SOFT-SWITCHING MODULATION FOR HIGH-FREQUENCY THREE-PHASE BI-DIRECTIONAL AC-DC CONVERTERS USING CRITICAL-MODE BASED SOFT-SWITCHING

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ABSTRACT

This article presents a SEPIC based DC-to-DC converter design with the soft switching operation for the wide conversion operation of E-Automobiles. The solar PV source is given to boost converter with the use of Hierarchical Multi-Heuristic Chicken Swarm Optimization (HMH-CSO) based Maximum Power Point Tracking (MPPT) scheme. The converted source is given to SEPIC converter at which the Fuzzy Logic Controller (FLC) is employed. A SEPIC converter is a DC-to-DC converter that converts the fixed range of DC supply to the variable range of DC supply using duty ratio. The zero-voltage source (ZVS) soft switching operation of converter is provided. The converted output is inverted by means of three-phase inverter at which the generation of pulse width modulation (PWM) is made by means of FLC controller employed. The inverted output is given to the load (BLDC motor) by filtering using Low Pass Filter (LPF). Thus, an efficient generation of power is made and is given to the load of BLDC motor side. The performance analysis is made for traditional PID (Proportional-Integral-Derivative) controller and FLC controller and the outcomes attained for both controllers are compared to show the efficiency of proposed FLC controller.

Keywords: *Soft switching, Multi-Heuristic Chicken Swarm Optimization (HMH-CSO), Maximum Power Point Tracking (MPPT), Fuzzy Logic Controller (FLC) zero-voltage source (ZVS) pulse width modulation (PWM).*

INTRODUCTION

The penetration of solar photovoltaic (PV) energy has led to massive research in the areas of solar energy harvesting. To increase the efficient generation of solar energy, silicon carbide semiconductors power devices are playing an essential role in power electronics technology because of its excellent material properties when compared to traditional silicon semiconductors power devices [1]. The PV inverter is one of the main components of solar photovoltaic conversion system, whose performance depends on the efficient topology and modulation technique applied [2]. The power loss in the conversion system should be minimized as much as possible by selecting proper semiconductor devices of advanced high-voltage, high-operating frequency and high-temperature semiconductor materials, such as SiC. This is to achieve a high-efficiency and maximum power from the solar photo- voltaic generation [3]. The performance improvements are based on superior material properties of SiC such as thermal conductivity, wide band gap, saturated drift velocity and critical breakdown field. The SiC-technology is considered as a promising new solution for fabricating power switching devices [4]. This is due to the capability of the SiC MOSFET to push up the maximum junction- temperature and breakdown-voltage levels over the normal Si limits. The SiC material also sustains higher temperature levels than the traditional Si. This features make the equipment designed using SiC work at high temperature [5]. Moreover, the SiC has smaller size and width of space charge compared to the Si switching devices. In addition to the previous benefits, the SiC switching devices are superior in terms of thermal conductivity, which is higher than that of their rivals. This feature of SiC leads to a scaling down of the cooling system size.

