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Design and Analysis of Modified AC to DC Converter Topology for Fast Electrical Vehicle Charging

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ABSTRACT
The rapid adoption of electric vehicles (EVs) necessitates the development of efficient and reliable fast charging stations. This work presents a comparative analysis of various existing power converter topologies with the proposed topologies that are used in fast EV charging stations, focusing on their efficiency, cost, complexity, and performance. The study covers traditional and emerging converter topologies, including isolated and non-isolated designs, multi-level converters, and soft-switching techniques. Key performance metrics such as device count, charging voltage and source harmonics are evaluated. The analysis highlights the trade-offs between different topologies, providing insights into the optimal design choices for specific applications. The findings indicate that while non-isolated topologies offer higher efficiency and lower cost, isolated topologies provide better safety and flexibility.
Keywords: AC/DC Converter; Electric Vehicle charging; Battery Charging; Total Harmonic distortion (THD); Charging voltage.

1. Introduction

The growing adoption of electric vehicles (EVs) has led to an increased demand for efficient and reliable charging infrastructure. Among the critical components of this infrastructure is the design of power conversion systems, particularly the AC to DC converters, which form the backbone of EV charging stations. These converters play a pivotal role in transforming the alternating current (AC) supplied by the grid into direct current (DC) suitable for charging EV batteries [1]. The performance of these converters directly affects the charging time, efficiency, and overall energy consumption of the charging stations. Fast EV charging stations, often referred to as DC fast chargers (DCFC), require high power levels to deliver rapid charging speeds, thus necessitating efficient power conversion technologies [2]. The design of AC to DC converters for such stations involves addressing challenges like high power density, thermal management, power factor correction (PFC), and achieving high conversion efficiency to minimize energy losses [3]. The selection of appropriate topologies for AC to DC conversion is crucial to ensure compatibility with grid requirements, reduce harmonic distortions, and provide stable DC output to EV batteries [4].

Various AC to DC converter topologies are available, each with its own set of advantages and trade-offs. These include single-stage and multi-stage converters, full-bridge rectifiers, boost converters, and advanced topologies like the Vienna rectifier and active front-end (AFE) converters [5]. The choice of topology depends on several factors, such as the desired power level, grid integration requirements, efficiency targets, and cost considerations. Additionally, the use of advanced control strategies, such as pulse-width modulation (PWM) and digital control, can significantly enhance the performance and reliability of these converters [6].

The analysis of AC to DC converter topologies is essential for optimizing their design to meet the requirements of fast charging applications [7]. This involves evaluating their performance in terms of efficiency, power quality, electromagnetic compatibility, and thermal management. Furthermore, as the adoption of renewable energy sources grows, the integration of hybrid systems, like solar PV arrays or wind turbines, with AC to DC converters for EV charging stations is becoming increasingly relevant. This integration can provide additional benefits like reducing grid dependency, improving energy efficiency, and supporting sustainable transportation solutions [8].

In this study, we focus on the design and analysis of various AC to DC converter topologies for fast EV charging stations, aiming to identify optimal solutions that can meet the growing demands for efficient and rapid charging. By examining different topologies and their performance characteristics, this research seeks to contribute to the development of more effective charging infrastructure, supporting the transition to electric mobility and reducing the environmental impact of transportation systems.

The proposed Converter is the modification of Vienna Rectifier circuit with the additional switches. The presented topology will work for the single-phase AC to DC converter for fast electrical vehicle charging stations. This topology is applicable to on board charging i.e at house hold applications.

