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Improving voltage conversion ratio in ev battery system using coupled inductor bidirectional dc-dc converter compared with unidirectional converter by optimizing duty cycle.

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Abstract

Aim: The aim of this research is to improve the voltage conversion ratio in electric vehicle battery systems using novel coupled inductor bidirectional DC-DC converter compared with unidirectional converter by optimizing duty cycle. **Materials and Methods:** The voltage conversion ratio of a bidirectional DC-DC converter is compared with a unidirectional DC-DC converter using seven samples per group and duty cycles ranging from 0.3 to 0.9. G power is taken as 0.8. **Results**: Based on the findings, it is inferred that the coupled inductor based bidirectional DC-DC converter has improved the average overall voltage ratio of 0.5182F while the unidirectional DC-DC converter has a voltage conversion ratio of 0.4006. The significance value is determined as 0.32 (p>0.05, statistically insignificant) based on SPSS analysis. **Conclusion:** Compared to a unidirectional DC-DC converter, a novel coupled inductor based bidirectional DC-DC converter provides a better voltage conversion ratio for the selected data.

Keywords

Novel coupled inductor bidirectional DC-DC converter, unidirectional converter, Electric Vehicle, Control technique, Battery system, Duty cycle, Power Electronics,

INTRODUCTION

Batteries are typically used in series strings to generate a high voltage (HV). Charge imbalance can shorten the battery's lifespan if it is caused by, for example, temperature differences or small mismatches. Even though the batteries are connected in parallel, the output voltage is still low (Rong-Jong Wai and Duan 2007). This means that an efficient bidirectional DC-DC converter with a high conversion ratio is essential for battery applications. By adjusting the turn ratio of the transformer, isolated DC-DC converters such as half and full bridge (Gules et al. 2008; R-J Wai, Duan, and Jheng 2012; Duan and Lee 2012) dc-dc converters can achieve high step-up and step-down voltage gains. Both the high addition and high voltage gain can be accomplished with the control technique of this method. Between four and eight switches are typical. On the low voltage (LV) side, some isolated bidirectional converters are equipped with current-fed rectifiers, while the HV side is equipped with volt-fed rectifiers. (Ayachit et al. 2019) The main applications of the proposed method are areas (Shukla et al. 2020) such as car parking, solar panels, wind energy conversion system, and battery banks.

Based on the literature, about 2138 papers have been published in IEEE and Google scholars are reviewed. The HV spike on the main switch is caused by the transformer's leakage inductor. As a result, a flyback snubber circuit -based isolated bidirectional full-bridge dc–dc converter was proposed (Wu et al. 2010) by improving voltage conversion ratio. Isolated boost full-bridge zero voltage switching (ZVS) pulse width modulation DC-DC converter was found (Zhu 2006) to improve voltage conversion ratio. The leakage inductor's energy is reused and not lost. The total number of switches, on the other hand, has increased. In addition, flyback or forward converter-based bidirectional converters (Bhattacharya et al. 2009; Qian and Lehman 2008; Liu et al. 2010) are proposed to improve voltage conversion ratio. The transformer's leakage inductor also causes HV spikes at switches. For the proposed bidirectional converter, an active clamp circuit is used.

Previously our team has a rich experience in working on various research projects across multiple disciplines (Venu and Appavu 2021; Gudipaneni et al. 2020; Sivasamy, Venugopal, and Espinoza-González 2020; Sathish et al. 2020; Reddy et al. 2020; Sathish and Karthick 2020; Benin et al. 2020; Nalini, Selvaraj, and Kumar 2020).Based on the literature review, in a unidirectional converter the switches with diodes allow electric current only in one direction the main purpose of it is to perform conversions on input power and deliver the output towards the load. The conventional unidirectional DC-DC converter has the less voltage conversion ratio of an electric vehicle battery system. The aim of this research is to improve the voltage conversion ratio in electric vehicle battery systems using novel coupled inductor bidirectional DC-DC converter compared with unidirectional converter by optimizing duty cycle.

MATERIALS AND METHODS

The research was done in the power Electronics lab, Department of Electrical and Electronics Engineering, Saveetha school of Engineering, Saveetha institute of Medical and Technical sciences. Two topologies have been compared and its sample size has been calculated by using G power software. It was determined that each method has 7 samples and a total number of 14 samples (g power = 0.8) (Pascual-trenor 2019). The system is simulated using the MATLAB simulink software (Siano and Jamuna 2020).

