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DC POWER SUPPLY WITH POWER FACTOR CORRECTION USING INTEGRATION OF FLYBACK-FORWARD TOPOLOGY IN PARALLEL CONNECTION

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ABSTRACT

This paper presents a new configuration of a dc power supply with power factor correction using integration of flyback and forward topology in parallel connection. Flyback converter is used for power factor corrector and it operates in discontinuous conduction mode so that it becomes as a natural resistance. Forward converter is used as a dc regulator and operates in continuous conduction mode. A prototype circuit, which has 20 Volt of output voltage and 5 A of output current is designed and tested by a simulation and experiment. According to the simulation and experiment results, the power factor of this circuit can be achieved up to 0.96 and the input current meets the international harmonics standard of IEC61000-3-2 class A and class D so it can be used as power supply for computer, monitor and television.

Keywords: *Power factor correction, Flyback converter, Forward converter, IEC61000-3-2*

1. INTRODUCTION

Rectifier circuit commonly is used to provide a power supply for electronics equipment such as computer, television, ICT equipment, office equipment, battery charger, electronic ballast and home appliances by converting an ac input voltage to dc output voltage. A large capacitor filter is connected to the output side of the rectifier circuit to obtain purely dc voltage. However, it causes the input current become not purely sine waveform. Consequently, the input current contains high harmonic and low power factor.

To reduce high harmonic current and to improve power factor can be done by several methods, such as: (1) Installing the passive filter which consists of inductor and capacitor. This method is not commonly used due to increasing the size and the weight of rectifier because of low operating frequency at 50 – 60 Hz. (2) Inserting a PFC (Power Factor Correction) pre-regulator or well-known as two stage power factor correction converter using buck, boost, buck-boost, sepic, cuk and other topologies [1]-[4]. The two stage power factor correction scheme can produce a purely sine wave of input current, unity power factor, and low harmonic. But, it has disadvantages, such as low efficiency, complex control system, and high cost.

To solve some problems above, a single stage power factor correction converter is developed. The configuration of this system is simpler than the configuration of two stage power factor correction scheme, so that it has simple controller and low cost.

Many types of single-stage power factor correction converter have already been published. They are generally the integration of two converters based on dc-dc converters [5]-[9]. The simple single stage PFC based on flyback converter [5] and a PFC One-Stage Forward-Type have been proposed [6]. The PFC are operated in discontinuous conduction mode to yield high power factor.

In this paper, the new configuration of a dc power supply with power factor correction is proposed. It is the merger between a power factor correction converter and a dc-dc converter. It is different with the previous single stage power factor correction scheme. The proposed power supply circuit is the integration of flyback-forward topology connected in parallel circuit. The goal of this merging is to obtain a simple configuration, low cost and good performances such as high power factor, low harmonics and meets the IEC61000-3-2 of harmonic standard [10] so that it can be used as power supply for electronics equipment such as computer, monitor, television multimedia devices, fax, printers and others.

The proposed power supply circuit has been observed by simulation and experiment to clarify that this converter has good performances.

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2. CIRCUIT CONFIGURATION

The block diagram of the proposed power supply with power factor correction is shown in Figure 1.

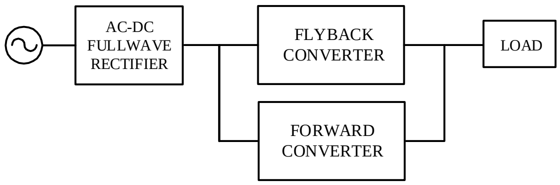

Figure 1. Block Diagram Of The Proposed Power Supply With Power Factor Correction

It is a merger of flyback-forward topology. The detail circuit of the proposed power supply with power factor correction is shown in Figure 2. This circuit consists of power factor corrector (PFC) part and dc regulator part. PFC part is flyback converter and it contains transformer Tr_1 that includes a magnetizing inductor (L_{m1}), ac-dc full-wave rectifier, diode D_1 and active switch Q.

