JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

AN AC-DC LLC RESONANT CONVERTER WITH POWER FACTOR CORRECTION

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Abstract : LLC resonant converters integrating power factor correction are becoming more common in AC-DC converters. However, single-phase setups often face challenges in effectively controlling the DC bus capacitor voltage during varying line and load conditions. A new approach in this study introduces a unique single-phase AC-DC LLC structure that utilizes a multi-level topology to manage this issue, resulting in a reduced number of switching devices. The innovative three-level inverter design ensures zero voltage switching, thus decreasing circulating current, switching voltage, ripple content and losses. Efficiency is further optimized through a transformer with a bridgeless rectifier system, while power factor correction is achieved by employing a source-side winding for discontinuous current control, nearly achieving unity power factor. By implementing variable switching frequency control for regulating the converter output voltage and utilizing pulse width modulation to govern the multilevel waveform , this system effectively maintains the DC bus voltage within a narrow range across various line and load fluctuations.

IndexTerms - **LLC resonant converters, AC-DC converters, soft switching, PFC, DC bus.**

I. INTRODUCTION

LLC resonant converters offer a number of advantages, including as soft switching of switching devices, built-in short circuit and open circuit safety, and high efficiency. They are appropriate for uses like charging the batteries in electric vehicles because they can function at extremely high switching frequencies, which reduces the converter's size and weight. To increase the power factor, however, a front-end power factor correction (PFC) stage is typically needed in AC-DC systems . A new trend involves controlling the LLC stage and the power factor stage with a single power transformer wherein the average input current can be varied without closed-loop control by running the input winding in discontinuous conduction mode, thus, improving the power factor. However, the average output power of the converter may not match the power of the PFC stage during load fluctuations and transients. The DC bus capacitor voltage fluctuates as a result of this power imbalance until energy balance is achieved. These variations may result in the converter operating unstablely or perhaps destroying the bus capacitor through overvoltage.

The regulator typically modifies the converter's switching frequency to avoid this issue and attain an acceptable energy balance with the DC bus voltage. However, at low loads, the converter's switching frequency can rise to extremely high levels, leading to significant switching losses and control issues. A burst mode control system is employed in , where the controller, upon reaching an extremely high switching frequency, halts the switching function depending on the voltage of the bus capacitor and the output DC voltage at specific time intervals. Elevated state the voltage and current waveforms shift as a result, disrupting the controller's regular operation. Furthermore, burst mode increases the voltage's low-frequency components, which need for extra filtering.

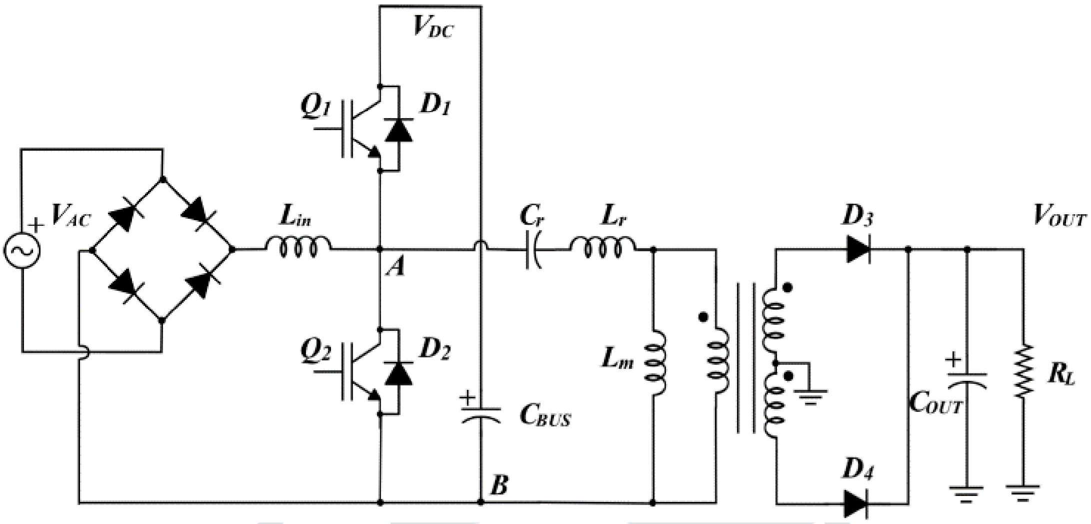


Figure-1. Conventional single-level LLC converter

A modular multilevel LLC resonant transformer is presented in [10]. By turning the modules on and off with an additional input regulator, the transformer may be controlled in a small frequency range and with a significant input voltage variation. However, they are only suitable for high voltage applications due to the need for a large number of switching devices and modular charge equalization. In [6], a bridgeless topology for resonant AC/DC converters is suggested. By returning the excess energy from the DC bus capacitor to the power source, the transformer controls the DC bus voltage. On the other hand, harmonic distortion (THD) and current waveform distortion are increased when power is fed back into the grid.

