# Performance Analysis of Renewable Energy Source and EV Integration: A Comprehensive Review

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**Abstract:** *The increasing penetration of renewable energy sources (RESs) and electric vehicles (EVs) is transforming modern power systems by promoting sustainable, reliable, and low-carbon electricity generation. Microgrids have emerged as an effective platform for integrating distributed renewable energy resources, battery energy storage systems (BESS), and EVs while improving energy efficiency, system reliability, and operational flexibility. However, the intermittent nature of renewable energy generation, uncertain EV charging demand, and bidirectional power flow associated with Vehicle-to-Grid (V2G) technology introduce significant challenges in microgrid planning, operation, and control. This paper presents a comprehensive review of renewable energy source and electric vehicle integration in microgrids. The review discusses the fundamentals of microgrids, renewable energy technologies, EV integration, V2G technology, energy management strategies, power electronic converter topologies, control techniques, optimization algorithms, artificial intelligence (AI) applications, and performance analysis. Recent advancements in intelligent energy management, hierarchical control, and AI-based optimization are critically analyzed to evaluate their impact on system stability, renewable energy utilization, operational cost, power quality, and reliability. Furthermore, current research gaps and future research directions are highlighted, focusing on battery health-aware optimization, distributed control, cybersecurity, digital twins, and AI-driven autonomous microgrids. The review concludes that the coordinated integration of RESs, EVs, and advanced energy management techniques can significantly enhance microgrid performance, improve grid resilience, reduce greenhouse gas emissions, and support the development of sustainable smart grid infrastructures.*

**Keywords:** *Renewable Energy Sources (RES), Microgrids, Vehicle-to-Grid (V2G), Battery Energy Storage System (BESS), Energy Management System (EMS), Smart Grid, Power Electronic Converters.*

## I. INTRODUCTION

The increasing demand for electrical energy, rapid depletion of fossil fuel resources, and growing concerns regarding climate change have accelerated the global transition toward sustainable energy systems. Renewable energy sources (RESs), including solar photovoltaic (PV), wind, hydroelectric, biomass, and geothermal energy, have emerged as viable alternatives to conventional fossil-fuel-based generation because of their environmental benefits and long-term sustainability [1–4]. According to recent studies, the widespread deployment of renewable energy technologies is supported by declining installation costs, technological advancements, and international policies aimed at achieving net-zero carbon emissions [3,4]. However, the intermittent and stochastic nature of renewable energy generation creates operational challenges such as voltage fluctuations, frequency deviations, power imbalance, and reduced system reliability, thereby requiring advanced control and energy management strategies for stable power system operation [2,5].

Microgrids have emerged as an effective solution for integrating distributed renewable energy resources while improving power system reliability, flexibility, and resilience. A microgrid is a localized electrical network comprising distributed generation units, renewable energy sources, battery energy storage systems (BESS), controllable loads, and power electronic interfaces capable of operating in both grid-connected and islanded modes [2,5]. Compared with conventional centralized power systems, microgrids reduce transmission losses, improve voltage regulation, enhance power quality, and increase the utilization of locally available renewable resources. Furthermore, their decentralized architecture enables rapid restoration during grid disturbances and improves energy security for residential, commercial, industrial, and remote-area applications [1,5].

Simultaneously, the transportation sector is experiencing a significant transformation through the rapid adoption of electric vehicles (EVs). The increasing penetration of EVs is primarily driven by improvements in lithium-ion battery technology, declining battery costs, government incentives, and stringent environmental regulations targeting greenhouse gas emission reduction [1,2]. Although EVs contribute substantially to transportation decarbonisation, uncontrolled charging can create severe impacts on distribution networks, including increased peak demand, transformer overloading, feeder congestion, voltage instability, and increased power losses [1,2]. Consequently, coordinated charging strategies and intelligent scheduling algorithms have become essential for maintaining reliable and economical operation of modern power systems.

The integration of EVs into renewable-energy-based microgrids offers significant opportunities to improve overall system performance. Through Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies, EV batteries can function as distributed energy storage systems by storing surplus renewable energy during periods of high renewable generation and supplying electricity back to the grid during peak demand [1,6]. This bidirectional energy exchange enhances renewable energy utilization, reduces renewable energy curtailment, improves frequency regulation, supports voltage stability, and provides ancillary services such as spinning reserve, reactive power compensation, and peak shaving [1,6]. Nevertheless, large-scale implementation of V2G technology introduces challenges related to battery degradation, charging infrastructure, communication protocols, cybersecurity, interoperability, and regulatory frameworks, which continue to be active research areas [1,6].

