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Analysis Of Smart Grid Integrated Hybrid Energy For Residential And E-Vehicle Charging Station: A Review

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Abstract:
From a technological point of view, the improvement of energy-efficient vehicles is one of the most efficient methods of apprehending a sustainable transportation system, hence promoting the automotive sector. More recently, advanced hybrid electric vehicles have gained attention because of their smaller battery size, outstanding energy efficiency and extended range of mileage. Also, the use of renewable energy resources and electric vehicles is being increased nowadays to reduce greenhouse gas emissions. Innovative grid technologies utilize electric vehicles to develop power system operations. Moreover, the advancement of commercial and residential charging stations is necessary for the advancement of electric vehicles. Few issues are encountered in EV charging infrastructures, which incorporate renewable energy sources like energy management, system optimization and so on. Therefore, in order to resolve these optimization issues in hybrid electric vehicles, artificial intelligence approaches and optimization approaches are implemented. Subsequently, this review intends to analyze the concepts of electric vehicles, such as Hybrid renewable energy sources integrated into the smart grid and residential and E-vehicle charging stations. In addition, this review examines the major challenges linked to the widespread adoption of electric vehicles, provides a classification of various charging infrastructures, and examines the control strategies employed for efficient electric vehicle operation. As a final point, the review performs aimpact of analysiswith assessment of electric vehicles with artificial intelligence and optimization techniques. Finally, the review concludes with a recommendation for the improvisation of hybrid electric vehicles.
Keywords: *Electric Vehicle,Renewable Energy Sources, Charging Station, Hybrid Electric Vehicle, Artificial Intelligence and Optimization Techniques*

INTRODUCTION

The inclinationtoward electric vehicles (EVs) is rapidly growing in current times because of various factors such as the advancement of renewable deployment, depletion of fossil fuels, and surging carbon dioxide emissions. The progress of charging stations is necessary to encourage the conversion of old-fashioned vehicles to electric vehicles (Hemavathi & Shinisha, 2022).The integration of renewable energy sources with electric vehicles can provide benefits such as reducing greenhouse gas emissions and meeting energy demand. The categorization of energy sources combined into a utility grid by means of sub-stations in order to control the EVs of end users in two energy charging systems: commercial and residential (Alsharif, Tan, Ayop, Ahmed, & Khaleel, 2022). The charging stations needconstant electricity demand and supply for their proper functioning. Subsequently, the production, transmission and distribution competence should be scheduled to manage any impending peaks in mandate (Brenna, Foiadelli, Leone, & Longo, 2020).

Because of the massive surge in energy consumption associated with demographic development, it is necessary for the energy liberalization market. Hence, the contemporary electricity grids are fixed to encounter a philosophical change in the forthcoming years, that is, the new generation Smart Grid, which is signified by the information and communication layer producing various components of grid communication (Melhem, Moubayed, & Grunder, 2016).Smart grids can enhance the energy efficiency of the power grid for end-users by coordinating and scheduling low-priority household devices. This enables users to optimize their power consumption by leveraging the most cost-effective or sustainable energy sources available at any given time.(Miceli, 2013).Electric vehicles are one of the conceptions of sustainable and green transportation systems. On the other hand, there are various uncertainties with regard to electricity demand and electric vehicle availability, as well as the electricity supply through renewable energy sources that impact optimal scheduling by means of intelligent charging approaches (Seddig, Jochem, & Fichtner, 2017).The use of renewable energy sources offers significant environmental benefits; however, their generation is highly variable and closely dependent on the availability of renewable energy potential. (Chakir, Tabaa, Moutaouakkil, Medromi, & Alami, 2020).Consequently, the integration of complementary energy sources through hybridization is strongly encouraged. (Suresh, Muralidhar, & Kiranmayi, 2020). The inconsistency in renewable energy usage within small-scale hybrid systems and electric transportation presents numerous research opportunities. In fact, the charging and discharging modes in transportation involve managing the flow and structure of shared energy systems. To develop an advanced electric vehicle charging station which incorporates renewable energy sources and energy storage systemsbased on power generation, several technical aspects must be addressed—such as system optimization, energy management strategies, power transfer rates, and overall system configuration.(Ahmad, Alam, & Chabaan, 2017). The intermittent nature of individual renewable energy sources compromises their reliability, leading to the development of hybrid renewable energy systems. Consequently, optimal planning of smart grid-integrated hybrid energy systems for electric vehicle charging stations—enhanced with advanced control algorithms—is of significant importance. Such planning not only facilitates the widespread adoption of electric vehicles but also provides an effective strategy for reducing carbon emissions associated with conventional internal combustion engine vehicles. Consequently, this paper intends to review the analysis of smart grid-integrated hybrid energy for Residential and E-Vehicle charging stations. Moreover, the study performs a comparative analysis to assess the performance of EVs. Finally, this paper provides futuristic recommendations for the advancement of EVs.

