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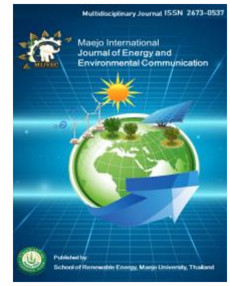

**ARTICLE**

# A comprehensive review of electric vehicle energy management techniques, optimizations, and controllers

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ABSTRACT

The terrible impact of environmental pollution and the greatest deficiency of fossil fuels, the development of electric vehicles (EVs) are alternatives to minimize the greenhouse gas emission and protect the environmental circumstances. Since most of the EVs are driven by energy storage sources (ESS), numerous researchers have conducted many investigations to ascertain the potentiality of ESS-based EVs. Nonetheless, the demand of end users is to enhance the lifetime of battery and reduce the consumption of hydrogen. Hence, advanced and newly designed control strategies are required for enriching the efficiency of the EVs with energy management systems (EMS). This work presents a state-of-the-art of various types of vehicles including ICE type, hybrid EVs, and all types EVs. The EMS strategies such as battery, ultra-capacitor (UC), flywheel energy storage (FES), fuel-cell, and hybrid energy storages are addressed in this work. Furthermore, different types of optimization methods are highlighted for solving the limitations and improving the performance of EVs in future. Diverse control techniques namely, classical controllers, fuzzy logic controller (FLC), model predictive control (MPC), and operational mode/state machine. Finally, this article provides a thorough analysis of these studies and makes recommendations for new researchers on how to proceed with their study in the future.

## 1. Introduction

In recent years, the greatest achievement in the automotive field is to move vehicles by electrification with the assistance of various energy management devices (Das et al., 2020; Cao et al., 2020; Solanke et al., 2020). Across the world, greenhouse gases (GHG) are uninterruptedly emitted by the transportation sector in this world. Besides, traditional vehicles operate through internal combustion engines (ICE) from various fossil fuels, such as diesel and gas. These fossil fuels release many gases namely, nitrogen oxides, hydrocarbons, carbon dioxide, carbon monoxide, etc. Since

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making substantial changes in the automotive field with electrification, it reduces the usage of fossil fuels and preserve the environmental conditions (Shi et al., 2020; Deng et al., 2020).

Diverse types of energy vehicles endure to be an optimistic and real-time solution for the forthcoming environmental and social obstacles. Regarding this, Electric vehicles (EVs) has attained an immense recognition from the past ten years, and have been the best solution for the GHG (Xu et al., 2021; Asadi et al., 2021). EVs are not only contributing to a fresher and quieter environment but also minimizing the operating cost dramatically as compared with the traditional vehicles. By owning the EVs, people can charge their vehicles at night and save approximately 15 hr/year at gas filling stations. Different energy management strategies such as batteries (Lipu et al., 2021), solar panel (Ghasemi-Marzbali, 2023), fuel cells (FCs) (Sun et al., 2023), super-capacitor (SC) (Çorapsiz & Kahveci, 2023), regenerative braking (Tummuru & Misra, 2023) and other appropriate energy generators (Amry et al., 2023; Rahman et al., 2023) are incorporated into the EVs. In addition to battery electric vehicles (BEVs), the BEVs are completely operates on electrification from battery and provides zero GHG emissions (Dutta et al., 2023). Nonetheless, the electricity is mostly generated by thermal plants, hence, the BEVs are not still solely alleviating the GHG emissions. Furthermore, the limitations of the BEVs are huge time for battery charging, driving range is very less, and scarcity of charging availability (Kumar et al., 2018; Gao et al., 2023).

Therefore, many researchers and manufactures in recent years focused on the fuel cell based electric vehicles (FCEVs) (M. A. Rahman et al., 2022; Rai & Pramanik, 2022). Regarding FCEVs, it can be operated by electric motors, which are fed with electricity from FC. The main energy mover in the FCEVs is hydrogen blended with oxygen from air. Moreover, many automobile industries have shown increased interest in EVs with the breakthrough of FCs. Though the FC based EVs run by electric motors fed with electricity from FC, the FCs still have their own demerits (Wei et al., 2023; H. Sun et al., 2020; Enescu et al., 2023). It has low power density and the maximum efficiency of FC is 60 % approximately. The infrastructure of hydrogen refueling is not available frequently and is more expensive.

