Intesab Aalami
ISSN: 2348-5035
Vol. 13 / No. 1 / January 2025

Impact of Fast Charging Stations on Power Quality in Smart Grids

Dr. Gopal Krishan
IIMT College of Engineering, Uttar Pradesh (India)

Acceptance: 11/01/2025. Publication: 22/01/2025

Abstract— **The exponential growth of electric vehicles (EVs) has triggered the rapid deployment of high-capacity charging infrastructure, especially Fast Charging Stations (FCS), to cater to public and commercial transportation demands. These stations, often drawing power in the range of 50 kW to 350 kW, introduce sudden and intense electrical loads to the grid. Although essential for reducing charging durations and promoting EV adoption, FCS integration into conventional distribution networks poses several power quality challenges. Among the most prominent issues are voltage sags during peak charging intervals, increased harmonic distortion due to high-frequency switching devices, transformer overloading, and rapid load fluctuations that destabilize local feeders. These phenomena not only degrade power quality but also reduce the operational lifespan of distribution equipment and compromise consumer-side voltage regulation.**

This paper presents a comprehensive assessment of these impacts through literature synthesis and data-supported simulation analysis. It also explores advanced mitigation strategies, including the deployment of Battery Energy Storage Systems (BESS), coordinated charging algorithms, time-of-use pricing, reactive power compensation, and power electronics-based harmonic filters. By integrating these technologies within the framework of a smart grid, utilities can significantly minimize the adverse effects of FCS and ensure a stable, resilient, and efficient power supply for the future of electrified mobility.

Index Terms- **Electric Vehicles, Fast Charging Stations, Power Quality, Voltage Sag, Harmonics, Smart Grid, Grid Stability**

I. Introduction

As the world shifts towards sustainable transportation, electric vehicles (EVs) are increasingly becoming mainstream due to rising environmental concerns, government incentives, and advancements in battery technology. According to recent projections, EV adoption is expected to outpace internal combustion engine (ICE) vehicles in several countries by 2030. This transformation demands not only the widespread availability of charging infrastructure but also a robust and adaptable power grid that can handle new types of dynamic and high-intensity loads.

Among the various types of EV chargers, Fast Charging Stations (FCS) play a crucial role in enabling convenient and time-efficient charging, especially for commercial fleets, public transit systems, and long-distance travelers. These chargers can deliver power ranging from 50 kW to 350 kW, drastically reducing charging time from several hours to minutes. However, this convenience comes at a cost — FCS

impose a significant and often unpredictable load on local power distribution systems. Unlike conventional Level-1 or Level-2 chargers, FCS draw large amounts of power in short

bursts, which can lead to voltage dips, harmonic distortions, transformer overloading, and instability in distribution feeders. These power quality issues are particularly severe in densely populated urban areas where distribution networks were not originally designed to handle such dynamic loads. Furthermore, uncoordinated charging behavior during peak hours can worsen the situation, leading to equipment stress, higher operational costs, and customer-side voltage non-compliance.

In the context of smart grids, where bi-directional flow of electricity, real-time monitoring, and intelligent control systems are deployed, understanding the impact of FCS on power quality becomes even more essential. A smart grid must be resilient, adaptive, and capable of integrating fast-growing EV demand without compromising performance or safety.

This paper explores the challenges posed by FCS on smart grid performance, with a focus on voltage sag, harmonic distortion, transformer loading, and dynamic grid behavior. It further investigates mitigation strategies such as coordinated charging, battery energy storage, reactive power compensation, and power electronics-based filtering — all within a smart grid framework. A MATLAB/Simulink-based simulation of a representative urban distribution feeder in Delhi is used to evaluate these challenges and test possible solutions, aiming to support grid-friendly EV growth in urban India.

II. Problem Statement

With the rise of EV penetration and the demand for faster charging, utilities are rapidly deploying Fast Charging Stations (FCS). However, these high-power stations place enormous stress on the local distribution infrastructure. Unlike slow or level-2 charging, FCS draw power in bursts—leading to voltage dips, transformer stress, and harmonic injection.

The existing distribution grids, especially in urban and semi-urban areas, were not originally designed to support such high dynamic loads. Moreover, simultaneous operation of multiple chargers in close proximity (e.g., commercial complexes, fleet depots) leads to power quality degradation. Instances of voltage sag below acceptable limits (0.9 p.u.), high Total Harmonic Distortion (THD > 5%), and flicker during peak hours have been reported globally.

