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Enhance Energy Management in Vehicle to Grid Systems with Blockchain and Machine Learning

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ABSTRACT

This study explores the integration of blockchain technology and reinforcement learning within Vehicle-to-Grid (V2G) systems to enhance energy management, operational efficiency, and sustainability. With the growing adoption of electric vehicles (EVs) and renewable energy sources, there is a pressing need for decentralized energy solutions that can handle dynamic energy exchanges reliably and securely. To address this, we propose a decentralized V2G framework where blockchain-enabled smart contracts facilitate automated, transparent, and tamper-proof transactions among EVs, grid operators, and distributed energy resources. This approach reduces dependency on centralized control, enhances trust among participants, and improves the scalability of energy trading systems. In parallel, reinforcement learning algorithms are employed to optimize the charging and discharging behaviour of EV batteries based on real-time grid conditions, energy prices, and usage patterns. This adaptive learning mechanism not only maximizes battery longevity and energy efficiency but also contributes to overall grid stability and flexibility. The proposed model is evaluated against key performance metrics, including transaction latency, energy efficiency, demand response capability, and system resilience. Our findings highlight that the synergy between blockchain and reinforcement learning offers a promising pathway for building intelligent, adaptive, and secure V2G systems. By combining the transparency and decentralization of blockchain with the adaptability of machine learning, the framework addresses limitations inherent in traditional centralized energy management. This research contributes a structured approach and a technological roadmap toward developing next-generation V2G infrastructures that are robust, scalable and aligned with global sustainability goals.

1. Introduction

Decentralized energy management enables energy producers and consumers to actively participate in the production, trading and regulation of energy [1]. This marks a substantial shift away from the conventional centralized energy grid system. Technological advancements such as the integration of blockchain and machine learning have driven this shift towards decentralization. These

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innovations offer possibilities for improving the energy flow and optimizing operations in distributed energy systems [2]. Decentralized energy management plays a crucial role in influencing the growth of renewable energy sources, enhancing energy efficiency and reducing reliance on centralized energy grids [3]. Wu *et al.,* [4] are enabling individual energy producers, including homes and companies, to actively participate in energy generation and trading, decentralized energy management contributes to the development of a stronger and more sustainable energy landscape. This approach promotes the growth of energy generation, leading to greater utilization of eco-friendly energy sources, such as solar, wind and hydroelectric power, at the community level. Additionally, Rahim *et al.,* [5] showed that localizing the production and distribution of energy improves the flexibility and durability of the energy infrastructure, lessens the effects of disruptions and reduces reliance on large-scale energy systems. Decentralized energy management holds significance because it has the potential to enhance energy efficiency through the utilization of demand-side management and localized decision-making [6].

Additionally, the incorporation of machine learning algorithms into decentralized energy management systems enables real-time energy optimization, load forecasting and predictive analytics. This integration not only enhances efficiency but also reduces costs within a distributed energy network [7]. Despite the implementation of decentralized energy management as a beneficial solution, this is not without difficulties. Addressing these challenges requires innovative solutions and structures to overcome their main obstacles.

Also, Ma *et al.,* [8] investigates the distribution of electric vehicle charging stations (EVCSs) and establishes a correlation between this distribution and the demand for EVs. Utilizing the Pearson Correlation method allows for a robust statistical analysis of how the availability of charging infrastructure affects EV adoption rates.

Farid *et al.,* [9] proposing optimized thermal management solutions, the research addresses critical aspects of battery reliability and safety. Enhanced thermal performance directly correlates with improved safety measures and operational efficiency in EV applications.

One of the key hurdles is establishing secure and transparent transactions within decentralized energy networks [10]. This necessitates the use of reliable techniques to verify energy transactions, safeguard data integrity and prevent potential security risks and fraudulent behaviour, considering the decentralized and peer-to-peer nature of energy trading and management. One pressing issue that must be tackled in decentralized energy management frameworks is the effective handling of the data. For meaningful analysis and precise decision-making, it is vital to gather, store and analyse the data generated by distributed energy networks efficiently [3]. This includes insights into consumption patterns, energy production measurements and market price data. Moreover, for seamless integration and collaboration within a decentralized energy system, it is imperative to establish stable data exchange protocols and standardized interfaces to enable interoperability between different energy management systems and devices [4]. Moreover, Nabil *et al.,* [11] proposed algorithm utilizes more than one encryption algorithm concurrently, differing from conventional methods that rely on a single encryption technique. This multiplicity introduces a layer of complexity and strengthens the security framework by making it harder for potential attackers to compromise the encrypted data Considering these factors, this study introduces a new approach to tackle the challenges and leverage the advantages of decentralized energy management. The proposed method involves merging blockchain technology with machine-learning algorithms. The main objective is to enhance the effectiveness of decentralized energy management by integrating cutting-edge computational intelligence with distributed ledger technology. This will establish a strong, streamlined and long-lasting energy framework in the future.

The primary objective of this study is to integrate machine learning and blockchain technology into vehicle-to-grid (V2G) systems, as shown in Figure 1. The figure effectively demonstrates the essential components and their connections within the framework, including the implementation of smart contracts, application of blockchain-based reinforcement learning methods, automation of energy transactions and improvement of electric vehicle battery performance. Additionally, the diagram depicts the interactions between electric vehicles, grid operators and renewable energy providers in the proposed blockchain-facilitated V2G ecosystem. This representation provides a clear understanding of the underlying concepts in the framework.

