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A Review on Hybrid Electrical Vehicles: Architectures, Classification and Energy Management

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Abstract: The developing environmental effects caused by automobiles are increasingly becoming a pressing social concern. In order to address these challenges and prevent the adoption of less desirable alternative technologies, the automobile industry must implement and introduce Hybrid Electrical Vehicles (HEVs) and Electrical Vehicles (EVs). EVs enable us to achieve a completely clean service with a 100% cleanliness rating. However, it is constrained by infrastructure limits and faces challenges related to its limited driving range. In order to surmount this challenge, we require the implementation of a hybrid system. A HEV is an aesthetically pleasing alternative to the conventional Internal Combustion (IC) engine-powered vehicle system, effectively mitigating the issues arising from emissions. It offers an effective option for addressing infrastructure limitations and reducing operating expenses. HEV, short for hybrid electrical car, is a fusion of an internal combustion engine car and an electrical vehicle. While internal combustion engine vehicles are powered by fuel, electrical vehicles are propelled by an electric motor. In a HEV, the Electrical Motor (EM) is linked to a rechargeable battery pack, enabling electrical motor propulsion. Simultaneously, a HEV utilizes both engines to enhance power and torque, or alternatively, relies on either one depending on the driving conditions. This paper gives a review on hybrid electrical vehicles and explains architectures, classification and energy management.

Keywords: Hybrid Electrical Vehicles (HEVs), Battery Storage System, Energy Management Strategies.

1 Introduction

The increasing use and consumption of energy is a result of the ongoing development of the world economy, population growth, and improvements in people's quality of life. In addition, this will harm the environment and exacerbate global warming [1]. Since the start of the twenty-first century, most countries have been discussing the negative effects of global warming. Numerous pertinent studies have shown how aggressively human activity is causing climate change. Fossil fuel consumption for transportation has increased significantly as a result of global civilization and industrialization, contributing to air pollution and global warming [2]. Vehicles' exhaust emissions are the primary driver of greenhouse gas impacts. The primary emissions consist of Carbon Monoxide (CO) and Carbon Dioxide (CO_2). These factors are also the primary cause of lung cancer and other severe respiratory illnesses. The transportation sector consumes around 50% of global oil supplies, making it the primary cause of depletion in non-renewable energy sources. Hence, there is a pressing necessity to replace non-renewable energy sources and employ appropriate energy-conserving technology. Developing alternative energy sources is imperative in order to enhance heat energy conversion efficiency and address the issue of environmental pollution [3, 4]. Electrical Vehicles (EVs) have undergone a comprehensive examination and are seen as a potential remedy for environmental issues related to transportation [5]. The classification of electric EVs is based on their propulsion devices and power supplements. There are three types: (1) Pure Electrical Vehicle (PEV), or Battery Electrical Vehicle (BEV), (2) Hybrid Electrical Vehicle (HEV), and (3) Fuel Cell Electrical Vehicle (FCEV).

The PEV is powered completely by electrical energy from the power storage unit and is propelled only by an electrical motor. The operating mechanism of HEVs involves an EM and an IC engine, with electric energy from the battery system and gasoline or diesel serving as the power source. The FCEV utilizes an EM for propulsion and has the capability to be fueled by a fuel cell [6]. This review article focuses on providing concise explanations of different EVs, storage facilities, and the utilization of Photovoltaic (PV) systems for charging EVs,

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as well as other socio-technical challenges related to the widespread adoption of EVs. Additionally, the research explores the global potential of EVs. The increase in EV adoption is dependent on government policies that provide attractive incentives and advantages [7].