Further, startup device is required to hybrid electric vehicles (HEV) when the FC is used as individual energy feeder (C. Zhang et al., 2020). Consequently, the automotive industries introduced the FC-based HEVs. These vehicles are amalgamated with FC and battery or FC and super capacitor (SC) (Park & Roh, 2023). The hybrid vehicles are Chevrolet volt by General Motors, Honda FCX by Honda, Mercedes Benz F-Cell by Daimler and Toyota FCHV by Toyota, which are integrated with FC and battery system. The necessary energy is required to supply for FCHEVs changes between battery system and FC, so needs a reliable and an effective energy management system (EMS).

The EMS can divide the electrical power between battery system and FC based on mode of operation of vehicle. Some researchers (Prasanthi et al., 2022; Tahri et al., 2018) are implemented the buck-boost DC to DC converters for hybrid vehicles in the presence of FC and SC. Hence, the power is divided effectively between FC and SC for satisfying the required load demand. A considerable amount of literature has been published on HEVs with diverse topologies like FC and SC, FC and 13 HP, FC and 0.45 UHP, and several EMS approaches (optimal FC power, frequency division). These studies show that the combination of FC and 13 HP, optimal FC power approaches yields better enhancement over other studied strategies with respect to consumption of hydrogen, weight, and volume. Nevertheless, these investigations are restricted to only effects the secondary source topologies and EMS methods towards sizing of FC-based hybrid vehicles. Many researchers (Xu et al., 2023; Çorapsiz & Kahveci, 2023) have examined the EMS approaches in HEVs. Moreover, modeled several methods and tested practically for validating the power division methods. Nonetheless, power division alone is not enough as per current state. Since hydrogen energy is not easy to generate and deposit, end users are required to use the productive system for optimizing the use of hydrogen fuel.

Subsequently, EVs, mostly plug in hybrid electric vehicle (PHEV) and battery electric vehicle (BEV), needs energy storage charging unit absolutely that makes a new challenge to interconnected utility grid (Padmanabhan et al., 2022; Khalid et al., 2019). Since the vehicle absorbed the energy when it's in transportation, it has changed from the traditional ICE into charging energy storage devices. Therefore, it may directly affect the utility gird electricity consumption. In recent years, a large and growing body of literature has been investigated with renewable/distributed energy sources for sustaining the required load demand (Dauda & Panda, 2023; Mamun et al., 2022). Regarding these renewable and distributed energy sources, it assists to minimize the peak demand at critical hours of power utilization, as well as very favorable the supply-side management as a result of the requirement of EV charging. So far, however, there has not been much discussion about renewable/sustainable/distributed energy sources for EVs. So, it is required to be conducted the deepest research for EVs with diverse energy sources.

Some researchers (Wang et al., 2023; Iacobucci et al., 2019) are implemented the vehicle-to-grid (V2G) system, however, these studies are rare to find in literature. It is the reverse mechanism for charging the vehicle and was suggested in recent years by researchers. Maximum number of vehicles are halted or parked, and the vehicle is connected to the utility grid as recorded in literature. During the reverse mechanism, great potential of energy is exported back to the utility grid when the peak power the demand. The objective of the present work paper is to review the state-of-the-art of the acquirable energy generators for EVs, usage of power electronic devices, diverse types of energy management strategies (EMS), various kinds of newly developed optimization methods. Furthermore, privileges and demerits of various approaches will be clearly addressed in this work. In this study, the performance of renewable/sustainable/distributed energy sources for EVs will be discussed briefly.

## 2. Types of vehicles

The vehicles can be divided into three types such as internal combustion engine (ICE) type, HEVs, and all types of EVs. The structure of the three types of vehicles are demonstrated in Figure 1. The following subsections clearly represent the detailed discussion of each vehicle.

### *2.1 ICE type vehicle*

It has a combustion chamber for converting the chemical energy into heat and kinetic energy (K.E) for propelling the vehicle (Ye et al., 2023; Pielecha et al., 2023). In fact, two types of ICE vehicle are available namely, traditional ICE and micro-hybrid electric vehicles (µ-HEV). The traditional ICE vehicles do not have any electric motor (EM) for assisting and obtaining the adorable fuel economy. On the other hand, the µ-HEV