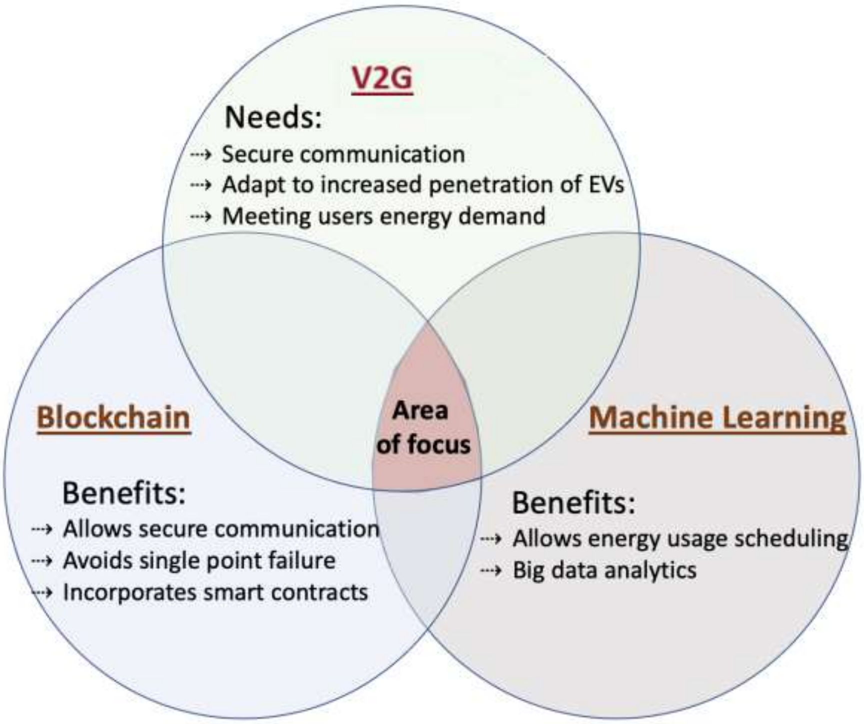

Fig. 1. Scope of the research

This study focused on integrating Blockchain and RL, as shown in Figure 1. The combination of blockchain technology and reinforcement learning (RL) in V2G systems is a novel integration of digital advancements that seek to transform energy management. Blockchain technology offers a reliable, open and distributed system for carrying out energy transactions, guaranteeing the accuracy of data and fostering trust among participants. When combined with Reinforcement Learning (RL), a branch of machine learning that enhances decision-making by interacting with an environment, integration enhances the system's capacity to adapt and optimize energy flows in real time. In the context of V2G, blockchain technology can independently verify and document transactions. Reinforcement Learning (RL) algorithms can constantly acquire knowledge and enhance battery charging and discharging strategies using both historical and real-time data. This collaboration enables the development of a self-enhancing system that not only supports effective energy distribution and usage but also prolongs the lifespan of electric vehicle batteries. An essential factor in expanding V2G capabilities to meet future needs is the implementation of a forward-thinking strategy that allows more intelligent and flexible energy ecosystems.

The framework incorporates blockchain technology to ensure the safe, transparent and tamper-proof storage of data and execution of smart contracts, facilitating trust in fewer energy transactions and administration. Machine learning algorithms are used to analyse patterns of energy consumption, predict demand, optimize the generation and distribution of energy and improve the predictive maintenance of energy assets. Distributed ledger technology on the blockchain platform guarantees secure and transparent documentation of energy transactions, enables peer-to-peer energy trading and automates the execution of contracts via smart contracts. The utilization of a decentralized strategy in energy transactions and operations diminishes the necessity for middlemen, thereby augmenting the efficiency and reliability of such processes.

Figure 2 shows the formation and structure of a blockchain featuring a series of interconnected blocks that store transactional data within a decentralized network. Each block consists of a header and set of transactions, with data from the transactions undergoing a hashing process to generate a consistent-length hash output. Importantly, this hashing process creates a unique identifier for each block and links it to the previous block in the chain.

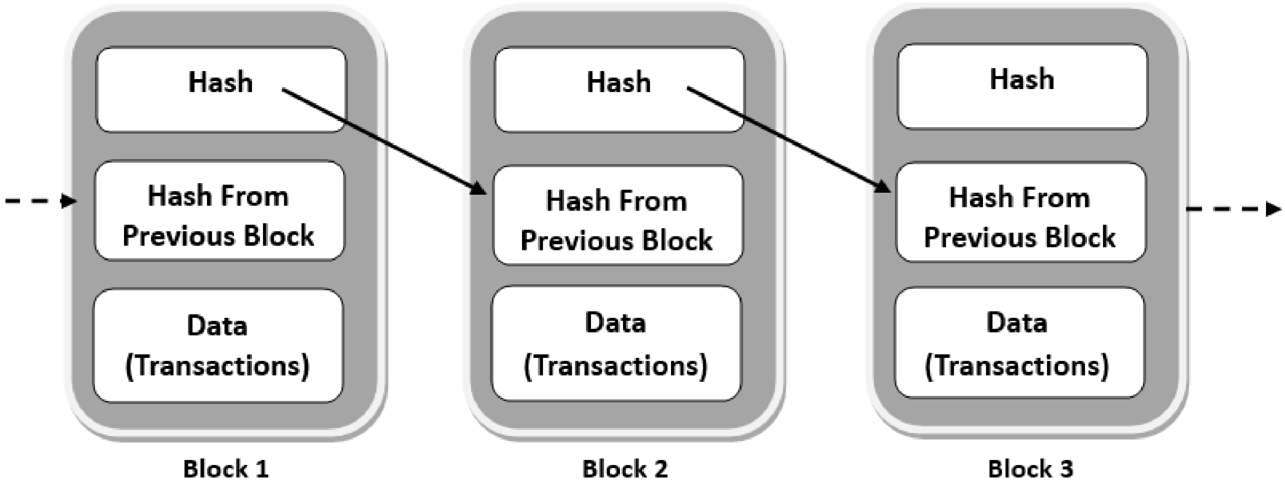

Fig. 2. Simplified blockchain diagram

Machine learning algorithms are employed to examine past energy consumption statistics, weather patterns and other pertinent variables to make precise predictions regarding energy demand. Furthermore, these algorithms aid in the optimization of energy generation and consumption, facilitating the discovery of potential avenues for energy conservation and peak load control. Moreover, machine-learning-driven predictive maintenance models improve the efficiency and durability of energy assets by forecasting maintenance requirements and detecting potential problems in advance. The integration of blockchain technology and machine learning facilitates a decentralized and data-centric approach to energy management, which is characterized by its ability to promptly respond, optimize efficiency and effectively adapt to dynamic circumstances. This framework seeks to enhance the resilience, sustainability and cost-effectiveness of energy systems by utilizing the advantages of both technologies. It also aspires to decrease dependence on centralized authorities and increase.