1. Electric vehicles (EVs) and renewables

EVs were introduced around the end of the 1800s and have been gaining popularity for the past few years. The technology has developed, and prices have been reduced considerably. Across the world, support for clean transportation options has surged in charging prospects, awareness, and the adoption of electric vehicles (Muratori et al., 2021).

a. Challenges

Consumers are utilizing smart devices such as EVs, laptops, inverters, uninterruptable power supplies, mobile, etc. Hence, the power quality of the inquiry is essential. Also, these devices are very expensive and require excellent power quality for device procedures. Additionally, the selection of electric power generation systems plays a crucial role. Renewable energy-based generation units are employed to meet excess power demand. Nevertheless, the variability and unpredictability of renewable energy sources continue to pose a critical issue that requires efficient and strategic management. The challenges mentioned above encourage the investigator to emphasize continual power generation, enhanced quality and reliability of the system, and suitable microgrid structures (Sahoo, Routray, Rout, & Alhaider, 2022).

b. Trends

The electric vehicle-to-grid interaction technology can enhance renewable energy applications and alleviate grid connection. Similarly, renewable energy can be employed for the microgrid adjacent to or amalgamated into an enormous grid to efficiently resolve the volatility of renewable energy sources. Inspired by the surging number of EV and the arbitrarinessof renewable energy output, an article(Shi, Li, Zhang, & Lee, 2020)establishes an efficient approach to developing the economy and security of the microgrid system.

Therefore, a paper(Tong, Mansouri, Huang, Jordehi, & Tostado-Véliz, 2023)Introduces a tri-level framework for the coordinated management of ancillary and energy service markets within integrated transmission and distribution networks, incorporating electric vehicles, smart homes, and renewable energy sources like solar and wind power.The growing integration of electric vehicles (EVs) and renewable energy (RE) sources into contemporary urban environments with smart homes requires the implementation of sophisticated mechanisms to effectively coordinate their interaction with distribution and transmission networks. This coordination is crucial, as the inherent uncertainty in the behavior of these resources can pose significant economic and technical challenges for system operators.

2. Hybrid RE sources integrated into the smart grid

The innovative smart grid model design with an enhanced optimal variation approach through applying RE sources is suggested by an article (Chandrasekaran, Selvaraj, Amaladoss, & Veerapan, 2021). The novelty of this study resides in the design and implementation of a renewable energy-based smart grid system integrated with an artificial neural network, aimed at enhancing voltage stability and achieving balanced reactive power distribution across the grid. This objective is realized through the deployment of renewable energy sources, including wind and solar, in conjunction with artificial intelligence methodologies and DSTATCOM for efficient reactive power management. The integration of the hybrid renewable energy system with the neural network significantly improves the voltage profile, attaining an enhancement level of approximately 98.45%.

a. Classification of energy sources integrated into the grid

The main classifications of energy sources integrated into the grid are,

- **Wind**

The growing use of renewable resources such as solar and wind energy has made accurate forecasting increasingly important, particularly in the context of smart electrical grids and the integration of these resources into the main power grid. Currently, wind energy is being widely adopted as an alternative energy source on a large scale.Similarly, an inquiry (U. Singh, Rizwan, Alaraj, & Alsaidan, 2021)Conducts a comparative analysis of various machine learning techniques for predicting wind power based on wind speed and wind direction data. To achieve this objective, the Yalova wind farm located in western Turkey was selected as the case study.

