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Analysis and Design of Single phase AC-DC Modified SEPIC Converter

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Abstract. Power electronic devices with front-end rectifier are widely used in industry, commerce and transportation, which result in low power factor. Though there are several proposed solutions to this, Single Ended Primary Inductance Converter (SEPIC) converter was the most successful one. But the conventional SEPIC converters suffer from high switching losses. Hence in this paper, a modified SEPIC converter is used to improve the power factor at the mains side. This paper presents the simulation and analysis of single phase single-switch, converter topologies of AC-DC SEPIC converter and modified SEPIC converter for Continuous Conduction Mode (CCM) of operation with 48V, 100W output power. The results of SEPIC converter and modified SEPIC converter are compared for closed loop analysis in simulation which is done in PSIM. It is found that modified SEPIC converter has high regulated output voltage and high power factor.

Introduction

The average current control technique is used to control both output voltage and inductor current [1], [2], [3],[4]. The results of open loop and closed loop operation of the converter are compared . The SEPIC converter boosts 24V dc voltage to 48V dc voltage, whereas, the modified SEPIC converter boosts the voltage from 16V to 48V with improved power factor and regulated output voltage. This shows that the modified SEPIC converter has high static voltage gain. The simulation is done for 100W output power. For practical reasons it has been reduced to 60W for hardware implementation.

SEPIC converter

A single ended primary inductance converter or SEPIC is basically a DC-DC buck-boost converter which can operate in continuous, discontinuous or boundary conduction mode [5]. The output voltage may be raised or lowered than the input voltage [6]. The voltage can be controlled by adjusting the duty cycle of the switch. The output voltage is non-inverted with respect to the input voltage. A coupled inductor is used for ripple current steering [7], [8], [9].

Problems of conventional SEPIC PFC

The conventional SEPIC suffers from high switching losses as in the normal switching method (i.e. hard switching) and the power switches (MOSFETs) have to cut off the current within turn off period while the complete DC source voltage is applied across it. Therefore the switch has to withstand high voltage as well as high current stresses resulting in high switching losses and thus limiting the switching frequency. As the switch voltage is equal to the sum of the input and output voltages, this topology is not used for a universal input high power factor rectifier.

Modified SEPIC topology

Modified SEPIC Power Factor Corrected Converter

A modified SEPIC PFC is used which is feasible to work in continuous and discontinuous conduction modes of operation. A multiplier capacitor and a multiplier diode are added in addition with the SEPIC converter to design a modified SEPIC converter [10]. The switch voltage of the modified SEPIC converter is equal to the voltage of the capacitor C_M. The advantages of modified SEPIC converter are an input current ripple lower than the classical boost converter is obtained, soft-switching commutation is obtained, high efficiency and high static gain [10] are obtained.

Block diagram

The block diagram and the power circuit diagram of the modified SEPIC converter is shown in the Fig. 1 and Fig. 2 respectively. When a single phase AC supply is given to the diode bridge rectifier, a conversion of AC-DC takes place. This DC voltage is given to the modified SEPIC converter. The output voltage, inductor current and the input voltage are required to generate manipulated duty cycle. It is given as the triggering pulse for the switch in the converter.

