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Improving Efficiency of Electric Vehicles: An Energy Management Approach Utilizing Fuzzy Logic

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Abstract*: The idea behind it is as simple as the development of electric vehicles (EVs) necessitates addressing their disadvantages like lower range, suboptimal acceleration, and battery durability. Typical EMSs usually have issues of versatility and ability to update and control instantly, which are critical for enhancing the efficiency of the EV. This research examines ways in which fuzzy logic-based control systems could enhance energy control in EVs, specifically, emphasising battery and ultracapacitor technology. Specifically, rule-based control and model predictive control, which are traditional EMS techniques, lack the needed flexibility and real-time dynamic computation. Unlike this, the fuzzy logic system is more flexible and adaptive to the situations of real-life driving conditions. Thus, within the framework of this research, fuzzy logic is used to design and test sophisticated EMS solutions that improve energy management, integrate renewable sources of energy, and increase vehicle efficiency. The study shows how adopted fuzzy logic trove drawbacks of conventional approaches in the way of better decision-making and performance. This approach provides working knowledge on how to engineer and construct fuzzy logic control systems and involves issues to do with fuzzification, the rule base, inference and defuzzification. The study advances the capabilities of current electric vehicles by exploring and developing more efficient and dependable energy management systems*

Keywords: Electric Vehicles, Energy Management System (EMS), Fuzzy Logic, Hybrid Power Sources, Model Predictive Control.

I. INTRODUCTION

Electric traction motors, which constitute the engine of an electric vehicle, are charged using energy storage devices such as power batteries or ultracapacitors[1]. More and more people are opting for electric vehicles.However, models with only one power source have issues, including short acceleration times, weak battery life, and poor endurance. A hybrid power source that combines a battery with an ultracapacitor seems to be a sensible way to solve the problems stated above. The battery may be effectively protected and its service life extended by an ultracapacitor [2]. Therefore, the energy management approach of a HEV has a direct impact on its performance. An energy management strategy's main goal is to balance the power battery and ultracapacitor's load power demands in order to satisfy their electrochemical properties, which are essential for system energy management[3][4].

The power battery's condition estimation, which comprises the state-of-charge and remaining discharge time, has a direct influence on the battery's reliability,safety, and servicelife [5][6]. However, the SOC of the battery cannot be determined directly because of the impact of variables such as temperature, charging and discharging current, cycle life, and others. However, indirectly, using a specialised technique, it can only be approximated. These days, the methods most often used to determine SOC include open circuit voltage (OCV), the ExtendedKalmanfilter, neural network algorithms, discharge tests, and the Ampere-Hour integral technique [7].

Two primary approaches to managing hybrid power supplies' energy consumption are rule-based and optimization-based [8]. The rule-based control technique uses mathematical models and expert knowledge to distribute energy sources in a multimemory situation according to pre-established criteria. Following its evolution from a straightforward

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deterministic logic threshold control, the rule control approach is now an intelligent, trustworthy, and resilient control method built on fuzzy rules[4][9]. However, there is a lack of adaptation and flexibility to periodic changes since human experience is overextended. Optimal control theory and optimisation concepts are used by optimization-based EMSs such as ECMS, DP, and PMP to control parameters or real-time operational data [10].However, the majority of real-time optimum control systems need further study because they are too complex to execute in actual vehicles or because microprocessor chips are limited.

Accurate mathematical models are not necessary for a fuzzy control technique. Its great adaptability, robustness, and practicability make it ideal for hybrid power systems whose models are time-varying, nonlinear, delayed, and uncertain. To address the problem with fuzzy control methods that rely too much on expert knowledge—namely, how to determine the logic rules and membership functions—QCPIO optimises the membership function of the fuzzy logic controller. In a series of comparisons made under different conditions of operation, it is compared to the initial fuzzy approach, PSO, and the power supply and emission SOC[11].Hybrid plug-in electric car parameter optimisation using quantum genetic algorithm. Performed optimisation of the rule-based strategy's threshold using particle swarm analysis, with the goal of achieving the vehicle's least overall energy cost[12]. Subsequently, the driving cycle was used to validate the method's online control performance.