The integration of blockchain and machine learning in V2G systems significantly enhances energy management, resulting in progress in electric mobility, improved support for the electrical grid, higher adoption of renewable energy and the utilization of decentralized energy sources. Promoting the connection between car users and the power grid facilitates a balanced and efficient V2G system. The V2G system efficiently distributes and allocates resources by leveraging technology to ensure equitable and balanced outcomes. Ensuring that the needs and expectations of all parties involved are met fosters sustainable practices and accelerates the advancement of a growing energy market. The integration of blockchain and machine learning effectively addresses the challenges of V2G environments by facilitating the utilization of clean energy and optimizing resource allocation.

V2G technology enables bidirectional energy exchange between EVs and power grids. This implies that EVs possess the capability to both consume electricity from the electrical grid and generate power to replenish it, thus assuming a significant role within the decentralized energy framework. Consequently, EVs have the potential to function as decentralized energy sources, offering grid services, such as frequency management, peak power demand reduction and overall stability enhancement. V2G technology ensures system stability and the incorporation of renewable energy sources, advancing towards a more environmentally friendly and sustainable future. V2G technology presents economic advantages to EV owners and grid operators. Through engagement in grid services, EV owners can generate income by utilizing the unused battery capacities of their vehicles. This enables individuals to transform their EVs into valuable assets that create income, thereby compensating for the expenses associated with owning an EV and promoting EV adoption of electric vehicles. Consequently, this has expedited the shift towards a more environmentally friendly transportation system. Nevertheless, certain technical obstacles must be overcome to achieve complete optimization of V2G technology. A significant obstacle is the degradation of batteries, which is a consequence of repeated charging and discharging cycles associated with engaging in V2G operations. However, the issue at hand is being tackled through the implementation of several techniques aimed at reducing the deterioration in battery technology and management systems. These strategies include intelligent battery management and state-of-charge (SoC) optimization algorithms. Another obstacle pertains to the prerequisites for establishing charging infrastructure.

To facilitate V2G operations, it is imperative to establish a robust and expansive network of charging stations equipped with bidirectional charging capabilities. These charging stations must be capable of accommodating the substantial power requirements of V2G transactions to guarantee seamless energy exchange and connection with the grid. Notwithstanding these technical obstacles, the increasing fascination and investigation in V2G showcases its remarkable capacity to enhance the sustainability and efficiency of the power grid system. Globally, governments, academics and business stakeholders are acknowledging the profound influence of V2G and allocating resources towards its advancement. With continuous innovation and collaboration, V2G technology will continue to advance, paving the way for a future in which electric vehicles serve not only as means of transportation but also as sources of power for our grid, thereby introducing a novel era of sustainable energy utilization.

In the transition towards sustainable transportation solutions, EVs have emerged as a pivotal technology for mitigating environmental impacts and reducing reliance on non-renewable energy sources. However, the scalability and efficiency of V2G networks are currently hampered by two significant challenges: the optimal management of EV battery life and usage and the secure and efficient integration of EVs into the broader energy ecosystem.

Current approaches to battery management in EV often fail to dynamically adapt to the fluctuating conditions of the energy markets, diverse vehicular usage patterns and energy demands of the grid. Additionally, conventional systems lack the robustness and transparency needed to manage complex transactions between EVs, charging stations and energy providers, leading to inefficiencies and vulnerabilities in data integrity and transaction security.

This study proposes a novel framework that leverages Q-learning, a reinforcement-learning algorithm, in conjunction with blockchain technology to comprehensively address these challenges. The goal is to autonomously develop and implement optimal battery management strategies that not only extend the operational life and efficiency of each vehicle in the V2G network but also facilitate secure and transparent energy transactions.

Objectives include:

i. A Q-learning model is developed that learns from operational data to identify optimal charging and discharging strategies for EVs, thereby enhancing battery longevity and overall fleet efficiency.
ii. Blockchain technology is used to create a decentralized and secure platform for energy transactions, ensuring the integrity and security of data across the EV ecosystem.
iii. Integrating smart contracts to automate the execution of optimal battery management strategies derived from Q-learning supports real-time adaptability to energy market conditions.
iv. Facilitating Peer-to-Peer (P2P) energy exchanges among EVs, allowing for efficient distribution and utilization of energy resources within the fleet and with the grid and optimizing the overall energy consumption.

1.1 Related Works

Extensive research has been conducted to investigate the potential utilization of blockchain technology in the field of building energy management. One notable application involves the use of blockchain technology to facilitate energy information sharing within communities and enhance heating strategies in buildings. For instance, Kolahan *et al*., [12] proposed a strategy that effectively reduced energy consumption to enhance thermal comfort and minimize the peak-to-average ratio of the load shape in community buildings. They devised a thermodynamic model that accurately reflects the transient energy consumption of each building. By leveraging blockchain, key parameters of energy consumption were shared, whereas smart contracts were employed to access energy data and determine the optimal operating schedule for boilers. Peer-to-peer energy trading is another area of focus.

Afzal *et al*., [13] developed a decentralized framework for managing electrical energy in smart buildings and local renewable energy systems. This framework encompasses localized optimization processes and a smart contract, enabling participants to collaboratively establish a planning profile. Similarly, Lei *et al*., [14] constructed a decentralized blockchain-based energy trading system specifically for electric vehicle V2G trading of renewable energy within microgrids. These platforms streamline trading, payments and settlement activities, ultimately reducing clearing time and minimizing delivery loss.

In addition, game theory has been explored by some researchers as a means of optimizing energy-trading schemes. Chen *et al*., [15] and Dong *et al*., [16] proposed distributed energy trading schemes, utilizing consortium blockchain and game theory. Their studies focused on developing mechanisms for matching energy transactions and selecting the most optimal consumers and prosumers by employing various game theories.