Group 1 and 2 sample preparation was done by collecting 7 different voltage values by varying duty cycle from 0.3 to 0.9, here the parameters considered are duty cycle and voltage.

Unidirectional converter

The conventional Unidirectional DC-DC converter for EV battery systems is presented in Fig.1. This system consists of source DC voltage which is connected to the battery a unidirectional DC-DC converter (Szymanski et al. 2020). The Unidirectional DC-DC converter output current is compared with reference duty cycle-based reference current. The error current is processed with the PI controller. The PI controller is generating the control signal and it is processed with a PWM generator. The PWM generator is generating the pulse for the Unidirectional DC-DC converter to charge the battery.

Coupled inductor bidirectional DC-DC converter

The proposed coupled inductor based bidirectional DC-DC converter for the electric vehicle battery system is presented in Fig.2. This system consists of source DC voltage connected to the battery with a novel coupled inductor based bidirectional DC-DC converter (Tomar, Srivastava, and Verma 2018). The coupled inductor based bidirectional DC-DC converter output current is compared with reference duty cycle-based reference current. The error current is processed with the PI controller. The PI controller is generating the control signal and it is processed with a PWM generator. The PWM generator is generating the pulse for a coupled inductor based bidirectional DC-DC converter to charge the battery (Singh Tomar, Srivastava, and Kumar Verma 2018). The findings of the suggested scheme have been confirmed by adjusting the duty cycle in the MATLAB/Simulink environment.

A Google Collab open source stage with a center i5, tenth era processor and 8 GB RAM is utilized for the proposed method.

Statistical analysis

Novel coupled inductor bidirectional DC-DC converters and Unidirectional DC-DC converters are statistically analyzed using SPSS software. For example, the independent variable in a voltage converter is its duty cycle, while its dependent variable is its voltage conversion ratio. Both converters are subjected to two independent group analysis tests to determine their voltage conversion ratios.

RESULTS

Table 1 Simulation results of coupled inductor based bidirectional DC-DC converter and Unidirectional DC-DC converter. Table 2 Shows the T-test comparison of bidirectional DC-DC converter and unidirectional DC-DC converter for men value, standard deviation value, the standard error of voltage conversion ratio. Bidirectional DC-DC (Mean value of .5182) based converter produces better voltage conversion ratio than the unidirectional DC-DC converter (Mean value of .4002). The standard error values for bidirectional DC-DC is (.0010) and for unidirectional DC-DC is (.0009) which ensures the proposed method's superiority. Table 3 shows the independent sample test for significance and standard error determination with bidirectional DC-DC and unidirectional DC-DC converter. Significance value obtained as 0.032 ($p>0.05$), considered to be statistically insignificant.
Figure 1 Displays the Simulink block diagram of unidirectional converter for EV battery system. Figure 2 Displays the Simulink block diagram of the proposed novel coupled inductor Bidirectional DC-DC converter coupled with a battery. Figure 3 displays the output voltage and output voltage conversion ratio in a unidirectional DC-DC converter. Figure 4 displays the output voltage and output voltage conversion ratio in a novel coupled inductor bidirectional DC-DC converter.
Figure 5 Depicts the bar graph analysis on the voltage conversion ratio of both bidirectional DC-DC and unidirectional DC-DC converters. It is inferred that the proposed converter produces better voltage conversion ratio compared to the conventional unidirectional DC-DC converter.

DISCUSSION

The voltage conversion ratio of a unidirectional DC-DC converter and a novel coupled inductor bidirectional DC-DC converter based on a coupled inductor for an electric vehicle battery system is examined and compared. Uni-directional DC-DC converter has a lower voltage conversion ratio when compared to the novel coupled inductor based bidirectional DC-DC converter.
This study reviewed all relevant data on EV setups, battery energy sources, electrical machines, recharging (Shukla et al. 2020) and optimization approaches, effects, patterns, and future possible orientations (Un-Noor et al. 2017). On the basis of bidirectional converter connectivity, high capacity, flexibility, and other aspects, several charging station architectures were developed and analyzed (Ahmadi, Mithulananthan, and Sharma 2016). The amount of electricity, recharging time frame, price, hardware, and (Trivedi et al. 2018)other considerations are discussed, analyzed, and reviewed for different power level charging stations and infrastructure setups. Power electronics converters for EV rapid charging stations are shown in the study, using a three-branch DC/DC converter (Sujitha

