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# Analysis of Fast Fourier Transform (FFT) Of Phase Staggered Pulse Width Modulator for Two Switch Forward Converter

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**ABSTRACT:** A **fast Fourier transform** (**FFT**) algorithm computes the discrete Fourier transform (DFT) of a sequence, or its inverse (IFFT). Fourier analysis converts a signal from its original domain (often time or space) to a representation in the frequency domain and vice versa. The Fourier transform is the mathematical tool used to make this conversion. Simply stated, the Fourier transform converts waveform data in the time domain into the frequency domain. The Fourier transform accomplishes this by breaking down the original time-based waveform into a series of sinusoidal terms, each with a unique magnitude, frequency, and phase. This process, in effect, converts a waveform in the time domain that is difficult to describe mathematically into a more manageable series of sinusoidal functions that when added together, exactly reproduce the original waveform. Plotting the amplitude of each sinusoidal term versus its frequency creates a power spectrum, which is the response of the original waveform in the frequency domain. In this paper FFT spectrum has been mentioned using two switch forward converter. The FFT of with and without phase staggering technique has been shown. In this technique, the respective switching PWM signals of power converters are given with a constant relative phase shift called phase staggering due to which the frequency of ripple increases. Phase staggered PWM technique can be used to control two or more than two power modules. This paper presents a comparison between with and without phase staggered PWM at output of two switch forward converter. Design parameters and principle operation of two switch forward converter is also described. A prototype of phase staggered PWM with two forward converters have been designed and simulated for theoretical validation. Switching converters could be operated at 50 kHz switching frequency. Simulation results are also presented for output FFT of voltage and current for two forward converters with and without phase staggering technique.

**KEYWORDS:** *Pulse Width Modulator (PWM), Phase Staggered* PWM, Fast Fourier Transform (FFT).

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## I. INTRODUCTION

Pulse Width Modulation (PWM) has become an integral part of almost every electronics system. Various PWM schemes are used and they are researched extensively. One of the most important applications of PWM lies in power electronics applications for controlling power converters (DC/DC, DC/AC, etc.). The application of PWM control in a two switch forward converter is shown in Fig.1 (a). The PWM control signal is used to control the power switch and modulate the DC input voltage, which is then stepped down through a transformer and then passed through a low pass filter for producing the DC output voltage across the load. The PWM signal is generated by comparing a control voltage, $v_c$ with a sawtooth voltage, $v_t$ of constant amplitude $V_T$ and frequency, $f_s \left(=\frac{1}{T_s}\right)$, as shown in Fig.1 (b). The DC output voltage, $v_o$ is kept to the desired value by fixing appropriate duty cycle.

Phase staggered control is a method of decreasing the ripple magnitude on the output voltage of switching converters without increasing the internal converter switching frequency. In this method the switching power converters are operated with a constant relative phase shift called phase staggering due to which the frequency of ripple increases.

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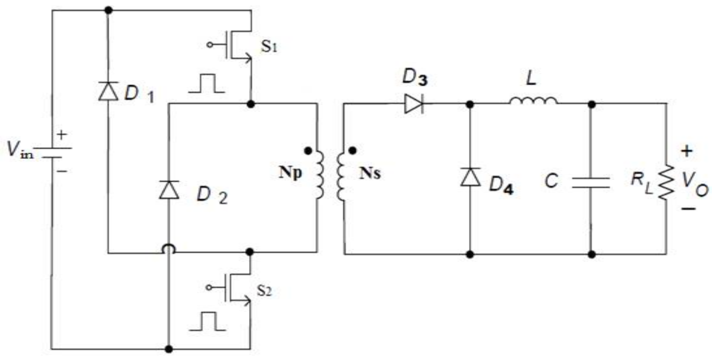