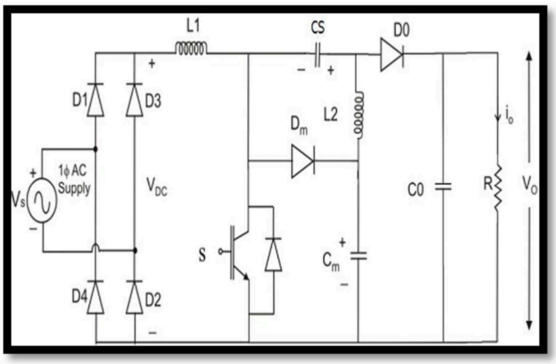

Fig. 1Power circuit diagram

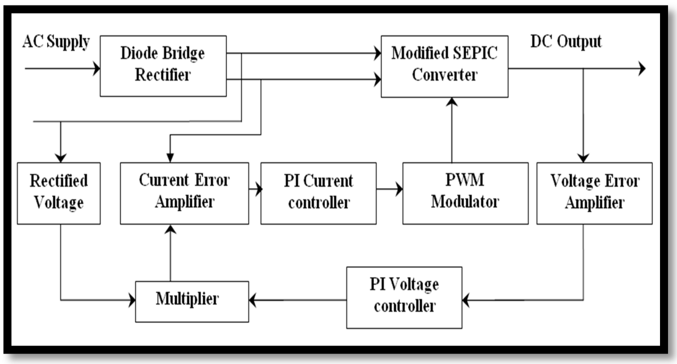

Fig. 2 Block diagram

The design steps for the modified SEPIC Converter [7] are as follows,

Switching Frequency $$F_{SW} = 20kHz$$

Duty Cycle $$D = \frac{V_O - V_I}{V_O + V_I}$$

Inductance L_1 and L_2 $$L_1 = \frac{V_I \times D}{\Delta I_{L1} \times F_{SW}} \qquad L_2 = \frac{L_1}{2}$$

Series Capacitance and Multiplier Capacitance $$C_S = C_M = \frac{I_{L_2} \times D}{\Delta V_C \times F_{SW}}$$

Output Capacitance $$C_{OUT} = \frac{P_{OUT}}{2 \times \pi \times F \times 2 \times V_{OUT} \times \Delta V_{OUT}}$$

Simulation results

Analysis of the modified SEPIC converter

The simulation circuit of closed loop modified SEPIC converter is shown in the Fig. 3.

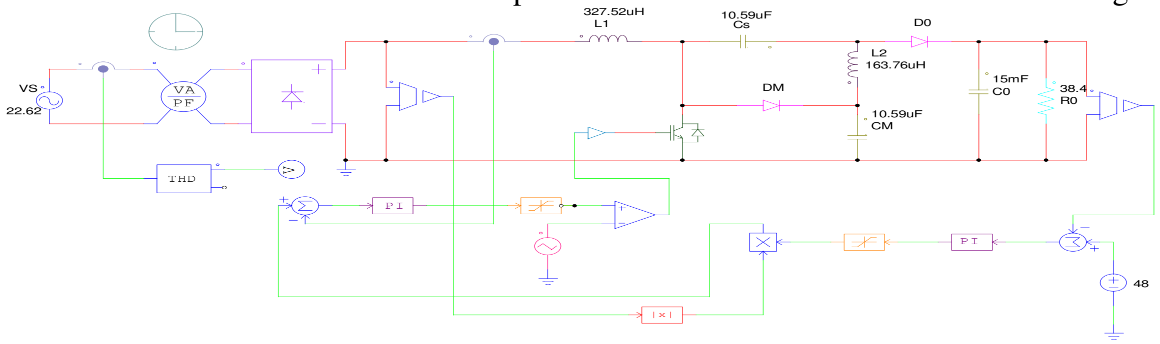

Fig.3 Closed loop simulation circuit of modified SEPIC converter

The input voltage and input current waveforms of the closed loop operation of the modified SEPIC converter is shown in Fig.4. The output voltage and output current waveforms of the closed loop operation of the modified SEPIC converter is shown in Fig.5. The gate pulse waveform of the closed loop operation of the modified SEPIC converter is shown in Fig.6.