The escalating environmental repercussions caused by autos are increasingly becoming a pressing societal concern. In order to address these challenges and prevent the adoption of less desirable alternative technologies, the automobile industry must implement and introduce HEVs and EVs. EVs enable us to achieve a completely clean service with a 100% reduction in emissions. However, it is constrained by infrastructure limits and faces challenges related to its limited driving range. In order to surmount this challenge, we require a hybrid system. HEVs offer an aesthetically pleasing alternative to the conventional Internal Combustion Engine (ICE) vehicle system, thereby mitigating the issues associated with emissions. It offers an appropriate resolution for addressing infrastructural constraints and decreasing operational expenses. HEV, short for Hybrid Electrical Vehicle, is a vehicle that combines both an internal combustion engine and an electrical motor [7]. An IC engine car operates using gasoline, while an electrical vehicle is powered by an EM. In a HEV, the EM is linked to a rechargeable battery pack, enabling EM propulsion. Simultaneously, a HEV utilizes both engines to augment power and torque, or alternatively, can depend on either engine based on the driving conditions.
Table 1 illustrates the many categories of vehicles, providing a comparison. Table 2 outlines the benefits, drawbacks, and range of applications for each type of vehicle [8].

Table 1: Different types of vehicles—A comparison.

Type of vehicle	Drive unit	Energy sources	Energy supplements
PEV	Electrical motor	Battery source, ultra capacitor	Electrical energy from power system or battery
HEV	Electrical motor and IC Engine	Battery, ultra capacitor, IC engine	Gasoline station and electrical energy from power system or battery
FCEV	Electrical motor	Hydrogen and oxidizing agent	Fuel cells
ICEV	Internal combustion engine	Gasoline or diesel	Gasoline station

Table 2: Advantages, disadvantages and application range for different types of vehicles.

Type of vehicle	Advantage	Disadvantage	Application range
PEV	Pollution-free, low cost and need a special infrastructure for charging	Short driving distance and huge battery pack is needed	Suitable for low-speed and short-range community
HEV	Hybrid technology and Suitable to adopt in the current infrastructure itself	High cost	Meet out the daily needs. Suitable for high-speed and long-range community
FCEV	Advanced technology and need a special infrastructure	Costlier than PEV, HEV	Long-range and high-speed community. Provides more mileage compared with other types of vehicles
ICEV	Existing in more numbers, no need for special infrastructure	Burning of fuels leads to environmental pollution	Mostly used in all range vehicles and suitable for high speed to low speed

In this paper, section 2 explains the architecture of HEV, section 3 shows the classification of HEV, section 4 presents battery management system, section 5 introduces the energy management, and finally section 6 briefs the conclusion of the work.

2 Architecture of HEV

An HEV has essential elements such as an EM, battery, converter, ICE, gasoline tank, and control board. The components can be classified into three distinct groups:
1. Drivetrains involve the physical integration of the ICE power source and the electrical drive.
2. The Battery Energy Storage System (BESS) focuses on significant or moderate energy storage and power capacities.
3. The control system directs the electric systems and ICE and oversees the Hybrid Energy Storage System (HESS).
The integration of these components in various ways and sizes leads to diversity in vehicle design. Drivetrains primarily consist of series, parallel, and power split designs, which are determined by the integration of their components. The HEV architecture has been categorized into six distinct types in [8]: mild/micro-parallel, parallel, series, power split, mixed, and Through-The-Road (TTR) hybrids.

In the HEV series, the power sources supply electrical energy to the Direct Current (DC) bus, which is subsequently transformed into traction power [9]. In parallel HEVs, the traction power can be provided by either the ICE or the EM individually, or by both sources simultaneously. The EM technology is utilized to recharge the HESS through the process of regenerative braking [10]. The parallel mild HEV is an optimal choice due to its ability to strike a favorable balance between the vehicle's cost and its performance [11]. Advanced HEVs combine elements of both parallel and series architectures.
The complex hybrid differs from the series-parallel hybrid mainly in terms of the motor's power flow, which is bidirectional as opposed to the unidirectional power flow in series-parallel HEVs. The drawback of a complicated hybrid is its intricate design [11].

3 Classification of Hybrid Electric Vehicle

HEV is classified based upon the construction, hybridization and refueling methods.

A) Based on the structure

From Fig. 1, the HEV is further classified into three different categories. They are (i) series hybrid configuration, (ii) parallel hybrid configuration and (iii) series–parallel hybrid configuration [12].