**Fig. 1(a)**

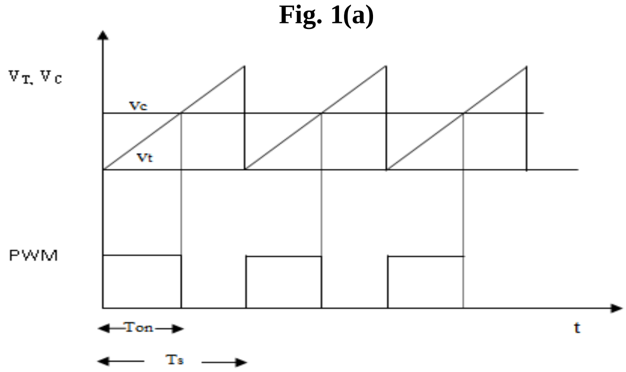


**Fig. 1 (b)**

**Fig. 1: PWM control of a forward DC/DC Converter: (a) Power Converter Diagram and (b) Associated Waveform**

## II. TWO SWITCH FORWARD CONVERTER

Switch mode power supplies (SMPS) have been used for many years in industrial and aerospace applications where good efficiency, light weight, low cost and small size were of major concern. There are many types of converter such as fly-back, push-pull, half bridge, full bridge, and forward. Two switch forward converter is chosen in this project for the validation of phase staggered PWM. Forward converter is derived from dc to dc buck converter with the addition of transformer. Forward converter is used to produce isolated and controlled dc voltage from unregulated dc input supply. The circuit diagram of two switch forward converter is shown in Figure 2.

**Case I: Switches $S_1$ and $S_2$ On**

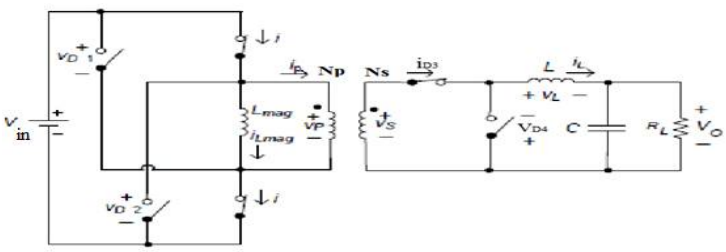


**Fig. 2: Equivalent Circuit of Forward Converter When Switches On**

The equivalent circuit of two switch forward converter when the switches are closed is shown in Fig.5.4. When switches $S_1$ and $S_2$ are closed, input dc voltage gets applied to the primary winding and simultaneously a scaled voltage, $V_{in}*N_s/N_p$ appears across the transformer secondary. Dotted sides of both the windings are having positive polarity.

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Diode, $D_3$ is connected in series with the secondary winding gets forward biased and the scaled input voltage is applied to the low pass filter circuit preceding the load. The primary winding current enters through its dotted end while the secondary current comes out of the dotted side [2].

**Case II: Switches $S_1$ and $S_2$ Off**

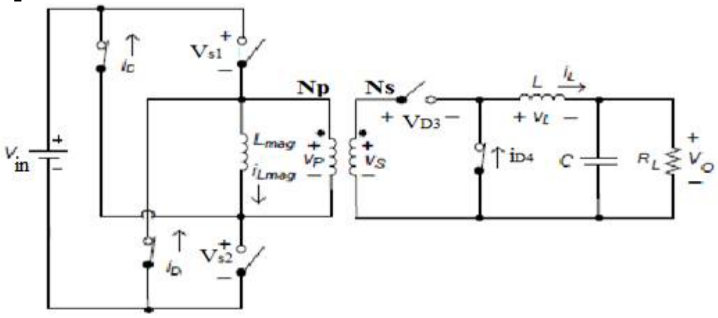


**Fig. 3: Equivalent Circuit of Forward Converter When Switches Off**

The equivalent circuit of two switch forward converter when the switches are open is shown in Figure 3. When the switches $S_1$ and $S_2$ are open, the dotted ends of both the windings are now negative polarity. The source voltage appears across the primary winding in opposite polarity, the diodes, $D_1$ and $D_2$ becomes forward biased and stored energy of primary is fed back to the source while diodes $D_3$ in the secondary side become reverse biased. Current through the filter inductor and load current continues to flow as diode $D_4$ provides the freewheeling path for this current [2].