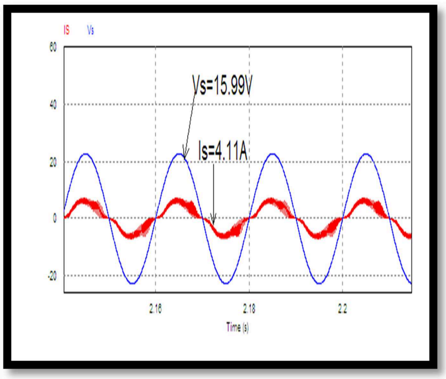

Fig. 4 Input voltage and input current waveform

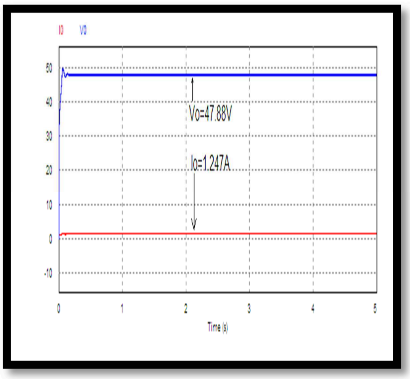

Fig.5 Output voltage and output current waveform

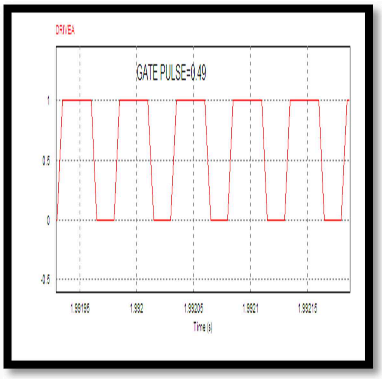

Fig. 6 Gate pulse waveform

Comparative study

The results of open loop and closed loop operation of SEPIC converter and modified SEPIC converter from simulation are tabulated in table 1.Modified SEPIC converter shows encouraging results. Thus modified SEPIC converter is chosen for hardware implementation.

TABLE 1
COMPARATIVE STUDY OF SEPIC AND MODIFIED SEPIC CONVERTER

parameters	SEPIC converter		modified sepic converter	
	open loop	closed loop	open loop	closed loop
Output voltage	45.78V	48 V	46 V	48 V
Power factor	0.76	0.89	0.813	0.988
THD	70.72%	9.32%	23.25%	6.04%

The stability of the modified SEPIC converter is verified by varying the AC RMS voltage to a wide range of (8-30)V. The output voltage is regulated to 48V DC which is shown in table2.

TABLE 2

BEHAVIOR OF MODIFIED SEPIC CONVERTER FOR VARIOUS INPUT VOLTAGES

S.NO.	V_{RMS}	V_O	POWER FACTOR	THD
1	08	48	0.995	06.50%
2	13	48	0.983	13.69%
3	14	48	0.974	15.50%
4	15	48	0.971	15.20%
5	16	48	0.972	15.31%
6	17	48	0.972	15.30%
7	18	48	0.970	15.40%
8	30	48	0.925	19.22%

TABLE 3

BEHAVIOR OF MODIFIED SEPIC CONVERTER FOR VARIOUS LOADS

S.NO.	RESISTANCE (Ω)	OUTPUT POWER (W)	POWER FACTOR	INPUT CURRENT DISTORTION (%)
1	76.80	30	0.948	19.22
2	46.08	50	0.972	15.31
3	38.40	60	0.984	14.48
4	28.80	80	0.987	11.69
5	23.04	100	0.988	6.04
6	15.36	150	0.989	6.32
7	05.76	400	0.996	6.01
8	04.61	500	0.996	5.59

The pictorial representation of the above tabulation is given in Fig. 7, Fig. 8.

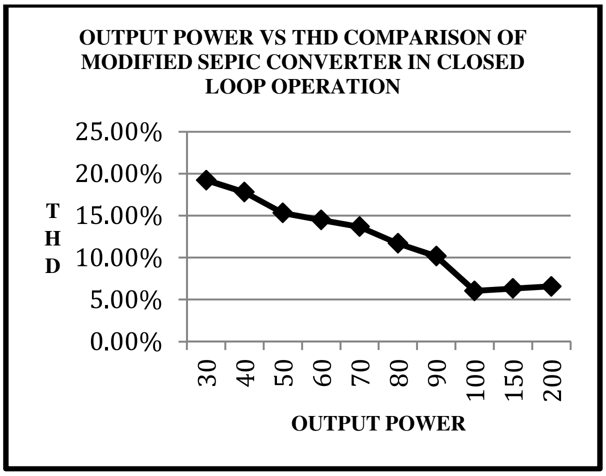

Fig. 7. Input current THD's for various loads in closed loop operation of modified SEPIC converters.