Battery Energy Storage Systems (BESS) constitute another essential component of renewable-energy-based microgrids. BESS mitigates renewable generation intermittency by providing energy arbitrage, load leveling, peak shaving, frequency regulation, voltage support, and backup power during grid outages [2,5]. Lithium-ion batteries remain the dominant technology because of their high energy density, long cycle life, and high efficiency. However, recent research has also focused on sodium-ion batteries, solid-state batteries, flow batteries, and hybrid energy storage systems to improve safety, lifespan, and economic viability [2,4]. Efficient battery sizing, state-of-charge estimation, thermal management, battery aging prediction, and lifecycle optimization remain major research challenges for large-scale renewable-integrated microgrids.

To coordinate renewable energy resources, battery storage, and EV charging infrastructure efficiently, advanced Energy Management Systems (EMSs) have become indispensable in modern smart microgrids. EMS optimally schedules distributed generation, storage systems, EV charging/discharging, and controllable loads while minimizing operating cost and maximizing renewable energy utilization [4,5]. Conventional optimization methods, including Linear Programming (LP), Mixed Integer Linear Programming (MILP), Dynamic Programming (DP), and Model Predictive Control (MPC), have been extensively investigated for optimal microgrid operation. More recently, Artificial Intelligence (AI), Machine Learning (ML), Deep Reinforcement Learning (DRL), Fuzzy Logic Controllers (FLC), Artificial Neural Networks (ANN), and metaheuristic optimization algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Grey Wolf Optimizer (GWO), and Whale Optimization Algorithm (WOA) have demonstrated significant improvements in adaptive control, renewable energy forecasting, load prediction, and real-time decision-making under uncertain operating conditions [4,5]. The development of smart grids has further accelerated renewable energy and EV integration through advanced sensing, communication, automation, and digital technologies. Smart grids utilize the Internet of Things (IoT), cloud computing, blockchain, big data analytics, and digital twins to enable real-time monitoring, distributed control, predictive maintenance, demand response, and peer-to-peer energy trading [3,4]. These technologies significantly improve system reliability, operational efficiency, cybersecurity, and resilience while facilitating high penetration of renewable energy resources and electric vehicles [3,4].

During the last few years, numerous review articles have investigated renewable energy integration, electric vehicle charging, microgrid control, energy management systems, and V2G technologies independently [1–6]. However, a comprehensive review that simultaneously evaluates renewable energy technologies, EV integration, BESS, intelligent energy management, optimization techniques, converter topologies, and overall microgrid performance remains limited. Therefore, this review presents a comprehensive performance analysis of renewable energy source and electric vehicle integration in microgrids. The paper critically examines renewable energy technologies, EV charging infrastructures, V2G operation, battery energy storage systems, hierarchical control architectures, energy management strategies, optimization algorithms, artificial intelligence applications, performance evaluation metrics, current research gaps, and future research directions. The outcomes of this review are expected to provide researchers, engineers, utility operators, and policymakers with a comprehensive understanding of the state-of-the-art technologies and future developments in renewable-energy-powered smart microgrids.

## II. Overview on Microgrids, Renewable Energy Sources, and Electric Vehicle Integration

Microgrids are localized power systems that integrate distributed energy resources (DERs), energy storage systems (ESSs), and electrical loads, operating either in grid-connected or islanded mode to improve reliability, resilience, and energy efficiency [7]. Renewable energy sources (RESs), including solar photovoltaic (PV), wind, hydro, and biomass, are increasingly deployed in microgrids to reduce greenhouse gas emissions and dependence on fossil fuels. However, the intermittent nature of renewable generation necessitates advanced control, energy storage, and energy management strategies to ensure stable operation [8]. The rapid adoption of electric vehicles (EVs) has further enhanced the functionality of microgrids by serving as flexible electrical loads and distributed energy storage through Vehicle-to-Grid (V2G) technology. Coordinated integration of RESs and EVs improves renewable energy utilization, enhances voltage and frequency regulation, reduces peak demand, and supports sustainable and resilient smart grid operation [9].

### *A. **Fundamentals of Microgrids***

A microgrid is a localized electrical network comprising distributed energy resources (DERs), renewable energy sources (RESs), battery energy storage systems (BESS), power electronic converters, and controllable loads that can operate either in grid-connected or islanded mode [10,11]. Microgrids have emerged as a key enabling technology for future smart grids because they improve system reliability, resilience, power quality, and energy efficiency while reducing greenhouse gas emissions and transmission losses [12]. The integration of distributed generation based on photovoltaic (PV) systems, wind turbines, fuel cells, and microturbines allows microgrids to supply local loads with minimum dependence on conventional centralized generation. During normal operation, the microgrid exchanges power with the utility grid, whereas in islanded mode it independently regulates voltage and frequency through coordinated control of distributed generators and energy storage devices, [13]. Hierarchical control architectures consisting of primary, secondary, and tertiary control layers have been widely adopted to ensure stable operation, optimal power sharing, and economic dispatch under varying load and renewable generation conditions [14]. Recent developments in communication technologies, Internet of Things (IoT), and advanced metering infrastructure have further enhanced the operational flexibility and intelligence of modern microgrids by enabling real-time monitoring, distributed control, and predictive maintenance [15]. Consequently, microgrids are considered an essential component of future sustainable and resilient power systems.