The dc regulator part is forward converter which contains forward transformer Tr_2 that includes a magnetizing inductor (L_{m2}), diode D_2, input capacitor C_s, diodes D_3, D_4, output inductor L_o, output capacitor C_o and switch Q. Both parts share some components such as input rectifier, output capacitor, switch and controller so that it is more efficient

The flyback converter as power factor corrector operates in discontinuous conduction mode. Hence, if the converter operates in discontinuous conduction mode, the converter will have a high power factor [5]. The fundamental of power factor correction converter can be explained by flyback converter which is shown in Figure 3. It operates in discontinuous conduction mode and has an input resistance (R_i) that is calculated from the input voltage $V_{i(t)}$ and the input current $i_{i(t)}$ at one switching period. The input current and magnetizing current waveforms of flyback converter that operates in discontinuous conduction mode are shown in Figure 4.

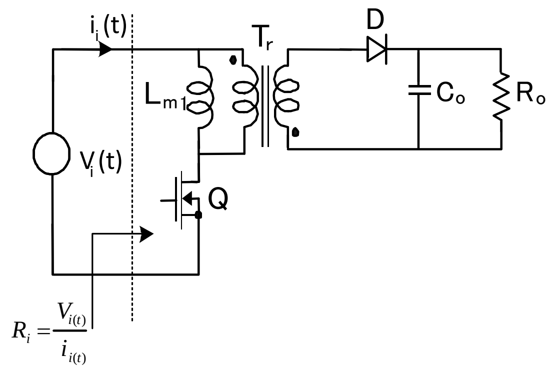

Figure 3. Flyback Converter In Discontinuous Conduction Mode Operation

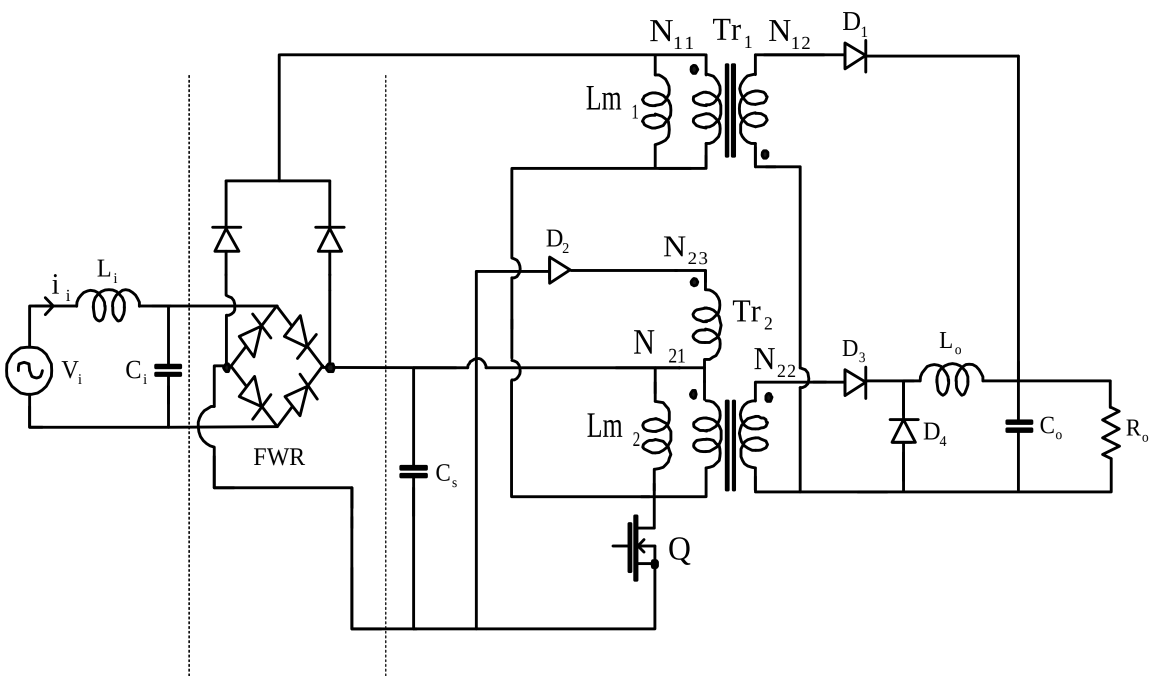

Figure 2. The Detail Circuit Of The Proposed Power Supply With Power Factor Correction