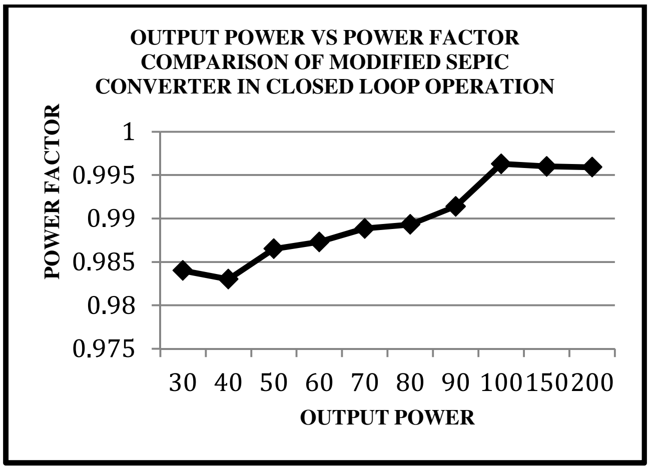

Fig. 8. Power factor for various loads in closed loop operation of modified SEPIC converters.

From the result analysis it is clear that, the power factor is maintained at almost unity irrespective to the change in load.Proportional-Integral (PI) control is the commonly used control algorithm in industry today. The PI controllers are popular because of their effectiveness in wide range of operating conditions, functional simplicity and it can be implemented using current computer technology. It will be a challenging task for finding the terms of PI controller. The strongest requirement of PI controller is the stability. For any set point, the process must not oscillate. Within certain time limits, the stabilizing effect must appear. There are several methods for tuning PI loop. After the controller is being tuned by suitable tuning method K_P and K_I values are selected as 0.1717 and 28 respectively.Modified SEPIC Converter can be used in practical applications such asbattery chargers, electronic ballasts, measurement and testing equipments, small rating motor drives in medical equipments,small rating refrigeration units.

Hardware implementation

For hardware implementation, LPC2148 ARM processor is used for control action. The reason for selection of LPC2148 is that, it has 6 PWM output ports, 14 -10 bit ADC channels, 60 MHz and 512kB on-chip flash memory. It is programmed to generate 50% duty cycle constantly when selected as open loop operation using the toggle switch and if selected as closed loop operation, the duty cycle [11] corresponding to the PI controller action is generated. It is observed that, during closed loop operation, when the load is varied, the output voltage is regulated to 48V, the power factor is improved to 0.988 and the THD is reduced to 12.9%.

Fig. 9 shows the complete hardware setup of the modified SEPIC converter. The ARM processor produces the PWM gate pulse of magnitude 4V according to the present output voltage in closed loop operation for modified SEPIC converter. This pulse is amplified by the buffer circuit to 18V for the IGBT. These gate pulse waveforms of before and after buffer circuit are shown in the Fig. 10 and Fig. 11 respectively.