### *B. Renewable Energy Sources in Microgrids*

Renewable energy sources play a fundamental role in modern microgrids by providing clean, sustainable, and decentralized electricity generation.

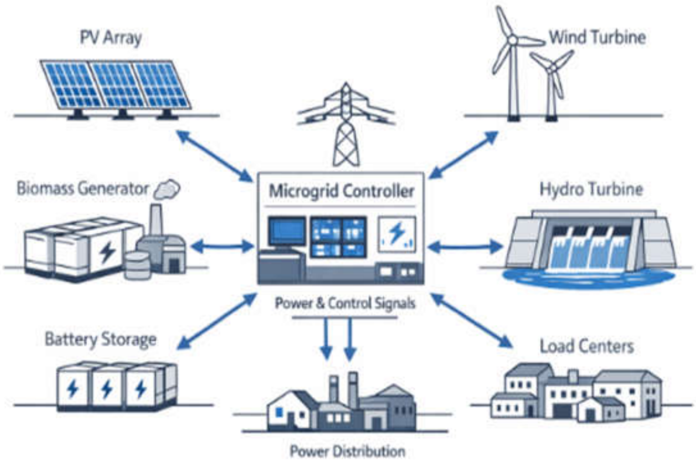


**Fig.1. Renewable Sources in Microgrids**

The figure presents a renewable energy-based microgrid managed by a central Microgrid Controller, which coordinates power flow between solar PV, wind, hydro, biomass, battery energy storage, and load centers. The controller ensures efficient power distribution, system stability, and reliable energy management, thereby improving renewable energy utilization, enhancing reliability, and supporting sustainable microgrid operation. Solar photovoltaic (PV) systems and wind energy conversion systems are the most widely deployed renewable technologies because of their declining installation costs, high energy potential, and favorable environmental characteristics [16]. Other renewable resources, including biomass, small hydroelectric plants, geothermal energy, and tidal energy, also contribute to diversified energy generation depending on geographical conditions [17]. Despite their environmental advantages, renewable energy sources exhibit intermittent and stochastic characteristics due to variations in solar irradiance, wind speed, and climatic conditions, resulting in voltage fluctuations, frequency deviations, and power imbalance within the microgrid [18]. To overcome these challenges, Battery Energy Storage Systems (BESS), supercapacitors, and hybrid energy storage technologies are integrated with renewable generators to smooth power fluctuations and improve system stability. Furthermore, maximum power point tracking (MPPT) algorithms, intelligent forecasting techniques, and advanced Energy Management Systems (EMS) have significantly improved renewable energy utilization while minimizing power losses and operating costs [19]. Recent studies also emphasize the importance of coordinated operation between renewable generators and distributed storage to maximize renewable energy penetration and reduce dependence on conventional fossil-fuel-based generation.

### *C. Electric Vehicle Integration*

The rapid increase in electric vehicle (EV) adoption has introduced both opportunities and challenges for modern microgrids. The figure illustrates the integration of electric vehicles (EVs) into a smart microgrid through an EV Energy Management System (EVEMS). The EVEMS coordinates EV charging/discharging, renewable energy sources, battery energy storage, the power grid, and consumer loads to ensure efficient energy management. It supports demand response, power distribution, and Vehicle-to-Grid (V2G) services, improving renewable energy utilization, grid stability, operational efficiency, and the overall reliability of the microgrid

