# AI-Driven Integration of Electric Vehicles into the Electric Power System for Indian market

[1]Dr. P. Ram Kishore Kumar Reddy, Professor, Department of Electrical and Electronics Engineering, Mahatma Gandhi Institute of Technology, prkumarreddy_eee@mgit.ac.in
[2]Dr. P. Nagasekhar Reddy Associate Professor Department of Electrical and Electronics Engineering Mahatma Gandhi Institute of Technology pnsreddy_eee@mgit.ac.in
[3]Mr. Ch. Vinay Kumar Assistant Professor Department of Electrical and Electronics Engineering Mahatma Gandhi Institute of Technology chvinaykumar_eee@mgit.ac.in

## Abstract

This paper presents a conceptual framework leveraging Artificial Intelligence (AI) for the successful integration of electric vehicles (EVs) into the electric power system, with a focus on the Indian market. The proposed framework addresses two critical domains: the technical operation of the grid and the electricity market environment. AI techniques are employed to optimize grid operations, enhance demand-side management, and improve market efficiency. The roles and activities of key stakeholders in these domains are described comprehensively. Furthermore, simulations are conducted to illustrate the potential impacts and benefits of AI-driven EV grid integration, including steady-state and dynamic behavior analyses tailored to the unique challenges of India's power system. The results underscore the transformative potential of AI in enabling sustainable EV adoption while maintaining grid reliability and market stability. The accuracy of 95.23%, Recall of 89.23%, throughput of 91.08% and F measure of 94.36% had been attained which was good improvement.

**Keywords:** AI-driven systems; electric vehicles; energy storage optimization; hierarchical control; microgrid integration; Multi microgrid coordination; Indian electricity market.

## Introduction

Growing acceptance of electric cars (EVs) has become a transforming factor in the worldwide change toward sustainable energy sources. This change, meantime, presents major difficulties for the integration of EVs into current electric power infrastructures, especially in dynamic markets like India. The fast-growing deployment of electric vehicles calls for strong systems that can balance grid dependability, maximize energy use, and enable a smooth interaction between vehicles, the grid, and auxiliary services. Using artificial intelligence (AI) in this framework presents a potential way to properly handle this complexity. More than just a means of mobility, electric cars are a new kind of mobile energy storage that, with right management, may greatly help the power grid. Vehicle-to---grid (V2G) technology's bidirectional energy transfer lets EVs run as energy storage units, therefore supporting grid stability and auxiliary services. But including these features into the electrical grid calls for sophisticated control systems, dynamic market strategies, and real-time decision-making— areas in which artificial intelligence-driven solutions can be rather important. In the Indian setting, where the diverse generating sources, significant demand unpredictability, and fast urbanization define the electric power system, integration of EVs offers special possibilities and difficulties. The great penetration of renewable energy sources, such solar and wind, which adds to the grid's volatility, highlights even more the requirement of a consistent and effective energy distribution system. By allowing predictive modeling, adaptive control, and effective market operations—that guarantees EV integration is both technically and commercially viable—AI-driven frameworks may solve these difficulties. Customized to the Indian market, this study offers a thorough framework for the AI-driven integration of EVs into the electric power system. Two important areas of focus of the framework are the environment of the electricity market and grid technical operations. AI is being applied in grid operations for real-time demand forecasting, cycle optimization of charging and discharging, and improved grid resilience. AI can help demand response programs, effective energy trading, and pricing systems encouraging EV involvement in the environment of the electricity market. To offer grid services including frequency control, peak load shaving, and energy arbitrage, the proposed framework emphasizes the part aggregators play in aggregating the energy resources of many electric vehicles. Microgrid and multi-microgrid systems are managed using hierarchical control strategies, therefore ensuring that local energy needs and supply variability are satisfied without endangering the general stability of the power system. Incorporating artificial intelligence methods such machine learning, deep learning, and reinforcement learning helps the framework to have adaptive decision-making capacity that can react to the dynamic character of both grid operations and market situations.