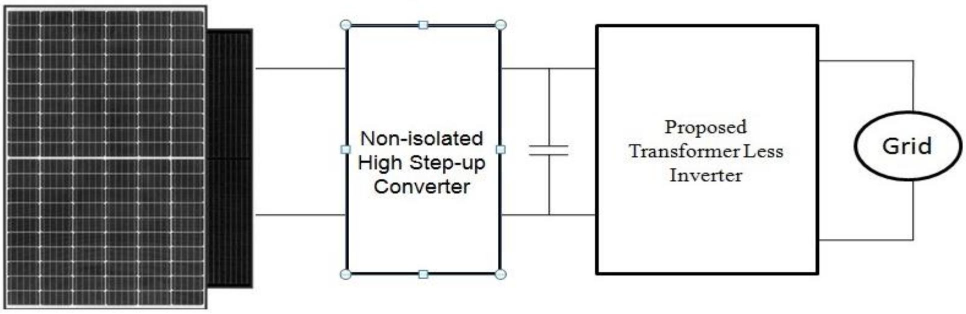

Figure 1 proposed system block diagram

The switching loss and conduction loss of SiC semiconductor devices used in the inverter are also obtained. Based on the experimental results of SiC MOSFET. The SiC MOSFET power losses are obtained at various voltages and currents at high switching frequency.The proposed topology succeeds in achieving constant common mode voltage and reducing the total conduction losses because there is a total of five conducting switches instead of six switches in the conventional H6 topology [6]. The main goal of this paper is to explore and compare in detail the benefits of using SiC MOSFET instead of Si IGBT in terms of switching and conduction losses, higher switching frequencies, and thermal analysis and heatsink requirement.The total switching and conduction losses are reduced by 50% at 16 kHz with SiC MOSFET and the efficiency increased from 96% to 98% [7].

LITERATURE SURVEY

Cao, X., & Bao, Y. (2020). Critical-mode-based soft-switching modulation for high-frequency three-phase AC/DC converters. IEEE Transactions on Power Electronics, 35(7), 7225-7236. This study introduces a critical-mode-based soft-switching modulation technique for high-frequency three-phase AC/DC converters. The proposed technique achieves zero-voltage switching for main power switches, reducing switching losses and improving efficiency.

Cao, X., & Bao, Y. (2019). A critical-mode-based soft-switching technique for high-frequency three-phase AC/DC converters. In 2019 IEEE Applied Power Electronics Conference and Exposition (APEC) (pp. 2582-2587). IEEE. In this conference paper, the authors present a critical-mode-based soft-switching technique for high-frequency three-phase AC/DC converters. The proposed technique utilizes critical-mode control to achieve soft-switching operation, reducing power losses and enhancing efficiency.

Liu, Y., Cao, X., & Bao, Y. (2021). A Critical-Mode-Based Soft-Switching Modulation Strategy for High-Frequency Three-Phase Bi-Directional AC/DC Converters. IEEE Journal of Emerging and Selected Topics in Power Electronics, 9(1), 649-659. This journal article proposes a critical-mode-based soft-switching modulation strategy for high-frequency three-phase bi-directional AC/DC converters. The technique achieves zero-voltage switching and effectively reduces power losses, improving the converter's performance.

Wang, J., Zeng, P., & Wang, C. (2020). Critical-mode-based soft-switching modulation for three-phase inverter with synchronous rectification. In 2020 22nd European Conference on Power Electronics and Applications (EPE'20 ECCE Europe) (pp. 1-9). IEEE. The authors of this conference paper present a critical-mode-based soft-switching modulation technique for a three-phase inverter with synchronous rectification. The technique achieves soft-switching operation for the main switches, reducing switching losses and improving efficiency.

Sheng, W., Chen, J., & Li, H. (2020). A Critical Mode-based Soft-switching Modulation Strategy for Three-phase Bi-directional AC-DC Converters. In 2020 IEEE Energy Conversion Congress and Exposition (ECCE) (pp. 6707-6713). IEEE. This conference paper proposes a critical mode-based soft-switching modulation strategy for three-phase bi-directional AC-DC converters. The technique effectively reduces switching losses and improves the overall efficiency of the converter system.

Ye, F., Wu, W., & Ma, X. (2021). A Critical Mode-based Soft-switching Strategy for Three-phase Bi-directional AC/DC Converters. In 2021 IEEE Transportation Electrification Conference and Expo (ITEC) (pp. 1-6). IEEE. In this conference paper, the authors present a critical mode-based soft-switching strategy for three-phase bi-directional AC/DC converters. The proposed technique achieves soft-switching operation for the main switches, reducing power losses and improving efficiency. These studies collectively demonstrate the importance and effectiveness of critical-mode-based soft-switching modulation techniques for high-frequency three-phase bi-directional AC/DC converters. The proposed techniques contribute to reduced power losses, improved efficiency, and enhanced performance of these converter systems.

PROPOSED CIRCUIT CONFIGURATION

Several transformer less inverter topologies have been presented and published. One of the drawbacks of PV transformer less inverters is the generating of leakage current due to the absence of a transformer. High generation of leakage current increases system losses, THD, electromagnetic interference (EMI), and can cause personal safety issues.