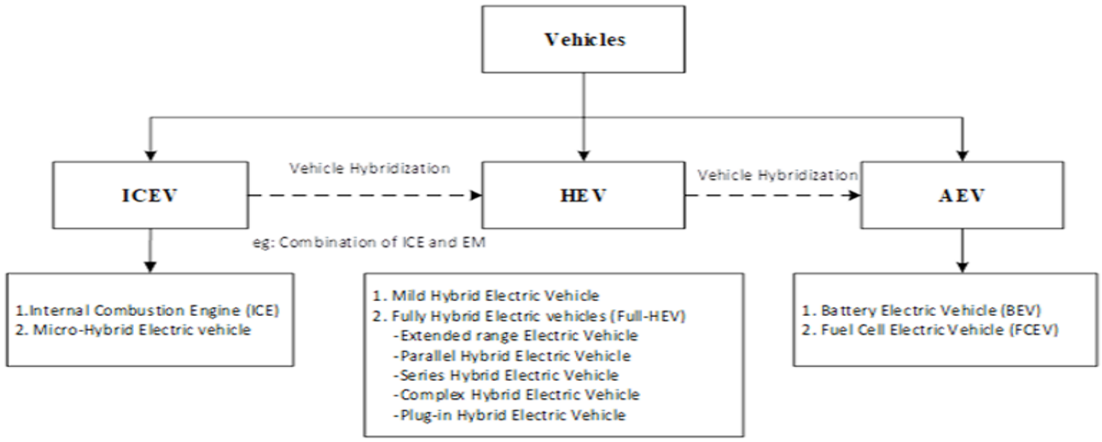


**Figure 1** The structure of the three types of vehicles.

does have EM with less operating voltage profile (12 or 14 V) and requires the less power (<5 kW) to restart the ICE from off-state without providing any supplementary power to move the vehicle.

### *2.2 HEV type*

In this, the coordination of ICE and EM is used as power sources for propelling the vehicle. In recent years, six types of drive train transactions are developed to the HEV (Liu et al., 2023; Lampon, 2023), which are illustrated in Figure 2. Regarding these six types, the mild-HEV has the great privileges like µ-HEV, however, mild-HEV requires 7-12 kW power and 150 V operating voltage (Cardoso et al., 2020; Benajes et al., 2019). The mild-HEV is not propel zwithout assist of ICE as a result of both are shared the same shaft and can be shown in Figure 2 (a). The configuration of mild-HEV is appropriate to improve the fuel efficiency up to 30 % as well as minimize the ICE size. Some examples of mild-HEVs are Honda Civic/Accord, GMC Sierra pickup, Saturn Vue. Nowadays, most of the car manufacture units need to contribute full type HEV because of it utilize of divide the power track for either driving on only ICE or motor or both. The full type HEV can save 40 % of fuel. Typically, this kind of HEV has a huge capacity of energy storage system (ESS) and operates at 288-330 V voltage range.

Besides, the full type HEV can be separated as extended range EV (EREV) or series full type HEV (Benevieri et al., 2021; García et al., 2020), which are represented in Figure 2 (b). Further, other types of HEVs such as parallel full type HEV (Lee & Shim, 2022), combination of series and parallel full type HEV (Xu et al., 2022), complex full type HEV (Pathak et al., 2022), plug-in-hybrid electric vehicle (PHEV) (Abd-Elhaleem et al., 2023) are demonstrated in Figure 2 (c)-(f) respectively. For EREV, the EM utilizes individual propulsion power like battery-based electric vehicle (BEV). Nonetheless, the disparity is they have great efficiency and high performance of generator for recharging in the event of batteries are low. In the present market, Chevrolet volt is one of the EREV-based vehicles, which is identified as the series full type HEV. The greatest benefit of this configuration is that the vehicle has the battery, and it may decrease the burden on generator supply and fuel capacity. It can be minimized the total vehicle efficiency about to 25.8 %. And, compared to all other full-type HEVs, this is the lowest.

Nevertheless, it is more appropriate in stop/run city driving pattern thus, it might conserve and store regenerative braking's energy for the ESS. According to the typical framework in Figure 2(c)-(e), parallel full HEV can increase the total HEV efficiency to 43.4% by using two propulsion powers (ICE and EM) in a mechanical coupler. In contrast, parallel full-HEV has a lower battery capacity. The EM and ICE work best together during driving, which is one of the benefits of full-HEV running in parallel. The parallel full-HEV is therefore a more intriguing car for both highway and city driving (H. Wang et al., 2023). Parallel full-HEV is more efficient than series full-HEV because its EM and batteries are smaller. Two mechanical and electrically powered power couplers are used in the series-parallel full-HEV drive system (Ahmadian et al., 2023). Despite having the benefits of both parallel and series full-HEV, it is comparatively more expensive and complex. Series-parallel hybrid appears to be a configuration identical to complex hybrid. However, the power converter is incorporated with the motor/generator and drive, which is the primary distinction. In comparison to series-parallel full-HEV, complicated full-HEV is more reliable and controllable. Additionally, the PHEV is like a full-HEV, but the battery system must be connected to the grid. As consider Figure 2(f), the PHEV is directly transmuting from series-parallel HEV by connecting charger beside battery (Williamson & Williamson, 2013).

