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Enhanced Electric-Drive-Reconstructed Onboard Charger for Solar-Powered Electric Vehicles Incorporating a Six-Phase Machine with Neural Network-Based Control and Three-Level Inverters

Abstract

This paper presents an improved Electric-Drive-Reconstructed Onboard Charger (EDROC) for solar-powered electric vehicles (EVs) by integrating a neural network-based controller and replacing conventional two-level three-phase inverters with three-level inverters. The conventional EDROC system, utilizing a proportional-integral (PI) controller and two-level inverters, often results in higher total harmonic distortion (THD). To address this issue, the proposed system employs a neural network controller for enhanced adaptability to reduce THD. Additionally, the three-level inverter topology also effectively minimizes voltage stress, reduce switching losses, and significantly lowers THD in both the simultaneous driving and charging mode (Mode A) and DC charging mode (Mode B). The system's performance is analyzed in MATLAB/Simulink, demonstrating reduced THD compared to the conventional setup. Simulation results validate that the neural network-based controller reduces significant amount of THD. The findings highlight the impact of advanced control strategies and power electronics in electric vehicle. This enhanced EDROC system contributes to the evolution of sustainable, good-performance solar-powered EVs by increasing energy utilization and reducing harmonic distortions, making it a promising solution for next-generation onboard charging systems.

Keywords: Electric-drive-reconstructed onboard charger, solar-powered EV, six-phase machine, neural network controller, three-level inverter, THD, power quality improvement.

1. INTRODUCTION

With the rapid growth of electric vehicle (EV) adoption, there is a growing demand for efficient, compact, and high-quality onboard charging systems. Traditional onboard chargers (OBCs) usually use separate power electronic components for propulsion and charging, which increases the system’s weight, cost, and complexity. To address this, Electric-Drive-Reconstructed Onboard Chargers (EDROC) have been developed. These systems reuse the existing traction inverter and motor drive, allowing the same hardware to handle both driving and charging functions, thereby saving space and reducing hardware redundancy.

Although EDROC systems are more integrated, conventional versions still face challenges, especially in terms of **Total Harmonic Distortion (THD)**. These problems are mainly due to the use of **two-level inverters**, which generate large voltage steps and more harmonics, and **PI controllers**, which have limited ability to improve waveform smoothness. As a result, THD is more and energy conversion becomes less efficient—an important issue in solar-powered EVs where energy efficiency is crucial.

This paper presents a modified EDROC system that addresses these limitations by introducing a **three-level inverter** and a **neural network-based controller**. The three-level inverter generates smoother voltage transitions, reducing harmonic content. The neural network controller replaces the traditional PI controller in certain modes, offering better control over the output voltage waveforms, which helps reduce THD and improve system stability.

The proposed system includes a **six-phase Permanent Magnet Synchronous Machine (PMSM)**, controlled by two three-level inverters. The vehicle can be powered from solar photovoltaic (PV) panels mounted on the roof or from the DC grid. The system operates in two main modes:

- **Mode A** – DC charging mode: The vehicle remains stationary and is charged from the grid.
- **Mode B** – Simultaneous driving and charging: The vehicle is driven using solar power while also charging the battery.

The system is simulated in MATLAB/Simulink, and performance is evaluated mainly based on THD reduction across both operating modes. From modelling the PV source and MPPT, to configuring the motor control and inverter strategy, and finally evaluating results through waveform analysis and THD calculation, this project covers the full development and performance analysis of a cleaner, smarter onboard charger. The simulation results show a clear improvement in THD values, confirming that the proposed system provides better optimization for solar-powered EVs.

2. LITERATURE SURVEY

Electric-Drive-Reconstructed Onboard Chargers (EDROC) have emerged as a key innovation in electric vehicles (EVs), enabling the use of the existing traction inverter and motor windings for both propulsion and battery charging [1]–[6]. This integration reduces hardware redundancy, overall system weight, and cost. Studies have explored various EDROC topologies, including three-phase and six-phase configurations, to optimize efficiency and modularity [1], [4], [5], [12].

However, conventional EDROC systems typically rely on two-level inverters and proportional-integral (PI) controllers, which result in high total harmonic distortion (THD), voltage ripples, and suboptimal dynamic response [6], [10], [13], [20], [25]. These issues degrade both power quality and system performance, especially under dynamic load and charging conditions.

To address these limitations, neural network-based controllers and intelligent control methods have been proposed. These adaptive techniques offer faster response, improved stability, and enhanced harmonic suppression [7]–[9], [15], [18], [19], [21], [26], [28]. Their ability to adjust switching behavior in real time makes them ideal for integrated systems like EDROC, where both drive and charging functions must be handled simultaneously.

Inverter topology also plays a critical role. While two-level inverters are simpler, they introduce significant harmonics and switching losses. In contrast, three-level inverters produce more sinusoidal waveforms with reduced switching stress and electromagnetic interference [6], [10], [14], [20], [22], [30]. These advantages make three-level inverters a preferred choice in modern EV chargers, particularly when combined with intelligent controllers.

Research on integrating solar photovoltaic (PV) energy into onboard charging has gained momentum. Vehicle-roof PV systems, when combined with Maximum Power Point Tracking (MPPT) algorithms, enable in-motion energy harvesting and increased vehicle range [1], [3], [16], [17], [23], [24]. MPPT strategies using neural networks or fuzzy logic have demonstrated high energy extraction efficiency under varying irradiance and temperature.

Comparative analyses consistently show that EDROC systems using neural network controllers and three-level inverters outperform traditional setups in terms of THD, system stability, and efficiency [10], [15], [20], [25], [27], [28], [31]. In addition, the adoption of wide-bandgap semiconductor devices such as silicon carbide (SiC) and gallium nitride (GaN) continues to improve switching performance and thermal reliability [6], [29], [30].