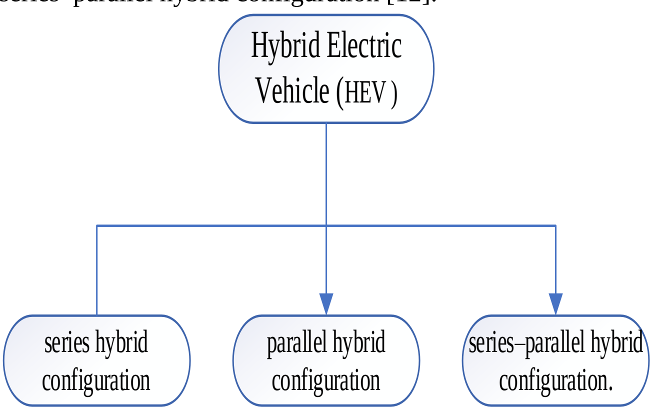

Fig. 1: Classification based upon the structure of HEV.

1) Series hybrid configuration

This particular vehicle is exclusively propelled by an electric motor. During regenerative braking, the motor functions as a generator. The power train design is simplified since the need for both a clutch and reduction gear is eliminated. By exclusively manipulating the electric motor, we have the ability to regulate both the velocity and the rotational force. In this setup, the primary function of the IC engine is to charge the battery using the generator and provide energy to the electrical motor, allowing for optimal efficiency. This is a strategy that contributes to enhancing overall efficiency. Hence, due to these factors, the series hybrid car is commonly referred to as an IC engine-assisted electric vehicle. An inherent limitation of this system is the requirement for a single internal combustion engine, generator, and motor [13].

2) Parallel hybrid configuration

In this particular HEV configuration, the vehicle's propulsion is achieved by the combined action of the ICE and the EM, resulting in the generation of torque. This technology allows for the independent utilization of the internal combustion engine and electric motor through the employment of two clutches. This design has higher dynamic performance compared to a series hybrid configuration. Parallel HEV refers to a type of vehicle that combines an internal combustion engine with an electric motor for assistance. The parallel hybrid design is most appropriate for the highest-priced car segment and the segment of cars that are fully hybrid. Parallel connection involves the simultaneous engagement of both electric motors and engines in the mechanical propulsion pathway. The engine efficiency and energy utilization are reduced due to the unmanageable velocity [14].

3) The series–parallel hybrid

The configuration of the system is a combination of both series and parallel hybrid setups, which is depicted by the representation. This setup will be more costly than the other two. It requires the installation of a planetary gear and an additional electrical generator. Automobile engineers like this model when aiming for fast cruising speeds and excellent dynamic performance [15].

B) Based upon the hybridization

The HEV is further classified into another three categories. They are (1) micro-hybrid, (2) mini hybrid and (3) full hybrid. The classification in question relies on the level of hybridization of HEV, as indicated in Fig. 2. Furthermore, it emphasizes the significance of the electric motor employed for vehicle propulsion. In a micro-hybrid system, an EM with a power output of around 2.5 kW and a voltage of 12V is utilized. This motor is mostly employed during start-and-stop conditions, making it particularly suitable for driving in urban areas or regions with heavy traffic. Thus, the EM is functioning as an auxiliary support for the ICE. The energy savings in this vehicle design amount to approximately 5–10%. It has the poorest economy, with a negligible impact on fossil fuel demands. A mild hybrid system utilizes an electric motor with a power output of approximately 10–20 kilowatts, operating at a voltage range of 100–200 volts. In this arrangement, the ICE and the EM propel the vehicle according to its current state (starting, stopping, accelerating, or decelerating). The energy savings in this vehicle design amount to approximately 20–30%. It offers somewhat favorable fuel efficiency in comparison to small hybrid vehicles. There are numerous commercial models available on the market that are based on this arrangement.

Despite its lower operational costs, this car is more expensive than the usual IC engine vehicle, which nonetheless draws a larger number of consumers. The full hybrid vehicle utilizes an electrical motor with an output of around 50 kilowatts, operating within a voltage range of 20 to 300 volts. The car can effectively operate the internal combustion engine by utilizing sophisticated control algorithms, activating it solely when necessary. Additionally, it channels the surplus energy towards the batteries. The energy efficiency of this model is around 30–50% higher compared to other models [16].