This research aims to better understand how electric cars and other energy systems might benefit from control systems that use fuzzy logic to enhance energy management efficiency. The study discusses the way in which fuzzy logic can be applied to energy management problems including grid and renewable energy management, energy management of hybrid storage systems, and charge level data management; thus, determining how the application of fuzzy system allows for overcoming shortcomings of traditional approaches. The study aims to design and test new sophisticated FLCs that will improve responsiveness, decision capability, and system performance with the goal of improving energy management systems efficiency. Major contributions of the study include the following:

The study introduces advanced fuzzy logic-based EMS for electric vehicles, demonstrating improvements in energy efficiency by optimising energy distribution and consumption.

It shows how the uncertainties can be handled by fuzzy logic in real-time and how the proposed EMS reacts in different driving scenarios, making it more functional than the conventional EMS methods.

It seeks to analyse fuzzy logic applications in relation to renewable energy forms and electricity storage technologies, which will enhance general control and utilisation of various energy inputs.

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This paper gives a thorough overview of fuzzification, rule-based construction, inference techniques, defuzzification, and the design and implementation of fuzzy logic controllers. It provides useful information and guidance for the current study and future developments of energy management systems.

Structure of this paper

Here is how the paper is organised: Section II discusses A fundamentals of electric vehicle efficiency, including types of EVs and factors influencing their adoption. Section III covers energy management strategies, focusing on conventional methods and their limitations. Section IV explores fuzzy logic-based energy management systems, detailing their benefits and control structures. Section V reviews recent literature on fuzzy logic applications in energy management. Finally, Section VI concludes with research gaps and suggests future work.

II. FUNDAMENTAL OF ELECTRIC VEHICLE EFFICIENCY

Electric vehicle (EV) efficiency is the measure of how effectively an EV converts battery energy into driving power, typically expressed as miles or kilometres per kilowatt-hour (kWh). Higher efficiency means the vehicle can travel further on less energy.Electric vehicle (EV) charging chances away from home have become a crucial concern as EVs have grown in popularity as a mainstream mobility option. A wireless charging EV is one that uses WPT technology, which transfers electricity without the need for physical touch. Smartphones, electronic toothbrushes, and medical gadgets are just a few of the portable electronics that WPT has been successfully used to charge. Additionally, it has

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found widespread use in automated material handling systems in semiconductor manufacturing and production lines for flat-panel displays [13][14].The components of a battery-powered EV are shown in Figure 1.

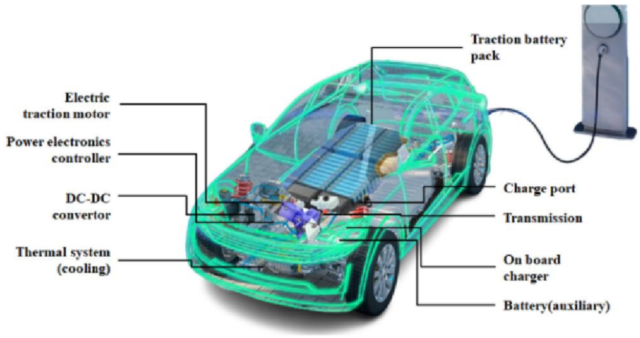

Figure 1: Components of battery electric vehicle

The increasing focus on EVs' capacity to lessen reliance on fossil fuels and emissions of greenhouse gases has contributed to their meteoric rise in popularity as a means of transportation[15][16]. EV uses an electric motor that communicates by a rechargeable battery pack instead of petrol or diesel. The number of people using EVs is projected to triple from 2011 levels by 2030. The effect of recent innovations in battery technology on car autonomy is to blame for this[17].

The environmental effects are one of the deciding advantages of electric vehicles. Controls of CO2 emissions from energy sources in the United States, China and Europe between the years 1983 and 2022. It should be noted, however, that even to this day, both China and the United States still continue to have a large population of traditional internal combustion engine-powered vehicles on the roads. These nations' energy demand increases have also led to increased utilisation of coal, which is the biggest source of carbon dioxide emissions.