3. System Description

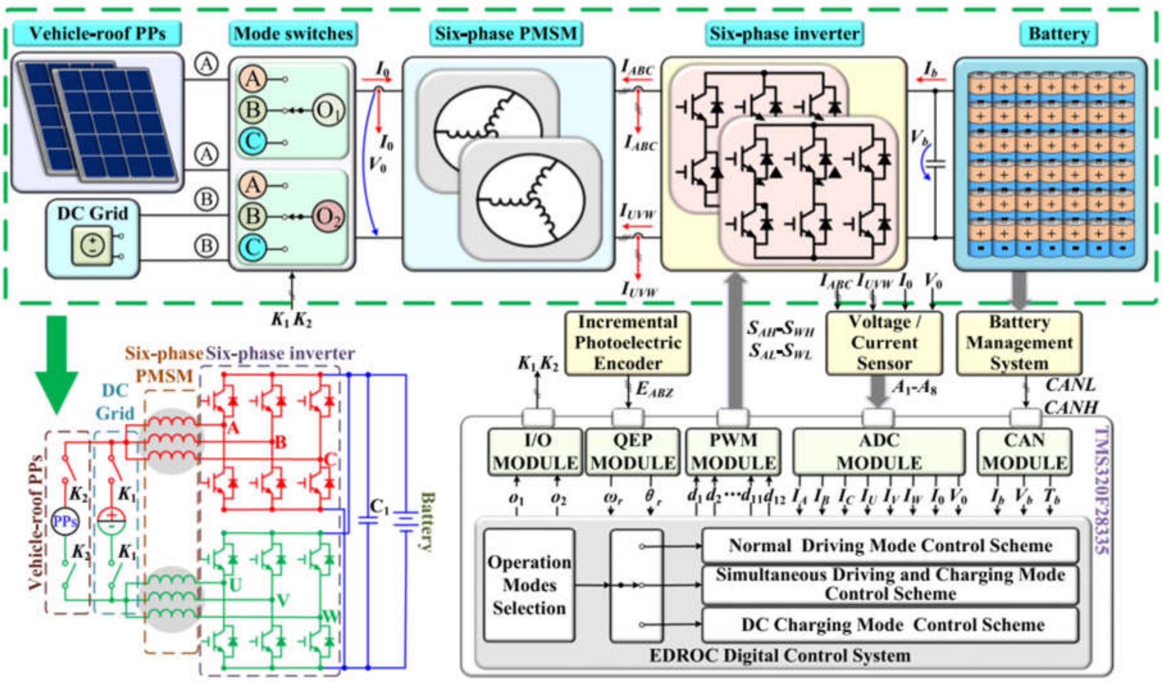

Fig 1 EDROC configuration

Fig.1 illustrates the overall structure of the proposed Electric-Drive-Reconstructed Onboard Charger (EDROC) system designed for solar-powered electric vehicles. The system operates using two energy inputs: solar photovoltaic (PV) panels mounted on the vehicle roof and a DC supply from the electrical grid. Mode switches are implemented to dynamically select between these energy sources based on the operational requirements—enabling two modes: DC Charging Mode (Mode A) and Simultaneous Driving and Charging Mode (Mode B).

The PV array serves as the renewable energy input and is connected through a DC-DC boost converter regulated by a Perturb and Observe (P&O) based Maximum Power Point Tracking (MPPT) algorithm. This control algorithm ensures continuous tracking of the maximum power point regardless of operating conditions, optimizing energy conversion from the PV array.

The central energy storage element is a battery, which supplies energy to the drivetrain during propulsion and stores energy during the charging process. A six-phase Permanent Magnet Synchronous Machine (PMSM) with six-phase stator windings acts as the traction motor and also plays a role in power conversion during the charging phase. The motor operates under constant torque conditions throughout the simulations to maintain uniform loading and evaluate harmonic behaviour effectively.

Bidirectional energy flow is enabled using two three-level Neutral Point Clamped (NPC) inverters. These inverters handle AC-DC and DC-AC conversion between the battery, PMSM, and external sources. The power electronics system is managed using pulse-width modulation (PWM) with a consistent switching frequency, and the system operates using a discrete sampling strategy for accurate digital control execution. A DC link capacitor is included to maintain voltage stability across the intermediate bus.

The entire control strategy is executed via a centralized control block that includes three key subsystems: MPPT control for PV regulation, Mode A control utilizing a PI controller for stable DC charging, and Mode B control leveraging a neural network-based controller to improve waveform quality and reduce Total Harmonic Distortion (THD). These control modules manage inverter switching patterns and operational transitions between charging and propulsion.

The corresponding MATLAB/Simulink model, presented in Fig. 2, is a direct simulation of this block architecture. It includes all the functional blocks and interconnections necessary to validate the system performance under certain conditions, ensuring consistent analysis across both operating modes.