- **Solar**

An advanced multicriteria A study has proposed an optimization methodology for the day-ahead scheduling of discharging and charging operations involving hybrid electric vehicles, battery energy storage systems, and photovoltaic systems.(Petrusic & Janjic, 2020). The study presents an advanced RE monitoring and tracking concept which makes it feasible to exploit the precise RE energy share while charging an electric vehicle. Additional norms which are concurrently optimized are the entire system costs and the battery degradation rate.

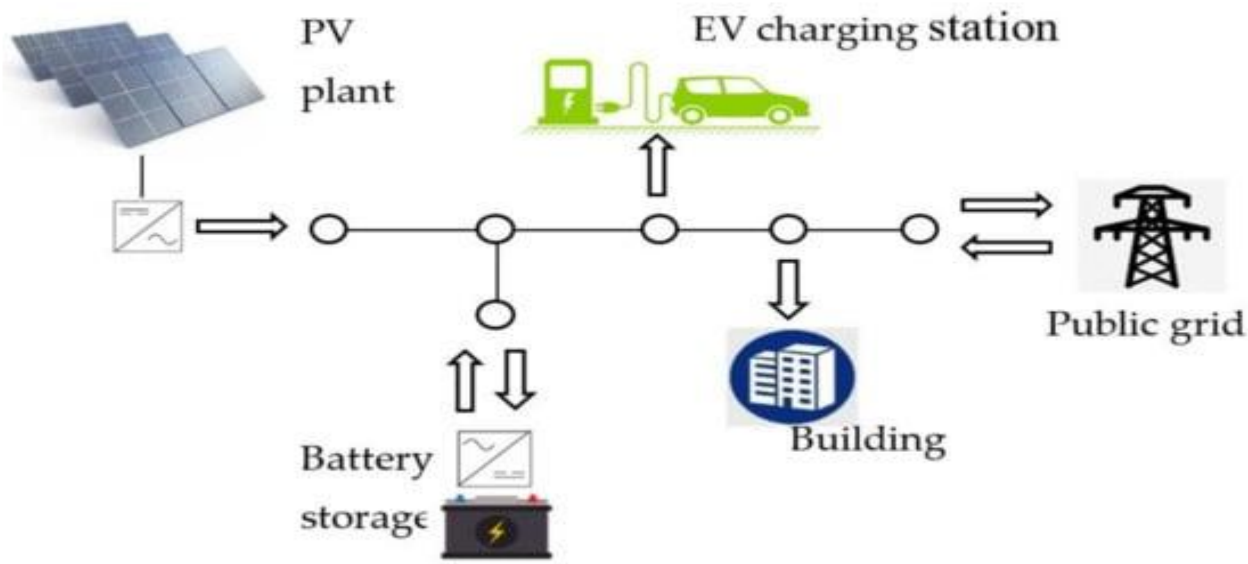

Figure1. Networking arrangement of Photo – voltaic (PV)/battery energy system (BES)/ EV charging system
(Source:(Petrusic & Janjic, 2020))

The conventional study analyzes the distinct charging system for EVs associated with the public distribution network that consists of an energy storage system and solar power plant. Figure 1 depicts the linking scheme of the EV charging system/ BES/PV. A balance between demand and supply is needed at all times for the smart utilization of electrical energy. In the context of a smart grid environment, demand-side management emerges as a viable solution for reducing peak load stress on utilities, made possible by the inherent inertia properties of the smart grid. Accordingly, a paper (Yadav, Hrisheekesha, & Bhadoria, 2023)introduces a robust optimization algorithm stimulatedby the grey wolf lifestyle, famously called the Grey-Wolf-Optimization algorithm and is employed to resolve the anticipated demand-side-management minimization problem. In three various cases: industrial and commercial loads, residential, and the demand-side-management minimization problem optimization utilizing Grey Wolf Optimization, it is established with respect to the times of use pricing scheme, including and excluding solar photo-voltaic energy. The Grey Wolf Optimization validation presents a significant decrease in peak load towards utility and price of energy of customers, including and excluding Solar Energy Photo Voltaic Energy.