An further drawback of these converters is the high voltage that the switching devices must endure. Multilevel inverters are utilized in conventional converters to lower the voltage between switching devices and boost LLC resonant converter power range. The literature has reported on a number of single-phase bridgeless PFC topologies. They do, however, have certain drawbacks, including high voltage, the need for multiple switching devices, high switching frequency with light loads, and poor DC bus voltage regulation. This work proposes a novel bridgeless architecture that utilizes a three-level flying capacitor converter. The voltage stress between the switching devices is lessened by the multi-level arrangement. Conduction loss is decreased via bridgeless operation. The three-level voltage waveform of the design gives the PFC stage's duty ratio more flexibility. Controlling the switching frequency regulates the converter's output voltage, while the duty cycle of the switches controls the DC bus capacitor voltage. Duty cycle control, on the other hand, is used to manage the output DC voltage while maintaining a consistent switching frequency for light loads. As a result, under low loads, the transformer is kept from running at an extremely high switching frequency. For all IGBT switches, the architecture offers zero voltage switching. For natural power factor adjustment, the transformer runs in intermittent conduction mode.

II. LITERATURE REVIEW

Many authors have proposed various solutions to address the limitations of traditional Conventional single-stage LLC converter. In response to these challenges, [1] Peter and Mathew's paper introduces a novel flying capacitor topology for a single-stage AC-DC LLC resonant converter. This topology aims to address limitations associated with conventional LLC converters, particularly in terms of efficiency and voltage regulation capability. The research investigates the potential benefits of this new topology by analyzing its performance and comparing it to existing designs. The findings of this study can contribute to the development of more efficient and well-regulated single-stage LLC resonant converters.

[2] Hillers, Christen focus on designing a highly efficient bidirectional isolated LLC resonant converter. Bidirectional converters enable power flow in both directions, making them suitable for applications like battery charging systems and grid-tied inverters. This paper emphasizes achieving high efficiency across the entire operating range of the converter. The research explores design techniques and control strategies that contribute to minimizing converter losses and maximizing efficiency. The findings can be valuable for engineers developing high-performance bidirectional LLC converters for various applications.

[3] Kim, Kim, Yeon, and Moon present an analysis and design methodology for a boost-LLC converter targeted at achieving high power density for AC-DC adapters. Boost converters are employed to step-up the output voltage to meet the required level for powering electronic devices. This paper focuses on designing a compact converter suitable for applications like laptop chargers. The research investigates techniques to optimize component selection and converter layout to achieve a high-power density while maintaining desired performance characteristics. The findings can guide engineers in developing compact and efficient AC-DC adapters for various applications.

[4] Qiu, Liu, Fang, Liu, and Sen provide a mathematical guideline for designing an AC-DC LLC converter that incorporates Power Factor Correction (PFC). PFC improves the input current waveform to be more sinusoidal, reducing harmonic distortion on the power grid. This paper offers a structured approach for designing an LLC converter with PFC functionality. The mathematical guidelines presented in the research can be a valuable tool for engineers developing AC-DC LLC converters that comply with power quality standards and minimize grid harmonic distortion.

[5] Chen, Li, and Chen's paper delves into the analysis and design of single-stage AC-DC LLC resonant converters. Single-stage converters offer advantages like reduced component count and improved efficiency compared to multi-stage designs. This research focuses on providing a comprehensive analysis and design methodology for single-stage LLC converters. The paper likely explores the operating principles of LLC resonant converters, analyses their steady-state and dynamic characteristics, and presents design procedures for selecting appropriate components and achieving desired converter performance. The findings can serve as a valuable resource for engineers developing single-stage AC-DC LLC converters for various applications.

