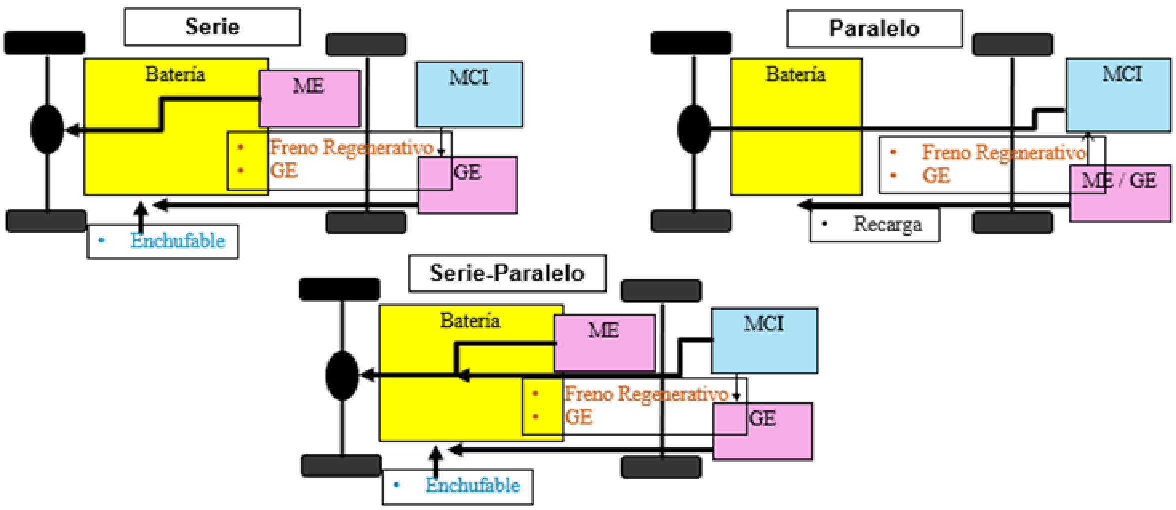
The management of energy management between the elements that store and demand it is done through controls that provide information on driving conditions, the dynamics of the route, the battery charge level and the ultracapacitor. In this way, the appropriate response is provided by the controller, which can obtain an increase of 2 h in the SOC (Sreedhar, Siegel & Choi, 2017). This result can be improved depending on the type C ultracapacitor and the battery. A simulated exercise in Simulink-Matlab, given with Zebra batteries and a DC-DC converter (Capasso and Veneri, 2017) for an urban cycle, using equivalent resistances and later similar tests carried out on a test bench, showed that the system adheres to the dynamic requirements demanded, which provides reliability for future durability tests (Capasso and Veneri, 2017).

On the other hand, a study on the use of a photovoltaic energy source instead of an MCI in an HEV shows a greater travel capacity in 19 km than the corresponding one achieved when the battery pack is used exclusively as an energy source. (Fathabadi, 2018a).

Alternative energy propulsion system architecture

The size and configuration of the ME gives the freedom to establish different technical location to provide the power to the brake with its corresponding energy storage system and the interaction with the MCI, which allows obtaining various effects on the vehicle's performance (distance traveled by SOC, handling stability, etc.). This distribution is known as architecture and is grouped into three: series, parallel and series-parallel (figure 6). They are found in electric (EV), hybrid (HEV), plug-in (PHEV), plug-in with charge return to the grid-V2G, fuel cells (FCHEV), by solar cells and turbo-air generator (Bloom, Niu y Krishnamurthy, 2013).

Figura 6. Arquitectura de los sistemas de propulsión híbridos



Fuente: Elaboración propia

The PHEV concept allows the battery pack to be recharged by plugging it into the mains, providing greater travel capacity and less activation of the MCI compared to non-pluggable HEV. It is found in medium-sized vehicles with parallel-type or series-parallel architectures, and series-type for large vehicles (Amjad, Neelakrishnan and Rudramoorthy, 2010; Bayindir, Gozukucuk and Teke, 2011; Guanetti et al., 2014). From these variants that seek to improve the travel capacity per charge, price and recharging time, it can be inferred that between the years 2040 and 2060 it will be possible for vehicles powered by renewable energy to outperform MCI type vehicles (Safari, 2018; Shunsuke, 2015).