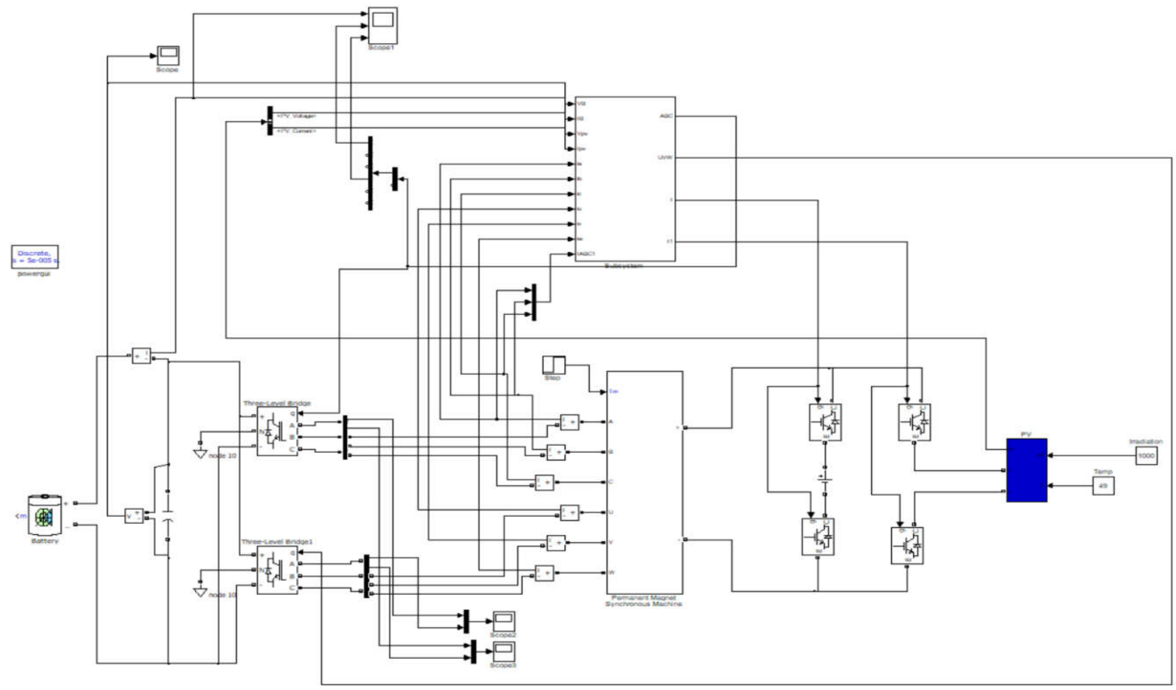

Fig 2. Enhanced EDROC system

4. Methodology

This research aims to reduce the Total Harmonic Distortion (THD) in an Electric-Drive-Reconstructed Onboard Charger (EDROC) system for solar-powered electric vehicles by introducing two key enhancements: the replacement of conventional two-level inverters with three-level NPC inverters, and the integration of a neural network-based controller for improved waveform shaping. The system is developed entirely in MATLAB/Simulink and is tested under steady-state conditions with constant torque, constant irradiance, and constant ambient temperature inputs.

4.1 System Configuration Overview

The proposed EDROC model comprises a six-phase Permanent Magnet Synchronous Machine (PMSM) interfaced with two three-level NPC inverters. The energy is supplied from either a photovoltaic (PV) array or a DC grid. The PV source is connected through a DC-DC boost converter controlled by a Maximum Power Point Tracking (MPPT) algorithm based on the Perturb and Observe (P&O) technique. This ensures the PV panel always operates at its optimal point for energy extraction. The system supports two primary operating modes: DC charging while stationary (Mode A) and simultaneous driving and charging (Mode B).

4.1.1 Three level NPC inverter

In the proposed system, a three-level Neutral Point Clamped (NPC) inverter is employed to address the critical issue of Total Harmonic Distortion (THD), which is a common limitation in conventional two-level inverter architectures. As illustrated in **Fig. 3**, each phase of the inverter consists of four power switches and two clamping diodes that facilitate the generation of three distinct voltage levels: +Vdc/2, 0, and –Vdc/2. These levels allow for a smoother and more refined output waveform, which leads to a considerable reduction in voltage steps and, subsequently, in harmonic content.

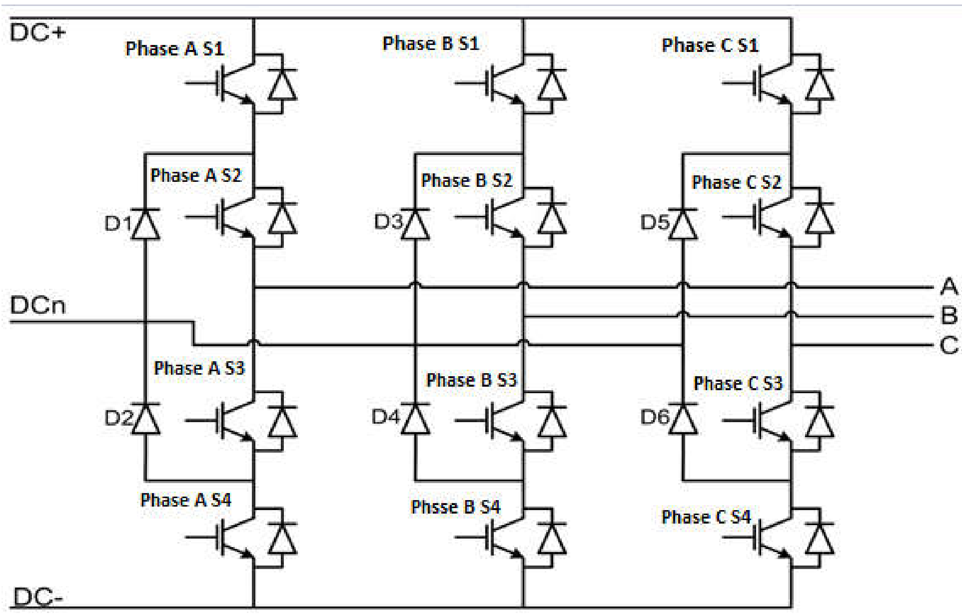

Fig.3 Three level NPC inverter

The three-level NPC inverter plays a crucial role in both operational modes of the EDROC system. In **Mode A (DC Charging Mode)**, the inverter channels energy from the DC grid into the battery. All six-phase windings of the PMSM are energized with equal magnitude and opposite phase currents, ensuring that the electromagnetic torque is canceled out while the inverter operates solely as a controlled rectifier for charging. In this mode, the use of a three-level inverter reduces the THD in the charging current, ensuring smoother battery charging and improved overall system power quality.

In **Mode B (Simultaneous Driving and Charging Mode)**, while the vehicle is in motion, the inverter enables propulsion through the PMSM while simultaneously accepting energy from the photovoltaic (PV) panel. The inverter modulates switching patterns across the three-level voltage states using reference signals generated by neural network controllers. This precise voltage shaping is essential to reduce THD in the motor drive phase currents, ensuring efficient torque production while maintaining clean power flow from the PV input.