- **Fuel cell**

Five countries' national transportation, heating, cooling, and energy systems are modeled for the anticipated year 2050, assuming that grid-connected fuel cell (FC) electric vehicles will account for half of passenger vehicles and battery electric vehicles (BEVs) will make up the remaining portion. Despite having low utilization rates (load factors ranging from 2.1% to 5.5%, or around 190 to 480 operating hours per car yearly), the grid-connected FC EV fleet shows that it can dependably assist energy system balance. Particularly in nations like Spain that heavily rely on solar energy, between 26 and 43 percent of the grid-connected FC EVs are needed during specific peak periods, which only happen for a few hours each year. In these situations, FC EVs are essential for grid stabilization, particularly at night, and provide a competitive edge over conventional driving.(Oldenbroek, Wijtzes, Blok, & van Wijk, 2021).

b. Electric vehicles

The EV charging station’s location is one of the main issues which constrains the EV's popularization, and the amalgamation of distributed RE and EV charging stations can alleviate the RE output’s fluctuation. Similarly, an article (Li et al., 2022)The study establishes a microgrid incorporating power distribution sources such as photovoltaic and wind energy. It primarily focuses on energy storage systems and EV charging stations, addressing the fluctuations in EV charging demand and the intermittent characteristics of distributed renewable energy generation.A robust optimization model is proposed for determining optimal charging station locations, integrating both grid infrastructure and road network considerations.

EV charging at an enormous scale negatively influences the power grid. Transformers may endure power loss, surplus voltage fluctuations, heat, and power loss when they are already functioning at full competence. In the absence of EV management, these issues cannot be resolved. Accordingly, a study (Mazhar et al., 2023)Presents a machine learning-based charge management system that oversees electric vehicles at charging stations, Integrating standard charging, rapid charging, and vehicle-to-grid (V2G) technologies.

c. Electric load management

An article examines the optimal configuration and energy management of a residential microgrid system by incorporating diverse distributed energy resources, integrated with combined heating, electrical, and cooling demands.(Tooryan, HassanzadehFard, Collins, Jin, & Ramezani, 2020). A microgrid comprises,

- Wind Turbine
- Photovoltaic(PV)
- Thermal Energy Storage System
- Battery Energy Storage System

In the context of a residential hybrid microgrid system, electrical demand is met using the output power from wind turbines, energy stored in battery energy storage systems, and fuel cell units. The power generated by photovoltaic panels and wind turbines is determined based on solar irradiance and wind speed, while accounting for the inherent uncertainties in weather data.

3. Residential and E-Vehicle Charging Station

In this present era, residential charging stations are very significant since they decrease the grid's load to a more considerable extent. Residential EV charging can be effectively managed by drawing low current from the grid, which helps alleviate additional voltage demand during peak load periods. Nighttime charging is considered the most optimal and efficient time, as it aligns with base load hours, thereby minimizing the impact on the grid and reducing electricity costs. Charging during these hours lowers overall grid stress and takes advantage of reduced per-unit electricity rates. Furthermore, vehicles can be conveniently charged within seven to eight hours using Level 1 chargers at residential charging stations.(Divyapriya & Vijayakumar, 2018).