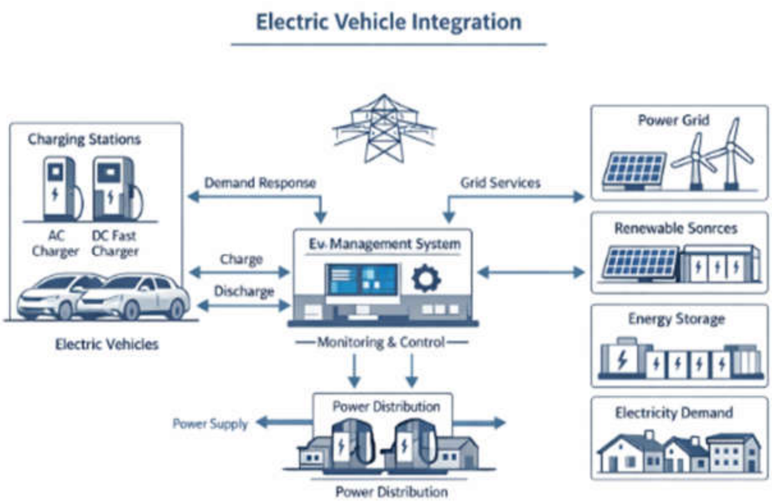


**Fig.2. Electric Vehicle Integration**

Advances in lithium-ion battery technology, decreasing battery costs, supportive government policies, and increasing environmental awareness have accelerated the deployment of EVs worldwide [20,21]. Although large-scale EV charging contributes to reducing greenhouse gas emissions in the transportation sector, uncontrolled charging may significantly increase peak electricity demand, overload distribution transformers, increase feeder losses, and deteriorate voltage profiles. Therefore, coordinated charging strategies have become essential for maintaining reliable and efficient microgrid operation. Intelligent charging scheduling based on demand response, time-of-use pricing, and real-time optimization enables EV charging during periods of high renewable energy generation or low electricity prices, thereby reducing operating costs and improving renewable energy utilization [22]. Furthermore, EV batteries can operate as distributed energy storage units capable of providing ancillary services such as peak shaving, frequency regulation, voltage support, and spinning reserve through bidirectional power flow. The integration of EV fleets with renewable-energy-based microgrids enhances operational flexibility, improves system resilience, and supports the transition toward carbon-neutral transportation systems. Nevertheless, battery degradation, charging infrastructure availability, communication latency, cybersecurity, and interoperability remain important research challenges requiring further investigation.

*D.* ***Vehicle-to-Grid (V2G) Technology***

The figure shows the integration of Electric Vehicles (EVs) into a microgrid through Vehicle-to-Grid (V2G) charging stations, enabling bidirectional power flow between EVs and the grid.

The system coordinates renewable energy, battery energy storage, and consumer loads to support demand response, grid services, and efficient power management. This integration enhances renewable energy utilization, improves grid stability and reliability, reduces operational costs, and promotes sustainable microgrid operation. Vehicle-to-Grid (V2G) technology has emerged as a promising solution for enhancing the flexibility and reliability of renewable-energy-based microgrids by enabling bidirectional power flow between electric vehicles (EVs) and the electrical grid.

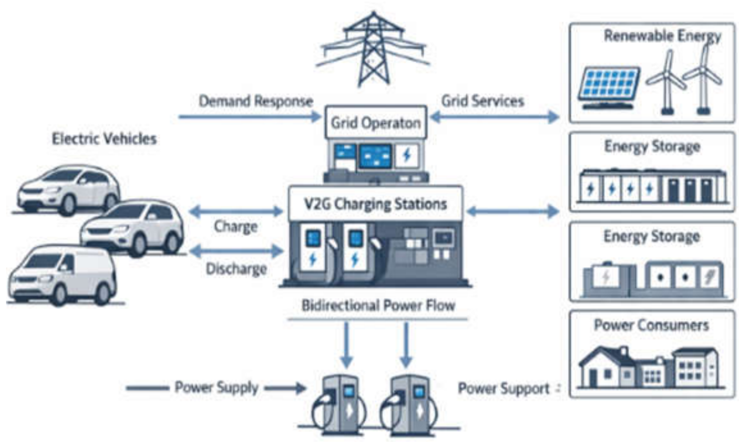


**Fig.3.Vehicle-to-Grid Technology**

Unlike conventional charging methods where EVs act solely as electrical loads, V2G allows EV batteries to discharge stored energy back to the grid during periods of peak demand and recharge during periods of surplus renewable energy generation [23,24]. This bidirectional operation improves renewable energy utilization, reduces peak demand, enhances voltage and frequency regulation, and provides ancillary services such as spinning reserve, reactive power compensation, and load balancing. Moreover, aggregated EV fleets can function as distributed energy storage systems, thereby reducing the need for large stationary battery installations and improving the economic operation of microgrids. Despite these advantages, practical implementation of V2G technology faces several challenges, including battery degradation, communication latency, charging infrastructure limitations, cybersecurity concerns, interoperability among different charging standards, and regulatory issues [25]. Consequently, recent research has focused on developing intelligent charging coordination algorithms and standardized communication protocols to facilitate large-scale deployment of V2G-enabled smart microgrids.

### *E.* ***Energy Management Strategies***

Energy Management Systems (EMS) are considered the central intelligence of renewable-energy-based microgrids because they coordinate distributed generation, battery energy storage systems, electric vehicle charging, and load demand while satisfying technical and economic constraints [26].