**Table I: Design Parameters of Forward Converter**

| Sr. No. | ***Parameters*** | ***Value*** |
|---|---|---|
| 1 | Nominal Input Voltage | 325 V |
| 2 | Input Voltage (min) | 275 V |
| 3 | Input Voltage (max) | 357.5 V |
| 4 | Output Voltage (DC) | 20 V |
| 5 | Output Current (DC) | 5 A |
| 6 | Duty Cycle | 0 < D < 50 % |
| 7 | Frequency | 50 kHz |
| 8 | Ripple Voltage | 1V |

## III. SIMULATION OF TWO SWITCH FORWARD CONVERTER

Simulation of two switch forward converter circuit has been done to check the validity of theoretical design as given in Table I. This section presents the simulation of two switch forward converter which will be used for experimental validation of phase staggered PWM. The circuit shown in the Fig.4 is a schematic of two switch forward converter.

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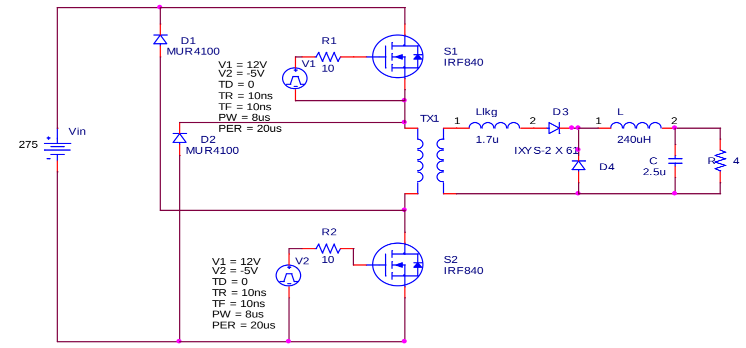


**Fig. 4: Schematic of Two Switch Forward Converter**

Figure 5 and Figure 6 shows simulated output voltage and current waveforms of output current, filter inductor current and filter capacitor current for *d* = 0.4, for the circuit of Figure 4.

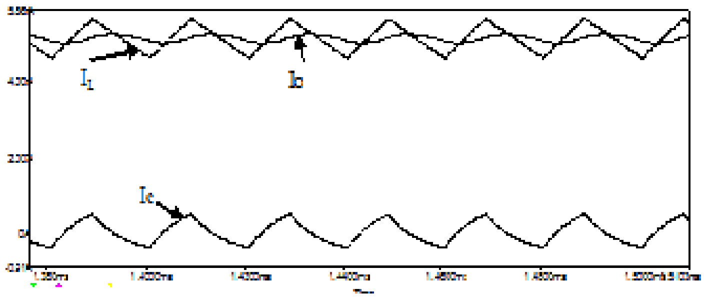


**Fig. 5: Simulated waveforms of output current, filter inductor current and filter capacitor current for *d* = 0.4**

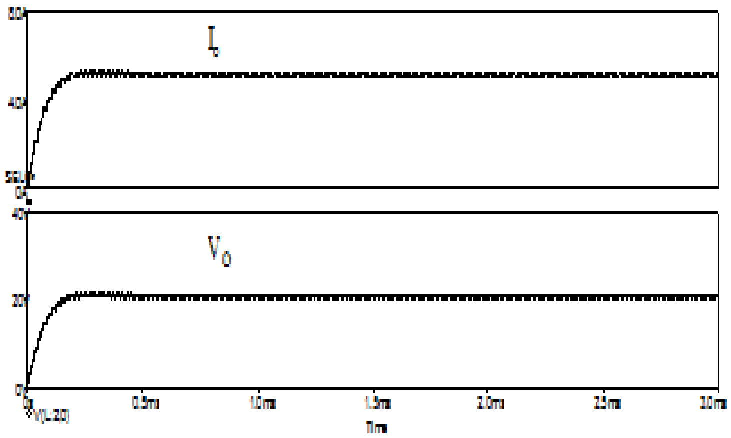


**Fig. 6: Simulated waveforms of output current and output voltage for *d* = 0.4**

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## IV. SIMULATED EXPERIMENTAL SET UP