Hassija *et al*., [17] introduced a lightweight blockchain system that is based on a directed acyclic network. The process of integrating an EV with a grid for energy transmission is based on the game theory model. Although it facilitates small-scale transactions, the grid maintains a fixed price that does not allow for any compromise in reducing the cost of energy delivery.

The study proposed by Zhou *et al*., [18] utilized smart contracts and edge computing to enhance the efficiency and stability of energy transactions. Consequently, there is no established protocol for the allocation of energy resources. Li *et al.,* [19] introduced an anonymous compensation mechanism for discharging electric vehicles. The proposed approach aims to facilitate the participation of a significant number of EVs in the energy transfer process. To encourage the involvement of EVs in supplying energy to the grid, a specific allocation of funds will be granted. Wang *et al*., [20] introduced an Artificial Intelligence-based approach to power management. An artificial neural network was employed to forecast the energy content of EVs.

Although the energy quantity is anticipated and the charging and discharging of EVs are separated, there is currently no approach for dynamically allocating the cost of energy. Sun *et al.,* [21] introduced a fog computing architecture to address the issue of maximizing welfare. The integration of the Byzantine fault algorithm and consortium blockchain has resulted in the development of a novel algorithm known as a delegated proof of work. The efficacy of the simulation conducted using the proposed algorithm was demonstrated in terms of the energy pricing and optimal charge.

Li *et al*., [22] propose a method to mitigate the impact of segregated network load volatility by implementing energy flow limits. This study examined the mixed-integer problem and proposed a heuristic methodology for its resolution. The trading system was constructed using a decentralized architecture that relies on a consortium blockchain. The KH algorithm improved the efficiency of this work. Nevertheless, this study failed to address the financial implications of energy trading.

Su *et al*., [23] introduced a method to improve security by incorporating blockchain technology into smart contracts. This study employs a consensus algorithm based on the Byzantine fault-tolerance problem. The allocation of energy to the charging EV is determined by the predetermined number of discharging EVs present at the charging station. However, this procedure does not guarantee the absence of charge in the mechanism.

This study highlights a deficiency in existing centralized energy management methods, underscoring the need for inventive strategies to fully utilize the capabilities of V2G systems. This study highlights the growing need for renewable energy and the widespread use of electric vehicles as important factors that drive the adoption of blockchain technology and machine learning in V2G systems. This setting provides the background for defining the goals of the study, which focuses on creating a framework that combines blockchain technology and machine learning to improve energy management and operational efficiency in V2G systems.

2. Methodology

The market is experiencing the growing popularity of electric vehicles. The numerical values are progressively increasing, suggesting that transit will become increasingly dependent on them in the future. Despite their growing prevalence, electric vehicles encounter a significant constraint in the form of their energy source for propulsion [24]. In contrast to vehicles powered by internal combustion engines, which can be refuelled at any petrol station, electric vehicles are required to transport their charger during the journey, which may result in a reduction in the vehicle's performance owing to the added weight. This problem can be mitigated through the implementation of a proficient energy management system for electric vehicles [3]. Electric vehicle users may optimize energy usage and maximize vehicle performance based on consumer preferences. Researchers have investigated techniques to reduce battery charging expenses owing to exorbitant electricity expenses.

A robust energy management system for EVs encompasses a range of technologies and tactics aimed at maximizing the efficiency of energy use, distribution and storage within a vehicle. To optimize efficiency, performance and sustainability, the primary objective of this system is to efficiently manage the finite energy resources of the EV [25].

2.1 Proposed System

Figure 3 shows the proposed block diagram of a V2G system. The proposed system relies on the grid as the primary source of electricity, which provides the fundamental electrical power required for operation. The Energy Storage component is a central feature of this architecture, representing the EV. Its primary purpose is to store and subsequently release energy, thereby demonstrating its dual functionality. The Power Conversion unit, known as the Charging Station, serves as the interface between the Grid and the EV. Its main function is to convert the energy from the grid into a form that can be used by the EV. In certain cases, it also allows the flow of energy from the EV back to the grid.

The Control Unit is responsible for managing the coordination of these energy flows, which is achieved through the implementation of a reinforcement-learning agent. This intelligent system utilizes sophisticated algorithms to make well-informed and optimized decisions regarding the timing and scale of charging and discharging operations of the EV, while considering a wide range of dynamic inputs. Simultaneously, the system utilizes a strong Data Management framework implemented through blockchain technology, which plays a crucial role in recording energy transaction data and offers a transparent, unchangeable ledger. The Control Unit relies heavily on this repository of data to optimize its decision-making processes, resulting in increased efficiency and improved energy consumption and distribution throughout the network.

Moreover, the operational dynamics of the system are defined by the simultaneous movement of energy and data in both directions. The energy is smoothly transferred from the Grid to the Charging Station and then to the EV for storage. The Charging Station also allows the energy to be sent back to the grid, showcasing the system's versatile energy management capability. Simultaneously, a constant flow of data regarding energy transactions, grid conditions and the status of the EV moves between the Blockchain, Control Unit and other relevant components. The exchange of information among different entities is crucial for creating a balanced and efficient decision-making system. This ensures that the charging and discharging cycles of EVs are in line with the overall goals of energy efficiency and sustainability in the power grid.