Simulations carried out in line with this research show the possible advantages and effects of AI-driven electric vehicle integration. These cover lower running costs, better energy storage use, and more stable grid. Furthermore, highlighting the scalability and robustness of the suggested framework, the simulations offer insights on the steady-state and dynamic behavior of the power system under various situations. These results highlight the major part artificial intelligence may play in solving the difficulties with EV integration in India's complex and fast changing energy scene. Furthermore, in line with India's larger policy objectives—achieving net-zero emissions, lowering reliance on fossil fuels, and encouraging the use of renewable energy—are AI-driven solutions for EV integration. The suggested framework not only facilitates the technical integration of EVs but also helps to ensure the economic and environmental sustainability of the Indian energy ecosystem by means of effective energy management and encouragement of cooperation among important stakeholders. This study seeks to offer a road map for industry players, legislators, and academics to fully exploit artificial intelligence in transforming the integration of electric vehicles into the power grid.

## 2. literature survey

Recent years have seen a lot of study on how best to include electric vehicles (EVs) into the electric power grid. The literature emphasizes numerous important areas of concentration including vehicle-to--grid (V2G) technologies, grid stability, energy storage optimization, and the part artificial intelligence (AI) plays in controlling these interactions plays. This part offers a thorough overview of the body of current studies, with particular focus on frameworks and approaches fit for the Indian market.

### *Vehicle-to-Grid (V2G) Technology*

Rising as a pillar of EV integration, V2G technology lets bidirectional energy transfer between EVs and the grid possible. Research by Kempton and Tomič (2005) set the stage for knowledge of V2G systems' ability to offer auxiliary services including load balance and frequency control. Recent developments have looked at how artificial intelligence-driven algorithms might maximize V2G operations. For example, Liu et al. (2021) investigated how reinforcement learning might improve V2G efficiency, hence lowering grid strain during times of maximum demand. Resilience and Grid Stability Because of their fluctuating charging demand and generation of renewable energy, EVs create problems for grid stability. Emphasizing the need of improved control systems, research by Hu et al. (2016) investigated how widespread EV adoption would affect grid stability. Rising use of artificial intelligence methods such adaptive control and predictive modeling has helped to solve these difficulties. Using machine learning algorithms, a 2020 study by Wang et al. projected EV charging trends, therefore enabling proactive grid management and lowering the risk of instability.

### *Enhancement of Energy Storage*

By balancing supply and demand, energy storage devices significantly help to enable EV integration. The 2014 work of Tarroja et al. underlined the possibilities of EV batteries as distributed energy storage systems. Building on this, more lately studies have concentrated on using artificial intelligence to maximize energy storage. For real-time energy storage management, Zhang et al. (2022) for instance suggested a deep learning-based system that significantly increases efficiency and cost savings.

### *Multi-microgrid and Microgrid Systems*

As localized solutions for merging EVs and renewable energy sources, microgrids and multi-microgrid systems have become rather popular. Emphasizing their part in improving grid resilience, Lasseter's (2002) research on microgrids first proposed them. Later research has looked at hierarchical control methods driven by artificial intelligence to run multi-microgrid systems. Especially, a 2019 Chen et al. study showed how well AI algorithms coordinate energy flow between microgrids so guaranteeing best use of resources.

***dynamics of the electricity market***

Particularly in dynamic markets like India, the question of how energy markets might support EV integration has attracted increasing attention. Conejo et al. (2010) conducted research looking at market systems for including EVs and renewable energy. Proposed to improve market efficiency are artificial intelligence-driven solutions like dynamic pricing techniques and demand response optimization. Sharma et al. (2023), for example, looked at how artificial intelligence might be used to forecast power prices, therefore allowing EV aggregators to participate more fully in energy trading.

***Result of the Literary Survey***

According to the literature, artificial intelligence has transforming power to solve problems related to EV integration. AI-driven solutions have shown great potential from improving grid stability and market efficiency to streamlining V2G operations. Still, the Indian market offers special difficulties that call for customized models and specific solutions. This study emphasizes the importance of ongoing research to fit worldwide developments to the particular needs of India's power grid, therefore opening the path for effective and sustainable EV integration.