[6] Peter, Amalraj, Philip, and Mathew introduce a new bus voltage stabilization technique for an AC-DC LLC resonant converter. Maintaining a stable output voltage is crucial for powering sensitive electronic devices. This paper investigates a novel technique to address bus voltage fluctuations that can occur in LLC converters. The research likely explores the causes of voltage instability in LLC converters and proposes a control strategy or circuit modification to mitigate these issues. The findings can contribute to the development of AC-DC LLC converters with improved output voltage regulation, enhancing their suitability for powering critical loads.

III. METHODOLOGY

In our methodology, Our research employs a systematic methodology to address challenges encountered in conventional single-stage LLC converters. This methodology is divided into distinct phases, each contributing to the overall improvement process.

The first phase focuses on identifying the problem statement. Here, we clearly define the limitations or drawbacks of existing single-stage LLC converters. This could involve inefficiencies at specific operating points, poor output voltage regulation, limited power output range, difficulties in achieving Power Factor Correction (PFC), or bulky designs with high component stress.

Following problem identification, phase two involves collecting specifications of existing models. We gather information about commercially available and research-based single-stage LLC converter models. This includes reviewing research papers, technical specifications, and key parameters like input voltage range, output voltage and power rating, efficiency curves, component selection, and control strategies. By analyzing existing models, we can identify their strengths and weaknesses, allowing us to target specific areas for improvement based on our problem statement.

Phase three delves into model selection and simulation. Based on the identified limitations and collected specifications, we select a suitable model for improvement. This may involve choosing a specific existing converter or developing a modified version. We then utilize MATLAB simulation software to create a virtual model of the converter's behavior. By simulating the performance of the chosen model under various operating conditions, we gain valuable insights.

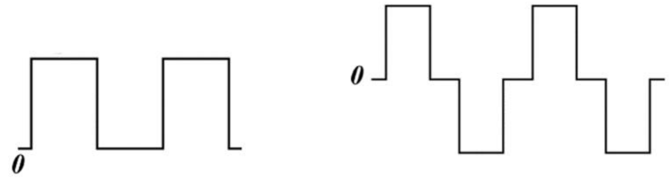
Phase four focuses on observing and analyzing the simulation results. Here, we confirm the identified problems within the chosen model and gain deeper understanding of how different parameters impact the converter's performance. This analysis helps us pinpoint areas for improvement or modifications to address the problem statement we established earlier.

The final phase, though titled "AC to DC conversion," serves as a refinement stage based on the findings from the previous phases. It's not about the core function of the converter itself, but rather about refining the AC-DC conversion process based on our analysis. This might involve modifying the converter model based on the observed simulation results. We can implement control strategies or component changes to achieve the desired improvements. Finally, we re-simulate the modified model to verify the effectiveness of the changes made. If necessary, we may iterate through phases three and four for further optimization until we achieve the desired performance improvements.

This systematic methodology provides a structured approach for identifying limitations, leveraging existing models, and implementing improvements through simulation and analysis. By following these phases and documenting our findings and rationale at each step, we can create a clear and well-defined path for enhancing the performance of single-stage LLC converters.

IV. PROPOSED TOPOLOGY

The suggested converter is put through both the LLC and rectification stages in this study. The converter operates in discontinuous conduction mode in this setup, guaranteeing a displacement power factor of unity. The voltage provided to the LLC stage comprises of three discrete levels (see Fig. 2b), as opposed to the two-level waveform seen in traditional single-stage converters (see Fig. 2a) . With the use of this three-level voltage pattern, the controller may adjust the duty ratio and manage the DC bus voltage without breaking the waveform's symmetry. To protect capacitors and reduce voltage stress on the switching devices over a wide range of load and input fluctuations, efficient regulation of the DC bus voltage is crucial.