A. Classification of Electric Vehicles

EVs, are cars that use electricity as their propulsion system rather than fuel or diesel. Each kind of EV uses a unique engine and set of specifications[18]. EVs are categorised according to the technology and layout of their engines in Figure 2:

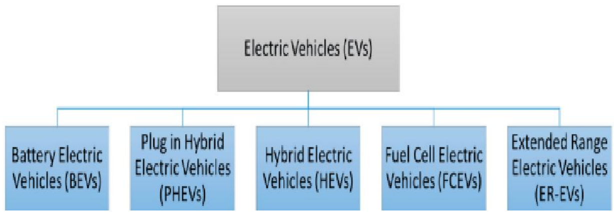

Figure 2: Classification of electric vehicles (EVs)

The following classifications of electric vehicles discussed below:

Battery Electric Vehicles (BEVs)

Rechargeable batteries are the sole power source for BEVs. Both a backup generator and a petrol engine are absent. BEVs are thought to be a most environmentally friendly kind of electric automobile since they don't emit any exhaust. However, their range is restricted due to the need to replenish the battery[19].

Hybrid Electric Vehicles (HEVs)

A hybrid electric vehicle (HEV) is one that uses both an electric motor and a petrol engine. During acceleration and at low speeds, the vehicle is propelled by an electric motor. The petrol engine kicks in as the need for power increases, particularly at greater speeds. Since HEVs recharge their batteries by regenerative braking, plugging them in is unnecessary. Though they produce less pollution than conventional gasoline-powered automobiles, they nonetheless use less fuel overall[19].

Plug-in Hybrid Electric Vehicles (PHEVs)

A PHEV is an HEV with bigger batteries thatcan be charged externally by plugging a charging wire into an electric powersource and internally by the combustion engine's generator. They can only run for a limited time on electricity

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before converting to a petrol engine. PHEVs simplify daily driving without a plug while still allowing power consumption or short journeys [20].

Fuel cell electric vehicles (FCEVs)

Hydrogen gas reacts with ambient oxygen to produce energy in FCEVs. They don't have a battery and produce just vaporised water as a waste product. Even though FCEVs can be filled up in a matter of minutes and provide more mileage than BEVs, the infrastructure for refuelling hydrogen is still lacking[21].

Extended Range Electric Vehicles (ER-EVs)

An Extended Range Electric Vehicle (ER-EV) is a hybrid electric vehicle that includes features from both PHEV and BEV. ER-EVs feature a larger battery pack compared to PHEVs, allowing them to go longer on electricity alone. But when the battery dies, a small gas engine kicks into power the electric motor and extends the vehicle's range[22].

B. Key Determinants Affecting the Adoption of Electric Vehicles

This section will address the main elements that impact Electric's success.

Political Determinants

It was determined that the credibility, coherence, and consistency of the policy mix significantly impact the desire to purchase EVs in China [23]. Identifies the murky regulations surrounding a switch from fossil fuel to EVs that, when addressed by financial incentives, information campaigns, etc., pose a serious obstacle to the adoption of EVs in India. In Taiwan, government incentives seem to have an impact on customers' intentions to switch to EVs[24].

Economic Determinants

High purchasing costs, largely attributed to the high cost of batteries, are the major economic barriers to EV adoption in Brazil, Ireland, and India, according to many research. According to studies, the high price of EVs is a big deterrent to their widespread use in countries like China, the UK, and the Nordic region.But in Korea, the price of an EV is a major consideration, especially when contrasted with the price of the customer's previous fossil fuel vehicle[25]. The research provides conflicting conclusions on the significance of purchase costs for EV uptake in India[23].

Social and Sociodemographic Determinants

The current societal tendency is that having an EV is a sign of success and prosperity. Attested to this pattern for shoppers in Wuhan, China. An further intriguing perspective on EV adoption in China is that of[26][27], who contended that end-users' interdependent, self-image reasons may impact their choice of EV.

Technological/Technical Determinants

According to studies done all around the world, a major problem with the broad use of EVs is the absence of a sufficient charging infrastructure. When it comes to EV adoption in China, the availability of charging infrastructure is crucial[28].

Legal Determinants

Recent literature has just scratched the surface of the legal aspect, touching on topics like incentives for low-income residents, the creation of duties to construct additional charging infrastructure, and regulations governing the ownership and use of automobiles[29].