## Materials and methods

The large-scale deployment of electric vehicles (EVs) in an AI-driven electric power system necessitates a combination of centralized hierarchical management and localized control mechanisms. These mechanisms are essential for optimizing battery charging and ensuring grid stability. While local control at the EV-grid interface can address specific issues such as voltage drops through approaches like voltage droop control, it alone is insufficient to manage broader challenges, such as branch congestion or enabling EV participation in electricity markets. For these scenarios, a coordinated and hierarchical control structure is critical. This hierarchical structure integrates both centralized and localized controls to manage the entire grid, including EV operations. The centralized control relies on an advanced communications infrastructure capable of exchanging real-time information between grid entities and EVs. This infrastructure enables efficient operation during normal grid conditions, with a new entity, the aggregator, playing a pivotal role. The aggregator groups EVs based on user preferences and facilitates their participation in electricity markets by optimizing charging schedules and leveraging market opportunities. In the Indian context, uncertainties in EV charging—due to unpredictable user behaviors regarding when and where charging occurs—necessitate the establishment of a robust grid monitoring system managed by the Distribution System Operator (DSO). This system ensures that charging activities align with grid constraints, particularly under abnormal operating conditions or emergencies, such as islanded operations. In such cases, dual control signals may arise: one from the aggregator and another from the DSO. To maintain grid reliability, the DSO's signals will override those from the aggregator, ensuring adherence to operational restrictions. Figure 1 illustrates the proposed technical and market management framework, highlighting the interplay between technical operations (left) and market dynamics (right). This AI-driven structure effectively addresses the complexities of EV integration, ensuring stable grid operation while enabling EVs to actively participate in electricity markets.