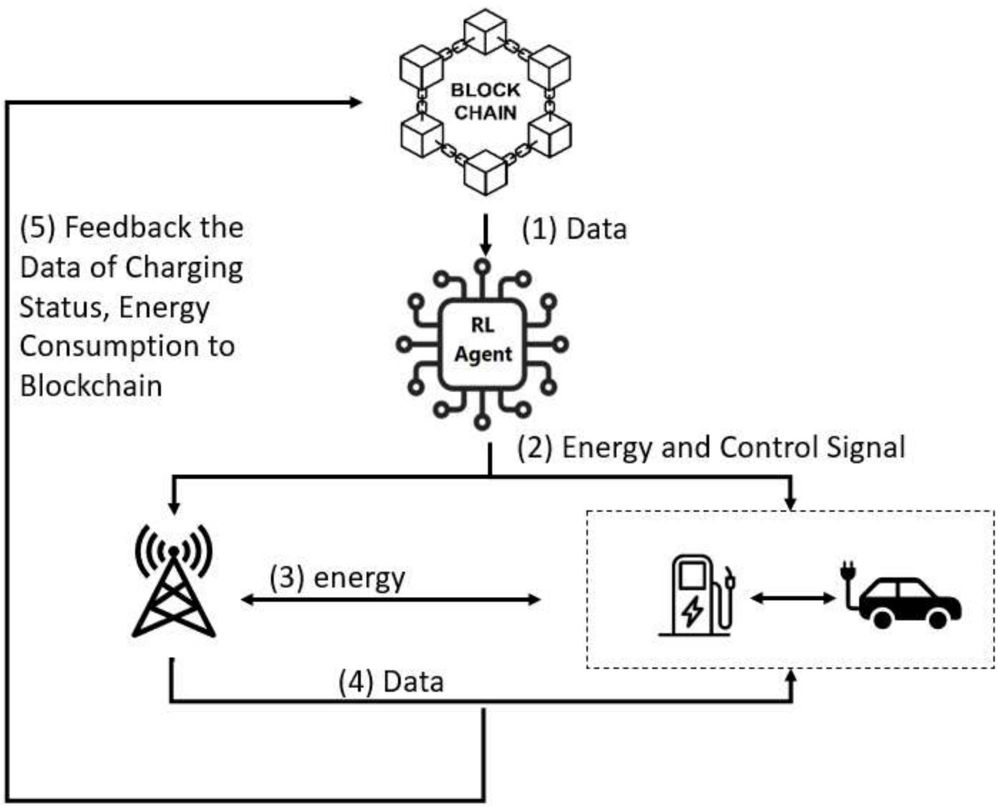

Fig. 3. System model

The system seeks to enhance the overall efficiency of the vehicle by effectively regulating the distribution and utilization of energy, thereby minimizing energy losses. This entails enhancing the efficiency of regenerative braking, reducing power losses throughout the charging and discharging processes and managing auxiliary systems to prevent superfluous energy usage [25]. Range optimization: The practical usability of an electric vehicle is heavily dependent on its range. The implementation of effective energy utilization algorithms in the energy management system aims to optimize the driving range by considering various elements, such as traffic conditions, driving style and environmental data. Additionally, it has the potential to offer range prediction and aid in route planning, thus enhancing the driving experience [25]. The system participates in the proactive monitoring of the battery's level of charge, temperature and other pertinent data to safeguard its overall well-being over an extended period. This technology endeavours to enhance the longevity and dependability of the battery pack by circumventing harsh operating circumstances and using intelligent charging algorithms [25].

The technique used in this study follows an organized and systematic approach that incorporates various essential elements to guarantee strength and reproducibility. First, a thorough examination of the existing literature was conducted to gather information about the latest practices and theoretical foundations of combining blockchain technology and machine learning in V2G systems. Subsequently, a research framework was created, which included the creation and use of smart contracts, investigation of reinforcement learning methods based on blockchain and design and execution of simulations and experiments to assess the overall performance of the system. The empirical component of the study included gathering simulated data from V2G systems, which included energy transaction histories, EV battery performance indicators and grid stability factors. Machine learning methods were utilized to analyse and extract practical insights from the collected data, whereas smart contracts were simulated and implemented in controlled environments to evaluate their effectiveness in automating and overseeing energy transactions. In addition, a set of experiments and simulations were carried out to assess the influence of incorporating blockchain technology on the demand response, integration of renewable energy and overall efficiency of the system.

The primary objective of this study is to develop a framework that seamlessly integrates blockchain technology and machine learning to advance V2G systems. Central to this framework is the implementation of smart contracts, which automate and govern energy transactions among EVs, grid operators and renewable energy producers. Smart contracts play a pivotal role in ensuring secure payment settlements, transparent pricing procedures and efficient energy trading within a decentralized peer-to-peer energy ecosystem.

The significant findings and outcomes of the study on integrating reinforcement learning with blockchain technology in V2G systems include the following:

i. <u>Enhanced Decision-Making:</u> Integration facilitates the development of a self-enhancing system that supports effective energy distribution and usage while prolonging the lifespan of electric vehicle batteries, thus enabling more intelligent and flexible energy ecosystems.
ii. <u>Improved Operational Efficiency:</u> The study demonstrates that the collaboration between blockchain technology and reinforcement learning enhances the system's capacity to adapt and optimize energy flows in real time, contributing to more efficient operational processes within V2G systems.
iii. <u>Secure and Transparent Transactions:</u> The integration of blockchain technology independently verifies and documents energy transactions, fostering trust among

participants and ensuring the accuracy of data, thereby addressing the need for secure and transparent energy transactions.

Moreover, the integration of blockchain technology is anticipated to improve the performance of various facets of V2G systems. Attention is directed towards the optimization of demand response mechanisms, the seamless integration of renewable energy sources and the enhancement of grid stability. To this end, a thorough examination of aspects such as energy efficiency, latency and scalability was conducted to ascertain the practical feasibility and efficiency of blockchain-based V2G systems.

2.2 Proposed Framework

The proposed design for enhancing the performance of EV batteries through the integration of blockchain technology and reinforcement learning methodologies is illustrated in Figure 4. The process commences with the "Start" node, which initiates the initialization phase of the blockchain. During this phase, the necessary data structures for contracts were established, laying the groundwork for future operations.