In electric vehicles, adding an additional power source to the battery (such as solar cells or wind turbines that use impact air when braking) results in an approximately 18% increase in battery power life (Fathabadi, 2018a, 2018b). Likewise, a hydrogen cell to generate electrical energy increases the duration of the stored (Fathabadi, 2018a).

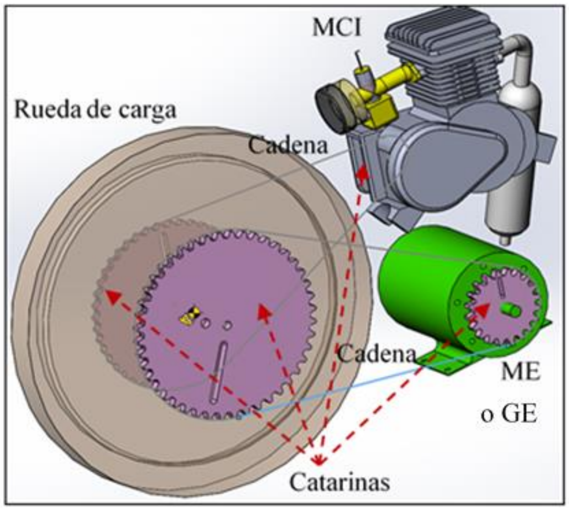
Power source batteries are highly susceptible to rapid charges and discharges, which affects the life and state of charge they provide. To protect them and reduce this effect, supercapacitors are added that provide energy during the peak loads demanded by the accelerations. These are recharged by slowing down the vehicle by converting kinetic energy into electrical energy (regenerative energy system when braking) or by solar cells, closely related to providing energy from sources with zero polluting emissions.

EVs are powered by an ME through renewable energy. In the case of hybrid vehicles, they still use gasoline or diesel ICMs due to the interaction with the ME. Thus they manage to reduce fuel consumption and the emission of polluting gases (between 4.8% and 52.1% depending on the type of ICM and the architecture and the interaction of the EM with the ICM) (Canals Casals, Martínez-Laserna, Amante García y Nieto, 2016; Oh, Park, Lee, Seo y Park, 2017; Peng, Ou y Yan, 2018; Solouk, Shakiba-Herfeh, Arora y Shahbakhti, 2018; Teixeira y Sodré, 2018).

System for recharging energy while driving

In order to increase the travel capacity and duration of the SOC charge provided by the battery pack, the energy storage system formed by the battery pack and ultracapacitors receive additional energy or recharge to that supplied when connected to the mains or when the MCI is activated with the function of generating electrical energy. This feedback comes from different techniques. The one most applied so far with much benefit is called regenerative braking (figure 7). This consists of using the kinetic energy achieved with speed into electrical energy. In this way, the battery and / or supercapacitors are charged when braking, using the torque opposite to speed, generated by directing the movement of the vehicle to move an electric generator. This reduces the speed, instead of using friction shoes that lose this energy in heat (Gantt, Perkins, Alley and Nelson, 2011; Loukakou et al., 2013; Naseri, Member, Farjah and Ghanbari, 2017; Qiu, Wang, Meng and Shen, 2018a), or the use of hydrogen cells (Burke, 2007; Fathabadi, 2018c), and / or the use of turbines moved by impact air (Fathabadi, 2018d), and / or recharging by self-induction without electrical connection (inductive power transfer IPT) (Joseph y Elangovan, 2018; Rim, 2018).

Figura 7. Sistema frenado regenerativo (conversión de inercia rotacional en energía eléctrica)



Fuente: Elaboración propia

Discussion

The technology to mobilize vehicles using renewable energy originated in parallel with that using non-renewable energy. However, because the latter always offered more competitive and economic advantages, it became the most exploited in the market, hence its counterpart was almost forgotten. In more detail, it can be said that MCI vehicles stood out over electric or hybrid vehicles due to the autonomy they offered for their gasoline or diesel charge, to which must be added the ease of recharging, the lower price of the vehicle. automobile and other aspects inherent to the supply of fuel and the technology itself. Therefore, to change this reality, electric or hybrid vehicles must address certain aspects that could be summarized as follows.

The energy management system, for example, must be able to increase the autonomy and protect the battery pack, establishing the appropriate moment, the direction of the energy flow, the supply source and the intensity of the energy flow according to the need and type of handling.

