Control Systems and Optimization Letters, Vol. 3 No 2, 2025
ISSN: 2985-6116, DOI: 10.59247/csol.v3i2.202

Energy Management Strategies for Electric Vehicle Charging in Microgrids: A Case Study of Optimization Techniques

Khairul Bashar Akash [1], Mst Sumi Akter [2,*], Md Afrad Hasan Emon [3], Muhammad Meisam Kazmi [4],
Asm Mohaimenul Islam [5]
[1] Department of Computer Science and Technology, Hubei University of Automotive Technology, China
[2] Department of Electrical and Electronic Engineering, World University of Bangladesh, Dhaka, Bangladesh
[3] Department of Electrical and Electronic Engineering, European University of Bangladesh, Dhaka, Bangladesh
[4] School of Information Engineering, Southwest University of Science and Technology, China
[5] Department of Computer Science, University of South Dekota, USA
Email: [1] Khairulbasharakash@gmail.com, [2] sumiislam51@gmail.com, [3] afrademon@gmail.com,
[4] meisamkazmi61@gmail.com, [5] midipto72@gmail.com
*Corresponding Author

***Abstract*—The integration of Electric Vehicles (EVs) into microgrids presents both significant opportunities and complex challenges in energy management. As the adoption of EVs increases, efficient charging strategies become essential for maintaining grid stability, reducing energy costs, and maximizing the utilization of renewable energy sources. This review explores various optimization techniques applied to energy management in EV charging within microgrids, including deterministic approaches, stochastic programming, Model Predictive Control (MPC), game theory, machine learning, and heuristic/metaheuristic methods. Each technique is evaluated based on its strengths, weaknesses, and applicability to different system requirements, such as real-time responsiveness, adaptability to uncertainties, and scalability. Moreover, the paper identifies emerging trends and key research areas, such as hybrid optimization frameworks, decentralized energy markets, Vehicle-to-Grid (V2G) technology, and the integration of explainable AI for enhanced decision-making transparency. Additionally, challenges related to cybersecurity, resilience to system faults, and the integration of large-scale EV infrastructure are discussed. The paper concludes by highlighting the need for multi-objective optimization approaches that balance cost efficiency, user satisfaction, and grid reliability. With rapid advancements in EV technology and microgrid systems, research must focus on developing scalable and secure energy management solutions. While AI-driven methods show strong potential, real-world adoption faces challenges such as high costs, technical complexity, and integration issues. Practical applications highlight feasibility, but broader implementation demands further refinement.**

***Keywords*—Electric Vehicles (EVs), Microgrids, Energy Management, Optimization Techniques, Cybersecurity, Sustainability**

I. INTRODUCTION

Electric vehicles' (EVs') explosive expansion is changing contemporary energy networks, especially in the context of microgrids [1], [2]. A possible platform for combining EVs with distributed energy resources (DERs) like solar photovoltaics and battery storage systems is provided by microgrids, which are distinguished by their capacity to function either independently or in tandem with the main grid [3], [4]. Advanced solutions are needed to ensure system reliability, economic efficiency, and environmental sustainability due to the dynamic and unpredictable charging behavior of EVs in microgrid management [5]. Voltage instability, extreme demand peaks, and rapid electrical infrastructure deterioration may all be caused by disorganized EV charging [6]. Because microgrids must carefully balance fluctuating demands against restricted generating and storage capacity, these risks are increased. Numerous optimization strategies have been put out to manage EV charging in microgrids in order to overcome these difficulties.

These strategies seek to coordinate energy flows in a way that satisfies technical, financial, and user-centric goals [7]. With their own advantages and disadvantages, strategies including machine learning-based approaches, game theory, stochastic programming, and model predictive control (MPC) have been more popular in recent years [8]-[10]. Despite significant advancements, the current corpus of research is dispersed across various modeling methodologies, optimization goals, and presumptions about user behavior and renewable energy production [11], [12]. Without providing a comprehensive understanding of how these objectives overlap or clash, many studies concentrate on certain facets of the issue, such as reducing energy prices, optimizing the use of renewable energy, or maintaining grid stability.

Furthermore, the optimization environment is constantly changing due to the increased penetration of intermittent renewables and the increasing deployment of vehicle-to-grid (V2G) technologies, which introduce additional variables and uncertainties that existing models need to account for [13]. Given the rapid speed of development in this field and the crucial role that EVs will play in future smart grid ecosystems, it is essential to conduct a comprehensive evaluation of energy management strategies and optimization approaches to keep pace with ongoing technological advancements [14]. This review critically examines EV charging optimization in microgrids, highlighting methods, applications, challenges, trends, and future research directions.

II. MICROGRID ARCHITECTURE AND EV INTEGRATION

Localized energy systems known as microgrids may function both alone and in tandem with the wider grid [15]. They consist of a mix of load components, storage systems, and distributed energy resources (DERs), all of which are controlled by an energy management system (EMS) [16], [17]. Because it requires controlling the two-way energy flow between the EVs, the grid, and other energy resources in the microgrid, integrating EVs into microgrids offers both possibilities and problems [18]. In Fig. 1, illustrates a microgrid system comprising solar power generation, energy storage units (ESUs), electric vehicle charging stations, and integration with the utility grid. The design of microgrids and the function of EVs in the system, including how they are included into energy management plans, are described in this section.

