

# A Systematic Review on Electric Vehicle Grid Stability based on Neural Network and Charging System

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**Abstract**—The rapid adaptation of the Electric Vehicles (EVs) provides the opportunities and challenges for the advancement in the power systems for the maintenance of the grid stability under dynamic charging demands. This comprehensive review explores the Electric Vehicle (EV) grid stability. The functioning of the grid stability was analysed based on neural networks and charging system. The neural network techniques comprise of Categorical Boosting Regression (CBL), Temporal Convolutional Network (TCN) and light gradient boosting machine (lightGBM) methods. The charging system contains Fast Inductive Wireless Charging (FIWC), Photovoltaic-Grid-integrated electric vehicle charging station (EVCS) and Photovoltaic-Electric Vehicle Charging Station (PV with EVCS) methods. The existing researches showed improvement in the energy consumption, cost efficiency and power scheduling. However, there still exist downsides such as power quality, voltage fluctuation, and boundary detection ability. Further the research focus on improving the power quality by the incorporation of advanced control strategy techniques in the system.

**Key Words:** Charging Station, Electric Vehicle, Grid Stability, Neural Network, Power Grid, Peak Load.

## 1. INTRODUCTION

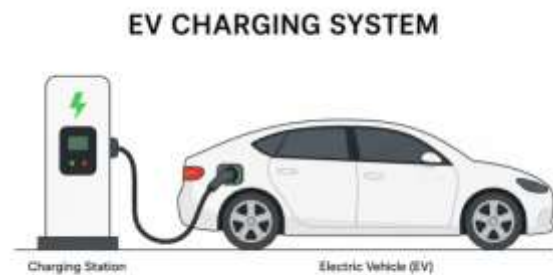


**Fig-1.** Basic representation of Electric Vehicle (EV) Charging System

The Electric Vehicle (EV) charging system is essential for the charging of EV batteries by supplying the electrical power from the renewable energy resources or power grids [1]. The high-speed transition towards the electric flexibility which is driven by the urgent requirements for the reduction of the carbon emissions that enhance the quality of air and minimizes the reliance of fossil fuels [2]. As the success has shifted the development of the charging infrastructures of the electric vehicles as the important bridge between the vehicle battery and electrical grid. The EV charging systems mainly comprise of charging controllers, communication modules, BMS, power source and power converters [3]. The onboard chargers and offboard chargers are the types of chargers where the onboard chargers are incorporated inside the vehicles as they are normal chargers, the offboard chargers are found as external charging stations which are utilized for the speed charging purpose. These are the main

types of charges which are presently available for charging [4][5]. Fig-1. Displays the basic representation of EV charging system.

Further the charging systems are divided into multilevel where level-1 charging is utilized for the standard household power supply [6]. The level-2 charging is utilized for speed charging on the basis of the charging equipment [7]. The dc fast charging system is for the highway and commercial applications. The advanced technologies like dynamic pricing, Internet of Things (IoT), Vehicle to Grid (V2G), bidirectional power flow and Artificial Intelligence (AI) based control strategies [8][9]. This are essential for the analysis of charging system performance by enhancing the grid stability, power quality, charging efficiency and improves user convenience. The EV system is not only the better solution for the charging by proper management of the power grids, renewable energy and charging stations [10]. This paper gives the comprehensive review of the various methods used for the analysis of EV charging system grid stability. The contributions of the current review paper obtained from the study of EV grid stability are given as follows:

- The EV grid stability was categorised based on neural network and charging system for the analysis techniques used for improving the energy efficiency.
- The existing technologies are analysed based on their advantages and limitations that indicates the consistency of the existing methods for the EV grid stability.
- The drawbacks of the existing techniques used for the EV grid stability are identified for the further enhancement of the functioning of the EV grid power quality.

The remaining sections of this review paper comprises of literature survey that gives the background study related to the grid stability, taxonomy that briefly explains the existing methodologies used for the analysis of power grid performance, comparative analysis that gives the difference occurred across various research papers, challenges that provides the problem statements of the existing methodologies, and finally the conclusion that gives the overview of this review paper.