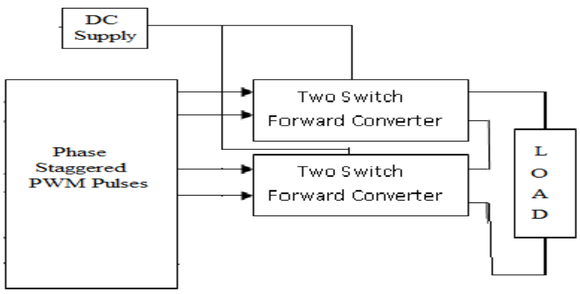


**Fig. 7: Block diagram of phase staggered PWM with three converters**

As shown in Figure 7, the input of converters is connected in parallel and output stages of converters are connected in series to give a total output voltage of 60 V. The converter output is connected to 12 ohm load. Schematic diagram of two switch forward converters with input parallel and output in series is shown below.

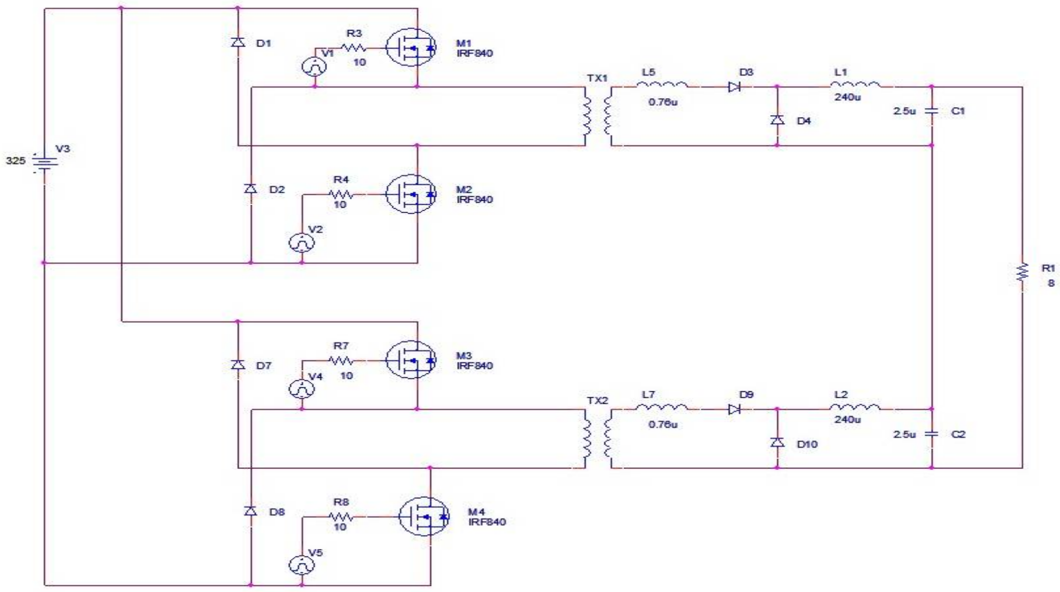

**Fig. 8: Schematic Diagram of Two switch Forward Converters with input parallel and output in series**

## V. SIMULATION RESULTS

Two forward converters with phase staggered PWM is simulated and results were obtained. Various waveforms are taken and are presented here.
Figure 9 shows the total output voltage FFT of converters without phase staggered PWM at duty ratio 40%.