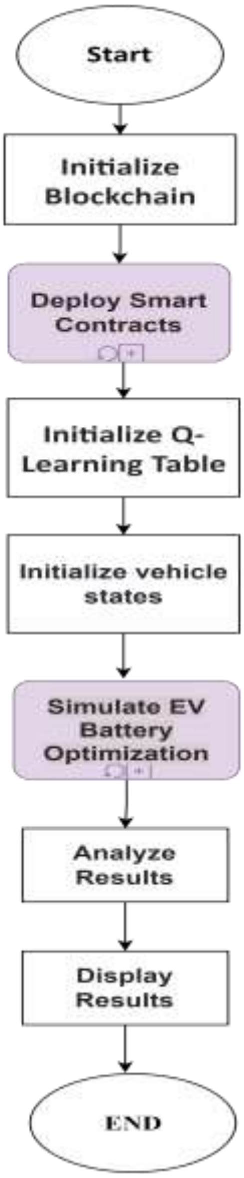

Fig. 4. Flowchart for the proposed results

The "Deploy Smart Contracts" node, represented by a loop symbol, encompasses the iterative procedure of generating and adding contracts to the blockchain, emphasizing the repetitive nature of this task until the designated number of contracts is completely deployed. This is followed by the "Simulate EV Battery Optimization" node, which is also indicated by a loop symbol. This symbol represents the simulation of battery management actions over multiple episodes, utilizing a Q-learning framework to support decision-making by considering the current state of the battery while also managing the balance between exploration and exploitation, which is a fundamental aspect of reinforcement learning.

The flowchart then proceeds to the "Analyze Results" and "Display Results" nodes, where the simulation outcomes are systematically processed and presented for assessment. Finally, the entire process reaches a conclusion at the "END" node.

An illustration of the deployment of a smart contract is shown in Figure 5. This figure effectively captures the process of deploying smart contracts. This shows the initialization of the loop counter, the decision-making process for whether to continue deploying contracts and the steps involved in creating and adding contracts to the blockchain. Arrows indicate the flow of the process, clearly illustrating the loop structure. After the loop was completed, the flowchart proceeded to the next part of the algorithm.

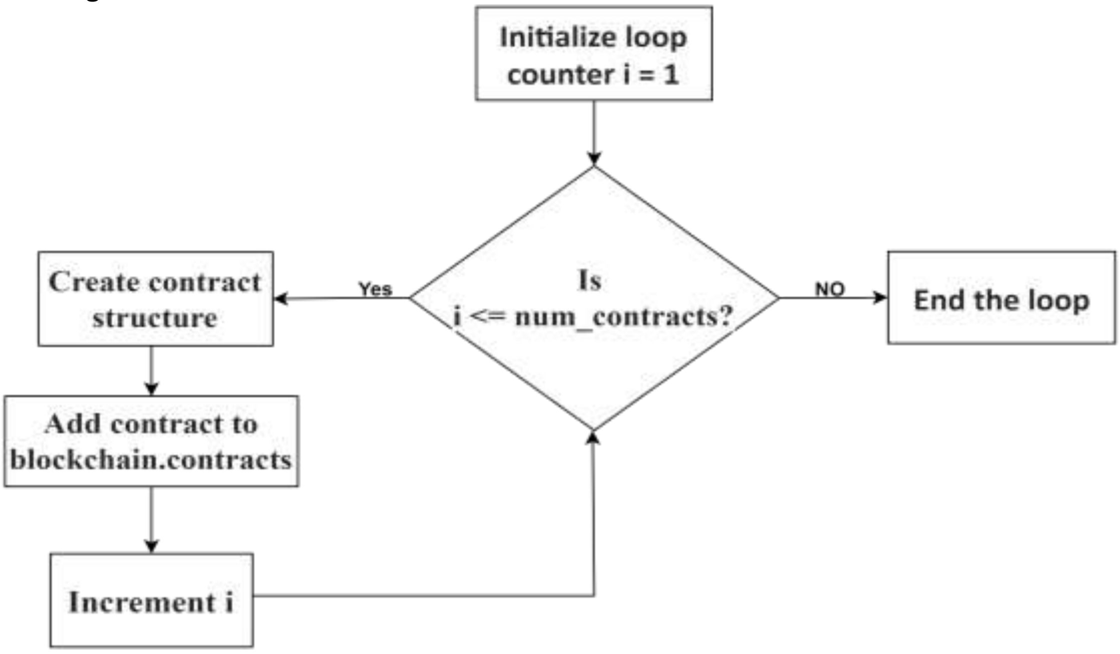

Fig. 5. Smart contract deployment

Figure 6 presents the "EV Battery Optimization" process, which is a crucial aspect of implementing a reinforcement learning algorithm for managing EV batteries within a smart contract framework based on blockchain technology. The iterative process was structured using two primary nested loops: an outer loop for episodes and an inner loop for individual vehicles. The flowchart delineates the epsilon-greedy strategy employed to select actions that balance exploration and exploitation during the learning process. The system incorporates critical decision points, such as assessing the battery levels and generating random numbers for epsilon comparison, to determine the optimal action for each vehicle under various conditions. The framework encompasses the essential elements of reinforcement learning, including observing the state, executing actions and updating the Q-table. The systematic recording of actions and episode data facilitated the analysis and evaluation of the performance after the simulation. This flowchart not only displays the sequential steps of the algorithm, but also emphasizes the interconnectedness between reinforcement learning principles, EV battery management strategies and blockchain technology, providing a comprehensive understanding of the optimization process.