### *2.3 All types of EVs*

All types of EVs can be moved by appropriate power sources. These vehicles have 6 types of power structures for moving and are illustrated in Figure 2. In Figure 2(a), it has been directly transmuted from a traditional ICE vehicle with proper energy storage device. Moreover, the drive train system designing is same for battery and fuel-based EVs (Chen et al., 2023). When consider Figure 2(b), it consists of a fixed gear box without need of clutch for minimizing the weight and size. Further to bring changes in structure of EVs, distinct types of differential and gearing systems are used for drive shafts to run the vehicle at different speeds (Mathur et al., 2021). Those structures are illustrated in Figure 2(c) and Figure 2(d). Nevertheless, Figure 2(e) is comprised of a motor and fixed gearing system without requires of drive shaft. The traction motor is inserted in a wheel for driving and has more reliable than other vehicles, and represented in Figure 2(f) (Chen et al., 2023). Nonetheless, this type of structure needs a huge torque-based motor for accelerating. Besides, the efficiency of this type of vehicle is not much better due to huge losses by high currents in motor windings.

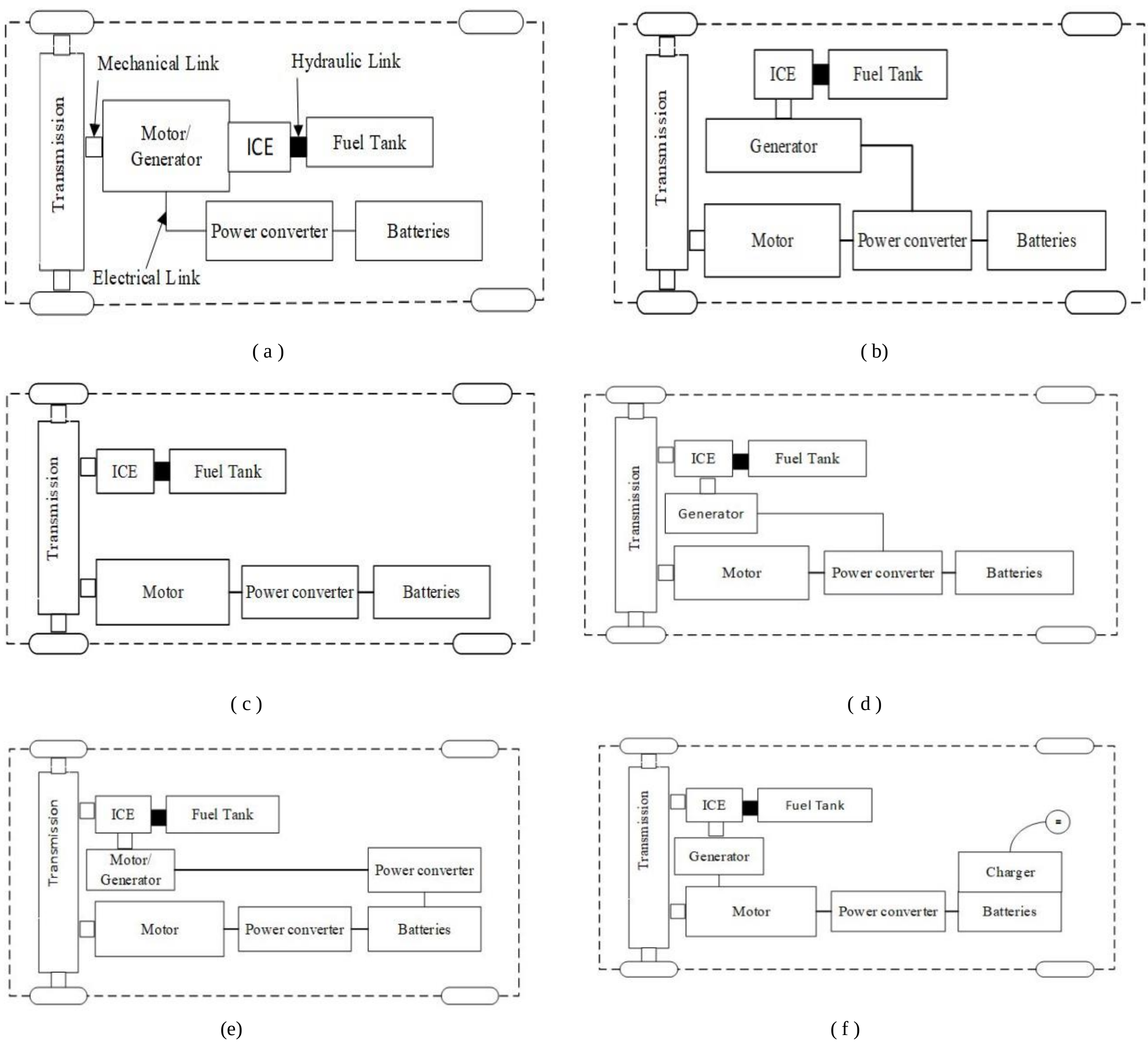


**Figure 2:** Topologies of six types of drive train transactions

## 3. Various Energy Management Devices (EMDs)

The energy storage units perform a significant and prominent role in electrical vehicles for reliable and effective operation. Over the decades, numerous examinations have been conducted by several researchers for incorporating diverse EMDs to the EVs for successful running. The energy storage units are battery, flywheel, ultra-capacitor (UC), hydrogen tank, fuel cell, and other hybrid sources. These units are used as auxiliary energy sources for EVs. In this section, briefly described all energy storage units and their performance in the EVs.

***3.1 Battery***

In real time applications, mostly used energy storage unit is battery. It consists of one or many electrochemical cells, which can transmit chemical energy into electrical energy. The greatest attribute of the battery is measuring in Ah (ampere-hour). The state-of-charge of battery is represented in percentage (%), which shows the present charging status of battery. In recent years, different types of batteries such as lead-acid, nickel-battery, zero emissions batteries, lithium-battery, and zinc-air battery are available in the automotive industry (Padmanaban et al., 2023; Ghazizadeh et al., 2023). In addition to lead-acid batteries, it