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Design and Analysis of High Efficiency DC- DC Boost Converter for EV Charging Applications

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Abstract: ***In today's scenario DC-DC converters plays a major role in EV Charging. Normally, a boost converter would only be used when the output voltage minimum is about 1.5 times the input voltage. The main drawback in conventional converters is high ripple input current, which reduces the lifespan of the converter and overall system. Thus, conventional boost converters are not suitable for high voltage applications. To Overcome these Problems Modified SEPIC Converter is developed. This Modified SEPIC Converter is able to increase the Input voltage by 10 times. Modification of the Conventional SEPIC Converter is done by adding Capacitors and Diodes. This Paper also talks about the Design and analysis of the DC-DC Modified SEPIC Converter and controlling the Output voltage of the converter with a PI controller. The converter works at high efficiency and the Converter is operated at Continuous Conduction Mode (CCM). This Converter can effectively be applied for Photovoltaic Systems. The results of the Modified SEPIC converter for open loop and closed loop are simulated in MATLAB/SIMULINK.***
Keywords: DC-DC Converter, Modified SEPIC Converter, Continuous Conduction Mode (CCM), Duty Cycle, PI Controller

I. INTRODUCTION

Nowadays, an integral part of any modern-day electric vehicle is power electronic circuits composed of DC-DC Converters. These converters supply from low voltage sources such as renewable energy systems are solar photovoltaic and fuel cell. However, the need for high power unidirectional DC-DC Converters in future electric vehicles had led to the development of many new topologies of DC-DC Converters.

The batteries of a Battery Electric Vehicle typically output several hundred volts of Direct Current. However, the electric components inside the vehicle vary in their voltage requirements, with most running on a much lower voltage. A DC-to DC converter is a category of power converters, which converts a DC source from one voltage level to another. It can be unidirectional, which transfers power only in one direction. Moreover, a DC-DC converter is a crucial component in the architecture of a battery electric vehicle, where it is used to convert power from the low voltage to the high Voltage to charge the battery of electric devices.

Banashankari and Hemalatha have proposed a Zeta converter [1] for speed control of BLDC motors. This proposed converter operates in both open-loop and closed-loop. This converter is able to operate in both Buck and Boost modes, and power factor correction and voltage regulation are achieved.

P Selvabharathi proposed a simulation of DC-DC converter [2] topology for solar PV systems under varying climatic conditions with an MPPT controller. This paper describes the operation of boost converter, buck-boost converter, Cuk converter, and SEPIC converter. Out of these converters, the Cuk Converter has achieved the highest efficiency (97.85%), maximum output voltage, current, and power. The Settling time of the Cuk converter is around 0.22 seconds. This converter is designed for 500W PV-based applications.

Sriramalakshmi Palanidoss and Vishnu Theja proposed the Experimental Analysis of the Conventional Buck and Boost Converter with an Integrated Dual Output Converter [3]. This paper deals with the single input and multiple outputs. This converter operates both buck and boost operations.

The input power is 100W. Input inductor current is always continuous for both buck and boost operations. The input is 30V and is boosted to 55V and bucked to 18V and uses the two switches for this converter.

Charles Muranda, Emre Ozsoy, Sanjeevikumar Padmanaban, Mahajan Sagar Bhaskar, Vilia Fedak and Ramachandaramurthy have proposed the Modified SEPIC DC-DC Boost Converter [4] with High Output-Gain Configuration for Renewable Applications. This proposed converter adds one inductor and one capacitor to the conventional SEPIC Converter, and this converter has six storage elements. The switching frequency of the converter is high.

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Manikandan, Sivabalan, Sundar and Surya had proposed the Study of Landsman, SEPIC and Zeta Converter [5] by Particle Swarm Optimization Technique. This paper uses the PSO [Particle Swarm Optimization Algorithms]. Input Voltage of three converters is 275V and boosted to 550V for Landsman and SEPIC and boosted to 530V for Zeta Converter. Out of these converters SEPIC has the highest Efficiency achieved (94.82%). This converter is suitable for PV powered Applications. SEPIC Converter operates both buck and boost mode. Zeta converter operates both boost and Buck-Boost mode.