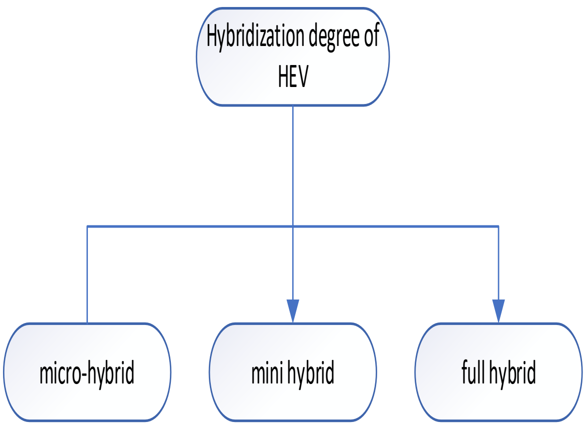

Fig. 2: Classification of HEV based upon hybridization.

C) Based upon the refuelling methods

In a similar way, the HEV can be further classified into two different categories. They are (i) plug-in HEV (PHEV) and (ii) Mild Hybrid Electrical Vehicle (MHEV). In a plug-in hybrid electrical vehicle (PHEV), the batteries can be charged from an external power source connected directly to the power grid. Various countries utilize different types of plugs for charging devices, depending on the available power source. MHEV does not include a plug-in option for recharging the batteries. The internal combustion engine is utilized for the purpose of recharging the batteries. Therefore, there is no requirement for any distinct charging stations for this particular kind of vehicle. However, when comparing MHEVs (mild hybrid electric vehicles) with PHEVs (plug-in hybrid electric vehicles), it is evident that PHEVs are more environmentally beneficial. Additionally, PHEV offers greater autonomy from fossil fuels [17].

4-Battery Management System

The role of Battery Management System (BMS) is to monitor the voltage and current of each cell, the State of Charge (SOC), provide on-off signals for safety devices, send battery status and diagnostic data to the PC and offer on-off signals for heating and cooling elements. The operations of BMS are depicted in Fig. 3.

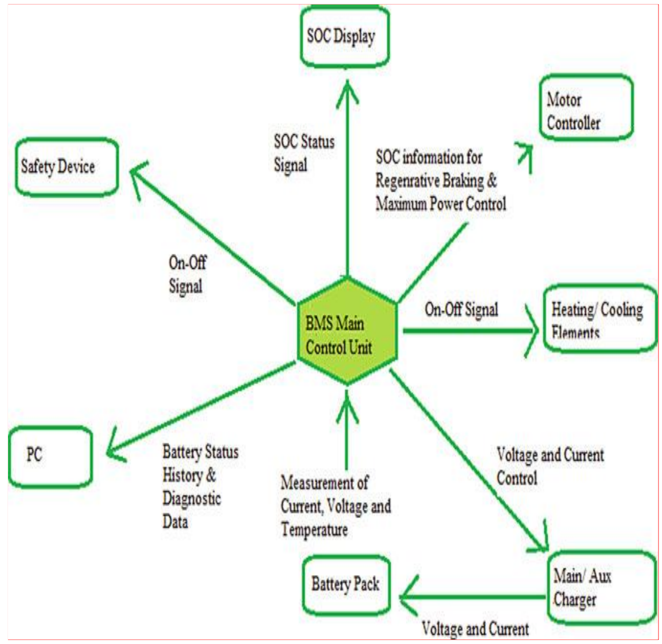

Fig. 3: Functions of battery management system.

The literature presents different approaches for battery charging, including the Constant Current (CC) method, the Constant Voltage (CV) method, and the Constant Current-Constant Voltage (CCCV) method. In the CC approach, the current is consistently maintained at an identical amount across all batteries that are linked in series. As the SOC increases, the batteries' internal resistance likewise tends to increase. In order to keep a consistent charging rate, it is necessary to increase the voltage [18]. Prudent consideration must be given to the choice of charging current, as an excessively high value might expedite battery charging but also risk overcharging and overheating. In the CV charging method, a higher current can be pulled due to the battery's lower initial resistance. Once the float voltage is reached, which is a secure voltage level, there is a progressive decline in the current value. As the SOC of the battery increases, the resistance of the battery likewise increases, resulting in a decrease in the current drawn by the battery [19]. In the CCCV charging method, the issue of overcharging or excessively draining voltage from the batteries is prevented by utilizing a constant-current charging approach until the battery hits a specific threshold. Subsequently, the constant voltage technique is prolonged [20].

