IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

National Level Conference – AITCON 2K25

Adarsh Institute of Technology & Research Centre, Vita, Maharashtra

Vol. 12, Special Issue 1, March 2025

# Impact of Electric Vehicle Charging on the Power Grid: A Review

**Kiran R. Jadhav[1], Abhishek Vijay Kumbhar[2], Swapnil S. Jadhav[3],Vedant R. Ingale[4]**

Department of Engineering Science, Bharati Vidyapeeth College of Engineering, Lavale, India[1]

Department of Electrical Engineering, D. Y. Patil Technical Campus, Talsande, India[2]

Department of Electronics & Telecommunication Engineering, Adarsh Institute of Technology and Research Centre, Vita, India[3]

LabVIEW Programmer, Kimaya Automation, Pune, India[4]

**Abstract**: Electric vehicles (EVs) are positioned as a crucial answer to lowering carbon emissions and reliance on fossil fuels as a result of the global transition towards sustainable mobility. As an ecologically beneficial substitute for traditional internal combustion engine vehicles, EVs are quickly changing the automotive industry because to developments in battery technology, charging infrastructure, and government incentives. Because these EVs require a lot of power to recharge their batteries, they have a significant effect on the power grid and distribution networks. When several EV charging stations are integrated with the utility grid, they create harmonics, alter the voltage profile, and ultimately degrade the quality of the power. The various impacts of EV Charging on the power grid are summarized in this paper.

**Keywords**: Electric Vehicle, Electric Vehicle charging station, power grid, power quality

## I. INTRODUCTION

Vehicles use the majority of the world's oil production, accounting for 30% of total global energy use. Conventional vehicles also account for 27% of total carbon emissions. Electric vehicles (EVs) are an economical way to save energy and minimize pollution from internal combustion vehicles. Aside from mobility, the main benefits of EVs include reduced air pollution, low noise, and great engine efficiency, as well as a reduction in the use of fossil fuel for power generation [1], [2].

Electric vehicles (EVs) consume and create electricity and are also known as prosumers. According to one study, just 10% of EVs use their batteries for travel, while 90% of the time the batteries are idle. During this idle time, the energy stored in an EV's battery can be reintroduced back into the power system. In such instances, EVs function as electricity producers. This is also called V2G. In a vehicle to grid (V2G) system, power can flow bidirectionally between the electric grid and EVs. When the system's load demand is high, the energy stored in EVs can be used to power the grid. When load demand is low, the energy from the electric network can be stored in EVs. The ease with which EVs can be recharged has a considerable impact on their adoption and utilization. The charging power level is often categorized into two classes: slow charging and FC [2]–[4].

The global capitalization of EVs is steadily expanding, particularly in countries that embrace encouraging policies like as tax exemption, dedicated parking areas, non-payment of taxes, and so on. As a result, the use of electric vehicles and their impact on the grid will expand in the future years. Increased EV penetration leads to increased load demand, potentially affecting grid performance. Random charging of EVs can cause voltage drops, unbalanced power systems, overloading of components, power losses, harmonic distortion, and deterioration of voltage and current transients during faulty conditions [5], [6].

In this paper, section II describes Fundamentals of EV charging which includes the types of EV charging. Section III explains Impact of EV charging on electrical grid which includes peak shaving, voltage regulation etc. Section IV explains various mitigation strategies used to reduce impact on grid. Section V and VI explains future scope and conclusion respectively.

## II. FUNDAMENTALS OF EV CHARGING AND GRID INTERACTION

**Types of charging:**

1. **Level 1 Charging**: Only nations with grid systems operating at 120 V and 60 Hz can use it. The power level ranges from 1.44 kW to 1.92 kW, and the maximum current capacity is 12 A/15 A per phase. Since the Indian grid's nominal voltage range is 220 V to 240 V (a.c., r.m.s.) with a frequency of 50 Hz, it does not apply there. It takes almost 20 hours to charge. Slow charging is a drawback of Level 1 chargers, whereas their low initial cost and minimal effect on peak demand charges are its positives.

  

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

National Level Conference – AITCON 2K25

Adarsh Institute of Technology & Research Centre, Vita, Maharashtra

Vol. 12, Special Issue 1, March 2025

2. **Level 2 Charging**: This kind of charging has a maximum current capacity of 80 A, a voltage of 240 V per phase, and power levels that range from 19.2 kW to 22 kW. Currently in use in India, this amount of charging is regarded as sluggish or typical charging and is utilized for both home and public charging. It takes around eight hours to charge. Compared to Level 1 chargers, Level 2 chargers have the advantages of quicker charging times and greater energy efficiency; however, they are more expensive and have a greater impact on peak demand charges.