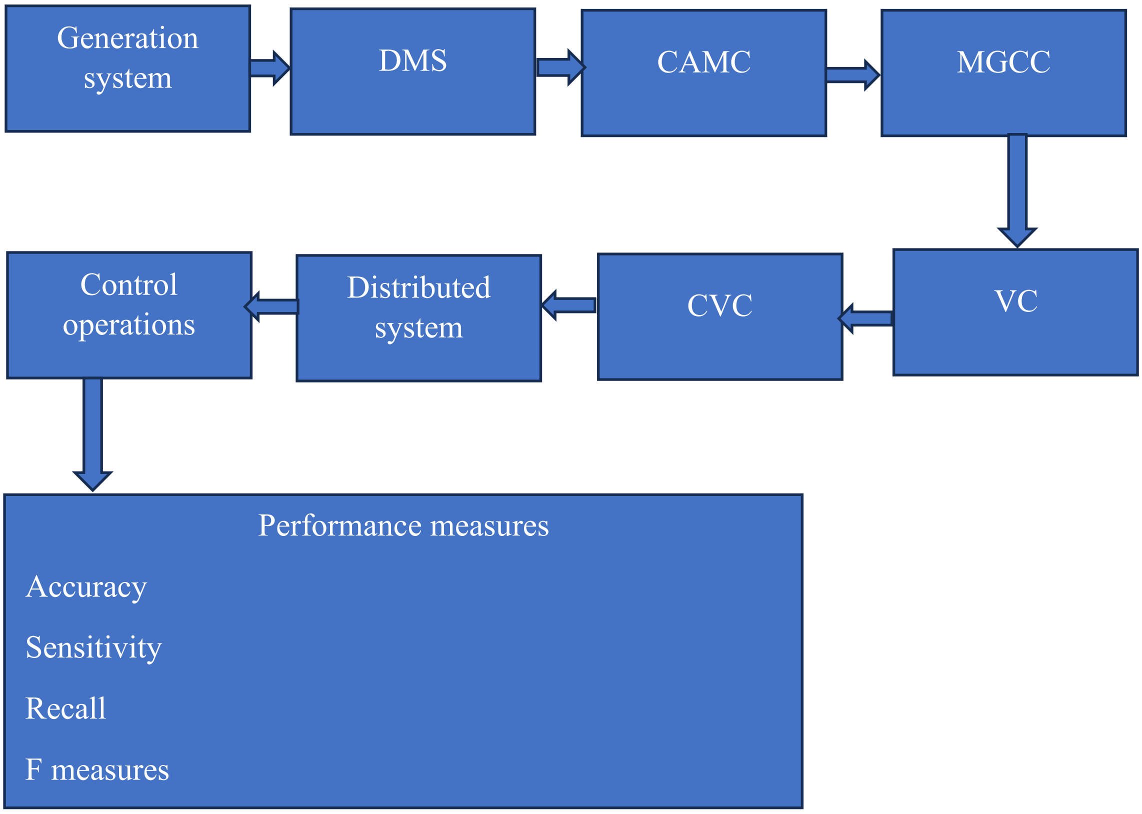


Figure:1 Proposed model and its block level analysis

Aggregators become crucial in order to properly control a lot of electric vehicles (EVs) spread over a vast geographical area including both medium-voltage (MV) and low-voltage (LV) grids. Between EVs and the electricity markets, aggregators act as middlemen allowing the grouping of EVs into a collective load or storage capacity large enough to actively engage in the energy markets. This idea corresponds with the method described in [10]. This research suggests a hierarchical management structure independent of the Distribution System Operator (DSO), based on the complexity of data aggregators must gather and process. This is shown in Fig. 1 Underlying two main entities—the Central Aggregator Unit (CAU) and the Medium-Voltage Aggregator Unit (MGAU)—each aggregator manages a huge geographic area. Every High Voltage (HV)/MV substation serves up to 20,000 consumers, and the CAU interacts with several downstream MGAUs. Managing a maximum of around 400 customers each, MGAUs are housed at the MV/LV substation level. By preparing data from EVs in LV grids for the CAU, the aggregator's basic unit, MGAUs less the communication and computing requirements of using the concept. Every EV has to have a Vehicle Communication Unit (VCU) to allow bidirectional connection with the charging management system. Furthermore, included is a new component called the Central Vehicle Controller (CVC), which controls the charge of sizable parking lots—like those attached to retail centers—directly to the MV network. Under a CVC's supervision, EVs do not need an active VCU for interaction with higher hierarchical controllers. Whereas CVCs directly engage with the CAU, VCUs interact with MGAUs in regular operations. To project market activity and create buy or sell bids for the next day, aggregators use past data. A first negotiation with the DSO guarantees that the distribution networks avoid voltage problems and significant congestion. Aggregators send the DSO their day-ahead plans, which the DSO reviews technically. Approved, the aggregator moves on with market discussions. Should changes be needed, the DSO works with the aggregator to guarantee stable grid operation. Sometimes the DSO might pay aggregators back-off for these changes. The DSO may ask for more adjustments to maximize the decrease of energy loss in the distribution network. Natural flattening of the daily load profile is expected if electricity market prices reflect production, transmission, and distribution costs as well as cost-reflective elements of generation. Load shifting, buying electricity at cheaper night-time rates to charge EVs, and maybe selling stored energy during peak daytime hours to profit on better pricing let aggregators respond to hourly changes in energy prices. For energy acquisition and with generation companies (GENCOs) for energy sales, aggregators compete directly with electricity retailers. Using EV storage features, aggregators can also provide system services to the Transmission System Operator (TSO), therefore vying once again with GENCOs. Following market closure, the TSO reviews load and generation plans to solve any transmission system problems by asking changes to guarantee practical operating conditions. Daily management of EVs is under the control of aggregators, who implement the TSO-verified strategy outlined during market discussions. To control charging rates or to ask for auxiliary services, they send setpoints to VCUs or CVCs. Aggregators need regular updates probably every 15 minutes—on the state of charge (SOC) of every EV battery if they are to effectively handle this difficult chore. This guarantees by the conclusion of the charging period batteries are charged in line with owners' wishes. As mentioned in [10] and shown in Fig. 1, aggregators might also participate in parallel markets, negotiate parking and battery supply services. Still, these parallel market activities go beyond the purview of our work. Other studies propose combining technical and commercial duties, depending on thorough knowledge of SOC at connection and completion periods for every EV and include network technical and load profile data [16].