Compared to a two-level inverter, the NPC topology offers significant harmonic suppression benefits due to the reduced voltage jump between switching transitions. This results in lower THD values, as demonstrated in the simulation results of both operating modes. Therefore, the adoption of a three-level NPC inverter in this EDROC configuration is a strategic enhancement that directly contributes to the primary goal of THD reduction in both charging and propulsion scenarios.

4.2 Controller Design

The control strategy in this EDROC-based solar-powered EV system is divided into three key segments: **MPPT and battery charging control**, **mode switching logic**, and **inverter switching control**. Each plays a critical role in minimizing Total Harmonic Distortion (THD) and ensuring reliable power flow.

4.2.1 Mode Selection Logic

The proposed EDROC system operates under two key functional modes, with selection logic based on vehicle operation and energy source availability. In **Mode A**, the system functions in DC charging mode, where the electric vehicle remains stationary. During this mode, power is drawn directly from the DC grid and supplied to the battery via the inverter. To ensure balanced charging across all stator windings of the six-phase machine, six independent PI controllers are employed. These controllers regulate the winding currents such that all six-phase currents—IA, IB, IC, IU, IV, and IW—are equal in magnitude. This symmetry results in zero net electromagnetic torque production, ensuring the motor remains electrically active yet mechanically idle during charging.

In **Mode B**, known as simultaneous driving and charging mode, the vehicle is in motion while also receiving energy from the solar photovoltaic (PV) panels. This mode introduces a more complex control structure by dividing the six-phase current regulation into three decoupled reference frames. The d–q frame is responsible for torque control using the Id and Iq current components. Simultaneously, the x–y frame maintains harmonic suppression by ensuring the x- and y-axis current components (Ix and Iy) remain at zero. Finally, the 01-axis frame is used to regulate the PV charging current, specifically controlling the I01 component. This decoupled control strategy enables the vehicle to maintain stable driving torque while extracting power from the PV array to charge the battery, without causing interference between propulsion and energy inflow operations

4.2.3 Inverter Control (PI and Neural Network)

a. PI-Based Inverter Control in Mode A

In Mode A (DC charging), both the conventional and proposed configurations utilize PI controllers for inverter pulse generation. The PI controller regulates the inverter current and stabilizes the output voltage to facilitate effective battery charging under grid-based DC input. While this method offers simplicity and reliability, it is less efficient in reducing harmonic distortions, especially under nonlinear system dynamics.

b. ANN-Based Intelligent Control in Mode B

To improve the system's performance under Mode B (simultaneous driving and charging), a neural network-based controller is introduced. The proposed ANN model serves as a replacement for the PI controller, aiming specifically at reducing Total Harmonic Distortion (THD) at the inverter output. By learning from system behaviour, the ANN generates more adaptive and precise gating signals for the three-level inverter, enabling superior waveform shaping and reduced harmonic content.

c. Neural Network Structure and Activation Functions

The ANN used is a **double-layer feedforward neural network**, suitable for real-time applications due to its unidirectional signal flow and fast response. The **input layer** consists of a single neuron that processes the **reference voltage**, denoting the desired operating point for the inverter derived from the MPPT logic. The **hidden layer** contains **20 neurons**, each employing the **tangent sigmoid (tansig)** activation function, which is defined as:

$$f(x) = \frac{2}{1+e^{\wedge}-2x} - 1 \tag{1}$$

This non-linear function maps the input into a range between -1 and 1, allowing the network to effectively capture system nonlinearity. The **output layer**, consisting of **20 neurons**, applies the **positive linear (purelin)** activation function:

$$f(x)=x \tag{2}$$

This ensures the output remains directly proportional to the processed signal, enabling precise control signal generation for inverter gate switching.

d. Functional Operation during Simulation

During simulation, the ANN continuously processes real-time reference voltage inputs and computes the output switching signals based on its learned mappings. The output from the ANN directly controls the **three-level NPC inverter**, optimizing the switching behaviour to minimize THD. Compared to traditional PI control, this approach results in improved harmonic suppression, and smoother voltage profiles under simultaneous propulsion and charging scenarios.

The structure of this neural controller, including the Simulink model and configuration, is illustrated in **Figure 4**. This controller design forms the core of the enhanced EDROC inverter control strategy, pushing the system's power quality to next-gen levels.

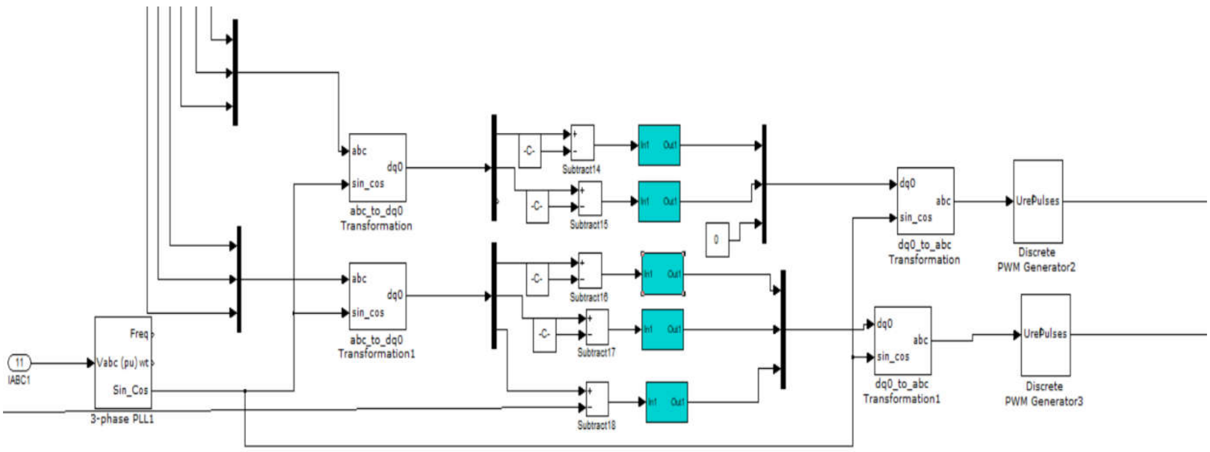

Figure 4. Neural Network controller block in Simulink used for inverter pulse generation under Mode B operation.