Likewise, the energy storage system must be capable of reducing its weight, cost, and recharging time, as well as increasing the recharging capacity and the safety of the occupants.

The power system, likewise, must be in accordance with the energy management and storage systems, so it must be able to change from engine to generator according to the driving situation to contribute to increasing autonomy and protect the system from storage.

In short, the continuous development and innovation of each of the technological areas of the electric and hybrid vehicle will lead it to reduce and equate them with the systems powered by MCI and reverse the trend of buying and selling in the market.

Conclusion

The development of electric and hybrid vehicles, as a strategy to reduce polluting gases and the consumption of non-renewable fuel, requires further development to match the performance and characteristics of MCI vehicles. To do this, emphasis should be placed on improving the energy storage system to achieve greater travels. In this sense, it is necessary to increase the energy density (kW / weight), reduce costs, prolong charging cycles and reduce recharging time. Hybrid vehicles (HEV) and plug-in vehicles to the electrical network (PHEV) are an intermediate step of improvement in the way to use renewable energy intensively for transportation, the following table 1 shows examples that could contribute to achieve this. end, according to Hannan, Azidin y Mohamed (2014, p. 147).

Tabla 1. Ejemplos de investigaciones-metodologías-resultados para mejorar la capacidad del HEV

Solar-asistido bicitaxi eléctrico de tres ruedas.	El diseño de un bicitaxi es simulado mediante ADVISOR y es vinculado a Matlab-simulink para su análisis.	No emisiones contaminantes. Se mejora la eficiencia energética y desempeño, pero el diseño del tren de potencia se hace complejo y de alto costo.
Gestión de un sistema de energía para la conducción eléctrica de una patineta.	Experimentar el comportamiento de un sistema de propulsión eléctrica con frenado regenerativo y controlado por un FPGA central a través de LabVIEW con mediciones en tiempo real.	El frenado regenerativo incrementa alrededor de 20 % la duración de carga de batería; el sistema se hace costoso y complejo.
Modelado y simulado de un sistema de gestión de energía para un PHEV.	A través de Matlab-simulink es simulado el flujo de energía acorde al tamaño del vehículo para un determinado patrón de manejo de un PHEV. Los resultados se comparan con ADVISOR.	El modelo de gestión de energía mejora el desempeño del PHEV, reduciendo el consumo de combustible de origen no renovable por patrón de manejo.

Fuente: Hannan, Azidin y Mohamed (2014, p. 147)

The use of simulations helps to assess the effectiveness of the research, which provides a preamble to what could happen when applied in real life. This broadens the window of possibilities to improve the vehicle's performance and its competitiveness against MCIs.

Future lines of research

Renewable energy-powered transportation systems have a very broad field of research. However, you can start with RPM-based power management in parallel-type hybrid systems or establish a review to choose batteries by charge density and recharge time for automotive mobility. Also, a review of the research of highly efficient electric motors for automotive application, or the research and definition of the technical requirements to satisfy the design of a generic series-parallel hybrid vehicle.

Abbreviations: Electric Vehicles (EV), Hybrid Electric Vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), Fuel Cell Electric Vehicles (FCVE), Magnetic Induction (IM) Electric Motor, Permanent Magnetic Induction (IPM), Direct Current (DC), alternating current (AC), three-phase alternating current (TAC), single-phase alternating current (MAC); internal combustion engine (MCI), electric motors (EM), internal combustion engine (ICE).

References

Alcantar, J. V., Assadian, F. and Kuang, M. (2018). Vehicle Dynamics Control of eAWD Hybrid Electric Vehicle Using Slip Ratio Optimization and Allocation. *Dynamic Systems, Measurement, and Control*, *140*(September), 1–12. Doi: https://doi.org/10.1115/1.4039486

Amjad, S., Neelakrishnan, S. and Rudramoorthy, R. (2010). Review of design considerations and technological challenges for successful development and deployment of plug-in hybrid electric vehicles. *Renewable and Sustainable Energy Reviews*, *14*(3), 1104–1110. Doi: https://doi.org/10.1016/j.rser.2009.11.001

Anwar, M., Teimor, M., Savagian, P., Saito, R. and Matsuo, T. (2016). Compact and high power inverter for the Cadillac CT6 rear wheel drive PHEV. *ECCE 2016 - IEEE Energy Conversion Congress and Exposition, Proceedings*. Doi: https://doi.org/10.1109/ECCE.2016.7854931