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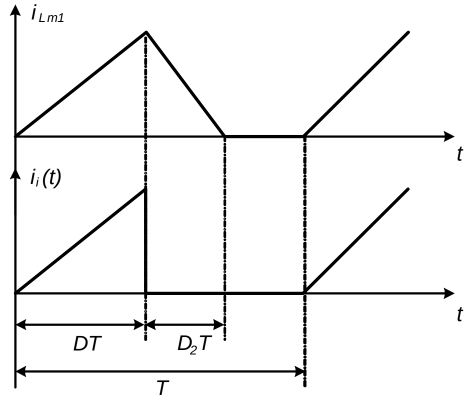

Figure 4. Waveform Of Inductor Magnetizing

The input resistance of the converter system can be calculated by equation 1:

$$R_i = \frac{V_{i(t)}}{i_{i(t)}} \quad (1)$$

According to Figure 4, the input current is determined by equation 2:

$$i_{i(t)} = \frac{\frac{1}{2} i_{Lm1} DT}{T} \quad (2)$$

where i_{Lm1} is magnetizing inductor current, D is the duty ratio and T is the switching period. The magnetizing inductor current can be calculated by equation 3:

$$i_{Lm1} = \frac{V_{i(t)} \left|\sin \omega t\right| DT}{T} \quad (3)$$

where $V_{i(t)}\left|\sin \mu t\right|$ is the input voltage. If the equation 3 is substituted into equation 2, the input current become as equation 4:

$$i_{i(t)} = \frac{V_{i(t)} \left|\sin \omega t\right| D^2 T}{2L_{m1}} \quad (4)$$

Finally, equation 4 is substituted into the equation 1, thus the input resistance is determined by equation 5:

$$R_i = \frac{V_{i(t)}}{i_{i(t)}} = \frac{2L_{m1}}{D^2 T} \quad (5)$$

The equation 5 shows the resistance (R_i) depends on the value of magnetizing inductance, switching period, and duty ratio. If the flyback converter operates in discontinuous conduction mode and in constant duty ratio, the input resistance becomes constant. Therefore, the shape of the input current waveform $i_{i(t)}$ follows the shape of the input voltage waveform $V_{i(t)}$ and the flyback converter becomes as power factor corrector.

Furthermore, the second part of this circuit is forward dc regulator that is designed to operate in continuous conduction mode. The circuit of the forward dc regulator is shown in Figure 5. It is designed using equation 6 to equation 8 [11].

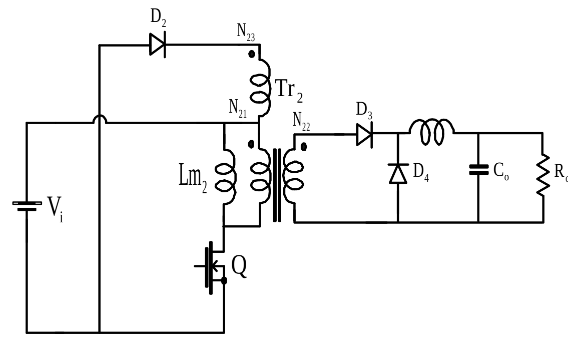

Figure 5. Circuit Of Forward Dc Regulator

Assume that d is duty cycle determined by equation 6:

$$d = \frac{N_{21}}{N_{22}} \times \frac{V_o}{V_i} \quad (6)$$

The output inductor can be obtained from equation 7:

$$L_o = \frac{V_o (1-d)}{f \times \Delta I_{Lo}} \quad (7)$$

The filter capacitor can be calculated by equation 8:

$$C_o = (1-d) \times \frac{V_o}{32 L_o f^2 \Delta V_o} \quad (8)$$

3. RESULTS AND ANALYSIS

To verify the theoretical discussion, a prototype of the proposed dc power supply with power factor correction using integration of flyback and forward topology in parallel connection was built using the following parameters which are shown in Table 1.

The operation of this circuit is simulated by SCAT K460PR1. The main observed parameter is the magnetizing inductance current in flyback's transformer to ensure the circuit operates in discontinuous conduction mode. Figure 6 shows the magnetizing inductance current waveform in discontinuous conduction mode operation.