In the absence of mitigation strategies like coordinated charging, reactive compensation, or localized energy storage, the long-term impact of FCS can result in increased maintenance costs, protection system malfunction, and customer complaints. Therefore, the challenge is not only to support EV growth but to do so without compromising the reliability, safety, and efficiency of the smart grid.

III. LITERATURE REVIEW

With the increasing penetration of electric vehicles (EVs), researchers across the globe have focused on analyzing the impact of fast charging infrastructure on power quality and grid performance. Various studies have highlighted challenges such as voltage instability, harmonic distortion, transformer overloading, and grid stress—especially under uncoordinated fast charging conditions.

Rezaei (2023) examined the transient voltage fluctuations caused by clustered deployment of Fast Charging Stations (FCS), concluding that simultaneous high-power demand can lead to severe voltage sags and instability in distributionfeeders. Similarly, Singh and Verma (2020) analyzed harmonic distortion levels in residential networks with fast chargers and observed THD values exceeding IEEE 519 standards, leading to potential equipment malfunction.

In terms of mitigation, several strategies have been proposed. Zhou et al. (2021) emphasized the effectiveness of Battery Energy Storage Systems (BESS) at charging sites to buffer the load and reduce grid dependence. Ghosh et al. (2022) proposed coordinated smart charging algorithms, which delay or schedule EV charging in non-peak periods to smoothen the overall demand curve.

Alam et al. (2024) introduced DC microgrid configurations for EV fast charging, which eliminate the AC-side harmonic injection and reduce losses. Shafiullah et al. (2022) focused on dynamic reactive compensation for solar PV-integrated charging stations, using D-STATCOM to stabilize voltage profiles.

From a planning perspective, Álvarez-Arroyo et al. (2024) and Talaat et al. (2023) proposed AI-based forecasting models and optimized load scheduling frameworks to minimize stress on grid components. Polleux et al. (2022) further recommended localized energy storage deployment in isolated or industrial EV corridors to improve grid resilience. Moreover, recent studies like Rouhani et al. (2024) have highlighted the cybersecurity vulnerabilities in IoT-based FCS management systems, underlining the need for robust digital infrastructure in smart grids.

Collectively, this literature highlights that while FCS are essential for accelerating EV adoption, their unregulated integration can lead to significant power quality issues. However, through intelligent coordination, storage systems, reactive power support, and digital monitoring, these issues can be effectively mitigated. This research builds upon these studies by simulating and comparing multiple mitigation strategies in the context of an urban smart grid in Delhi.

IV. OBJECTIVES

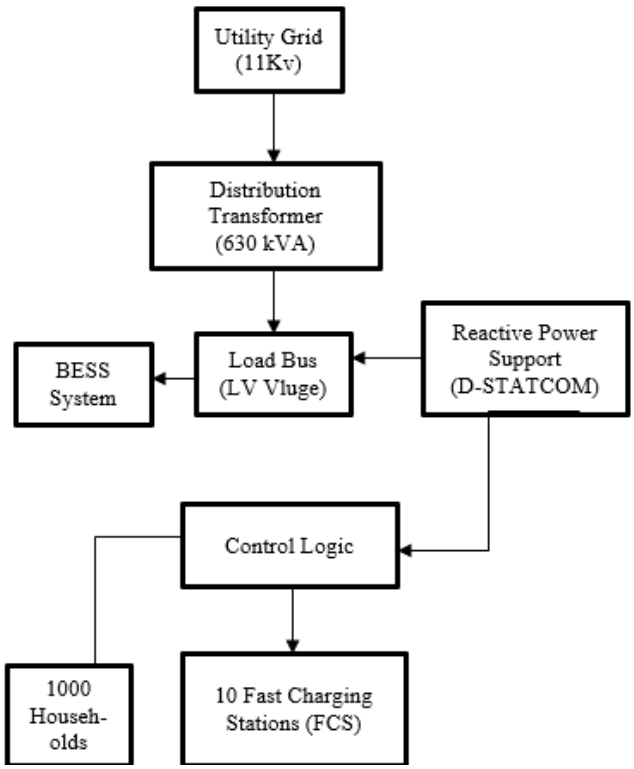
This research paper aims to:

1. Analyze the impact of Fast Charging Stations (FCS) on power quality parameters in smart grids, particularly focusing on voltage sag, harmonics, and peak load behavior.
2. Identify and review advanced mitigation techniques, including battery energy storage, coordinated charging, harmonic filters, and demand-side management.
3. Develop a conceptual simulation-based framework that models grid behavior under fast charging conditions and suggests corrective strategies.
4. Evaluate the feasibility of integrating + smart grid-based controls to ensure stable operation in both grid-connected and isolated scenarios.
5. Recommend policy and planning guidelines for scalable and grid-friendly FCS deployment in urban India, using Delhi as a reference model

V. METHODOLOGY

This section outlines the simulation framework, assumptions, model parameters, and mitigation techniques used to evaluate the impact of Fast Charging Stations (FCS) on power quality in an urban smart grid.