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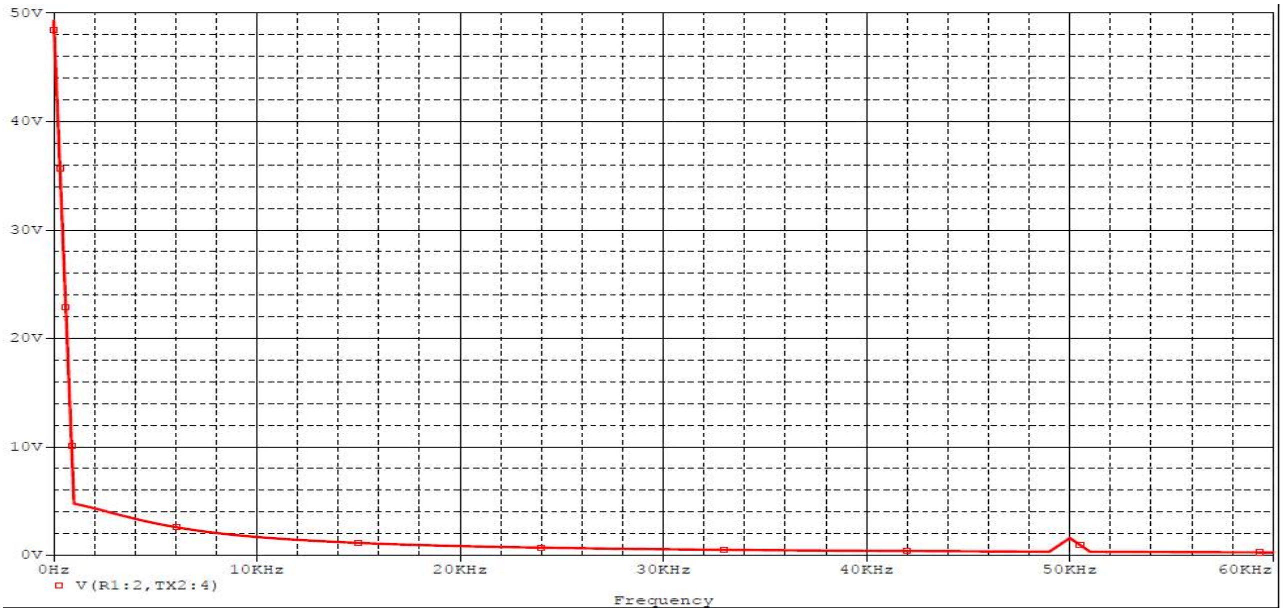


**Fig. 9: Simulated waveform of total output voltage FFT of Two switch Forward Converter without phase staggering and Duty = 40 % (Red is total output voltage FFT of converter)**

Figure 10 shows the the total output voltage FFT of converters without phase staggered PWM at duty ratio 40%.