Environmental Determinants

The importance of environmental considerations in getting Indian customers to buy EVs is emphasised[30]. This research suggests that factors such as local air pollution, greenhouse gas emissions, and the absence of recycling facilities for lithium-ion EV batteries can influence the adoption of EVs.

C. Challenges in EV Uptake

In this section, the obstacles that are associated with electric vehicles, including those that are technological, consumer behaviour, and government backing discussed below.

Technical

The range that EV manufacturers claim to have is often not accurate, and frequently EVs have ranges that are up to 17% less than anticipated[31][32]. The situation is now changing to include ultrafast charging facilities. They can charge a completely charged automobile in 10 minutes and have a 350 kW capacity, giving cars a 200 km range. However, cars aren't equipped to deal with this massive flow of current. The adoption of EVs is hampered by lengthy

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charging periods. A "battery swap" system, similar to oil refilling, would allow passengers to quickly go from an empty to a fully charged battery at any of the designated changing stations, eliminating the need to wait in queue at charging stations.

Consumer Behavior in the Context of Socio-Technical Factors

Customer conduct is the main cause of the general lack of EV availability [140]. Some obstacles that hinder the broad deployment of EVs include customer willingness to pay and accept, as well as purchase and usage intentions. It is still debated if consumers' gender, age, education level, income, and employment influence their EV purchases.It is clear from literature-based research that young, middle-aged, and educated male customers are more likely to acquire EVs[33].

Government Support and Policy

The worldwide market for EVs may be boosted by profitable government policies and incentives. Subsidies and tax breaks are examples of upfront actions that make buying an EV appealing. Although this is the situation in Norway and Denmark, EVs can only compete if ICE car taxes are higher than EV taxes.

III. ENERGY MANAGEMENT STRATEGIES IN ELECTRIC VEHICLES

EMS play a critical role in optimising the performance and efficiency of electric vehicles (EVs), as shown in Figure 3. An EMS must oversee energy control and energy management to handle energy in an EV most efficiently while the stored energy is situated in the battery [34]. This involves decision-making on energy distribution in real time between such areas of application as motor, climate control and other auxiliary loads, amongst others. The key purpose of designing an EMS is to enhance the overall vehicle range as much as possible while preserving vehicle driving performance and safety. In another way, EMS can greatly decrease the total cost of ownership while increasing the sustainability of EVs by adjusting the energy use at every detailed point[35].

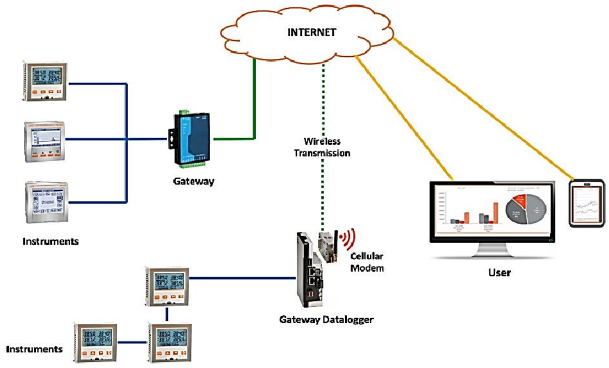

Figure 3; Energy Management Systems (EMS)

The complexity of energy management in EVs arises from the need to balance multiple, often conflicting, objectives. For instance, the driving range should be optimised without compromising vehicle performance or passenger comfort. As stated before, previous formulations of EMS strategies relied on rule and model-based structures, which may restrict real-time driving conditions and individual preferences. Consequently, there has been emerging interest in such a higher form of EMS like the fuzzy logic-based EMS that can account for the stochastic nature and dynamics in driving. These advanced systems provide a more flexible solution to the energy management which is the key to stability and comfort in EVs[36].

A. Limitations of Conventional Approaches

There is a need to concentrate on the limits of traditional methods in this section:

Lack of Adaptability:

Traditional EMS strategies like RBC and DP fail to respond to changes of driving conditions in real time, thus can hardly optimise the energy consumption[37].

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High Computational Demand:
These methods, including MPC and DP, are very computation-intensive, which raises problems in applying them to vehicles with constrained computational capabilities.

Dependency on Accurate Models:
These techniques mainly depend on mathematical formulation and hence take a long time to derive, and there is always a possibility of leaving out certain features that exist in a real road environment thus giving rise to errors.