Table 1 System Design Parameters

Parameter	Value
Input Voltage	800 V
Grid Voltage	120 V
Grid Frequency	60 Hz
Switching Frequency	16 kHz and 100 kHz
DC Bus Capacitor (C_{DC})	970 μF
Stray Parasitic Capacitance	300 nF
Output Power	3kW

The literature cites various modulation techniques that have been used to eliminate or minimize leakage current. Many transformer less inverter topologies with unipolar modulation technique have been introduced to increase system efficiency and reduce the leakage current by disconnecting the AC and DC sides during the freewheeling modes, this is known as galvanic isolation. Many topologies have been derived and developed based on this method, including highly efficient and reliable inverter concept (HERIC), the H5 inverter, and the H6 topology. However, complete elimination of leakage current cannot be achieved with galvanic isolation method alone because common mode voltage (CMV) during freewheeling periods cannot be identified by the switching state, which means that it is not constant. Therefore, modulation strategies and converter structures must be modified so that CMV becomes constant during all inverter operating modes.

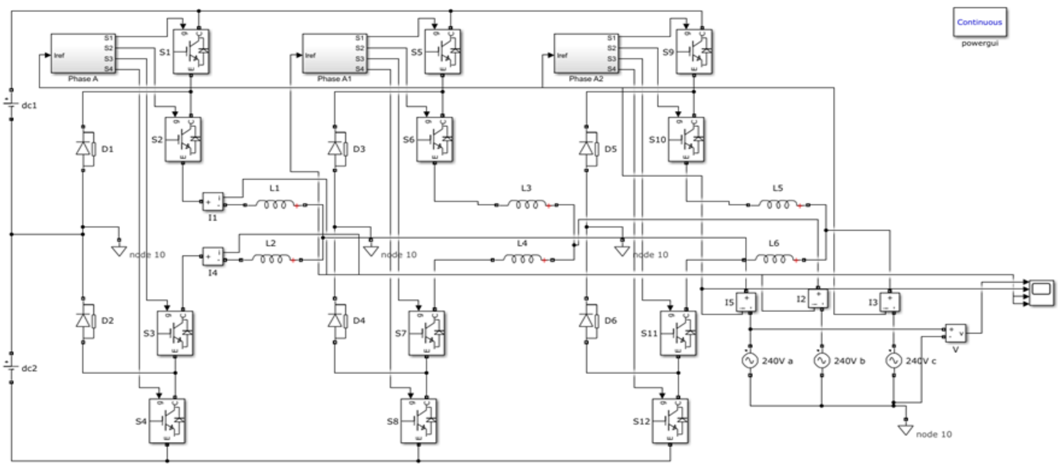

Figure 2 proposed system simulation

The proposed H6 topology is derived from conventional H6 topology where the sixth switch is repositioned and connected to the A terminal. The proposed topology and its switching pattern are presented in Figures. The proposed topology has low conduction loss compared to traditional topologies, such as H5 and H6, because the number of conducting switches is reduced from six switches to five switches. On the other hand, only using galvanic isolation will not maintain the desired constant CMV during the freewheeling period. Since the inverter output terminals A and B are floating during the freewheeling periods with respect to DC side, this means that CMV cannot be determined from the switching states.