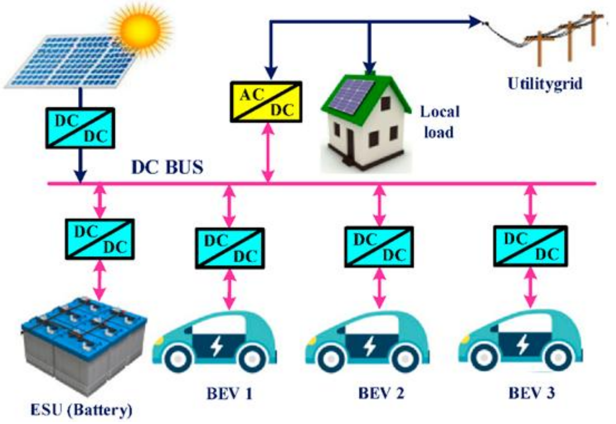

Fig. 1. Architecture of a microgrid with electric vehicle charging and energy storage units (ESU) [19]

A. Microgrids Architecture

A microgrid typically consists of the following key components:

- **Distributed Energy Resources (DERs)**: These include renewable energy sources (such as solar panels, wind turbines, or biomass) and conventional generation resources (like natural gas or diesel generators) [20]. These sources provide the energy needed to meet the demand within the microgrid. The amount of energy generated depends on the availability of renewable resources or the operational capacity of conventional generators.
- **Energy Storage Systems (ESS):** Energy storage devices such as batteries, flywheels, or supercapacitors are essential in microgrid architecture for storing excess energy generated during periods of low demand [21]. Storage systems help balance supply and demand, particularly when the microgrid relies on intermittent renewable energy sources. They also provide backup power during grid outages or when renewable generation is low.
- **Loads:** These are the consumers of the microgrid's energy, which can include residential, commercial, or industrial consumers [22]. The loads within the microgrid are dynamically managed by the energy management system to ensure efficient energy distribution.
- **Energy Management System (EMS):** The EMS is the central brain of the microgrid [23]. It monitors the performance of the microgrid, optimizes energy production, storage, and consumption, and ensures grid stability. It coordinates the operation of DERs, storage devices, and loads, making real-time decisions based on factors such as energy price, weather forecasts, and consumption patterns.
- **Grid Connection Point (PCC):** The point of common coupling (PCC) is where the microgrid connects to the larger utility grid [24]. This allows for the import or export of energy to the grid, enabling the microgrid to draw power during periods of high demand or export surplus energy when there is an excess of generation.

B. Electric Vehicle Integration into Microgrids

Microgrids are increasingly using electric vehicles (EVs) as dynamic loads and mobile energy storage devices [25]. Integrating electric vehicles into a microgrid offers significant advantages, such as accelerating renewable energy adoption, enabling surplus energy storage, and strengthening grid stability [26]. But there are also a lot of issues with this integration that need to be resolved with efficient energy management techniques. In Fig. 2, showed a microgrid system with renewable energy sources (solar and wind), base loads, electric vehicle charging, and integration with the central control and power grid.

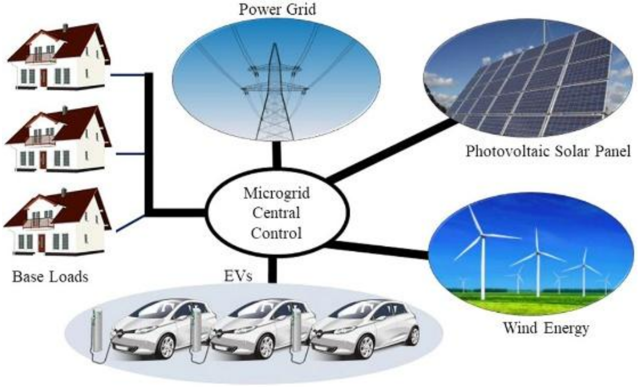

Fig. 2. Integration microgrid architecture with renewable energy sources and electric vehicle charging [27]

- **Energy Storage:** EVs equipped with large-capacity batteries can act as distributed energy storage systems within the microgrid [28]. They can charge when surplus renewable energy is available and discharge back into the microgrid when demand is high or renewable generation is insufficient. This concept, known as vehicle-to-grid (V2G) or vehicle-to-home (V2H), allows the EVs to provide grid services, such as frequency regulation and voltage support, enhancing the overall stability of the microgrid.
- **Flexible Loads:** As EVs are often plugged in for extended periods, they can serve as flexible loads within the microgrid. Charging schedules can be optimized to take advantage of low-cost or surplus renewable energy, thereby reducing energy costs and improving the efficiency of the microgrid. Additionally, EVs can be scheduled to charge during off-peak hours when grid demand is lower, helping to avoid congestion on the larger grid.
- **Demand Response:** EVs can participate in demand response programs by adjusting their charging patterns in

response to signals from the energy management system. For example, the EMS can delay or accelerate charging based on grid conditions, electricity prices, or the availability of renewable energy. This flexibility allows the microgrid to manage its overall demand more efficiently and reduce its reliance on fossil-fuel-based generation.