Electric Power Systems and Infrastructure: Current electrical grid statistics for India, with an eye toward generation, distribution, and control systems. specifics of renewable energy sources (like solar and wind) included into the grid. For power delivery, substations, transformers, and distribution nodes. Electric cars (EVs): EV specifications common in the Indian market, including battery capacity and charging strategies. Information on rates of EV acceptance and forecasts. EV chargers together with their grid standard compliance. AI Algorithms and Frameworks: Load prediction and demand-response optimizing machine learning (ML) models Techniques of deep learning (DL) for voltage regulation, energy distribution, and fault detection. Reinforcement Learning (RL) for distributed energy resource (DER) control and grid stability. Platform tools and software: MATLAB/Simulink, PSS/E, or DIgSILent PowerFactory are among power system simulation tools available. AI tools for model development including TensorFlow, PyTorch, or Scikit-learn. Geographic Information System (GIS) data for grid component mapping including EV charging stations. Information Sources: Demand and load data from regional power distribution companies (DISCOMs) historically. EV user behaviour data and charging trends. Public repositories including load forecasting archives and vehicle-to---grid (V2G) datasets. Devices for Control and Communication: IoT gadgets for real-time data collecting and smart meters. For grid-device interfacing, communications protocols including MQTT or OPC-UA. Performance Standards: Evaluating AI-driven models: accuracy, sensitivity, recall, F-measures. Improvements in system dependability and efficiency. Tools System modelling and simulation refer to: Create a thorough model of the electric grid combining control systems, generating sources, and EV loads. Stochastic models let you replicate several load situations to assess grid performance under EV integration. Data gathering and preprocessing: Compile information from user activity patterns, EV chargers, and distributed energy resources (DERs). Normalize the data, eliminate outliers, and apply feature extraction to guarantee it is fit for artificial intelligence models. Development of AI Models: Train ML models using historical data and EV charging trends to project both long-term and temporary electricity needs. Demand Response Management: Utilize RL to maximize the distribution of energy resources under highest demand. Use DL techniques to identify abnormalities in voltage, frequency, and grid stability measures. Control and Improvement: Create centralized and distributed energy storage as well as centralized and decentralized control systems for running electric vehicle charging stations. Predictive models help to optimize charging plans thereby reducing grid load. Use vehicle-to---grid (V2G) systems for bidirectional energy movement, therefore optimizing the use of EV batteries. Performance Review: Utilizing conventional performance criteria, assess the load forecast and fault detection accuracy of the system. See how well demand-response systems lower peak loads. Under several scenarios, evaluate the grid's general dependability and stability including integrated EVs. Pilot Testing and Implementation: Verify the AI models and grid control systems by doing trial projects in rural and metropolitan locations. Start with highly EV penetration zones and then gradually implement AI-driven solutions. Feedback loop for ongoing development: Retrained and updated AI models using real-time grid and EV charging data. Based on performance reviews and new challenges, refine control plans.

**Results and discussions**

Distribution grids are typically designed to accommodate all connected loads during peak hours, considering a certain simultaneity factor. However, the integration of electric vehicles (EVs) into the network presents significant challenges, especially if EVs are allowed to charge freely without management or control. This unregulated charging approach can lead to grid congestion, necessitating substantial investments in grid reinforcement to maintain stability and reliability. To address these challenges, adopting a smart and AI-driven framework for EV charging is crucial. By leveraging AI, charging patterns can be optimized to minimize congestion, enhance grid efficiency, and integrate a larger number of EVs without requiring costly infrastructure upgrades. Studies on this issue have been conducted on various distribution grids, revealing that intelligent charging strategies can significantly mitigate the negative impacts of EV integration. In this context, we present the results of an analysis on the effects of EVs on a typical medium-voltage (MV) distribution grid, along with a proposed AI-enhanced charging strategy. This approach demonstrates how the Indian market can effectively manage the increasing demand from EVs, ensuring a seamless transition to a sustainable and efficient electric mobility ecosystem**.**