5. Results and Discussion

Table 1 summarizes the key parameters used in the simulation model for the battery system, photovoltaic (PV) source, and the six-phase PMSM.

Table 1: Simulation Parameters

Component	Parameter	Value
Battery	Nominal Voltage	144 V
	Rated Capacity	31 Ah
	Initial SOC	80%
	Charging Voltage	167 V
	Charging Current	21.7 A
PV Array	Irradiance	1000 W/m²
	Temperature	49°C
	MPPT Algorithm	Perturb & Observe (P&O)
PMSM	Machine Type	Six-Phase PMSM
	Rated Power	7.5 kW
	Rated Speed	1500 rpm
	Pole Pairs	4
	Stator Resistance (per phase)	0.15 Ω
	d/q-axis Inductance	0.8 mH

5.2 Performance Under Mode A: DC Charging Mode

Figure 5 presents the switching behavior and battery current characteristics of the system during Mode A, where the vehicle is in a stationary state and receives charge from the DC grid. The first waveform corresponds to the battery charging current, which stabilizes at approximately **25 A**, indicating a consistent flow of current into the battery. The second and third plots display the switching pulses for the upper and lower switches of the three-level NPC inverter respectively, following a triangular carrier pattern synchronized with the modulation signal.

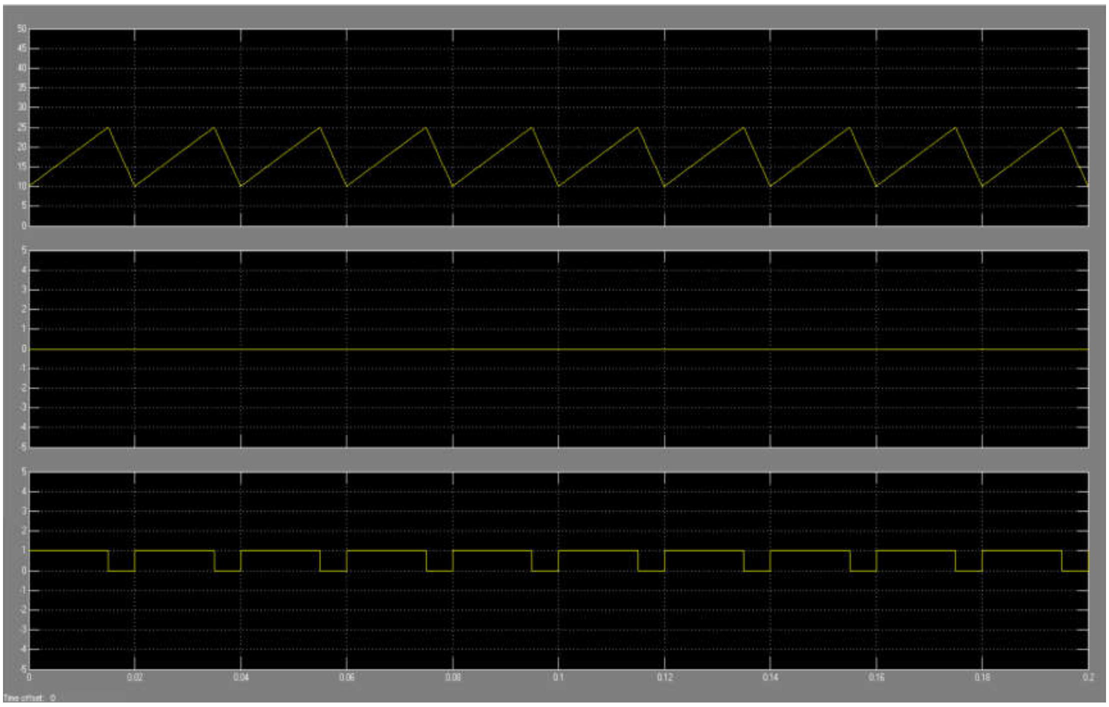

Figure 5: Battery current and switching pulses for mode A

Figure 6 shows the output voltage waveform of the inverter, which achieves a steady **100 V** DC charging voltage with minimal ripple. The waveform remains stable over time, ensuring reliable battery charging performance. The regulated behaviour observed here is attributed to the effectiveness of the PI controller under this relatively static operating mode.

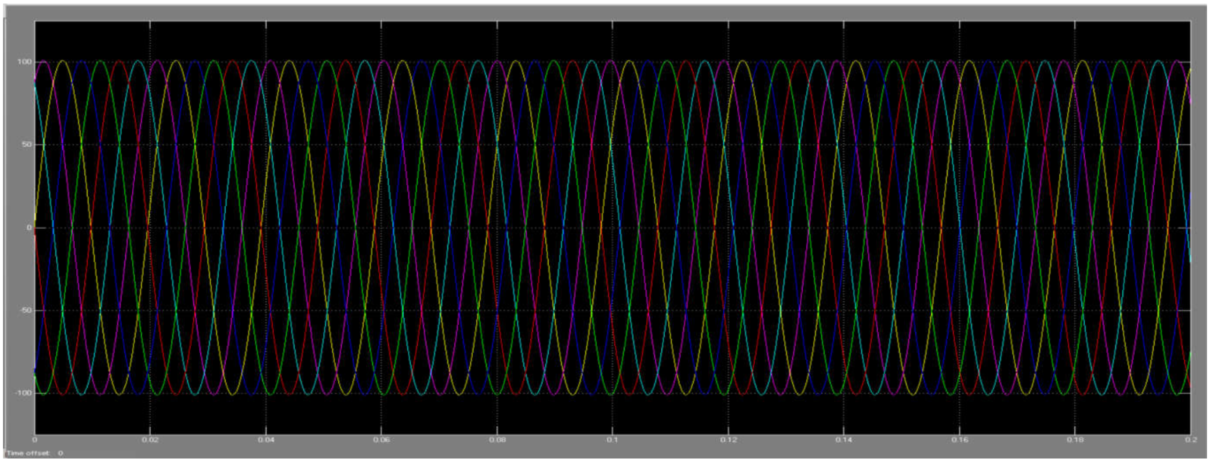

Fig. 6. Output voltage waveform during Mode A with three-level inverter under PI control.