Bayindir, K. C., Gozukucuk, M. A. and Teke, A. (2011). A comprehensive overview of hybrid electric vehicle: Powertrain configurations, powertrain control techniques and electronic control units. *Energy Conversion and Management*, *52*(2), 1305–1313. Doi: https://doi.org/10.1016/j.enconman.2010.09.028

Bloom, A., Niu, G. and Krishnamurthy, M. (2013). Design considerations for wireless electric vehicle charging. *2013 IEEE Transportation Electrification Conference and Expo (ITEC)*, (6), 1–6. Doi: https://doi.org/10.1109/ITEC.2013.6574492

Boukhnifer, M., Ouddah, N., Azib, T. and Chaibet, A. (2016). Intelligent energy management for hybrid fuel cell/battery system. *COMPEL - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, *35*(5), 1850–1864. Doi: https://doi.org/10.1108/COMPEL-08-2015-0309

Burke, A. F. (2007). Batteries and Ultracapacitors for electric, hybrid, and fuel cell vehicles. *Proceedings of the IEEE*, *95*(4), 806–820. Doi: https://doi.org/10.1109/JPROC.2007.892490

Canals Casals, L., Martinez-Laserna, E., Amante García, B. and Nieto, N. (2016). Sustainability analysis of the electric vehicle use in Europe for CO2 emissions reduction. *Journal of Cleaner Production*, *127*, 425–437. Doi: https://doi.org/10.1016/j.jclepro.2016.03.120

Cao, J. and Xiong, R. (2017). Reinforcement Learning-based Real-time Energy Management for Plug-in Hybrid Electric Vehicle with Hybrid Energy Storage System. *Energy Procedia*, *142*, 1896–1901. Doi: https://doi.org/10.1016/j.egypro.2017.12.386

Capasso, C. and Veneri, O. (2017). Integration between Super-capacitors and ZEBRA Batteries as High Performance Hybrid Storage System for Electric Vehicles. *Energy Procedia*, *105*, 2539–2544. Doi: https://doi.org/10.1016/j.egypro.2017.03.727

Capasso, C., Lauria, D. and Veneri, O. (2017). Optimal control strategy of ultra-capacitors in hybrid energy storage system for electric vehicles. *Energy Procedia*, *142*, 1914–1919. Doi: https://doi.org/10.1016/j.egypro.2017.12.390

Denis, N., Dubois, M., Trovao, P. and Desrochers, A. (2017). Power Split Strategy Optimization of a Plug-in Power Optimization of a Plug-in Parallel Hybrid Electric Vehicle. *IEEE Transactions on Vehicular Technology*, *67*(October), 315–326. Doi: https://doi.org/10.1109/TVT.2017.2756049

Emadi, A. (2014). *Advanced Electric Drive Vehicles*. *Advanced Electric Drive Vehicles*. Boca Raton: CRC Press. Doi: https://doi.org/10.1201/9781315215570

Fadul, S. M. E., Aris, I. B., Misron, N., Halin, I. A. and Iqbal, A. K. M. (2018). Modelling and Simulation of Powertrain System for Electric Car. *Journal of the Society of Automotive Engineers Malaysia*, *2*(1), 23–34.

Farina, S., Firdaus, R. N., Azhar, F., Azri, M., Ahmad, M. S., Suhairi, R., … Sutikno, T. (2018). Design and analysis of in-wheel double stator slotted rotor BLDC motor for electric bicycle application. *International Journal of Power Electronics and Drive Systems*, *9*(1), 457–464. Doi: https://doi.org/10.11591/ijpeds.v9n1.pp457-464

Fathabadi, H. (2018a). Fuel cell hybrid electric vehicle (FCHEV): Novel fuel cell/SC hybrid power generation system. *Energy Conversion and Management*, *156*(October 2017), 192–201. Doi: https://doi.org/10.1016/j.enconman.2017.11.001

Fathabadi, H. (2018b). Novel battery/photovoltaic hybrid power source for plug-in hybrid electric vehicles. *Solar Energy*, *159*(October 2017), 243–250. Doi: https://doi.org/10.1016/j.solener.2017.10.071