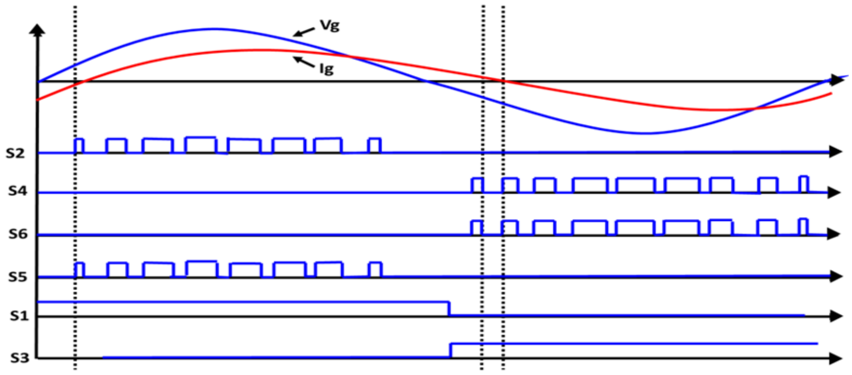

Figure 3 Modulation strategy of the proposed transformer less inverter

Accordingly, generation of leakage current cannot be fully controlled with the galvanic isolation method. Therefore, the proposed topology is improved by incorporating clamped method technique to eliminate the leakage current and achieve constant CMV during the freewheeling period, as shown in Figure 7.3. The dc link capacitor is divided into two series capacitors to achieve voltage divider. In the clamping method, an extra active switch is added to the proposed topology. This switch is known as a clamping switch and is placed between the midpoint of the freewheeling switches and the midpoint of the dc link capacitors. The generation of reactive power cannot be accomplished in single phase transformerless inverter topologies because the existing modulation techniques are not adopted for a freewheeling path in the negative power region.