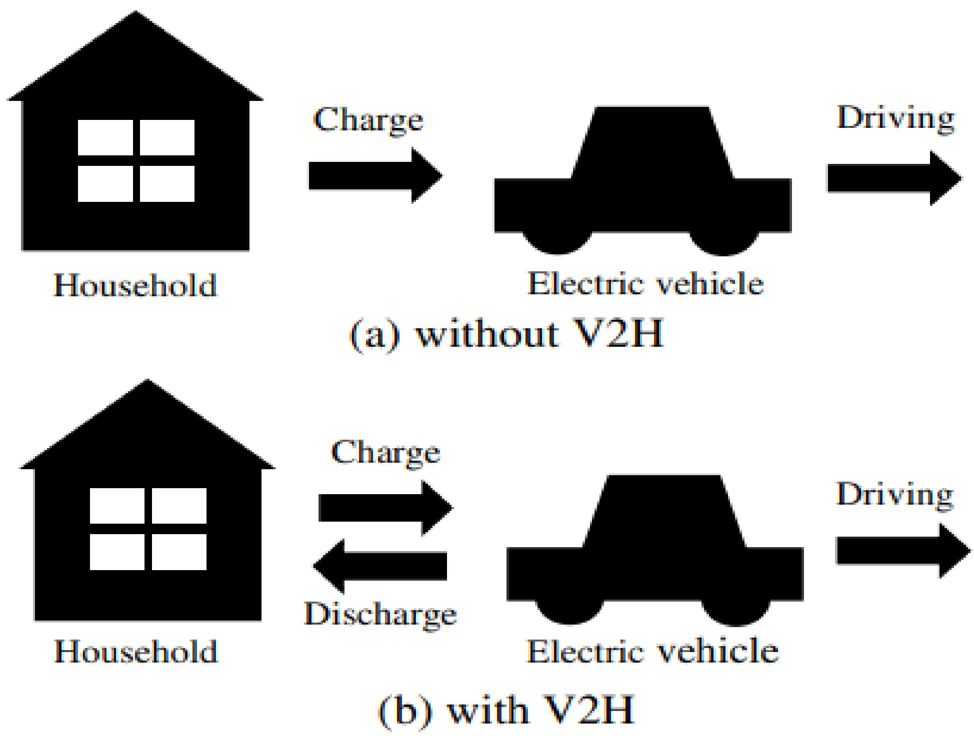

Figure 2. **Vehicle – to – home (V2H) system**
(Source :(Higashitani, Ikegami, Uemichi, & Akisawa, 2021))

An electric vehicle (EV) can also supply its stored electricity to a household when equipped with a power conditioning system that connects the EV to the home's distribution board. Figure 2 depicts the vehicle-to-home (V2H) system.(Higashitani et al., 2021).

a. Challenges to the Widespread Adoption of EVs

The literature has deliberated on various issues concerning the integration of the EV charging station with the grid (Mullan, Harries, Bräunl, & Whitely, 2011). The charging station's maximal power necessitates various negative impacts on the power system in the form of voltage deviation, degradation of power quality, and surged distribution losses (Waltrich, Duarte, & Hendrix, 2012). The problem of surged network loading also depends on incorporation because of the volatile behaviour of EV charging.

The incorporation of EVs into the electrical grid is the central aspect of recent transportation systems. This incorporation creates multifaceted opportunities and challenges, impacting the grid's stability, environmental sustainability, and energy management. An evolving significant scheme to address these issues through optimizing charging patterns, increasing renewable energy usage, and harmonizing grid demand is smart charging solutions(Ahsan, Tanvir, Rahman, Ahmed, & Islam, 2023).

b. Classification of different charging infrastructures for EVs

In integrating EV fleets into the smart grid framework, charging infrastructures serve as the critical interface between the power grid and electric vehicles, thereby significantly influencing the impact of EV operations on the smart grid. Consequently, a study was conducted to investigate this interrelationship. (Kong, Fowler, Entchev, Ribberink, & McCallum, 2018), The influence of charging infrastructure on the efficiency of various EV operational modes was examined through a multi-component modeling framework, which incorporates the stochastic characteristics of EV fleet charging behavior alongside an optimal energy dispatch strategy.

This paper provides a comprehensive overview of three distinct types of charging infrastructure:

- **Distributed**

A study (Sachan, Deb, & Singh, 2020) found that various charging infrastructures are correlated based on factors such as plug availability, battery competence, charge state, electric vehicle availability, charging time, driving pattern, time for the return of the last journey, and so onLikewise, the paper introduces a framework for choosing an excellent charging infrastructure. It has been revealed that the distributed infrastructure displays optimal outcomes for electric vehicle charging.

- **Fast charging**

The primary objective of the study aims to evaluate the impact of deploying fast-charging stations for electric vehicles on the power distribution networks of mid-sized cities in Latin America. (González, Siavichay, & Espinoza, 2019). Moreover, the paper systematically examines the technical, geographical, and socio-economic factors that influence the determination of the minimum required charging infrastructure for the selected case study. It offers a detailed methodological framework for assessing fast-charging infrastructure in urban settings and analyzing its impact on the power distribution system.

- **Battery swapping infrastructures**

An article presents ainclusivescientificscheme for analyzingthe prospective function of battery swapping stations integrated with the power gridequipped with vehicle-to-grid (V2G) capabilities. (Zeng, Luo, Zhang, & Liu, 2020) for developing the supply reliability of forthcoming distribution networks. To attain the motive, the researcher created an empirical model for defining the EV energy demand and its available generation capacity that can be used to run a station that swaps batteries. This station is expected to play a vital role in supporting large-scale EV integration as an intelligent power component, while also enhancing the reliability of the distribution network.

