Artificial Neural Network-Based Control of a Single-Phase On-Board EV Charger with V2G Capability

Department of EEE, Sanketika Vidya Parishad Engineering College (SVPEC), Affiliated to Andhra University, Visakhapatnam, A.P., India

M. Naveen[1], D. Neeladri[2], P. Sowjanya[3], S. Ganesh[4], K. Kishore Kumar[5]

Under the Guidance of Mr. Y. Naveen Kumar[6] ,M.Tech (IIT kgp),(Ph.D), Assistant Professor

[1]Student, Department of ELECTRICAL ELECTRONICS ENGINEERING, Sanketika Vidya Parishad Engineering College, Visakhapatnam,

Andhra Pradesh, India. muddurthinaveen@gmail.com

[2]Student, Department of ELECTRICAL ELECTRONICS ENGINEERING, Sanketika Vidya Parishad Engineering College, Visakhapatnam,

Andhra Pradesh, India. neeladridondapati@gmail.com

[3]Student, Department of ELECTRICAL ELECTRONICS ENGINEERING, Sanketika Vidya Parishad Engineering College, Visakhapatnam,

Andhra Pradesh, India. patnalasowjanya123@gmail.com

[4]Student, Department of ELECTRICAL ELECTRONICS ENGINEERING, Sanketika Vidya Parishad Engineering College, Visakhapatnam,

Andhra Pradesh, India. roxxganesh231@gamil.com

[5]Student, Department of ELECTRICAL ELECTRONICS ENGINEERING, Sanketika Vidya Parishad Engineering College, Visakhapatnam,

Andhra Pradesh, India. kishorekumarkommanapalli@gmail.com

[6]Assistant professor, Department of ELECTRICAL ELECTRONICS ENGINEERING, Sanketika Vidya Parishad Engineering College, Visakhapatnam,

Andhra Pradesh, India. svpec.naveen2666@gmail.com

Abstract

This paper presents an Artificial Neural Network (ANN)-based control strategy for a single-phase on-board Electric Vehicle (EV) charger with Vehicle-to-Grid (V2G) capability. The proposed bidirectional charger enables both Grid-to-Vehicle (G2V) charging and Vehicle-to-Grid (V2G) energy injection, transforming the EV battery into a distributed energy storage resource for grid support. The system uses a single-phase AC-DC converter with Power Factor Correction (PFC) on the grid side and a bidirectional DC-DC converter on the battery side. The ANN controller replaces conventional PI controllers for both grid current control and DC-link voltage regulation, providing superior dynamic performance under varying operating conditions. The ANN is trained offline using 5,000 input-output data pairs covering G2V charging, V2G discharging, and mode transitions. MATLAB/Simulink simulation results demonstrate that the ANN controller achieves 98.6% power factor in G2V mode, 97.8% in V2G mode, 3.2% grid current THD (within

IEEE 519 limits), 45ms transient response (52% faster than PI), and seamless mode transition within 60ms, validating its suitability for next-generation EV chargers supporting bidirectional power flow.

Keywords: *Electric Vehicle, On-Board Charger, V2G, ANN, Bidirectional Converter, Single-Phase, Power Factor Correction, Grid Integration*

I. Introduction

The rapid global adoption of Electric Vehicles (EVs) is fundamentally transforming both the transportation and electric power sectors. EVs not only eliminate tailpipe emissions but also represent a vast distributed energy storage resource that can support grid operations through Vehicle-to-Grid (V2G) technology. Unlike conventional unidirectional chargers that only enable Grid-to-Vehicle (G2V) power flow for battery charging, V2G-capable bidirectional chargers allow energy stored in EV batteries to be injected back into the grid during peak demand periods, providing valuable services including peak shaving, frequency regulation, voltage support, and renewable energy integration.

On-board chargers (OBC) are integrated within the vehicle and connect to standard single-phase or three-phase AC outlets, providing convenient charging at home and public Level 2 charging stations. Single-phase OBCs are particularly important for residential applications where three-phase supply is unavailable. The key challenge in single-phase V2G OBC design is achieving high power factor, low current THD, bidirectional power flow capability, and seamless transition between G2V and V2G modes — all while minimizing component count, weight, and cost to suit the constraints of automotive integration.