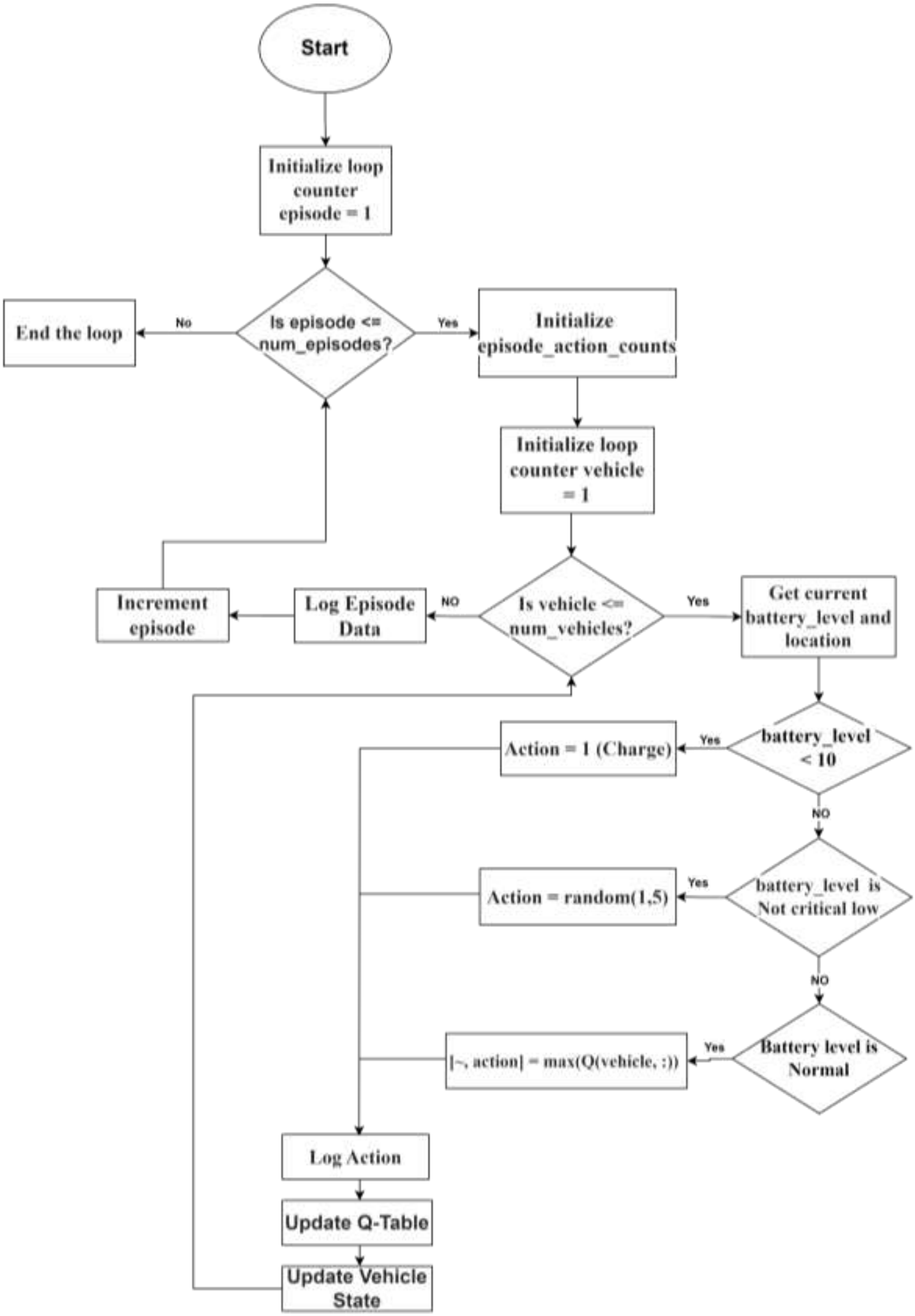

Fig. 6. EV battery optimization process

2.3 Performance Analysis

i. Result Visualization: Various plots were generated to visualize the results, including the Q-values and battery levels.
ii. Battery Performance Enhancement: The optimal actions derived from the Q-learning process are used to enhance the initial battery performance of the vehicles and the results are compared against the initial performance metrics.

2.4 Tools Used

i. MATLAB: The primary programming environment used to implement the simulation. MATLAB's powerful matrix operations and built-in functions of MATLAB facilitate the modelling of complex systems.
ii. MATLAB Graphics: Various plotting functions are utilized to visualize the results, including plots, bars and areas, which help in understanding the performance and behaviour of the system over time.
iii. Reinforcement Learning Concepts: The implementation of Q-learning is based on established reinforcement learning principles, allowing for the optimization of decision-making processes in uncertain environments.

3. Simulation and Results

MATLAB was used to simulate the deployment of smart contracts for energy transactions and reinforcement learning was used to optimize battery management for EVs in vehicle-to-grid V2G networks. where the number of smart contracts to be deployed on the blockchain was 100.The number of electric vehicles participated in the energy transaction system is 50. The total number of episodes for running the simulation used for the reinforcement learning process was 2000.The rate at which the learning algorithm updated the Q-values in the Q-table was 0.2. The exploration rate for the epsilon-greedy strategy is 0.8. The rate at which the epsilon decayed after each episode was 0.995.

Figure 7 shows a heatmap displaying the Q-values for each vehicle across the five possible actions (charging, discharging, idling, selling and buying). The Q-values show a clear preference for the actions (e.g., charging when battery levels are low and selling when prices are high), indicating that the reinforcement learning algorithm has effectively learned the optimal strategies.

Figure 8 shows the final battery level of each vehicle at the end of the simulation. Each bar represents a vehicle and the height of the bar indicates the battery level percentage. Enhancement is observed if the majority of vehicles have high battery levels, suggesting that the learned strategies effectively maintain the battery health. Low battery levels in many vehicles may indicate issues with the charging strategy or excessive energy selling.