Karuppiah, Dinesh Kumar, and Karthik Kumar proposed the design of an electric vehicle charger based on SEPIC Topology with a PI controller [6]. This paper describes the solar cell that is used as the input source and operated in continuous conduction mode. This converter has closed loop analysis and four storage elements are present. A PI controller is used in a closed loop to feedback control loop and calculates an error signal by the difference between the output system and

Furthermore, this paper describes the circuit configuration, design of a Modified SEPIC DC-DC converter, open loop analysis, and closed loop analysis of the converter and their corresponding results and waveforms.

II. CIRCUIT CONFIGURATION

The circuit configuration of the Modified SEPIC DC-DC Converter is shown in Figure 1. The input voltage operates at 16–24V. The converter circuit consists of two inductors, three capacitors, two diodes, and one MOSFET switch operating at 30 kHz. The converter is designed for 300W applications. Here the Converter has two operating modes and operating in Continuous Conduction Mode (CCM).

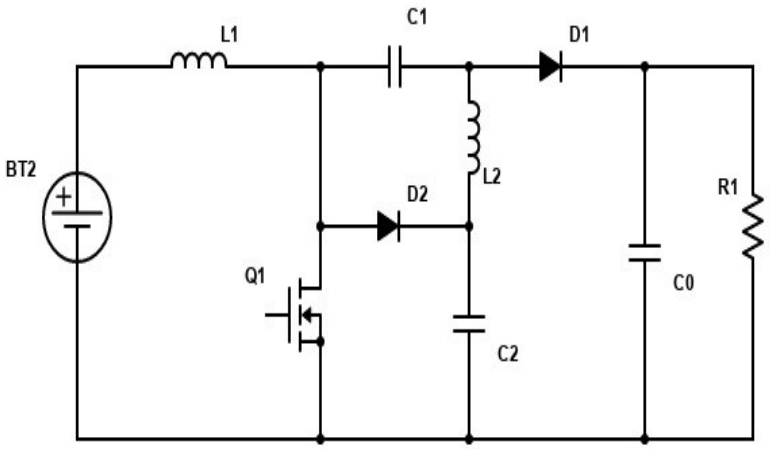

Figure 1. Modified SEPIC DC-DC Converter

III.DESIGN OF MODIFIED SEPIC DC-DC CONVERTER

The Duty Cycle of the Modified SEPIC DCDC Converter can be obtained by using this formula.

$$\frac{\text{Vo}}{\text{Vin}} = \frac{1+\text{D}}{1-D}$$

The Inductor Value of the Modified SEPIC DC-DC Converter can be obtained by using this formula.

$$L1 \;\&\; L2 \;= \frac{Vin * D}{\Delta \text{Il} * \text{f}}$$

The Capacitor of the Modified SEPIC DC-DC Converter can be obtained by using this formula.

$$C1 \;\&\; C2 \;= \frac{\text{Io}}{\Delta \text{Vc} * \text{f}}$$

The Co is the output capacitor of Modified SEPIC DC-DC Converter. were,

$$\Delta Io = 2\% \; of \; Io$$

$$\Delta Vo = 5\% \; of \; Vo$$

TABLE I
DESIGN SPECIFICATIONS OF THE CONVERTER

PARAMETERS	VALUES
Input Voltage (V_{in})	16 - 24 V
Output Voltage (V_o)	60 V
Output power (P_o)	300 W
Switching frequency (f_s)	30 kHz
Inductor(L_1)	823.32 µH
Inductor(L_2)	3087 µH
Capacitor(C_1)	87.742 µF
Capacitor(C_2)	87.742 µF
Capacitor (C_0)	4600 µF
Output Current (I_0)	5 A

IV. RESULTS AND DISSCUSSIONS

The Modified SEPIC DC-DC Converter open loop is simulated in MATLAB/Simulink.