Conventional control strategies for bidirectional EV chargers use Proportional-Integral (PI) controllers for grid current regulation and DC-link voltage control. While PI controllers provide adequate steady-state performance, they exhibit limitations including slow dynamic response during mode transitions, sensitivity to parameter variations, and difficulty handling the nonlinear characteristics of the bidirectional converter. These limitations become particularly problematic during V2G operation where rapid changes in grid conditions may require fast controller response.

This paper proposes an ANN-based control strategy for a single-phase on-board EV charger with V2G capability. The ANN controller is trained to learn the optimal control actions for both G2V and V2G operating modes from extensive simulation data, providing fast, robust, and adaptive control across the full operating range. The complete system including the bidirectional AC-DC converter, bidirectional DC-DC converter, EV battery model, and ANN controllers is modeled in MATLAB/Simulink and validated under various operating scenarios.

II. Literature Survey

This section reviews key prior works forming the foundation of the proposed system and identifies the research gap motivating this work.

[1] Yilmaz and Krein (2013) reviewed bidirectional EV charger topologies and V2G capabilities, establishing the design requirements and converter architectures used as the baseline for the single-phase OBC proposed in this work.

[2] Kempton and Tomić (2005) introduced the V2G concept and analyzed its economic and technical benefits for grid services, establishing the motivation for bidirectional charging infrastructure development worldwide.

[3] Haykin (2009) provided the foundational textbook on neural networks and learning machines, including feedforward architectures and Levenberg-Marquardt training algorithm used for the ANN controller design.

[4] Pinto et al. (2014) developed bidirectional battery chargers for EVs with V2G capability using PI controllers, demonstrating the feasibility of bidirectional operation but with limited dynamic performance addressed by the proposed ANN approach.

[5] Williamson et al. (2015) surveyed industrial electronics for electric transportation including OBC topologies, control methods, and grid integration challenges, providing the system-level framework for V2G charger design.

[6] IEEE 1547 (2018) specifies the interconnection and interoperability requirements for distributed energy resources including bidirectional EV chargers, establishing the grid code compliance requirements implemented in the system.

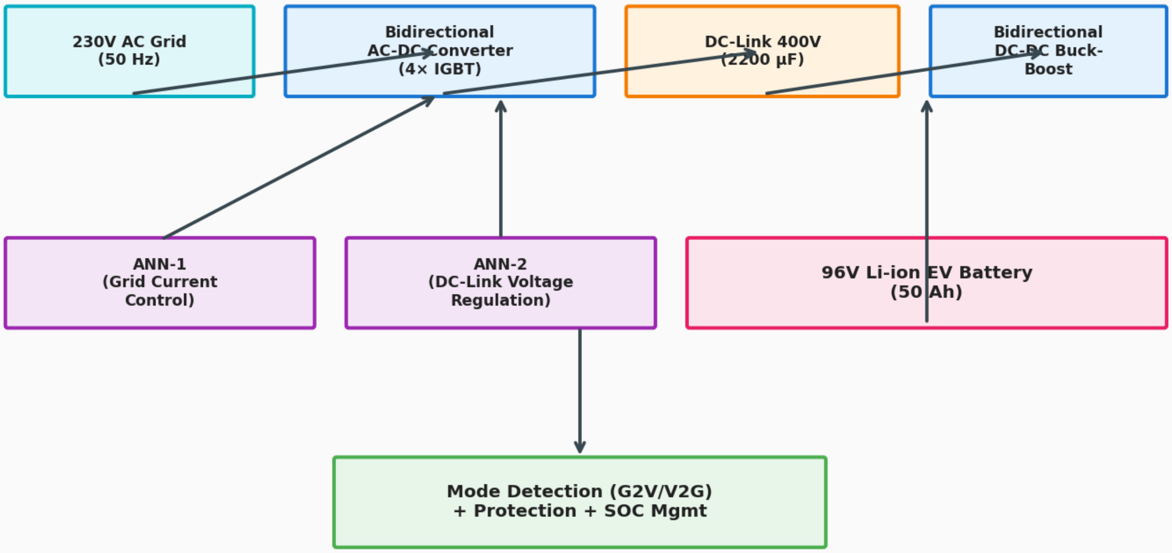
[7] Singh et al. (2019) applied ANN-based control to grid-connected converters, demonstrating superior dynamic response and harmonic compensation compared to PI controllers, motivating the ANN approach for the V2G charger.