III. ENERGY MANAGEMENT STRATEGIES OVERVIEW

In order to ensure efficient, dependable, and sustainable operation, energy management strategies (EMS) for electric vehicle (EV) charging within microgrids are essential [29]. A well-designed EMS must match EV charging activities with microgrid goals, which include minimizing operational costs, maximizing the use of renewable energy sources, reducing peak demand, and maintaining grid stability. It is difficult to design effective strategies because these goals are diverse and frequently conflicting. Broadly, energy management strategies for EV charging in microgrids can be classified into four primary categories based on their dominant objectives:

A. Objectives of Energy Management Strategies

Electric vehicle (EV) charging optimization in microgrids is motivated by a number of interrelated goals that center on enhancing the system's technical and financial performance [30]. Well-thought-out solutions that can adjust to a range of circumstances are necessary due to the dynamic nature of EV charging and the integration of renewable energy sources. In addition to enhancing microgrid performance, these aims also try to match up with more general objectives like grid stability, sustainability, and cost effectiveness.

- **Cost Minimization:** One of the most important objectives in EMS for EV charging within microgrids is cost minimization. Microgrids typically rely on a mix of grid-supplied electricity and locally generated renewable energy, both of which have associated costs [31]. When EVs charge during peak periods or at times when renewable energy generation is low, the cost of electricity can rise significantly due to the reliance on higher-priced grid energy. By using advanced optimization techniques, EMS can schedule EV charging during off-peak hours when electricity is less expensive or when renewable energy production is abundant [32]. This reduces the dependency on expensive, grid-supplied electricity, leading to lower operational costs. In addition, when EVs are integrated with storage systems (such as battery storage), charging during periods of low energy demand (e.g., nighttime) can further optimize the energy consumption of the entire microgrid. The key here is to optimize charging schedules in alignment with energy pricing signals, thus reducing the overall electricity bill for microgrid operators and EV owners alike.
- **Peak Shaving and Load Balancing:** In order to avoid demand spikes that might put undue burden on the local microgrid infrastructure and the wider utility grid, peak shaving is an essential tactic [33]. EVs greatly increase the system's load when they charge concurrently or during times of high demand, which may lead to voltage instability and grid congestion. By spreading out EV charging across time, EMS hopes to mitigate this issue by balancing the demand curve and avoiding the system from experiencing periods of high load. By effectively matching power production from renewable resources (such solar or wind) with demand, load balancing reduces the need for imported energy. By diverting electricity to EVs when the generation surpasses the demand and storing the extra energy for later use, EMS may strategically postpone charging or modify the load during times of low renewable production.
- **Maximizing Renewable Energy Utilization:** Maximizing the use of renewable energy in EV charging is another crucial objective of EMS. Microgrids are increasingly relying on renewable energy sources like solar power and wind, which are intermittent by nature. When these resources are abundant, it is advantageous to use them for EV charging, thereby reducing reliance on conventional energy sources that are typically fossil-based [34]. EMS can prioritize charging EVs during periods of high renewable generation, thus minimizing the reliance on imported electricity. In many cases, the local renewable generation is a surplus, such as when there is excess solar power during the day. EVs can absorb this excess energy, which might otherwise be wasted, and store it in their batteries for later use. This not only enhances the sustainability of the system but also optimizes the microgrid's operational efficiency by making full use of the available renewable energy. Additionally, the integration of Vehicle-to-Grid (V2G) technology allows EVs to return power to the grid when renewable energy is scarce, providing a source of flexible storage and enabling the grid to rely on clean energy even when renewable generation is low. This two-way flow of energy contributes to the overall reliability and resilience of the microgrid, promoting a more sustainable energy ecosystem.
- **Grid Stability and Power Quality:** Maintaining power quality and ensuring grid stability are crucial goals for any microgrid system, particularly when EV integration is included. Unmanaged or disorganized EV charging may result in frequency imbalances, voltage swings, or even grid outages [35]. Transformer overloads brought on by an increase in EVs inside a microgrid may result in expensive repairs or even blackouts due to the unchecked demand. To avoid overloading, EMS must continuously check grid settings and modify charging patterns. This involves controlling the EV charging schedule to prevent unexpected spikes in power use. Additionally, by modifying EV charging in real-time in response to demand and renewable generation estimates, the EMS should be able to maintain a constant frequency and voltage across the grid. By doing this, the grid is able to handle variations from renewable energy sources, maintaining excellent electricity quality and preventing damage to nearby equipment.

B. Energy Management Strategies Approaches

Energy management strategies (EMS) in EV-integrated microgrids aim to balance supply and demand, optimize energy flow, and ensure grid stability, sustainability, and operational efficiency [36]. Table 1, provides a detailed comparative analysis of several optimization techniques commonly used in energy management systems. The table outlines the strengths, weaknesses, and best use cases of each technique, allowing for a deeper understanding of their applicability in different scenarios. Depending on the objectives, scalability, and resources available, several strategies and tactics are used to tackle the intricacies of EV charging, each providing a distinct solution.

Table 1. Comparative Analysis of Optimization Techniques for Energy Management in Microgrids

Techniques	Strengths	Weaknesses	Best Use Case
Model Predictive Control (MPC)	Can handle multi-variable control problems with constraints; optimizes future performance.	Requires an accurate model of the system and can be computationally demanding.	Control problems in dynamic systems such as robotics, autonomous vehicles, and industrial processes.
Stochastic Programming	Effectively handles uncertainty in optimization by modeling future uncertainties.	Computationally intensive and may require significant data.	Risk management, financial optimization, supply chain management, and energy systems.
Game Theory-Based Approaches	Ideal for decision-making in competitive or cooperative environments; analyzes strategic interactions.	Can be complex to model and solve, especially with many players and strategies.	Competitive market analysis, multi-agent systems, and negotiation-based applications.
Machine Learning and Reinforcement Learning	Learns from data and adapts to dynamic environments; great for problems with large datasets and non-linear relationships.	Requires substantial data and computational resources; no explicit model for decision-making.	Autonomous systems, recommendation systems, robotics, and predictive analytics.
Heuristic and Metaheuristic Methods	Efficient for large and complex problems; adaptable to a wide variety of problems.	May not guarantee optimal solutions and can be computationally expensive.	Combinatorial optimization, scheduling, traveling salesman problems, and other NP-hard problems.