The figure illustrates an Energy Management System (EMS) that optimally coordinates renewable energy sources, battery storage, EV charging, and consumer loads in a smart microgrid. By integrating forecasting, optimization, and demand response, the EMS improves energy efficiency, reduces operational costs and emissions, enhances grid reliability, and maximizes renewable energy utilization.

The primary objectives of an EMS include minimizing operating cost, maximizing renewable energy utilization, reducing greenhouse gas emissions, maintaining voltage and frequency stability, and extending battery lifetime [27]. Conventional optimization approaches such as Linear Programming (LP), Mixed Integer Linear Programming (MILP), Dynamic Programming (DP), and Model Predictive Control (MPC) have been widely adopted for optimal scheduling of distributed resources.

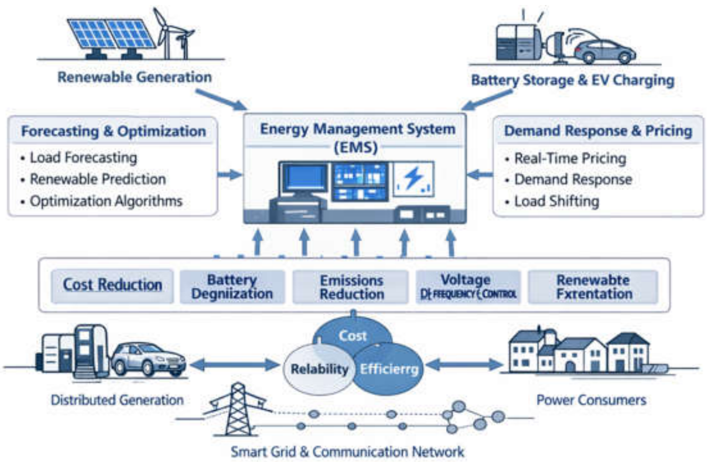


**Fig.4. Energy Management System**

Recently, stochastic optimization and robust optimization methods have been employed to address the uncertainties associated with renewable energy generation and EV charging behavior. Furthermore, demand response programs, real-time electricity pricing, and coordinated EV charging significantly improve system efficiency by shifting flexible loads to periods of high renewable generation. Intelligent EMS frameworks integrated with forecasting algorithms and distributed control have demonstrated superior performance in enhancing microgrid resilience and reducing operational costs under dynamic operating conditions.

### *F.* ***Power Electronic Converter Topologies***

Power electronic converters constitute the fundamental interface between renewable energy sources, battery energy storage systems, electric vehicles, and electrical loads within modern microgrids [28]. DC–DC converters, including boost, buck, buck–boost, SEPIC, Cuk, and bidirectional converters, are widely employed for voltage regulation, maximum power point tracking (MPPT), and battery charging applications [29]. Likewise, voltage source converters (VSCs), current source converters (CSCs), multilevel inverters, and modular multilevel converters (MMCs) are extensively used for DC–AC power conversion and grid synchronization [30]. Bidirectional converters are particularly important in Vehicle-to-Grid (V2G) applications because they facilitate seamless charging and discharging of EV batteries while maintaining high conversion efficiency and low harmonic distortion. Recent research has also focused on high-frequency isolated converters, wide-bandgap semiconductor devices based on silicon carbide (SiC) and gallium nitride (GaN), and soft-switching converter topologies to improve power density, efficiency, thermal performance, and reliability [31]. The integration of advanced converter technologies with intelligent control algorithms significantly enhances the overall performance, stability, and energy efficiency of renewable-energy-powered microgrids.

## III. Advanced Control and Performance Analysis

Advanced control techniques are vital for the reliable and efficient operation of RES-EV integrated microgrids by maintaining voltage stability, frequency regulation, and power quality while coordinating renewable energy sources, energy storage systems, and EV charging/discharging. Optimization algorithms and artificial intelligence (AI) improve energy management through real-time control, forecasting, and optimal scheduling. Performance is evaluated using metrics such as system efficiency, voltage and frequency deviations, total harmonic distortion (THD), power losses, operational cost, battery state of charge (SOC), renewable energy utilization, reliability, and carbon emission reduction, enabling the development of intelligent and sustainable microgrid systems.