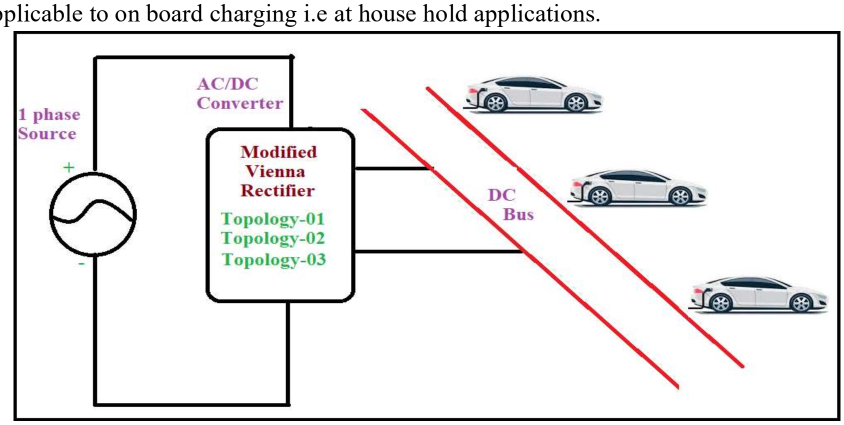


Figure 1.1: Functional Block Diagram of EV charging Structure

2. **Proposed Topology**

The employed topology involves a single-stage Vienna rectifier configuration. The input structure of these configurations features an inductor, denoted as L, with the resistor R representing the resistive components within the inductor. The configuration described in this study closely resembles that of a single-phase T-type inverter, where the external switches of the inverter are substituted by the diodes present in the rectifier. In these rectifier topologies, the internal switch operates when the upper capacitor is undergoing charging. The minimized alterations in the circuit contribute to reduced total harmonic distortion (THD) in the line current due to the switching frequency, thereby leading to an enhancement in the power factor at the source side. Notably, this converter, referred to as the split capacitor, incorporates two capacitors positioned at the output side, effectively reducing the voltage stress imposed on the power semiconductor switches.

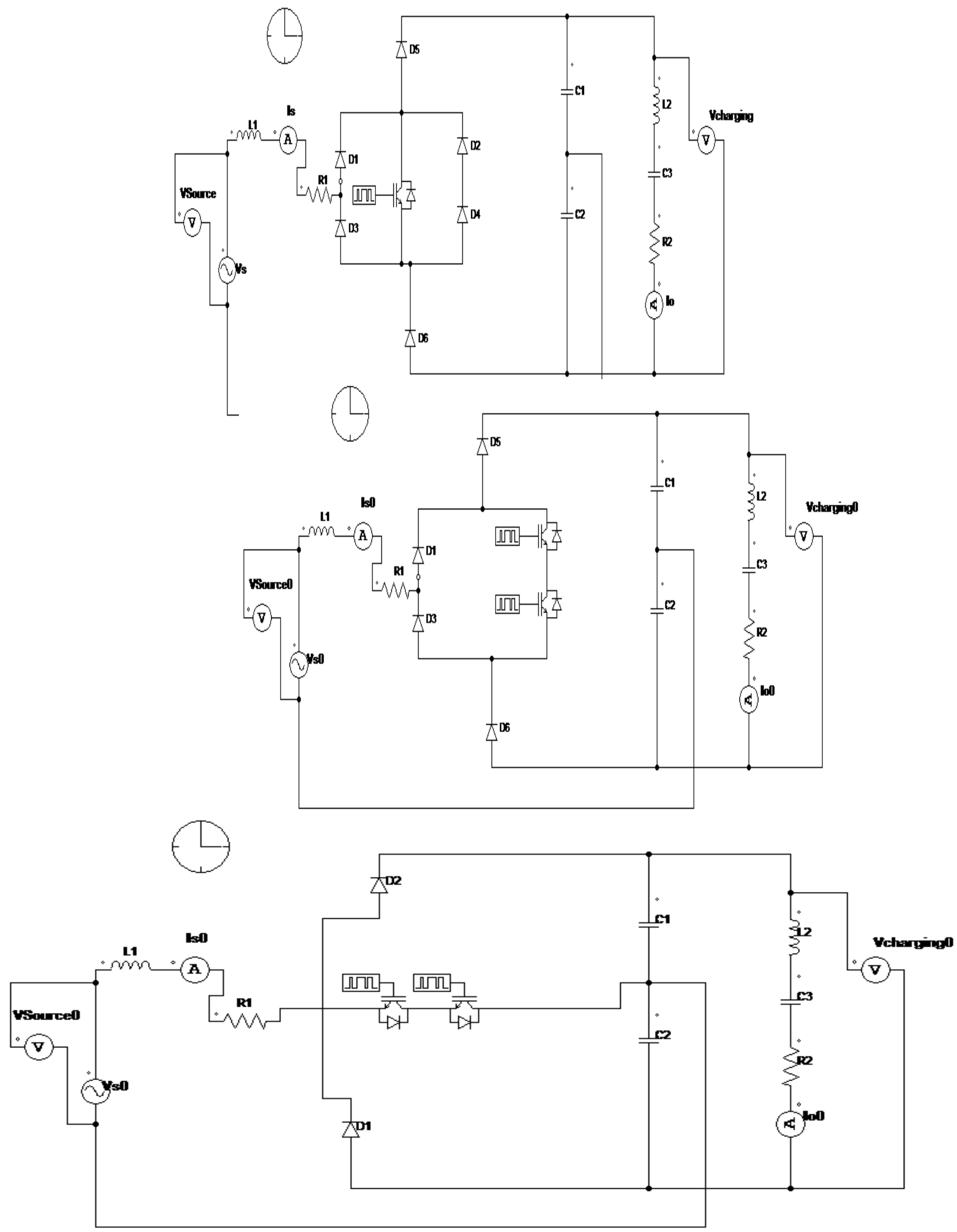


Figure 2.1: Circuit of Converter-: (a) Topology -01 (b) Topology-02 (c) Topology -03 for EV Charging