## 2. LITERATURE SURVEY

The literature survey is the section which indicates the existing methodologies, advantages and disadvantages of the research papers used for the analysis of EV charging system. S. Adhikary et al. [11] presented research on Dynamic Performance of Bidirectional EVSE for IoT-Based Monitoring and Cost Estimation for Reducing Grid Stress. The minimum values of the integral time absolute error (ITAE) for the proportional integral (PI) parameter along with the two optimal tuning methods were associated with the PI controller's error computation. The Time-of-Use pricing reduced the charging costs by boosting off-peak charging that helped to balance demand and reduced the grid stress. However the repeated bidirectional charging and discharging cycles had accelerated battery degradation that reduced long-term efficiency of the charging station. Kaibalya Prasad Panda et al. [12] developed a research paper on Common-Ground Boosting Compact Multilevel Inverter Topology based Solar PV Applications. The improved design efficiency, reduced component count, and enhanced performance characteristics further contribute to system reliability and practicality. However the presented model relied on specific assumptions or controlled conditions in the study that limited real-world applicability, affecting overall system performance in practical scenarios. Alessandro Roveri et al [13] published a research paper on Power Decoupling Methods for Grid Support Provided by Ultra-Fast Bidirectional Chargers. The Virtual Synchronous Machine (VSM) control was adapted in this charging system for the enhancement of grid functioning. The Active Front-End (AFE) converter removed the reactive power injection as the internal support that reduced the stress during the station charging and enhanced the efficiency of the grid power. However, the model did not read the sufficient fluctuation and failed to handle the sensitive sequences that minimized the lifespan of the grid power.

Shahid Jaman et al [14] published a research work on Development and Validation of an Integrated EV Charging Station with Grid Interfacing Inverter for Residential Application. The enhanced modular bidirectional inverter was proposed in this research for enhancing the battery charger functioning capability. The integrated system had reduced the cost of the electricity by handling the grid traffics. However, the model struggled to identify the sensitive boundary fault response that decreased the reliability of the grid

power. Sugunakar Mamidala and Y.V. Pavan Kumar [15] presented a research paper called Zeta converter integration for improved power quality in bidirectional V2G energy charging stations. The incorporation of the zeta converter with the bidirectional EV power charging system is the proposed method. This helped for the reduction of grid stress during the EV charging by minimizing the ripple current that enhanced the protection of the battery in the system. However, the developed method lacks the identification of reactive power spikes at the time of transition mode that minimized the performance of the existing EV charging system. The repeated bidirectional charging of the battery and the discharging cycles had accelerated battery degradation that reduced long-term efficiency of the grid charging station. The existing model relied on specific assumptions or controlled conditions in the study that limited real-world applicability, affecting overall system performance in practical scenarios. The existing model did not read the sufficient fluctuation and failed to handle the sensitive sequences that minimized the lifespan of power grid which minimizes the transmission functioning. The available model struggled to identify the sensitive boundary fault response that decreased the reliability of the grid with the power interaction. The available method lacks the identification of reactive power spikes at the time of transition mode that minimized the performance of the EV charging system.

### 3. TAXONOMY

This section gives the taxonomy of this review for the study of EV grid stability based on neural networks and charging system. Various research papers related to the grid stability along with their methodologies are analysed here. Fig- 2. Taxonomy of EV grid stability based on neural network and charging system