Fathabadi, H. (2018c). Novel fuel cell/battery/supercapacitor hybrid power source for fuel cell hybrid electric vehicles. *Energy*, *143*, 467–477. Doi: https://doi.org/10.1016/j.energy.2017.10.107

Fathabadi, H. (2018d). Utilizing solar and wind energy in plug-in hybrid electric vehicles. *Energy Conversion and Management*, *156*(October 2017), 317–328. Doi: https://doi.org/10.1016/j.enconman.2017.11.015

Fernando, A. (2017). Análisis de los gases de escape de los motores de combustión interna. *CESI*, 8. Retrieved from http://www.cise.com/portal/notas-tecnicas/item/302-análisis-de-los-gases-de-escape-de-los-motores-de-combustión-interna.html

Gantt, L. R., Perkins, D. E., Alley, R. J. and Nelson, D. J. (2011). Regenerative brake energy analysis for the VTREX plug-in hybrid electric vehicle. *Vehicle Power and Propulsion Conference (VPPC), 2011 IEEE*, *2*(2), 1–6. Doi: https://doi.org/10.1109/vppc.2011.6043049

Gardner Conrad. (1994). *Gardner C. US 005,346,031*.

Guan, Y., Zhu, Z. Q., Afinowi, I. A. A., Mipo, J. C. and Farah, P. (2016). Comparison between induction machine and interior permanent magnet machine for electric vehicle application. *COMPEL - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, *35*(2), 16. Retrieved from https://dialnet.unirioja.es/servlet/articulo?codigo=6239179

Guanetti, J., Formentin, S., Savaresi, S. M., Elettronica, D., Bioingegneria, I. and Vinci, P. L. (2014). Total cost minimization for next generation hybrid electric vehicles. *IFAC-PapersOnline*, *47*(3), 4819–4824. Doi: https://doi.org/10.3182/20140824-6-ZA-1003.02003

Hannan, M. A., Azidin, F. A. and Mohamed, A. (2014). Hybrid electric vehicles and their challenges: A review. *Renewable and Sustainable Energy Reviews*, *29*, 135–150. Doi: https://doi.org/10.1016/j.rser.2013.08.097

Hayes, J. G. and Goodarzi, G. A. (2018). Batteries. In John Wiley and Sons Ltd (ed.), *Electric power train energy* (pp. 68–110). Wiley. Retrieved from https://www.amazon.com/-/es/John-G-Hayes/dp/1119063647

Huang, Y., Lu, Y., Huang, R., Chen, J., Chen, F., Liu, Z., … Roskilly, A. P. (2017). Study on the thermal interaction and heat dissipation of cylindrical Lithium-Ion Battery cells. *Energy Procedia*, *142*, 4029–4036. Doi: https://doi.org/10.1016/j.egypro.2017.12.321

Hussain, Q., Schwartz, W., Baker, C. A., Richens, D., Brighman, M. and Jennings, J. (2018). *Quazi, Patent US 9896987 B2*.

Inegi (2020). *StatisticCars*. Retrieved from https://www.inegi.org.mx/temas/vehículos/

Joseph, P. K. and Elangovan, D. (2018). A review on renewable energy powered wireless power transmission techniques for light electric vehicle charging applications. *Journal of Energy Storage*, *16*, 145–155. Doi: https://doi.org/10.1016/j.est.2017.12.019

Loukakou, D., Chetangny, P., Soufan, H., Dubas, F., Espanet, C. and Soussou Houndedako, V. (2013). Regenerative braking in a small low cost plug-in hybrid electric vehicle for urban use. *2013 8th International Conference and Exhibition on Ecological Vehicles and Renewable Energies, EVER 2013*, 1–5. Doi: https://doi.org/10.1109/EVER.2013.6521540

Maamria, D., Gillet, K., Colin, G., Chamaillard, Y. and Nouillant, C. (2018). Computation of eco-driving cycles for Hybrid Electric Vehicles: Comparative analysis. *Control Engineering Practice*, *71*(October 2017), 44–52. Doi: https://doi.org/10.1016/j.conengprac.2017.10.011

Mahmoudzadeh Andwari, A., Pesiridis, A., Rajoo, S., Martinez-Botas, R. and Esfahanian, V. (2017). A review of Battery Electric Vehicle technology and readiness levels. *Renewable and Sustainable Energy Reviews*. Elsevier Ltd. Doi: https://doi.org/10.1016/j.rser.2017.03.138