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Table 1. Parameters Of The Proposed Dc Power Supply Circuit

Parameter	Value
AC input voltage	100 Volt
Output voltage	20 Volt
Switching frequency	100 kHz
Transformer T_{r1}	N_{12}:N_{12}= 24:8
L_{m1}	70μH
Transformer T_{r2}	N_{21}:N_{22}:N_{23}= 24:8:12
L_{m2}	360μH
Switch Q_1	MOSFET
Diode D_1, D_3, D_4	F40U60DN
Diode D_2	2×FR307
L_o	500 μH
Capacitor C_s	470 μF, 450 Volt
Capacitor C_o	2200 μF, 50 V

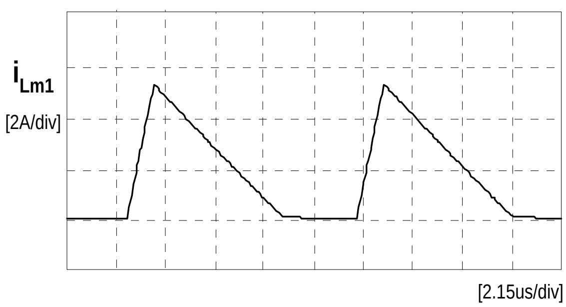

Figure 6. Waveform Of Magnetizing Inductance Current In Discontinuous Conduction Mode Operation

Other observed parameters are the input voltage, the input current, and the spectrum of harmonics shown in Figure 7 and Figure 8.

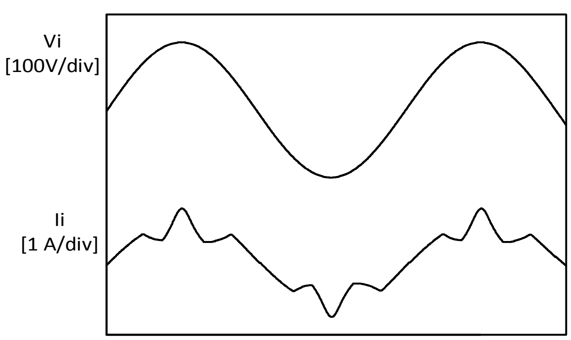

Figure 7. The Input Voltage And Current Waveform

The simulation results shows the proposed dc power supply meets the International Harmonic Standard of IEC61000-3-2 class D.

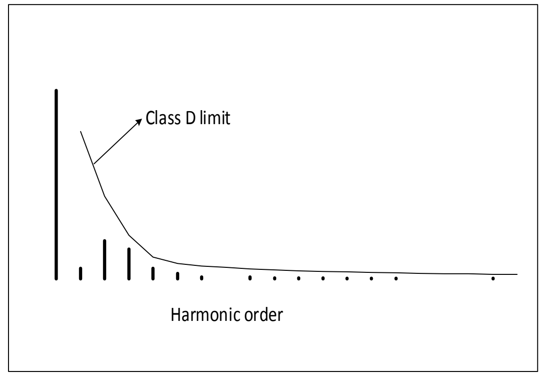

Figure 8. The Harmonic's Spectrum Of Input Current

To confirm the simulation result, the prototype of hardware is tested in laboratory. The observed parameters are the same as the simulation observation. They are the input current and its harmonic's spectrum. Figure 9 and Figure 10 show the experiment result of its.