2.1. Circuit Topology -01

In this configuration, a power factor correction controller is employed to ensure a consistent output voltage and generate a sinusoidal input current. Nevertheless, the utilization of only one semiconductor switch and six diodes in this topology leads to a reduction in system efficiency. One notable benefit is the limited voltage stress on each component, which translates to a reduction of half the total DC bus voltage during each interval. Through analytical approximations, the semiconductor's average and RMS current ratings have been computed . By integrating an inductor on the input side, converters of this kind can enhance both power quality on the input side and the DC output voltage.

2.2. Circuit Topology -02

In Topology 2, the currents flowing through the freewheeling diodes, I D2 and I D4, as well as the capacitor surge current, I C, remain unchanged from Topology 1. However, the current through the MOSFET is divided between two separate MOSFETs. To alleviate the voltage stress on the switches, two capacitors are linked in parallel to help minimize losses within the switches.

2.3. Circuit Topology 3

Topology 3 addresses the lack of inherent voltage regulation in both Topology 1 and Topology 2, which can lead to excessive voltage swell at the DC output. This drawback prompts the need for consistent voltage adjustments. Topology 2 manages voltage swell by employing two anti-parallel connected switches to regulate the voltage. In contrast, Topology 3 maintains the same freewheeling diode current as the others. However, it distinguishes itself by employing a switch composed of two MOSFETs. This distinction helps alleviate the voltage stress on the switches and reduces the circuit to only two diodes, minimizing diode losses.

This design modification contributes to reduced diode losses and lowers the switch rating, resulting in cost reduction and improved efficiency. In this topology, the switches are linked at the rear connection of the MOSFETs. During the positive half cycle, MOSFET S1 and the diode of S2 conduct, while during the negative half cycle, MOSFET S2 and the diode of S1 are in conduction.

3. Converter Simulation in PSIM

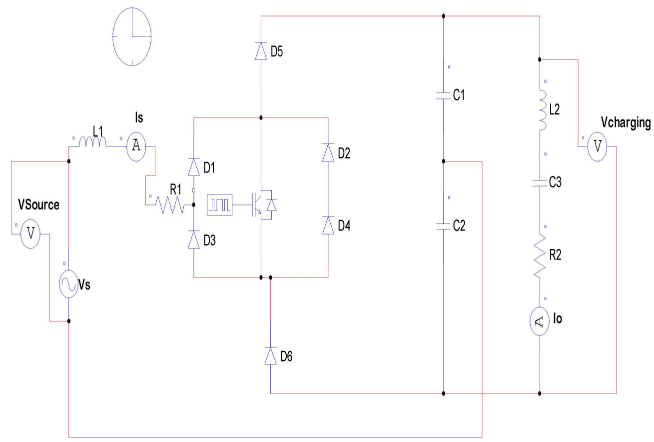
With the increasing adoption of electric vehicles (EVs), the demand for efficient, reliable, and fast charging stations is rising [9]. The AC to DC power conversion process is crucial in these stations, as it ensures that the alternating current from the grid is converted to the direct current required to charge EV batteries [10,11]. This paper presents a modified topology for an AC to DC converter specifically designed for fast EV charging stations. The proposed design aims to enhance efficiency, reduce total harmonic distortion (THD), and ensure high power delivery. The performance of this modified topology is analyzed using PSIM (Power Simulation) software.

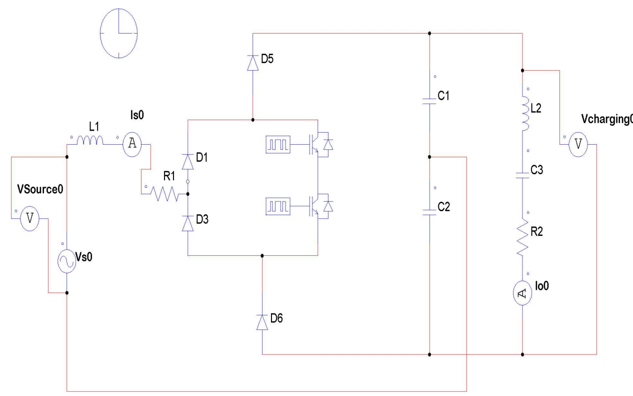
To evaluate the performance of the proposed topology, PSIM software is used for detailed simulation. The following steps outline the simulation setup:

1. **Circuit Design:** Design the proposed topology circuit using PSIM software.
2. **Component Selection:** Select appropriate components such as switches, diodes, inductors, capacitors, and control elements.
3. **Parameter Setting:** Define the parameters for each component, including ratings, switching frequencies, and control methods.
4. **Simulation Configuration:** Configure the simulation parameters, including time step, total simulation time, and output variables.
5. **Control Scheme Implementation:** Implement proper control schemes such as PWM (Pulse Width Modulation) for switching control.
6. **Running Simulation:** Run the simulation and observe the results.
7. **Data Analysis:** Analyze the simulation data to evaluate the performance metrics such as efficiency, THD, voltage stress, and current ripple.