After usage, the EV's battery should be charged. With the increasing of the individual battery rating and number of EV, the charging load cannot afford to be neglected from the grid point of view. From the standards, the EV/PHEV charging methods can be divided into three categories, listed in Table 3 [21].

Table 3: Charging modes of EV/PHEV.

Type	KVA	Charging time	Charging method
Slow/Normal	1–5	6 h	AC: 1 phase, 230 V, 16/32 A
Semi-fast/Medium	10–25	1–3 h	AC: 3 phase, 230 V, 32/63 A
Fast	180–400	5–15 min	Undetermined, DC off-board charging

While Alternating Current (AC) charging requires on-board power electronics, Direct Current (DC) also allows for off-board charging. On-board chargers (OBCs) are constrained in their size, and therefore their charging capacity, due to weight, cost, and space restrictions. Off-board Chargers (OfBCs) are less limited in terms of size and weight and thus allow for higher charging capacities. OfBCs are currently the standard for all charging capacities greater than 22 kW.

Life Cycle Assessments (LCAs) have been intensively used in the literature to estimate the environmental impact of electric vehicles compared to fuel-based vehicles. The potential of DC-based off-board charging technology to reduce the environmental impact and costs of charging technologies for EVs. A comparative LCA for both charging technologies: AC-based on-board charging and DC-based off-board charging. Further, we assess the systemic impact when up scaling the systems (i.e., larger vehicle stock, more charging infrastructure) as well as the potential cost savings that come with OfBCs within different scenarios [22-25].

5 Energy Management

A) Energy Management of Hybrid Electric Vehicles

Controlling a HEV involves primarily two distinct sets of duties. The low-level or component-level control challenge involves the use of classical feedback control methods to individually control each powertrain component. The second responsibility, known as high-level or supervisory control, aims to optimize the energy distribution within the vehicle while ensuring that the battery's state of charge remains within a specific operational range. The Energy Management System (EMS) is responsible for receiving and analyzing data from both the vehicle and the driver. It then generates the most efficient set-points, which are communicated to the actuators and carried out by the low-level control layer. The EMS also determines the optimal operational modes of the hybrid powertrain, such as start-stop, power split, and electric launch. The control scheme of a HEV that consisting of two tasks, as illustrated in Fig. 4 [26].

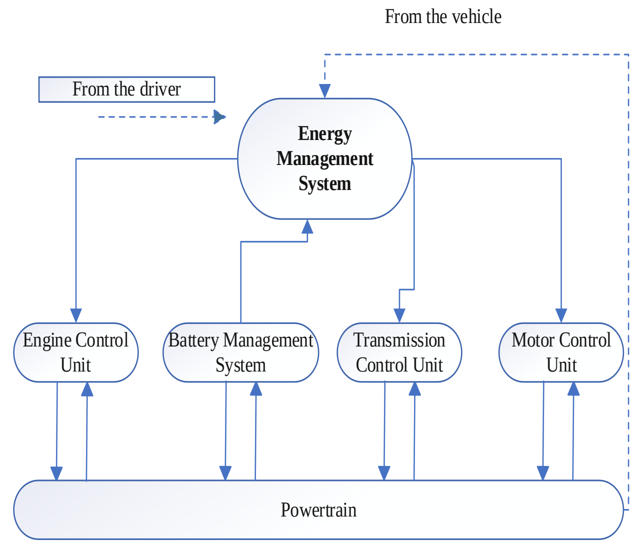

Fig. 4: control scheme of an HEV.