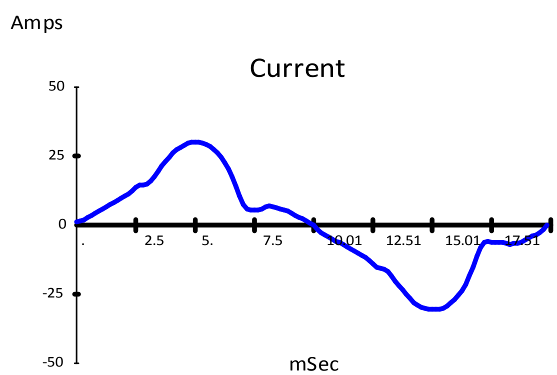

Figure 9. The experimental input current waveform

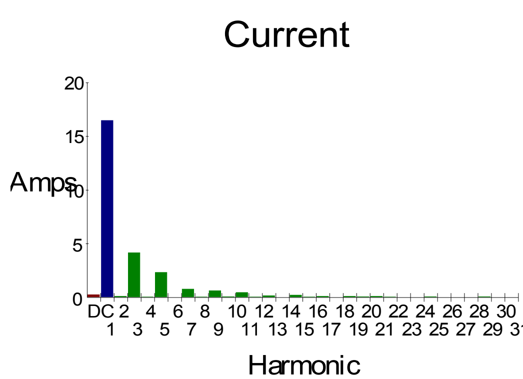

Figure 10. The Harmonic's Spectrum Of Input Current

Based on the experimental data, especially the harmonic's spectrum of input current, it can be

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made comparison between measurement result of the prototype circuit on 2.5 A and 3 A of loads with the IEC61000-3-2 of harmonic standard of class A. The comparison data of class A individual harmonic are shown in Table 2.

Table 2. The Comparison Data Of Class A Individual Harmonics

Harmonics (n)	IEC61000-3-2 Standard Class A (A)	Prototype circuit on 2.5 A of load (A)	Prototype circuit on 3 A of load (A)
3	2.3	0.132	0.66
5	1.14	0.086	0.093
7	0.77	0.042	0.03
9	0.4	0.0244	0.026
11	0.33	0.0176	0.018
13	0.21	0.0064	0.0064

It is seen in Table 2, the harmonics contents of the input current of prototype circuit are lower than class A limits. Data in Table 2 can be made two graphs which are shown in Figure 11 and Figure 12 to make the comparison more clear. These figures clarify that the proposed power supply circuit meets the IEC61000-3-2 of harmonic standard of class A, so that it can be used as power supply for class A loads such as household appliances, portable tools, dimmer for incandescent lamps, multimedia devices, printer, scanner, fax and telecommunication devices.

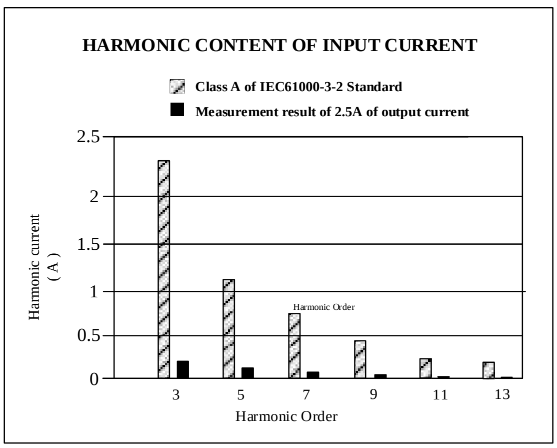

Figure 11. The Comparison Of Class A Harmonic's Input Current On 2.5 A Of Output Current

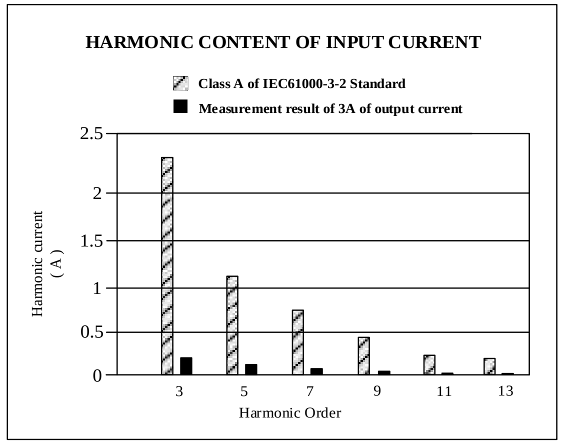

Figure 12. The comparison of class A harmonic's input current on 3 A of output current

Furthermore, the comparison between measurement result on 2.5 A and 3 A of loads with the IEC61000-3-2 of harmonic standard of class D are shown in Table 3. Individual harmonic contents of class D is calculated in mA/watt. It is seen in Table 3 that the individual harmonic contents of input current of prototype circuit are lower than class D limits on both 2.5 A and 3 A of loads