(a) Conventional topology (b) Proposed Topology

Figure-2. Input Voltage to LLC Stage

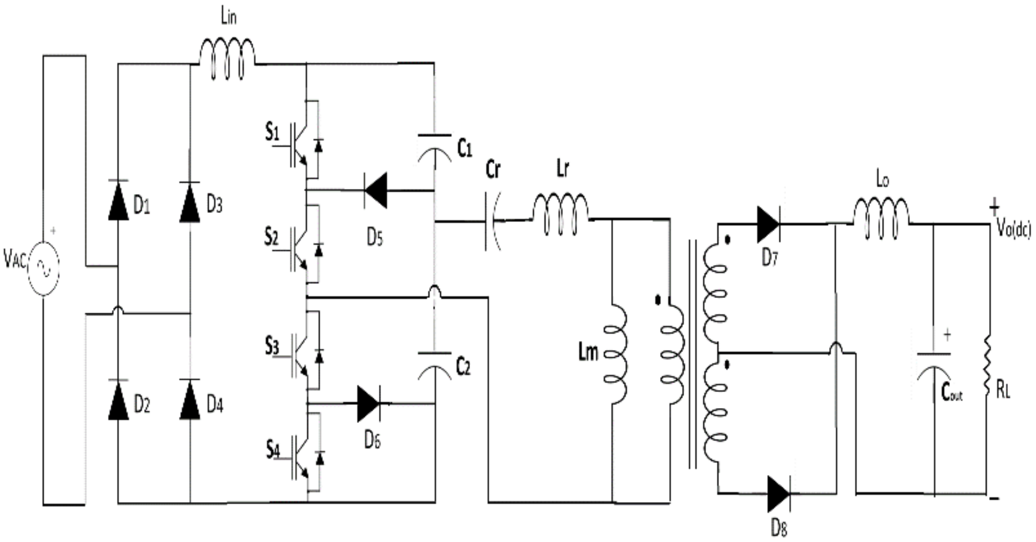


Figure-3 . Proposed Three Level LLC Converter

By integrating an LLC based resonant stage, the proposed topology naturally enables zero voltage switching (ZVS) of the IGBT switches. To achieve voltage symmetry across the LLC terminal, capacitors C1 and C2 should maintain the same voltage level (Vdc). The switch pairs S1, S2 and S3, S4 operate in a complementary manner.