and Krithiga 2019) that employs a half-bridge inverter model to create DC charging for EV batteries. Based on computation testing, the researchers of such a work presented the characteristics of the converter model (Pinto et al. 2019). Some of the opposing papers, expensive voltage/current stress, high costs and poor efficiency are some of the arguments against this study. Soft-switching converters have many drawbacks, including design complexity, instability due to high frequency transformer saturation and poor switch use (Ayachit et al. 2019).

The limitations of proposed technology other than conversion and charging of the load, the selection of a controller to fine tune the switching cycle present in the proposed converter. So, additional care in selecting control logic is considered an important aspect. Another limitation in the proposed study is the constant DC-source. In today's environmental conditions, renewable resources are the right choice for replenishing load requirements and saving the environment from pollution and pollutants. Installing charging stations near renewable power farms reduces the cost of transmission and improves the power quality.

In the future, the converter might be studied by enhancing various artificial controllers such as neural controllers, hybrid genetic algorithms, and so on to optimize power flows and system losses.

CONCLUSION

Based on the results the proposed coupled inductor based bidirectional DC-DC converter has a better voltage conversion ratio of 0.5182 when compared to the conventional Unidirectional converter of 0.4006 for the selected data. So the proposed method is an attractive solution. Based on the independent T test the significance value is 0.32 ($p > 0.05$) statistically insignificant within the limit of study.

DECLARATION

Conflicts of Interest

No conflict of interest in this manuscript.

Author Contributions

The Author was involved in data collection, data analysis and manuscript writing. Author Duan was involved in conceptualization, data validation and critical review of manuscripts.

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TABLE AND FIGURES

Table 1. Simulation results of coupled inductor based bidirectional DC-DC converter and Unidirectional DC-DC converter.

Duty cycle	**Voltage Conversion ratio (VCR)**	
	Coupled inductor based bidirectional DC-DC Converter	**Unidirectional DC-DC converter**
0.9	0.5182	0.4006
0.8	0.5182	0.4005
0.7	0.5182	0.4004
0.6	0.5182	0.4003
0.5	0.5182	0.4002
0.4	0.5182	0.4001
0.3	0.5182	0.3999

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Table 2. Group statistical analysis of novel coupled inductor bidirectional DC-DC and conventional unidirectional DC-DC converter by taking7 samples per group. The standard error mean for the modified bidirectional DC-DC converter is .0010 and for the conventional unidirectional converter is .0009.

Group Statistics					
	Group Name	**N**	**Mean**	**Standard Deviation**	**Standard Error Mean**
Voltage Conversion Ratio (VCR)	**Bidirectional DC-DC converter**	7	.5182	.00026	.0010
	Unidirectional DC-DC converter	7	.4002	.00018	.0009

Table 3. Independent sample T-test is performed for the two groups for significance and standard error determination. Since the value of significance is 0.32 (p > 0.05) which is considered to be statistically insignificant.

Independent Samples Test										
Levene's Test for Equality of Variances				T-test for Equality of Means						
		F	Sig.	T	Df	sig. (2-tailed)	Mean Difference	Std.Error Differences	95% Confidence Interval of the difference	
									Lower	Upper
Voltage Conversion Ratio (VCR)	Equal Variances assumed	17.0	0.320	1217.576	12	.001	.1179	.0001	0.117	0.118
	Equal Variances not assumed			1217.576	6	.000	.1179	.0001	0.117	0.118