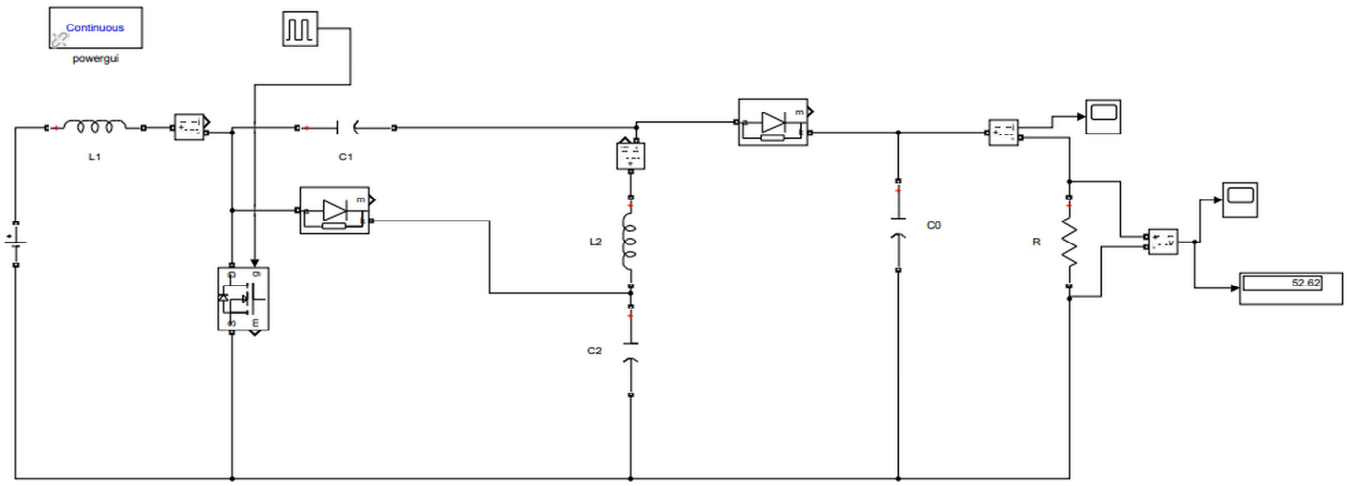

Figure: 2 Open loop Simulation Diagram of Modified SEPIC Converter

The figure 2 shows the open loop simulation of modified SEPIC converters that have been carried out for 16 V input and 60 V output. The open loop Simulation has been designed in MATLAB/SIMULINK.

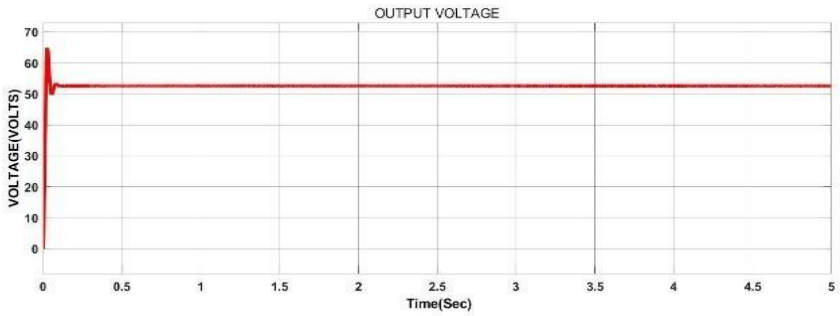

Figure: 3 Output voltage Waveform of Modified SEPIC DC-DC Converter

Figure 3 shows the output voltage waveform of the Modified SEPIC DC-DC Converter under open loop simulation. The desired output voltage is not obtained in open loop simulation.

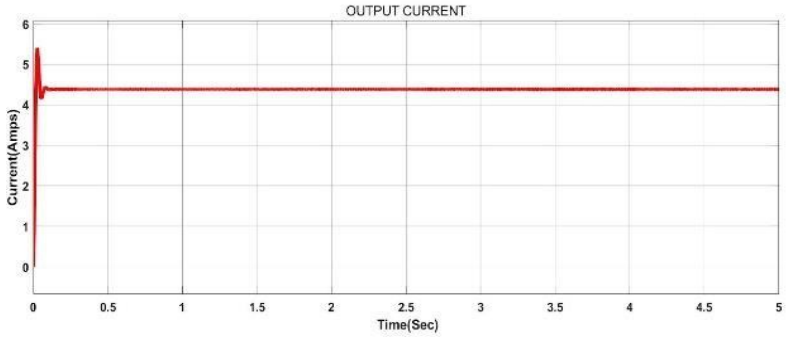

Figure: 4 Output Current Waveform of Modified SEPIC DC-DC Converter

Figure 4 shows the output current waveform of the Modified SEPIC DC-DC Converter. The output current is obtained around 4.4A.