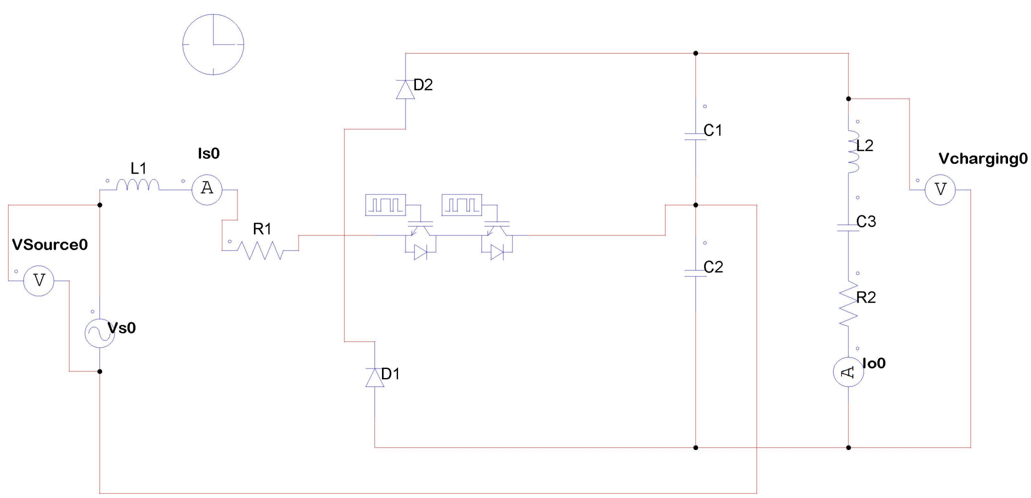
The simulation was conducted using PSIM software, a powerful tool for power electronics simulation. The key parameters and performance metrics, such as switching losses, efficiency, and thermal performance, were analyzed for each topology. The simulation of power converters for a single-phase electric vehicle (EV) charging station is a critical aspect of optimizing charging efficiency and ensuring robust performance. This study examines three distinct topologies for power converters using PSIM simulation software, providing detailed insights into their performance and efficiency.

Topology -01 utilizes 6 diodes per phase and 1 power MOSFET as electrical switches. Also the configuration is designed to handle substantial currents and voltages, making it suitable for high-power applications. The PSIM simulation is presented in figure 3.1.





(a) (b)



(c)

Figure 3.1: PSIM Simulation of Converter -: (a) Topology -01(b) Topology -02 (c) Topology-03

Topology-02 incorporates 4 diodes, capable of operating within a voltage range of 200 V to 600 V. This topology aims to balance the complexity and cost of components with the need for reliable performance across a broad voltage range. Topology -03 features a lower switch count compared to the other two topologies, simplifying the design. This configuration is optimized for efficiency, minimizing losses due to reduced switching components. The simulation parameters are presented in table 3.1.

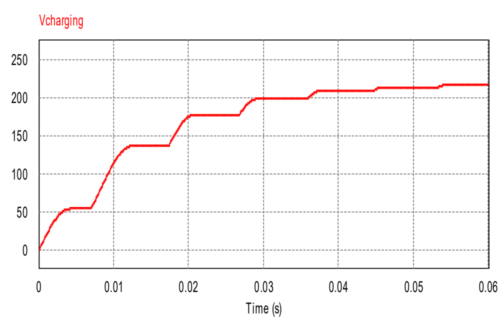
Table 3.1: Simulation Parameters

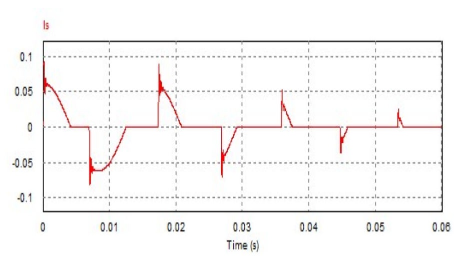
S.No.	Component	Specification
1	Source Voltage (Vs)	110 V (P-P)
2	IGBT	Ideal
3	Diode	Ideal
4	Rs (Source Resistance)	10 ohm
5	R2 (Load Resistance)	10 ohm
6	Source Inductance (Ls)	0.001 H
7	Capacitor	0.1 uF