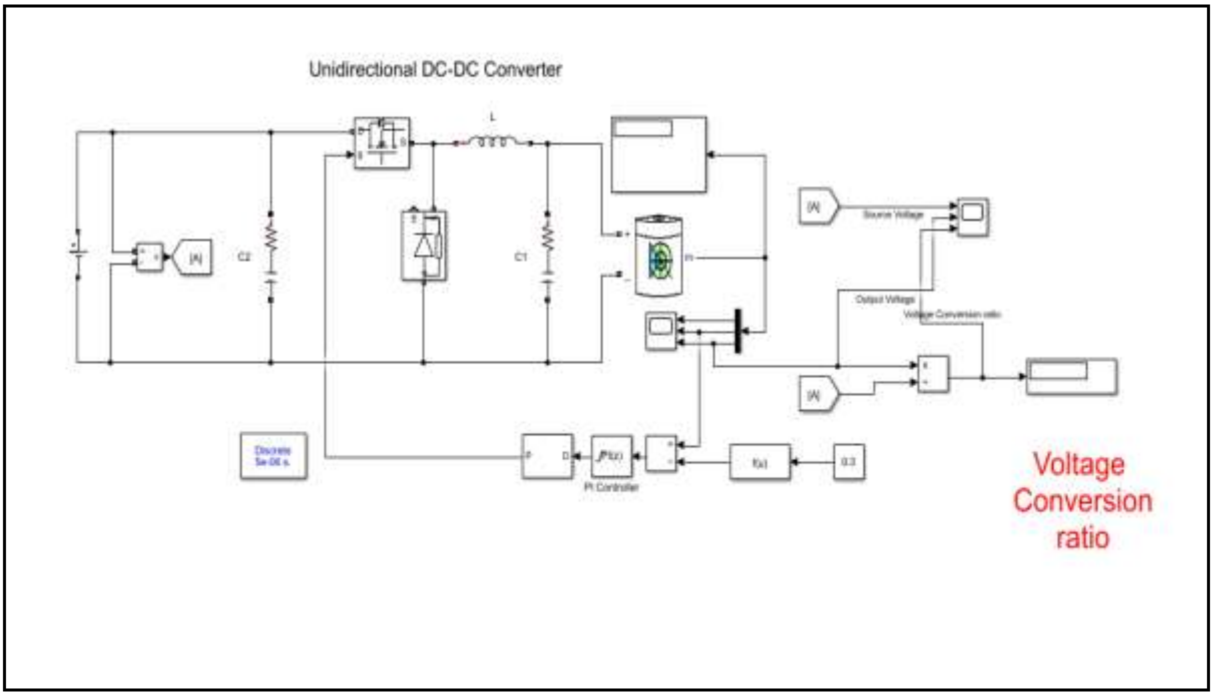

Fig. 1. Displays the unidirectional DC-DC converter for EV battery system.