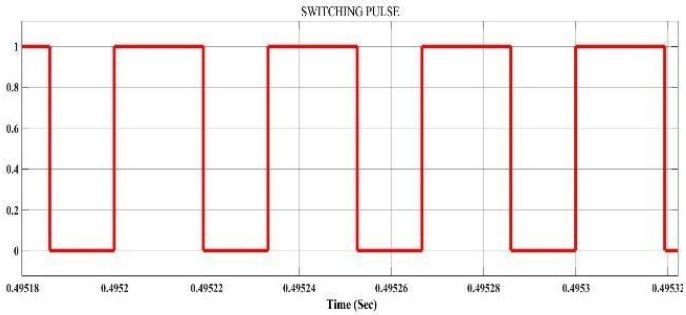

Figure: 5 Switching Pulse Waveform of Modified SEPIC DC-DC Converter

Figure 7 shows the Switching Pulse Waveform of Modified SEPIC DC-DC Converter Generated by Pulse Generator. The switching frequency (fs) of the converter is 30 kHz.

In Closed Loop Simulation the desired output voltage is obtained by using PI Controller. The PI controller is the most commonly used in closed loop systems because of its performance in terms of simplicity. It produces an error signal by comparing the desired output signal with the actual output signal. There are different methods to tuning the Controller such as Ziegler-Nichol's method, Ciancone and Marline Method, Cohen-Coon Method, FertickMethod.

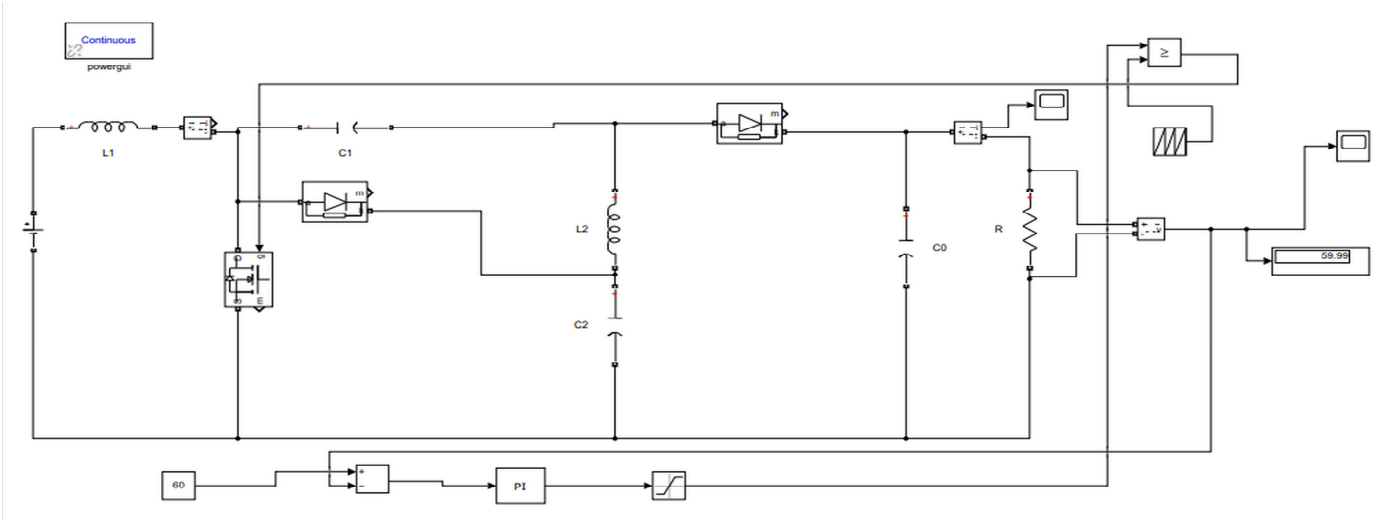

Figure 6. Closed Loop Simulation Diagram of DC-DC Modified SEPIC Converter

Figure 6 shows that the closed loop simulation of a modified SEPIC Converter has been carried out for 16 V input and 60V output.