4. Results & Discussion

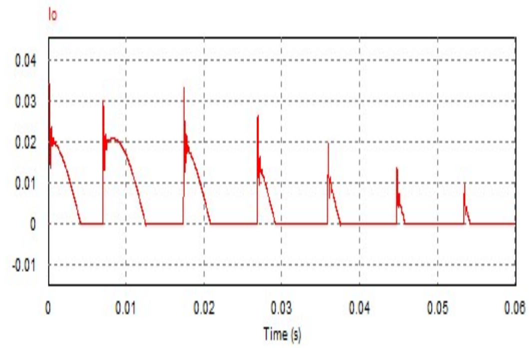
The simulation results for Topology 1 demonstrate several key performance aspects. Firstly, the charging voltage reaches a stable value of 210 V, as depicted in Figure 4.1(a). This indicates that Topology 1 is effective in achieving the desired charging voltage under the given operating conditions. Furthermore, the load current, shown in Figure 4.1 (c), has a pulsating DC nature. This characteristic of the load current can be mitigated by using active filters, which convert the pulsating DC into pure DC, ensuring a smoother and more consistent output suitable for sensitive applications.

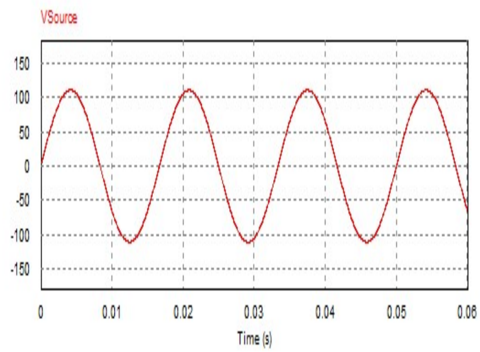
The source voltage is maintained as sinusoidal, which is crucial for reducing electrical noise and ensuring the efficient operation of the rectifier. The input voltage's total harmonic distortion (THD) is measured to be 6% of the fundamental frequency as shown in figure 4.2. This level of THD is relatively low, indicating that Topology 1 produces a clean input signal with minimal harmonic interference, which is essential for maintaining power quality and reducing the potential for harmonic-related issues in the electrical system.





(a) (b)





(c) (d)

Figure 4.1- Converter Topology -01:- (a) Battery Charging Voltage (b) Input Source Current (c) Load current (d) Source Current

The simulation results for Topology 2 indicate that the charging voltage reaches 210 V, as illustrated in Figure 4.3(a). Additionally, the load current, depicted in Figure 4.3 (b), exhibits a pulsating DC characteristic. This pulsating nature of the load current can be converted into pure DC by employing active filters. The source voltage remains sinusoidal throughout the simulation, and the total harmonic distortion (THD) of the input voltage is observed to be 6.5% of the fundamental frequency ass presented in figure 4.4.

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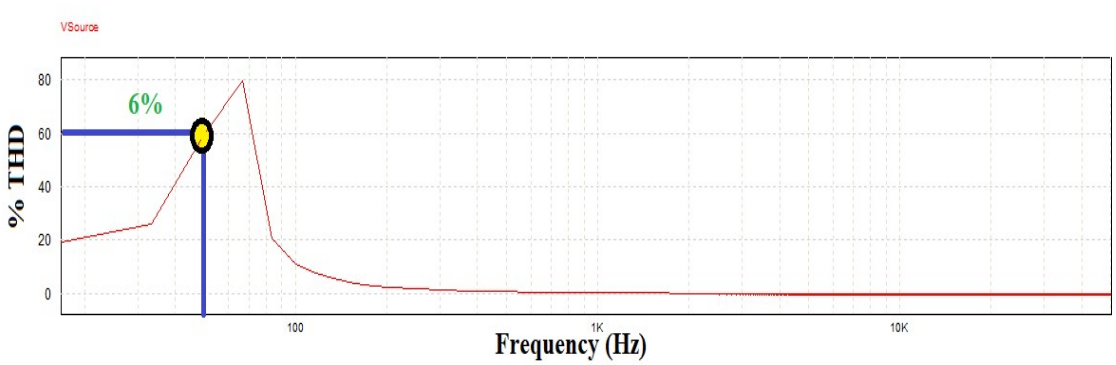