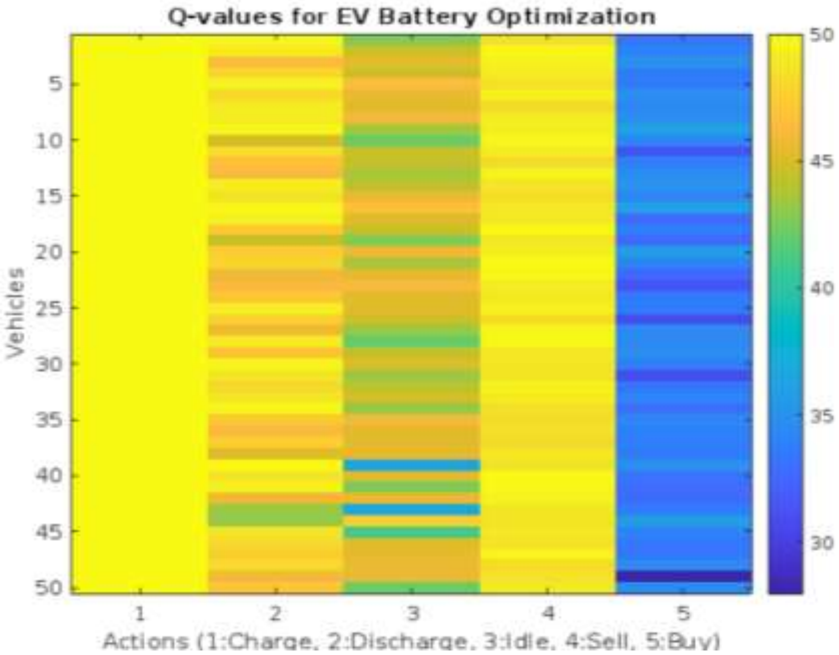

Fig. 7. Q-Values for EV battery optimization

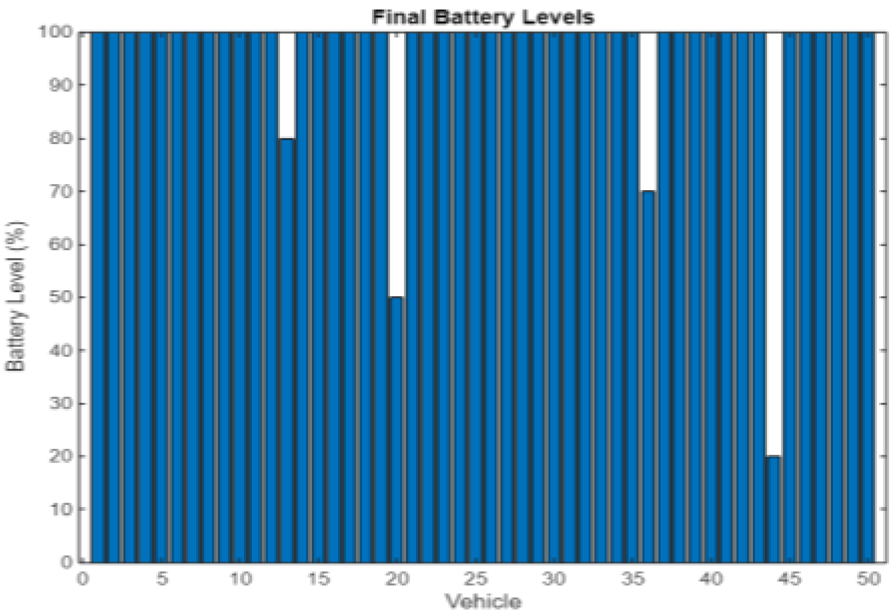

Fig. 8. Final battery level

Figure 9 compares the initial and enhanced battery performance for each vehicle. The x-axis represents the vehicles and the y-axis represents the performance percentage. The black bars represent the initial performance and the yellow bars represent the enhanced performance. Enhancement was observed if the yellow bars (enhanced performance) were consistently higher than the black bars (initial performance). This indicates that the learned strategies effectively improved battery performance.

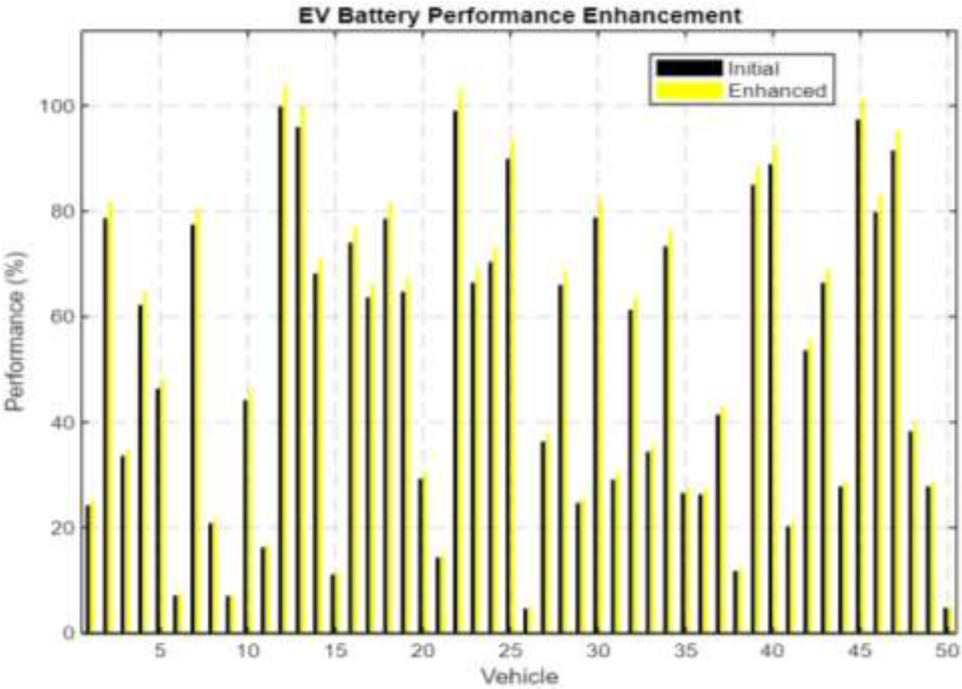

Fig. 9. EV battery performance enhancement

4. Conclusion

In summary, this study provides clear evidence of the significant potential of combining blockchain technology and machine learning to strengthen V2G systems. This study provides strong proof of a strong and effective system that improves the ability to respond to demand, integrates renewable energy sources smoothly and strengthens the stability of the power grid. This study has a significant transformative influence. As the global energy landscape changes, this framework is a crucial tool for addressing urgent energy concerns and promoting sustainable practices at a faster pace. The demand for ongoing interdisciplinary collaboration and the unwavering pursuit of the specified objectives serves as a motivating factor for significant innovation in the fields of electric vehicles and renewable energy. This study emphasizes the need for coordinated and focused efforts to guide V2G systems towards a strong and influential future.

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