is utilized in the traditional ICE vehicles and the cost is low. However, it affects the environmental circumstances due to the generation/disposal process. Another battery is nickel-zinc, it is very adaptable to environmental conditions, however, it has a very small life cycle. The major drawback of this battery is to have more weight, huge cost for maintenance, and high self-discharge capacity.

Regarding a zero emission battery, it is consisted by sodium nickel chloride (NaNiCl) and has huge temperature attribute around 300 to 350 0C (Gilbert Zequera et al., 2023). For an effective and efficient operation, high temperature-based technologies are suitable. However, this battery has a short life span as compared with lead-acid batteries. Another demerit of this battery is easily loss 90 W energy even if it is not in progress. One of the promising energy storage technologies is the lithium battery and very competitive nature in vehicle applications as a result of having high energy and power densities. They have good life cycle than other studied batteries (Philippot et al., 2023; Tian et al., 2023). Nevertheless, it needs more cost for lithium metal than nickel batteries. With regards to zinc-air battery, it is another trustable energy storage unit (Tran et al., 2021). As compared to lithium batteries, it has great particular energy and energy densities. Nonetheless, the demerit of this battery is to have less specific power and short life cycle. Presently, many researchers are still continuing their investigations on lithium batteries and have not been commercialized yet. It will greatly affect all EVs because lithium-air batteries have a higher energy density than zinc-air batteries.

***3.2 Ultra-capacitor (UC)***

The UC is also called as super-capacitor (SC), it works as normal capacitor. However, the dissimilarity is that the UC has a high storing capacity over normal capacitors. The attributes of the UC are requiring less maintenance, high span life and does not vary with atmospheric conditions. Furthermore, the UC can ensure the rapid burst of powers with finer performance. It can charge or discharge at high currents (Mohammed et al., 2023). The cell voltage and charge times are 2.3 to 2.75 V and 1 to 10 S respectively. The specific energy and power are 5 Wh/kg and 10000 Wh/kg respectively. The life cycle of UC is around 10 to 15 years. The drawbacks of the UC are low cell voltage needs series connections for sustaining the required voltage, the specific energy is low, cost is very high per watt, and have high self-discharge capability.