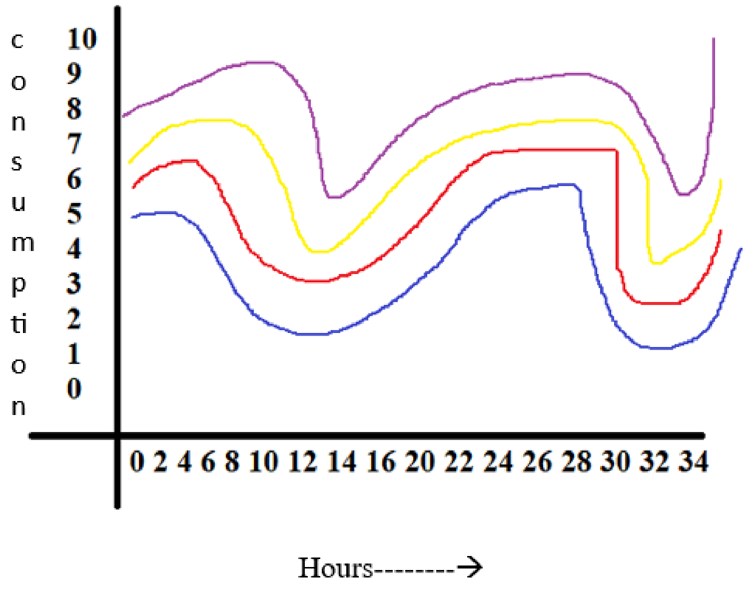


**Figure: 2** Load profile on typical day

The maximum number of electric vehicles (EVs) that can be safely integrated into the distribution grid was assessed using a "dumb charging" methodology. In this scenario, electric vehicle owners can connect and charge their vehicles immediately upon parking, without any control or scheduling overseen by an aggregator. Charging initiates upon connection of the EV and persists for a duration of four hours. Electric vehicles were allocated throughout the grid in accordance with the residential power capacity installed at each node. To ascertain the maximum proportion of electric vehicles (EVs) that the grid could support under the basic charging method, their penetration was incrementally increased until a grid limitation was breached. Violations were recognized as infringements of voltage limits or power flow constraints within the distribution network. This evaluation's methodology is detailed in Fig. 4.

Figure 3 presents the electric vehicle load distribution derived from this algorithm, reflecting standard traffic patterns in residential areas of Portugal. It was presumed that all electric vehicle owners would initiate charging of their vehicles immediately upon returning home from their last trip of the day. This behavior leads to a significant rise in load demand over a four-hour duration. Under these conditions, the grid could accommodate a substitution of 10% of conventional vehicles with electric vehicles before facing a limitation. The influence of electric vehicle integration on voltage profiles and power line congestion in the medium-voltage distribution grid was examined through steady-state simulations using PSSE software. Power flow studies were performed for two scenarios: the baseline scenario, which excludes any electric vehicles (EVs) connected to the grid, and the scenario featuring 10% EV penetration utilizing the dumb charging method. The results presented a clear assessment of variations in voltage levels and congestion across grid branches, yielding essential insights into the impact of unregulated EV charging on grid stability and performance.