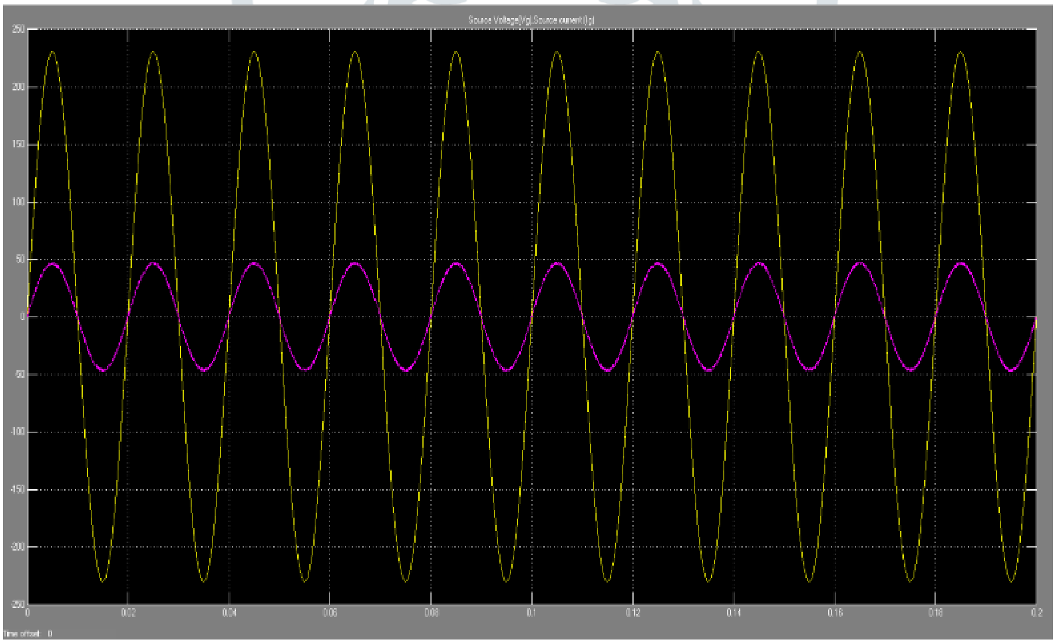


Figure-4 . Source voltage and current waveform

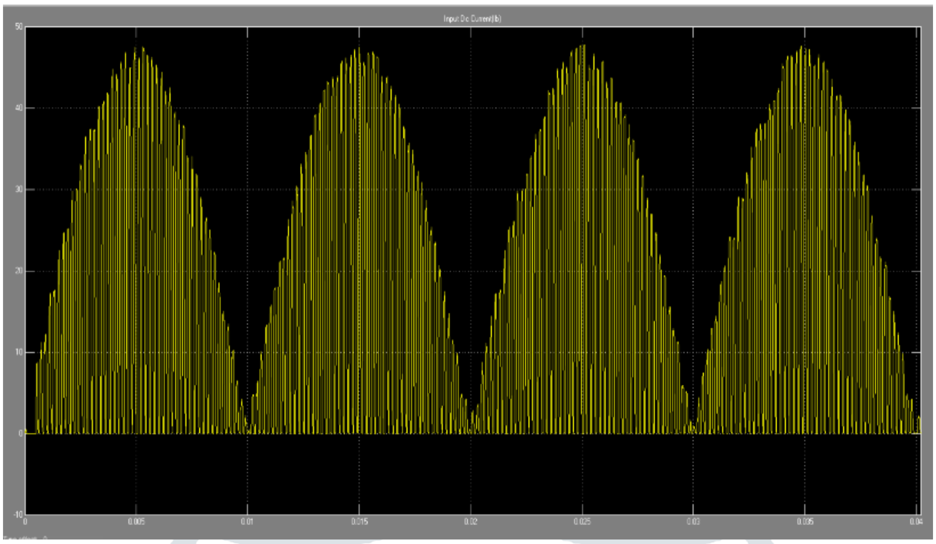


Figure-5 . Input current in discontinuous conduction mode

V. DESIGN ANALYSIS

LLC STAGE :

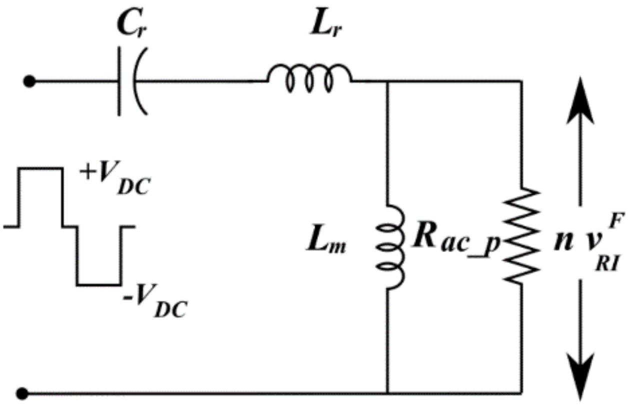


Figure 6- Equivalent representation of the LLC converter

Figure 6 shows the main equivalent representation of the LLC converter. Presumably, the primary circuit receives an input voltage in the form of a stepped square wave with a peak voltage of ±Vdc. The essential part of the voltage input to the LLC stage is supplied by

$$v_{in}^{F} = \frac{8V_{DC}\sin(\frac{D}{2})}{2\pi}\sin\omega t$$

On the output side, the fundamental component of nv_{RI}^{F} voltage is given by:

$$nv_{RI}^{F} = \frac{4nV_o}{\pi}\sin\omega t$$

The LLC stage’s voltage gain will depend on A,Q and f_{sw}, where A is the is the ratio of magnetizing inductance Lm to resonant inductance Lr.

$$A = Lm / Lr$$

The converters resonant frequency (fo) will be given by

$$f_o = \frac{1}{2\pi\sqrt{L_r C_r}}$$

Q is the quality factor which is given by:

$$Q = \frac{\sqrt{L_r/C_r}}{R_{ac\_p}}$$

$$R_{ac\_p} = \frac{8n^2 R_o}{\pi^2}$$

The AC equivalent of the load resistance referred to the primary side is represented by Rac_p. Meanwhile, Ro indicates the output load resistance. The selection of Q and A values is based on the desired voltage gain and the required frequency range of operation. The converter needs a significant frequency variation to accommodate a wide range of output power. If the converter operates at low frequencies away from series resonance, the circulating current through the LLC will increase, leading to higher losses. When the switching frequency is higher than the series resonant frequency, the circulating current is minimal, but this increases the switching losses. The flow of circulating current is similar to that of traditional LLC converters, and the operation and function of the resonant tank closely resemble those in a conventional topology .