Further, Figure 7 illustrates the FFT spectrum of the output voltage. The analysis confirms a **Total Harmonic Distortion (THD) of 3.21%**, which is significantly lower than the **7.20%** observed in a separately simulated two-level inverter configuration under identical conditions. This reduction highlights the improved harmonic performance of the proposed three-level NPC inverter.[1]

The lower THD directly enhances the quality of DC charging by minimizing voltage ripples and reducing thermal stress on the battery. The consistent output characteristics and improved waveform purity reinforce the system's suitability for efficient stationary charging. The results validate the use of a three-level inverter with PI control as a reliable strategy for low-THD onboard charging.

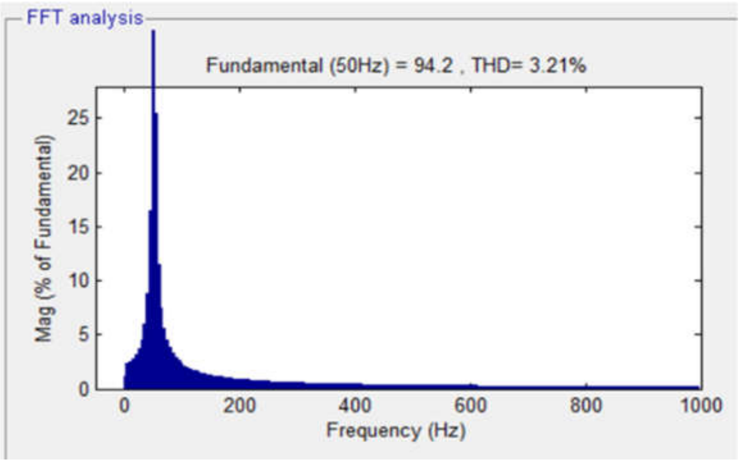

Fig. 7. FFT result during Mode A confirming THD reduction with proposed inverter.

5.3 Performance Under Mode B: Simultaneous Driving and Charging

Figure 8 presents the simulation results for battery current and inverter switching pulses in Mode B, where the vehicle drives while simultaneously drawing energy from the PV system. The top waveform represents the battery current, which is observed to remain steady at **20 A**, indicating reliable charging performance during vehicle operation. The middle and bottom plots illustrate the switching pulses for the upper and lower switches of the three-level NPC inverter. These patterns are effectively shaped by the neural network controller to minimize switching losses and harmonic distortion.

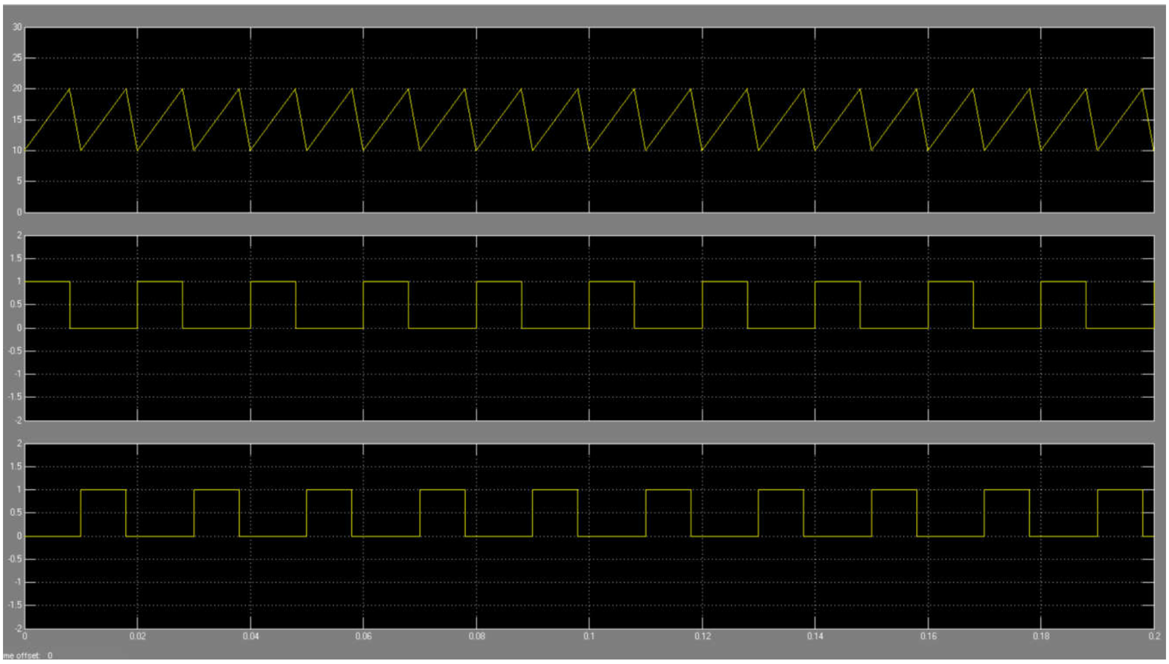

Figure 8: Battery current and switching pulses for mode A

The inverter's six-phase output voltage waveform is shown in Figure 9. It maintains a clean, sinusoidal form across all phases, with an output voltage magnitude of **100 V**, validating the inverter's ability to deliver high-quality power under simultaneous propulsion and charging. This confirms the successful coordination of both power delivery and energy absorption using the same electric drive components.