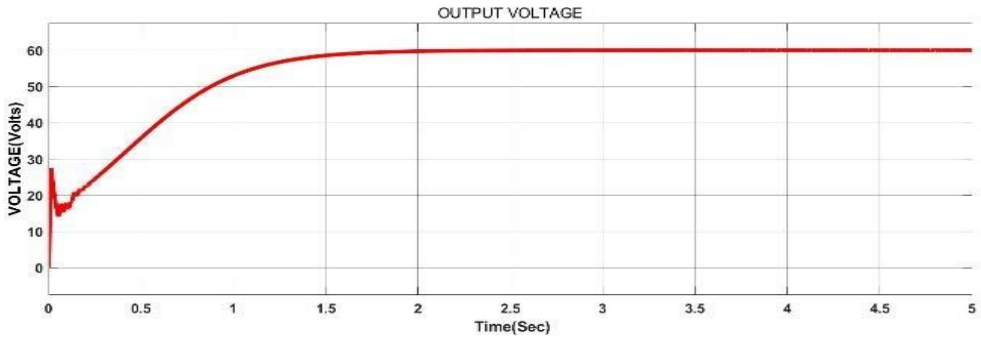

Figure 7. Output voltage Waveform of DC-DC Modified SEPIC Converter in Closed Loop

Figure 7 shows the Output Voltage waveform of DC-DC Modified SEPIC Converter. In this closed loop desired Output voltage is achieved. The desired output voltage is obtained at 2.7 seconds. Figure 8 shows the output current waveform in closed Loop. The desired output current (5A) is achieved in a closed loop.

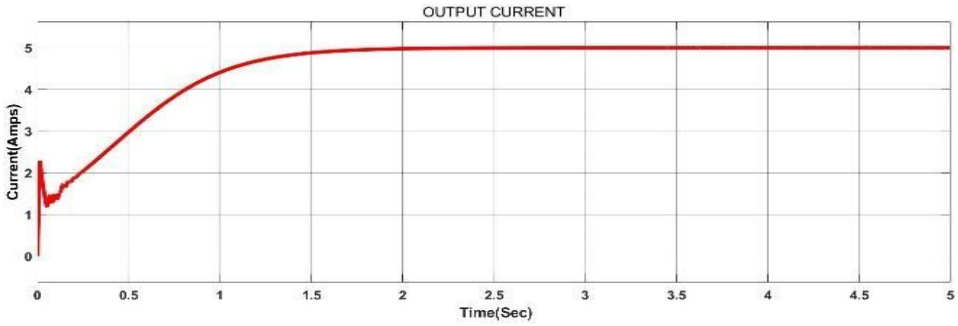

Figure 8. Output Current Waveform of DC-DC Modified SEPIC Converter in Closed Loop.

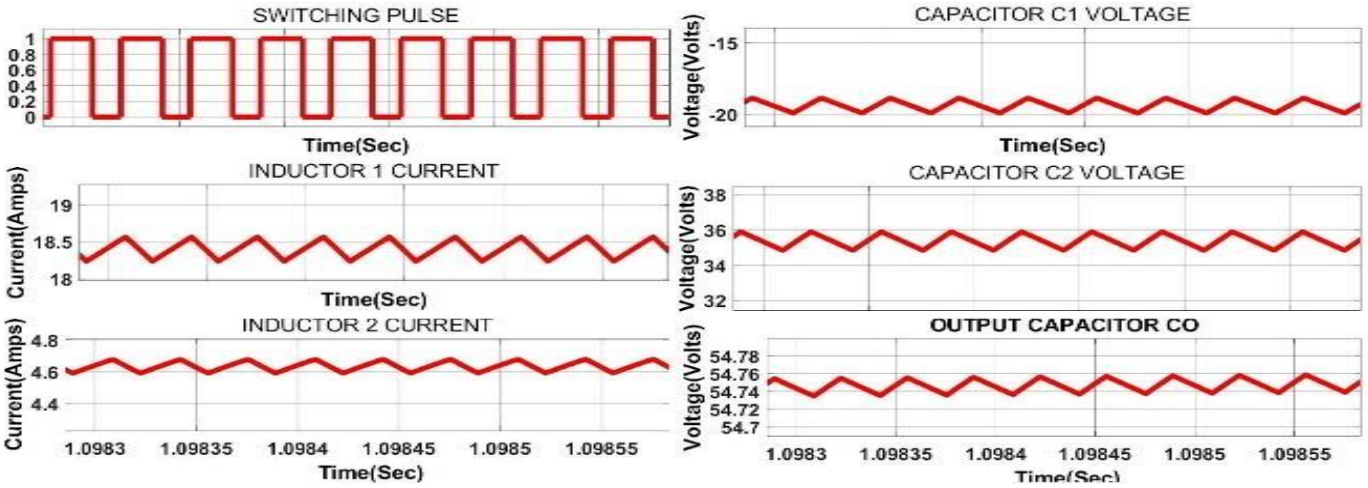

Figure 9. Waveforms of Switching pulse, Inductor L1 Current, Inductor L2 Current, Capacitor C1 Voltage, Capacitor C2 Voltage and Output Capacitor Co under Closed loop.