1) *Centralized Vs Decentralized Approaches*

Energy management strategies can be broadly categorized into centralized and decentralized approaches, each with distinct characteristics. A single controller manages the whole microgrid system in centralized EMS [37]. This controller controls every facet of energy flow, including energy consumption, storage use, renewable energy production, and EV charging schedules. By analyzing all of the data from various system components, the central controller may make choices that maximize system performance and guarantee that EV charging takes place at the most cost-effective times.

In contrast, decentralized EMS distributes control among multiple agents within the microgrid. Each agent, such as an individual EV or local energy management system, operates based on its own data and local information. These agents make independent decisions about charging and energy use, coordinating with other agents when necessary. Individual parts may function independently while yet contributing to the system's overall optimization, which makes the decentralized method flexible and scalable. Without requiring a central controller, communication protocols may be used to govern agent coordination and make sure that each agent's choices are in line with the microgrid's overarching goals.

2) *Optimization Techniques*

Microgrids use a variety of optimization strategies to efficiently handle EV charging. These methods concentrate on enhancing system performance in real-time while accounting for variables like as energy use, the accessibility of renewable energy sources, and the requirements of specific EV users.

- **Model Predictive Control (MPC):** Sophisticated optimization method called Model Predictive Control (MPC) is utilized to manage microgrids, which includes EV charging [38]. In order to forecast future circumstances, including energy consumption and renewable production, MPC uses a dynamic model of the system. The controller uses these forecasts to calculate the best EV charging plan, taking into account variables like cost, grid stability, and energy supply. In order to update the control strategy as new information becomes available, MPC depends on solving an optimization problem over a predetermined time horizon. This guarantees effective energy utilization and lowers expenses by enabling the system to adjust to changing circumstances and continue operating at peak efficiency.
- **Stochastic Programming:** Stochastic programming is used to handle uncertainties in microgrid operations, particularly in relation to renewable energy generation and EV charging behavior [39]. This technique involves creating probabilistic models to account for the uncertainty in future states of the system. By considering multiple possible scenarios for factors like solar or wind energy production, stochastic programming finds a solution that performs well across all potential outcomes. This approach allows the system to manage risks and adapt to varying conditions by planning for different possible futures. It is particularly useful for managing the unpredictability of renewable energy and user behavior, ensuring that the system remains efficient even in the face of uncertainty.
- **Game Theory-Based Approaches:** Game theory is applied in EMS to manage the interactions between multiple agents in the system, such as EVs, storage devices, and the grid operator [40]. In a game-theoretic approach, each participant makes decisions based on their individual goals, such as minimizing charging costs or maximizing convenience. The system uses game theory to model these interactions and find an equilibrium where all participants' actions lead to optimal outcomes for the entire microgrid. Through strategic decision-making, game theory enables decentralized control of the system,

allowing each agent to make informed choices that align with the overall objectives of the microgrid. This approach can handle a variety of objectives, such as balancing cost reduction with maximizing renewable energy use.

- **Machine Learning and Reinforcement Learning:** To maximize EV charging in microgrids, machine learning (ML) and reinforcement learning (RL) approaches are being used more and more [41], [42]. Through trial and error and feedback based on its behaviors, an agent learns the best behavior via reinforcement learning. By continuously modifying its approach in response to the benefits or penalties it gets from the environment, the agent gradually improves its decision-making technique. When the system has to adjust to shifting circumstances, such shifting energy costs or variable renewable production, ML and RL are especially well-suited. By enabling real-time optimization, these techniques help the energy management system learn and improve over time.
- **Heuristic and Metaheuristic Methods:** Heuristic and metaheuristic algorithms, such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO), are commonly used to solve optimization problems in microgrids [43]. These methods are particularly effective for complex systems with multiple conflicting objectives, such as minimizing costs while maintaining grid stability.

IV. CYBER-PHYSICAL RESILIENCE IN ENERGY MANAGEMENT SYSTEMS

Advanced energy management techniques that take into consideration the intricacies of energy optimization as well as the system's resilience to different threats are necessary for the integration of electric vehicles (EVs) into microgrids [44]. These dangers may include physical disturbances like hardware failures or power outages as well as cyberattacks that target communication networks. The Fig. 3, illustrates the power generation sources (solar, thermal, hydro, wind, nuclear), transmission and distribution systems, control center, and connections to consumers and storage units. The capacity of the system to carry on operating efficiently in spite of these difficulties is known as cyber-physical resilience, and it guarantees the dependability, safety, and security of the complete microgrid infrastructure. To achieve robust cyber-physical resilience in energy management systems (EMS), several critical strategies must be employed:

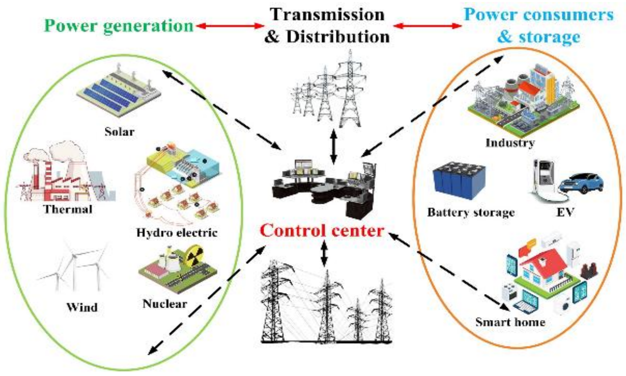

Fig. 3. Power generation, transmission, and distribution system with consumers and storage integration [45]

- **Anomaly Detection and Predictive Analytics:** Anomaly detection plays a pivotal role in identifying potential cyber-attacks or system malfunctions in real-time. By leveraging machine learning algorithms, such as supervised learning or deep learning models, the system can detect unusual patterns in energy consumption, EV charging behaviors, or network traffic. Predictive analytics further enhances resilience by forecasting potential failures before they occur, allowing for proactive measures such as system shutdowns, rerouting, or fault isolation. This can drastically reduce downtime and mitigate the impact of threats. Machine learning models trained on historical data can be used to predict load spikes or unusual charging patterns, signaling potential cyber threats or system failures.
- **Fault-Tolerant Control Algorithms:** Fault-tolerant control algorithms are designed to ensure that an energy management system can still operate effectively even when parts of the system experience failure or degraded performance. In the context of microgrids, these algorithms allow the system to continue managing EV charging operations even during faults in energy production (e.g., a renewable energy source failure) or power distribution (e.g., a transformer malfunction). Techniques such as fault detection and isolation (FDI) and reconfiguration strategies can help isolate affected areas and prevent widespread failure. If a renewable energy source like a solar panel experiences a malfunction, the control system can automatically adjust charging schedules based on available energy from backup storage or the grid.
- **Robust Optimization Models:** Optimization models for energy management must be designed to operate under conditions of uncertainty, such as fluctuating renewable energy generation, unpredictable EV arrival times, or potential cyber disruptions. By incorporating risk management into the optimization process, robust optimization ensures that the system can maintain efficient operations even when facing unexpected disturbances. These models account for worst-case scenarios, enabling the EMS to make decisions that minimize the likelihood of disruptions. A robust optimization model can prioritize critical infrastructure (e.g., hospitals or emergency services) in the event of an energy shortage while minimizing energy costs during normal operations.
- **Redundant Communication and Control Infrastructure:** The integrity of communication and control systems is critical for maintaining stable and reliable microgrid operations. Redundancy in communication channels and control infrastructure helps prevent failures from single points of attack or malfunction. Using techniques such as distributed control, blockchain for secure transactions, and multiple communication pathways (e.g., wired, wireless, and satellite) ensures that even if one channel is compromised, others can maintain secure and accurate control over the system. A dual-layer communication network can allow for seamless transition between primary and backup systems, ensuring that EV charging operations continue without interruption during communication failures.

- **Adaptive Response and Self-Healing Mechanisms:** Self-healing mechanisms allow microgrids to dynamically adjust and recover from faults. These mechanisms enable the system to detect failures and automatically reroute power flows, adjust charging schedules, or reallocate resources. Additionally, adaptive response strategies ensure that the system learns from past failures, improving its ability to predict and respond to similar threats in the future. In case of a detected attack on the EMS or a natural disaster that damages infrastructure, the system could automatically reduce non-essential loads, prioritize critical infrastructure, and shift to more resilient energy sources such as stored battery power or backup generators.
- **Cybersecurity Best Practices:** Given the increasing threat of cyber-attacks, robust cybersecurity measures must be integrated into the EMS to protect against malicious activity. These measures include data encryption, multi-factor authentication, secure access controls, and continuous monitoring for vulnerabilities. Regular penetration testing and vulnerability assessments can identify potential weaknesses before they are exploited, ensuring the long-term security of the EMS. Implementing a zero-trust architecture, where every user and device must be authenticated and authorized before accessing any part of the system, ensures that unauthorized access is minimized.
- **Integration of Security and Energy Management:** The integration of energy management systems with security protocols is essential for cyber-physical resilience. Ensuring that both domains (security and energy management) work together allows for a holistic approach where operational decisions are made with both security and energy optimization in mind. This can be achieved by embedding security algorithms directly into the energy management layer, enabling rapid response to both energy demands and security threats.

V. FUTURE RESEARCH DIRECTIONS

The dynamic nature of the energy and transportation sectors presents a number of issues that must be addressed for microgrid energy management in the future, especially with the incorporation of electric vehicles (EVs). Hybrid optimization frameworks, which integrate many approaches including deterministic, stochastic, and data-driven methods to improve EV charging management while balancing different system constraints, represent a potential research direction. Peer-to-peer (P2P) and decentralized energy trading methods are essential as decentralized energy markets expand. By enabling safe and equitable energy transactions between prosumers and the grid, blockchain technology and game theory may improve grid efficiency and resilience. Explainable AI is another important research topic that guarantees the interpretability, transparency, and reliability of machine learning models in energy management. Scalable optimization methods that can effectively manage bigger, more complicated systems will be crucial as microgrids expand in size to address the increasing number of EVs and grid interactions.