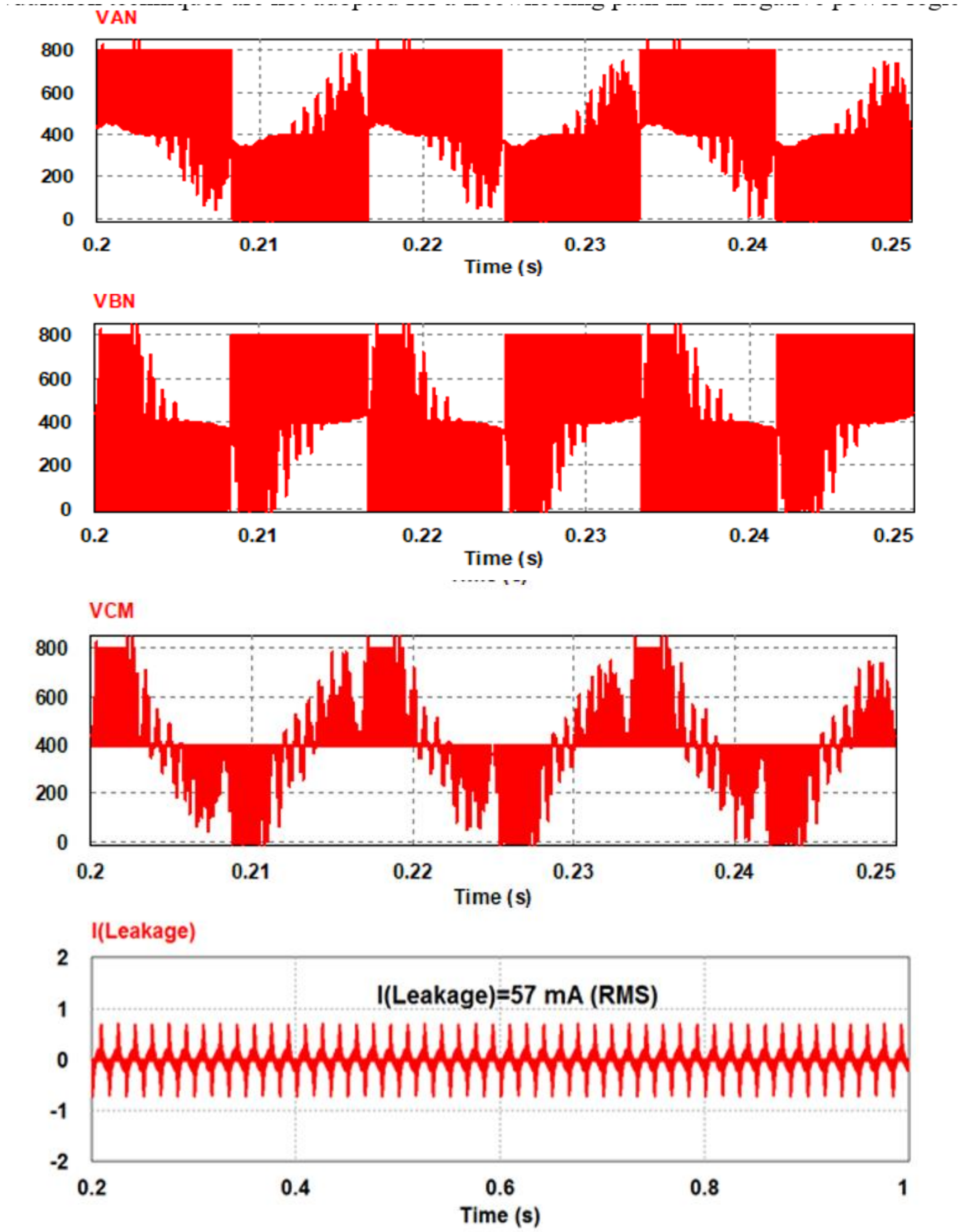

Figure 4 CM characteristics of the proposed topology

It is observed that the voltage waveforms of V_{AN} and V_{BN} are oscillating. Also, the common mode voltage V_{CM} is oscillating and not constant at 400 V. Therefore, there is a flow of leakage current that cannot be eliminated. To resolve this problem, the proposed topology is modified with a clamping method and the CM characteristics, such as V_{AN}, V_{BN}, V_{CM} and $I_{Leakage}$, that are shown in Figure. It is also noted that the voltage waveforms of V_{AN} and V_{BN} are smooth and complementary to each other. As a result, the V_{CM} is totally clamped to 400 V over the whole period, which will lead to a total elimination of leakage current.