Figure 9 shows Waveforms of Switching Pulse, Inductor L_1 Current, Inductor L_2 current, Capacitor C_1 Voltage, Capacitor C_2 Voltage, and Output Capacitor C_0 in Closed Loop. When MOSFET Switch is turned on Inductor L_1 and Inductor L_2 Charging. When the MOSFET Switch is turned OFF the inductor L_1 and L_2 are discharging and Capacitor C_1, Capacitor C_2 and Output capacitor C_0 are getting charged. The Converter Operated in Continuous Conduction Mode (CCM).

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TABLE -II
Analysis of Modified SEPIC DC-DC Converter in Open Loop by Varying Input Voltage and Constant Duty Cycle

V_{in} (V)	Duty Cycle (D)	Iin (A)	V_o (V)	I_o (A)	Efficiency (%)
16	57.89	16.35	52.6	4.38	88.19%
18	57.89	18.45	59.3	4.94	88.46%
20	57.89	20.55	66.1	5.51	88.67%
22	57.89	22.79	72.8	6	88.19%
24	57.89	24.79	79.0	6.63	88.99%

This table describes the Modified SEPIC DCDC Converter in open loop by varying the input voltage and constant duty cycle. Even Though the supply voltage varies, the high output voltage is obtained at constant duty cycle. The efficiency of the converter varies with respect to the output voltage.

TABLE-III
Analysis of Modified SEPIC DC-DC Converter in Open Loop by Constant Input Voltage and Variable Duty Cycle

V_{in} (V)	Iin (A)	Duty Cycle (D)	V_o (V)	I_o (A)	Efficiency (%)
16	2.723	20	22.16	1.847	93.96%
16	6.614	40	34.44	2.87	93.4%
16	13.98	55	49	4.086	89.55%
16	18.39	60	55.42	4.618	87%
16	33.3	70	70.66	5.888	78%

This table describes the Modified SEPIC DC-DC Converter in open loop by constant input voltage and variable duty cycle. The duty cycle of the converter is minimum, the converter obtained its maximum efficiency. The duty cycle of the converter is maximum, the output voltage is also maximum and the efficiency is minimum.

TABLE- IV
Analysis of Modified SEPIC DC-DC converter in Closed Loop by Variable Input Voltage and Constant Output Voltage

V_{in} (V)	*Iin (A)*	*V_o (V)*	*I_o (A)*	*Efficiency (%)*
16	22.12	60	5	84.76%
18	18.9	60	5	88.18%
20	16.57	60	5	90.52%
22	14.79	60	5	92.19%
24	13.37	60	5	93.49%

This table infers the Modified SEPIC DC-DC Converter in a closed loop by varying input voltage and constant output voltage. Even Though the supply voltage deviates, the output voltage of the converter is maintained at constant (60V). The converter obtained its maximum efficiency (93.49%) of the supply voltage 24V.

TABLE-V
Analysis of DC-DC Modified SEPIC Converter in Closed Loop by
Constant Input Voltage by Varying Resistive Load

% Of the load	Vin (V)	Iin (A)	V_o (V)	I_o (A)	Efficiency (%)	Resistive load (R)
50 %	16	22.3	60	5	83.74%	6
60 %	16	43.7	60	8.33	71.44%	7.2
70 %	16	34.9	60	7.14	76.60%	8.4
80 %	16	29.3	60	6.24	79.84%	9.6
90 %	16	25.3	60	5.55	82%	10.8
100%	16	22.3	60	5	83.74%	12

This table describes the Modified SEPIC DC-DC converter in closed loop by constant input voltage by varying resistive load. By varying the resistive load, efficiency also varies. Even though the resistive load varies the output voltage is maintained at constant. At maximum load the efficiency of the converter is high.