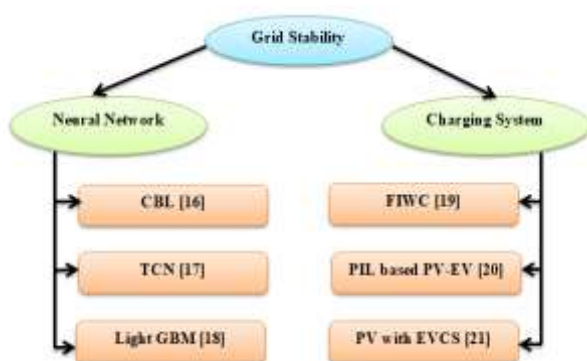


**Fig-2.** Taxonomy of EV grid stability based on neural network and charging system

#### A. Based on Neural Networks

A.V. Sreekumar and R.R. Lekshmi [16] presented an analytic paper named Electric vehicle charging station demand prediction model deploying data slotting for advancing the operational performance of the charging station. The Categorical Boosting Regression (CBL) method was adapted for controlling the operations of the analysis that improved the charging station efficiency. However, the developed model failed for the identification of the losses during the peak load that affected the internal grid stability and minimizes the prediction capability of the EV model during the real time analysis.

A. Selim Türkoğlu et al [17] introduced an advanced research paper named Maximizing EV profit and grid stability through Virtual Power Plant considering V2G. Here the model was developed as the mixed-integer quadratically constrained programming (MIQCP) by incorporating the Temporal Convolutional Network (TCN) to forecast the data. The proposed model advanced the performance of the grid by predicting accurate load demand by reducing the uncertainties during the scheduling. However, the arbitrage performance of the EV affected the losses in the line due to fluctuating voltage that increased the power losses and reduced the durability of the grid.

K Sujit et al [18] presented a research article on an efficient battery management system for electric vehicles using IoT & Blockchain. The integration of the blockchain with the light gradient boosting machine (lightGBM) model was used for the upgradation of the analysis. The use of power scheduling approach (PSA) had improved the performance by reducing the power consumption had advanced the functioning of the charging station. However, the developed model failed to handle the complexity of the data that led to the minimization of the learning ability during the training that affected the purity of the power.

#### B. Based on Charging System

Charan Singh Banothu et al [19] developed a research paper called Impacts of wireless charging system for electric vehicles on power grid for the accurate distribution of the power network. The Fast Inductive Wireless Charging (FIWC) method is used here and that helped for the advancing the charging infrastructure without any physical connectors that improved the scalability of the charging system.

However, the fluctuation in the voltage during the transmission led to imbalanced charging that harms the purity of power from the stress.

Lindiwe Bokopane et al [20] established a progressive research on optimal power dispatching for a grid-connected electric vehicle charging station microgrid with renewable energy, battery storage and peer-to-peer energy sharing. The PV-Grid-integrated electric vehicle charging station (EVCS) method was presented beside with the battery storage for optimizing the operational cost. The incorporation of the renewable energy helped for the maintenance of peak demands. However, the adaptation of dynamic charging created the traffics in the network that led to complication of the infrastructure and minimized the effectiveness of the grid power charging station.

Aziz Watil and Hamid Chojaa [21] developed a research on Enhancing grid-connected PV-EV charging station performance through a real-time dynamic power management using model predictive control. The off grid and on grid conditions were analysed here on the basis of the availability of the grid network and weather conditions. The process-in-the-loop (PIL) approach was utilized in the simulation process that enhanced the grid stability by training the model with precised real time value. However the performance of the developed model did not focus on the power consumption that affected the performance of the grid power charging station.

#### 4. COMPARATIVE ANALYSIS

This section indicates the comparative analysis of existing methodologies used for the grid stability on the basis of EV charging system. The methodologies, advantage, limitations and performance criteria are deliberated for the comparison. The Root Mean Square Error (RMSE), Mean Square Error (MSE), accuracy, precision, Mean Absolute Error (MAE), peak demand, cost demand, voltage deviation, energy losses, f1-score, Integral Absolute Error (IAE) and daily active losses are some of the parameters used for the analysis of charging stations. Table-1 gives the comparative analysis of methodologies used for the grid stability.