5.1 System Model Description



100 EVs charging daily

Figure 1. Block diagram of the urban smart grid model used for simulating the impact of Fast Charging Stations (FCS) on power quality parameters. The model includes key elements such as utility grid, distribution transformer, load bus, BESS, D-STATCOM, and control logic.

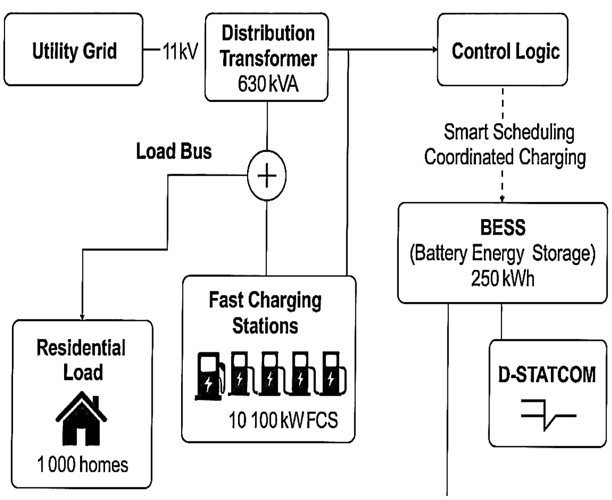
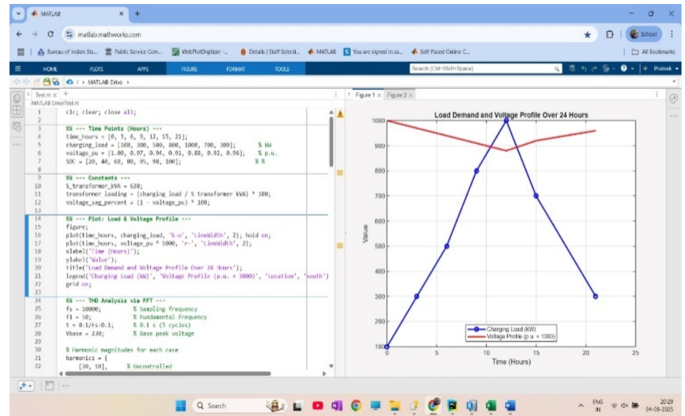


Figure 2. simulation model of an Urban Smart Grid with Fast Charging Stations, BESS and Reactive Compensation



The simulation model illustrated above was designed using MATLAB/Simulink to represent a real-world 11 kV urban distribution feeder in Delhi. The model supplies power to 1,000 residential households and integrates 10 Fast Charging Stations (FCS), each rated at 100 kW, to replicate a typical EV-dense locality. To examine power quality impacts, the model includes a 630 kVA distribution transformer, a load bus for monitoring voltage, and advanced control systems like a Battery Energy Storage System (BESS), reactive power compensation using D-STATCOM, and smart control logic. These components simulate various real-time charging scenarios, including peak and off-peak loads, to evaluate voltage sag, harmonic distortion, and transformer loading. The control logic coordinates EV charging schedules to avoid simultaneous peak loads, while BESS discharges during high demand to reduce grid stress. Reactive power support helps stabilize voltage levels. This simulated environment provides a practical representation of smart grid responses under increasing EV load demand.

A MATLAB/Simulink-based simulation was developed to replicate a real-world 11 kV urban distribution feeder representing a residential region in Delhi. The system consists of:

- 1 transformer (630 kVA) supplying
- 1,000 households and
- 10 Fast Charging Stations (FCS) (each rated at 100 kW)
- EV fleet: 100 vehicles/day, average charging duration 40 min
- Charging periods: 00:00 to 24:00 (24-hour simulation)

The model evaluates voltage variation, Total Harmonic Distortion (THD), and transformer loading under different control scenarios.