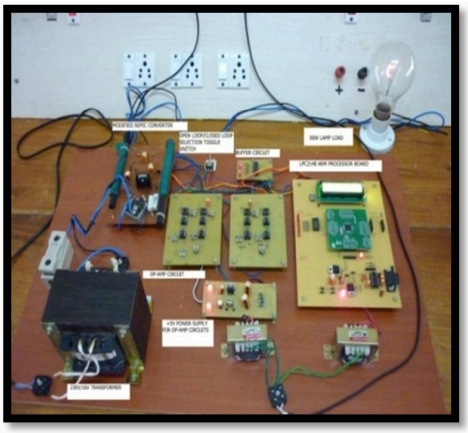

Fig. 9Hardware setup

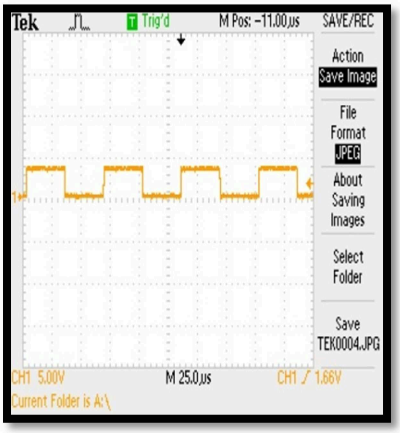

Fig. 10 Gate pulse waveform before buffer circuit

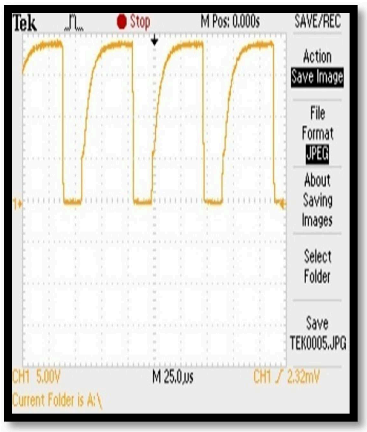

Fig. 11 Gate pulse waveform after buffer circuit

The THD and power factor waveform which is captured from the power quality analyzer is shown in Fig.12 and Fig.13 respectively. In closed loop analysis, the modified SEPIC converter has THD as 12.9% and power factor as 0.988.

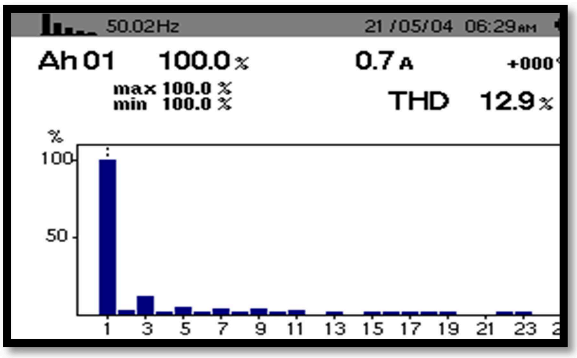

Fig. 12 THD

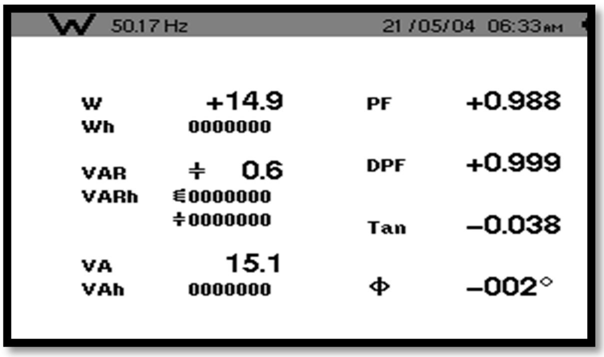

Fig. 13 Power factor

The hardware results of open loop and closed loop operation of the modified SEPIC converter are compared and are tabulated in the table 5.

TABLE 5
COMPARATIVE STUDY OF MODIFIED SEPIC CONVERTER

control parameters	simulation		hardware	
	open loop	closed loop	open loop	closed loop
output voltage	46.9V	48V	46.7V	48V
power factor	0.813	0.999	0.729	0.988
thd	23.25%	6.04%	26.45%	12.9%

Conclusion

The design and development of single switch SEPIC converter and modified SEPIC converter with high frequency non-isolation has been carried out for 48V output. An attempt for the power factor correction using PI controller has been implemented to improve the power factor and to control the output voltage to the load in such a way that current wave-form is proportional to supply voltage waveform. The closed loop modified SEPIC converter shows the encouraging results of improved performance of the designed PI controller in terms of controlled output voltage and improved power factor of AC mains have been achieved. The PI controller shows a promising future in the application of modified SEPIC converter.

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