### *A. Control Techniques*

Efficient control techniques are essential for ensuring the stable, reliable, and economical operation of renewable-energy-based microgrids integrated with electric vehicles (EVs). Due to the intermittent nature of renewable energy sources and the dynamic behavior of EV charging loads, advanced control strategies are required to maintain voltage regulation, frequency stability, power sharing, and system resilience [32]. Microgrid control is generally organized into three hierarchical levels: primary, secondary, and tertiary control. Primary control employs droop characteristics to regulate voltage and frequency without requiring communication among distributed generators, while secondary control restores voltage and frequency deviations caused by primary control actions. Tertiary control focuses on economic dispatch, energy optimization, and power exchange between the microgrid and the utility grid [33]. In recent years, distributed and decentralized control techniques based on multi-agent systems have gained considerable attention because they improve scalability, communication reliability, and fault tolerance [34]. Furthermore, adaptive control, Model Predictive Control (MPC), sliding mode control, fuzzy logic control, and robust control techniques have demonstrated superior performance in handling uncertainties associated with renewable generation and EV charging demand [35]. These intelligent control approaches significantly improve transient response, enhance power quality, reduce harmonic distortion, and increase the operational flexibility of modern microgrids.

### *B. Optimization Algorithms*

The figure shows the use of classical and metaheuristic optimization algorithms to manage renewable energy generation, EV charging, energy storage, and power consumption in microgrids. These algorithms optimize operational cost, battery performance, emissions, voltage regulation, and renewable energy utilization, resulting in improved efficiency, reliability, and sustainable microgrid operation.

Optimization techniques play a crucial role in the design and operation of renewable energy-based microgrids by minimizing operational cost while maximizing renewable energy utilization, system reliability, and energy efficiency [36]. Classical optimization methods such as Linear Programming (LP), Nonlinear Programming (NLP), Mixed Integer Linear Programming (MILP), and Dynamic Programming (DP) have been extensively employed for optimal scheduling of distributed generation, battery energy storage systems, and EV charging infrastructure [37].

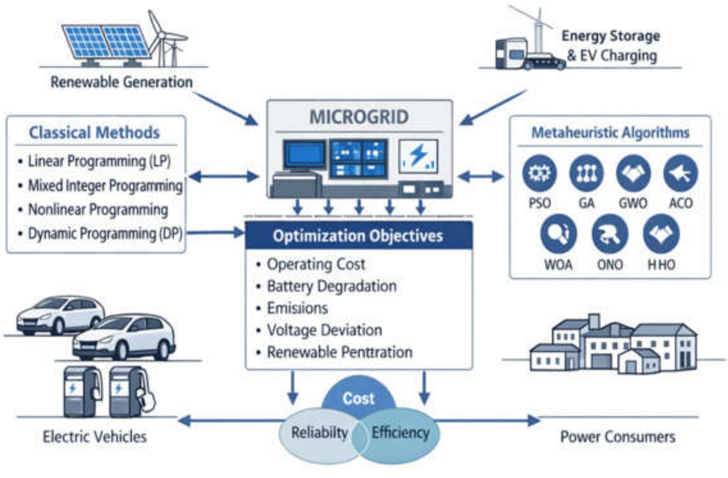


**Fig.5. Optimization Algorithms**

However, the nonlinear and stochastic characteristics of renewable generation have encouraged researchers to adopt metaheuristic optimization algorithms capable of solving complex multi-objective problems. Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Grey Wolf Optimizer (GWO), Ant Colony Optimization (ACO), Whale Optimization Algorithm (WOA), Differential Evolution (DE), and Harris Hawk Optimization (HHO) have demonstrated excellent convergence characteristics for economic dispatch, battery sizing, energy management, and power loss minimization [38,39]. Multi-objective optimization approaches simultaneously consider conflicting objectives such as operating cost, battery degradation, greenhouse gas emissions, voltage deviation, renewable energy penetration, and power quality, thereby providing balanced and practical solutions for real-world microgrid applications.

### C. *Artificial Intelligence Applications*

Artificial Intelligence (AI) has become one of the most promising technologies for improving the intelligence and autonomy of renewable-energy-powered microgrids.

The figure demonstrates the application of Artificial Intelligence (AI) and Machine Learning (ML) in smart microgrids for renewable energy forecasting, load prediction, EV charging coordination, fault detection, adaptive control, and energy management. Supported by technologies such as IoT, cloud computing, digital twins, edge computing, and blockchain, these AI-driven solutions improve forecasting accuracy, operational efficiency, system reliability, and the resilience of renewable energy-based microgrids.