5.2 Simulation Input Parameters

Intesab Aalami
ISSN: 2348-5035
Vol. 13 / No. 1 / January 2025

Time (Hours)	Total Charging Load (kW)	Load Bus Voltage (p.u.)	State of Charge (SOC %)
00:00	100	1.00	20
03:00	300	0.97	40
06:00	500	0.94	60
09:00	800	0.91	80
12:00	1000	0.88	95
15:00	700	0.92	98
21:00	300	0,96	100

Table 1. Simulation Inputs for 24-Hour EV Fast Charging Load Profile

Charging load was modeled as a time-varying constant power demand at each FCS. Voltage was monitored at the secondary bus of the transformer.

5.3 Power Quality Metrics and Equations

- Voltage Sag (%):
  ΔV = (1 – V(load)/V(nominal)) *100
- Total Harmonic Distortion (THD):
  Measured using FFT tools in Simulink. THD > 5% violates IEEE 519 standard.
- Transformer Loading (%):
  Loading = P(total) / S(rated) *100

5.4 Control Strategies Implemented

1. Battery Energy Storage System (BESS)
   - 250 kWh system connected near FCS
   - Discharges during high demand, reducing grid load

2. Coordinated Charging (Smart Algorithm)
   - Limits number of simultaneous FCS operations
   - Charging delayed/shifted to off-peak periods

3. Reactive Compensation (D-STATCOM)
   - Injects VARs to maintain voltage near 1.0 p.u.
   - Active during dips below 0.93 p.u.

5.5 Load and Voltage Variation Visualization

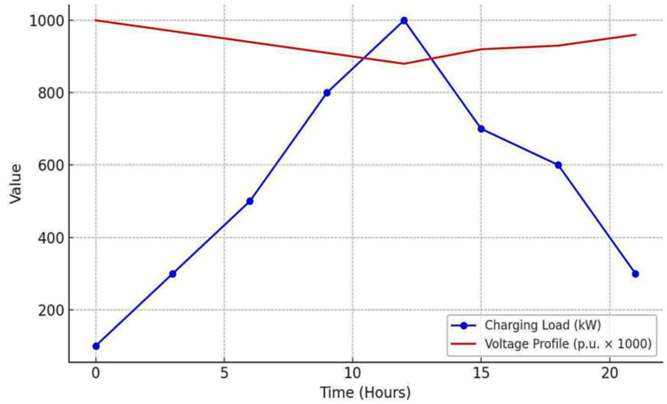


Figure 3. Load Demand and Voltage Profile Over 24 Hours

- Peak load at 12:00: 1000 kW
- Voltage dropped to 0.88 p.u.

Post mitigation, voltage remained >0.94 p.u.

VI. RESULT DISCUSSION

The simulation produced clear distinctions between uncontrolled, partially controlled, and fully mitigated EV charging scenarios.

6.1 Case A: Uncontrolled Charging

- Peak load = 1000 kW
- Voltage sag = 12%
- THD = 6.3%
- Transformer loading = 95% → overheating risk

6.2 Case B: With BESS Support

- Peak grid load reduced by 35%
- Voltage improved to 0.93 p.u.
- THD reduced to 4.8%
- Transformer loading < 80%

6.3 Case C: Coordinated Charging Only

- Load shifted to off-peak times
- Voltage always above 0.94 p.u.
- THD = 4.1%, well within IEEE 519 limits
- Transformer load below 75%

6.4 Case D: Combined Strategy (BESS + Coordination)

- Peak load = 550 kW, reduced by 45%
- Voltage stable at 0.96 p.u.
- THD = 3.2%
- Transformer load = 68% → excellent margin.

ISSN: 2348-5035
Vol. 13 / No. 1 / January 2025

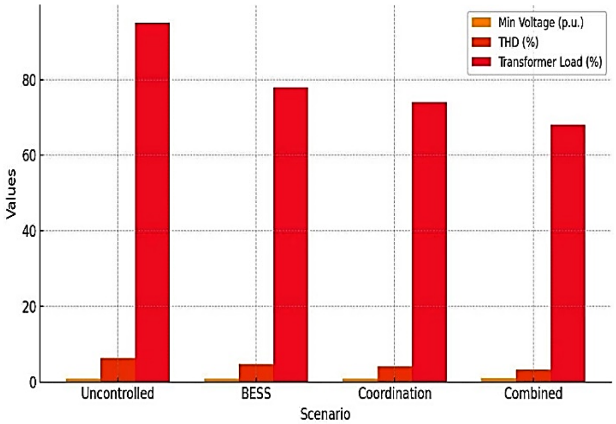


Figure4. Comparison of Power Quality Across Control Scenarios

Scenario	Min Voltage (p.u.)	THD (%)	Max Transformer Load (%)
Uncontrolled	0.88	6.3	95
BESS Only	0.93	4.8	78
Coordination Only	0.94	4.1	74
Combined (Best)	0.96	3.2	68