V. CONCLUSION

The Modified SEPIC DC-DC Converter is designed and simulated using MATLAB/SIMULINK for Electric Vehicle Charging having a load of 300W output power. The performance analysis of Modified SEPIC Converter is done with the help of Simulated output waveforms. The Converter is operated in Continuous Conduction Mode (CCM). The Efficiency of the converter is high in the open loop. Analysis is made for both open and closed loop. The desired output voltage and output current is obtained in closed loop. In future the hardware of Modified SEPIC Converter will be implemented for EV Charging.

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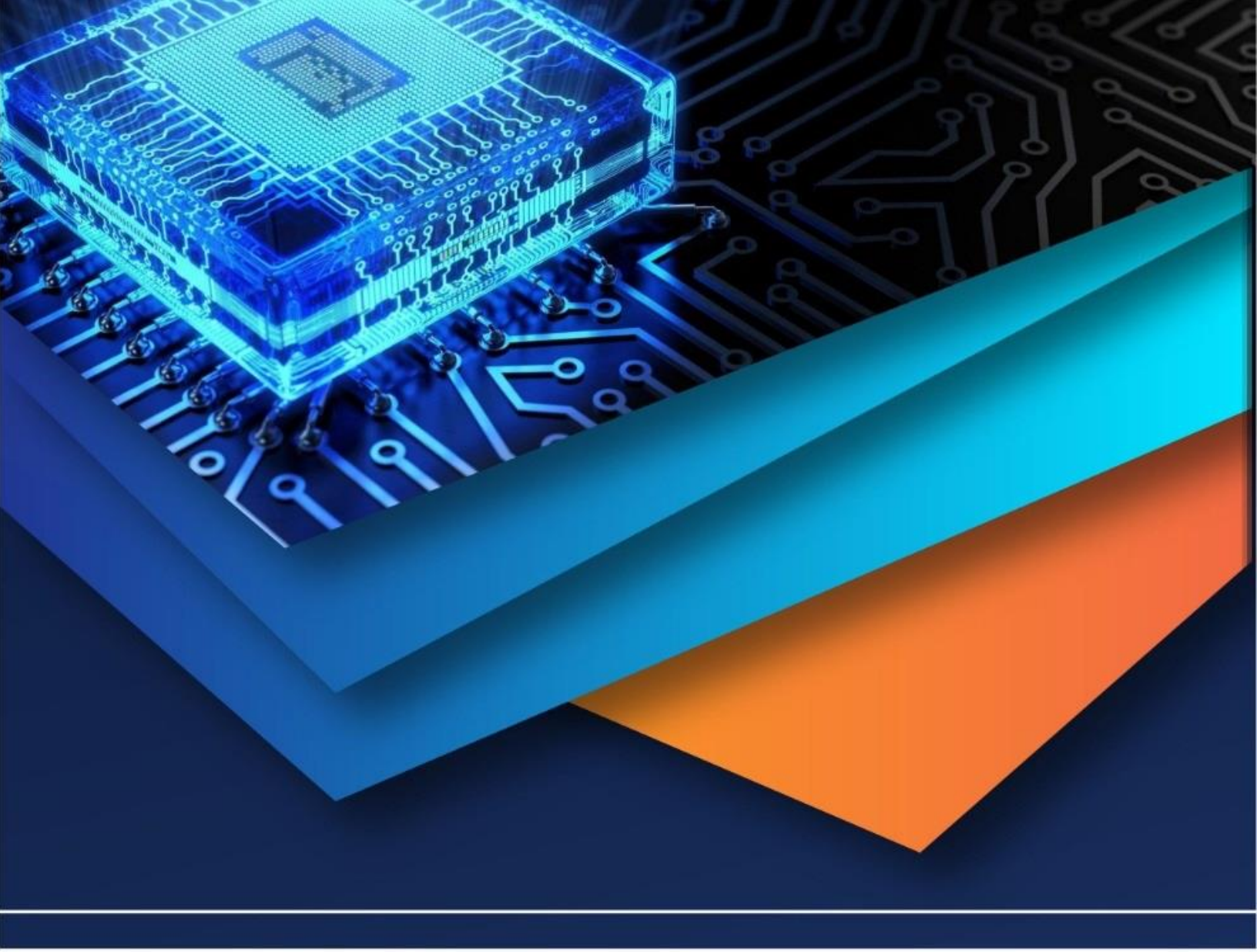

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