- Combine multiple optimization techniques (deterministic, stochastic, and data-driven) to enhance EV charging management.
- Leverage blockchain and game theory to enable fair, secure energy trading and improve grid resilience.
- Develop interpretable machine learning models to improve transparency and trust in energy management systems.
- Create models that can handle the increasing complexity of microgrids and large-scale EV adoption.
- Optimize V2G systems to allow EVs to contribute power to the grid during peak periods, ensuring grid stability.
- Balance trade-offs between cost, grid stability, renewable energy use, and user satisfaction in charging strategies.
- Develop smart charging networks and integrate energy storage systems to support renewable energy and EV charging needs.

VI. CONCLUSION

In conclusion, integrating Electric Vehicles (EVs) into microgrids is a complex yet promising endeavor for modern energy management systems. As EV adoption accelerates, the need for efficient and scalable strategies becomes increasingly critical to address dynamic energy demand, renewable generation variability, and grid conditions. Among current optimization methods, Model Predictive Control (MPC) stands out for its real-time adaptability, stochastic programming for handling uncertainty, and machine learning for predictive capabilities. While each offers unique strengths, none alone provides a universal solution. Future research should focus on hybrid frameworks that combine these strengths to address diverse operational needs. In addition, peer-to-peer energy trading and blockchain offer promising tools for decentralized energy distribution, while Vehicle-to-Grid (V2G) technologies can enhance flexibility by enabling EVs to act as mobile storage units. Ensuring system resilience to failures and cyber threats is equally vital, with fault-tolerant controls and explainable AI offering paths to transparent, secure decision-making. Ultimately, a multifaceted approach combining hybrid optimization, V2G integration, decentralized markets, and robust control will be key to unlocking affordable, reliable, and sustainable energy solutions in the evolving smart grid landscape.

REFERENCES

[1] M. R. Khan, Z. M. Haider, F. H. Malik, F. M. Almasoudi, K. S. S. Alatawi and M. S. Bhutta, “A comprehensive review of microgrid energy management strategies considering electric vehicles, energy storage systems, and AI techniques,” *Processes*, vol. 12, no. 2, p. 270, 2024, https://doi.org/10.3390/pr12020270.

[2] A. Uzzaman and W. Muhammad, “A Comprehensive Review of Environmental and Economic Impacts of Autonomous Vehicles,” *Control Systems and Optimization Letters*, vol. 2, no. 3, pp. 303-309, 2024, https://doi.org/10.59247/csol.v2i3.131.

[3] T. Saha, A. Haque, M. A. Halim, and M. M. Hossain, “A review on energy management of community microgrid with the use of adaptable renewable energy sources,” *International Journal of Robotics and Control Systems*, vol. 3, no. 4, pp. 824-838, 2023, https://doi.org/10.31763/ijrcs.v3i4.1009.

[4] L. Strezoski and I. Stefani, “Enabling mass integration of electric vehicles through distributed energy resource management systems,” *International Journal of Electrical Power & Energy Systems*, vol. 157, pp. 109798, 2024, https://doi.org/10.1016/j.ijepes.2024.109798.

[5] C. K. Carberry and J. E. Rager, "The impact of environmental contaminants on extracellular vesicles and their key molecular regulators: A literature and database-driven review," *Environmental and molecular mutagenesis*, vol. 64, no. 1, pp. 50-66, 2023, https://doi.org/10.1002/em.22522.

[6] Y. Jang *et al*., "Grid-connected inverter for a PV-powered electric vehicle charging station to enhance the stability of a microgrid," *Sustainability*, vol. 13, no. 24, p. 14022, 2021, https://doi.org/10.3390/su132414022.

[7] N. Himabindu, S. Hampannavar, B. Deepa, and M. Swapna, "Analysis of microgrid integrated Photovoltaic (PV) Powered Electric Vehicle Charging Stations (EVCS) under different solar irradiation conditions in India: A way towards sustainable development and growth," *Energy reports*, vol. 7, pp. 8534-8547, 2021, https://doi.org/10.1016/j.egyr.2021.10.103.

[8] V. Ashokkumar and C. B. Venkatramanan, "PSO-ANFIS-Based Energy Management in Hybrid AC/DC Microgrid along with Plugin Electric Vehicle," *International Journal of Photoenergy*, vol. 2023, no. 1, p. 2852972, 2023, https://doi.org/10.1155/2023/2852972.

[9] P. L. Nguyen *et al*., "Strategic EV Charging Optimization Using Stackelberg and Non-Cooperative Game Models for Cost Efficiency and Profit Maximization with Renewable Energy and Battery Storage," *Smart Grids and Sustainable Energy*, vol. 10, no. 1, p. 26, 2025, https://doi.org/10.1007/s40866-025-00255-3.

[10] E. O. Arwa, "Reinforcement learning for power scheduling in a grid-tied pv-battery electric vehicles charging station," *Open UCT*, 2021, http://hdl.handle.net/11427/36821.

[11] S. Cheikh-Mohamad, M. Sechilariu, and F. Locment, "Real-time power management including an optimization problem for PV-powered electric vehicle charging stations," *Applied Sciences*, vol. 12, no. 9, p. 4323, 2022, https://doi.org/10.3390/app12094323.