Mangusson, T. and Berggren, C. (2001). Enviromental innovation in auto development managing technological uncertainty within stric time limits. *International Journal of Vehicle Design*, *26*(2-3), 101 115. Retrieved from https://www.inderscienceonline.com/doi/abs/10.1504/IJVD.2001.001932

Marzougui, H., Amari, M., Kadri, A., Bacha, F. and Ghouili, J. (2017). Energy management of fuel cell/battery/ultracapacitor in electrical hybrid vehicle. *International Journal of Hydrogen Energy*, *42*(13), 8857–8869. Doi: https://doi.org/10.1016/j.ijhydene.2016.09.190

Mehrdad, E., Yimin, G. and John, M. M. (2007). Hybrid Electric Vehicles - Architecture and Motor Drives. *IEEE Transactions on Power Electronics*, *95*(4), 719-728. Doi: https://doi.org/10.1109/JPROC.2007.892492

Melo, P., Ribau, J. and Silva, C. (2014). Urban Bus Fleet Conversion to Hybrid Fuel Cell Optimal Powertrains. *Procedia - Social and Behavioral Sciences*, *111*, 692–701. Doi: https://doi.org/10.1016/j.sbspro.2014.01.103

Michalczuk, M., Ufnalski, B. and Grzesiak, L. (2018). Fuzzy logic based power management strategy using totpographic data for an electric vehicle with a battery - ultracapacitor energy storage. *Emeraldinsight COMPEL*, *34*(1), 173–188.

Naseri, F., Member, S., Farjah, E. and Ghanbari, T. (2017). An Efficient Regenerative Braking System Based on Battery / Supercapacitor for Electric, Hybrid and Plug-In Hybrid Electric Vehicles With BLDC Motor. *IEEE Transactions on Vehicular Technology*, *66*(5), 3724–3738.

Oh, Y., Park, J., Lee, J. T., Seo, J. and Park, S. (2017). Estimation of CO2reduction by parallel hard-type power hybridization for gasoline and diesel vehicles. *Science of the Total Environment*, *595*, 2–12. Doi: https://doi.org/10.1016/j.scitotenv.2017.03.171

Palmer, K., Tate, J. E., Wadud, Z. and Nellthorp, J. (2018). Total cost of ownership and market share for hybrid and electric vehicles in the UK, US and Japan. *Applied Energy*, *209*(October 2017), 108–119. Doi: https://doi.org/10.1016/j.apenergy.2017.10.089

Panday, A. and Bansal, H. O. (2015). Hybrid Electric Vehicle Performance Analysis under Various Temperature Conditions. *Energy Procedia*, *75*, 1962–1967. Doi: https://doi.org/10.1016/j.egypro.2015.07.238

Passalacqua, M., Lanzarotto, D., Repetto, M. and Marchesoni, M. (2017). Advantages of Using Supercapacitors and Silicon Carbide on Hybrid Vehicle Series Architecture. *Energies*, *10*(7), 920. Doi: https://doi.org/10.3390/en10070920

Passalacqua, M. Lanzarotto, D. Repetto, M. and Marchesoni, M. (2018). Conceptual design upgrade on hybrid powertrains resulting from electric improvements. *International Journal of Transport Development and Integration*, 2(2). Doi: https://doi.org/10.2495/TDI-V2-N2-146-154

Peng, T., Ou, X. and Yan, X. (2018). Development and application of an electric vehicles life-cycle energy consumption and greenhouse gas emissions analysis model. *Chemical Engineering Research and Design*, *131*, 699–708. Doi: https://doi.org/10.1016/j.cherd.2017.12.018

Porras, A., Bryan, B., Christopher, O. and Joseph, S. (2018). *Porras Angel. et al. US 9,884,619 B2*. USA.