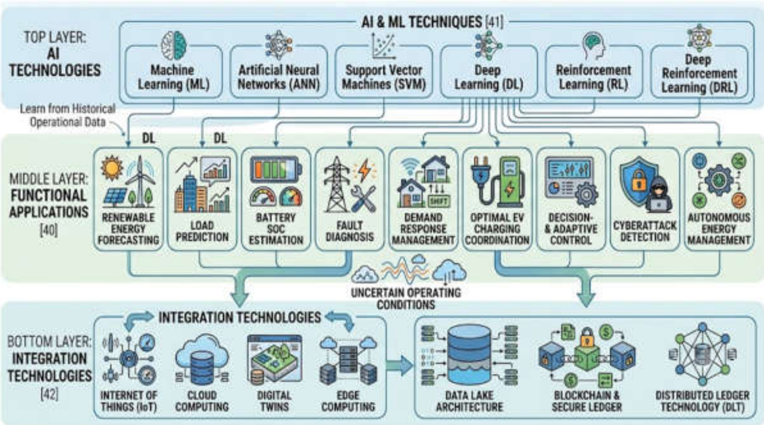


**Fig.6. AI Applications in Renewable**

AI-based techniques enable accurate renewable energy forecasting, load prediction, battery state-of-charge estimation, fault diagnosis, demand response management, and optimal EV charging coordination under uncertain operating conditions [40]. Machine Learning (ML), Artificial Neural Networks (ANN), Support Vector Machines (SVM), Deep Learning (DL), Reinforcement Learning (RL), and Deep Reinforcement Learning (DRL) have been successfully applied to enhance decision-making and adaptive control in modern microgrids [41]. AI algorithms are capable of learning from historical operational data, thereby improving prediction accuracy and reducing computational complexity compared with conventional optimization approaches. Moreover, the integration of AI with Internet of Things (IoT), cloud computing, digital twins, and edge computing facilitates real-time monitoring, predictive maintenance, cyberattack detection, and autonomous energy management [42]. These technologies significantly improve operational efficiency, increase renewable energy utilization, reduce operating costs, and enhance the resilience of future smart grids with high penetration of electric vehicles and distributed renewable generation.

### D. *Performance Analysis*

The performance of renewable-energy-based microgrids integrated with electric vehicles is commonly evaluated using technical, economic, and environmental performance indicators.

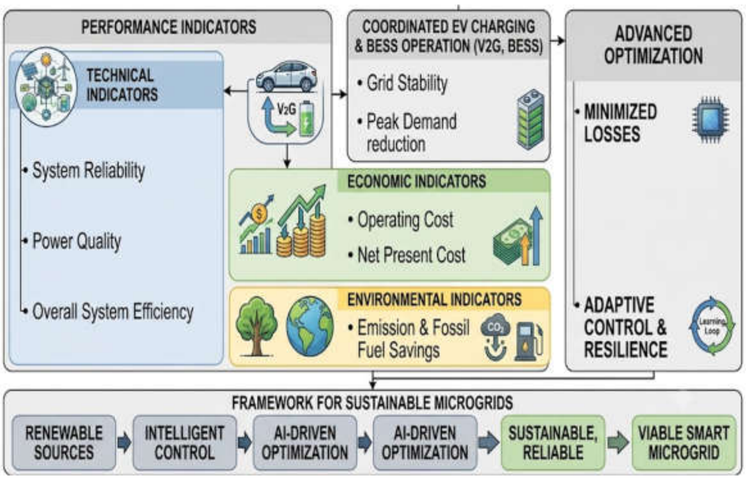


**Fig.7. performance analysis**

The figure illustrates the performance analysis of renewable energy-based microgrids integrated with electric vehicles (EVs) using technical, economic, and environmental indicators. Coordinated EV charging, Vehicle-to-Grid (V2G), and Battery Energy Storage Systems (BESS) enhance grid stability, reduce operational costs and emissions, improve energy efficiency, and support the development of sustainable, reliable, and intelligent smart microgrids.

Technical indices include voltage regulation, frequency stability, power quality, total harmonic distortion (THD), system reliability, renewable energy penetration, converter efficiency, battery state-of-charge, and overall system efficiency [43]. Economic performance is assessed through operating cost, electricity purchasing cost, battery replacement cost, net present cost, and levelized cost of energy (LCOE), whereas environmental performance is evaluated based on greenhouse gas emission reduction and fossil fuel savings [44]. Numerous studies have reported that coordinated EV charging combined with Vehicle-to-Grid (V2G) operation and Battery Energy Storage Systems (BESS) substantially improves renewable energy utilization, reduces peak demand, enhances grid stability, and minimizes operating costs . Furthermore, AI-assisted energy management systems integrated with advanced optimization algorithms have demonstrated superior performance in reducing energy losses, improving voltage profiles, minimizing battery degradation, and increasing system resilience under uncertain renewable generation and dynamic load conditions. Consequently, the integration of renewable energy sources, intelligent control strategies, advanced optimization techniques, and artificial intelligence provides an effective framework for developing sustainable, reliable, and economically viable smart microgrids.