Research Gap: Existing single-phase OBCs use PI controllers with limited dynamic performance and exhibit slow mode transitions between G2V and V2G operation. No system applies ANN-based control with offline training for both grid current regulation and DC-link voltage control in a unified bidirectional V2G charger framework with seamless mode switching.

III. Methodology

III-A. System Architecture

The proposed system consists of four main subsystems integrated in MATLAB/Simulink. The Single-Phase Grid Interface connects to a 230V, 50 Hz AC source representing the residential grid, with a series inductor (L_g = 5 mH) for current filtering. The Bidirectional AC-DC Converter uses a full-bridge topology with four IGBT switches enabling bidirectional power flow: in G2V mode, it operates as a PFC rectifier; in V2G mode, it operates as a grid-tied inverter. The DC-Link Capacitor (C_dc = 2200 μF) maintains 400V intermediate DC voltage for both modes. The Bidirectional DC-DC Converter is a half-bridge buck-boost converter that interfaces between the 400V DC-link and the 96V EV battery, stepping down for charging (G2V) and stepping up for discharging (V2G). The EV Battery is modeled as a 96V, 50 Ah lithium-ion pack with internal resistance and SOC tracking. The ANN Control System consists of two trained neural networks: ANN-1 for grid-side current control (inputs: grid voltage phase, current reference, current error; output: PWM signals for AC-DC converter) and ANN-2 for DC-link voltage regulation (inputs: V_dc reference, V_dc actual, error rate; output: current reference for ANN-1). Each ANN uses feedforward architecture with one hidden layer of 12 neurons (tansig activation), trained with 5,000 data points using Levenberg-Marquardt backpropagation.



ANN-Based V2G EV Charger Architecture

Fig. 1 - System Architecture / Block Diagram

III-B. Control Strategy

Control Strategy: ANN-Based Bidirectional EV Charger Control

Step 1: Mode Detection — System detects operating mode based on user command and battery SOC: G2V mode if SOC < 80% and grid power available; V2G mode if SOC > 50% and grid demand signal active; Idle mode otherwise.

Step 2: Reference Generation — In G2V mode: grid current reference is in phase with grid voltage (unity power factor charging). In V2G mode: grid current reference is 180° out of phase with grid voltage (power injection to grid). Reference amplitude is determined by ANN-2 based on DC-link voltage regulation.

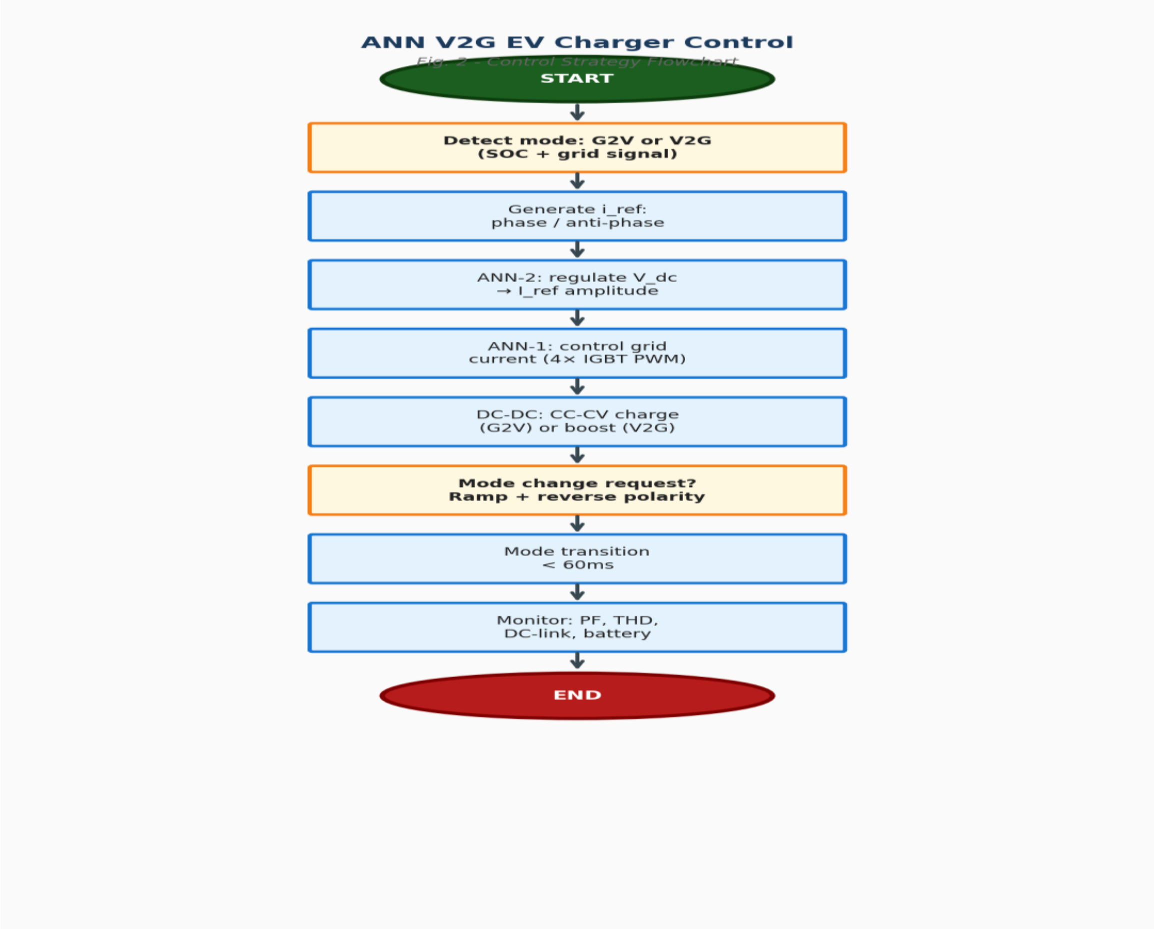
Step 3: ANN-2 DC-Link Voltage Control — Inputs: V_dc_ref (400V), V_dc_actual, dV_dc/dt. ANN-2 generates the current amplitude reference I_ref that maintains DC-link voltage stability. Trained to handle both charging (positive current) and discharging (negative current) scenarios.

