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# A Low Harmonic Control Method of Bi-Directional Three- Phase Z- Sources

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**Abstract -** Three-phase Z-source inverters offer a voltage boosting solution of single-stage topology. They can also operate bidirectionally as rectifiers, hence have excellent potential for applications in the area of transportation electrification like Vehicle-to-Grid (V2G) chargers. In this paper, three new modulation schemes for three-phase Z-source converters are presented and analyzed. The best performed one is further extended to a closed-loop PI control technique. Although the voltage conversion ratio is adjustable, the output voltage. Total Harmonics Distortion (THD) is less than 3% between the voltage ratio range of 0.5 to 2.5. The effectiveness of the developed method has been completely verified in MATLAB/Simulink simulations and RT- LAB Hardware-In-Loop (HIL) experiments according to the real-time simulator OPAL-RT OP4510. The proposed one is compared with conventional control techniques operates better with lower harmonics, adjustable voltage gains, and less complex control algorithm. Index Terms—Z-source converter, Bi-directional converter, shoot-through states, voltage harmonics, closed-loop control.

***Key Words***: Z-source inverter, power electronics, vehicle-to-grid (V2G), renewable energy, three-phase inverter, low harmonic control, power conversion efficiency, bidirectional operation.

## 1.INTRODUCTION

The increasing need for high-performance power converters has driven research into advanced inverter technologies for applications such as transportation electrification and microgrid integration. Conventional full-bridge three-phase inverters serve as a fundamental topology for energy conversion in DC voltage systems. However, these inverters require dead time between switching actions to prevent short-circuit failures, which inevitably leads to waveform distortions and efficiency losses. Additionally, conventional two-stage inverter designs often incorporate DC-DC converters between the input and output stages, further decreasing efficiency and response time in dynamic environments. To address these issues, Z-source inverters have emerged as a promising alternative due to their single-stage power conversion and ability to operate in shoot-through states. These inverters eliminate the need for dead time while enhancing voltage boosting capabilities without additional passive components. Their unique structure allows simultaneous activation of two switches in a bridge without short-circuiting the input voltage source. Furthermore, bidirectional Z-source inverters offer promising applications in V2G scenarios, providing efficient power transfer between EV batteries and the grid.

## 2. Proposed System Modeling

The fundamental structure of a Z-source inverter consists of an impedance network arranged in an X-shaped configuration with inductors and capacitors. This topology enables the inverter to perform both voltage buck and boost functions using shoot-through states. Unlike traditional voltage-source inverters, which require separate boost converters, Z-source inverters achieve voltage regulation within a single stage. A key challenge in deploying Z-source inverters lies in optimizing their control strategies. Existing modulation techniques often involve complex calculations and additional passive devices, increasing control system complexity. This research proposes an enhanced low harmonic control strategy focused on three novel shoot-through state modulation schemes. Sine variable modulation is particularly emphasized for its ability to suppress harmonics effectively within a closed-loop control framework. By refining the control methodology, the proposed approach minimizes power losses, reduces current distortion, and improves overall inverter performance.

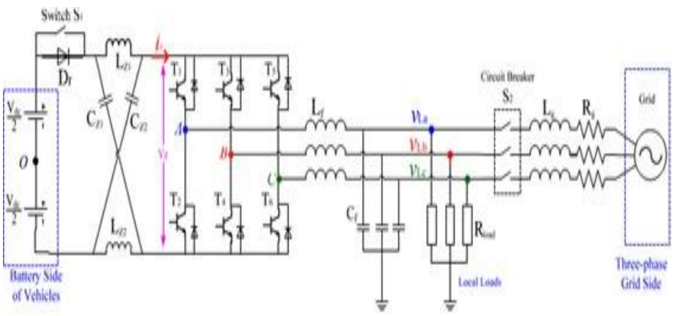
### Working Principle

### A. Vehicle-to-Grid(V2G) Mode (Discharging)

In V2G mode, the battery supplies DC power, which is regulated by the Z-source converter to adjust voltage levels as needed. The three-phase inverter then converts the DC power into AC. To ensure stable operation and minimize harmonics, the AC power is filtered by inductors and capacitors before being transmitted through the circuit breaker to the three-phase grid. The Z-source inverter effectively manages voltage regulation and synchronization with grid voltage and frequency, ensuring efficient energy transfer from EV batteries to the grid.

