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DESIGN AND IMPLEMENTATION OF BATTERY CHARGER WITH POWER FACTOR CORRECTION USING SEPIC CONVERTER AND FULL-BRIDGE DC-DC CONVERTER

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Abstract

This paper presents a design and implementation of a converter which has a high power factor for battery charger application. The converter is a combination of a SEPIC converter and a full-bridge DC-DC converter connected in two stages of series circuit. The SEPIC converter works in discontinuous conduction mode and it serves as a power factor corrector so that the shape of input current waveform follows the shape of input voltage waveform. The full-bridge DC-DC converter serves as a regulator of output voltage and operates at continuous conduction mode. The experimental results show that the power factor of this converter system can be achieved up to 0.96.

Keywords: SEPIC converter, full-bridge DC-DC converter, discontinuous conduction mode, power factor correction, battery charger.

I. INTRODUCTION

Most of modern electronic applications are equipped with battery which works as energy storage. Battery charger can be developed using conventional diode rectifier. However, this type of rectifier produces harmonics and low power factor. The harmonics and power factor are recognized as sources of disturbance in power quality issues. Many researchers have been conducting research to develop rectifiers having low harmonics and high power factor. Furthermore, the rectifier should produce low output voltage ripple to reduce losses in battery charger.

Several methods for reducing high harmonics and improving power factors of rectifier circuit above have been proposed in several ways, such as installing passive filter and Power Factor Correction (PFC) converter. Some researchers have proposed to install a passive filter by using an inductor on the system [1]. However, this solution may increase the size and the weight of the rectifier which operates in low frequency of 50–60 Hz. Some other researchers have proposed power factor correction converter to increase the power factor of AC-DC conversion. This system can be developed by two stage power factor correction converter which commonly uses pre-regulator buck [2,9], pre-regulator boost [5,8], pre-regulator buck-boost [3,4], and others [6,10,11,12].

This paper proposes a high power factor battery charger. The charger consists of combination of two converters connected in two stages of series circuit. The series converters are SEPIC converter and full-bridge DC-DC converter. The block diagram of the proposed converter system is shown in Figure 1.

II. CIRCUIT CONFIGURATION

One of the methods for improving low power factor is to install a SEPIC converter as a power factor corrector. The SEPIC converter is series connected to a full bridge DC-DC converter in two stages which is shown in Figure 2. The SEPIC converter is operated in discontinuous conduction mode so that it will have a high power factor and operate as a voltage follower.

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Figure 1. Block diagram of SEPIC converter and full- bridge DC-DC converter connected in series circuit

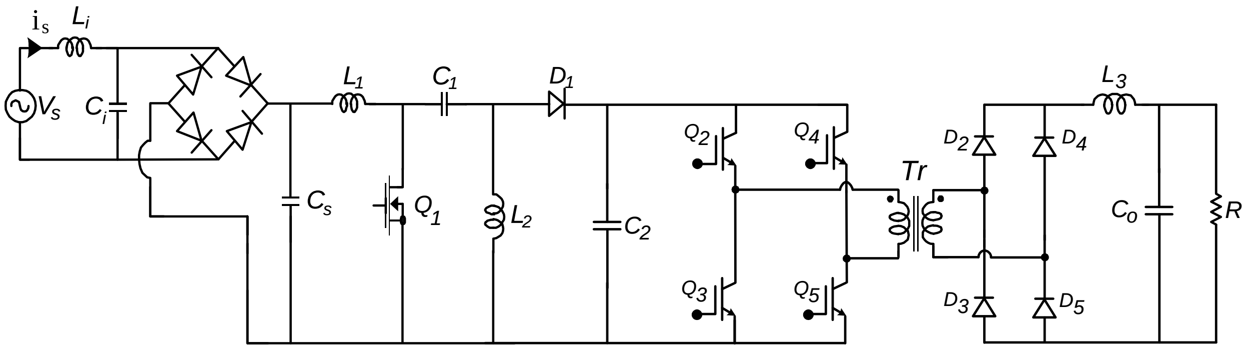

Figure 2. Circuit of a SEPIC converter and a full-bridge DC-DC converter connected in the two stage of series circuit

This operation principle means that the input current waveform follows the input voltage waveform [5]. Thus, the power factor will be close to unity.