4. Different types of control techniques and hybrid energy management strategies used in EV application

An elegant, well-formulated energy management approach is necessary for the excellent operation of Hybrid EVs with respect to pollutant emissions reduction and fuel economy, irrespective of the particular powertrain architecture. Accordingly, an investigation (Donatantonio, Ferrara, Polverino, Arsie, & Pianese, 2022) introduces two advanced supervisory control approaches for Hybrid EVs from various optimization algorithms. The study assesses the reduction in fuel consumption of hybrid electric vehicles (HEVs) in comparison to conventional vehicles. The methodologies employed are drawn from existing literature and have been adapted by the authors to develop innovative algorithms for solving the optimization problem. One such approach, known as forward dynamic programming, features a unique implementation aimed at improving both computational efficiency and accuracy.Another one is grounded on the Equivalent Consumption Minimization Strategy technique, which acclimatizes advanced driving conditions by utilizing information collected in a finite-length, backwards-looking horizon.

5. Impact assessment of EVs: Comparative analysis (AI – Artificial Intelligence algorithms and Optimization techniques)

Table 1. Comparative analysis on Evaluation of EVs using Artificial intelligence approaches and optimization techniques

S.No.	Author	Objective	Artificial algorithms and optimization approaches	Outcomes of the study	Limitations / Future work
1.	(Almousa, Rezk, & Alahmer, 2024)	The study introduces an optimized energy management strategy for fuel-cell hybrid EVs.	The introduced Energy management strategy performs the hybridization of the Artificial Hummingbird algorithm and ECMS.	The study's outcomes reveal that there is a surge in the entire system efficacy of around 15.45 per cent.	It is significant to note that the requisite for high-speed computing competence inhibits the real-time application of the introduced approach to effectively increase the objective function. On the other hand, progressions in physical processing systems are expected to soon overcome this restraint.
2.	(Benhammou, Hartani, Tedjini, Rezk, & Al-Dhaifallah, 2023)	The study intends to improve EV performance by utilizing robust controllers and Direct current generators.	A speed controller-based artificial intelligence method.	The EV's fuel consumption has decreased by up to thirty per cent. Also, the introduced approach improves the reliability of the EV.	The remarkable findings of kinetic energy exploitation smearing robust controllers will be the motivation for the futuristic work.
3.	(Aissa, Hamza, Yacine, & Amine, 2023)	The article examines a hybrid EV with two-wheel drives motorized by super capacitors, batteries,	The researchers compared the energy management strategies of the Adaptive Neuro-Fuzzy Inference System (ANFIS) with conventional	The introduced ANFIS technology decreases the fuel consumption ratio by up to eight per cent.	The complexities encountered in the proposed study motivate the authors to explore additional intelligent methodologies and to evaluate their effectiveness

		generators, and fuel cells.	energy management approaches.		through experimental investigation in future research.
4.	(Narasimhulu, Krishnam Naidu, Falkowski-Gilski, Divakarachari, & Roy, 2022)	The research introduces a hybrid energy system for an all-EV	Aquila Optimizer algorithm (AOA) and Artificial Neural Network (ANN) are employed.	The proposed ANN-AOA approach demonstrates superior performance compared to other techniques, including the Genetic Algorithm-based Proportional-Integral-Derivative and Modified Harmony Search methods, by more accurately forecasting energy consumption for the upcoming time interval and enabling a higher EV speed of 91 km/h.	The introduced framework's architecture can be developed by embracing a hybrid optimization-based approach to promote the Hybrid EV's battery competence further.
5.	(Mounica & Obulesu, 2022)	The paper establishes a hybrid power management scheme	ANFIS and ECMS are being utilized	The combination of ECMS and ANFIS reduces hydrogen consumption by up to 8.7 per cent.	-
6.	(Pritima, Rani, Rajalakshmy, Kumar, & Krishnamoorthy, 2022)	The equivalent factor is tuned for attaining near-optimal fuel efficiency	Artificial intelligence is employed to determine equivalent factors in the equivalent consumption minimum strategy (ECMS) through the	The introduced strategy delivers enhanced fuel economy.	-