Inflexibility in Multi-Objective Optimization:
These techniques mainly depend on mathematical formulation and hence take a long time to derive, and there is always a possibility of leaving out certain features that exist in a real road environment thus giving rise to errors[38].

Calibration Challenges:
Indeed, most conventional EMS methods must be calibrated or tuned to operate optimally and may even need periodic tuning due to changing environmental conditions.

IV. FUZZY LOGIC-BASED ENERGY MANAGEMENT SYSTEMS

Fuzzy logic is a type of multivalued logic that focuses on giving an uncertain reality of human decision-making. Unlike conventional two-valued logic computations, fuzzy logic uses numbers on interval [0,1] which denote probability of truth and membership of an element in a set. This flexibility enables fuzzy logic to handle complex, imprecise, or ambiguous information more effectively[39][40]. It operates through the use of fuzzy sets, membership functions, and rule-based systems to approximate human reasoning and make decisions based on qualitative data. In a context of EMS for EV, fuzzy logic can provide adaptive and intuitive solutions to optimise energy distribution and performance by incorporating a wide range of variables and uncertainties that conventional methods might struggle to address[41].

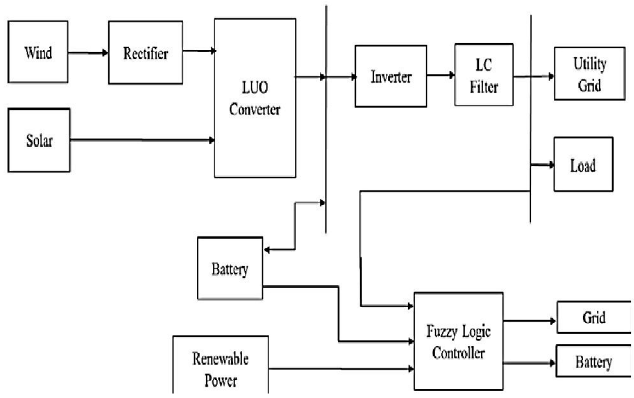

Figure 4; Example of Fuzzy Logic controller-based Energy Management[42]

Using fuzzy logic controllers, the renewable hybrid system manages the energy produced by a wind turbine, PV array, multiple input DC/DC converter, and PWM inverter. The hybrid generating system that is controlled by FLC and uses PV and wind is shown in Figure 4 as a block diagram [42].

A. Benefits of Fuzzy Logic in Energy Management

This section examines the advantages of fuzzy logic, which are as follows:

Handling Uncertainty and Vagueness:
This paper concludes that fuzzy logic is suitable when dealing with uncertainty and imprecision since it exists in most practical applications. Compared to the binary systems that depend on accurate information provided in the decision-making process, fuzzy logic is well applicable when the exact information is incomplete, which is common in open spaces.

Flexibility and Adaptability:
Thus, fuzzy logic systems are inherently adaptive or self-tuning, or easily modified according to changes in the conditions, and the user's preference. This capability is especially important in energy management because driving

conditions, load demands as well as users' behavior are unpredictable and the system should be able to adapt automatically without having to be reprogrammed or fine-tuned.

Improved Decision-Making:

Because of the use of multiple input values and human-like reasoning, fuzzy logic tends to deliver better solutions than hard decision-making. This results in improved and selective strategies in energy control to achieve various objectives including energy efficiency, system performance, and user comfort.

Simplified Rule-Based System Design:

Fuzzy logic enables a designer to model an involvement of human concepts as well as their reasoning in decision-making. Being based on linguistic relativity, these systems can be described by easily comprehensible rules and linguistic variables to enhance the modelling and to make the system more suitable for further real-life applications.

Enhanced Performance and Efficiency:

Fuzzy logic can be used in energy management; for instance, it can factor in energy distribution and usage all at once. This has a tendency to enhance performance and efficiency since the organisation might be better placed to make better decisions on how best to distribute energy depending on the analysis of different inputs and conditions [43].

Fuzzy Logic Control Structure

Fuzzy logic is a control structure that enables decision-making to emulate human decision processes. The process that forms the core of a fuzzy logic controller includes fuzzification where crisp inputs are converted to fuzzy sets; rule base, which uses the knowledge of an expert to form IF-THEN rules; inference engine which implements these rules to come up with fuzzy output; defuzzification comes after where fuzzy outputs are converted to crisp outputs for action. As a result, it allows for developing opening solutions that can be adjusted as needed as the surroundings remain volatile and unpredictable.