Table 3. The Comparison Data Of Class D Individual Harmonics

Harmonics (n)	IEC61000-3-2 Standard Class D (mA/watt)	Prototype circuit on 2.5 A of load (mA/watt)	Prototype circuit on 3 A of load (mA/watt)
3	3.4	2.39	2.67
5	1.9	1.55	1.5
7	1.0	0.76	0.5
9	0.5	0.44	0.41
11	0.35	0.32	0.295
13	0.296	0.16	0.1

The comparison data in Table 3 are also presented as graph that are shown in Figure 13 and Figure 14. These figures confirms that this prototype circuit meets the Class D mA/W limit and prove that the proposed power supply circuit meets the IEC61000-3-2 of harmonic standard of class D. So it can be implemented for power supply of class D loads such as computer, monitor, and television

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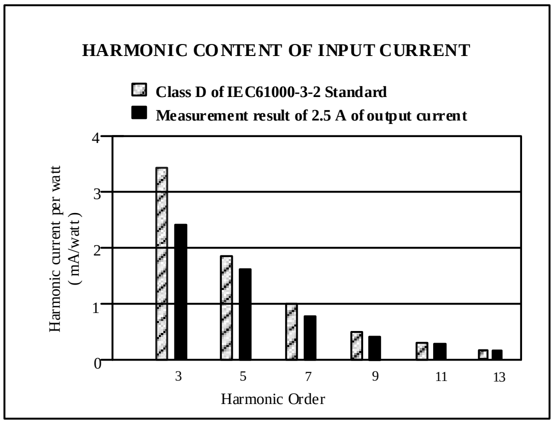

Figure 13. The Comparison Of Class D Harmonic's Input Current On 2.5 A Of Output Current

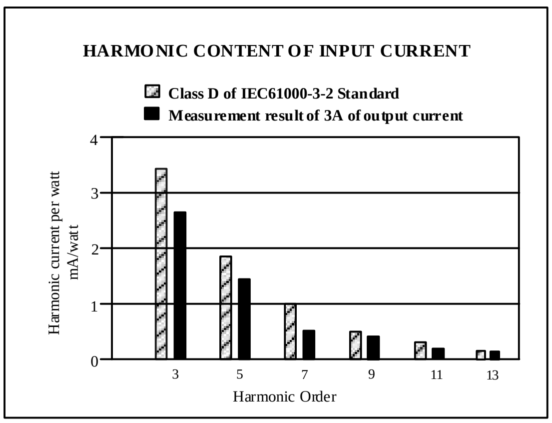

Figure 14. The Comparison Of Class D Harmonic's Input Current On 3 A Of Output Current

Finally, the experimental parameter measured is power factor of the prototype circuit. Figure 15 shows the graph of output current vs power factor that declare the relationship between output current and power factor.

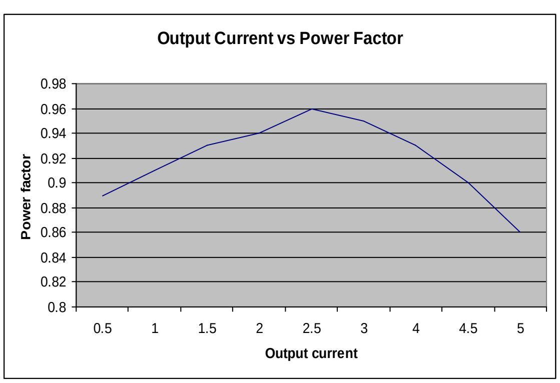

Figure 15. The Graph Of Power Factor Vs Output Current

According to Figure 15, the maximum power factor of the proposed power supply can be achieved up to 0.96

And a photograph of prototype of the proposed power supply with power factor correction had been tested on laboratory is shown in Figure 16.

Figure 16. A Prototype Of The Proposed Dc Power Supply With Power Factor Correction

4. CONCLUSION

This paper has already discussed about the new configuration of a dc power supply with power factor correction using integration of flyback and forward topology in parallel connection. A prototype circuit have already been designed and tested by simulation and experiment. According to the simulation and experiment results, this circuit has a high power factor and achieves up to 0.96 and meets the international harmonic standard of IEC1000-3-2 class A and class D and it can be used as power supply for computer, monitor and television.

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