The circuit of SEPIC converter in Figure 3 consists of two inductors (i.e., the first inductor is in input (L_1) and the second inductor is in output (L_2)). It operates in discontinuous conduction mode and is used to improve the power factor. The shape of input current waveform, which is shown in Figure 4, is represented by L_1's current. By assuming the output current (I_o), the input current (i_i) is determined in Equation 1 [6].

$$i_i(t) = \frac{D^2 \cdot T}{2 \cdot L_1} V_{i(t)} \left|\sin \omega t\right| + I_o \cdot D \quad (1)$$

where D is duty cycle, T is the switching period, V_i is the input voltage and I_o is the output current.

According to Equation 1, the SEPIC converter is operated in discontinuous conduction mode and in constant duty cycle, then the current $i_{i(t)}$ follows the shape of input voltage waveform and it means the SEPIC converter acts as a PFC converter.

To obtain the function of PFC, SEPIC converter is designed to operate in discontinuous conduction mode with the following steps [6].

Assume that M is ratio of the output voltage (V_o) and the input voltage (V_i), then:

$$M = \frac{V_o}{V_i} \quad (2)$$

K_a is conduction parameter and $K_{a,crit}$ is critical conduction parameter which are determined by:

$$K_{a,crit} = \frac{1}{2(M)^2} \quad (3)$$

which $K_a < K_{a,crit}$. Then

$$D = \sqrt{2} \cdot M \cdot \sqrt{K_a} \quad (4)$$

The values of L_1 and L_2 which operate in discontinuous mode are determined by using Equation 5 and Equation 6.

$$L_1 = \frac{V_1 \cdot D \cdot T}{I_{rip}} \quad (5)$$

and L_2 can be obtained from

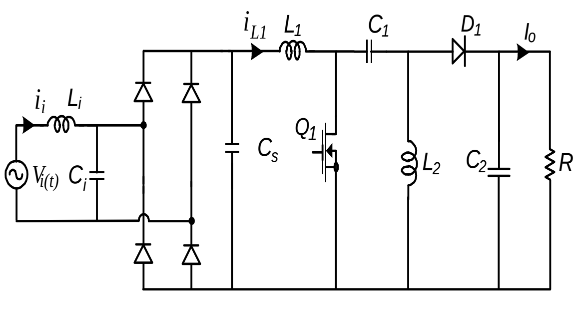

Figure 3. Circuit of SEPIC converter

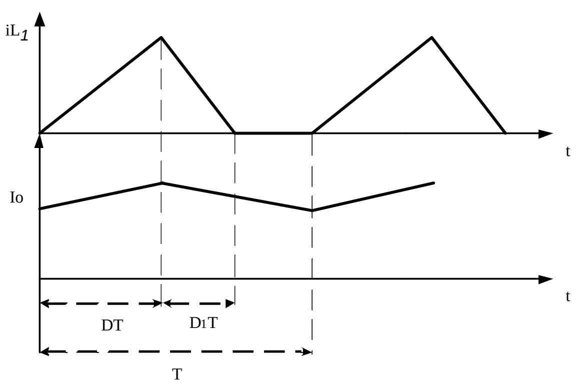

Figure 4. Inductor current and output current

$$L_2 = \frac{L_1 L_{eq}}{L_1 - L_{eq}} \quad (6)$$

The equivalent inductance L_{eq} from both inductors can be determined as:

$$L_{eq} = \frac{R \cdot T \cdot K_a}{2} \quad (7)$$

where R is resistive load and I_{rip} is peak to peak of input current. The intermediate capacitor C_1 is determined by assuming that resonant frequency of C_1, L_1, and L_2 must be higher than the fundamental frequency. Therefore, the resonant frequency of C_1 and L_2 must be lower than the switching frequency [10]. The value of C_1 can be obtained from:

$$C_1 = \frac{1}{\omega_r^2 (L_1 + L_2)} \quad (8)$$

Furthermore, the full-bridge DC-DC converter which is shown in Figure 5 serves as DC voltage regulator. It is designed in normal operation which consider to Equation 9 to Equation 11.