Fuzzification Process:

Fuzzification is one of the approaches that is used to map clear input into fuzzy values by the use of membership functions. This step quantises the inputs into degrees of memberships for different fuzzy sets so that the system can well manage the approximations.

Rule Base Development:

Defining a rule base is in defining an if-then rule set that defines the relationship between fuzzy inputs and outputs. Depending on the decision-making problem at hand, these rules establish conditions and actions, which the system aims to embody expert knowledge[44].

Inference Mechanism:

The inference mechanism performs fuzzy inference by firing fuzzy rules and demulsifying fuzzy results derived from the inputs. They include fuzzy AND, OR and NOT which enable it to assess the rules as well as deducing the overall output of the fuzzy system.

Defuzzification Process:

The inference mechanism's fuzzy output values are transformed into precise values using defuzzification, which enables useful control actions. This step gives quite a clear decision or control signal, as the fuzzy outcomes reassembled and comprehended by the system[45].

V. LITERATURE REVIEW

This section covers a lot of the research on using statistical methods to solve Energy Management Approach Using Fuzzy Logic issues.

Muaiz Ali et al. (2022)present a strategy for the DCMG's energy management that is based on fuzzy logic and controllers. The projected DCMG's HESS achieves energy balance, with a dieselgenerator acting as a backup. Keeping the SoC within a reasonable range is what the EMS does to prolong the life of the battery. The suggested approach provides a quick reaction to load variation and RER intermittency by managing the charging and discharging of the HESS, which keeps the DC bus's voltage level steady and prevents fluctuations. The results confirm that the suggested fuzzy logic controller is effective[46].

Sadasiva Behera et al. (2022) study is showing that using battery energy management (BEM), the output power is controlled with the help of PI and fuzzy logic controller. Further such controlled techniques are performing well with

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the help of slime mould algorithm (SMA). Lastly, MATLAB 2022b simulation settings were used to confirm the efficacy of the controller constructed utilising the BEM-based SMA approach under various loading situations [47].
Wang et al. (2022) enable the power management of a HESS that includes a supercapacitor (SC) and a VRFB by using an AFLC. The HESS's rated power and capacity are determined using a probabilistic technique, and its power distribution is intended to make efficient use of each ESS's unique features using an AFLC. Various scenarios of the system under study are examined to find out how the chosen capacity combined with the planned AFLC affects the system's smoothing power [48].
AbirZgalmi et al. (2021) an energy management technique based on fuzzy logic has been devised. Based on the three tanks' states, the suggested water/energy management approach can fulfil the load demand profile and distribute produced power among the various subsystems in response to variations in solar radiation and wind speed and direction.On a southern Tunisian location, a dynamic simulator with one-hour acquisition is used to treat the PV/Wind reverse_osmosis desalination plant and EMSbased on a fuzzy logic method. The data used in the simulation is real weather and water use data from a year ago. The suggested smart power energy management technique produced positive outcomes[49].
Mohab Gaber et al. (2021) explores the efficacy of a fuzzy logic-based intelligent EMS. The hybrid power system's performance may be optimised with the help of this energy management system. It extends the life of fuel cells and batteries simultaneously and delivers enough power to the load while using very little fuel. Mathworks and MATLAB are used to create and run simulations of the fuzzyEMS system [50].
Rafael S. Salles et al. (2020) In order to facilitate the functioning of a microgrid that is powered by photovoltaic (PV) farms, this article presents an algorithm that is based on fuzzy logic and was created for the Battery and Load Management System. Also included is a comparison of monetary cost reductions. The various situations were developed andsimulated using the software MATLAB/Simulink®. Fuzzy logic improved the system by allowing for lower-cost operation and better load management, according to the findings [51].
Mohammad Zand et al.(2020) the authors provide an energy management technique that utilises adaptive fuzzy logic for a power-generating system that combines FC, battery, and ultracapacitor components. The suggested energy management method is tested by simulating several components of the hybrid car using the ADVISOR toolbox in Matlab software. The Social Spider Algorithm (SSA) is also recommended for adjusting the scaling parameters of the proposed system to decrease fuel consumption and speed mistakes. Simulation findings in Matlab confirm that the suggested approach outperforms the popular Power Tracking Control (PTC) system due to the online parameter updating strategy. Table 1 provides the summary of the related work for the electric vehicles and EMSutilising fuzzy_logic