The attainable enhancement in fuel efficiency for HEVs varies from 10% for mild hybrids to over 30% for full hybrid vehicles [27]. Realizing this potential requires a sophisticated control system that efficiently manages the flow of energy within the vehicle. The application of systematic model-based optimization methods, utilizing meaningful objective functions, has been acknowledged as the most effective approach to attain near-optimal results in developing the vehicle EMS [28].

B) Classification of Energy Management Strategies

Multiple energy management solutions have been suggested in the literature.

There are two main approaches to addressing the energy management problem: rule-based and model-based optimization methods [29].

Rule-based techniques are particularly successful when implemented in real-time. These methods do not require explicit minimization or optimization. Instead, they rely on a predefined set of rules to determine the appropriate value of the control to be applied at each time step. Rules are typically formulated using heuristics [30], intuition, or derived from the knowledge of the best global solutions obtained using mathematical models and optimization techniques [31–33].

Model-based optimization procedures involve calculating the ideal actuator set-points by minimizing a cost function during a predetermined and well-defined driving cycle, resulting in a globally optimal solution. This results in a noncausal solution as it determines the minimal value of the cost function by utilizing future driving information. Model-based optimization control approaches are not suitable for real-time implementation or practical application due to their predictive nature and computational complexity. However, they are still helpful as a design tool. Indeed, they can be employed to establish guidelines for online implementation or utilized as a standard solution to assess the effectiveness of alternative management measures. Model-based optimization methods can be categorized into two types: numerical approaches and analytical approaches. Numerical optimization approaches, such as dynamic programming [34, 35], simulated annealing [36], genetic algorithms [37], and stochastic dynamic programming [38, 39], consider the complete driving cycle and determine the global optimum using numerical calculations. Analytical optimization approaches employ a problem formulation that is analytical in nature to obtain the answer in a closed, analytical form. Alternatively, these methods may offer an analytical formulation that accelerates the numerical solution compared to purely numerical methods. Out of these strategies, Pontryagin's minimum principle [40] holds the most significance. The equivalent consumption minimization approach is likewise classified in this category as it involves minimizing a suitably defined instantaneous cost function at each time step of the optimization horizon. Ultimately, this results in a reduction of the overall cost function, assuming that the immediate cost function (comparable to immediate gasoline use) is appropriately defined. Alternative model-based techniques incorporate knowledge about future driving circumstances in addition to past and current information. This is achieved through the utilization of a receding-horizon optimization strategy [41–42].

6 Conclusion

HEVs are quickly becoming a viable alternative to current transportation methods since they consume less petroleum and produce fewer hazardous emissions. The future of road transport will be driven by the combination of strict CO_2 emission regulations and heightened public awareness, leading to the prominence of HEVs. The market penetration of PHEVs would significantly alter the functioning of the electric grid, prompting initiatives to establish a bidirectional communication system between users and the grid. EMS architectures, like the one suggested, utilizing multi-agent system technology, can efficiently address significant network operation challenges. Furthermore, the implementation of advanced tools that can synchronize EV charging with other available flexibility resources on distribution networks might greatly enhance the accessibility of the auxiliary services market for aggregators.

References

[1]. C. Zhang, Q.X. Zeng, H. Zhu, Review on development of hybrid electric vehicles. Mech. Eng. Autom. 2, 95, 2016.

[2]. A. Emadi, Handbook of Automotive Power Electronics and Motor Drives (CRC press, 2017)

[3]. Wang, Haomiao, et al. "Overview of hybrid electric vehicle trend." AIP Conference Proceedings. Vol. 1955. No. 1. AIP Publishing, 2018.

[4]. Li, Xuefang, and Simos A. Evangelou. "Torque-leveling threshold-changing rule-based control for parallel hybrid electric vehicles." IEEE Transactions on Vehicular Technology 68.7 : 6509-6523, 2019.

[5]. J.Y. Yong, V.K. Ramachandaramurthy, K.M. Tan, N. Mithulananthan, A review on the stateof- the-art technologies of electric vehicle, its impacts and prospects. Renew. Sustain. Energy Rev. 49, 365–385, 2015.

[6]. M.A. Hannan, F.A. Azidin, A. Mohamed, Hybrid electric vehicles and their challenges: a review. Renew. Sustain. Energy Rev. 29, 135–150, 2014.