3. **DC Charging (off-board charger)-**The DC voltage range for this kind of charging is 50 V to 1500 V DC, and the maximum current capacity is 80 A to 400 A or more. The power output must be between 48 kW and 400 kW or more. Known by another name, DC Fast Chargers (DCFC), this kind of charger is typically chosen for usage as a public charging station.

It takes roughly 0.5 hours to charge. The battery's capacity and state of charge (SOC) at a specific charge power level determine this.

4. **Superchargers (off-board charger)-**Since they are exclusive to TESLA EVs produced by the firm, they are also known as TESLA superchargers. Both 120 V, 240 V, and 400 V or greater voltage levels are available for the charger. Power capacity starts at 120 kW and goes up to 250 kW. Another name for superchargers is DCFC. It takes roughly 0.33 hours to charge. The battery's capacity and state of charge (SOC) at a specific charge power level determine this. Extreme fast charging (xFC) is a benefit; however, the drawbacks include a special design that is uncommon and exclusive to Tesla EVs .

While DC chargers and superchargers are only DC-based since they are fast chargers that take less time to charge the batteries in EVs, Level 1 and Level 2 charging methods only transfer AC power [7], [8].

## III. ANALYSIS OF GRID IMPACT

Integration of EV into grid is capable of providing a vast range of services such as auxiliary services, peak load reduction, voltage regulation, and, specifically, frequency regulation. The load profile of the residential system is designed to accommodate various charging modes and EV penetration levels. These charging solutions are centred mostly on moving charging loads away from peak hours. The authors demonstrated that using these charging approaches improves the electric grid load factor by reducing the peak load of the EV system.

In [9], the authors addressed the implications of charging and discharging an EV on:

1) Reduced peak load.
2) Increased over and under voltage.
3) Inconsistent voltage and overall power generation

**1) Reduced Peak load or Peak shaving:** Peak shaving refers to reducing electricity demand during peak hours to improve grid stability and reduce generation costs. EVs can either increase or decrease peak loads depending on charging strategies.

*A. Uncontrolled EV Charging Increases Peaks*

Without proper management, EV charging can amplify peak demand, increasing grid stress and requiring more peaker plants (expensive, carbon-intensive power generation).

*B. Smart Charging for Peak Shaving*

Smart charging (V1G) schedules charging away from peak hours, reducing overall system stress.

- Time-of-Use (ToU) Tariffs: Encouraging EV charging during off-peak hours using dynamic pricing.
- Load Shifting: Charging EVs at night (when electricity demand is lower) instead of during evening peaks.
- Grid-Aware Charging: EV chargers can respond to real-time grid conditions, delaying or reducing power draw.

*C. Vehicle-to-Grid (V2G) for Peak Shaving*

With bidirectional charging (V2G), EVs can supply power back to the grid during peak demand hours.

- Peak Load Reduction: EVs discharge stored energy into the grid when demand is highest.
- Ancillary Services: EVs help with frequency regulation and voltage support during peak loads.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

National Level Conference – AITCON 2K25

Adarsh Institute of Technology & Research Centre, Vita, Maharashtra

Vol. 12, Special Issue 1, March 2025

**2) Increased over and under voltage or Regulation Voltage and Stability:**

In response to the annual exponential increase in global sales of electric vehicles and the predicted penetration of electric vehicles, there is a need for the development of appropriate charging infrastructure as well as ongoing study into the effects of increased charging penetration on the grid. Using a practical time variable load, this study investigates the effect of various levels of electric vehicle charging penetration on voltage regulation. This study found that as the electrical distance to the feeder increased, so did the occurrence of sustained voltage decreases. Also, as penetration grows, so does the likelihood of violating the ANSI voltage limit. As a result, utility planners must prioritise these problem regions when implementing demand side management and VAR compensation strategies to ensure the grid can handle the predicted charge integration. In comparison to prior studies that used static electric car load profiles, the method used in this study gives a more practical analysis of the voltage regulation consequences on the grid, with voltage deviation occurring as early as 10% penetration at all times.

**3) Power Quality and Harmonics:**

**Voltage Fluctuations**

- Voltage Sags & Swells: High-power EV chargers (especially fast DC chargers) draw large amounts of power, leading to temporary voltage drops (sags). When charging stops, voltage may rise (swells).
- Voltage Flicker: Frequent plugging and unplugging of EVs can lead to flickers, affecting sensitive loads like industrial equipment or lighting. Single-phase chargers create unbalanced loads in three-phase distribution networks.
- This leads to negative sequence currents, causing overheating of transformers and increased losses.