***3.3 Flywheel Energy Storage (FES)***

The FES is utilized for storing/sustaining kinetic energy (K.E) through rotor or flywheel rotations. It has two technologies such as the K.E and electrical energy. Energy economy from braking to the FES is 70%. The sustainable energy is transmuted into electrical energy from braking and then ensure to the FES (Mehraban et al., 2023; Krishna et al., 2023). Since vacuums and magnetic-based bearing are utilized, the mechanical and round-trip efficiencies of the FES can be increased up to 97 % and 85 % respectively. Recently, researchers have been showing an increased interest in extending the attributes of the FES for EVs. Recent developments in the field of the FES have led to a renewed interest in developing reliable/an effective EVs for uninterrupted transportation. Nonetheless, the demerits of the FES are not having assured safety measures and having the pressure of gyroscopic. The privileges of the FES are having long lifetime (> 15 years), requires low cost for maintenance, needs less time for charging which are very significant to electrical vehicles.

***3.4 Fuel-cell***

Over the years, researchers have shown an increased interest in the automotive industry with newly designed energy storage technologies. Among these, full cell based EVs perform a prominent role in the transportation industry. Full cell based EVs would move by electric motors that are fed with FC generated electricity. Hydrogen amalgamated oxygen (from air) is the phenomenal factor in the Full cell based EVs. In recent years, there has been an increasing amount of literature on FC-based EVs (Huang et al., 2023; Liang et al., 2023). Besides, many researchers and manufacturing companies have shown increased interest in designing the new aspects in FC-based EVs. Though FC-based EVs are run by electric motors that are fed with FC generated electricity, they still have some demerits namely, low density attribute, ensure maximum efficiency up to 60 %, does not have proper refuelling infrastructure for hydrogen, and cost is in high.

***3.5 Hybrid Energy Sources***

Hybrid energy sources are contributing to the crucial role in automotive industry for overcoming the limitations of individual energy sources. In hybrid applications of energy sources, diverse energy sources such as batteries, FC, UC, photovoltaic panels, and flywheel are hybridized for successful operation of electric vehicles. In this section, clearly presented the hybrid energy storage units for the EVs.

### 3.5.1 Hybridization of FC and Batteries

This is the most prevalent hybrid topology for EVs. Regarding this, the FC and battery are connected to the unidirectional and bi-directional DC to DC converters respectively. The battery can be protected the FC from low efficiency zone of operation (Zou et al., 2023). Hence, it can contribute huge current to operate the motor at initial stage. The FC would actively sustain the required operation of the motor for EVs after initialization.

### 3.5.2 Hybridization of FC and UC

In this topology, the FC and UC are hybridized for a productive operation of the EVs. With regards to this structure, the UC is placed in the place of battery for the support of FC to meet the power demand in the event of sudden situations (Song et al., 2023). Nevertheless, UC is not suitable to contribute energy because of having low energy density.

### 3.5.3 Hybridization of FC, UC and Battery

In this topology, three energy storage devices are hybridized for the EVs. The FC in this structure is utilized as primary energy source and remaining sources such as battery and UC used as supplementary units. As compared to the previous structures, the FC is tied to the DC bus through unidirectional DC to DC converter. Besides, the battery and UC are connected to the DC bus through bi-directional DC to DC converter (Yao et al., 2023; Yuan et al., 2022). The greatest privileges of the three energy storage sources hybridization can be provided the uninterrupted energy and improves the dynamic performance of the system at nonlinearities.

### 3.5.4 Hybridization of FC, UC and PV

One of the most significant current discussions in the EVs is PV hybridization with other energy sources. In recent years, there has been an increasing interest in EVs with incorporation of PVs for contributing the continuous energy (Alhumade et al., 2023). According to this structure, DC voltage can be produced by PV panels, and it is connected to the DC bus through unidirectional-based converters. Moreover, the FC is utilized as primary source as well as PV and battery is employed as supplementary energy generators. As PV, the FC is tied to the DC bus through unidirectional based converter (Salameh et al., 2021). However, the battery is connected to the DC bus through a bi-directional based converter. The generated power from the PV panels can be varied by atmospheric conditions. This power can feed directly to electric motor/ charging of battery.

### 3.5.5 Hybridization of FC and Flywheel

In this structure, the FC is presented as main source and flywheel is utilized as additional energy source for battery (Sun et al., 2022; Ali et al., 2022). The purpose of the flywheel is to store mechanical energy with huge rotational mass and transmute the mechanical energy into electrical energy through a generator. The transmuted electric power can support the electric motor id needs high energy. Compared with batteries, flywheels have high efficiency, huge power rating, long lifetime, and great charging capability. It appears from the aforementioned investigations that numerous examinations have been conducted on the effects of diverse energy storage units for the EVs. So far, however, there has been little discussion about superconductive magnetic energy storage (SMES) systems and redox flow batteries (RFBs). Hence, it is necessary to do deep research on the combination of SMES and RFBs with other energy sources.