## IV. Research Outlook

Future research should focus on intelligent energy management, artificial intelligence (AI), multi-objective optimization, Vehicle-to-Grid (V2G) coordination, battery health management, and cybersecurity to improve the efficiency, reliability, and sustainability of RES-EV integrated microgrids. These advancements will enable the development of resilient, flexible, and carbon-neutral smart energy systems.

### *A. **Research Gaps***

Despite significant advancements in renewable energy source (RES) integration, electric vehicle (EV) technologies, and microgrid operation, several research gaps remain unresolved. First, the intermittent nature of renewable energy and the stochastic charging behavior of EVs introduce considerable uncertainty into microgrid operation, requiring more accurate forecasting and uncertainty-aware energy management techniques [40,44]. Second, most existing Energy Management Systems (EMSs) optimize operational cost or energy efficiency independently, while limited studies simultaneously consider battery degradation, renewable energy utilization, carbon emissions, user charging preferences, and grid reliability using multi-objective optimization frameworks [36,44]. Third, although Vehicle-to-Grid (V2G) technology has demonstrated significant potential for providing ancillary services, large-scale practical implementation remains constrained by battery aging, inadequate charging infrastructure, interoperability issues, communication delays, and cybersecurity concerns. Furthermore, existing control techniques often rely on centralized architectures that may suffer from scalability limitations, single-point failures, and communication dependency in large microgrid networks [24]. Another important research gap is the limited application of digital twins, blockchain-enabled energy trading, federated learning, and edge intelligence for autonomous microgrid operation. Finally, standardized performance evaluation methodologies and benchmark datasets are still lacking, making it difficult to compare different control strategies, optimization algorithms, and artificial intelligence (AI)-based energy management approaches under identical operating conditions [31,44].

### *B. **Future Research Directions***

Future research should focus on developing intelligent, autonomous, and resilient microgrids capable of efficiently integrating high levels of renewable energy sources and large fleets of electric vehicles. Artificial Intelligence (AI), Deep Reinforcement Learning (DRL), and explainable machine learning techniques should be further explored for adaptive energy management, renewable energy forecasting, predictive maintenance, and autonomous decision-making under uncertain operating conditions [40]. The development of battery health-aware charging algorithms that simultaneously optimize battery lifetime, charging cost, and grid support services will become increasingly important with growing EV penetration [16]. Moreover, digital twin technology integrated with Internet of Things (IoT) sensors and cloud-edge computing can enable real-time monitoring, fault diagnosis, predictive analytics, and virtual testing of microgrid operation before physical implementation. Blockchain-based peer-to-peer energy trading platforms should also be investigated to facilitate secure, transparent, and decentralized energy transactions among prosumers, EVs, and utility operators. In addition, future research should emphasize distributed and decentralized control architectures, cyber-secure communication protocols, resilient microgrid protection schemes, and hybrid AC/DC microgrid configurations utilizing wide-bandgap semiconductor devices such as silicon carbide (SiC) and gallium nitride (GaN) for improved efficiency and reliability [28], [30]. Finally, comprehensive techno-economic and environmental assessment frameworks incorporating lifecycle analysis, carbon footprint evaluation, and battery recycling strategies are essential for the sustainable deployment of renewable-energy-powered smart microgrids.

## V. Conclusion

This paper presented a comprehensive review of renewable energy source integration with electric vehicles in modern microgrids, emphasizing recent developments in Vehicle-to-Grid (V2G) technology, energy management strategies, power electronic converter topologies, intelligent control techniques, optimization algorithms, artificial intelligence applications, and overall system performance. The review demonstrates that integrating photovoltaic systems, wind energy, battery energy storage systems, and coordinated EV charging significantly enhances renewable energy utilization, improves voltage and frequency regulation, reduces greenhouse gas emissions, and increases the operational flexibility of microgrids. Advanced Energy Management Systems combined with AI-based forecasting, hierarchical control strategies, and metaheuristic optimization algorithms have shown considerable potential for minimizing operating costs, reducing power losses, improving power quality, and enhancing system reliability under uncertain operating conditions. Nevertheless, challenges related to renewable energy intermittency, battery degradation, cybersecurity, communication infrastructure, interoperability, and large-scale V2G deployment continue to limit practical implementation. Future research should focus on intelligent distributed control, battery health-aware optimization, digital twins, blockchain-enabled energy trading, and AI-driven autonomous microgrids to achieve highly resilient, sustainable, and economically viable energy systems. Overall, the integration of renewable energy sources with electric vehicles is expected to play a pivotal role in the evolution of next-generation smart grids, supporting global decarbonization objectives and accelerating the transition toward a clean and sustainable energy future.

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