### B. Grid-to-Vehicle (G2V) Mode (Charging)

During G2V mode, AC power from the grid is supplied to the system. The Z-source converter rectifies this AC power into DC using the bidirectional Z-source inverter. The regulated DC voltage is then stored in the battery for charging. This process allows efficient and stable energy transfer while maintaining a controlled voltage level for safe battery charging. The ability of the Z-source inverter to perform both rectification and inversion within a single-stage topology enhances system efficiency and reliability.




- **Battery Side** – Represents the energy storage system, which acts as the primary power source in V2G mode.
- **Z-Source Converter** – Regulates voltage, enabling voltage boost and shoot-through states.
- **Three-Phase Inverter** – Converts DC to AC power for grid synchronization.
- **Circuit Breaker (S2)** – Ensures controlled switching between the V2G system and the grid.
- **Three-Phase Grid** – The final point of power transmission, ensuring synchronization with grid voltage and frequency.
- **Local Load** – The system can also supply power to connected loads when required.

**Results and Analysis**

Simulation and experimental studies validate the proposed control strategy's effectiveness. The bi-directional three-phase Z-source inverter, operating with the new modulation techniques, demonstrates reduced harmonic distortion in output voltage and improved efficiency in energy conversion. Bidirectional operation is successfully achieved, making the inverter suitable for V2G applications and integration with renewable energy sources. Additionally, comparative analyses highlight the advantages of the proposed approach over conventional control methods, particularly in terms of reduced power losses and enhanced dynamic response. The experimental setup confirms that the refined control logic offers practical implementation benefits without introducing excessive circuit complexity.

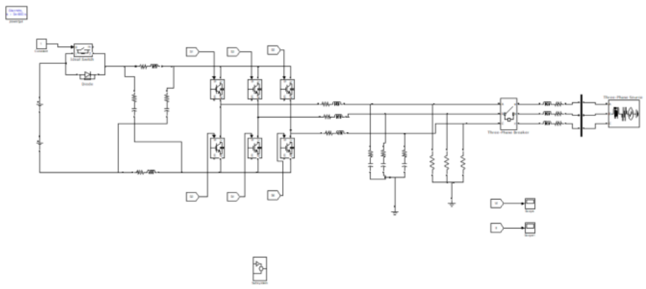


**Fig: Topology of a bi-directional three-phase Z-source converter**

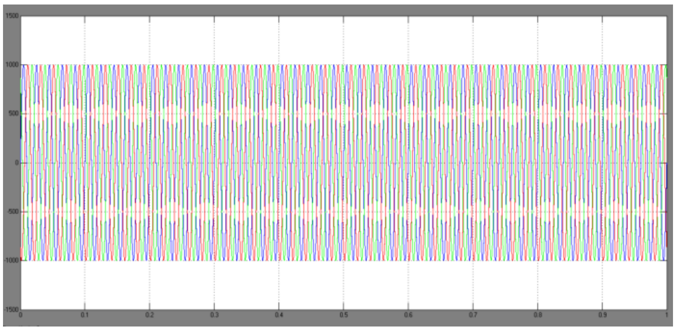


Fig: Output phase voltages of sine variable method at rated output voltage

This diagram presents the phase voltage waveforms obtained using the sine variable method at the rated output voltage. It likely demonstrates how the modulation technique ensures proper voltage levels and waveform quality.

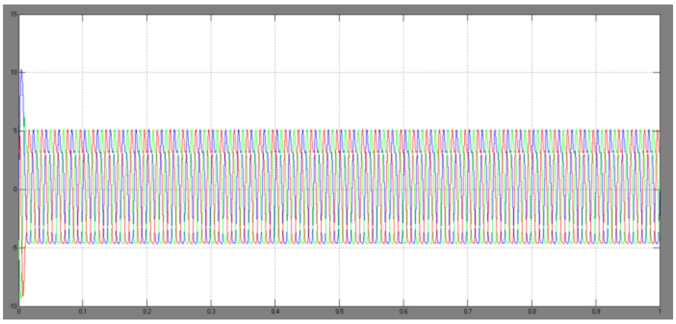


Fig:: Output phase current of sine variable method at rated output voltage

This diagram showcases the phase current waveforms at the rated voltage using the sine variable method. It provides insight into how current behaves under this control technique.

## 3. CONCLUSIONS

This study presents an enhanced low harmonic control strategy for bi-directional three-phase Z-source inverters, addressing key challenges in conventional power conversion systems. By implementing novel modulation schemes, the proposed approach improves power conversion efficiency, minimizes harmonics, and supports bidirectional operation. These advancements position Z-source inverters as a reliable solution for transportation electrification, renewable energy integration, and V2G applications. Future work will focus on further refining control methodologies and exploring real-world deployment scenarios in smart grid environments.

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