[12] E. Khatun, M. M. Hossain, M. S. Ali, and M. A. Halim, "A Review on Microgrids for Remote Areas Electrification-Technical and Economical Perspective," *International Journal of Robotics & Control Systems*, vol. 3, no. 4, 2023, https://doi.org/10.31763/ijrcs.v3i4.985.

[13] V. Blazek *et al*., "A novel approach to utilization vehicle to grid technology in microgrid environment," *International Journal of Electrical Power & Energy Systems*, vol. 158, p. 109921, 2024, https://doi.org/10.1016/j.ijepes.2024.109921.

[14] M. R. H. Mojumder, F. Ahmed Antara, M. Hasanuzzaman, B. Alamri, and M. Alsharef, "Electric vehicle-to-grid (V2G) technologies: Impact on the power grid and battery," *Sustainability*, vol. 14, no. 21, p. 13856, 2022, https://doi.org/10.3390/su142113856.

[15] M. A. Halim, M. M. Hossain, and M. J. Nahar, "Development of a Nonlinear Harvesting Mechanism from Wide Band Vibrations," *International Journal of Robotics and Control Systems*, vol. 2, no. 3, pp. 467-476, 2022, https://doi.org/10.31763/ijrcs.v2i3.524.

[16] L. Strezoski, "Distributed energy resource management systems—DERMS: State of the art and how to move forward," *Wiley Interdisciplinary Reviews: Energy and Environment*, vol. 12, no. 1, p. e460, 2023, https://doi.org/10.1002/wene.460.

[17] A. Kudzin, S. Takayama, and A. Ishigame, "Energy Management Systems (EMS) for a Decentralized Grid: A Review and Analysis of the Generation and Control Methods Impact on EMS Type and Topology," *IET Renewable Power Generation*, vol. 19, no. 1, p. e70008, 2025, https://doi.org/10.1049/rpg2.70008.

[18] H. Masrur, M. Shafie-Khah, M. J. Hossain and T. Senjyu, "Multi-Energy Microgrids Incorporating EV Integration: Optimal Design and Resilient Operation," *IEEE Transactions on Smart Grid*, vol. 13, no. 5, pp. 3508-3518, 2022, https://doi.org/10.1109/TSG.2022.3168687.

[19] D. A. Savio, V. A. Juliet, B. Chokkalingam, S. Padmanaban, J. B. Holm-Nielsen, and F. Blaabjerg, "Photovoltaic integrated hybrid microgrid structured electric vehicle charging station and its energy management approach," *Energies*, vol. 12, no. 1, p. 168, 2019, https://doi.org/10.3390/en12010168.

[20] F. Gulotta, E. Daccò, A. Bosisio, and D. Falabretti, "Opening of ancillary service markets to distributed energy resources: A review," *Energies*, vol. 16, no. 6, p. 2814, 2023, https://doi.org/10.3390/en16062814.

[21] H. Pan, X. Feng, F. Li, and J. Yang, "Energy coordinated control of DC microgrid integrated incorporating PV, energy storage and EV charging," *Applied Energy*, vol. 342, p. 121155, 2023, https://doi.org/10.1016/j.apenergy.2023.121155.

[22] Y. Huang *et al*., "Multi-objective optimization of campus microgrid system considering electric vehicle charging load integrated to power grid," *Sustainable Cities and Society*, vol. 98, p. 104778, 2023, https://doi.org/10.1016/j.scs.2023.104778.

[23] S. Vuddanti and S. R. Salkuti, "Review of energy management system approaches in microgrids," *Energies*, vol. 14, no. 17, p. 5459, 2021, https://doi.org/10.3390/en14175459.

[24] S. Ahmad, H. Mubarak, U. K. Jhuma, T. Ahmed, S. Mekhilef, and H. Mokhlis, "Point of Common Coupling Voltage Modulated Direct Power Control of Grid-Tied Photovoltaic Inverter for AC Microgrid Application," *International Transactions on Electrical Energy Systems*, vol. 2023, no. 1, pp. 3641907, 2023, https://doi.org/10.1155/2023/3641907.

[25] A. Abuelrub, F. Hamed, J. Hedel and H. M. K. Al-Masri, "Feasibility Study for Electric Vehicle Usage in a Microgrid Integrated with Renewable Energy," *IEEE Transactions on Transportation Electrification*, vol. 9, no. 3, pp. 4306-4315, 2023, https://doi.org/10.1109/TTE.2023.3243237.

[26] V. Nikam and V. Kalkhambkar, "A review on control strategies for microgrids with distributed energy resources, energy storage systems, and electric vehicles," *International Transactions on Electrical Energy Systems*, vol. 31, no. 1, p. e12607, 2021, https://doi.org/10.1002/2050-7038.12607.

[27] L. Yazdi, R. Ahadi and B. Rezaee, "Optimal Electric Vehicle Charging Station Placing with Integration of Renewable Energy," *2019 15th Iran International Industrial Engineering Conference (IIIEC)*, pp. 47-51, 2019, https://doi.org/10.1109/IIIEC.2019.8720644.

[28] R. M. Salgado, F. Danzi, J. E. Oliveira, A. El-Azab, P. P. Camanho, and M. H. Braga, "The latest trends in electric vehicles batteries," *Molecules*, vol. 26, no. 11, p. 3188, 2021, https://doi.org/10.3390/molecules26113188.