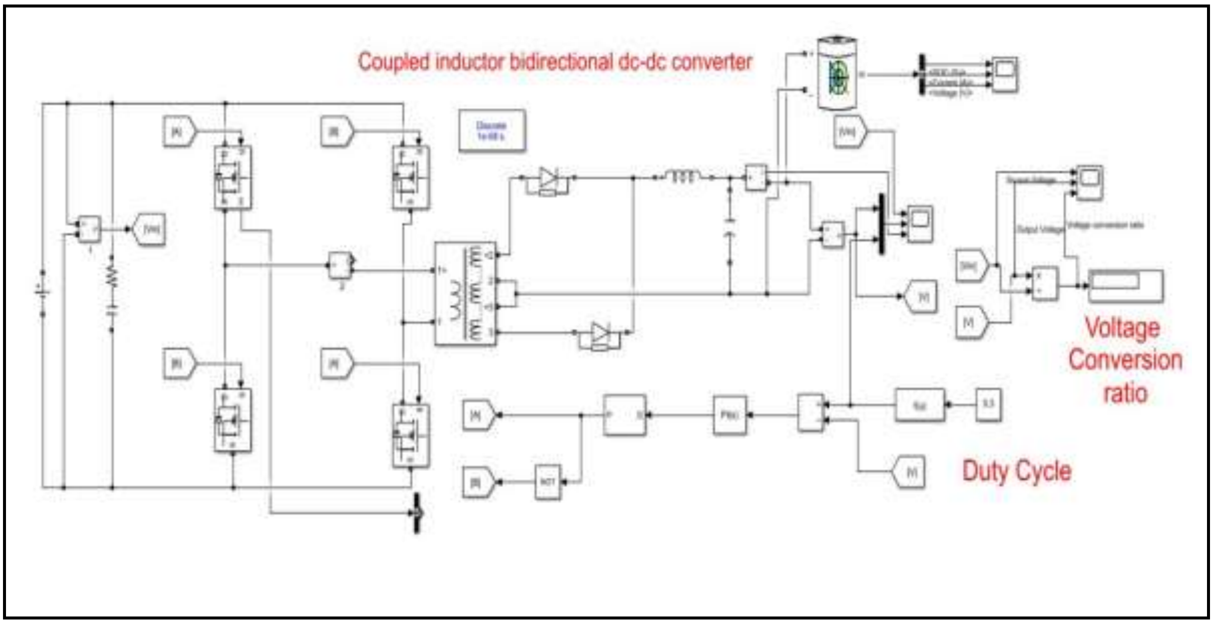

Fig. 2. Displays the proposed Coupled Inductor based bidirectional DC-DC converter for EV battery system.

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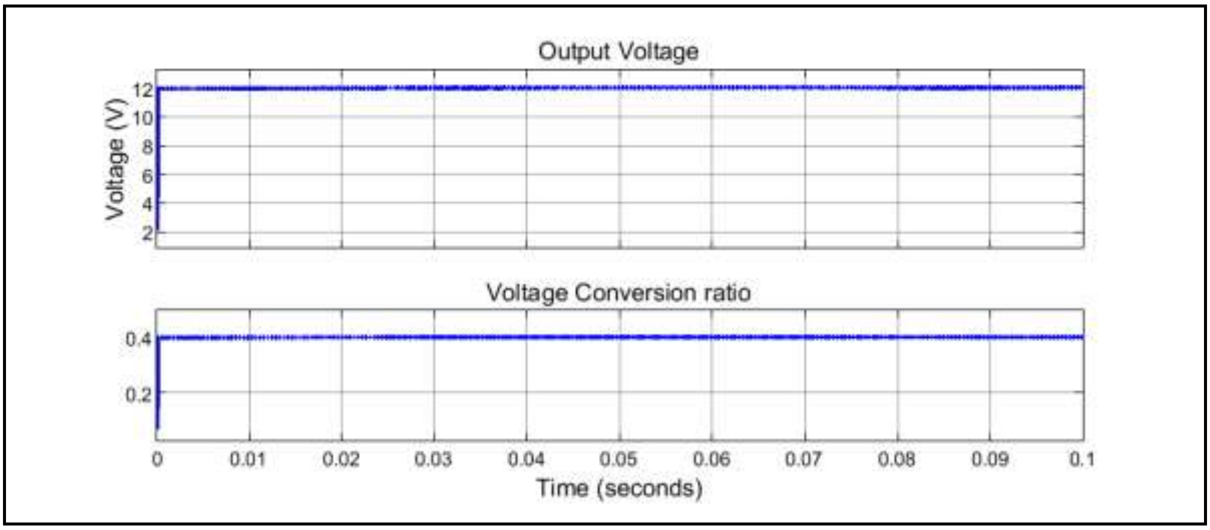

Fig. 3. Displays the output voltage and output voltage conversion ratio in unidirectional DC-DC converter.