Table 1: Electric Vehicles: An Energy Management Approach Utilizing Fuzzy Logic

Paper	**Energy Source/System**	**Control Technique**	**Key Features**	**Outcome**	**Limitations**	**Future Work**
Muaiz Ali et al. (2022)	Hybrid Energy Storage System (HESS), Diesel Generator	Fuzzy Logic Controller	Fast response to load variation and renewable energy intermittency, stable DC bus voltage	Effective SoC control, voltage stabilisation	Limited real-world testing, focused only on DC microgrid systems	Test on larger microgrid setups, explore integration with AC grids
Sadasiva Behera et al. (2022)	Battery	PI Controller, Fuzzy Logic, Slime Mould Algorithm	SMA optimisation for power control, MATLAB 2022b simulations	Improved performance under different load conditions	Simulation-based, lacks real-world implementation	Apply to real-world systems, explore alternative metaheuristic algorithms

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		(SMA)				
Wang et al. (2022)	Vanadium Redox Flow Battery (VRFB), Supercapacitor (SC)	Adaptive Fuzzy Logic Controller (AFLC)	Probability approach for rated power, AFLC for power distribution	Improved power smoothing and ESS utilisation	Requires complex tuning, limited large-scale validation	Improve parameter tuning techniques, test on other hybrid systems
Abir Zgalmi et al. (2021)	PV/Wind Reverse Osmosis Desalination Unit	Fuzzy Logic Controller	One-year dynamic simulation, real meteorological and water consumption data	Encouraging results in power and water management for desalination	Limited to a specific site in Tunisia, not scalable to other environments	Expand testing to different regions and larger scales
Mohab Gaber et al. (2021)	Battery, Fuel Cell	Fuzzy Logic Controller	Extends battery and fuel cell lifetime, provides sufficient power	Reduced fuel consumption, increased system lifetime	Focused on MATLAB simulations, lacks real-world experimentation	Apply in real-world hybrid systems, explore AI-based optimisations
Rafael S. Salles et al. (2020)	Photovoltaic (PV) Generation	Fuzzy Logic Controller	Load management for lower-cost operation, MATLAB/Simulink simulations	Lower operational cost, better load management	Simulation-based, limited validation with real-world data	Real-world testing, explore integration with other renewable energy sources
Mohammad Zand et al. (2020)	Fuel Cell, Battery, Ultracapacitor	Adaptive Fuzzy Logic, Social Spider Algorithm (SSA)	Online parameter updating using SSA, MATLAB/ADVISOR toolbox	Better performance than Power Tracking Control (PTC) system	Limited to simulation results, requires extensive computational resources	Explore real-world applications, test on different hybrid systems

VI. CONCLUSION AND FUTURE WORK

The integration of fuzzy logic-based control systems in energy management for electric vehicles (EVs) and other energy systems offers a promising enhancement over traditional approaches. On the basis of digressing limitations associated with adaptability, real-time flexibility and efficiency in energy distribution, the present work various fuzzy logic as a robust platform for enhancing the performance and sustainability of EVs. As applied to the hybrid power system, the payoffs derived from the use of fuzzy logic also show its significance in real-world applications, and the utilisation of energy resources to enhance the driving range, as well as vehicle performance and efficiency.

However there are still some important areas for future research, as follows: The improvement of the FLC in executing roles of controlling and handling complex problems in various applications should be the main area of study in the future. This involves the enhancement of sophisticated fuzzy algorithms for fuzzification and rule base refining the marriage of fuzzy logic in the rising technologies like machine learning and artificial intelligence fuzzy application in innovative fields like renewable power and smart grid. The unfeasibility of conducting fuzzy logic-based systems in real-time should also be exercised in future research. These lines of questioning could potentially reveal enhanced, more adaptable and optimised energy control strategies for EVs and other subsequent applications.

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