## 4. Control Techniques for EMS-based EVs

Various types of control techniques have been developed by several researchers (Zhao et al., 2022; Madheswaran et al., 2022; Falahati et al., 2016) over the decades for sustaining the reliability and increasing the efficiency of the EVs performance. A multi-loop non-linear controller is implemented by Lyapunoy stability tool for EVs in the presence of FC and UC. Hence, the simulation findings show that the power sharing between the energy sources is done effectively. Nevertheless, this work is restricted to power spilt simulation level only. Some researchers utilize microcontrollers for distributing the power between the suggested energy sources such as FC, UC and battery. Furthermore, the experimental findings reveal that the efficiency of the EV with FC, UC, and battery is enriched up to 96 % at rated power. Nonetheless, this work focuses on the EVs performance for only particular parameters or ratings. Genetic algorithm-based fuzzy logic controller (FLC) is applied to optimize the FC, UC and battery for improving the EVs performance. Besides, different types of control approaches are presented and discussed briefly in the following sub sections with their merits and demerits.

### 4.1 Classical Controller

Classical controllers are very flexible controllers and utilized by many industries for abating disturbance at various uncertainties conditions. Proportional integral derivative (PID) controller is used to contribute the steady and reliable power for FC-based EVs (Ahmed et al., 2022). However, the PID controller is not required to share the power in the EMS. Few researchers (Safiullah et al., 2022; N. Ali et al., 2022) are presented the PID for controlling and regulating the DC voltage. In some studies of EMS, the PID is utilized as to control the state of charge (SOC) of the battery (Turksoy et al., 2020). Math function based PID controller is developed for smooth transaction between the battery and UC in the EVs (George et al., 2022).

### 4.2 Fuzzy Logic Controller (FLC)

It is the rule-based control strategy and depends on some rules of the input parameters of the EMS in EVs. The goal of this strategy is producing the rule set, which are in the form of IF-THEN rules. So far, many investigations have been conducted with this rule-based control strategy in the EV/HEV systems (Shen et al., 2022; Vijaya Kumar et al., 2022). Many times, this strategy has been proved for successfully sharing the power between energy sources, even if it has been tested in real time applications. The FLC is presented in the combination of battery and UC in EVs (Mounica & Obulesu, 2022). Some researchers have introduced the adaptive FLC and wavelet-FLC for contributing the reliable power between the energy sources in EV/HEV systems (Anbazhagan et al., 2022). The amalgamation of FLC and enabled energy management strategy is used to the HEV based on SOC of battery and torque demand (C. Wang et al., 2022). Management strategy based on FLC is introduced in the EV system by FC/UC/battery storage system (Podder et al., 2021).

#### *4.3 Model Predictive Control (MPC)*

It is a model and predictive strategy based on future outputs and current values. This is a significant approach in EV/HEV system for tracing the vehicles predicted trajectory. The MPC algorithm is presented for particular case of heavy duty EVs (Wei, Fan, et al., 2022). A long short term memory-based MPC method is suggested for expecting the driving cycle for the hybridization of battery/UC of EVs (Machacek et al., 2022). Non-linear MPC strategy is designed for the EMS of series-parallel EVs (Xiang et al., 2017). Adaptive MPC strategy is suggested to the Li-ion battery and UC of EVs (Hou et al., 2019). Scenario-based MPC method includes stochastic and robust approaches are utilized for reducing the operational cost of EMS (Valencia et al., 2015). Model predictive multi-objective control approach is designed to examine the interplay between inter-vehicle safety, fuel economy, and vehicle exhaust emissions (Nguyễn et al., 2021; Bachtiar et al., 2016).

#### *4.4 Operational Mode/State Machine*

Numerous studies have attempted to investigate the EMS based EV/HEV by operational mode/ state machine energy strategy (Hu et al., 2016; Tie & Tan, 2013). State machine approach is implemented as output, which is based on the decision tree of stable situations and flow chart (Konara et al., 2020). On the other hand, the operation mode method can be employed on the particular operation/ state of the vehicle such as acceleration, starting, climbing, cruising and idle (Truntič et al., 2018). In EMS based EV/HEV system, the operation modes are greatly depending on the input specifications of the vehicle (Vahedipour-Dahraie et al., 2017). The input specifications are vehicle speed, load power and SOC of the battery. An enhanced state machine theory is presented for FC based hybrid electric vehicles.