[29] P. J. Chacko and M. Sachidanandam, "An optimized energy management system for vehicle to vehicle power transfer using micro grid charging station integrated Gridable Electric Vehicles," *Sustainable Energy, Grids and Networks*, vol. 26, p. 100474, 2021, https://doi.org/10.1016/j.segan.2021.100474.

[30] A. F. Güven, & E. Yücel, "Sustainable energy integration and optimization in microgrids: enhancing efficiency with electric vehicle charging solutions," *Electrical Engineering*, pp. 1-33, 2024, https://doi.org/10.1007/s00202-024-02619-x.

[31] O. Aldosari, Z. M. Ali, S. H. Abdel Aleem, and M. H. Mostafa, "Optimizing microgrid performance: Strategic integration of electric vehicle charging with renewable energy and storage systems for total operation cost and emissions minimization," *Plos one*, vol. 19, no. 10, p. e0307810, 2024, https://doi.org/10.1371/journal.pone.0307810.

[32] H. I. Shaheen, G. I. Rashed, B. Yang, and J. Yang, "Optimal electric vehicle charging and discharging scheduling using metaheuristic algorithms: V2G approach for cost reduction and grid support," *Journal of Energy Storage*, vol. 90, p. 111816, 2024, https://doi.org/10.1016/j.est.2024.111816.

[33] M. M. Rana, M. F. Romlie, M. F. Abdullah, M. Uddin, and M. R. Sarkar, "A novel peak load shaving algorithm for isolated microgrid using hybrid PV-BESS system," *Energy*, vol. 234, p. 121157, 2021, https://doi.org/10.1016/j.energy.2021.121157.

[34] A. Hirsch, Y. Parag, and J. Guerrero, "Microgrids: A review of technologies, key drivers, and outstanding issues," *Renewable and sustainable Energy reviews*, vol. 90, pp. 402-411, 2018, https://doi.org/10.1016/j.rser.2018.03.040.

[35] A. Tavakoli *et al*., "Impacts of grid integration of solar PV and electric vehicle on grid stability, power quality and energy economics: A review," *IET Energy Systems Integration*, vol. 2, no. 3, pp. 243-260, 2020, https://doi.org/10.1049/iet-esi.2019.0047.

[36] H. Pan, X. Feng, F. Li, and J. Yang, "Energy coordinated control of DC microgrid integrated incorporating PV, energy storage and EV charging," *Applied Energy*, vol. 342, p. 121155, 2023, https://doi.org/10.1016/j.apenergy.2023.121155.

[37] C. L. Bhattar and M. A. Chaudhari, "Centralized Energy Management Scheme for Grid Connected DC Microgrid," *IEEE Systems Journal*, vol. 17, no. 3, pp. 3741-3751, 2023, https://doi.org/10.1109/JSYST.2022.3231898.

[38] C. Wu, S. Gao, Y. Liu, T. E. Song, and H. Han, “A model predictive control approach in microgrid considering multi-uncertainty of electric vehicles,” *Renewable Energy*, vol. 163, pp. 1385-1396, 2021, https://doi.org/10.1016/j.renene.2020.08.137.

[39] F. Garcia-Torres, C. Bordons, J. Tobajas, R. Real-Calvo, I. Santiago and S. Grieu, "Stochastic Optimization of Microgrids with Hybrid Energy Storage Systems for Grid Flexibility Services Considering Energy Forecast Uncertainties," *IEEE Transactions on Power Systems*, vol. 36, no. 6, pp. 5537-5547, 2021, https://doi.org/10.1109/TPWRS.2021.3071867.

[40] W. Liao, F. Xiao, Y. Li, & J. Peng, “Comparative study on electricity transactions between multi-microgrid: A hybrid game theory-based peer-to-peer trading in heterogeneous building communities considering electric vehicles,” *Applied Energy*, vol. 367, p. 123459, 2024, https://doi.org/10.1016/j.apenergy.2024.123459.

[41] M. J. Salehpour, and M. J. Hossain, “Leveraging machine learning for efficient EV integration as mobile battery energy storage systems: Exploring strategic frameworks and incentives,” *Journal of Energy Storage*, vol. 92, p. 112151, 2024, https://doi.org/10.1016/j.est.2024.112151.

[42] P. I. N. Barbalho, A. L. Moraes, V. A. Lacerda, P. H. A. Barra, R. A. S. Fernandes and D. V. Coury, "Reinforcement Learning Solutions for Microgrid Control and Management: A Survey," *IEEE Access*, vol. 13, pp. 39782-39799, 2025, https://doi.org/10.1109/ACCESS.2025.3546578.

[43] H. I. Shaheen, G. I. Rashed, B. Yang, and J. Yang, “Optimal electric vehicle charging and discharging scheduling using metaheuristic algorithms: V2G approach for cost reduction and grid support,” *Journal of Energy Storage*, vol. 90, p. 111816, 2024, https://doi.org/10.1016/j.est.2024.111816.

[44] N. Bhusal, M. Gautam and M. Benidris, "Cybersecurity of Electric Vehicle Smart Charging Management Systems," *2020 52nd North American Power Symposium (NAPS)*, pp. 1-6, 2021, https://doi.org/10.1109/NAPS50074.2021.9449758.

[45] S. Suprabhath Koduru, V. S. P. Machina, and S. Madichetty, “Cyber attacks in cyber-physical microgrid systems: A comprehensive review,” *Energies*, vol. 16, no. 12, p. 4573, 2023, https://doi.org/10.3390/en16124573.