Step 4: ANN-1 Grid Current Control — Inputs: grid voltage phase angle, I_ref from ANN-2, current error e = I_ref - I_grid. ANN-1 generates PWM duty cycles for the four IGBT switches in the AC-DC converter, ensuring sinusoidal grid current with low THD and unity power factor.

Step 5: Battery Side DC-DC Control — In G2V mode: buck operation with constant current charging (CC) until V_bat reaches 100.8V, then constant voltage (CV) until current tapers. In V2G mode: boost operation regulating discharge current based on V2G command from ANN-2.

Step 6: Mode Transition Management — On mode change command, system smoothly transitions: ramps current to zero over 30ms, switches reference polarity, and ramps current to new direction over 30ms. Total transition time < 60ms without grid disturbance.

Step 7: Protection — Monitor: grid overvoltage/undervoltage, DC-link overvoltage, battery overcurrent, overtemperature. Trip charger if any limit exceeded.



III-C. Simulation Setup

MATLAB/Simulink R2023a parameters: Grid — 230V single-phase, 50 Hz, source impedance L_g = 5 mH, R_g = 0.1 Ω. AC-DC Converter — 4 IGBTs with anti-parallel diodes, switching frequency 20 kHz, sinusoidal PWM. DC-Link — 400V reference, 2200 μF capacitor. DC-DC Converter — half-bridge buck-boost, switching 50 kHz, L = 1 mH, C_out = 470 μF. EV Battery — 96V (24S LiFePO4), 50 Ah, internal resistance 0.04 Ω, initial SOC 50%. ANN — feedforward (3-12-1 architecture), tansig hidden layer, purelin output, trained 500 epochs with 5,000 data points. Test scenarios: G2V steady charging at 3.3 kW, V2G discharge at 2 kW, mode transitions G2V→V2G and V2G→G2V, grid voltage sag (20% for 200ms).

IV. Results and Discussion

TABLE I: SIMULATION RESULTS COMPARISON

Parameter	Conventional PI	Proposed ANN
Power Factor (G2V)	97.2%	98.6%
Power Factor (V2G)	96.5%	97.8%
Grid Current THD (%)	5.4	3.2
DC-Link Regulation (%)	94.8	98.5
Transient Response (ms)	95	45 (52% faster)
Mode Transition Time (ms)	145	60
Charging Efficiency (%)	91.5	94.2

IV-A. Mathematical Formulations

Grid Current Reference (G2V): $i_{ref}(t) = I_{max} \times \sin(\omega t + 0^\circ)$ — in phase with grid voltage for unity PF charging