			evaluation of existing data.		
7.	(Sarvaiya, Ganesh, & Xu, 2021)	The paper conducts a comparative analysis of battery life optimization using various control strategies in a parallel hybrid electric vehicle (EV) system.	Four various control approaches are evaluated, This includes exploring advanced techniques such as Q-Learning, Thermostat-based control, Fuzzy Logic, and the "Adaptive Equivalent Consumption Minimization Strategy (A-ECMS)" , which also accounts for battery aging effects.	The study's consequences reveal that the ECMS displays a twenty-five per cent enhanced fuel economy when correlated to the rule-based approach.	The driving pattern may affect the fuel economy and battery life of a Plug-in Hybrid EV, and these impacts must be evaluated as futuristic work.
8.	(K. V. Singh, Bansal, & Singh, 2021)	The study proposes an energy management strategy (EMS) tailored for a series-parallel hybrid electric vehicle (HEV).	Adaptive Network-Based Fuzzy Inference System - ANFIS	The outcomes of the research denote that the introduced ANFIS-based procedure leads to enhanced energy optimization and, therefore, provides excellent fuel economy	--

From the outcomes of Table 1, it is revealed that ANFIS and ECMS techniques are the most employed for energy management schemes in the hybrid EV. Several studies concentrate on reducing fuel consumption and increasing the fuel economy of Hybrid EVs, while few studies emphasize increasing the efficacy of hybrid EVs. Various AI approach algorithms, such as artificial neural networks, AOA, and artificial hummingbird algorithms, are being applied to improve the fuel economy of hybrid EVs. ANFIS technique reduces fuel consumption by up to eighty per cent.

DISCUSSION

The persistent requirement to improve clean energy vehicles has become more prominent with the exhaustion of natural resources and the progressively dismal state of environmental pollution (Quan, Guo, Li, Zhang, & Chang, 2024). Hence, it is very vital to analyze the EV. Compared to the well-established fossil fuel-powered automobiles, EV has fewer components. Also, various benefits provided by EVs include being environmentally beneficial, quiet, highly durable, and so on (Azeem, Armghan, Ahmad, & Hassan, 2020). Likewise, a paper (Rezk et al., 2023) introduces This study presents an advanced energy management strategy for hybrid fuel cell electric vehicles, with its key contribution being the development of an optimized system derived from an improved version of the External Energy Maximization Strategy, utilizing the Harris Hawks Optimizer for implementation. The proposed approach focuses on enhancing fuel efficiency, overall system performance, and the operational effectiveness of hybrid power systems applied to fuel cell EVs. From the outcomes of this review, it is revealed that the ECMS is an optimization approach executed online for Hybrid EVs to enhance fuel economy and is extensively used in various investigations. As per the study (Zheng, Tian, Wang, Zhang, & Cai, 2022), an instantaneous optimization technique is ECMS, and to attain the near-optimal efficiency of ECMS for various powertrains and driving cycles, equivalent factors should be well-tuned. Also, this review identifies that hybrid EVs are the potential solution to decrease environmental pollution and the consumption of fuel. Furthermore, it is determined that a well-formulated energy management strategy is crucial to deal with the power distribution complexity in hybrid EVs. It is recognized that enhancements in the hybrid EV's fuel efficiency and also decreased emissions are hugely reliable in their energy management strategies. Also, the review reveals that the optimization-based energy management strategy outperforms the rule-based energy management strategies in improving fuel economy in hybrid EVs.

CONCLUSION

The attractiveness and fascination for electric vehicles are currently being developed. The primary motivating factor behind it is their environmental gains since they create zero emissions.The greenhouse effect for the past few decades has motivated the improvement of zero-emission EVs that are battery-powered and contribute to a sustainable environment. Therefore, currently, various nations have promoted the growth of EVs. Subsequently, with the enhancements in electric transportation and the progress towards smart grids, the deployment of smart charging approaches on a large scale for EVs becomes possible. Moreover, the incorporation of a smart grid with EV offers various gains to the environment. Accordingly, this study provides a comprehensive review of electric vehicle (EV) applications, the challenges associated with their adoption, and the integration of renewable energy sources with EV systems. It offers an in-depth examination of the operational mechanisms within EV charging stations and highlights the role of smart grid technologies in advancing charging infrastructure. Additionally, the review underscores the importance of optimization-based energy management strategies in enhancing the fuel efficiency of hybrid electric vehicles.

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