V. EXPERIMENTAL RESULT

A Resonant converter simulation model is designed, and implemented. The converter ratings are: input supply voltage: 230 V, output voltage: 520V, resonant frequency: 15kHz. Table 1 gives detailed converter parameters.

Parameter	**Value**
Input Voltage, V_{AC}	230V
Output Voltage, V_o	520V
Resonant frequency, f_r	15KHz
Input inductor, L_{in}	27µH
Series Resonant inductor, L_r	7.4mH
Series Resonant capacitance, C_r	15nF
Magnetizing inductance, L_m	18mH
DC bus capacitor,C_1,C_2	470µF
Output filter capacitor, C_{out}	100µF
Output Resistor load, R_L	12Ω

Table 1 . Converter Parameter

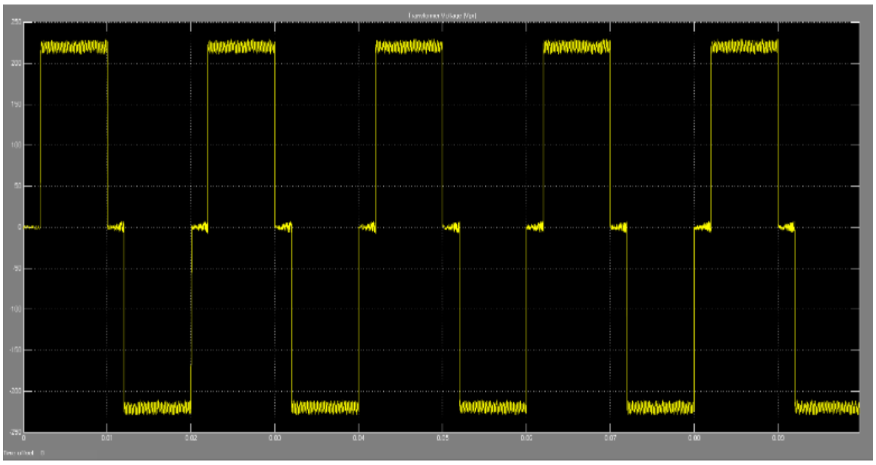


Figure-7. Voltage waveform across LLC terminals

The figure-4 shows the voltage and current waveform from the source and also the figures tell that converter runs at unity power factor. Figure-5 shows the discontinuous current through the input inductor Lin and voltage waveform. The primary side voltage i.e. three level output was shown in figure-7 .The voltage was stepped up using a centre-tapped transformer. Then with help of the diode it is converted into dc. The output voltage was shown in figure-8.

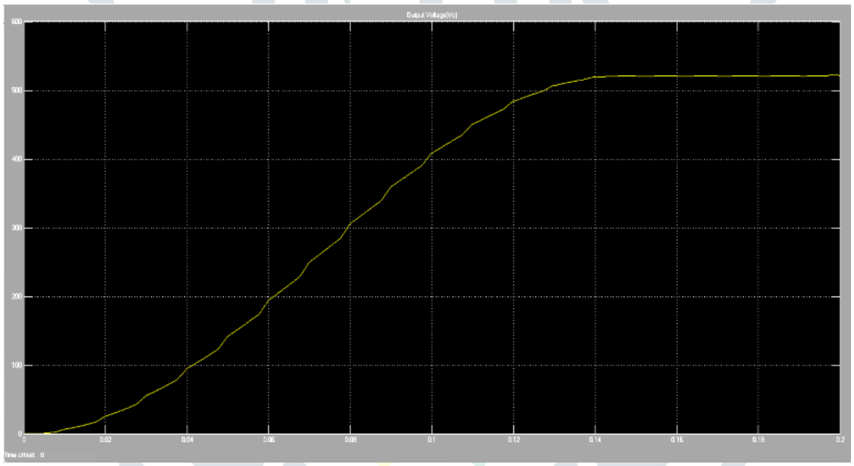


Figure -8. Output DC waveform(Vo)

VI. CONCLUSION

In this paper, for AC/DC LLC resonant converters with power factor adjustment, a three-level converter topology has been developed. Without the use of active current control methods, the converter is made to run in discontinuous conduction mode and achieve a power factor that is almost equal to unity. Additionally, the converter aids in lowering the ripple content that arises at the source. In addition, the topology lowers losses and offers low voltage stress and ZVS for each of the four switches. Additionally, the multilevel converters aid in a wide range of output operation.

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