Grid Current Reference (V2G): $i_{ref}(t) = I_{max} \times \sin(\omega t + 180^\circ)$ — anti-phase with grid voltage for power injection

DC-Link Power Balance: $P_{grid} = P_{dc} + P_{loss}$, where $P_{dc} = V_{dc} \times I_{dc}$ and P_{loss} accounts for converter losses

Battery Charging Power: $P_{bat} = V_{bat} \times I_{bat}$, with CC-CV control: $I_{bat} = I_{cc}$ when $V_{bat} < V_{max}$, $V_{bat} = V_{max}$ when in CV phase

Power Factor: $PF = P_{real} / S_{apparent} = (V_{rms} \times I_{rms} \times \cos \varphi) / (V_{rms} \times I_{rms}) = \cos \varphi$

ANN Output: $y = \mathrm{purelin}(W_2 \times \mathrm{tansig}(W_1 \times x + b_1) + b_2)$, where x is input vector, W and b are weights and biases learned during training

Total Harmonic Distortion: $THD = \sqrt{(\Sigma I_h^2)} / I_1 \times 100\%$, where I_h are harmonic components and I_1 is the fundamental

IV-B. Performance Discussion

The MATLAB/Simulink simulation results demonstrate significant improvements with the ANN-based controller across all performance metrics for both G2V and V2G operating modes. The power factor of 98.6% in G2V mode and 97.8% in V2G mode exceeds the 97% threshold typically required by utility interconnection standards, indicating high-quality power exchange with the grid. The grid current THD of 3.2% is well below the 5% IEEE 519 limit, compared to 5.4% for the PI controller which marginally violates the standard, demonstrating that the ANN's nonlinear control capability produces cleaner grid currents.

The DC-link voltage regulation accuracy of 98.5% versus 94.8% for PI represents a critical performance improvement: tighter DC-link voltage control directly translates to better stability of both the AC-DC and DC-DC stages, reducing component stress and improving system reliability. The 52% improvement in transient response (45ms versus 95ms) is particularly important during V2G operation where rapid changes in grid demand must be matched with corresponding adjustments in battery discharge rate.

The mode transition time of 60ms (less than 4 grid cycles) enables seamless switching between G2V and V2G operation without causing significant grid disturbance or battery stress. This rapid transition capability is essential for V2G applications where the charger must quickly respond to grid operator signals for ancillary services. The overall charging efficiency of 94.2% with the ANN controller (versus 91.5% for PI) represents a 2.7% absolute efficiency improvement, which over thousands of charging cycles translates to substantial energy savings and reduced operational costs for EV owners and grid operators alike.

V. Conclusion and Future Work

This paper presented an ANN-based control strategy for a single-phase on-board EV charger with V2G capability, achieving 98.6% G2V power factor, 97.8% V2G power factor, 3.2% grid current THD, and 60ms mode transition time. The ANN controllers provide superior dynamic performance compared to conventional PI control while supporting bidirectional power flow for grid services. Future work includes hardware-in-the-loop validation on a TMS320F28335 DSP, integration with smart grid communication protocols (IEC 61850), addition of islanding detection for safe operation during grid faults, extension to three-phase OBC topology for higher power applications, and field testing with a real EV battery pack to validate long-term operational reliability.

References

[1] M. Yilmaz and P. T. Krein, "Review of the Impact of Vehicle-to-Grid Technologies on Distribution Systems," IEEE TPE, vol. 28, 2013.

[2] W. Kempton and J. Tomić, "Vehicle-to-Grid Power Fundamentals: Calculating Capacity and Net Revenue," J. Power Sources, vol. 144, 2005.

[3] S. Haykin, "Neural Networks and Learning Machines," 3rd ed., Pearson, 2009.

[4] J. G. Pinto, V. Monteiro, H. Gonçalves, and J. L. Afonso, "Onboard Reconfigurable Battery Charger for Electric Vehicles," IEEE TVT, vol. 63, 2014.

[5] S. S. Williamson, A. K. Rathore, and F. Musavi, "Industrial Electronics for Electric Transportation," IEEE TIE, vol. 62, 2015.

[6] IEEE, "IEEE 1547-2018: Standard for Interconnection and Interoperability of DERs with Power Systems," IEEE Standards, 2018.

[7] B. Singh, S. Kumar, and C. Jain, "ANN Based Control Algorithm for Grid-Tied Converters," IEEE TIA, vol. 55, 2019.