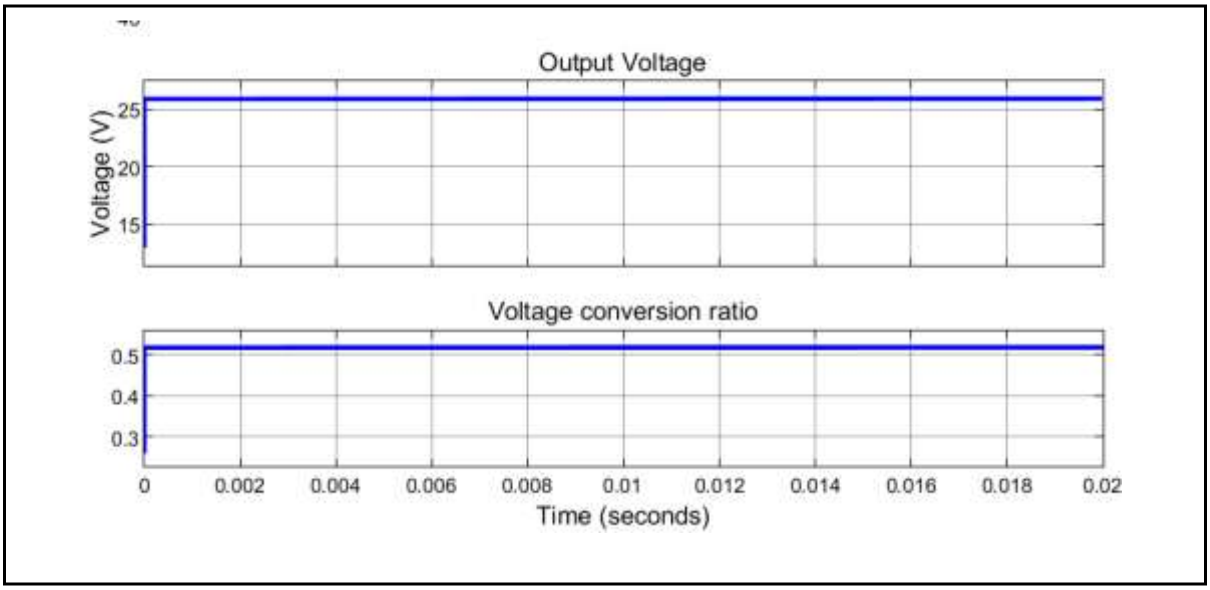

Fig. 4. Displays the output voltage and output voltage conversion ratio in coupled inductor bidirectional DC-DC converter.

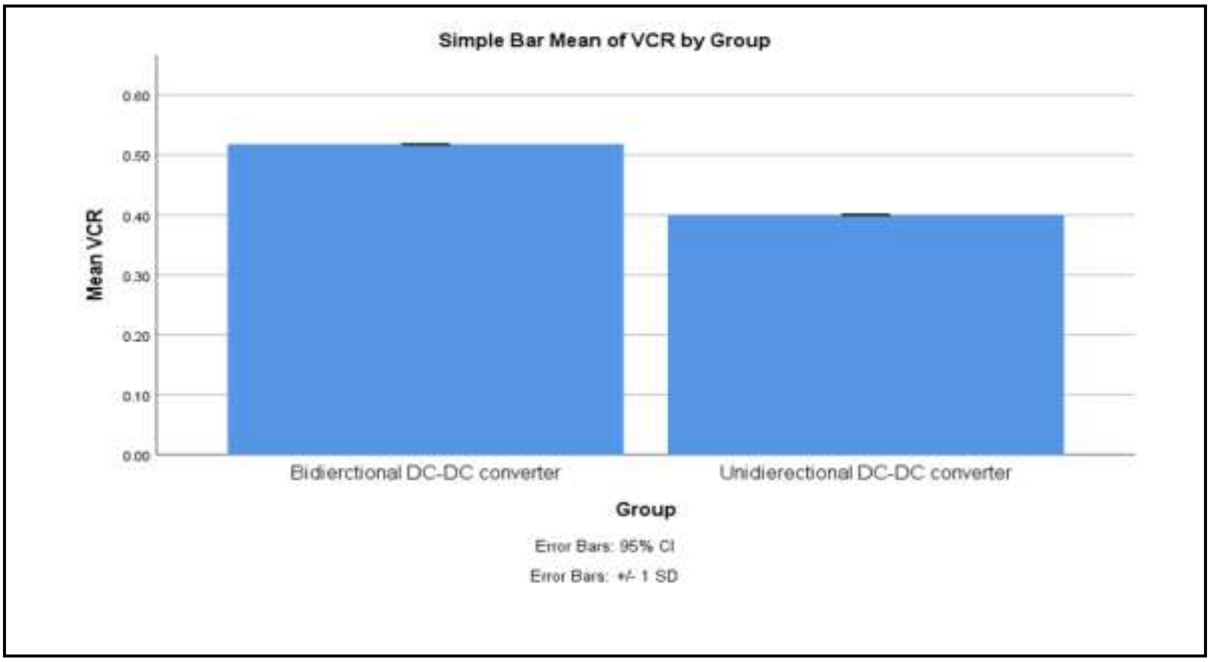

Fig. 5. Comparison of conventional unidirectional DC-DC and modified Bidirectional DC-DC converter method in terms of voltage conversion ratio. The voltage conversion ratio of the modified bidirectional DC-DC converter is 0.53% and for the conventional unidirectional DC-DC converter is 0.40%, which proves that the proposed converter technique is better than the conventional converter. Device count with ±1SD.