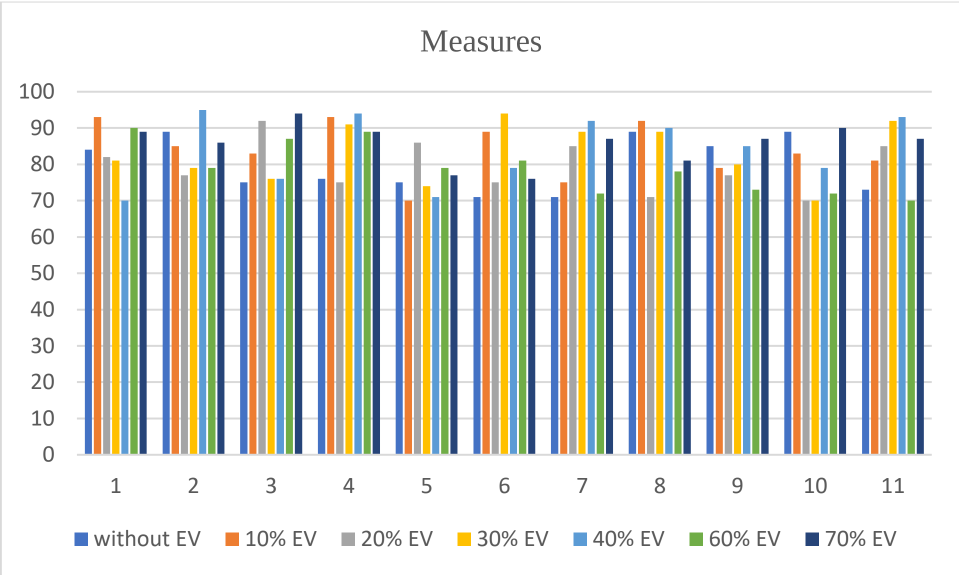


Figure: 3 Measures on EV

**Table: 1** Measures on EV vs Losses

| Losses VS sales | without EV | 10% EV | 20% EV | 30% EV | 40% EV | 60% EV | 70% EV |
|---|---|---|---|---|---|---|---|
| 0 | 84 | 93 | 82 | 81 | 70 | 90 | 89 |
| 1 | 89 | 85 | 77 | 79 | 95 | 79 | 86 |
| 2 | 75 | 83 | 92 | 76 | 76 | 87 | 94 |
| 3 | 76 | 93 | 75 | 91 | 94 | 89 | 89 |
| 4 | 75 | 70 | 86 | 74 | 71 | 79 | 77 |
| 5 | 71 | 89 | 75 | 94 | 79 | 81 | 76 |
| 6 | 71 | 75 | 85 | 89 | 92 | 72 | 87 |
| 7 | 89 | 92 | 71 | 89 | 90 | 78 | 81 |
| 8 | 85 | 79 | 77 | 80 | 85 | 73 | 87 |
| 9 | 89 | 83 | 70 | 70 | 79 | 72 | 90 |
| 10 | 73 | 81 | 85 | 92 | 93 | 70 | 87 |