Figure 4.2: % THD of the Source Voltage of Converter Topology-01

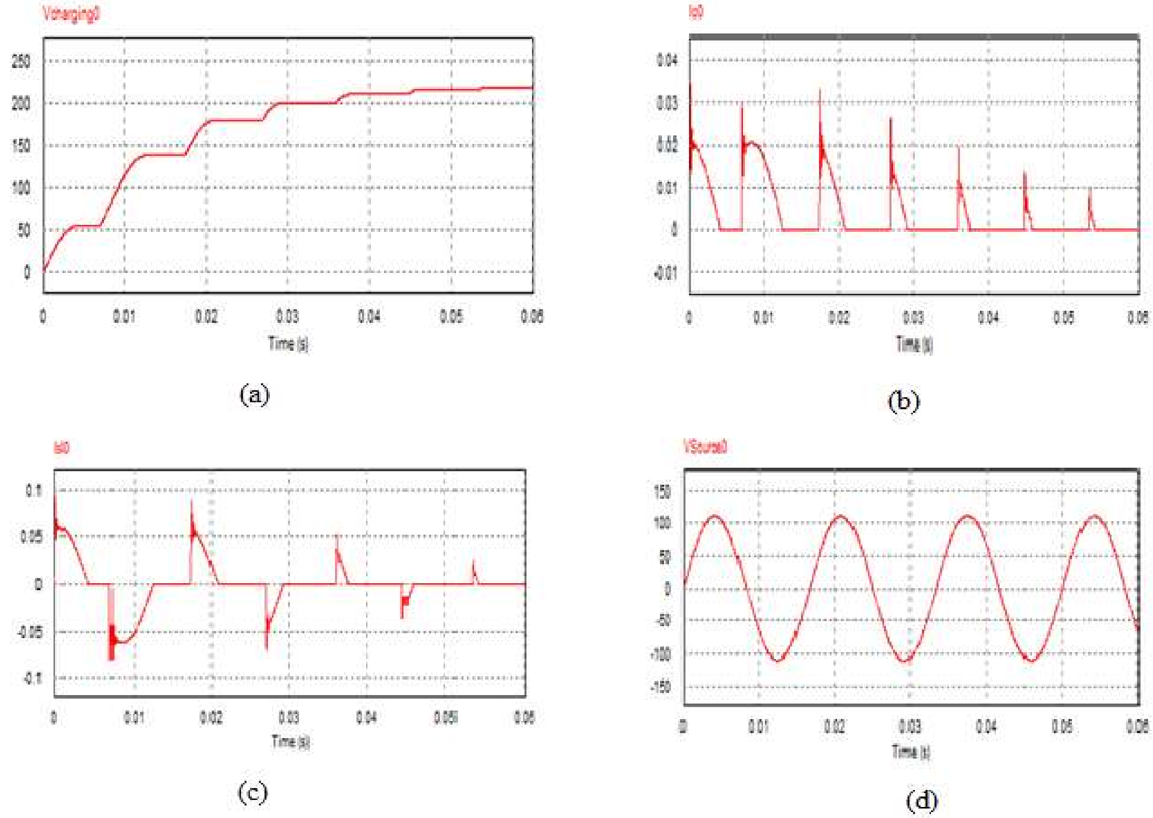

Figure 4.3- Converter Topology -02:- (a) Battery Charging Voltage (b) Input Source Current (c) Load current (d) Source Current