Assume that d is duty cycle, then:

$$d = \frac{N_1 x\ V_o}{2\ x\ N_2 x\ V_{in}} \quad (9)$$

The filter inductor can be obtained from:

$$L_{cri} = \frac{(1-d)}{4}\ x\ R\ T \quad (10)$$

And, the filter capacitor is

$$C_o = (1-d) x \frac{V_o}{32\ L_o f^2\ \Delta V_o} \quad (11)$$

III. IMPLEMENTATION AND EXPERIMENT

To verify the design that has already been discussed, the converter system was built using the following parameters which are shown in Table 1 and Table 2.

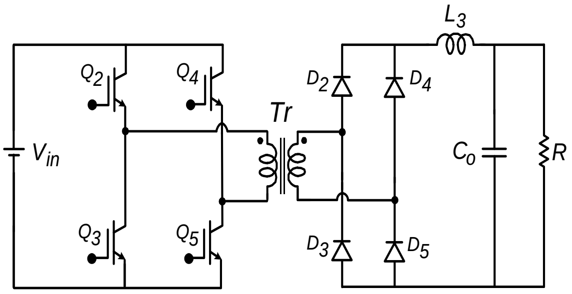

Figure 5. Fullbridge DC-DC converter circuit

The above parameters are designed parameters for the converter to deliver unity power factor and to verify the function of battery charger. In this experiment, a conventional rectifier and a SEPIC converter are compared to verify the effectiveness of the design criteria. First test was done by providing 120 V_{dc} from full wave rectifier to full-bridge converter.

The observed parameters are input current, harmonic spectrum, power factor and performance of full-bridge DC-DC converter. Figure 6 shows the values of the input current waveform, and the harmonic spectrum of input current and Figure 7 shows the value of power factor. Data in this experiment was obtained using Fluke 41B. By providing dc voltage source of 120 V from full wave rectifier, the experimental results show that the system has a low power factor (0.69) and high harmonic distortion of 70.8% of THD.

Second experiment system was done using the proposed system as shown in Figure 2. Figure 8 shows the values of the input current waveform, and the harmonic spectrum of input current and Figure 9 shows the value of power factor. The experimental results verify that the converter system has high power factor of 0.96 and harmonic distortion decreases to 24.2% of THD.

Table 1.
Parameters of SEPIC converter

Parameter	Value
AC input voltage	220 Volt
Output voltage	120 Volt
Switching frequency	25 kHz
Inductor L_1	2.6 mH
Inductor L_2	83 µH
Diode D_1 (ultra fast recovery diode)	STTH 1B0L0BCWG
Switch Q_1	IGBT
Capacitor C_1	2 µF,1000 Volt
Capacitor C_2	680 µF,450 Volt

Table 2.
Parameters of full-bridge DC-DC converter

Parameter	Value
Input voltage	120 Volt
Switching frequency	25 kHz
Inductor L_3	860 µH
Diode D_2, D_3, D_4, D_5 (ultra fast recovery diode)	STTH 1B0L0BCWG
Switch Q_{2-5}	IGBT
Transformer T_r	N_{11}:N_{12}= 48:43
Capacitor C_o	86 µF ,450 Volt

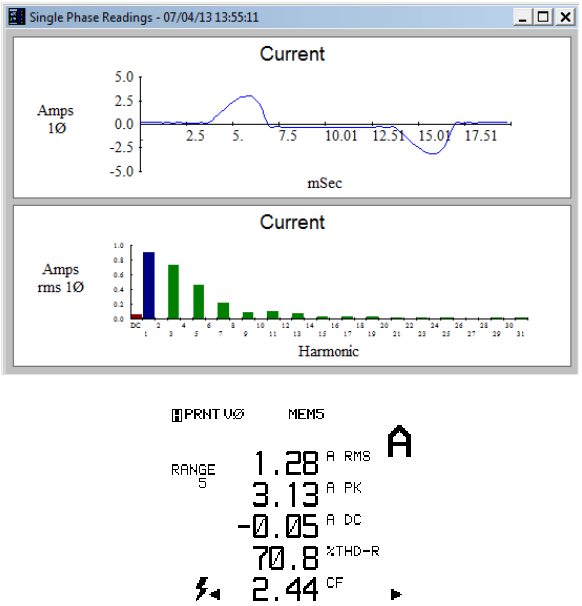

Figure 6. Input current waveform and its parameter analysis of conventional rectifier