**Power Factor Degradation**

- Nonlinear loads from chargers cause low power factors, leading to inefficient energy use and increased system losses.
- High reactive power demand can overload transformers and cables [8][10][11][12].

**4) Transmission Network Impacts**

EV charging significantly impacts transmission networks by increasing demand, voltage instability, transmission losses, and congestion. Solutions such as grid upgrades, smart charging, V2G, and energy storage can help mitigate these challenges. High-power EV charging (especially DC fast charging) increases peak electricity demand. This may require upgrading transmission lines, substations, and transformers to handle higher capacity. EV charging demand is unpredictable and can fluctuate based on time-of-use (TOU) patterns. Rapid changes in load can cause frequency deviations in the transmission system.

Large-scale EV adoption leads to higher electricity demand, especially in areas with fast-charging stations along highways. High-power DC fast chargers (e.g., 350 kW chargers) require substantial power, potentially overloading transmission lines during peak periods. Electricity transmission over long distances inherently causes resistive losses ($I^2R$ losses). Higher EV charging demand increases the power flow, exacerbating these losses and reducing overall transmission efficiency. Rapid EV charging can cause voltage fluctuations and power quality issues, especially in areas far from generation sources.

Congestion in transmission lines may require load balancing strategies to prevent localized blackouts or brownouts. EV charging demand may not always align with renewable energy generation (e.g., solar peaks in the afternoon, but EV charging may peak in the evening). Long-distance power transfer is crucial to move renewable energy (from wind/solar farms) to EV charging hubs, requiring grid expansion and storage solutions. To handle high EV penetration, utilities may need reinforced transmission lines, smart grid solutions, and decentralized energy storage. Strategies like Vehicle-to-Grid (V2G) and distributed energy resources (DERs) can help mitigate transmission burdens by enabling local power generation and storage [13][14].

## IV. MITIGATION STRATEGIES AND GRID INTEGRATION TECHNOLOGIES

Integrating renewable energy sources (RES) into EV charging infrastructure is essential for reducing carbon emissions, enhancing grid stability, and ensuring sustainable transportation. These are discussed below [15]–[17]

1) **Solar Power:**

- Rooftop solar panels on charging stations.
- Large-scale solar farms supplying grid-connected chargers.

2) **Wind Energy:**

- Offshore/onshore wind farms supplying EV charging hubs.

- Integration with battery storage for reliability.

3) **Hydropower & Biomass:**

- Used in regions with existing hydroelectric or bioenergy infrastructure.
- Provides baseload power to support charging demands.

Benefits of Renewable-Powered EV Charging are mainly Lower Carbon Footprint**,** Grid Decentralization and Energy Cost Savings. But there are some challenges of Integrating renewable energy sources into EV charging infrastructure and their possible solutions are [18]:

| Sr. No. | Challenges | Possible solution |
|---|---|---|
| 1 | Solar and wind are variable energy sources. EV charging demand may not always align with generation. | ✓ Energy Storage Systems (ESS)<br>✓ Vehicle-to-Grid (V2G)<br>✓ Smart Charging |
| 2 | Existing grid infrastructure may not support high-power renewable charging stations. | ✓ Microgrids<br>✓ HVDC |
| 3 | Setting up renewable-powered EV charging stations requires high initial investment. | ✓ Government incentives, subsidies, and carbon credits.<br>✓ Public-private partnerships for funding and infrastructure development. |

## V. FUTURE TRENDS AND RESEARCH DIRECTIONS

The integration of autonomous electric vehicles (A-EVs) with shared mobility is set to revolutionize urban transportation by improving efficiency, reducing costs, and lowering environmental impact. It provides Optimized Driving Patterns like AI-driven systems minimize harsh acceleration, braking, and idling, improving energy efficiency etc., Platooning Effect like reduced aerodynamic drag, lowering energy consumption on highways, and smart charging algorithms can charge A-EVs during periods of peak renewable energy generation [19], [20].

The advancement of ultra-fast charging (UFC) technologies is crucial for the widespread adoption of electric vehicles (EVs). By significantly reducing charging time, these technologies address range anxiety, improve charging convenience, and accelerate the transition to EVs. Ultra-fast charging refers to high-power EV charging (≥150 kW), capable of replenishing an EV's battery within minutes instead of hours. Some advanced systems even exceed 350 kW, enabling 80% charge in under 10 minutes.