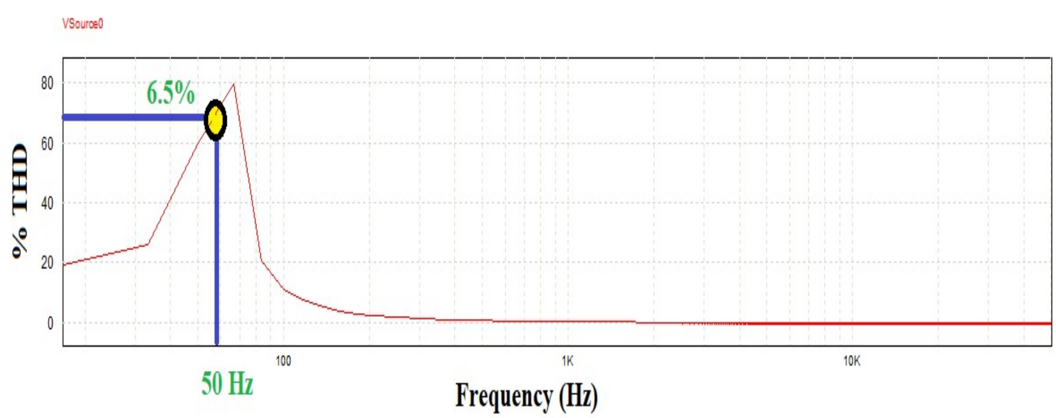

Figure 4.4: % THD of the Source Voltage of Converter Topology-02

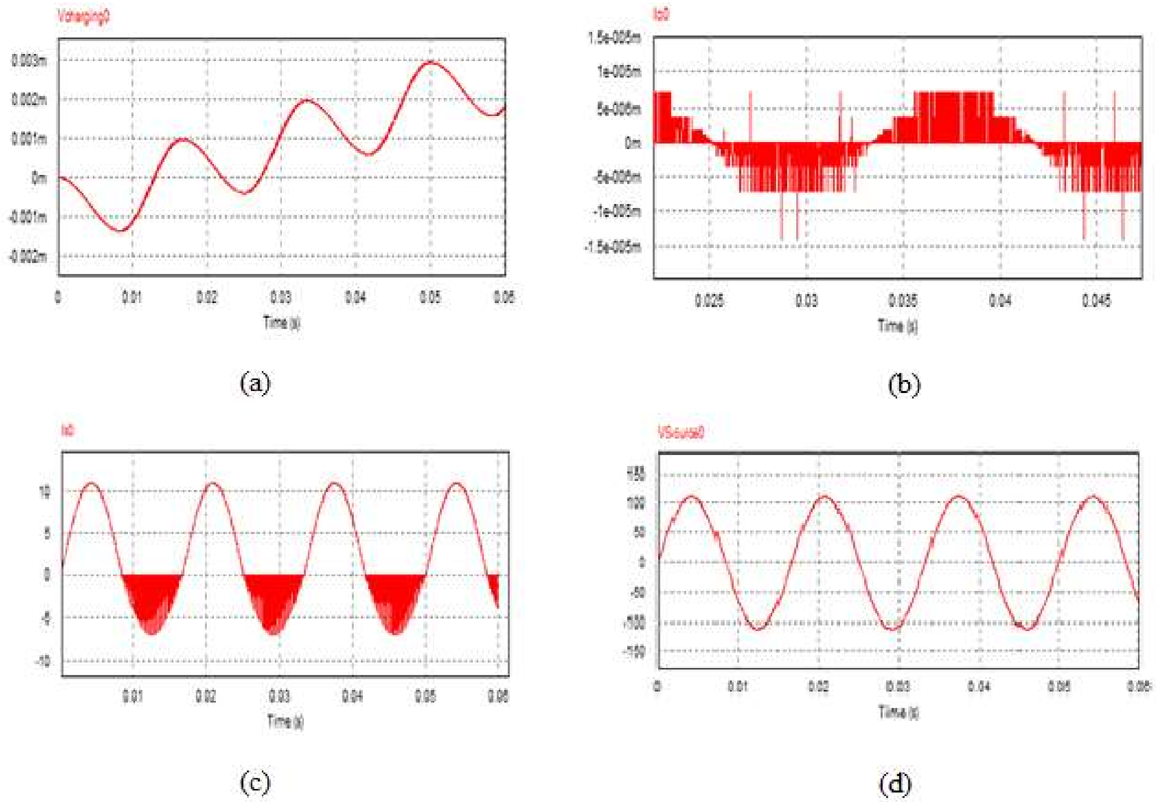

Figure 4.5- Converter Topology -03:- (a) Battery Charging Voltage (b) Input Source Current (c) Load current (d) Source Current

The simulation results for Topology 3 indicate that the charging voltage reaches 210 V, as illustrated in Figure 4.5 (a). Additionally, the load current, depicted in Figure 4.5(b), exhibits a more pulsating DC characteristic as compare to topologies 1 & 2. This pulsating nature of the load current can be converted into DC by employing filters circuit. The source voltage remains sinusoidal throughout the simulation, and the total harmonic distortion (THD) of the input voltage as observed from the figure 4.6 is 6.5% of the fundamental frequency.