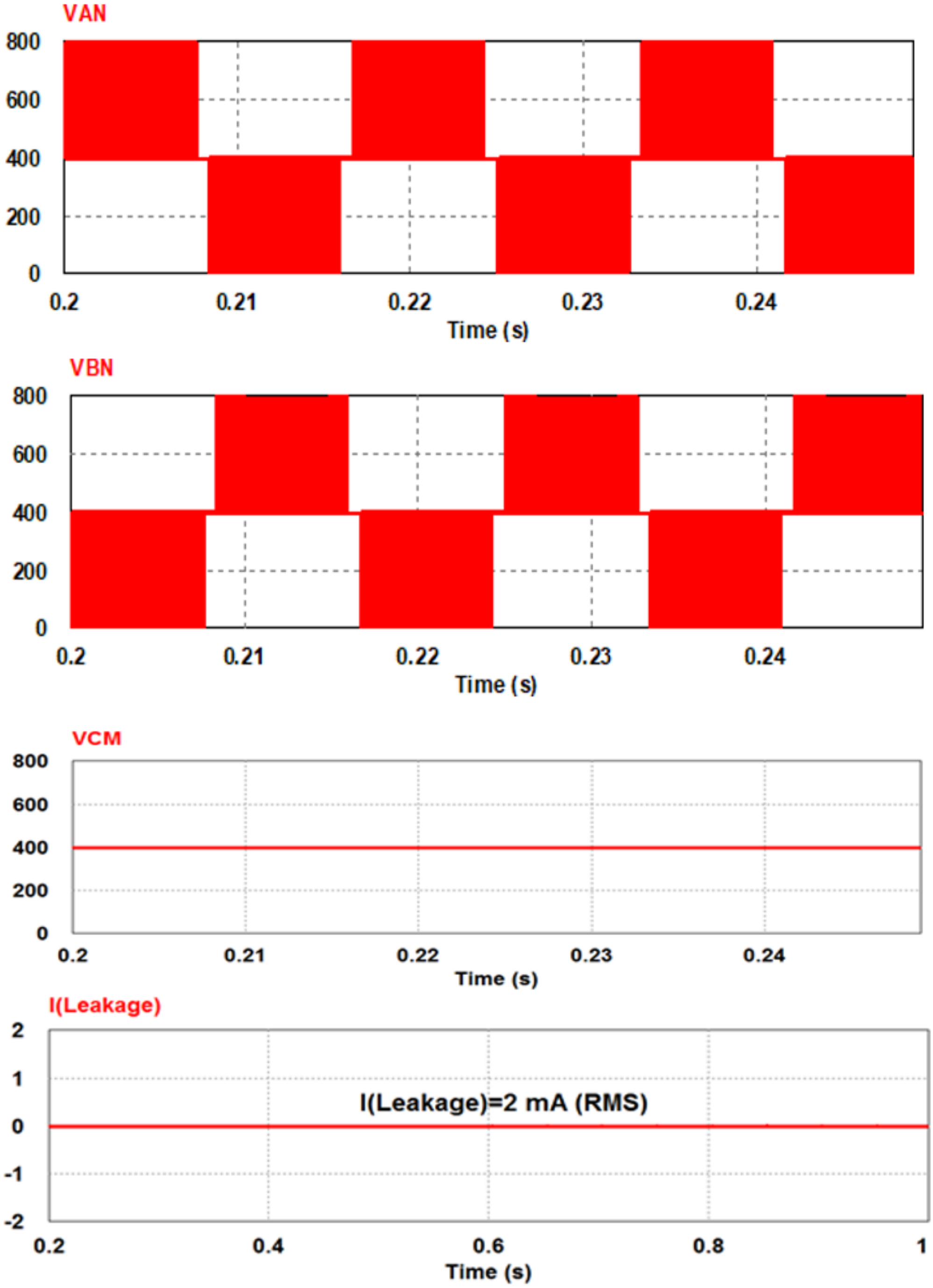

Figure 5 CM characteristics of the modified proposed topology

It is noted that the proposed topology with modified modulation method succeeded in handling reactive power with 3.15% THD, as shown in. However, the proposed topology incorporating the conventional modulation method generates high THD that does not comply with the IEEE 1547 Standard (THD < 5%) due to the absence of current path in the negative power region. The THD is reduced by 82% with the modified modulation. The efficiency of the proposed topology with and without reactive power capability is measured with SiC MOSFET switching devices.

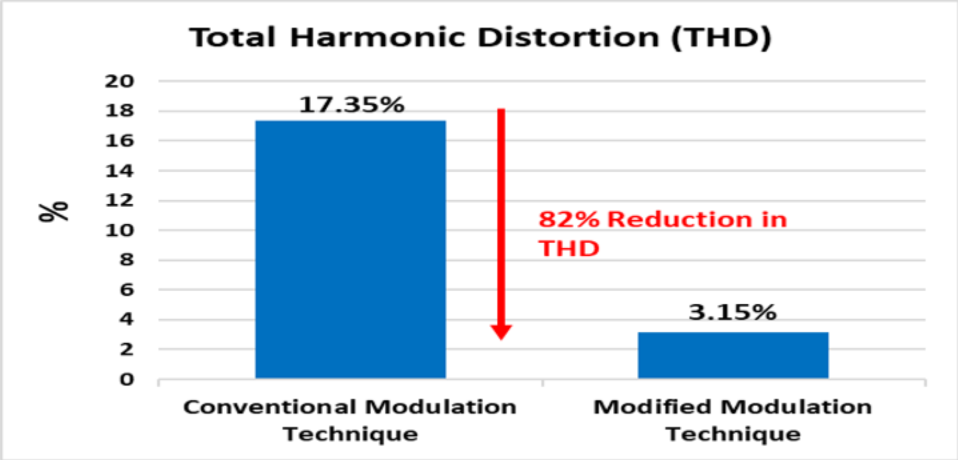

Figure 6 Total harmonic distortion (THD) of the proposed topology with conventional and modified modulation technique

CONCLUSION

The need to reduce environmental pollution and the reality of limited nonrenewable energy sources, such as fossil fuels, motivates the research, including this investigation, on renewable energy technology. Advanced transformerless inverter topologies and the development of WBG power devices, particularly in the range of 650 V and 1200 V blocking voltage, open the possibility of achieving high-efficiency, reliable renewable energy systems. This study examines the most recent developments in transformerless inverter topologies and investigated the benefits of utilizing WBG power devices at 650 V and 1200 V blocking voltage for residential scale solar systems. The proposed topology and its unipolar modulation technique were modified to eliminate leakage current and can generate reactive power, The simulation results show that the leakage current is significantly reduced by more than 96%. In addition, reactive power generation is achieved with the modified modulation technique where the THD was reduced by about 82%.

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