Also, the integration of electric vehicles (EVs) with smart homes and smart cities is transforming the way energy is consumed, stored, and managed. By leveraging advanced vehicle-to-grid (V2G) technology, IoT connectivity, and AI- driven energy management, EVs can serve as both transportation and energy assets, enhancing urban sustainability and efficiency [21], [22].

## VI. CONCLUSION

The increasing adoption of electric vehicles (EVs) presents both challenges and opportunities for modern power grids. This paper has explored the various impacts of EV charging, including increased peak demand, grid congestion, voltage fluctuations, power quality issues, and the strain on renewable energy integration. If left unaddressed, these challenges could lead to higher electricity costs, reduced grid reliability, and infrastructure bottlenecks.

To mitigate these impacts, several strategies have been discussed, including smart charging, vehicle-to-grid (V2G) technology, decentralized energy resources, demand response programs, and the expansion of renewable-powered charging infrastructure. These solutions, when effectively implemented, can optimize grid performance, reduce costs, and enhance the sustainability of EV adoption**.**

## REFERENCES

[1] A. Lucas, F. Bonavitacola, E. Kotsakis, and G. Fulli, "Grid harmonic impact of multiple electric vehicle fast charging," *Electr. Power Syst. Res.*, vol. 127, no. October, pp. 13–21, 2015, doi: 10.1016/j.epsr.2015.05.012.

[2] S. R. Kiran, C. H. Basha, A. Kumbhar, and N. Patil, "A new design of single switch DC-DC converter for PEM fuel cell based EV system with variable step size RBFN controller," *Sadhana - Acad. Proc. Eng. Sci.*, vol. 47, no. 3, 2022, doi: 10.1007/s12046-022-01897-0.

  

[3] L. Wang, Z. Qin, T. Slangen, P. Bauer, and T. Van Wijk, "Grid Impact of Electric Vehicle Fast Charging Stations: Trends, Standards, Issues and Mitigation Measures - An Overview," *IEEE Open J. Power Electron.*, vol. 2, no. November 2020, pp. 56–74, 2021, doi: 10.1109/OJPEL.2021.3054601.

[4] S. Habib, M. Kamran, and U. Rashid, "Impact analysis of vehicle-to-grid technology and charging strategies of electric vehicles on distribution networks - A review," *J. Power Sources*, vol. 277, pp. 205–214, 2015, doi: 10.1016/j.jpowsour.2014.12.020.

[5] H. Xiao, Y. Huimei, W. Chen, and L. Hongjun, "A survey of influence of electrics vehicle charging on power grid," *Proc. 2014 9th IEEE Conf. Ind. Electron. Appl. ICIEA 2014*, pp. 121–126, 2014, doi: 10.1109/ICIEA.2014.6931143.

[6] R. Bass and N. Zimmerman, "Impacts of Electric," 2013.

[7] K. Jeykishan Kumar, S. Kumar, and V. S. Nandakumar, "Standards for electric vehicle charging stations in India: A review," *Energy Storage*, vol. 4, no. 1, pp. 0–2, 2022, doi: 10.1002/est2.261.

[8] M. R. A. Ashish Kumar Karmaker, Sujit Roy, "Analysis of the impacts of Electric Vehicle Charging Station in Bangladesh," *ECCE, IEEE Conf.*, pp. 7–9, 2019.

[9] I. Kim, "Impact of electric vehicles on peak load reduction," *2016 IEEE Transp. Electrif. Conf. Expo, Asia- Pacific, ITEC Asia-Pacific 2016*, no. June, pp. 514–518, 2016, doi: 10.1109/ITEC-AP.2016.7513008.

[10] A. Comprehensive, "US," 2019.

[11] L. Kutt, E. Saarijarvi, M. Lehtonen, H. Molder, and J. Niitsoo, "A review of the harmonic and unbalance effects in electrical distribution networks due to EV charging," *12th Int. Conf. Environ. Electr. Eng. EEEIC 2013*, pp. 556–561, 2013, doi: 10.1109/EEEIC.2013.6549577.

[12] P. Sivaraman, J. S. S. S. Raj, and P. A. Kumar, "Power quality impact of electric vehicle charging station on utility grid," *Proc. IEEE Madras Sect. Int. Conf. 2021, MASCON 2021*, no. August 2021, pp. 1–4, 2021, doi: 10.1109/MASCON51689.2021.9563528.