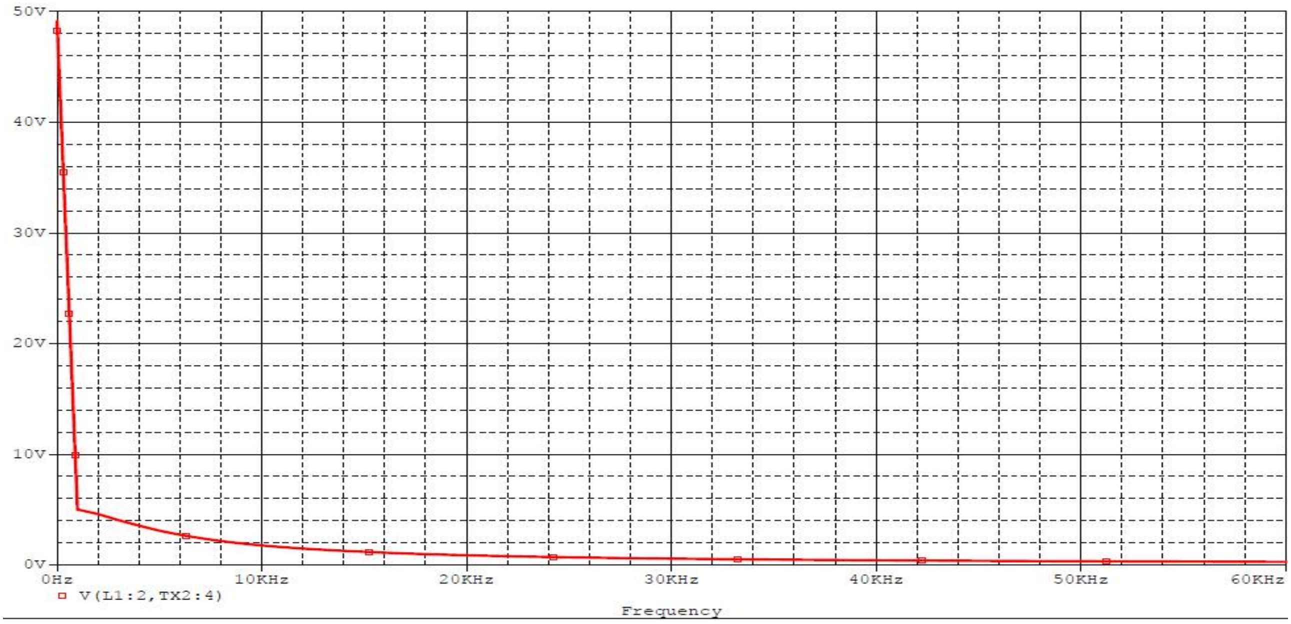


**Fig. 10: Simulated waveform of total output voltage FFT of Two switch Forward Converter with phase staggering and Duty = 40 % (Red is total output voltage FFT of converter)**

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Figure 11 shows the output current FFT of converter without phase staggered PWM at duty ratio 40%.

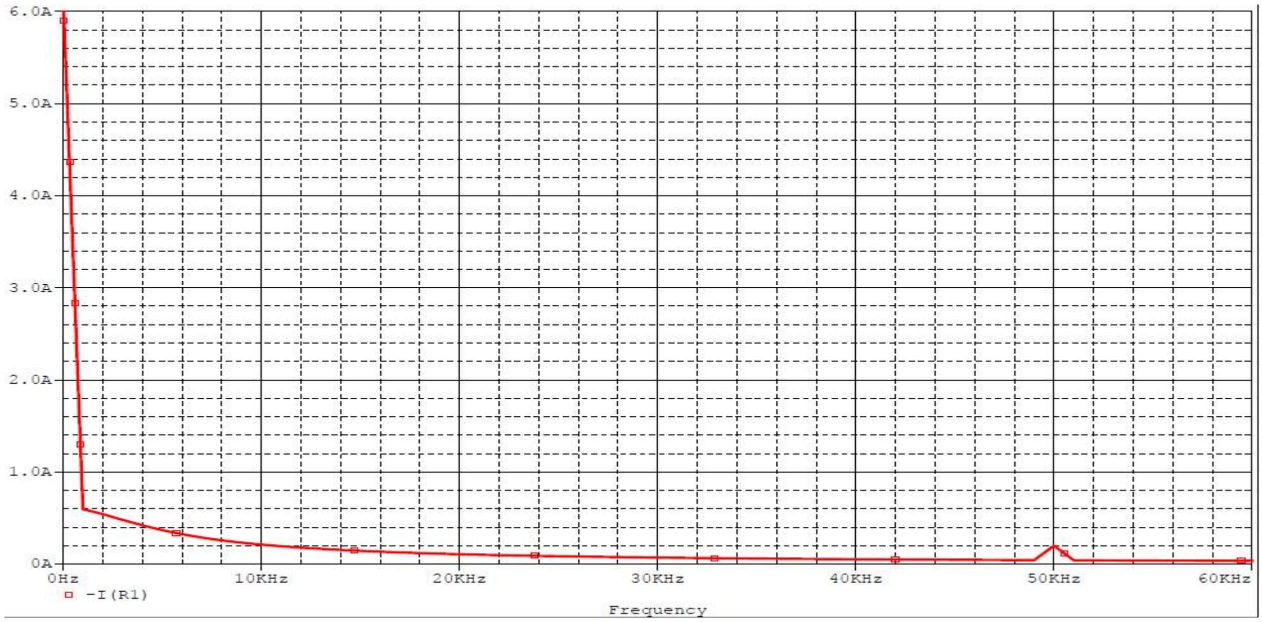


**Fig. 11: Simulated waveform of Output current FFT of Two switch Forward Converter without phase staggering and Duty = 40 % (Red is total output current FFT of converter)**

Figure 12 shows the output current FFT of converter without phase staggered PWM at duty ratio 40%.