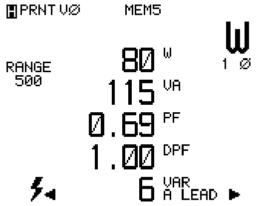

Figure 7. Power analysis of conventional rectifier

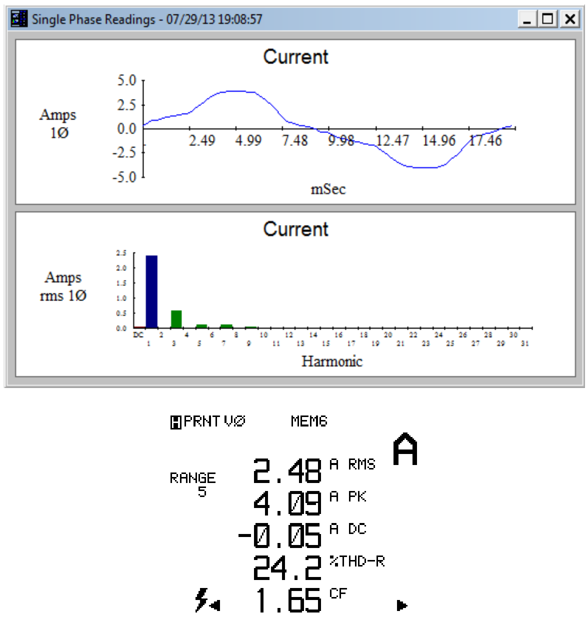

Figure 8. Input current waveform and its parameter analysis of SEPIC converter

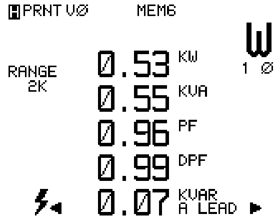

Figure 9. Power analysis of SEPIC converter

Table 3 shows the experiment data of varying load and PFC results. This experiment is done by operating the proposed system with input AC voltage source of 220 V. The load is increased by around 0.5 A step. The converter can deliver power factor up to 0.96 which is close to unity. The largest power factor is 0.96 when the output current is 3.14 A. These results verify that the converter can be operated as PFC.

Furthermore, Figure 10 shows the value of the power factor according to load and shows the trends of data in Table 3. Overall hardware experimental results obtained a high power factor. Based on data above, the correction of power factor is achieved from 0.69 to 0.96.

After the experiment of PFC had already done, then characteristic of battery charging were going to be observed. There are two parameters which must be concerned about battery charging. The first parameter is the charging current and it should be kept to around 10% to 30% of the capacity of the battery (Ah: Ampere-hours) and the second parameter is the charging voltage and it should be set to 2.3 - 2.4 Volt per 2 Volt cell. For example a 12 Volt battery (6 cells of 2 Volt) is charged at 6 × 2.3 = 13.8 Volt to at 6 × 2.4 = 14.4 Volt.

The battery used for this experiment has a 72 Volt of voltage that consists of 6 pieces of 12 Volt of battery or 36 cells of 2 Volt. The capacity of battery that is used for this experiment is 20 Ah (Ampere-hours). So, to meet the requirement of charging voltage and charging current, the output voltage of converter system is adjusted at 87 Volt (36 cells times 2.4 Volt) and produces the charging current about 3.14 A or 10% of the capacity. Charging characteristic is shown in Figure 11. According to this figure we know that the battery charger can work well.