[13] E. Veldman and R. A. Verzijlbergh, "Distribution grid impacts of smart electric vehicle charging from different perspectives," *IEEE Trans. Smart Grid*, vol. 6, no. 1, pp. 333–342, 2015, doi: 10.1109/TSG.2014.2355494.

[14] S. Schey, D. Scoffield, and J. Smart, "A first look at the impact of electric vehicle charging on the electric grid in the EV project," *World Electr. Veh. J.*, vol. 5, no. 3, pp. 667–678, 2012, doi: 10.3390/wevj5030667.

[15] F. Mwasilu, J. J. Justo, E. K. Kim, T. D. Do, and J. W. Jung, "Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration," *Renew. Sustain. Energy Rev.*, vol. 34, no. May 2020, pp. 501–516, 2014, doi: 10.1016/j.rser.2014.03.031.

[16] P. Sinha, K. Paul, S. Deb, and S. Sachan, "Comprehensive Review Based on the Impact of Integrating Electric Vehicle and Renewable Energy Sources to the Grid," *Energies*, vol. 16, no. 6, 2023, doi: 10.3390/en16062924.

[17] C. Systems *et al.*, "Integration of Renewable Energy , Microgrids , and EV Charging Infrastructure : Challenges and Solutions," vol. 2, no. 3, 2024, doi: 10.59247/csol.v2i3.142.

[18] G. Alkawsi, Y. Baashar, U. Dallatu Abbas, A. A. Alkahtani, and S. K. Tiong, "Review of renewable energy- based charging infrastructure for electric vehicles," *Appl. Sci.*, vol. 11, no. 9, 2021, doi: 10.3390/app11093847.

[19] S. Gnanavendan *et al.*, "Challenges, Solutions and Future Trends in EV-Technology: A Review," *IEEE Access*, vol. 12, no. January, pp. 17242–17260, 2024, doi: 10.1109/ACCESS.2024.3353378.

[20] Sanchari Deb and Karuna Kalita, "Proceedings of 2017 IEEE International Conference on Technological Advancements in Power and Energy : 'exploring energy solutions for an intelligent power grid' : December 21st to 23rd, 2017," *2017 Int. Conf. Technol. Adv. Power Energy ( TAP Energy)*, vol. 1, pp. 1–6, 2017.

[21] B. P. Rimal, C. Kong, B. Poudel, Y. Wang, and P. Shahi, "Smart Electric Vehicle Charging in the Era of Internet of Vehicles, Emerging Trends, and Open Issues," *Energies*, vol. 15, no. 5, pp. 1–24, 2022, doi:10.3390/en15051908.

[22] P. Alaee, J. Bems, and A. Anvari-Moghaddam, "A Review of the Latest Trends in Technical and Economic Aspects of EV Charging Management," *Energies*, vol. 16, no. 9, 2023, doi: 10.3390/en16093669.

**IARJSET** ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

National Level Conference – AITCON 2K25

Adarsh Institute of Technology & Research Centre, Vita, Maharashtra

Vol. 12, Special Issue 1, March 2025

**BIOGRAPHY**

Mr. Kiran Rajendra Jadhav is Assistant Professor at Department of Engineering Science at Bharati Vidyapeeth College of Engineering, Lavale. He holds Masters and Bachelor's degree in Electrical Engineering from TSSM'S Bhivarabai Sawant College of Engineering and research, Pune. His research interest includes Reactive power compensation, FACTS, Renewable energy sources and EVs.

Mr. Abhishek Vijay Kumbhar is Assistant Professor at Department of Electrical Engineering, D. Y. Patil Technical Campus, Talsande. He has completed B.E. and M.Tech. from Annasaheb Dange College of Engineering and Technology, Ashta and Rajarambapu Institute of Technology, Sakhrale respectively. His research interest includes Renewable Energy sources, Power Electronics, Electric vehicles and FACTS. He has published multiple research articles in reputed journals and has presented at international conferences.

Mr. Swapnil Sanjay Jadhav is currently working as Lecturer at Adarsh Institute of Technology and Research Centre, Vita. He has completed Bachelor of Engineering in Electrical Engineering at Annasaheb Dange College of Engineering and Technology, Ashta. His research interest includes Electric vehicles, grid integration and renewable sources.

Mr. Vedant Rajan Ingale. He is a LabVIEW Programmer working at Kimaya Automation, Pune. He has completed Bachelor of Technology in Electrical Engineering at Ashokrao Mane Group of Institutions, Vathar. His research interest includes Automation, Electric vehicles, grid integration and renewable sources.