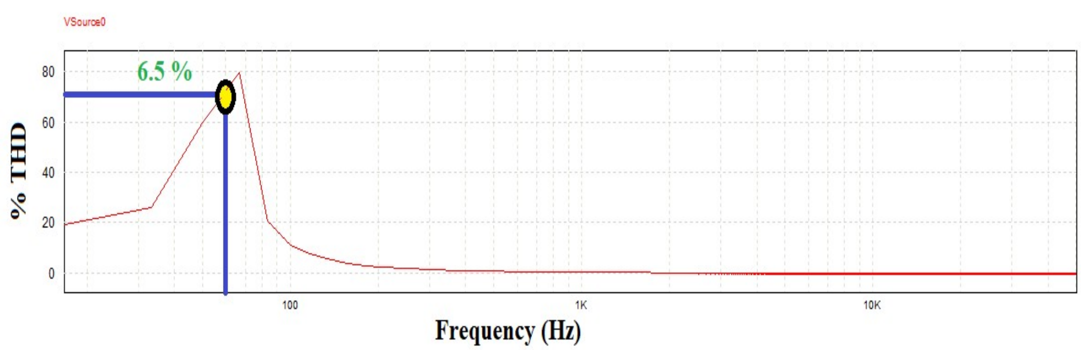

Figure 4.6: % THD of the Source Voltage of Converter Topology-02

4.1. Comparative Analysis of Converter Topologies

Among the three topologies, Topology 3 exhibits the highest efficiency across a wide input voltage range. The streamlined design minimizes both conduction and switching losses, resulting in superior performance. The efficiency gains are most notable beyond 200 V, where Topology 1 suffers from increased losses. With fewer components generating heat, Topology 3 also benefits from simpler and more effective thermal management. This contributes to the longevity and reliability of the power converter, making it an ideal choice for sustained high-efficiency operation.

Table 4.1: Detailed Analysis of Device Count, % THD and Power Factor for Converter Topologies

The comparative analysis of the proposed converter topology with the already existing topology is presented in table 4.2.

Parameters	No. of Switch	No. of diodes per phase	% THD	Power factor
Topology -1,	1	6	6	0.91
Topology-2,	2	4	6.5	0.93
Topology-3,	2	2	5.5	0.96

5. Conclusion

The simulation of power converters for single-phase EV charging stations using PSIM software highlights the trade-offs between different topologies. Topology 1, while capable of handling high power, suffers from increased switching losses and reduced efficiency at higher voltages. Topology 2 offers a balanced approach with moderate complexity and stable performance across a wide voltage range. Topology 3, with its lower switch count, provides the highest efficiency and simplest design, making it the most favorable option for efficient and reliable power conversion.

Table 4.2: Comparative Analysis of the Parameters

Converter Topology	Reference	Mode of operation	Device count	Phase current THD (%)	Efficiency (%)	Power density (kW/ dm3)
Unidirectional Boost converter	[11]	Boost	6	30	63.5	2.6
SWISS Rectifier	[15]	Buck	6	5	99.3	4
Matrix converter	[18]	Buck-Boost	8	20	98	4
Vienna Rectifier	[21]	Boost	4	5	98	12
Proposed Topology	-	Buck Boost	4	6	98	Not presented

REFRENCES

1) Dwivedi, A., Pahariya, Y. Design and Analysis of Hybrid Multilevel Inverter for Asymmetrical Input Voltages. J. Electr. Eng. Technol. 16, 3025–3036 (2021).
2) Rodriguez KJ, Franquelo LG, Kouro S, Leon JI, Portillo RC, Prats MAM, Perez MA (2009) Multilevel converters: an enabling technology for high-power applications. Proc IEEE 97(11):1786–1817
3) De S, Banerjee D, Siva Kumar K, Gopakumar K, Ramchand R, Patel C (2011) Multilevel inverters for low-power application. IET Power Electron 4(4):384–392

4) Gupta KK, Ranjan A, Bhatnagar P, Kumar Sahu L, Jain S (2016) Multilevel inverter topologies with reduced device count: a review. IEEE Trans Power Electron 31(1):135–151

5) Gautam SP, Kumar L, Gupta S (2015) Hybrid topology of symmetrical multilevel inverter using less number of devices. IET Power Electron 8(11):2125–2135

6) Gupta KK, Jain S (2014) A novel multilevel inverter based on switched DC sources. Indus Electron IEEE Trans 61(7):3269–3278

7) Babaei E, Laali S, Bayat Z (2015) A single-phase cascaded multilevel inverter based on a new basic unit with reduced number of power switches. IEEE Trans Indus Electron 62(2):922–929

8) Sadigh AK, Dargahi V, Corzine KA (2015) New multilevel converter based on cascade connection of double flying capacitor multicell converters and its improved modulation technique. IEEE Trans Power Electron 30(12):6568–6580

9) A. Dwivedi, Y. Pahariya. Techno-economic Feasibility Analysis of Optimized Stand-alone PV and Hybrid Energy Systems for Rural Electrification in INDIA. J. Inst. Eng. Ser. B2023, 104 (4), 911–919.

10) B. Liu, L. Wang, D. Song, et al. Input Current Ripple and Grid Current Harmonics Restraint Approach for Single-Phase Inverter under Battery Input Condition in Residential Photovoltaic/Battery Systems. IEEE Trans. Sustain. Energy2018, 9 (4), 1957–1968.

J. Chattoraj, A. Dwivedi, Y. Pahariya. Enhancement of Power Quality in Saps System with Multilevel. Int. J. Eng. Sci. Res. Technol.