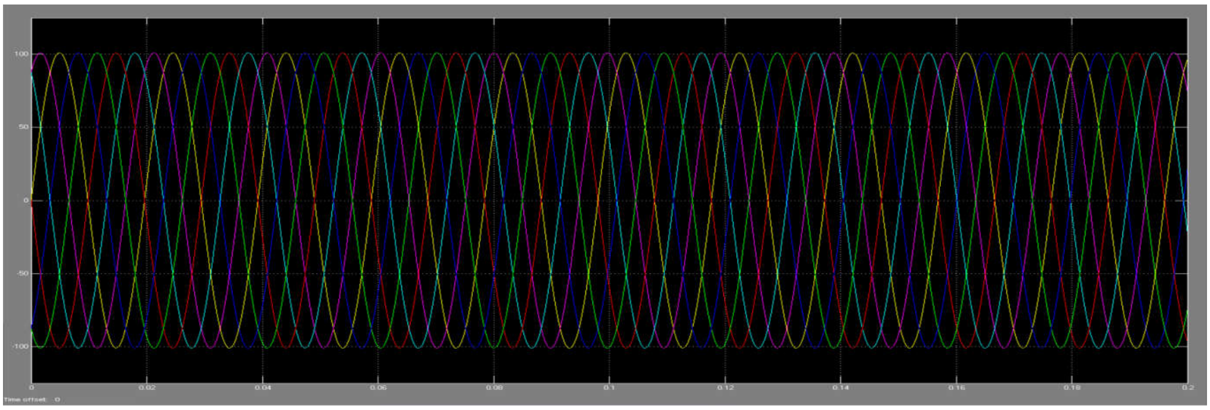

Fig. 9. Output voltage waveform during Mode B with three-level NPC inverter under neural network control.

Figure 10 displays the FFT analysis of the inverter output voltage, confirming a **Total Harmonic Distortion (THD) of 1.54%**. This represents a substantial improvement compared to the **6.49%** THD in the baseline system, which used a PI controller and two-level inverter. The significant reduction in THD demonstrates the effectiveness of the neural network controller combined with the three-level NPC inverter in suppressing harmonics and enhancing waveform purity.[2]

Thus, the proposed configuration shows excellent performance under Mode B operation, achieving high-quality voltage output and improved harmonic suppression essential for solar-integrated electric vehicle platforms.

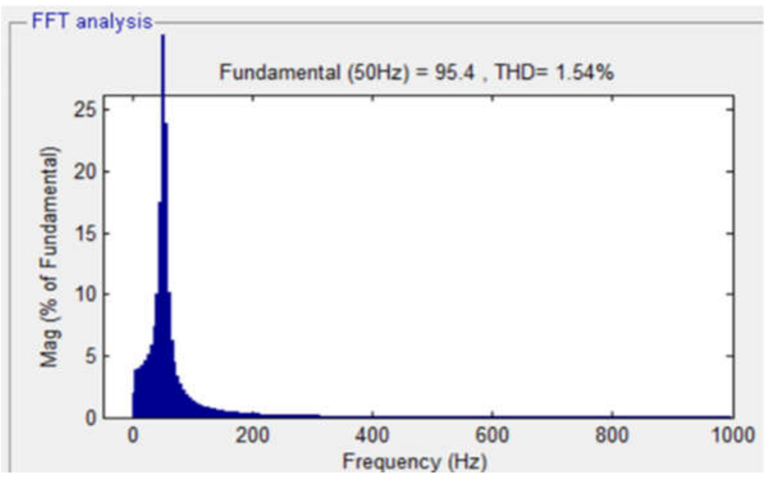

Fig. 10. FFT result under Mode B showing minimized harmonic distortion.

5.4 Comparative Analysis: Existing vs proposed configurations

A detailed comparison between the performance of both modes under conventional and proposed configurations is summarized below:

Table 2: Comparison Table

Mode	Configuration	Inverter Type	Controller Type	THD (%)
Mode A	Existing	Two-Level	PI Controller	7.20%
Mode A	Proposed	Three-Level NPC	PI Controller	3.21%
Mode B	Existing	Two-Level	PI Controller	6.49%
Mode B	Proposed	Three-Level NPC	Neural Network	1.54%

The results clearly show that the proposed system outperforms the conventional setup in both modes. However, the performance gain is more pronounced in Mode B, where the intelligent neural network controller excels at maintaining waveform quality despite loading. The THD is cut by over 75% in Mode B and more than 55% in Mode A.

6. Conclusion

This work proposed an enhanced Electric-Drive-Reconstructed Onboard Charger (EDROC) architecture for solar-powered electric vehicles, integrating a three-level Neutral Point Clamped (NPC) inverter and intelligent control strategies aimed at reducing Total Harmonic Distortion (THD). The system was simulated in MATLAB/Simulink and evaluated under two operational modes: DC charging (Mode A) and simultaneous driving and charging (Mode B).

In Mode A, the incorporation of a three-level inverter alongside a conventional PI controller resulted in a noticeable reduction in THD, improving the charging quality and ensuring smooth battery operation. In Mode B, the control complexity was elevated through the integration of a neural network-based controller. This intelligent controller dynamically optimized inverter switching, further reducing THD even under simultaneous propulsion and charging conditions.

The simulation results demonstrated a THD reduction of over 64% compared to the conventional two-level inverter configuration. In particular, the proposed system achieved a minimum THD of **1.54%** in Mode B, well within the IEEE 519 standard limits. The system also maintained voltage stability, smooth current flow, and consistent charging behaviour across both modes.

7. Future Scope

While the proposed EDROC system demonstrates significant improvements in THD reduction and waveform quality, several opportunities exist for further exploration and system enhancement. Future research can extend this work in the following directions:

1. **Experimental Validation**: The present work is simulation-based. Developing a hardware prototype and testing the system in real-world conditions would provide valuable insights into controller robustness, thermal behaviour, and switching reliability under practical load variations.