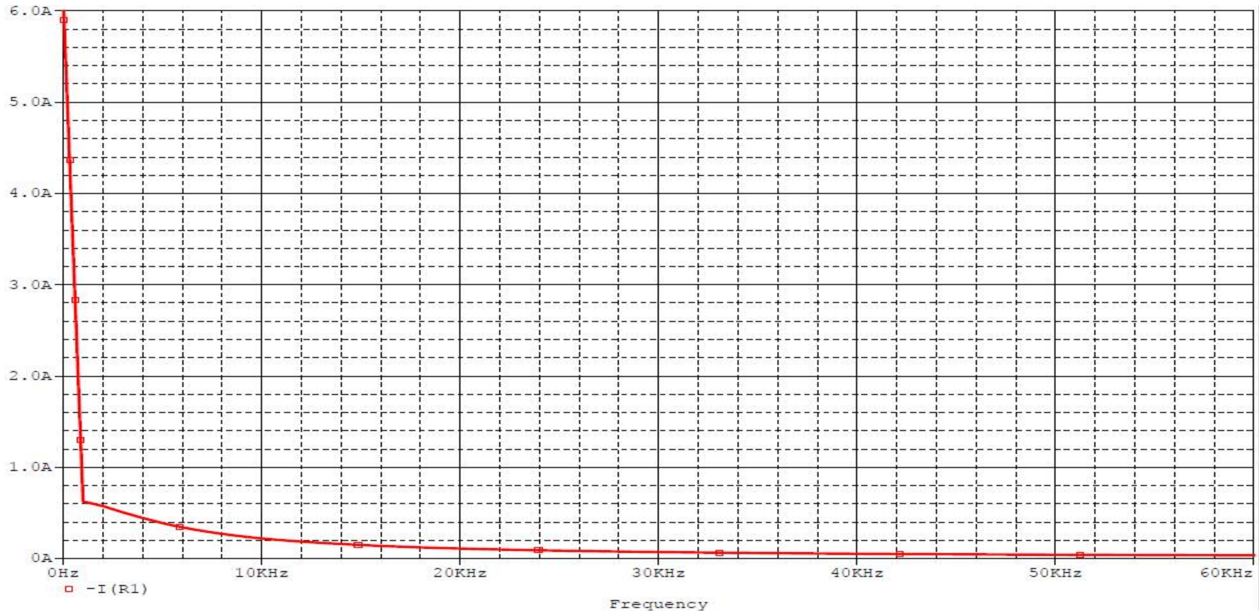


**Fig. 12: Simulated waveform of Output current FFT of Two switch Forward Converter with phase staggering and Duty = 40 % (Red is total output current FFT of converter)**

It is observed that through the FFT of output voltage with and without phase staggered PWM, the 50 kHz (switching

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frequency) component is present in output voltage FFT and output current FFT when operated without phase staggered mode while the 50 kHz (switching frequency) component is eliminated in the output voltage FFT with phase staggered mode of converters.

## VI. CONCLUSION AND PERSPECTIVES

A simulated comparison of Phase staggered PWM implemented to two switch forward converters is presented in this paper. It is observed that with phase staggering technique the 50 kHz (switching frequency) component is present in output voltage FFT and output current FFT eliminated. Phase staggered control technique is implemented on two forward converters with parallel input and serial output to demonstrate the impact of phase staggering on 50 kHz (switching frequency) component of output voltage FFT and output current FFT of power converters.

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