**Table-1:** Comparative Analysis of Methodologies Used for Grid Stability

| Author                                 | Methodology     | Advantage                       | Limitation                             | Performance Criteria                                 |
|----------------------------------------|-----------------|---------------------------------|----------------------------------------|------------------------------------------------------|
| A.V. Sreeku mar and R.R. Leksh mi [16] | CBL             | Improv ed chargin g efficien cy | Failed to identify the internal losses | RMSE, MSE, MAE                                       |
| A. Selim Türko ğlu et al [17]          | TCN             | Accura te power schedul ing     | Minimi zed durabilit y                 | RMSE, $R^2$                                          |
| K Sujit et al [18]                     | Light GBM       | Minimi zed power utilizati on   | Did not handle the comple xity         | Accurac y, Precisio n, Recall, F1-Score              |
| Chara n Singh Banot hu et al [19]      | FIWC            | Improv ed scalabil ity          | Poor power quality                     | Peak demand, voltage deviatio n, daily active losses |
| Lindi we Bokop ane et al [20]          | PIL based PV-EV | Peak deman d maintai ns         | Failed to handle dynami c changes      | Cost demand, Energy losses                           |
| Aziz Watil and Hamid Chojaa [21]       | PV with EVCS    | Precise d real time analysi s   | Higher power consump tion              | IAE                                                  |

#### 5. CHALLENGES

The problem faced by the existing various methodologies for the EV based grid stability using neural networks and charging systems are presented in these sections which are given below as follows:

- The existing model did not read the fluctuation of voltage sufficiently and failed to handle the sensitive sequences that minimized the lifespan of the power grid.
- The bidirectional converters in EV charging systems still exhibit harmonic distortion, which affects grid stability and violates power quality standards.
- Conventional PI-based controllers used in bidirectional EV chargers fail to provide optimal dynamic response that reduced the stability of grid.
- The available method lacks the identification of reactive power spikes at the time of transition mode that minimized the performance of the EV charging system.
- The available model struggled to identify the sensitive boundary fault response that decreased the reliability of the grid with the power interaction.

## 6. CONCLUSION

The current section provides the quick view of the review paper of EV grid stability-based energy efficiency performance. The grid stability of power was differentiated on the basis of the neural network and charging system techniques. The neural network techniques consist of CBL [16], TCN [17] and light GBM [18] methods for improving the efficiency of grid stability. The charging station techniques comprises of FIWC [19], PIL based PV-EV [20] and PV with EVCS [21] for advancing the grid reliability performance. The methodologies, advantages and limitations of the existing research papers of grid stability performances are compared here. The existing techniques overcome issues such as energy consumption, cost efficiency and power scheduling. However, there still occur downsides such as power quality, voltage fluctuation, and boundary detection ability. Further the research field focus on modifying the conventional methods with the advanced strategic controllers for refining the functioning of EV grid stability by advancing the power quality.

## REFERENCES

1. Singh AR, Kumar RS, Madhavi KR, Alsaif F, Bajaj M, Zaitsev I. Optimizing demand response and load balancing in smart EV charging networks using AI integrated blockchain framework. *Scientific Reports*. 2024 Dec 30;14(1):31768.
2. Rashid, T.S., Refat, K.A., Islam, M.N., Khan, R., Mostofa, E.R., Hossain, M.A., Kabir, H. and Ali, M.F., 2025. Machine learning-driven PV forecasting and coordinated PV-BESS dispatch for optimizing distribution grid performance under high EV penetration. *Energy Conversion and Management*: X, p.101418.
3. Singh S, Bansal HO. Hardware-in-loop implementation of an adaptive MPPT controlled PV-assisted EV charging system with vehicle-to-grid integration. *Scientific Reports*. 2025 Aug 5;15(1):28565.
4. Das, D., Chakraborty, I., Bohre, A.K., Kumar, P. and Agarwala, R., 2024. Sustainable integration of green hydrogen in renewable energy systems for residential and EV applications. *International Journal of Energy Research*, 2024(1), p.8258624.
5. Alfaverh, F., Denai, M. and Sun, Y., 2023. Optimal vehicle-to-grid control for supplementary frequency regulation using deep reinforcement learning. *Electric Power Systems Research*, 214, p.108949.
6. Rajendran, G., Vaithilingam, C.A., Naidu, K., Alsakati, A.A., Oruganti, K.S.P. and Fauzan, M.F., 2022. Dynamic voltage stability enhancement in electric vehicle battery charger using particle swarm optimization. *IEEE Access*, 10, pp.97767-97779.
7. Güven, A.F., Ateş, N., Alotaibi, S., Alzahrani, T., Amsal, A.M. and Elsayed, S.K., 2025. Sustainable hybrid systems for electric vehicle charging infrastructures in regional applications. *Scientific Reports*, 15(1), p.4199.
8. Shaheen, H.I., Rashed, G.I., Yang, B. and Yang, J., 2024. Optimal electric vehicle charging and discharging scheduling using metaheuristic algorithms: V2G approach for cost reduction and grid support. *Journal of Energy Storage*, 90, p.111816.