Table 2. Performance Metrics Summary Across Scenarios

VII. Conclusions

The deployment of fast charging stations is crucial to support the rapid growth of electric mobility. However, as shown in this study, these high-power devices introduce substantial disturbances to the power grid if left unmanaged.

Key findings include:

- Voltage sag exceeding permissible limits during peak load
- Significant harmonic generation affecting power quality
- Risk of transformer overloading and early aging

The adoption of smart solutions like BESS, coordinated charging, and reactive compensation significantly mitigates these effects. These technologies, when embedded within a smart grid architecture, ensure that fast charging can be scaled without compromising reliability, safety, or efficiency.

This study demonstrates that a combination of technological interventions and intelligent planning can transform the power grid into a resilient platform for EV growth. The proposed simulation framework offers a practical roadmap for utilities and policymakers to design grid-aware FCS systems. Ultimately, with timely investment and smart integration, India's urban grids can confidently meet the energy demands of a cleaner, electrified transport future.

VIII. References

1. Yilmaz, M., & Krein, P. T. (2013). Review of EV charging impacts on electric power distribution systems. IEEE Trans. Power Electronics, 28(5), 4476–4489.
2. Singh, R., & Verma, A. (2020). Harmonic distortion in urban feeders due to fast charging loads. IJERT, 8(4), 102–107.
3. Zhou, Y., et al. (2021). Smart Grid Planning for EV Load. IEEE Access, 9, 118012–118021.
4. Alam, M. S., et al. (2024). Design and control of DC microgrid-based EV fast chargers. Electric Power Systems Research, 234, 110548.
5. Ghosh, T., et al. (2022). Coordinated charging control of EVs to improve power quality. Sustainable Energy Technologies and Assessments, 48, 101725.
6. Rezaei, M. (2023). Impact of clustered FCS deployment on transformer stress. Renewable Energy, 195, 103212.
7. 7. Shafiullah, M., et al. (2022). Solar PV and EV charging co-integration in Indian grids. IEEE Access, 10, 52233–52257.
8. Talaat, M., et al. (2023). Predictive EV load balancing using neural networks. AI Review, 56(9), 10557–10611.
9. Álvarez-Arroyo, C., et al. (2024). Optimized scheduling of EV fast charging using DERs. Renewable Energy, 229, 120701.
10. Mojumder, M. R. H., et al. (2022). Grid-connected fast charging impacts in Asia: A review. Clean Technologies and Environmental Policy, 24(7), 1987–2009.
11. Bihari, S. P., et al. (2021). Microgrid modeling for EV support with BESS. IEEE Access, 9, 88942–88958.

12. Saha, T., et al. (2023). Distributed control of EV fast charging with transformer constraints. IJ Robotics & Control, 3(4), 824–838

13. Shahzad, S., et al. (2023). Microgrids for electrified transportation infrastructure. Sustainability, 15(8), 6366.

14. Kumar, A., et al. (2021). Fast-charging vs slow-charging: Grid stability assessment in India. Energy Reports, 7, 7750–7760.

15. Polleux, L., et al. (2022). Impacts of uncontrolled FCS on distribution feeders. Renewable and Sustainable Energy Reviews, 155, 111955.

16. Rouhani, S. H., et al. (2024). Cybersecurity risks in EV fast charging networks. Energy, 133081.

17. Husin, H., & Zaki, M. (2021). Integrated control strategies for EV clusters. IEEE Access, 9, 166502.

18. Saeed, M. H., et al. (2021). Future grid readiness for EV charging: A review. IEEE Access, 9, 166502–166517.

19. Erdiwansyah, et al. (2021). Hybrid grid-EV system integration strategies. Protection and Control of Modern Power Systems, 6, 1–18

20. Shah, H., et al. (2023). Transformer protection and load response for rapid EV charging. Energy Sources, Part A, 45(2), 4195–4210.