[7]. Y. Chao,M. Zha,W.Wang, K. Liu, C. Xiang, Efficient energy management strategy for hybrid electric vehicles/plug-in hybrid electric vehicles: review and recent advances under intelligent transportation system. IET Intell. Transp. Syst. 14 (7), 702–711, 2020.

[8]. Raduenz, Henrique. "On machine learning-based control for energy management in construction machines." Linköping University Electronic Press, 2022.

[9]. Dathu, K. P. M. Y. V., and R. Hariharan. "Modelling of plug-in hybrid electric vehicle (PHEV) with multi source." Materials Today: Proceedings 44: 4020-4023, 2021.

[10]. İnci, Mustafa, et al. "A review and research on fuel cell electric vehicles: Topologies, power electronic converters, energy management methods, technical challenges, marketing and future aspects." Renewable and Sustainable Energy Reviews 137: 110648, 2021.

[11]. Babu A, Ashok S, "Parallel mild hybrid equivalent to the Tata Safari. In: Proc IEEE int. conf. technol. Adv. power energy (TAP energy), pp 506–510, 2015.

[12]. C. Zhang, Q.X. Zeng, H. Zhu, Review on development of hybrid electric vehicles. Mech. Eng. Autom. 2, 95, 2016.

[13]. J.Y. Yong, V.K. Ramachandaramurthy, K.M. Tan, N. Mithulananthan, A review on the stateof- the-art technologies of electric vehicle, its impacts and prospects. Renew. Sustain. Energy Rev. 49, 365–385, 2015.

[14]. Y. Chao,M. Zha,W.Wang, K. Liu, C. Xiang, Efficient energy management strategy for hybrid electric vehicles/plug-in hybrid electric vehicles: review and recent advances under intelligent transportation system. IET Intell. Transp. Syst. 14(7), 702–711, 2020.

[15]. Zhang, Lei, et al. "Hybrid electrochemical energy storage systems: An overview for smart grid and electrified vehicle applications." Renewable and Sustainable Energy Reviews 139: 110581, 2021.

[16]. Ghosh, Aritra, Possibilities and challenges for the inclusion of the electric vehicle (EV) to reduce the carbon footprint in the transport sector: a review. Energies 13(10), 2602, 2020.

[17]. F. Zhang, L.Wang, S. Coskun, H. Pang, Y. Cui, J. Xi, Energy management strategies for hybrid electric vehicles: review classification, comparison, and outlook. Energies 13 (13), 3352, 2020.

[18]. Yu, Hang, et al. "Electric vehicles integration and vehicle-to-grid operation in active distribution grids: A comprehensive review on power architectures, grid connection standards and typical applications." Renewable and Sustainable Energy Reviews 168: 112812, 2022.

[19]. F. Ahmad, M.S. Alam, M. Asaad, Developments in EVs charging infrastructure and energy management system for smart microgrids including EVs. Sustain. Cities Soc. 35, 552–564, 2017.

[20]. F.Mwasilu, J.J. Justo, F.K. Kim,T.D. Do, J.W. Jung, Electric vehicles and smart grid interaction: a review on vehicle to

grid and renewable energy sources integration. Renew. Sustain. Energy Rev. 34, 501–516, 2014.

[21]. Malviya, Gajendra, Bharat Nandan, and Himanshu J. Bahirat. "Analysis of Impact of Electric Vehicles Penetration on Indian Distribution Network." ISUW 2019: Proceedings of the 5th International Conference and Exhibition on Smart Grids and Smart Cities. Springer Singapore, 2022.

[22]. Hawkins, T.R.; Singh, B.; Majeau-Bettez, G.; Strømman, A.H. Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. J. Ind. Ecol. 17, 53–64, 2012.

[23]. Nordelöf, A.; Messagie, M.; Tillman, A.-M.; Söderman, M.L.; Van Mierlo, J. Environmental impacts of hybrid, plug-in hybrid, and battery electric vehicles—What can we learn from life cycle assessment?, Int. J. Life Cycle Assess. 2014, 19, 1866–1890.