9. Sharma, A., Rani, S. and Shabaz, M., 2025. Artificial intelligence-augmented smart grid architecture for cyber intrusion detection and mitigation in electric vehicle charging infrastructure. *Scientific reports*, 15(1), p.21653.
10. Rene, E.A., Fokui, W.S.T. and Kouonchie, P.K.N., 2023. Optimal allocation of plug-in electric vehicle charging stations in the distribution network with distributed generation. *Green Energy and Intelligent Transportation*, 2(3), p.100094.
11. Adhikary, S., Biswas, P.K., Ahmad, F. and Boumaiza, A., 2026. Dynamic Performance of Bidirectional EVSE for IoT-Based Monitoring and Cost Estimation for Reducing Grid Stress. *IEEE Access*.
12. Panda, K.P., Dalai, S.K., Sharma, R., Solanki, S. and Panda, G., 2025. Common-Ground Boosting Compact Multilevel Inverter Topology for Solar PV Applications. *IEEE Access*, 13, pp.206198-206210.
13. Roveri, A., Mallemaci, V., Mandrile, F. and Bojoi, R., 2025. Power decoupling methods for grid support provided by ultra-fast bidirectional chargers. *IEEE Open Journal of Industry Applications*, 6, pp.107-119.
14. Jaman, S., Abdel-Monem, M., Geury, T. and Hegazy, O., 2023. Development and validation of an integrated EV charging station with grid interfacing inverter for residential application. *IEEE Access*, 11, pp.115751-115774.
15. Mamidala, S. and Kumar, Y.P., 2025. Zeta Converter Integration for Improved Power Quality in Bidirectional V2G Energy Charging Stations. *Results in Engineering*, p.107346.
16. Sreekumar, A.V. and Lekshmi, R.R., 2024. Electric vehicle charging station demand prediction model deploying data slotting. *Results in Engineering*, 24, p.103095.
17. Türkoğlu, A.S., Güldorum, H.C., Sengor, I., Çiçek, A., Erdiñ, O. and Hayes, B.P., 2024. Maximizing EV profit and grid stability through virtual power plant considering V2G. *Energy Reports*, 11, pp.3509-3520.
18. Kumar, S., Ramaswamy, K.C., Mathiyalagan, S.R., Giri, J. and Kanan, M., 2025. An efficient battery management system for electric vehicles using IoT & Blockchain. *Results in Engineering*, p.106284.
19. Banothu, C.S., Gorantla, S.R., Attuluri, R.V.B. and Evuri, G.R., 2024. Impacts of wireless charging system for electric vehicles on power grid. *e-Prime-Advances in Electrical Engineering, Electronics and Energy*, 8, p.100561.
20. Bokopane, L., Kusakana, K., Vermaak, H. and Hohne, A., 2024. Optimal power dispatching for a grid-connected electric vehicle charging station microgrid with renewable energy, battery storage and peer-to-peer energy sharing. *Journal of Energy Storage*, 96, p.112435.
21. Watil, A. and Chojaa, H., 2024. Enhancing grid-connected PV-EV charging station performance through a real-time dynamic power management using model predictive control. *Results in Engineering*, 24, p.103192.