Table 3.
Overall systems performance

V_{in} (V)	I_{in} (A)	V_o (V)	I_o (A)	pF
217	0.54	87	0.56	0.87
218	0.83	87	1.13	0.94
220	1.32	87	1.68	0.95
218	1.71	87	2.15	0.96
216	2.33	87	2.8	0.96
220	2.48	87	3.14	0.96

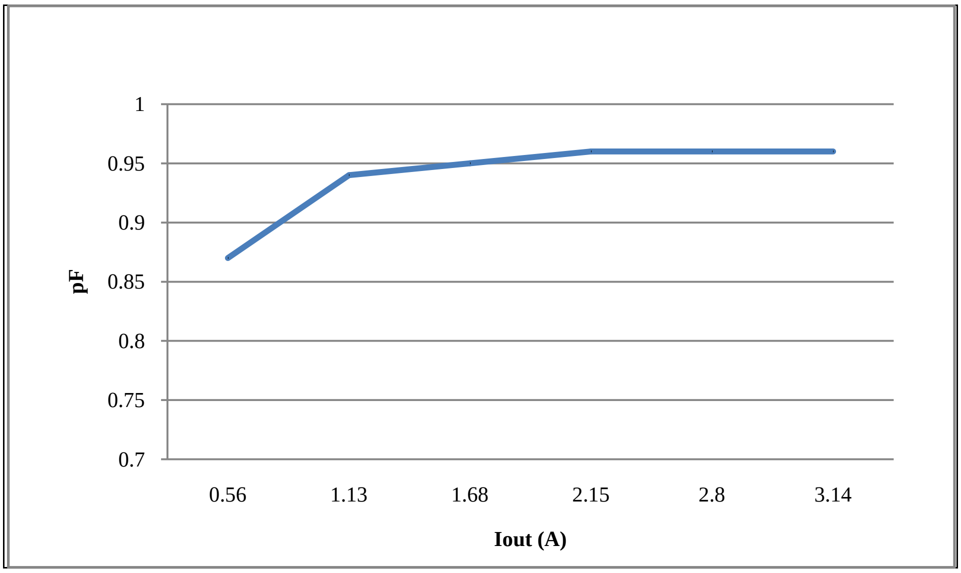

Figure 10. Chart of pF *vs* output current

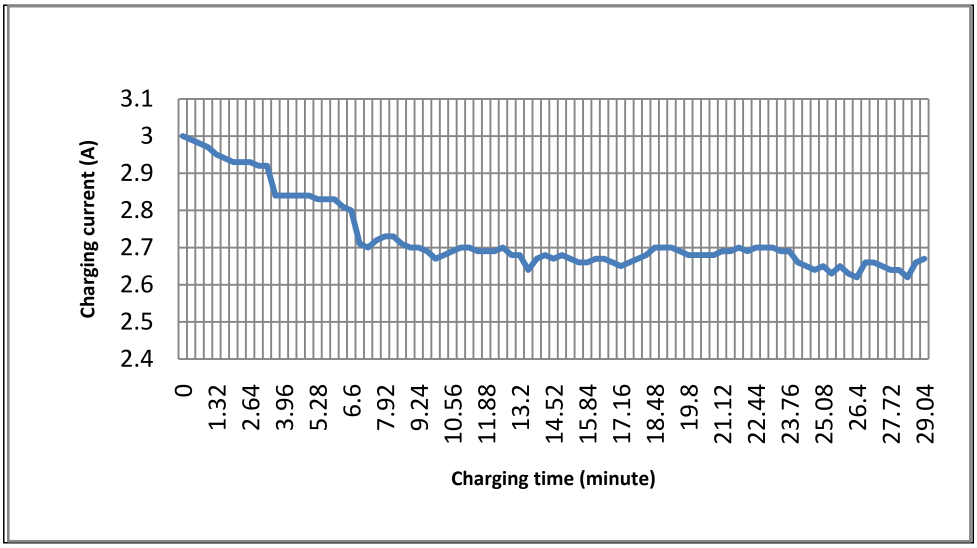

Figure 11. Characteristic of battery charging

IV. Conclusion

This paper has already discussed about the design and implementation of a combination of SEPIC converter and full bridge DC-DC converter for battery charger application with power factor correction. The experimental results have confirmed that this converter provides high power factor correction up to 0.96. This converter can be used for battery charger application such as electric vehicle and electronic appliances.

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