Qi, Y., Xiang, C., Wang, W., Wen, B. and Ding, F. (2017). Model predictive coordinated control for dual mode power split hybrid electric vehicle. *International Journal of Automotive Technology*, *19*(2), 345–358. Doi: https://doi.org/10.1007/s12239

Qiu, C., Wang, G., Meng, M. and Shen, Y. (2018). A novel control strategy of regenerative braking system for electric vehicles under safety critical driving situations. *Energy*, *149*, 329–340. Doi: https://doi.org/10.1016/j.energy.2018.02.046

Rim, C. T. (2018). *Power Electronics Handbook* (4th ed.). Doi: https://doi.org/10.1016/B978-0-12-811407-0.00038-6

Rodríguez, F. and Lukie Srdjan, W. S. (s. f.). *Rodriguez et al. US 8,011.461 B2*. USA. Doi: https://doi.org/10.1016/j.(73)

Ruan, J., Walker, P. D., Zhang, N. and Wu, J. (2017). An investigation of hybrid energy storage system in multi-speed electric vehicle. *Energy*, *140*, 291–306. Doi: https://doi.org/10.1016/j.energy.2017.08.119

Safari, M. (2018). Battery electric vehicles: Looking behind to move forward. *Energy Policy*, *115*(February 2017), 54–65. Doi: https://doi.org/10.1016/j.enpol.2017.12.053

Salman, M., Schouten, N. J. and Kheir, N. (2000). Control strategies for parallel hybrid vehicles. In *American Control Conference, 2000. Proceedings of the 2000* (vol. 1, pp. 524–528). Doi: https://doi.org/10.1109/acc.2000.878955

Shen, C., Shan, P. and Gao, T. (2011). A comprehensive overview of hybrid electric vehicles. *International Journal of Vehicular Technology*. Doi: https://doi.org/10.1155/2011/571683

Shunsuke, M. (2015). Analysis of Alternative Fuel Vehicles by Disaggregated Cost Benefit. *ResearchGate*, (March 29), 39.

Solouk, A., Shakiba-Herfeh, M., Arora, J. and Shahbakhti, M. (2018). Fuel consumption assessment of an electrified powertrain with a multi-mode high-efficiency engine in various levels of hybridization. *Energy Conversion and Management*, *155*(November 2017), 100–115. Doi: https://doi.org/10.1016/j.enconman.2017.10.073

Song, Z., Zhang, X., Li, J., Hofmann, H., Ouyang, M. and Du, J. (2018). Component sizing optimization of plug-in hybrid electric vehicles with the hybrid energy storage system. *Energy*, *144*, 393–403. Doi: https://doi.org/10.1016/j.energy.2017.12.009

Sreedhar, S., Siegel, J. B. and Choi, S. (2017). Topology Comparison for 48V Battery-Supercapacitor Hybrid Energy Storage System. *IFAC-PapersOnLine*, *50*(1), 4733–4738. Doi: https://doi.org/10.1016/j.ifacol.2017.08.864

Teixeira, A. C. R. and Sodré, J. R. (2018). Impacts of replacement of engine powered vehicles by electric vehicles on energy consumption and CO 2 emissions. *Transportation Research Part D: Transport and Environment*, *59*, 375–384. Doi: https://doi.org/10.1016/j.trd.2018.01.004

Tremblay, O., Dessaint, L. and Dekkiche, A. (2007). A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles. *2007 IEEE Vehicle Power and Propulsion Conference*, (V), 284–289. Doi: https://doi.org/10.1109/VPPC.2007.4544139

Trent James (2018). *Trent J. US 2018/0022200 A1*. USA.

Tribioli, L., Barbieri, M., Capata, R., Sciubba, E., Jannelli, E. and Bella, G. (2014). A real time energy management strategy for plug-in hybrid electric vehicles based on optimal control theory. *Energy Procedia*, *45*, 949–958. Doi: https://doi.org/10.1016/j.egypro.2014.01.100

Uthaichana, K., De Carlo, R., Bengea, S., Zefran, M. and Pekarek, S. (2011). Hybrid Optimal Theory and Predictive Control for Power Management in Hybrid Electric Vehicle. *Preprint, Appeared in Journal of Nonlinear Systems and Applications*, *2*(2), 96-110. Retrieved from http://dcdis001.watam.org/JNSA/volumes/abstract_pdf/2011v2/v2n1-pdf/12.pdf

Yan, F. Y. and Emadi, A. (2014). Internal Combustion Engines. In CRC Press (ed.), *Advanced*

Electric Drive Vehicles. Ontario Canada: CRC Press taylor & Francis Group.

Zing *et al*. (2018). *US 9,855,859 B2*. USA.

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