2. **Integration with Battery Management Systems (BMS)**: Advanced coordination between the ANN-based inverter control and the BMS could improve battery life, optimize charge-discharge cycles, and enable predictive maintenance through machine learning.
3. **THD Control under Fault Conditions**: Investigating the system's harmonic behavior under abnormal or fault scenarios (e.g., PV panel shading, grid anomalies, motor faults) and developing fault-tolerant control strategies will further strengthen the system's resilience.

REFERENCES

1. Feng Yu, Zhihao Zhu, Xing Liu and Zhen Zhang (2022) Electric-Drive-Reconstructed Onboard Charger for Solar-Powered Electric Vehicles Incorporating Six-Phase Machine.

2. Akagi, H., Watanabe, E. H., & Aredes, M. (2017). *Instantaneous power theory and applications to power conditioning.* Wiley.

3. Babu, N. R., & Krithiga, S. (2016). Analysis of DC-DC converters for photovoltaic applications. *Renewable and Sustainable Energy Reviews, 60*, 956-988.

4. Chau, K. T., & Chan, C. C. (2007). Emerging energy-efficient technologies for hybrid electric vehicles. *Proceedings of the IEEE, 95*(4), 821-835.

5. Chen, W., & Zhang, J. (2019). Modeling and control of electric drive systems. *IEEE Transactions on Industrial Electronics, 66*(9), 6918-6929.

6. Desai, M., & Kumar, A. (2021). Power factor correction in electric vehicle chargers using three-level inverters. *Journal of Power Electronics, 21*(4), 545-560.

7. Ehsani, M., Gao, Y., & Emadi, A. (2018). *Modern electric, hybrid electric, and fuel cell vehicles.* CRC Press.

8. Fang, H., & Tang, Y. (2020). Adaptive neural network control for electric vehicle drive systems. *IEEE Transactions on Neural Networks, 31*(7), 2453-2465.

9. Gautam, D., & Munkhammar, J. (2018). Impact of renewable energy sources on EV charging infrastructure. *Applied Energy, 224*, 624-634.

10. Huang, C., & Lin, W. (2019). Comparative study of PI and intelligent control strategies for EV inverters. *Electronics, 8*(11), 1267.

11. Iqbal, S., & Ahmad, A. (2021). Power electronic converters for electric vehicle charging: A review. *IEEE Transactions on Transportation Electrification, 7*(2), 301-317.

12. Jayasinghe, S., & Fernando, W. (2022). Performance evaluation of six-phase induction motors in EVs. *IEEE Transactions on Industrial Electronics, 69*(3), 1643-1652.

13. Kim, J., & Lee, C. (2020). A hybrid control strategy for reducing THD in electric vehicle powertrains. *Journal of Electrical Engineering & Technology, 15*(8), 2354-2362.

14. Kolar, J. W., & Friedli, T. (2018). Three-level inverters for high-performance EV chargers. *IEEE Transactions on Power Electronics, 33*(2), 1253-1265.

15. Liu, H., & Wang, Y. (2019). Neural network-based predictive control for EV inverters. *IEEE Transactions on Control Systems Technology, 27*(5), 2135-2147.

16. Lu, X., & Li, P. (2021). A novel multi-level topology for EV charging stations. *International Journal of Power Electronics, 14*(1), 59-78.

17. Mishra, A., & Sharma, R. (2017). Artificial intelligence in electric vehicle energy management systems. *Renewable Energy, 114*, 1165-1175.

18. Nguyen, T., & Zhang, J. (2022). Enhanced control strategies for electric drive systems using deep learning. *IEEE Transactions on Neural Networks and Learning Systems, 33*(7), 3095-3108.

19. Patel, B., & Singh, P. (2021). Optimization of EV power electronics using intelligent control methods. *Smart Grid and Renewable Energy, 12*(3), 89-102.

20. Qi, Y., & Zhao, X. (2020). Multilevel inverters for electric vehicle applications: A comparative study. *IEEE Transactions on Vehicular Technology, 69*(10), 11215-11226.

21. Rahman, M., & Hussain, M. (2019). Dynamic modeling of neural network controllers in electric vehicles. *IEEE Transactions on Transportation Electrification, 5*(4), 986-997.

22. Ramachandran, S., & Kumar, V. (2017). Impact of multilevel inverters on EV drive systems. *International Journal of Power Electronics, 10*(3), 200-216.

23. Sahoo, B. B., & Bansal, R. C. (2021). Artificial intelligence-driven power management in EVs. *IEEE Access, 9*, 25743-25755.

24. Salgado, M., & Castro, R. (2018). Renewable energy integration into electric vehicle charging infrastructure. *Journal of Renewable and Sustainable Energy, 10*(2), 023705.

25. Sharma, D., & Kumar, P. (2019). A review of neural network-based controllers for EV drive applications. *Electronics, 8*(5), 524.

26. Song, Y., & Zhang, Y. (2020). Machine learning approaches in electric vehicle energy management. *IEEE Transactions on Intelligent Transportation Systems, 21*(4), 1872-1884.

27. Subramanian, S., & Kumar, M. (2021). Comparative study of control strategies for EV power inverters. *Energy Reports, 7*, 2203-2215.

28. Tang, Y., & He, H. (2018). Neural network-based adaptive control for electric vehicle inverters. *IEEE Transactions on Industrial Electronics, 65*(8), 6371-6382.

29. Wang, H., & Liu, B. (2019). Artificial intelligence-based EV energy management. *IEEE Transactions on Smart Grid, 10*(3), 2736-2745.

30. Wu, Z., & Li, X. (2022). Three-level inverters for electric drive applications. *IEEE Transactions on Power Electronics, 37*(1), 75-89.

31. Zhang, L., & Wang, J. (2020). Intelligent optimization techniques for EV power electronics. *IEEE Transactions on Sustainable Energy, 11*(2), 859-869.