[24]. Tintelecan, A.; Dobra, A.C.; Marțiș, C. Literature Review—Electric Vehicles Life Cycle Assessment. In Proceedings of the 2020 ELEKTRO, Taormina, Italy, 23 March 2020; pp. 1–6.

[25]. Zhang, Z.; Sun, X.; Ding, N.; Yang, J. Life cycle environmental assessment of charging infrastructure for electric vehicles in China. J. Clean. Prod. 2019, 227, 932–941.

[26]. Verbruggen, Frans, et al. "Joint design and control of electric vehicle propulsion systems." 2020 European Control Conference (ECC). IEEE, 2020.

[27]. Guanetti, Jacopo, Yeojun Kim, and Francesco Borrelli. "Control of connected and automated vehicles: State of the art and future challenges." Annual reviews in control, 45 : 18-40, 2018.

[28]. Li, Zhenhe, Amir Khajepour, and Jinchun Song. "A comprehensive review of the key technologies for pure electric vehicles." Energy, 182 : 824-839, 2019.

[29]. S. Onori, in Model-Based Optimal Energy Management Strategies forHybrid Electric Vehicles, ed. by H. Waschl, I. Kolmanovsky, M. Steinbuch, L. del Re. Lecture Notes in Control and Information Sciences, vol. 455 (Springer, New York, 2014), pp. 199–218, 2014

[30]. Huang, Yanjun, et al. "Model predictive control power management strategies for HEVs: A review." Journal of Power Sources, 341: 91-106, 2017.

[31]. Enang, Wisdom, and Chris Bannister. "Modelling and control of hybrid electric vehicles (A comprehensive review)." Renewable and Sustainable Energy Reviews 74: 1210-1239, 2017.

[32]. Wei, Caiyang, et al. "A review of the integrated design and control of electrified vehicles." Energies, 13.20: 5454, 2020.

[33]. R. Biasini, S. Onori, G. Rizzoni, A rule-based energy management strategy for hybrid medium duty truck. Int. J. Powertrains 2(2/3), 232–261, 2013.

[34]. Yadav, Kusum. "Design, Optimization and Performance Analysis of Microgrids Using Multi-agent Q-Learning." Data Analytics for Smart Grids Applications—A Key to Smart City Development. Cham: Springer Nature Switzerland, pp 15-24, 2023.

[35]. Alsharif, Abdulgader, et al. "A comprehensive review of energy management strategy in Vehicle-to-Grid technology integrated with renewable energy sources." Sustainable Energy Technologies and Assessments, 47: 101439, 2021.

[36]. Tran, Dai-Duong, et al. "Thorough state-of-the-art analysis of electric and hybrid vehicle powertrains: Topologies and integrated energy management strategies." Renewable and Sustainable Energy Reviews 119: 109596, 2020.

[37]. Saiteja, Pemmareddy, and B. Ashok. "Critical review on structural architecture, energy control strategies and development process towards optimal energy management in hybrid vehicles." Renewable and Sustainable Energy Reviews, 157: 112038, 2022.

[38]. Dong, Peng, et al. "Practical application of energy management strategy for hybrid electric vehicles based on intelligent and connected technologies: Development stages, challenges, and future trends." Renewable and Sustainable Energy Reviews, 170: 112947, 2022.

[39]. Bêkir, Wissem, Lilia El Amraoui, and Frédéric Gillon. "Optimal Energy Control applied to an Hybrid Stepper Motor." 2019 19th International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering (ISEF). IEEE, 2019.

[40]. Romijn, T. Constantijn J., et al. "A distributed optimization approach for complete vehicle energy management." IEEE Transactions on Control Systems Technology, 27.3: 964-980, 2018.

[41]. Wu, Jinglai, et al. "An optimized real-time energy management strategy for the power-split hybrid electric vehicles." IEEE Transactions on Control Systems Technology, 27.3: 1194-1202, 2018.

[42]. Wu, Yuankai, et al. "Deep reinforcement learning of energy management with continuous control strategy and traffic information for a series-parallel plug-in hybrid electric bus." Applied energy, 247: 454-466, 2019.