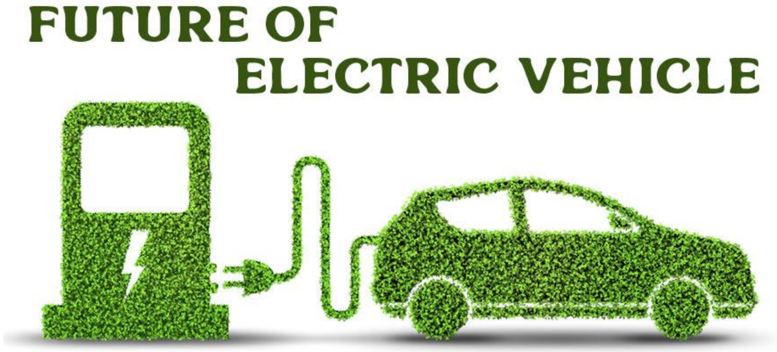


Figure :4 EVs in India

**Conclusion and future scope**

The extensive integration of electric vehicles (EVs) poses considerable challenges for the operation and management of future electric power systems. Addressing this scenario requires the establishment of strong technical and market operation frameworks, as proposed in this study. These frameworks seek to reduce the potential adverse effects of extensive electric vehicle adoption while enhancing their advantages. The initial phase of the electric mobility transition should prioritize the gradual adoption of electric vehicles (EVs) within fleets, including taxis, transportation services, commercial operations, and municipal services. This incremental method enables stakeholders to acquire knowledge and improve solutions prior to their broader implementation. This also allows grid operators to improve strategies for the design, management, and control of the power system. This work presents case studies that illustrate how advanced, centralized EV charging control strategies enhance the integration of EVs into the grid without necessitating infrastructure upgrades. These strategies contribute to the maintenance of reduced stress in network conditions, enhancement of voltage profiles, and mitigation of congestion levels. Incorporating localized control mechanisms at the vehicle-grid interface improves operational performance, especially in islanded operation modes. It enables the secure incorporation of intermittent and variable renewable energy sources, including wind and solar power, into isolated power systems. Electric vehicle batteries demonstrate the capability to offer rapid compensation to the grid, thereby enhancing the integration of renewable energy sources. This work did not focus on transformer rating; however, it may become a critical factor for increased EV integration in distribution networks. Transformers are capable of managing temporary overloading, contingent upon a subsequent phase of reduced loading to facilitate cooling. To support increased EV penetration, smart charging algorithms can be improved to incorporate transformer thermal dynamics, thereby ensuring sustainable and efficient system operation.

**References**

[1] Sanguesa, J. A., Torres-Sanz, V., Garrido, P., Martinez, F. J., & Marquez-Barja, J. M. (2021). A review on electric vehicles: Technologies and challenges. *Smart Cities*, *4*(1), 372-404.

[2] Sun, X., Li, Z., Wang, X., & Li, C. (2019). Technology development of electric vehicles: A review. *Energies*, *13*(1), 90.

[3] Hannan, M. A., Azidin, F. A., & Mohamed, A. (2014). Hybrid electric vehicles and their challenges: A review. *Renewable and Sustainable Energy Reviews*, *29*, 135-150.

[4] Hannan, M. A., Azidin, F. A., & Mohamed, A. (2014). Hybrid electric vehicles and their challenges: A review. *Renewable and Sustainable Energy Reviews*, *29*, 135-150.

[5] Kempton, W., & Letendre, S. E. (1997). Electric vehicles as a new power source for electric utilities. *Transportation Research Part D: Transport and Environment*, *2*(3), 157-175.

[6] Lopes, J. A. P., Soares, F. J., & Almeida, P. M. R. (2010). Integration of electric vehicles in the electric power system. *Proceedings of the IEEE*, *99*(1), 168-183.

[7] Gärling, A., & Thøgersen, J. (2001). Marketing of electric vehicles. *Business Strategy and the Environment*, *10*(1), 53-65.

[8] Chan, C. C., & Wong, Y. S. (2004, August). The state of the art of electric vehicles technology. In *The 4th International Power Electronics and Motion Control Conference, 2004. IPEMC 2004.* (Vol. 1, pp. 46-57). IEEE.

[9] Ajanovic, A. (2015). The future of electric vehicles: prospects and impediments. *Wiley Interdisciplinary Reviews: Energy and Environment*, *4*(6), 521-536.

[10] Ajanovic, A. (2015). The future of electric vehicles: prospects and impediments. *Wiley Interdisciplinary Reviews: Energy and Environment*, *4*(6), 521-536.

[11] Hidrue, M. K., Parsons, G. R., Kempton, W., & Gardner, M. P. (2011). Willingness to pay for electric vehicles and their attributes. *Resource and energy economics*, *33*(3), 686-705.

[12] Sciarretta, A., & Guzzella, L. (2007). Control of hybrid electric vehicles. *IEEE control systems magazine*, *27*(2), 60-70.

[13] Hawkins, T. R., Gausen, O. M., & Strømman, A. H. (2012). Environmental impacts of hybrid and electric vehicles—a review. *The International Journal of Life Cycle Assessment*, *17*, 997-1014.

[14] Chan, C. C., & Chau, K. T. (1997). An overview of power electronics in electric vehicles. *IEEE transactions on Industrial Electronics*, *44*(1), 3-13.

[15] Li, Z., Khajepour, A., & Song, J. (2019). A comprehensive review of the key technologies for pure electric vehicles. *Energy*, *182*, 824-839.