#### *4.5 Optimization techniques*

As discussed previously, many researchers have been focused on the EMS of EVs/HEV for alleviating the changes and enriching the system dynamic performance. However, dividing the energy is not appropriate when considering the hydrogen fuel consumption, replacement cost of the battery, and operating cost of the system. When considering the cost of battery pack in EVs/HEV is more expensive over cars. Therefore, manufacturing industries are looking to bring amendments in battery such as extend the battery life instead of replacing the battery. Thus, may minimize the maintenance cost of the vehicles. Appropriate methods are essential to increase the life span of battery, decreased the fuel consumption, and minimized the operational cost. It appears from the aforementioned investigations that there are only a few studies in literature that deal with optimization methods for the EMS in EV/HEV.

Moreover, optimization techniques are very imperative methods for extending the battery life, decreasing the hydrogen fuel consumption and operational cost (Li et al., 2019). In this section, diverse optimization approaches are discussed briefly for the EMS of EV/HEV. Optimization methods such as jaya algorithm (JA)-based EMS for battery and UC (Annamraju & Nandiraju, 2019), particle swarm optimization (PSO) for battery (Dechanupaprittha & Jamroen, 2021), neural network for the combination of UC, FC and battery (Yavasoglu et al., 2020), multi-optimization method for battery and UC (Teng et al., 2020), dynamic programming technique for optimizing the EV charging (Xu et al., 2019), genetic algorithm (GA) for series-parallel hybrid vehicles (Ding et al., 2021), spike neural network learning (SNNL) algorithm and golden eagle optimizer (GEO) algorithm for minimizing the cost (Ilango et al., n.d.), adaptive frame work algorithm (AFWA) for optimizing the control parameters of the EMS methods (Yang et al., 2022), biogeography-based optimization (BBO) for hybrid EVs charging (de Oliveira-Assis et al., 2021), bayesian optimization (BO) for optimizing the hyper parameter of deep Q-learning based EMS (Kong et al., 2020). It should be noted from the above literature review, however, that limited studies are available on optimization methods for the EMS of EV and HEV system. Furthermore, individual algorithms have some restrictions and limitations, nonetheless, few of researchers have been concentrated on the hybrid algorithms for the optimizing the EMS. So, it is required to conduct profound research on the hybrid algorithms for the EMS of EV and HEV system.

#### *4.6 Other recently published methods*

More recent studies on EVs with advanced techniques have been published by many researchers in recent years. Distinct new methods are designed for enhancing the EVs' performance and regulating cost constraints. Various methods are thermally modulated lithium iron phosphate batteries (Yang et al., 2021), micro-traffic low model (Xu et al., 2021), intelligent algorithms (Lipu et al., 2021), norm activation and the theory of planned behavior model (Asadi et al., 2021), deep reinforcement learning (DRL)-based direct control method (Wei, Zhang, et al., 2022), hydrogen proton-exchange membrane FC (Dimitrova & Nader, 2022), phase change materials-based hybrid battery thermal management (Mohammed et al., 2022), multi-agents-based optimal energy scheduling approach (Khan & Wang, 2022), modified gravitational search (MGS) and PSO (X. Zhang et al., 2022), improved mixed real and binary vector-based swarm optimization algorithm (Hemmatpour et al., 2022). It appears from the aforementioned investigations that numerous investigations have been conducted into the effects of EVs with diverse methods. Nevertheless, limited studies are available on the EVs/HEV with new methods. Hence, it is essential to conduct profound research on EVs/HEV with newly designed approaches.

## 5. Conclusion

This paper reviewed the previous studies and investigations of the EVs for further breakthroughs in EVs/HEV. The driven train's structures of the EVs/HEV are explained briefly with recent technologies. Diverse types of EVs such as ICE type, HEV, other types of vehicles are discussed and addressed their advantages and limitations. This paper has conducted an in-depth review on energy management strategies for future directions of EVs/HEV. Further, optimization methods and other control techniques are analyzed in this review for the EVs for upcoming examinations. Though several investigations have presented on the optimized EMS for the EVs, many of them are restricted to simulation not for the real time applications. Hence, further researchers should be validated and checked their simulation outcomes in real time applications.

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